

Groundwater monitoring system and groundwater policy in relation to unified water resource management in Korea

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Abstract

The demand for water resources is consistently increasing due to industrialization and urbanization. Water resource management can become difficult because of climate change and social issues. Due to the difficulty in securing stable water resources, reasonable utilization and management of water is crucial for the sustainable development of groundwater resources that are an efficient alternative to surface water. For groundwater management, the National Groundwater Information Management Service (GIMS) Center for K-Water measures groundwater data hourly (groundwater level, water temperature, and electrical conductivity) at national groundwater monitoring stations and analyzes the long-term variation of groundwater with regard to climate change. According to the Groundwater Act (1993), auxiliary groundwater monitoring stations for groundwater use and water quality are activated by local governments. The observed data after the calibration process are provided for utilization by citizens, industries, schools, institutes, and government policies through annual reports on groundwater monitoring by the GIMS Center. In 2018, the Korean government merged water resources affairs that were once divided between the Ministry of Environment and the Ministry of Land, Infrastructure, and Transport. The change will be favorable for effective management of the surface water and groundwater resources as well as ensuring both quality and quantity.

Keywords: Auxiliary groundwater monitoring stations; Groundwater Act; National Groundwater Information Management Service (GIMS) Center; National groundwater monitoring stations (NGMSs)

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Introduction

The frequency and fraction of heavy rainfall to total rainfall is expected to increase in many regions of the world during the 21st century (Lubchenco & Karl, 2012). The amount of groundwater use varies in the world. For example, in the United States, groundwater makes up ~22% ($3 \times 10^8 \text{ m}^3/\text{d}$) of total water use ($\sim 1.34 \times 10^9 \text{ m}^3/\text{d}$), based on data from 2010 (Maupin et al., 2014), and China uses groundwater for as much as ~20% of the total water supply (Ministry of Water Resources, 2011a, 2011b; Shen, 2015). In Korea, groundwater makes up ~11.0% (i.e., $4 \times 10^9 \text{ m}^3/\text{year}$) of the total water use ($37.2 \times 10^9 \text{ m}^3/\text{year}$), based on data from 2015 (Kim, 2017).

In 1993, the Groundwater Act (GA) was established by Korea's Ministry of Land, Infrastructure, and Transport (MOLIT) to properly develop and utilize groundwater through efficient maintenance and management, and to prevent groundwater pollution for public welfare and the national economy. The GA stipulates guidelines for the investigation, development, use, maintenance, and management of groundwater, groundwater-related industries (construction industry, environmental assessment and investigation consultants, groundwater remediation businesses, etc.), financial budget acquisition, and management for groundwater. In the context of the GA, the master plan for groundwater management (MPGM) is established every 10 years for national groundwater management, as well as for the national groundwater policy. The MPGM is utilized to establish the conservation and management policy of groundwater resources, including the analysis of the cause and preparation of countermeasures against the deterioration of groundwater quality and the severe decline of groundwater quantity. Groundwater monitoring is fundamental in groundwater management, groundwater recharge rate, water balance, and groundwater-related research. It is also used for establishing groundwater-related policies. According to the GA and the MPGM, the National Groundwater Information Management Service (GIMS) Center in K-Water measures groundwater data (groundwater level, water temperature, and electrical conductivity) hourly using the national groundwater monitoring network (NGMN), and conducts detailed surveys on water-level changes, and potential anomalies in water quality.

In 2018, the Korean government decided to merge water resources originally separated between the Ministry of Environment (MOE) and the MOLIT. The MOE is now responsible for managing both surface water and groundwater resources in terms of water quality and quantity. The scope of groundwater quantity that was once monitored by the MOLIT and K-Water is now monitored by the MOE (Table 1). The responsibility of conservation, use, and development of water resources has also been transferred from the MOLIT to the MOE. The MOE now administers five laws, including the Act on the Survey, Planning and Management of Water Resources (Water Law), Dam Construction and Supporting Surrounding Areas, the Hydrophilic Zone Act, the GA, and the Korea Water Resources Corporation Act. The MOLIT is still responsible for two laws: the River Act and the Compensation Act for Land Transferred to River. Kim & Kim (2019) compared Korea's Soil Environment Conservation Act and the GA, and suggested that a legal framework for groundwater remediation be established.

