Report of the CCOP-GSJ-DGR Groundwater Project Phase IV Meeting

21-23 March 2023, Bangkok, Thailand

COORDINATING COMMITTEE FOR GEOSCIENCE PROGRAMMES IN EAST AND SOUTHEAST ASIA (CCOP)

in cooperation with

GEOLOGICAL SURVEY OF JAPAN (GSJ), AIST

Gaurav Shrestha (Chief Editor)

I. PREFACE

Groundwater is one of the important natural resources essential for various purposes in human life. However, its improper exploitations have resulted in various groundwater issues and problems, mainly in the late 20^{th} century. In recent days, land subsidence, seawater intrusion and groundwater pollution by toxic substances are serious problems all around the world. East and Southeast Asia also have faced many of these problems which need international cooperation to be solved. The CCOP-GSJ Groundwater Project has been launched aiming to provide some solutions for groundwater management in the CCOP region.

The CCOP-GSJ-DGR Groundwater Project Phase IV Meeting was held on 21-23 March 2023 in Bangkok, Thailand. It was attended by 37 participants (29 onsite and 8 online) from Brunei Darussalam, Cambodia, China, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, Mongolia, Myanmar, Papua New Guinea, Philippines, Thailand, Vietnam and the CCOP Technical Secretariat. In the meeting, participants confirmed the outcomes of the CCOP-GSJ Groundwater Project Phase IV and discussed the upcoming plans and objectives.

Each CCOP member country made a presentation on the topic of “Current monitoring system of groundwater and surface water in one’s country and existing problems” (For Countries with existing monitoring system) and “Future plan and policy for the monitoring system of groundwater and surface water in one’s country, and problems to establish the system” (For Countries without existing monitoring system). All the participants discussed the monitoring system, existing issues, and future plan and policies in each member country.

This publication compiles all the country reports presented in the CCOP-GSJ-DGR Groundwater Project Phase IV Meeting, 21-23 March 2023, Bangkok, Thailand.

I am very grateful to the authors for their invaluable contribution to the project and to their organization for giving the permission for this publication.

Gaurav SHRESTHA

Chief Editor

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II. The Minutes of the CCOP-GSJ
Groundwater Project Phase IV Meeting
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Dr. Young Joo Lee, CCOPTS Director and Dr. Gaurav Shrestha, the GSJ Groundwater Project Phase IV Leader welcomed all the participants to the meeting. Mr. Thanya Netithammakun, Director-General, Department of Groundwater Resources (DOR), Thailand officially opened the meeting.

Dr. Gaurav Shrestha, the GSJ Groundwater Project Phase IV Leader, presented the Past Achievements of CCOP-GSJ Groundwater Project and, Review of Plan and Objectives of Phase IV.

The Phase IV kicked-off in 2019 in Bali, Indonesia, and its meeting report has been published and its electronic version has been made available at the GSJ website, https://www.gsj.jp/en/publications/ccop-gsj/index.html as well as at the CCOP website, https://ccop.asia/e-library. During this phase, the project will update, expand and improve the CCOP Groundwater Database made accessible via the GSi System, https://ccop-gsi.org/gsi/groudnwater/index.php. The project's annual meetings will include technical field survey and discussions to solve groundwater pollution problems in DB II countries.

Country reports on "Current monitoring system of groundwater and surface water in one's country, and existing problems" (For Countries with existing monitoring system) and "Future plan and policy for the monitoring system of groundwater and surface water in one's country, and problems to establish the system" (For Countries without existing monitoring system) were presented and discussed among the participants.

Dr. Joel Bandibas, the GSi System developer from the Geological Survey of Japan, led the workshop on Groundwater Database Compilation using CCOP GSi System which included training of the usage of the system. Hands-on exercises in uploading groundwater well data to the GSi system were also carried out.

There will be a training session in the next project annual meeting as well. Participants can also contact their respective GSi Project National Coordinator for assistance in using the GSi system. They may also contact the CCOP Technical Secretariat or to Dr. Joel Bandibas directly.

The next project meeting will be held in early 2024. It may be held in Nha Trang City, Khanh Hoa Province, Vietnam. The CCOP Technical Secretariat will contact Permanent Representative of Vietnam to CCOP for confirmation. Duration and schedule of the meeting with technical survey is as follows.

Duration (6 days including arrival and departure davs).
Dayl: Arrival in host country
Day2: Technical groundwater survey and discussions
Day3: Meeting (Project updates & Country reports)
Day4: Meeting (GSi Training & Discussions)
Day5: Excursion
Day6: Departure from host country to home country

In the next meeting in early 2024, the participants committed to populate the Groundwater Well Database in CCOP Groundwater Portal as follows.

Country	**Number of Well Data/ Area**
Brunei Darussalam:	2 wells
Cambodia:	2 wells
China:	Need discussion and update current data
Indonesia:	Middle and East Java area
Japan:	Chikushi and Fujii area
Republic of Korea:	Update and edit data
Lao PDR:	10 wells
Malaysia:	100 wells
Myanmar:	10 wells
Mongolia:	Need to confirm
Papua New Guinea:	50 wells
Philippines:	
Thailand	10 wells
Vietnam	Mekong Delta Vietnam

The third day of the workshop is field excursion at Ratchaburi Province visiting four geological and cultural sites as follows:

- Large-Scale Groundwater Development Project under the Royal Initiatives
- Groundwater Monitoring Station@ Wax Garbage Recycle Center Company
- Geology and Cultural Excursion @ K.hao Ngu Stone Park, Ratchaburi Province
- Cultural Excursion@ Phra Pathom Chedi, Nakhon Pathom Province

CCOP and GSJ record its thanks and appreciation to the Department of Groundwater Resources (DGR), Thailand for arranging this field excursion.

The meeting was officially closed by Dr. Youhei Uchida, Project Supervisor.

This minute has been agreed as signed below by participating country representatives onsite.

Brunei Darussalam

Cambodia

China

Indonesia

Japan

Republic of Korea

Lao PDR

Malaysia

Mongolia

Myanmar

Papua New Guinea

Thailand

Vietnam

CCOP Technical Secretariat

Ongoing plan for the monitoring system of groundwater and surface water in Brunei Darussalam

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Abstract

Water stands as a critical resource in Brunei Darussalam, extensively utilized in large-scale industries, particularly in the oil and gas sector, Farming, and for daily consumption. Situated on the north-western coast of Borneo, the country experiences a tropical climate characterized by uniformly high temperatures and intermittent rainfall across two dry and two wet seasons. Despite an average annual rainfall exceeding 2,800 mm and occasionally surpassing 4,000 mm further inland, challenges persist, particularly in agricultural areas facing water scarcity between seasons, resulting in strain on crop production. In response, initiatives have been launched to explore additional groundwater resources, employing geophysical techniques to unravel subsurface geological formations and identify potential aquifer zones. The findings inform targeted borehole drilling, offering insights into aquifer prevalence and distribution within specific geological strata. Simultaneously, groundwater mapping using GIS interpolation techniques concentrates on urban and coastal areas in the Brunei-Muara district, generating detailed contour maps to enhance understanding of groundwater dynamics. This comprehensive approach represents a proactive response to water resource challenges, aiming to achieve sustainable water security in Brunei Darussalam's agricultural landscape and aligning with the broader objectives set for the country's future development.

Keywords: Brunei Darussalam, Groundwater, Hydrogeological map, Asia, Resources

1. Introduction

Groundwater, recognized as the largest and most accessible freshwater source on Earth, assumes a critical role in meeting diverse human needs, spanning daily consumption in arid regions, sustaining industrial processes, and fostering agricultural development. The dependence of millions on groundwater wells and springs underscores its significance, particularly in arid and semi-arid regions where surface water may be scarce. Moreover, groundwater serves as a linchpin for economic growth and development, contributing significantly to food security and various industrial activities.

In Brunei Darussalam, surface water sources dominate the water supply (comprising about 99.5% of the total), the confluence of industrialization and urbanization poses a dual challenge to both surface and groundwater reservoirs. Despite the ease of accessibility with surface water, the burgeoning population and rapid urbanization exert increasing stress on the water resources in the country. Situated on the north-western coast of Borneo, the country encompasses four districts (Brunei-Muara, Tutong, Belait and Temburong) shown on Figure 1 with varying topography and population distribution. In particular, the Brunei-Muara district, with its urban and coastal areas, faces unique challenges in ensuring a sustainable and secure water supply. Notably, Brunei Darussalam's geographical and demographic characteristics add layers of complexity to its water management challenges despite its annual rainfall that is typically high, with an average of over 2,800 mm throughout Brunei Darussalam and can occasionally exceed 4,000 mm further inland (Figure 2). There are two high rainfall periods which are from September to January and from May to July. The September to January period receives the highest amount of rainfall. Meanwhile, February to April is identified as the drought period. As a response to these pressing issues, it becomes imperative to implement effective management strategies and establish robust monitoring networks to safeguard this crucial water resource for future generations.

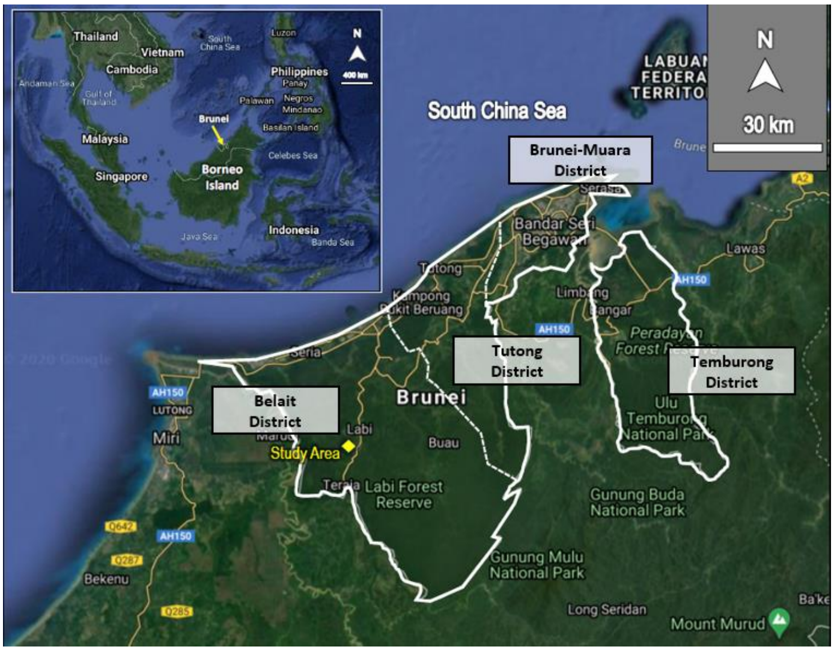

Fig. 1. Map of Brunei Darussalam (Obtained from Google Maps)

The popularity of regional mapping activities, particularly groundwater mapping using advanced tools like Geographic Information Systems (GIS), has seen a substantial increase. GIS, with its capability to organize information into discrete layers connected by georeferencing, has proven indispensable for visualizing, analyzing, and interpreting geographic data. In the realm of groundwater mapping, GIS has played a pivotal role in providing insights into the dynamic nature of groundwater systems, helping identify potential zones for various uses and assess the impacts of human activities.

This comprehensive groundwater mapping initiative from various Brunei Darussalam agencies, employing GIS interpolation techniques and utilizing remote sensing data, including digital elevation models and aerial photographs, aims to evaluate critical hydrological parameters such as groundwater depths, elevations, hydraulic gradients, and flow paths for the Brunei-Muara district. The resulting groundwater contour map, coupled with thematic layers such as geology and land cover, will provide a nuanced understanding of groundwater dynamics, enabling informed decision-making in the realm of water resource management.

The endeavour extends beyond conventional studies, aiming to define potential aquifer zones and pinpoint opportunities for drilling groundwater wells. This forward-thinking approach not only tackles existing challenges but also establishes the foundation for sustainable water management practices specifically tailored to Brunei's unique circumstances. The overarching objective is to align with Brunei's commitment to achieving water security, acknowledging the intricate interplay of environmental factors, climate variability, and the growing water demands of the population. To address these goals, initiatives have been initiated to explore additional groundwater resources. Techniques such as Vertical Electrical Sounding (VES) Electrical Resistivity Tomography (ERT) are employed to unveil subsurface geological formations and identify potential aquifer zones.

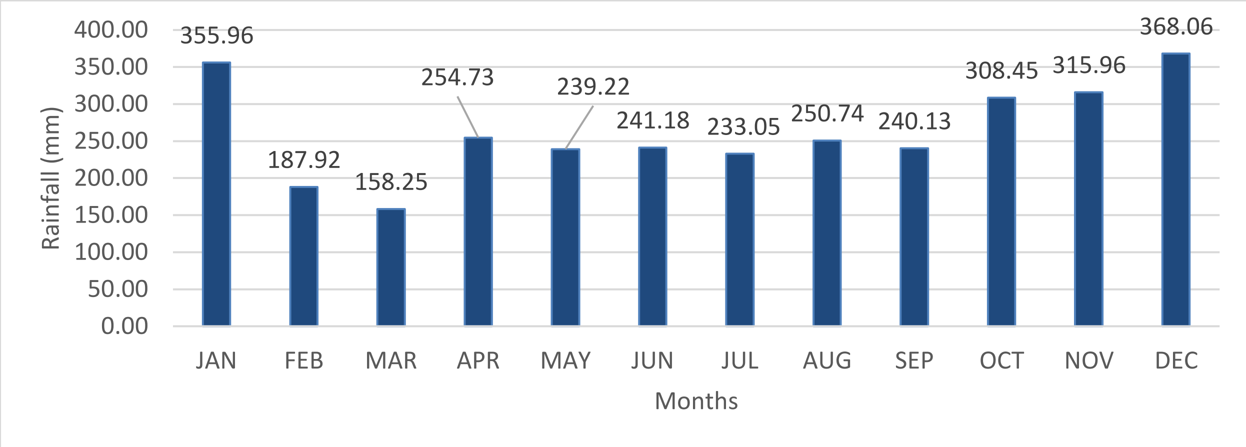

Fig. 2. Average monthly rainfall from 1998-2017 by the Brunei Darussalam Meteorology Department (2017)

The recent reconnection of the Temburong District through the Sultan Haji Omar Ali Saifuddien Bridge in 2020 adds a dynamic element to the nation's landscape. The tropical climate, characterized by high temperatures and intermittent rainfall driven by monsoon winds, presents both opportunities and challenges for water resource management. The initiative to address water scarcity becomes imperative within this dynamic environmental context, aiming to navigate the intricate challenges posed by climate variability and population growth. By undertaking this comprehensive groundwater mapping endeavour and geophysical techniques, aims not only to contribute valuable insights into Brunei's water resources but also to lay the foundation for a resilient and sustainable water future for the nation.