Under the direction of the MOE, the National Institute of Environmental Research (NIER) carried out the Safe Groundwater Supply Project between 2012 and 2016. Its initiative was to supply safe groundwater to areas that lack a municipal water supply (Lee et al., 2017). Lee & Kwon (2016) summarized the NGMN, the national groundwater-quality monitoring network (NQMN), an auxiliary groundwater monitoring network (AGMN), a saltwater intrusion monitoring network (SIMN), a rural groundwater monitoring network (RGMN), and a drinking water monitoring network. Lee et al. (2007) reviewed the NGMN and gave suggestions on the installation of rain gauges, gathering

Table 1. Korea's groundwater management-related acts and their corresponding ministries.

Ministry (before 2018)	Ministry (before 2018)	Groundwater-related acts in Korea	Regulated objects	Regulation contents	Groundwater monitoring network
Ministry of Land, Infrastructure and Transport (MOLIT)	MOE	GA	All groundwater, regardless of whether it is regulated by another act	General act for groundwater development, use, conservation, and management	NGMN and AGMN (groundwater level/quality)
	MOE	Special act for Jeju island ^a	Groundwater on Jeju island	All groundwater surveying, development, use, conservation, and management in Jeju island	
	MOLIT	Housing Act	Multi-unit residential districts	Groundwater for multi-unit dwelling	
Ministry of Environment (MOE)	MOE	Drinking Water Management Act, GA	Quality of drinking and bottled groundwater	Quality control of drinking and bottled groundwater	DGMN and BGMN
		GA	General groundwater quality	General act for groundwater development, use, conservation, and management	NQMN and LQMN (groundwater quality)
Ministry of Agriculture, Food and Rural Affairs (MAFRA)	MAFRA	Rearrangement of Agricultural and Fishing Villages Act, GA	Groundwater in rural areas	Groundwater for agriculture and fishery	RGMN
		Rearrangement of Agricultural and Fishing Villages Act, GA	Groundwater in coastal area	Saline groundwater intrusion monitoring	SIMN
Ministry of the Interior and Safety (MOIS)	MOIS	Hot Spring Act	Hot spring	Develop and manage related over 25°C hot spring	HSMN
		Civil Defense Act	Emergency water supply facility	Emergency water supply facility-related framework	
Ministry of National Defense (MND)	MND	Act on National Defence and Military Installation Projects	Groundwater in the national defense facility	Groundwater for national defense facility	

^aThe special act has been established for groundwater management of Jeju Special Self-governing Province and Free International City.

hydrochemical data, periodic groundwater data analysis, and additional construction of groundwater monitoring stations.

The goal of this study was to compile and relay facts on the national groundwater monitoring system and its relation to Korea's recent unification of water resource management in order to effectively secure safe water resources and cope with global climate change.

Overview of groundwater methods

The purpose of the national groundwater monitoring system is to monitor groundwater level and quality. The system consists of the primary groundwater monitoring network (PGMN) and an AGMN. There is also the RGMN in agricultural areas where groundwater is highly developed and used, and the SIMN (Figure 1 and Table 2). In the past, the PGMNs operated by the central government consisted of the NGMN, engaged by K-Water and affiliated with the MOLIT, and the national groundwater quality-monitoring network (NQMN), facilitated by the MOE (Table 1). At locations of interest on a national basis, the NGMN monitors groundwater-level fluctuation and quality, and how does the