1.1 Water supply in Brunei Darussalam

Over the past several decades, Brunei Darussalam has been heavily reliant on surface water, constituting a staggering 99.5% of its overall water supply, with a minor 0.5% sourced from groundwater, primarily allocated to the bottled water industry. This intricate water distribution system encompasses various pivotal facilities, including pumping stations and dams, each playing a crucial role in meeting the diverse water needs of the nation. Notably, the Badas pumping station stands out, exclusively catering to the oil and gas industry and contributing a substantial 69 million m3/year. Simultaneously, the Benutan dam and Mengkubau dam collectively supply 3.6 million hectares/year for the agricultural sector, along with an estimated 23 million m^3/year for various other purposes, equating to approximately 350 liters/day per person. Complementing these sources, water is also abstracted from the Tutong river, illustrating the multifaceted and integrated nature of Brunei's water supply infrastructure.

2. Ground water development and assessment in Brunei Darussalam

In recent years, various agencies in Brunei Darussalam have been actively addressing the challenges posed by the limitations of water sources in the region. The scarcity and strain on water resources have been persistent issues, prompting concerted efforts to mitigate these challenges. These initiatives aim to ensure a sustainable and secure water supply for the growing population in the face of increasing demand.

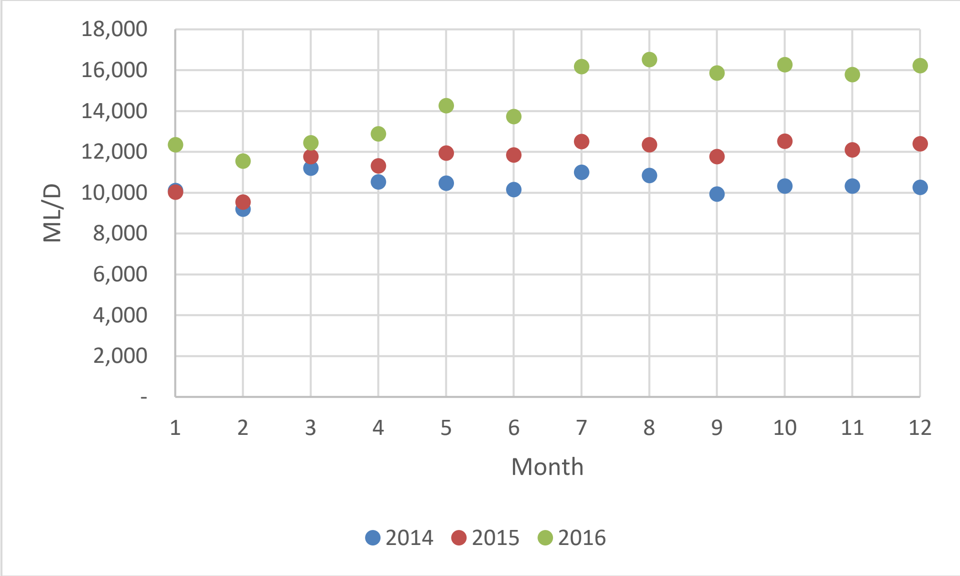

Fig. 3. Example of monthly abstraction from Sg. Tutong for the years 2014 to 2016 (Gödeke et al. 2020)

The actions taken by these agencies likely include the exploration and development of alternative water sources through Vertical Electrical Sounding (VES) method and ground water assessment through Geographic Information System (GIS) mapping obtained from soil investigation reports to identify potential location for groundwater exploration.

2.1 Ground water exploration for agriculture in Brunei Darussalam

While Brunei has achieved remarkable success in rice cultivation, evidenced by the production of 4000 metric tons in 2020, a notable increase from previous years, challenges persist in attaining national sufficiency. Only 8.25% of the targeted 30,517 metric tons has been realized, pointing to a significant gap in achieving self-sufficiency in rice farming. The primary contributing factor to this issue becomes evident during the dry season, wherein the agricultural sector heavily depends on surface water. The inadequacy of water supply from reservoirs during this crucial period becomes a limiting factor, necessitating strategic interventions to bolster the nation's agricultural resilience.

In response to these challenges, the Ministry of Primary Resources and Tourism (MPRT) has spearheaded several governmental projects aimed at enhancing water availability and security. Central to these initiatives is the exploration and utilization of groundwater resources, a critical aspect underscored by the introduction of the Vertical Electrical Sounding (VES) method. This innovative technique involves estimating ground resistivity variations by injecting an artificially generated current into the underground medium and measuring voltage differences at potential electrodes. Through the determination of resistivity values using Ohm's law, aquifers and potential groundwater storage locations are identified. An illustrative example of a VES survey conducted in the Brunei-Muara district shown on Figure 4 unveils the fourth layer as a promising aquifer zone, characterized by favorable resistivity contrasts and values ranging between 10 and 150 Ωm at depths of approximately 30 to 60 m from the surface. Moreover, the alignment of the profile line with the flow direction of the nearby river suggests that this identified aquifer zone holds significant potential for providing a sustainable water supply for the rice farms in the surrounding area.

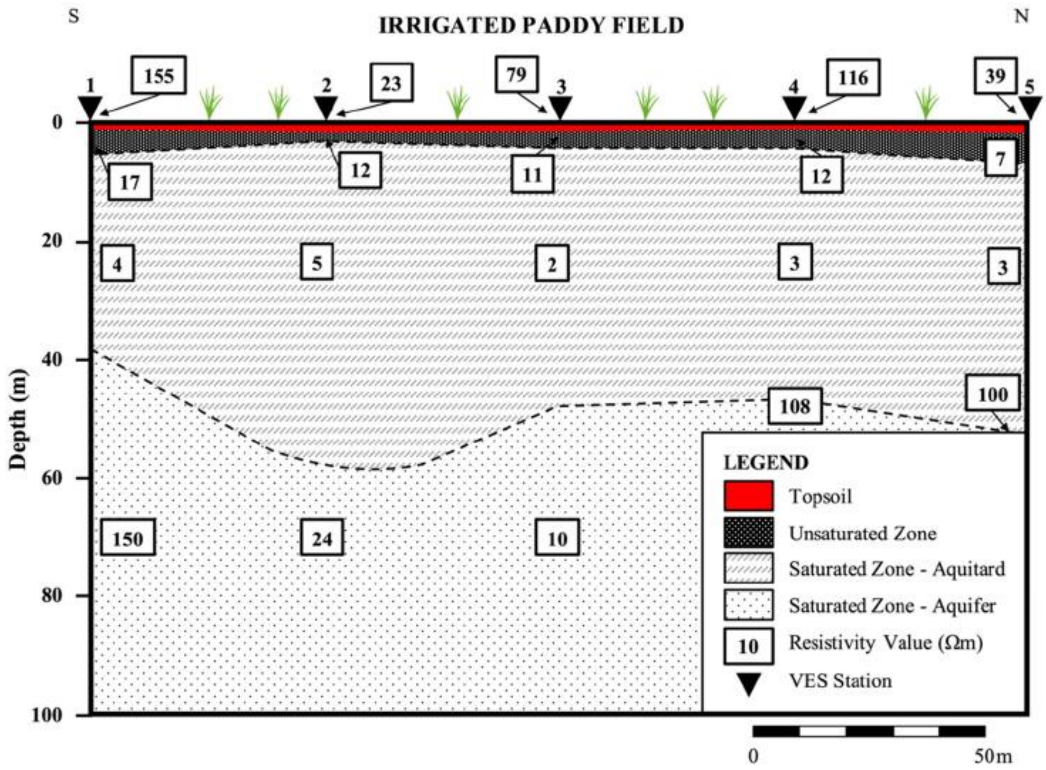

Fig. 4. Geoelectrical section of one of a rice fields in Brunei-Muara District (Azffri et al, 2022)

Meanwhile using the ERT method, it has been proven useful to use in another location with a highly heterogeneous layer to identify a potential water zone (Figure 5). The information that was acquired showed the location has a wide zone 130m depth that has a mixture of Sand, Silt, Clay and Gravel with a chargeability of 1-4 msec that can provide a substantial volume of groundwater for agricultural activities.

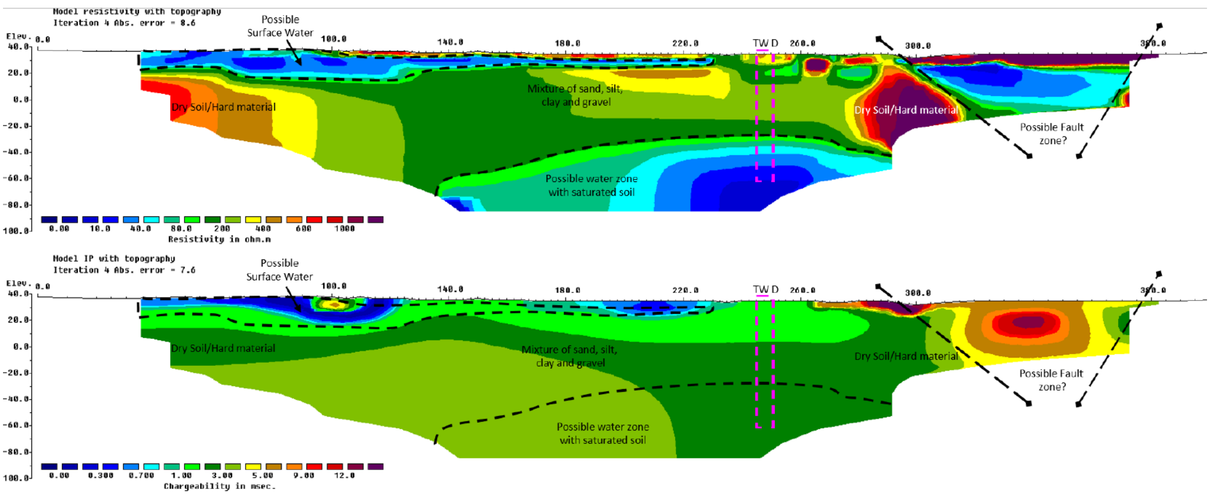

Fig. 5. Electrical Resistivity Tomography (ERT) one an agricultural site in Brunei-Muara District (Department of Agriculture and Agrifood (2023))

This multifaceted and proactive approach, combining surface water and groundwater management strategies, underscores Brunei Darussalam’s commitment to addressing water scarcity, enhancing agricultural productivity, and fostering sustainable water management practices tailored to the unique environmental context of the nation. In doing so, these initiatives position Brunei at the forefront of forging a resilient and sustainable water future.

2.2 Solutions to manage problems related to water resources

The Geotechnical, Geological, and Research Section of the Public Works Department within the Department of Technical Services as well as Universiti Brunei Darussalam is actively engaged in a comprehensive initiative to digitize geotechnical reports emanating from soil investigation projects conducted in adherence to the British Code BS 5930:2015+A1:2020. These projects, constituting a core aspect of the department's responsibilities, serve as crucial support for government-led initiatives by providing foundational advice, particularly in terms of advising on foundations for various projects. The digitized reports encompass a wide array of data, including physical and laboratory testing parameters such as coordinates, borehole information, soil/rock sampling (both undisturbed and disturbed), standard penetration tests, water level measurements, rock coring, and an extensive suite of laboratory tests covering moisture content, bulk and dry density, Atterberg limits, sieve analysis, 1D consolidation test, chemical testing (pH value, salinity, total sulphate, organic matter, chloride contents), and unconfined compressive strength.

As of the latest update in 2022, the ongoing digitization effort has successfully converted 1400 soil investigation reports, spanning data collected from 1967 to the present (See figure 6). This digitization initiative stands as a cost-effective and valuable strategy, utilizing the capabilities of the ArcGIS software to generate informative maps, including but not limited to soil maps. The interpolation of this digitized data offers nuanced interpretations of various soil types within the designated area, providing essential insights into soil hardness.

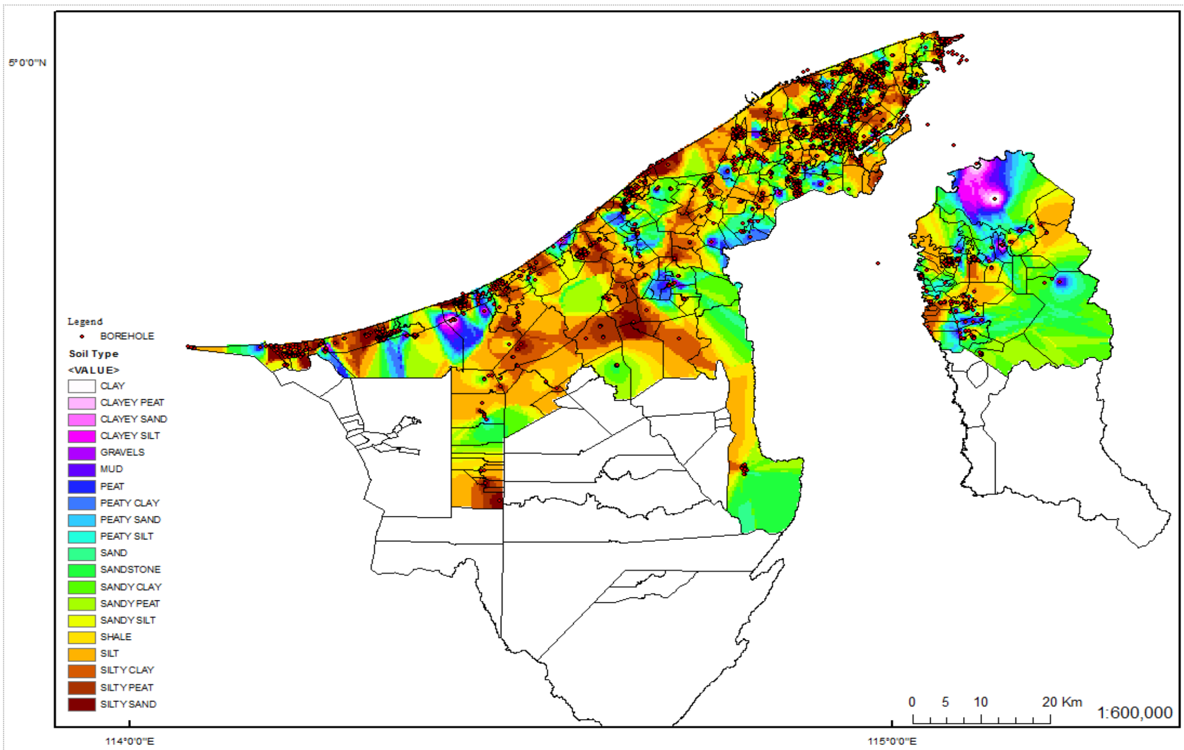

Fig. 6. Topsoil map of Brunei Darussalam with 18 soil classification (Department of Technical Services (2021)

Furthermore, the study incorporates data from 572 sacrificial boreholes to monitor groundwater levels in an area of Brunei-Muara District. A visual representation of the groundwater elevation contours in the study area is illustrated in Figure 6. The groundwater analysis reveals that depths to groundwater in the study area are notably high and shallow, ranging from 0 to 18 meters below ground level, with a mean value of 2.9 meters below ground level. The surface elevation in the area fluctuates between 0.4 and 95 meters above sea level, with a mean value of 22.5 meters below sea level. Simultaneously, groundwater elevations vary from -5.7 to 94.7 meters below sea level, with a mean value of 19.6 meters below sea level. The evaluation of geo-thematic layers and groundwater elevations provides insights into the occurrences and flow paths of groundwater, contributing to a better understanding of the dynamics of the groundwater system in the study area. In coastal regions, groundwater flows towards the South China Sea, while the Brunei River serves as the primary flow path further inland.

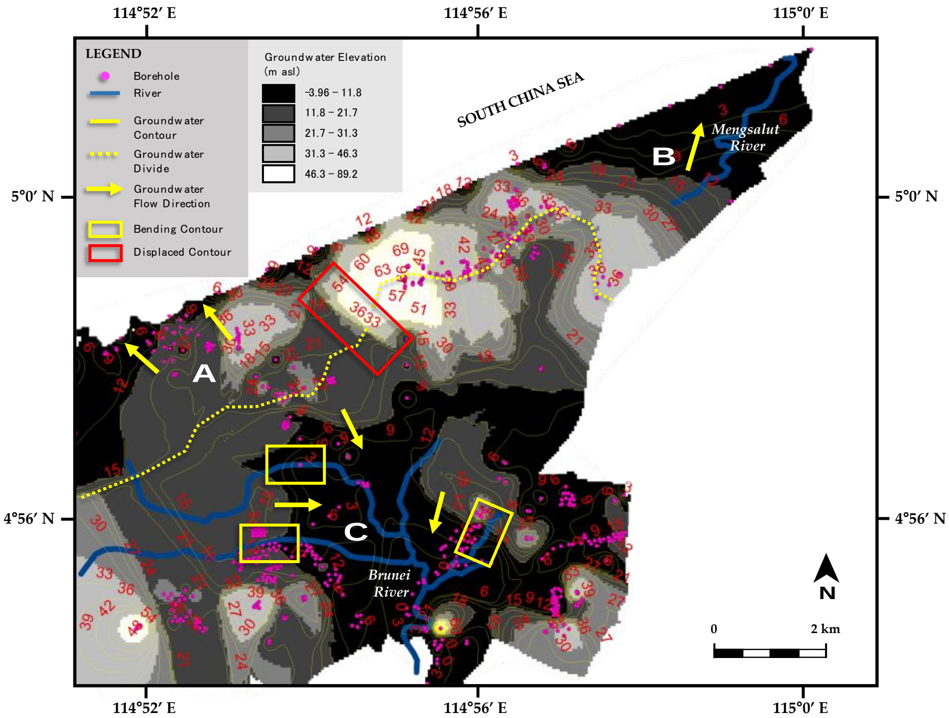

Fig. 7. Groundwater contour map of the study area generated using ArcGIS software

Recognizing the critical role of groundwater monitoring, the study emphasizes its significance in comprehending the availability, sustainability, and health of groundwater resources. Regular monitoring is fundamental for effective water resource management, aiding informed decisions regarding water usage and contributing to the protection of ecosystems reliant on groundwater. Monitoring trends in groundwater levels over time assists in identifying fluctuations, including declining levels or seasonal variations, and provides valuable information for assessing replenishment rates, identifying areas of high recharge, and evaluating the impact of land use practices. This, in turn, allows authorities to implement targeted water restrictions in areas at risk of water degradation.

Looking forward, the study proposes that future investigations should delve into the impact of land use practices on groundwater levels, especially in the burgeoning capital districts of Brunei. Despite limited groundwater exploitation for potable drinking in the country, the potential consequences of overexploitation remain unknown, necessitating dedicated studies. Additionally, distinguishing groundwater elevations between dry and wet seasons becomes a crucial aspect for consideration. The study also sheds light on the connection between poor soil compaction and a high groundwater table as significant contributors to housing structure failure in Brunei, underscoring the importance of groundwater monitoring and mapping in other regions for identifying suitable grounds for future urban development.

As the study establishes the groundwork for a hydrogeology map of Brunei, it sets the stage for future decision-making processes related to groundwater exploration, land-use planning, and environmental impact assessment. The recommendation for continued groundwater mapping and regular monitoring in various regions, particularly in the growing capital districts, underscores the commitment to responsible and sustainable water resource management in Brunei Darussalam. This comprehensive study not only enriches the scientific understanding of groundwater dynamics in the region but also provides practical insights for shaping policies and practices that ensure the judicious use and preservation of this invaluable resource. To ensure sustainable water resource management in Brunei Darussalam, the study advocates for a comprehensive and integrated approach involving collaboration among government agencies, industries, institutions, and communities.

3. Conclusion

In summary, water is crucial for various sectors in Brunei Darussalam, but challenges arise due to the nation's tropical climate. Initiatives, such as exploring additional groundwater resources and using advanced techniques like Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT), demonstrate a proactive approach. The focus on digitizing geotechnical reports and regular groundwater monitoring reflects a commitment to informed decision-making. Brunei's pioneering efforts in groundwater mapping and hydrogeology lay the foundation for sustainable water management, aligning with the country's dedication to water security and a resilient future.

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Current monitoring system and future plan of groundwater in China

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Abstract

The groundwater monitoring work began from 1956 in Beijing, Jinan, Xi'an and Baotou. In 2018, the NGMP with 20,469 automatic monitoring wells was conducted and operated to monitor real-time change of groundwater in major plains and basins. Since it was officially put into operation in 2019, the monitoring project has acquired groundwater level and water temperature monitoring data every year through real-time transmission through the Internet of Things, Beidou Navigation Satellite System et al. By the end of 2021, the daily online operation rate of automatic monitoring equipment for monitoring projects has remained above 95%. Based on the data, the Natural Resources Departments have basically mastered the change of groundwater level, dynamic characteristics and water quality in major plains and basins across the country. Recently, a national groundwater annual observation network has been organized, covering 7.4 million km^2, realizing effective monitoring of groundwater in China's main plain basins and human activities and economic development areas. It provides a stable and reliable data source for national water resources management and water resources research of scientific research institutes, and serves the needs of the public and scientific research and teaching.

Keywords:

China is one of the earliest countries in the world to exploit and utilize groundwater, starting with the Hemudu culture 7,000 years ago. Since 1950s, a series of groundwater monitoring programs have been conducted throughout the country. The National Groundwater Monitoring Project (Phase I) has been built and automatic monitoring data has been used for national groundwater resource assessment and national groundwater quality assessment since 2018.

In 2021, the total water consumption in the country amounted to 5,920.2 billion cubic meters. Surface water accounted for 4,928.1 billion cubic meters or 83.2% of the total water supply. Groundwater supplied 853.8 billion cubic meters, representing 14.5% of the total supply, while other water sources contributed 138.3 billion cubic meters or 2.3% of the total supply. The country's underground water resources totaled 8,553.5 billion cubic meters, with 1,198.2 billion cubic meters of non-duplicated underground water resources distinct from surface water(China Water Resources Bulletin 2021，2022)

Water deficits and pollution have become exacerbated at a global scale due to increased human activities and global climate change (Gao et al., 2020, Gao et al., 2021a, Xiao et al., 2019, Arto et al., 2016). Groundwater utilization in China faces two main challenges (Wang et al., 2023). Firstly, there is a serious overexploitation of groundwater. The demands for water from residents, industry, and agriculture have increased sharply with recent socioeconomic development, leading to unsustainable groundwater exploitation in some areas and a deterioration in groundwater quality (Liu, et al., 2023). The intensive exploitation of aquifers has caused a continuous decline in groundwater levels in several parts of the world, including northwest India, north China, and the central United States (He et al., 2015). However, recent developments in water conservation and groundwater exploitation management have resulted in a decrease in the amount of groundwater exploitation in China in recent years. Secondly, pollution has become a prominent issue. In 2021, water quality data was collected from 1900 national groundwater environmental assessment sites, which revealed that 79.4% of the sites were classified as Class I to IV water quality, whereas the remaining 20.6% were designated as Class V water quality. Sulfates, chlorides, and sodium were the primary pollutants that exceeded the permissible standards (Ren, et al., 2022).

To respond to the aforementioned challenges, substantial efforts have been undertaken over the past decade. These include not only implementing management measures to reduce groundwater extraction as previously mentioned, but also compiling a new generation of high-quality hydrogeological maps, identifying and verifying groundwater quality background values, enhancing techniques for exploring groundwater layers. and integrating the key and practical techniques of layer exploration and monitoring (Wu.et al., 2020).

1. Introduction

1.1 History of Groundwater Monitoring

Groundwater level monitoring has been conducted for many decades in China since 1950s, data from these networks have been used to help identify, develop and manage groundwater supplies. Groundwater quality monitoring programs have been developed more recently in response to the focus on water quality that resulted from the comprehensive environmental response. The groundwater monitoring work can be divided into four primary stages. The first stage involved the establishment of local groundwater monitoring networks in seven provinces' typical cities, namely Beijing, Jinan, Baotou, Xi'an, Shanghai, Tianjin, and Shijiazhuang, during the period from 1950 to the 1970s.The second stage, spanning from the 1980s to 2003, involved the establishment of a regional groundwater monitoring network in 17 provinces located in northern China. In the third stage, from 2003 to 2013, the regional network expanded to cover 31 provinces. Notably, during this stage, three cities, namely Beijing, Jinan, and Urumchi, implemented an Automatic Groundwater Monitoring Demonstration Project. The fourth and final stage is the National Groundwater Monitoring Program (NGMP). Through each of these stages, China's groundwater monitoring efforts have gradually progressed from being locally implemented to covering most parts of the country, with an increase in monitoring density and the achievement of basic automation, significantly improving monitoring capabilities and standards. The establishment and management of a National Groundwater Monitoring Network in China would represent a significant achievement in water-resource management. The need for groundwater monitoring focused on the major aquifers and aquifer system in China is increasingly important as a key element of sustainable groundwater resource management and use.

1.2 Status of National Groundwater Monitoring Project

The National Groundwater Monitoring Program (Phase I) was jointly initiated and implemented by the Ministry of Natural Resources and the Ministry of Water Resources, with approval from the National Development and Reform Commission， construction principle is With main hydrogeological unit as the basic unit, the groundwater in large plains, basins and karst areas was monitored regionally by points and crossing sections. In densely populated areas, National ecological construction and environmental protection areas, large energy and mining bases, National major engineering areas, large groundwater source areas, groundwater overextraction areas, comprehensive monitoring system was adopted by point, line and area control.