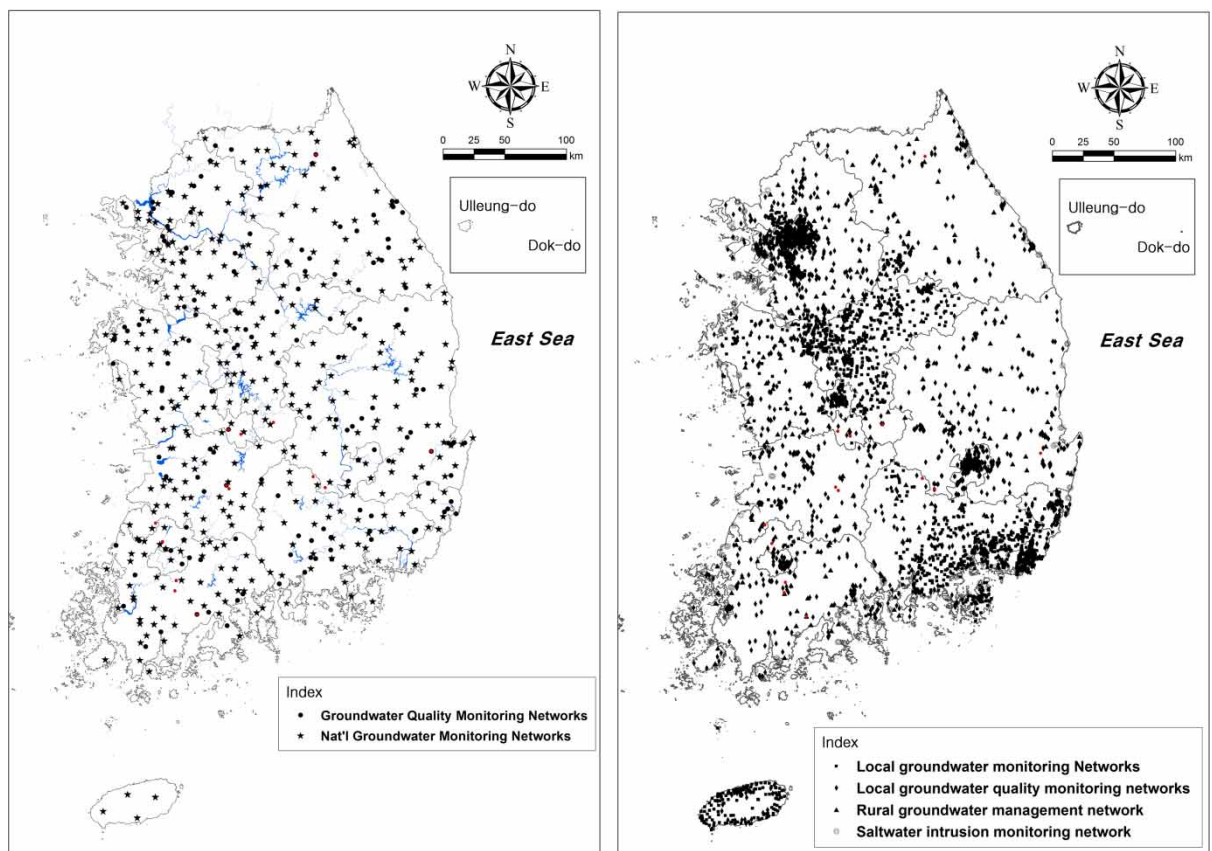


Fig. 1. Location map of primary monitoring networks (left) and secondary monitoring networks (right).

Table 2. PGMN of the 2,711 wells and AGMN of the 2,272 wells in Korea.