As of 2018, the National Groundwater Monitoring Program (Phase I) has been completed and put into operation, with a total of 20,469 automated groundwater monitoring stations and the National Groundwater Monitoring Center established. This has formed a national groundwater monitoring network, covering an area of 3.5 million square kilometers, with a resolution of 0.58 monitoring points per 100 square kilometers. The monitoring network is deployed in 31 provinces (municipalities and regions) across seven major river basins, including the Hai River Basin, Huai River Basin, Yellow River Basin, Yangtze River Basin, SongHua River Basin, Liao River Basin, and Northwest Inland River Basin. In densely populated areas, urban built-up areas, large and extra-large groundwater sources, major national engineering areas, overexploited groundwater areas totaling 1.26 million square kilometers, monitoring has been intensified with a resolution of 1.03 monitoring points per 100 square kilometers. In large plain basins and karst areas totaling 2.24 million square kilometers, the monitoring resolution is 0.36 monitoring points per 100 square kilometers. All dynamic groundwater level monitoring information is automatically monitored in real-time, and monitoring devices in wells can realize online monitoring of parameters such as groundwater level, temperature, and conductivity, with a monitoring frequency of once per hour. Groundwater quality monitoring is conducted once a year, with 37 testing indicators. The NGMP information center and service platform provides the real-time data via Geo-Cloud and mobile App.

Considering the inadequate coverage of the existing national groundwater monitoring project, the China Geological Survey (CGS) has organized a national groundwater level survey once a year since 2019. On the one hand, this is to strengthen the groundwater level monitoring in areas with intensive exploitation of groundwater in the central and eastern plains. On the other hand, it is to conduct a water level survey in the northwestern and southwestern regions of China where the existing groundwater monitoring project has not yet fully covered, in order to obtain the groundwater level data of the major river basins nationwide. After the implementation of the survey supplement, the coverage of national dynamic groundwater monitoring has reached 7.3 million square kilometers, which can support the realization of national groundwater resource evaluation and zoning and other related work. CGS organized and established national groundwater resources annual assessment operation mode from 2019 to 2021 for supporting natural resources management; and annual assessment of national groundwater resources from 2020 to 2021 were conducted via the online assessment system.

The National Groundwater Monitoring Center comprises of an Operations and Monitoring Center, a Data Application Service Center, and a Water Quality Testing and Quality Control Laboratory. The Operations and Monitoring Center includes systems for communication, monitoring station operation, and data management, which constantly monitor the operational status of monitoring stations in real-time. The Data Application Service Center includes systems for processing, analyzing, and evaluating data, as well as information dissemination. It also forms a business interaction platform with departments such as the Ecology and Environment, Education, and the Chinese Academy of Sciences, as well as 31 provincial natural resource departments. The Water Quality Testing and Quality Control Laboratory conducts testing for all 93 national groundwater quality standards for organic and inorganic water chemistry.

2. **Existing Problems**

China has a vast territory. The coverage and monitoring accuracy of the existing national groundwater monitoring projects are far from the national demand and the international advanced level. Two thirds of the land area has not been effectively covered, and the monitoring density is less than one percent of the international advanced level. There are 3 main problems for national groundwater monitoring in China, the first one is Inadequate coverage: the monitoring stations only cover one third of national terrestrial area, there are still vacancies for 95 out of 102 fourth-grade groundwater conservation sites in Qilian Mountain and Qinghai-Tibetan glacial permafrost region. The second one is Low density: the current density is only one fourth of national standard of 120 stations per ten thousand km^2, and one sixth in the agricultural areas like Songnen Plain and Sanjiang Plain. The third one is inadequate intelligent operation and service: small capacity of information infrastructure led to incomplete intelligent control, and there is inadequate integration between artificial intelligence, deep learning, knowledge spectrum and groundwater prediction and warning.

3. Plan for Future

It's intended to take 5-10 years to build National Groundwater Monitoring Project (Phase II) with high precision and resolution, real-time online and intelligent operation and maintenance, and multi-dimensional output. More groundwater monitoring stations will be built to achieve effective coverage of groundwater monitoring in ecologically fragile areas, major agricultural production areas and densely populated areas.

Promote groundwater monitoring in the ecological vulnerable areas: To Fully cover the ecological vulnerable and water conservation areas like Qinghai-Tibet Plateau, Sanjiangyuan, Qilian-Qinling, Inner Mongolian Plateau, and Northern forestation area.

Increase monitoring density in agricultural area and groundwater over exploitation regions: To increase monitoring stations in Huanghuaihai Plain, Fenwei basin, North-eastern Plain, Jianghan Plain and the north slope of Tianshan, and strengthen layered monitoring of multi-layered aquifer systems.

Strengthen groundwater monitoring in mineral resources prospecting regions and major urban areas: To increase monitoring stations in Loess Plateau-Taihang Mountain, Northern Hebei-Western Liaoning, et al, and urban areas along the middle reaches of Yangtzi River, and reinforce monitoring of influence of mineral prospecting and urban construction over groundwater.

4. Conclusion

The development and utilization of groundwater has played an important role in supporting China's economic development and improving people's livelihoods. The continuous progress and development of groundwater monitoring work has provided important support for detailed understanding of China's groundwater dynamics. The completion of the first phase of the National Groundwater Monitoring Project has greatly improved China's groundwater monitoring capabilities and standards. However, there are still certain gaps in terms of coverage, monitoring density, and intelligent services, which need to be continuously improved and perfected by enhancing the monitoring network and monitoring technologies.

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Groundwater monitoring system in Indonesia

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Abstract

Groundwater extraction in Indonesia is increasing, especially in big cities such as Jakarta, Surabaya, Medan and Bali. Efforts are needed to control groundwater damage by integrating surface water and groundwater management such as the application of conjunctive use of surface water and groundwater by prioritizing the use of surface water first. One of the efforts to control groundwater damage in Indonesia is carried out by groundwater monitoring based on groundwater basins.

Groundwater monitoring is carried out by the Geology Agency, the ministry of energy and mineral resources. The groundwater monitoring system uses the concept of groundwater basin management. In Indonesia there are 421 groundwater basins. The groundwater monitoring system in Indonesia is carried out directly and indirectly. Groundwater monitoring is directly carried out by making groundwater conservation zone maps which are updated every 5 years and groundwater data inventory periodically in groundwater basins with intensive groundwater extraction. The result of direct groundwater monitoring is a groundwater conservation zone map. Making a conservation zone map aims to determine the zones of groundwater damage as a basis for granting groundwater extraction permits.

Indirect groundwater monitoring by constructing groundwater monitoring wells in each groundwater basin. Currently, there are 82 groundwater monitoring wells built by the Geology Agency, the Ministry of Energy and Mineral Resources, besides that there are also several monitoring wells built by local governments. Information and data obtained from groundwater monitoring wells, namely groundwater table data. Groundwater level from monitoring wells can be obtained in real time using the AWLR (Automatic Water Level Recording) method, this data can be accessed via http://mypatriot.id/. Groundwater monitoring results show that there are several areas in Indonesia that have experienced groundwater damage and the process of forming groundwater is decreasing, including the Jakarta Groundwater Basin, Serang-Tangerang Groundwater Basin, Bogor Groundwater Basin, Karawang-Bekasi Groundwater Basin, Groundwater Basin Bandung Land, Pekalongan-Pemalang Groundwater Basin, Semarang-Demak Groundwater Basin, Karanganyar Groundwater Basin, and Denpasar-Tabanan Groundwater Basin. The damage that occurred was an extreme decrease in the groundwater level of more than 40% of the initial condition groundwater level and experienced seawater intrusion, especially in coastal areas such as the coasts of Jakarta, Semarang, Demak and Pekalongan.

Keywords: groundwater basins, monitoring wells, groundwater conservation

1. Introduction

The need for water resources is mostly met from groundwater sources. Based on data from the Indonesian Central Bureau of Statistics in 2022, more than 70% of the need for clean water for households and industry in Indonesia is met from groundwater (Fig. 1). The fulfillment of water needs for the agricultural sector in the Southeast Asian region is predominantly fulfilled from groundwater. (Villholth, 2013). Groundwater supply for the needs of the agricultural sector is more than 40% (Fig. 2). The need for groundwater is increasing along with population growth, expansion of agricultural land and industrial development (Jasrotia et al, 2012).

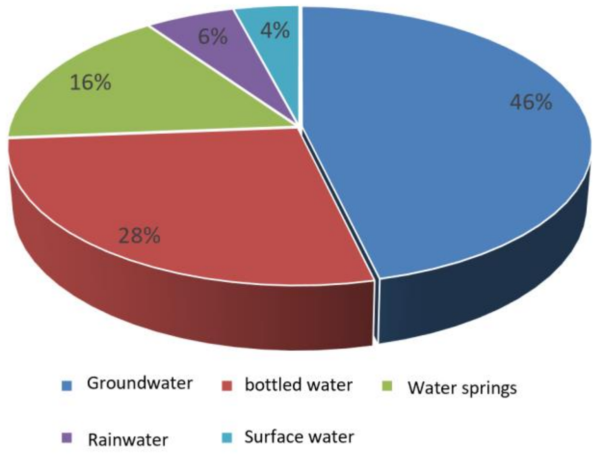

Fig. 1. Fulfillment of clean water needs for households in 2022 in Indonesia (BPS-Statistics Indonesia, 2022)

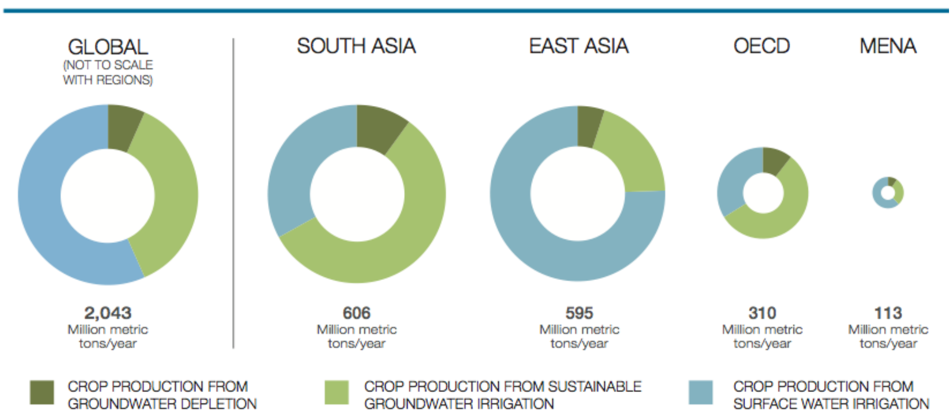

Fig. 2. Diagram of groundwater demand for the agricultural sector in the Southeast Asia Region (Villholth, 2013).

2. Groundwater Management system in Indonesia

Groundwater management in Indonesia begins with collecting groundwater data related to aquifer lithology and aquifer productivity, then analysis is carried out and the output is in the form of a hydrogeological map (Fig. 3). Basic groundwater data in Indonesia is a hydrogeological map, from which the hydrogeological map was developed into a groundwater basin map containing information on hydrogeological boundary conditions. Each groundwater basin in Indonesia is developed into a groundwater potential map and a groundwater conservation zone map.

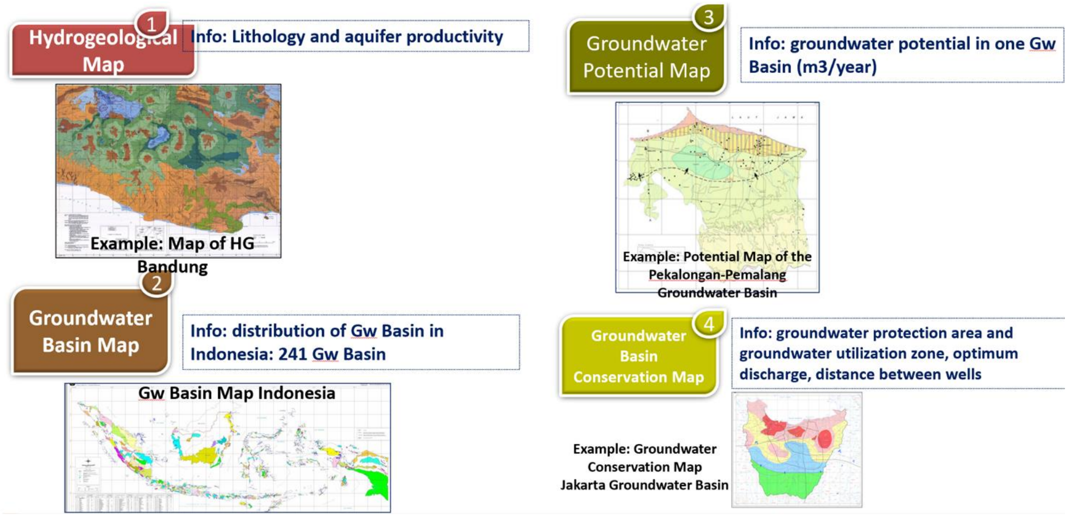

Fig. 3. Technical flow of groundwater management in Indonesia

3. Current monitoring system of groundwater in Indonesia

Indonesia already has a groundwater monitoring system that is carried out directly and indirectly. Groundwater monitoring is directly carried out by measuring groundwater condition parameters in the field with the object of measuring drilled wells, dug wells, springs (Fig. 4). Parameters measured were the groundwater table, groundwater quality such as pH value, conductivity, and groundwater chemical parameters. The output of direct groundwater monitoring is groundwater quantity and groundwater quality data periodically.

Fig. 4. Direct groundwater monitoring in Indonesia

Indirect groundwater monitoring is carried out by building a network of groundwater monitoring wells. The function of this groundwater monitoring well is to obtain real-time and periodic groundwater data. The workings of groundwater monitoring wells are by using the automatic water table recorder (AWLR) method. Groundwater measuring sensors are installed in monitoring wells and these sensors will send data to a server at the Center for Groundwater and Environmental Geology, Indonesian Geological Agency (Fig. 5).