Local government (area, km ²)	PGMN		AGMN				Wells	Well nos./100 km ²
	NGMNs	GQMNs	LGMNs	LQMNs	RGMNs	SIMNs		
Seoul (605)	3	–	136	–	209	–	348	57.52
Busan (770)	3	1	122	–	185	–	311	40.39
Daegu (884)	4	4	190	–	137	–	335	37.90
Incheon (1,063)	3	2	68	–	–	10	83	7.81
Kwangju (501)	2	4	49	–	–	–	55	10.98
Daejeon (539)	2	3	49	–	39	–	93	17.25
Ulsan (1,061)	4	7	58	–	36	2	107	10.08
Sejong (465)	2	1	15	–	3	–	21	4.52
Gyeonggi (10,183)	58	26	269	37	144	15	549	5.39
Gangwon (16,875)	57	37	129	33	46	15	317	1.88
Chungbuk (7,407)	31	21	117	22	280	–	471	6.36
Chungnam (8,226)	50	27	127	27	170	20	421	5.12
Jeonbuk (8,069)	40	23	130	21	6	8	228	2.83
Jeonnam (12,319)	54	36	152	44	13	53	352	2.86
Gyeongbuk (19,031)	67	44	203	45	12	13	384	2.02
Gyeongnam (10,540)	44	26	166	39	430	27	732	6.94
Jeju (1,849)	4	–	41	–	131	–	176	9.52
Sum (100,387)	428	262	2,021	268	1,841	163	4,983	4.96
Well nos./100 km ²	0.43	0.26	2.01	0.27	1.83	0.16	4.96	

network prevent disturbances, such as depletion of groundwater sources and ground subsidence, by observing changes in the groundwater level and providing the basic data necessary for governmental policy establishment. The NQMN monitors changes in groundwater quality at the locations of interest equivalent to the NGMN, identifies background water quality relative to water pollution, and provides the basic data necessary for governmental policy decisions. The AGMN is operated by the central government or local governments and monitors changes in groundwater quantity and quality due to man-made influences, such as groundwater pumping and pollution facilities.

In addition, the MOE controls the drinking groundwater monitoring network (DGMN) and the bottled groundwater monitoring network (BGMN) for securing the quality of drinking and bottled groundwater. The Ministry of the Interior and Safety (MOIS) operates the hot spring monitoring network (HSMN). According to the GA, local governments operate local groundwater monitoring networks (LGMNs) to assist the NGMNs and local groundwater-quality monitoring networks (LQMNs) in areas of groundwater contamination concerns in order to assist the NQMN. The LGMNs and the LQMNs are installed in the areas of interest (i.e., those with over-pumping or water quality deterioration) and are used for monitoring groundwater level and quality, respectively, providing basic data for local governments' policy decisions.

Korea Rural Community Corporation ((KRCC), which is affiliated with the Ministry of Agriculture, Food and Rural Affairs (MAFRA)), operates the rural groundwater management network (RGMN) and the saltwater intrusion monitoring networks (SIMNs) to monitor groundwater level and water quality.

National groundwater monitoring system

National groundwater monitoring stations

At national groundwater monitoring stations (NGMSs), groundwater level and quality data have been obtained from the national, municipal, or public areas since the first installation in 1995, without transfer of the stations except for the case of large national projects. The locations of the NGMSs are selected based on recharge and discharge areas, hydrogeological productivity, and altitude (Table 3). The NGMSs consist of a bedrock monitoring well and an alluvium monitoring well, in the event that alluvial beds are developed in the area. At the end of 2017, 428 NGMSs consisting of 428 bedrock monitoring wells and 171 alluvium monitoring wells were installed; by the end of 2021, a total of 530 NGMSs will be installed nationwide. Nine stations among the NGMSs have an auxiliary rain gauge that is installed to supplement the surrounding rain gauging station, and is set to operate as a multipurpose gauging station with complimentary functions in the future.

Acquisition and transmission of groundwater data

The monitoring facilities of the NGMSs consist of a well, protection facility for the well, a probe, a transducer cable, a data logger unit, and a power unit. The protection facility is for both the well itself and the monitoring equipment. An external facility is installed after an internal protection facility is installed, featuring a board noting the installation time, location (coordinates), elevation, and emergency contact person. The probe measures groundwater level, temperature, and electrical conductivity. The transducer cable, within which a tube and wires are inserted with a waterproof connector, can correct atmospheric pressure and prevent measurement error that originates from cable tension.

The data logger consists of a device that stores measured data, an equipment controller, and a data transit instrument, which transmits the stored data to the national groundwater network server through wireless communication on a daily basis. The transmission system for groundwater data has been changed from the old MtoM remote communication system to a new TCP/IP remote communication system (Figure 2). The MtoM communication system synchronizes data through data inquiry communication to

Table 3. NGMN of 530 wells installation by recharge and discharge areas, hydrogeological productivity, and altitude.

Monitoring station		Through 2017	New stations until 2021	Stations sum	Total
Recharge and discharge areas	Recharge	135	81	216	530
	↓	53	15	68	
	Discharge	240	6	246	
Hydrogeological productivity	High	131	20	151	530
	↓	36	18	54	
	Low	53	38	91	
Altitude		208	26	234	530
	0–70 m	231	38	269	
	71–180 m	114	34	148	
	181–370 m	63	24	87	
	>371 m	20	6	26	
Total	–	428	102	530	–

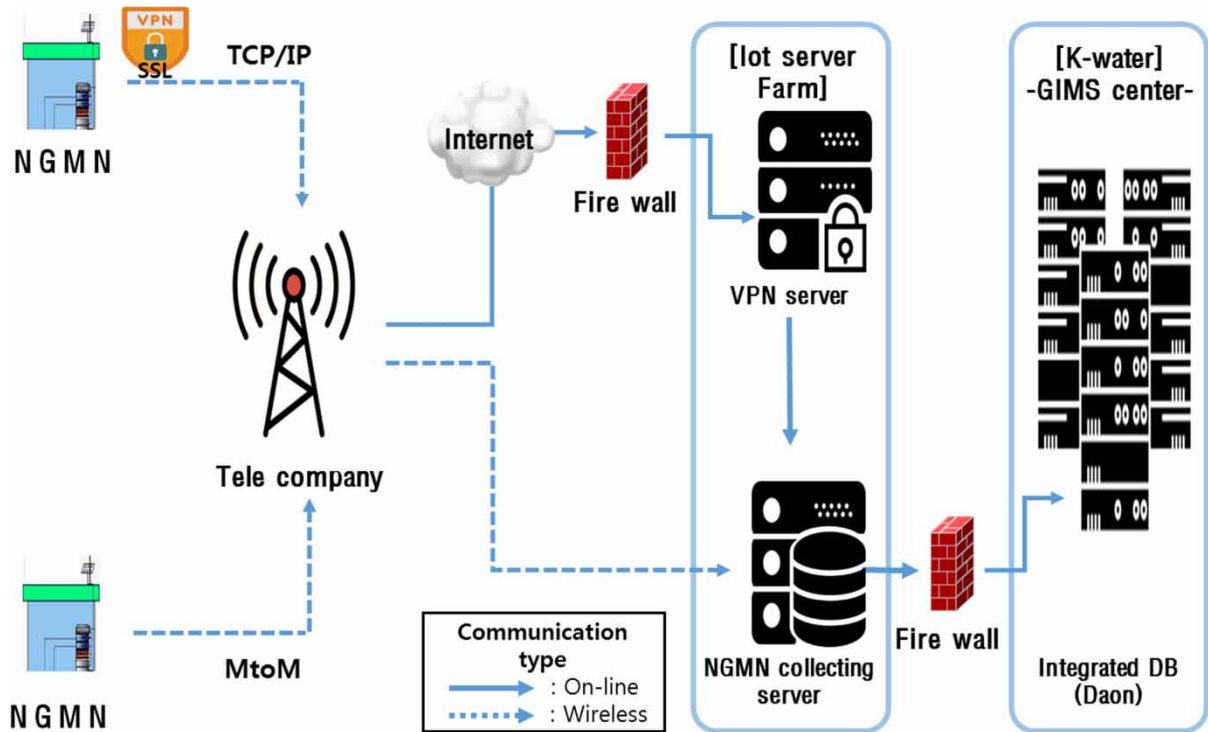


Fig. 2. Transmission system of groundwater data.

a data collection server. The TCP/IP communication can remotely control the setting of the measuring – data acquisition interval, communication on and off time, communication connection duration, information on the pressure transducer installation, and power reset – all through text message transmission.