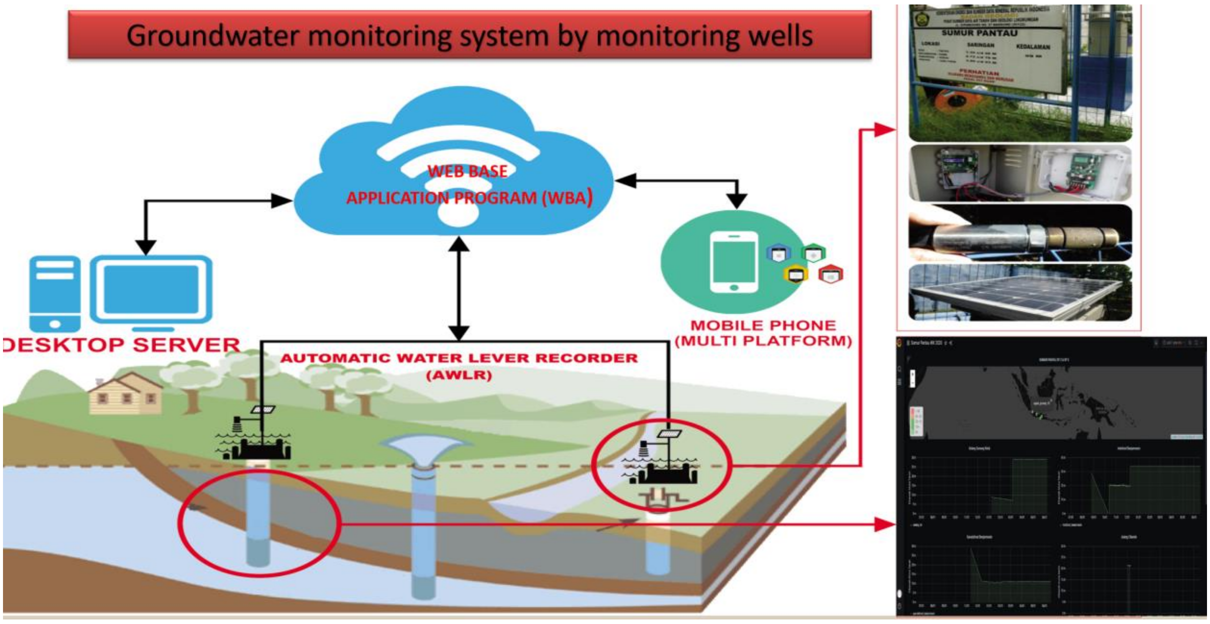

Fig. 5. Groundwater monitoring system using monitoring wells

Currently there are 82 groundwater monitoring wells with AWLR installed. Specifically for the Indonesian Capital City, Jakarta, there are 35 groundwater monitoring wells with AWLR installed (Fig. 6). Data from groundwater monitoring results with monitoring wells can be accessed via http://mypatriot.id/.

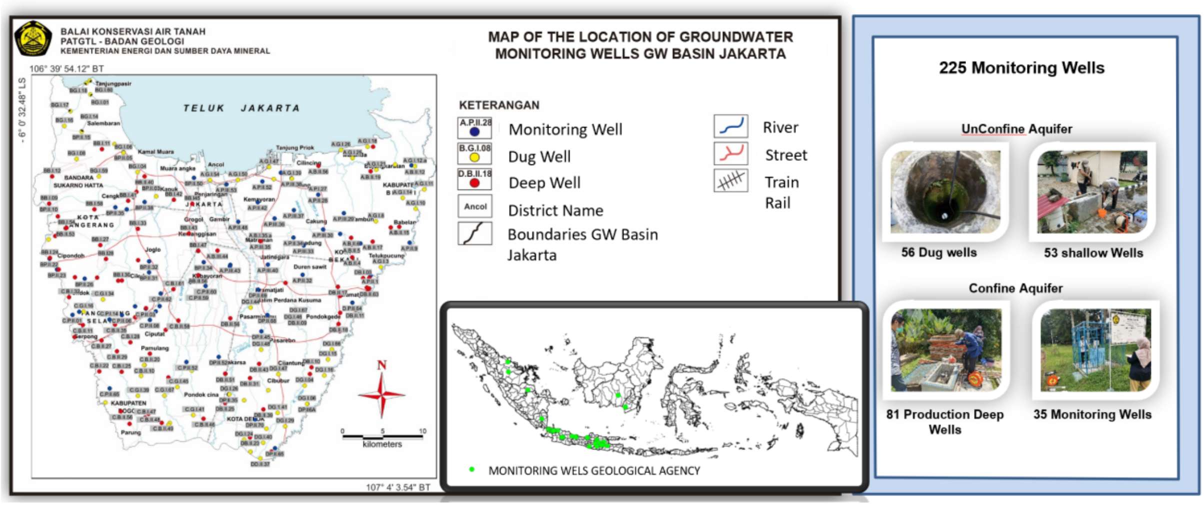

Fig. 6. Network of groundwater monitoring wells in the Indonesian Capital City, Jakarta

4. Groundwater Monitoring System Results

Groundwater monitoring results show that there are several areas in Indonesia that have experienced groundwater damage and the process of forming groundwater is decreasing, including the Jakarta Groundwater Basin, Serang-Tangerang Groundwater Basin, Bogor Groundwater Basin, Karawang-Bekasi Groundwater Basin, Groundwater Basin Bandung Land, Pekalongan-Pemalang Groundwater Basin, Semarang-Demak Groundwater Basin, Karanganyar Groundwater Basin, and Denpasar-Tabanan Groundwater Basin (Fig. 7). The damage that occurred was an extreme decrease in the groundwater level of more than 40% of the initial condition groundwater level and experienced seawater intrusion, especially in coastal areas such as the coasts of Jakarta, Semarang, Demak and Pekalongan.

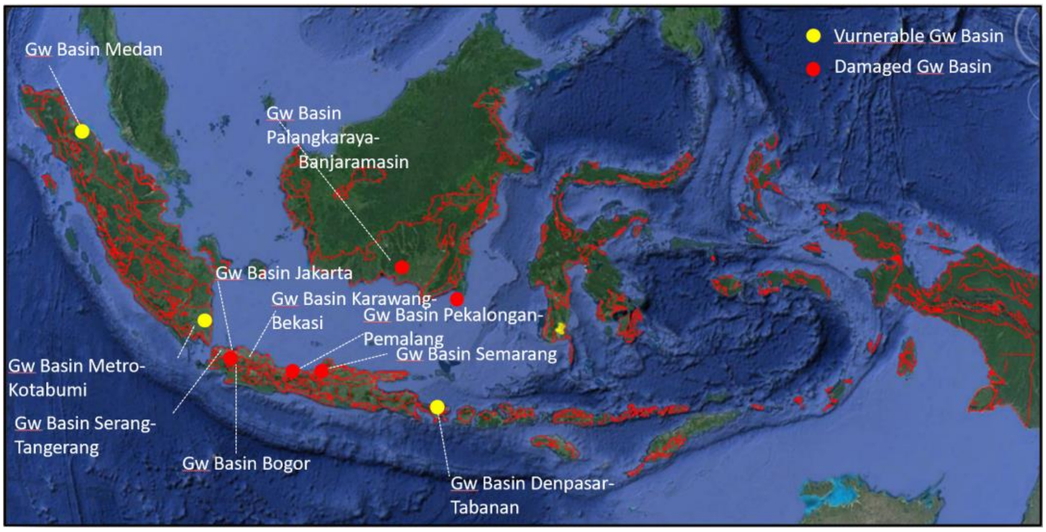

Fig. 7. Distribution map of critical-damaged groundwater basins in Indonesia

Criteria for Critical or Damaged Groundwater Basin is obtained based on groundwater monitoring with a product in the form of a groundwater conservation zone map. The groundwater conservation zone map contains information on groundwater extraction restriction zones. There are 5 zones namely safe zone, vulnerable zone, critical zone, damaged zone and groundwater protection zone or groundwater recharge zone based on the Regulation of the Minister of Energy and Mineral Resources No 31 of 2018 concerning Guidelines for Establishing Groundwater Conservation Zones. The groundwater conservation zone is used as the basis for limiting groundwater extraction for the industrial sector's clean water needs.

Based on groundwater monitoring results in the Jakarta Basin, groundwater conditions have improved, namely there are several areas experiencing rising groundwater levels in confined groundwater aquifers with depths of up to 125 m, such as the Kapuk area and Pulogadung area.

The groundwater level in the Pulogadung-East Jakarta area, in 2016 was at a level of 22.46 m below the ground level, experiencing an increase in the groundwater level from 2018 to 2021, the value of the increase in the groundwater level in this area is 3.81 m in span of 5 years. (Fig. 9). The groundwater level in the Kapuk-North Jakarta area, in 2016 was at a level of 14.03 m below the ground level, experienced an increase in the groundwater level from 2016 to 2019, the value of the increase in the groundwater level in this area was 1.76 m in span of 3 years. (Fig. 9).

Based on the contour map of the groundwater table, there is a change in the contour of the groundwater table from 2013 to 2021 which indicates an increase in the groundwater level. In 2013 in the Pulogadung area the deepest groundwater level was -40 m below sea level, in 2021 the groundwater level has increased to -35 m below sea level. (Fig. 10)

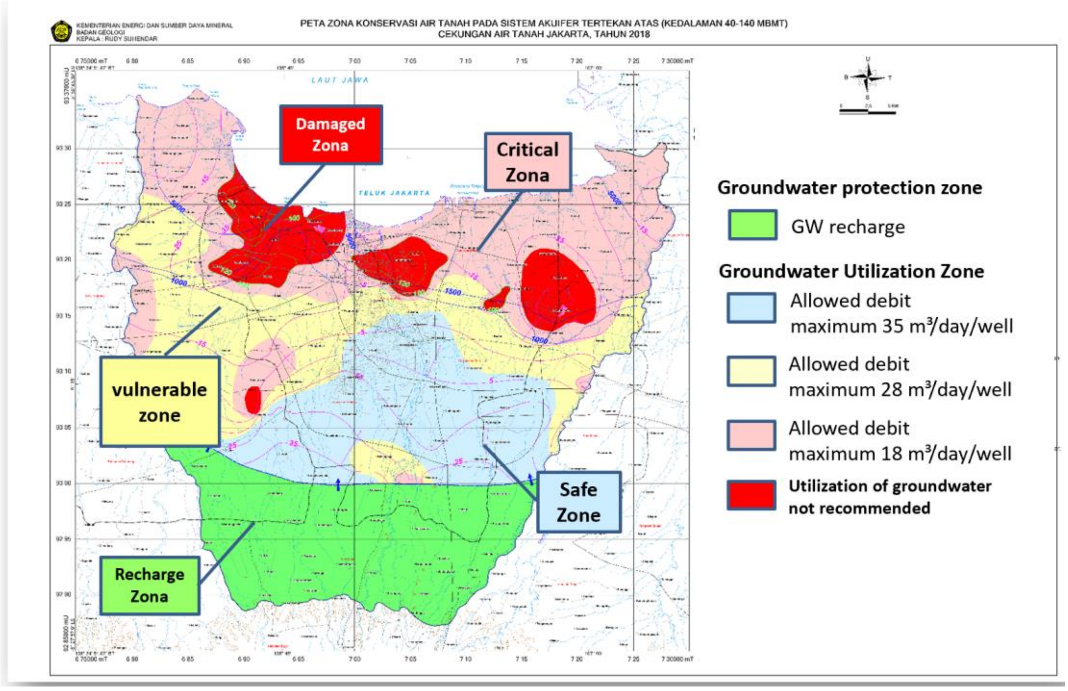

Fig. 8. Groundwater Conservation Zone Map of the Jakarta Groundwater Basin

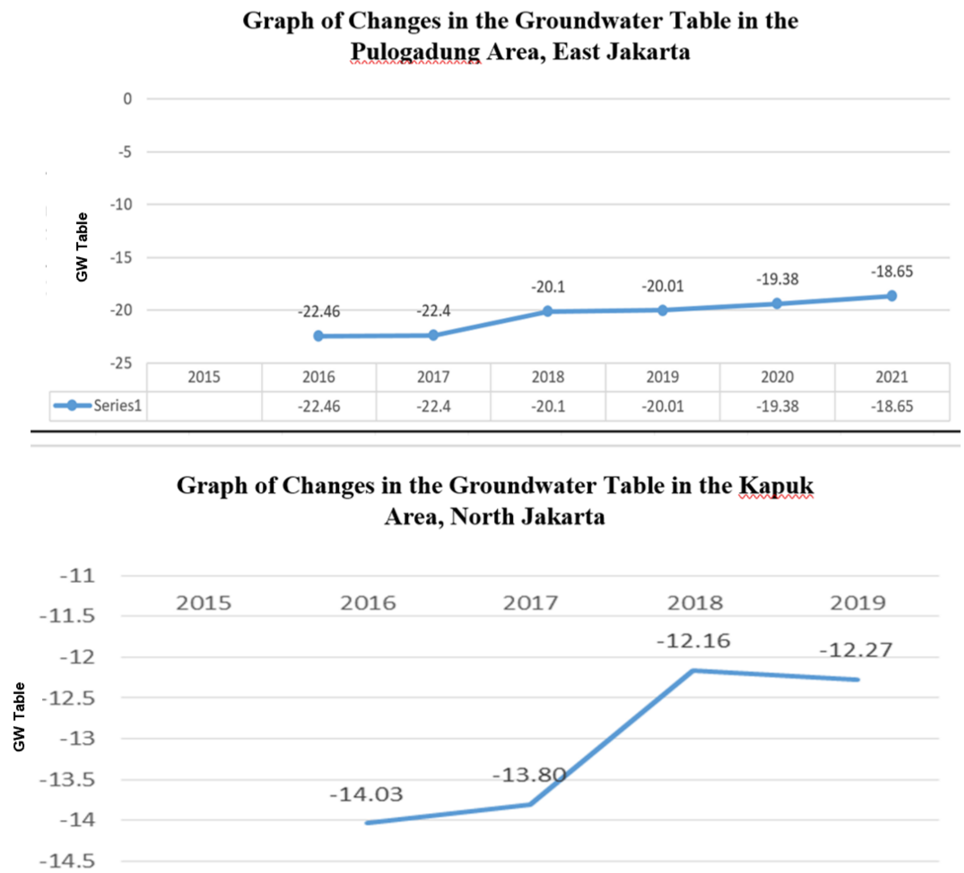

Fig. 9. Trend of groundwater Table rise in the Pulogadung area and Kapuk area in the Jakarta Groundwater Basin

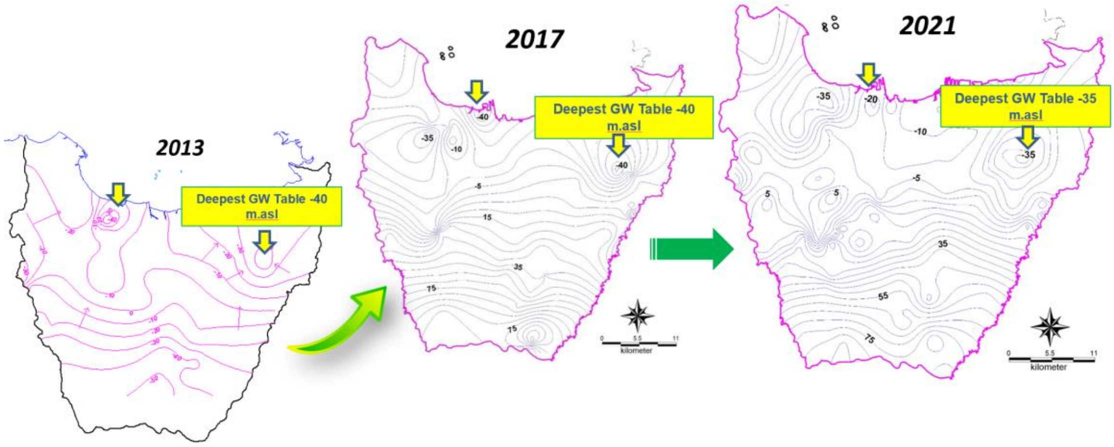

Fig. 10. Map of the evolution of groundwater surface contour changes in the Jakarta Groundwater Basin in 2013 – 2021

5. Conclusion

Indonesia already has a groundwater monitoring system that is carried out directly and indirectly. Direct groundwater monitoring by taking groundwater data directly in the field by collecting data periodically, while indirect groundwater monitoring is using a groundwater monitoring well network system and the data obtained is in the form of groundwater levels which are sent in real time to the server. The groundwater monitoring system in Indonesia is used to create groundwater conservation zone maps, the use of this map is to control groundwater extraction.

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Current monitoring system of groundwater and surface water in Japan, and existing problems

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Abstract

Total usage of river water and groundwater in Japan is 70.2 and 8.8 billion m^3/year, respectively. Groundwater and surface water are monitored by four ministries, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Ministry of Environment (MoE), Ministry of Health, Labor and Welfare (MHLW) and Ministry of Economy, Trade and Industry (METI). Hydrological water quality database of MLIT can be taken as a representative monitoring system of Japan. MoE’s Water and Air Environment Department particularly monitors groundwater contamination. MHLW monitors the tap water supply quality and publishes its database. METI manages database mainly for industrial water facilities. The monitoring system in Japan is not integrated and centralized. The Basic Law on the Water Cycle enacted in 2014 is strict in the case of point sources of pollution, however, in the case of non-point sources of pollution it is not strict enough. Although the law does not address penalties for causing pollution of water sources, local governments can construct suitable local ordinances based on this law.

Keywords: monitoring, groundwater, surface water, database, Japan

1. Introduction

Total usage of river water and groundwater in Japan is 70.2 and 8.8 billion m^3/year, respectively (Fig. 1). As a result of abundant rainfall and steep topography, there is a constant supply of good quality river water. Thus, river water is the main water source (89 %) in Japan. Groundwater is also used in Japan (11 %) and its economic efficiency, consistent quality, and stable temperature have greatly contributed to the development of regional economies. However, there are several water-related disasters and problems, such as land subsidence, water shortages in dry summers, and floods after typhoons, which pose potential issues in maintaining current water supply and sustainable use of groundwater.

In Japan, groundwater and surface water are monitored by the four ministries, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Ministry of Environment (MoE), Ministry of Health, Labor and Welfare (MHLW) and Ministry of Economy, Trade and Industry (METI). Hydrological water quality database of MLIT can be taken as a representative monitoring system of Japan, which includes rainfall, water level, flow rate, water quality, groundwater level, groundwater quality, snow depth etc. The database is open to public. Representative staffs contracted by MLIT conduct groundwater monitoring at monitoring wells every month. MoE’s Water and Air Environment Department monitors groundwater contamination. MHLW monitors the tap water supply quality and publishes its database. METI manages database mainly for industrial water facilities. There are separate water quality standards for tap water supply and groundwater. In addition, groundwater maps and hydrogeological maps were also developed for the appropriate use and conservation of groundwater.

The monitoring system in Japan is not integrated and centralized. The Basic Law on the Water Cycle enacted in 2014 is strict in the case of point sources of pollution, however, in the case of non-point sources of pollution it is not strict enough. Although the law does not address penalties for causing pollution of water sources, local governments can construct suitable local ordinances based on this law.

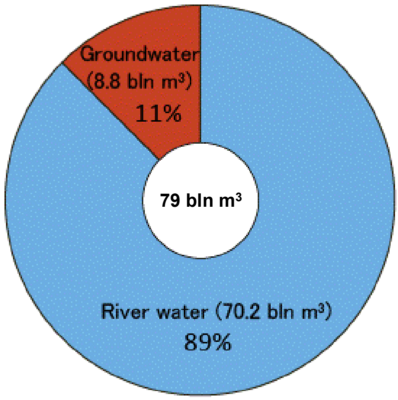

Fig. 1. The annual percentage usage of river water and groundwater in Japan (MLIT, 2021)

2. Current monitoring system of groundwater and surface water in Japan

In Japan, groundwater and surface water are monitored by the four ministries, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Ministry of Environment (MoE), Ministry of Health, Labor and Welfare (MHLW) and Ministry of Economy, Trade and Industry (METI). MLIT is actively conducting groundwater and surface water surveys, and their monitoring, for which a budget is allocated. Representative staffs contracted by MLIT conduct groundwater monitoring at monitoring wells every month. Hydrological water quality database "Water Information System" of MLIT can be taken as a representative monitoring system of Japan. It publishes monitored data and is downloadable for free.

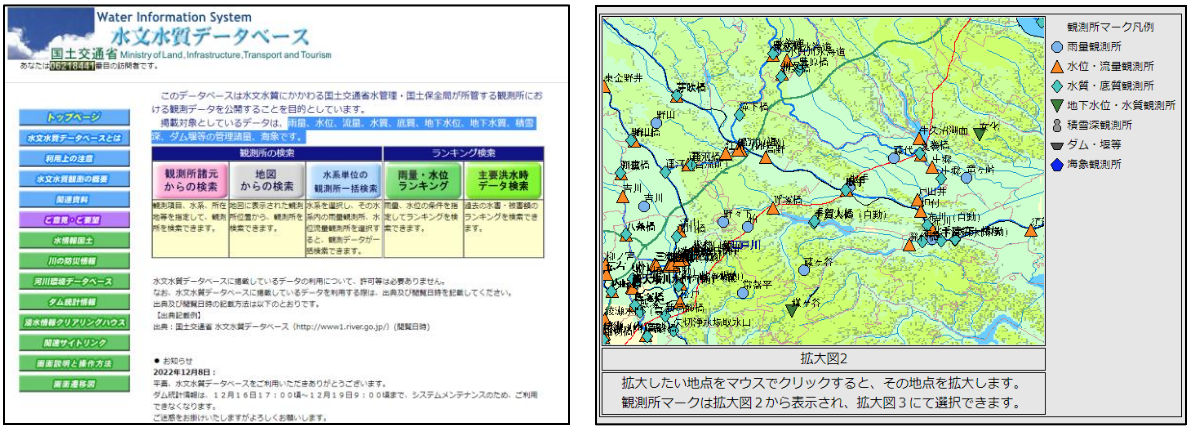

Fig. 2. Water Information System of MLIT (Reference: MLIT homepage)

Water and Air Environment Department of Ministry of Environment (MoE) particularly monitors groundwater contamination. Results of groundwater quality monitoring done each year are published in an annual report. MoE conducts three types of surveys, 1) General survey, 2) Polluted well's surrounding area survey and 3) Continuous survey at areas where pollution is confirmed. In General survey, there are about 4,000 monitoring points. A method called "rolling method" is used in the General survey, in which some parts are monitored in a year and the remaining parts in other years.

Ministry of Health, Labor and Welfare (MHLW) generally monitors tap (or pipe) water supply quality. More than 80 % of tap water sources use river water, so river water data is more in the Database of Water Quality of Aqueduct. Water quality data of both source and treated water are published.

Ministry of Economy, Trade and Industry (METI) monitors water sources being used for industries and the database is for industrial water facilities. The database basically includes river water data. Although groundwater is used for industrial purposes, it accounts for about 6 % only.

Additionally, for appropriate use and conservation of groundwater, and mapping of national groundwater data record (inventory), MLIT developed Groundwater Maps for 11 regions in the period of 1990 to 2002. These maps feature aquifer types, specific discharge, groundwater usage etc. Recently, Geological Survey of Japan has been continuously developing Water Environment Maps with groundwater information.

3. Monitoring items, purpose/ usage of monitored data and database

The main objective of the monitoring system is to protect water sources' quantity and quality. MoE and MHLW are checking if the legal standards are clear or not. Basically, there are two standards set for water quality monitoring. One is the Tap water quality standard and the other is the Groundwater environment standard.

"Water Information System" database of MLIT publishes the monitored data of monitoring station, which includes rainfall, water level, flow rate, water quality, groundwater level, groundwater quality, snow depth etc. The database is open to the public. Representative staffs contracted by MLIT conduct groundwater monitoring at monitoring wells every month. Geological Survey of Japan also conduct measurements at these wells for the research purposes after obtaining a permission. Further, MLIT manages basic information and data on national land such as water sources, land use, topography, public facilities etc. and publishes as GIS data. MoE basically monitors groundwater with items such as Cd, Pb, As, NO_3, NO_2, 1,2-dichloroethane, 1,1-dichloroethylene, fluorine, boron, 1,4-dioxane etc. (Fig. 3). Data on monitoring points is open but detailed addresses are not published for privacy reasons.

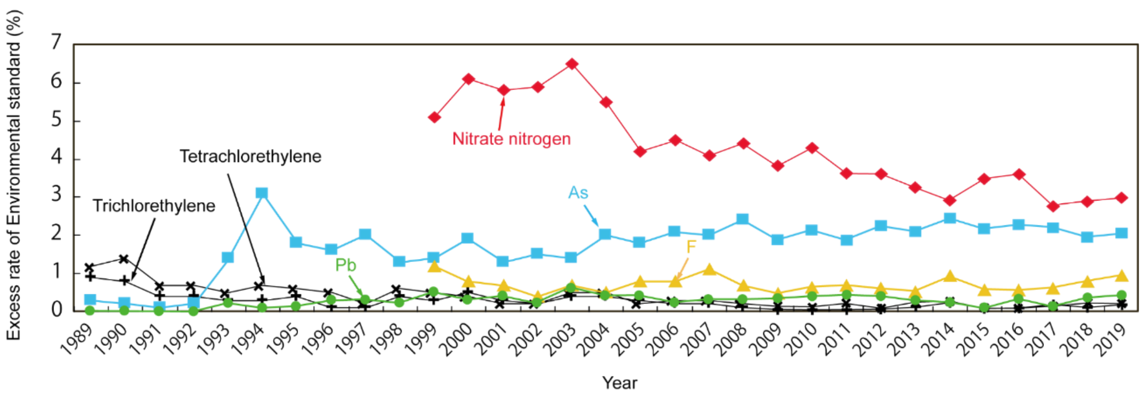

Fig. 3. Percentage exceeding environmental standard (10 mg/L of NO_3-N; MoE, 2021)

MHLW monitors tap water supply quality of both water source and treated water. The monitoring items are based on WHO drinking water quality guidelines. There is a control target for toxic items such as uranium and nickel, not commonly detected in Japan. Sites where these items are detected are under investigation and monitoring.

4. Existing problems and future tasks

Monitoring system in Japan is not centralized and integrated. Different ministries have different monitoring systems and respective databases with different objectives and purposes. The Basic Law on the Water Cycle enacted in 2014 is strict for the point sources of pollution, however, in the case of non-point sources of pollution it is not strict enough. Although the law does not address penalties for causing pollution of water sources, local governments can construct suitable local ordinances based on this law for the conservation of the water sources in the near future.

5. Conclusions

Monitoring system in Japan is not centralized and integrated. Groundwater and surface water are monitored by the four ministries, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Ministry of Environment (MoE), Ministry of Health, Labor and Welfare (MHLW) and Ministry of Economy, Trade and Industry (METI). "Water Information System" database of MLIT can be taken as a representative monitoring system of Japan. Different ministries have different monitoring systems and databases with different objectives and purposes. The Basic Law on the Water Cycle enacted in 2014 is strict for the point sources of pollution, however, in the case of non-point sources of pollution it is not strict enough.