The power supply unit supplies power to the pressure transducer and the logger unit. Electricity at most stations is supplied by a solar collector that can continuously operate the data logger for ~20 days (theoretically for a maximum of ~40 days) without sunlight at the hourly data acquisition interval of every hour. The other stations require a constant power source. Collected data are automatically transmitted on a daily basis to the data collection server through a remote communication system. If necessary, engineers can check and acquire real-time data through remote communication with the NGMSs. Water quality analysis is executed at the first half and second half of each year to assess seasonal water quality variation. The quality is measured according to the groundwater quality standard for domestic use. The standard codes of characters and units for groundwater monitoring information are given in Table 4. Units for water quality analysis items follow those by the water quality analysis agencies. As different codes are used among different ministries, the executive council of the related ministries can set the standard codes through discussion.

In groundwater monitoring, sampling frequency, location, and continuity are the most important factors for intensive and extensive reviews on data (Lee & Kwon, 2016). It would be beneficial to use precipitation data in combination with groundwater data (groundwater level, water temperature, and

Table 4. Standard codes for a groundwater monitoring well.

Items	Type	Unit	Remark
Standard well name	Text (11 characters)		AA-AAA-A0-○○○○ (regional name code – local name code – monitoring well type – serial number)
Monitoring well type	Digital (decimal point 0)		1: Developed in alluvium 2: Developed in bedrock
Monitoring date	Text		yyyy/mm/dd
Groundwater use amount	Digital (0 decimal places)	m ³ /d	Daily average
Groundwater level ^a	Digital (2 decimal places)	amsl, m	Daily average
Groundwater depth	Digital (2 decimal places)	depth to water, m	Daily average
Electrical conductivity	Digital (0 decimal places)	μS/cm	Daily average
pH	Digital (1 decimal places)		Daily average
Temperature	Digital (1 decimal places)	°C	Daily average

^aGroundwater level is designated by both depth to water (DTW) and average mean sea level (amsl).

electrical conductivity), which would allow for the estimation of when to initiate groundwater recharge by installing rainfall gauges at the NGMSs for broadening hydrological information (Jousma & Roelofsen, 2004; Lee *et al.*, 2007).

Operation of national groundwater monitoring networks

Periodic inspection and maintenance is carried out to obtain reliable groundwater data from NGMNs. There are six monitoring station maintenance teams – each consisting of two people – that visit the NGMSs every 2 months to download data from the stations for comparison with the automatically transmitted data. Emergency inspection promptly handles extraordinary situations, such as lightning and floods. The NGMS inspection and maintenance is performed for the inside and outside parts of the protection facility, operation state of the monitoring facility, confirmation of power source, cleaning of pressure transducer, data calibration, and data acquisition.

Utilization of the national groundwater monitoring networks

The groundwater data acquired by the NGMSs from 1 January to 31 December are compiled into a report and distributed to the major libraries, including the National Assembly library, and local governments. The report is also uploaded on the GIMS Center website (www.gims.go.kr) for people who require the NGMS's groundwater data. The GIMS Center also provides groundwater information to universities, research institutes, private companies, and government policymakers.

These groundwater data are used for the analysis of local groundwater system recharge, the estimation of potential groundwater development, and baseline data for groundwater fluctuations due to natural disasters (earthquakes, subsidence, etc.). In addition, the basic data related to the NGMSs – location, drill depth, well diameter, casing material, installation depth of casing, type of bedrock at the station, transmissivity, and hydraulic conductivity – are also provided in the annual report. The NGMS's groundwater data are provided for domestic and agricultural purposes in the object areas around the NGMSs during the drought season. Drought frequency and severity has unexpectedly increased in