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Current monitoring system of groundwater and surface water in Republic of Korea, and existing problems

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Abstract

The Republic of Korea has several monitoring systems of water resources. The monitoring data are provided to the public through web sites (e.g., WAMIS, GIMS) and annual reports. The WAMIS (Water Resources Management Information System) provides hydro/meteorological data including rainfall and surface water levels, which are hourly measured at gauging stations. In addition, Water Now Map is updated every day at WAMIS to visualize the current condition of outflows compared to previous data. Groundwater data are collected through National Groundwater Monitoring Network (NGMN), Groundwater Quality Monitoring Network (GQMN), Supplementary Groundwater Monitoring Network (SGMN), Rural Groundwater Monitoring Network (RGMN), and Seawater Intrusion Monitoring Network (SIMN). In NGMN, water levels, electrical conductivity, and temperature are automatically and hourly measured, while water quality is determined twice a year for 35 parameters. In GQMN, water quality is quarterly determined for the 35 parameters. All data are provided through GIMS (National Groundwater Information Center) and summarized in annual reports. Despite the well-developed monitoring networks and information systems, a few problems remain to be solved. First, some automatically monitored data show poor quality, which needs to be solved for big data analytics. Second, EC and temperature, which are automatically measured at boreholes without pursing, sometimes do not represent groundwater in aquifers, particularly when water is stratified due to physicochemical properties (e.g., CO_2-rich water and seawater). Automated monitoring probes should be suitably located, e.g., at screened zones. KIGAM has conducted a basic research project (Technology development for securing large-scale groundwater resources and optimum utilization in response to climate change) since 2020 to 2024 to (1) validate the groundwater data that are available to the public, (2) collect reliable and high-resolution hydrogeological data in some areas, (3) provide groundwater maps, and (4) suggest areas with large groundwater productivity for sustainable water supply in response to climate change.

Keywords: monitoring network, information system, groundwater, Republic of Korea (ROK)

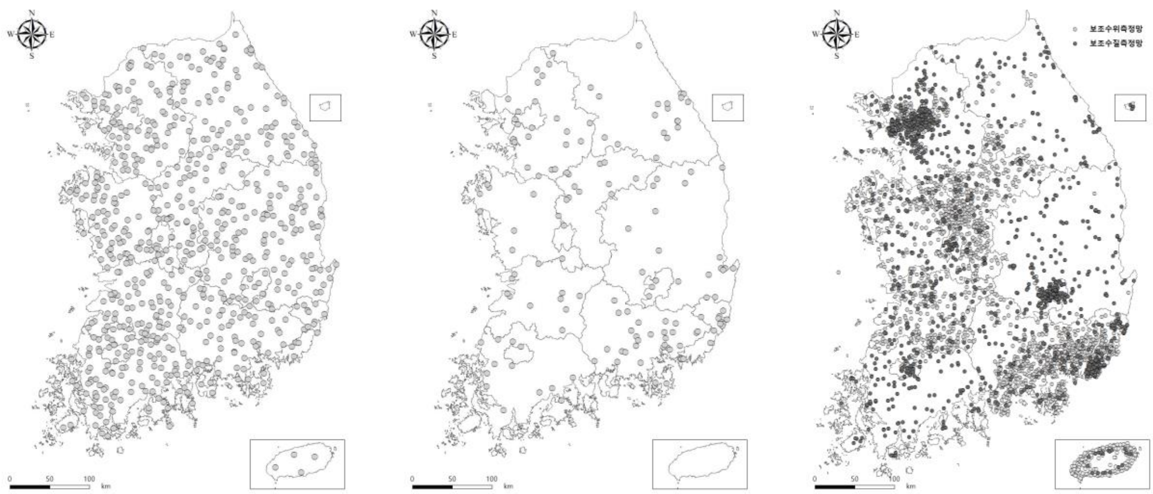
1. Introduction

The Republic of Korea (ROK) has several monitoring networks and information systems of water resources. The monitoring data are provided to the public through web sites and annual reports. Some information is accessible in English for international users. Monitoring networks and information systems of groundwater and surface water in ROK are summarized, and two existing problems from automated monitoring data are provided in this paper.

2. Current monitoring system of groundwater and surface water in ROK

One of the web sites about water resources is Water Resources Management Information System (WAMIS; http://www.wamis.go.kr/). The WAMIS provides many kinds of information on water resources, including rainfall and surface water levels. They are hourly measured at 93 gauging stations for rainfall in 2018 (Han River Flood Control Office, 2019) and 888 stations for water levels in 2023 (http://www.wamis.go.kr/) in five watersheds (Han, Nakdong, Geum, Seomjin, Youngsan) and jeju, and transmitted in two ways: TeleMetering (T/M) and recording. WAMIS provides information using maps, one of which is Water Now Map. It is updated every day at WAMIS to show the current condition of outflows at each gauging station compared to previous data using quartiles. WAMIS provides some information on groundwater as well.

Groundwater monitoring data are provided to the public via National Groundwater Information Center (GIMS; https://www.gims.go.kr/). The groundwater data at GISM are collected through five monitoring networks: National Groundwater Monitoring Network (NGMN; 688 stations (1,303 wells) in 2021; MOE, 2022), Groundwater Quality Monitoring Network (GQMN; 157 stations (306 wells) in 2021; MOE, 2022), Supplementary Groundwater Monitoring Network (SGMN; 4,028 stations in 2021; MOE, 2022), Rural Groundwater Monitoring Network (RGMN; 718 stations in 2023; https://www.groundwater.or.kr/mw/main/main.do), and Seawater Intrusion Monitoring Network (SIMN; 257 stations in 2023; https://www.groundwater.or.kr/mw/main/main.do).



(a) (b) (c)

Fig. 1. Location of National Groundwater Monitoring Network (a), Groundwater Quality Monitoring Network (b), and Supplementary Groundwater Monitoring Network (c) in 2021 (MOE, 2022).

3. Monitoring items, purpose/ usage of monitored data and database (data management)

NGMN and GQNM are managed by the Ministry of Environment (MOE). Most of NGMN consists of shallow (alluvium) and deep (bedrock) monitoring wells. For each well, water levels, temperature, and electrical conductivity (EC) are automatically measured every hour in NGMN, and the data are provided at GIMS. In addition, water quality is analyzed twice a year for 20 parameters which have groundwater quality standards (e.g., pH, total coliforms, Cl, NO_3-N, phenol, As, Hg, TCE), 6 field measurements (e.g. dissolved oxygen), and major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}). The water quality data is also provided at GISM. In GQMN, the water quality is analyzed four times a year for the same 20 parameters, 6 field measurements, and 9 major ions, which are also provided through GIMS.

SGMN is managed by local governments and divided into two: one to supplement water levels (bright gray in Fig. 1c) and the other to supplement water quality (dark gray in Fig. 1c). Some stations are used to supplement both. Water levels, temperature, and EC are measured every month or hour, while water quality once or twice a year. Some hourly data are accessible at GIMS.

RGMN and SIMN are managed by the Ministry of Agriculture, Food, and Rural Affairs (MAFRA). Water levels, temperature, and EC are monitored every hour, while major ions once a year. Some data are accessible at GIMS. More detailed data are provided at another information system operated by MAFRA, which provides warning alarms for drought and seawater intrusion as well (https://www.groundwater.or.kr/mw/main/main.do).

Every year monitoring data are summarized in annual reports. The recent report published in 2022 shows the average depth to water table, temperature, and EC for each watershed as in Fig. 2. Mean depths to water table were 6.12 m for bedrock aquifers and 5.08 m for alluvial aquifers, when excluding the data at Jeju. Mean EC was 525 μS/cm for bedrock aquifers and 396 μS/cm for alluvial aquifers. Jeju shows deep depth to water table and low EC. Jeju is the volcanic island. Groundwater is the only source of water because there are no constant rivers and streams. Thus, the local government operates its own groundwater monitoring network and information system (https://water.jeju.go.kr/gis/main.cs).

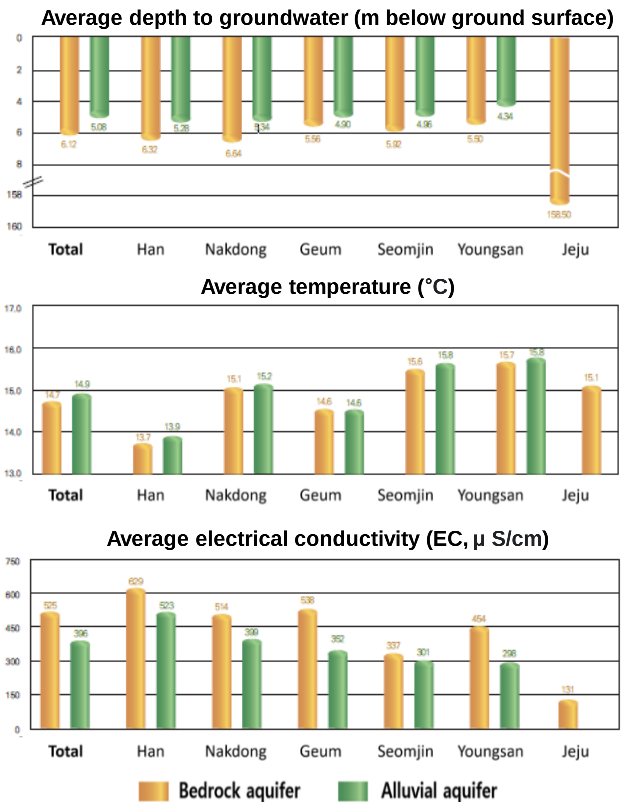


Fig. 2. Average for each watershed. Automated monitoring data from 587 stations (901 wells) in NGMN in 2021 were used for statistics (MOE, 2022).

As for groundwater quality, the annual report summarizes the rate exceeding the water quality standards in five years for each monitoring network. In 2021, the rate increased by 3.5%p compared to 2020 (MOE, 2022). pH and total coliforms exceeded the standards the most frequently.

4. Existing problems and future tasks

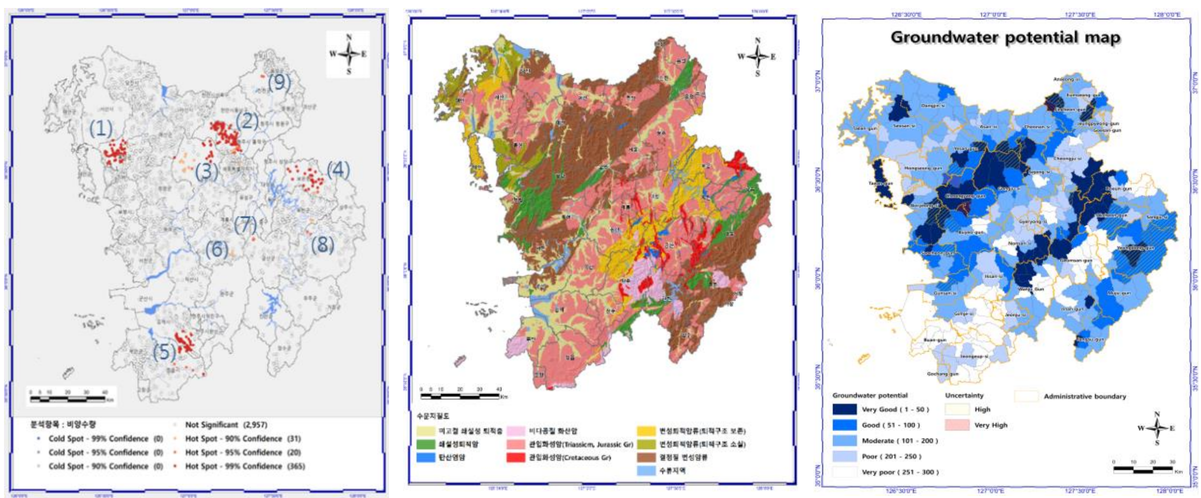
Despite well-developed monitoring networks and information systems, a few problems remain to be solved, in particular from automated monitoring data. Two are discussed in this section.

First, some of automated monitoring data show poor quality, e.g., SGMN. For instance, sudden changes in values are occasionally observed, which makes it difficult to use this information for further analysis such as statistical or time-series analysis. This issue should be dealt with to use these big data to assess the groundwater environment.

Second, EC and temperature, which are automatically measured at boreholes without pursing, sometimes do not represent groundwater in aquifers, in particularly when water is stratified due to physicochemical properties (e.g., CO_2-rich water and seawater). For instance, Do et al. (2022) found two anomalies of EC every year at the Andong-Giran groundwater monitoring station in South Korea, and recognized that the high EC peaks were detected when groundwater was purged at a depth of 25 m below ground surface (bgs) for well maintenance. According to Do et al. (2022), the anomalies were observed since the aquifer in this area is CO_2-rich, whereas the monitoring probe is installed at a shallow depth (20 m bgs) although the screened zones are located at depths of 50–54, 58–62, and 66–70 m bgs. This study result suggests that monitoring probes should be installed at a suitable location (e.g., screened zone).

5. Conclusions

The groundwater environment research center at KIGAM has conducted a basic research project titled ‘technology development for securing large-scale groundwater resources and optimum utilization in response to climate change’ since 2020 to 2024. This project aims to (1) validate the groundwater data that are available to the public, (2) collect reliable and high-resolution hydrogeological data in some areas, (3) provide groundwater information maps for each watershed (e.g., Fig. 3), and (4) suggest areas with large groundwater productivity for sustainable water supply in response to climate change.