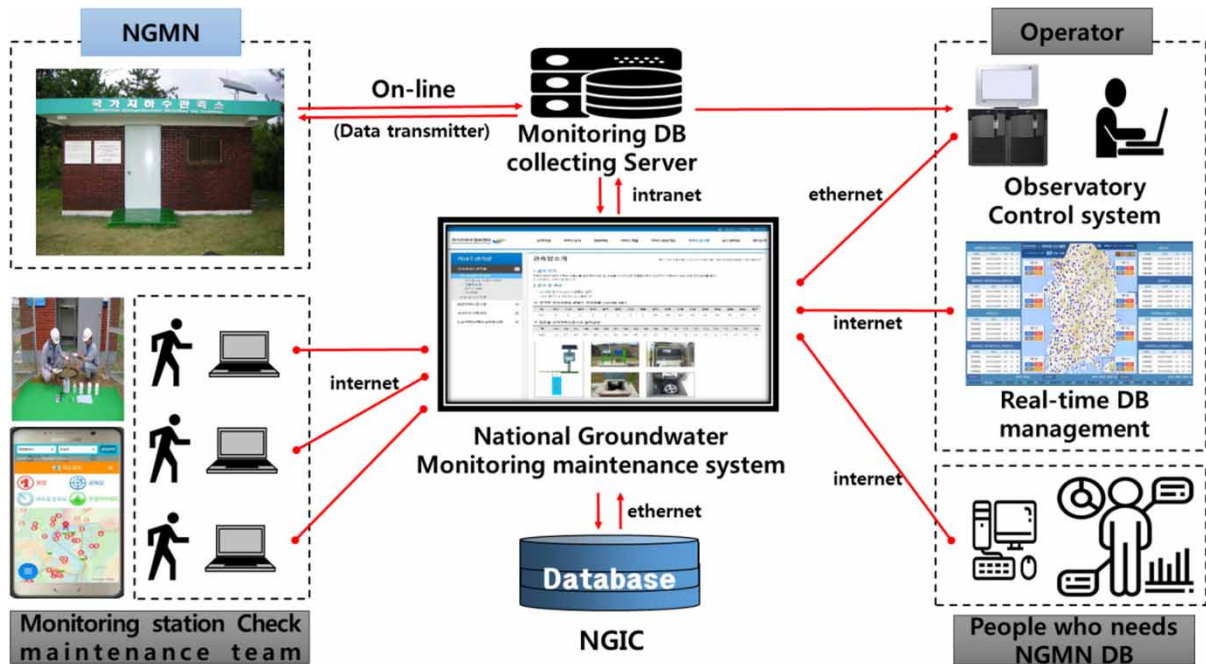


Fig. 3. Management scheme of the NGMSs.

recent years in Korea due to climate change. In addition, the GIMS Center website provides information, as well as the available amount of groundwater at the NGMSs, on secure, safe water when water-related disasters such as droughts take place (Figure 3).

The collected data on groundwater quantity and quality at the NGMSs are subjected to time-series and trend analyses over a certain monitoring period, as well as detailed field surveys for building countermeasures in the event of a groundwater anomaly. During the first stage, time-series and trend analyses, using at least 5 years of continuously monitored data, are executed to examine the anomalous phenomena, such as a rising or declining tendency in water level, continuous exceeding of water quality standards in periodical water quality tests. At the second stage, detailed field surveys are conducted to reveal the characteristics of the locations featuring anomalous phenomena. In general, the detailed field surveys are executed over the course of 2 years: basic environmental surveys of topography, geology, and land use, well installation, monitoring of groundwater level and quality change, and the interpretation of groundwater-level fluctuation and abnormal water quality. During the final stage, appropriate countermeasures are proposed to the licensees of groundwater use in order to restore the water level or water quality. Under the GA, the licensees of groundwater use shall take all necessary measures for proper management of groundwater quantity and quality, such as restricting groundwater pumping and use, as well as ordering water pollution prevention to the owners or managers of the facilities of groundwater pollution sources.

The NGMS groundwater information has greatly contributed to not only the monitoring of groundwater levels and quantity conditions throughout Korea, but also promoting scientific research in hydrogeology. For instance, Lee & Hahn (2006) evaluated groundwater temperatures across the

nation from the NGMN for evaluating its use for the purpose of heat pumps. Using the NGMN, a relationship between groundwater change and precipitation from 2000 to 2010 was established (Lee *et al.*, 2014), and the groundwater-level change from 2000 to 2100 was predicted in relation to the regional climate model (Jang *et al.*, 2015). Lee *et al.* (2005) evaluated groundwater-level and chemical constituent data from the AGMN in Seoul megacity.

Discussion and conclusions

According to the GA, the MPGM specifies the installation and operation of the NGMSs to monitor the fluctuation of groundwater levels throughout the country. A goal is to have installed 530 NGMSs by 2021, taking into account the groundwater recharge and discharge, hydrological characteristics, and the surface elevation of the station. The MPGM has called for additional research projects in relation to a higher utilization of groundwater data for revealing groundwater circulation through the estimation of groundwater residence time, groundwater origin evaluation through the analysis of trace elements, the relationship between earthquakes and groundwater through groundwater-level change, and so on.

The frequency and intensity of droughts has increased across Korea in recent years. In order to prepare for such intense droughts and emergency situations of water shortage, the Korean government plans to enlarge the MPGM to include multipurpose stations for supplying water in an emergency situation. The stations will also increase the utility of the monitoring wells, and broaden their scope in order to analyze the groundwater cycle characteristics, including groundwater residence time, origin, flow patterns through tracer tests, and microorganism analyses. Additionally, multipurpose stations enable the study of water balance through groundwater recharge and discharge analyses, and the identification of the relationship between earthquakes and groundwater response using groundwater-level analyses. In this circumstance, the Korean government regularly holds central and local ‘Groundwater Councils’ composed of practitioners of related ministries in order to integrate, jointly utilize, and standardize groundwater data obtained by different ministries.

In 2018, the Korean government merged water resources having been past separated between the MOE for water quality and the MOLIT for water quantity. In order to implement the unified management of water resources, the Korean government launched the Principal Act of Water Management on 13 June 2019. Since 2018, the MOE is responsible for managing both surface and groundwater resources for the conservation of water quality and quantity and established the Water Resources Policy Bureau (WRPB), which is comprised of the Water Resources Policy Division, the Water Resources Development Division, and the Water Resources Management Division. However, the MOLIT abolished the WRPB, and the River Planning Division has been assigned to the Territorial and Urban Development Office. In addition, the flood control centers on the four rivers in charge of flood and drought forecasting and control, dam and river operation, and other river-related functions have been transferred from the MOLIT to the MOE. Among the river-related tasks, the MOE takes charge of river water licensing, determination of river maintenance flow rate, dam and river barrage connected operation, river water use and management, and river water dispute settlement. However, river management has been divided into two systems: the river facility management system belonging to the MOLIT and the streamflow management system now the responsibility of the MOE. This separation has been criticized by NGO societies and experts, even if water quantity and quality management have been unified to the MOE.

The change will be beneficial to effectively manage groundwater and surface water. Thus far, Korea's water policy has been more focused on surface water, as opposed to groundwater. The use of groundwater is advantageous in that it has less effect on climate change, less vulnerability to contamination, and a greater potential of water resource, in general, with only 31.9% being used out of the total groundwater available in Korea (Moon, 2007), compared to surface water. However, an adverse aspect of groundwater is the potential lack of groundwater recharge due to increased variability in rainfall – rainfall exceeding the infiltration capacity of soil causes increased surface runoff (Hetzel et al., 2008). These facts promote the importance of groundwater monitoring in Korea.

In Korea, the present water policy relies on a central, large-scale municipal water system that is not economic in terms of water usage. It is also an ineffective portable water system, because the municipal water is used for several things, including domestic and industrial activities (bathing, washing clothes, car washing, etc.). Therefore, groundwater policy in Korea should be changed in order to meet global climate change and the uncertainty of securing water resources, as groundwater is less vulnerable to contamination and changes in precipitation. Moreover, when a rainstorm occurs, groundwater reservoirs can be effectively utilized for storing surface water using artificial recharge techniques.

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