(a) (b) (c)

Fig. 3. Groundwater information map for the Geum River basin: (a) hot spot analysis (specific

capacity); (b) hydrogeological units reclassified; (c) groundwater potential (KIGAM, 2021)

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Ongoing plans and policies for the monitoring system of groundwater and surface water in Lao PDR, and problems to establish the system

(For countries without existing monitoring system)

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Abstract

Although the amount of groundwater in Laos is sufficient to meet the demand. Therefore, groundwater conditions are still a problem that have to be solved. Data and information on groundwater still priority problem such as the data on hydrogeological, flow direction, quantity and quality and changing the purpose of groundwater use including climate change also demand for groundwater use have been increasing in every year.so, it is request the a management tools, such as policies, regulations and management plans.

Keywords: groundwater, hydrogeological, policies, regulation, management plan.

1. Introduction

The Lao PDR is located in the southeast of the Asian continent, in the center of the Indochina Peninsula, between 14-23 degrees north latitude and 100-108 degrees longitude, with an average height of 1,500 meters above sea level. It is located in the 7th time zone. It is a landlocked country. The total area of the country is 236,800 square kilometers. The total population is 7.3 million people (National Statistics Center 2021). Bordering Countries China in the North, Vietnam in the East, Cambodia in the South, Thailand in the West and Myanmar in the North West. There are 18 provinces in Laos and it consists of 17 provinces and 1 Capital.

Previously groundwater is an important resource for people's livelihood in Laos especially for people in the rural areas, at the present also in the future. The use of groundwater is still very visible, especially in areas far from water sources and lack of surface water and river areas where water supply is inaccessible. Groundwater is used a lot for consumption-utility, farming-livestock activities, agriculture, industry, construction work and others. 80% of the population in rural areas uses groundwater for daily living and is also an important source of water for consumption and other purposes. The use of groundwater by the people of Laos in rural and suburban areas is a large number, which shows from the results of the 2015 population survey that it accounts for 50.4% or equal to 596,888 households or 3,163,506 people in urban areas and rural areas. in urban areas there are 385,405 people using groundwater by pipe water and 2,778,101 people using groundwater by deep and shallow wells. Estimated use of groundwater in the country is about 80 liters or 0.08 cubic meters/person/day and in rural areas 200 liters or 0.2 cubic meters/person/day.

Fig. 1. Photography map of Lao PDR
(Source: Peter Hermes Furian)

The use of underground water in urban areas is used in the form of tap water based on information from the Department of Water Supply, Ministry of Public Works and Transport, the population in some provinces are using tap water produced from groundwater such as Vientiane Capital, Bokeo Province, Xiengkhouang Province, Vientiane Province, Borikhamxay Province, Khakmouan Province, Savannakhet Province and Sekong Province. In this, it can be summarized that the population that uses tap water is 226,152 people. The average water use is 14,638 cubic meters per day or 5,416,158 cubic meters per year. The rate of water use in urban areas is 50.7%. Below Map shows the use of groundwater in the households across the country.

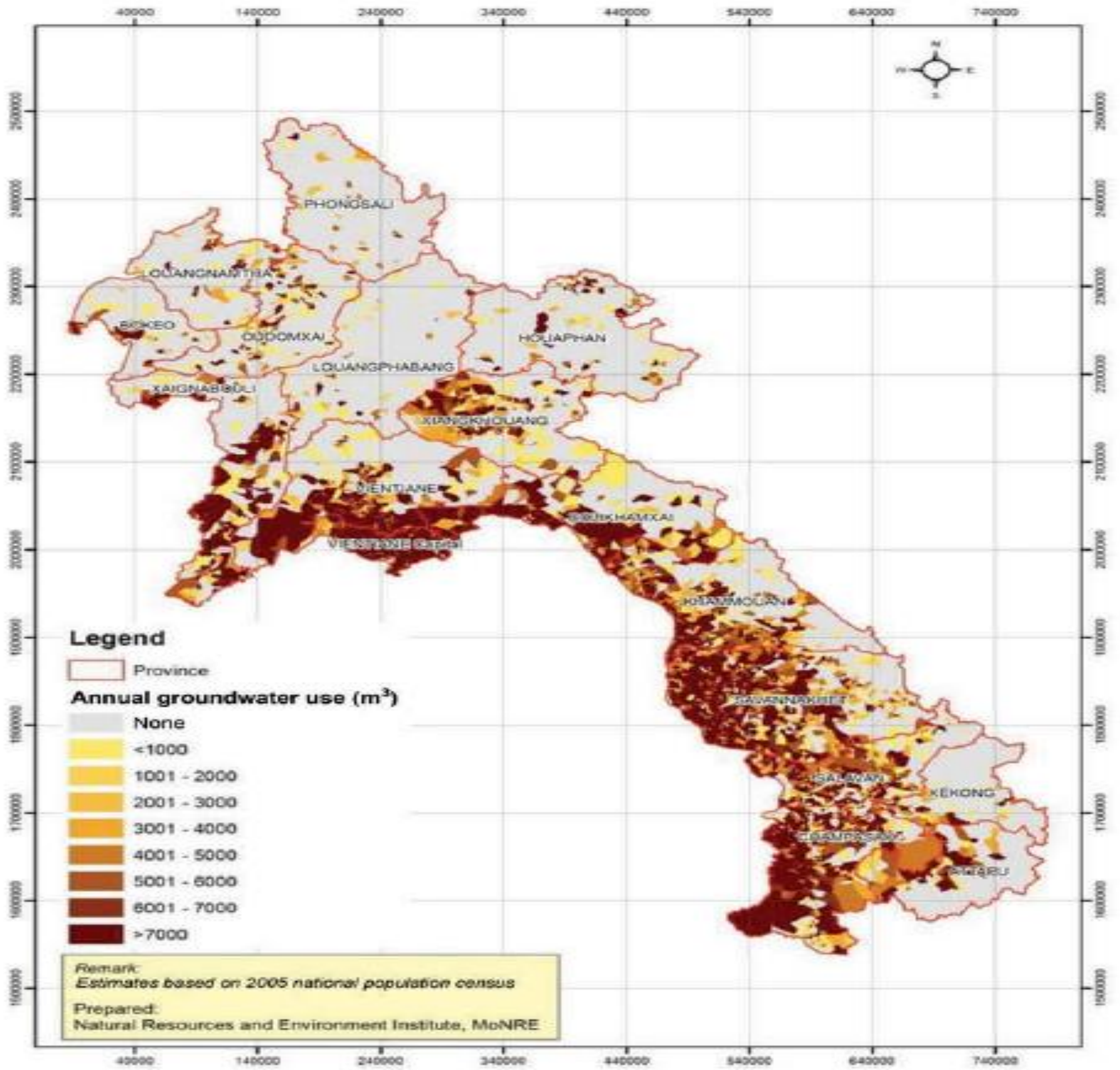

Figure 1. Distribution of groundwater use by householders in Laos, estimated from village-level census data in 2005 for the proportion of the population using groundwater and an assumed per capita use of 100 L/day.

Source: Natural Resources and Environment Institute.

Fig. 2. Map showing groundwater use in households

2. Ongoing plans and policies for the monitoring system of groundwater and surface water in Lao PDR

The Ministry of Natural Resources and Environment, abbreviated as "MoNRE," is a government branch tasked with the role of Chief Executive Officer for the government. Its primary responsibilities involve macro-management related to the management of natural resources and the environment. This encompasses the supervision of land, water, air, biodiversity, and the overall environment. The Ministry is also dedicated to addressing the social and natural environment, including efforts in natural disaster response, protection from climate change, and oversight of meteorology and hydrology within the country.

The Department of Water Resources, commonly abbreviated as "DWR," operates as a vital component within the Ministry of Natural Resources and Environment. Its primary function is to serve as the chief of staff to the Ministry's leadership committee dedicated to water resources management. This committee falls under the direct responsibility of the Ministry and operates at a national level, overseeing water resource management initiatives throughout the country.

The Department of Groundwater Management, under the Ministry of Natural Resources and Environment, assesses the current and future trends in the management, development, and use of groundwater. It collaborates with relevant parties at both central and local levels to identify specific characteristics, potentials, and problems in each area related to groundwater. The department actively promotes, recommends, and implements monitoring techniques for groundwater management, utilizing personnel at various levels across the country. Modern technological tools are employed to explore, research, and establish groups of groundwater users and technical teams. This includes accounting for groundwater sources and addressing water shortage problems, especially in areas distant from watercourses and prone to drought. Furthermore, the department participates in sustainable groundwater management, researches the issuance of permits for underground water usage, and carries out additional duties as assigned.

The Ministry of Agriculture and Forestry manages underground water for various activities, including irrigation, fishing, agricultural production, forestry, and related endeavors. It collaborates with the natural resources and environment sector to ensure a comprehensive and coordinated approach to the management of underground water resources.

The Ministry of Energy and Mineral Resources oversees and regulates the use of underground water for mineral mining activities. It holds both rights and responsibilities to ensure that the extraction aligns with environmental and resource management considerations, coordinating closely with the natural resources and environment sector.

The Ministry of Public Works and Transport has the authority and responsibility to manage underground water for purposes such as tap water production, drainage pipe installation, and urban sewage treatment systems. This is done in coordination with the natural resources and environment sector to ensure a comprehensive and sustainable approach to using underground water for public infrastructure and services.

The Ministry of Industry and Trade manages underground water for industrial activities, ensuring its use aligns with environmental sustainability and resource management. Coordination with the natural resources and environment sector is integral to these efforts.

The Ministry of Public Health manages underground water for health purposes, ensuring clean water for public consumption. In rural areas, it monitors drinking water quality and usage, collaborating with the natural resources and environment sector to meet environmental and health standards.

The Ministry of Information, Culture, and Tourism is vested with the authority and responsibility to manage the use of groundwater specifically for tourism purposes. It coordinates with the natural resources and environment sector to ensure sustainable utilization.

The Ministry of Education and Sports holds the right and responsibility to manage groundwater, focusing on education, scientific research, and the development of human resources in accordance with national education principles. This management is carried out in coordination with the natural resources and environment sectors.

The Government, led by the Ministry of Natural Resources and Environment, is the overall manager of waterworks and water resources in the country. This coordination involves various ministries, including Agriculture and Forestry, Energy and Mines, Public Works and Transport, Industry and Commerce, Public Health, Culture and Tourism, and Education and Sports, along with local authorities. The roles and duties of each organization are outlined (in Article 76 of the Water Law and Water Resources, as per the updated version No. 23 of the National Assembly, dated May 11, 2017). Detailed responsibilities are summarized in Table 18:

Table 1. Roles and responsibilities of organizations in Water Management

Duties	Development Develop infrastructure And use groundwater In urban / rural areas	Management Create and Implementation All Policy , law And Regulations . Awareness raising And Information sharing	Education And Research Monitoring And Collect information And Creating a simulation model
Organization	City Planning Department Environmental Health Center And Provide clean water Department of Mines Office Adjust the tap water Ministry of Information , Culture and Tourism	Department of Water Resources Department of Industry And Craft Inspection Department Natural resources And Environment _	Department of Irrigation Institution Research Agriculture And Forest Institution Research resources Nature And Environment

3. Related policies and legislation in water management

Groundwater management involves regulating its use in accordance with legal frameworks, strategic management plans, and the principles of water resource utilization. The objective is to ensure the reasonable, efficient, and effective utilization of underground water while safeguarding its quantity and quality to maintain a balanced ecosystem and environment. The management process encourages the participation of individuals, legal entities, and relevant organizations in the responsible use and protection of underground water. Those responsible for any damages resulting from activities related to groundwater use must be held accountable. Therefore, groundwater management must align with established policies and legislation as below:

- The government envisions a new developmental era by 2030, aiming for Laos to become a medium-high income developing country. The strategy prioritizes socio-economic, intellectual, and sustainable development, with increased national income per capita and industry as a key economic driver. The vision includes societal harmony, democracy, justice, and unity, addressing development disparities, promoting social closeness, enhancing human resources, ensuring citizens' rights, strengthening governance, and protecting the natural environment. The political system is envisioned to be stable, strong, and globally connected, marking a significant turning point in the nation's progress.
- The government's policy in the natural resources and environment sector envisions Laos as a green, clean, and beautiful nation, abundant in natural resources. The strategy for the next decade (by 2030) focuses on developing a green economy for sustainable growth, transforming Laos into an industrial and modern country. The policy also emphasizes the need to enhance preparedness for climate change and natural disasters.
- The water management strategy reflects the government's commitment to ensuring fair water use, benefit sharing, and contributing to poverty reduction, along with protecting and restoring the water environment. However, challenges exist in the systematic management of underground water, including the lack of detailed plans, limited budgets, and insufficient personnel. Additionally, revenue collection from water usage fees, royalties, pollution fees, restoration fees, and environmental service obligations is not organized systematically. To address these challenges, the strategy emphasizes the need for regional and international cooperation for information exchange and financial and technical support. The strategy outlines plans and action plans for groundwater management to achieve the vision and goals set in the broader strategic plan as follow:

The groundwater management program, designated as the 4th program, focuses on ensuring the abundance and restoration of groundwater. Its key objectives include promoting the well-being of residents in areas lacking surface water sources and contributing to green and sustainable economic, social, and environmental development. The operational plan for 2021-2025 outlines specific goals, focus tasks, and detailed activities, providing a framework for the effective implementation of the water management strategy for national water resources as follow:

Action Plan 4: Groundwater Management

Goal 1: Ensure effective management and use of groundwater

Focus Task 1: Create and improve legislation related to groundwater
Activity 1: Issue permissions for underground water extraction
Activity 2: Develop and enhance legislation on groundwater management
Activity 3: Create a technical guide on groundwater management

Focus Task 2: Study, survey data, and create a groundwater management plan
Activity 1: Survey, collect data, and record groundwater across the country
Activity 2: Identify areas vulnerable to groundwater quantity and quality
Activity 3: Generate a report on the state of groundwater in Lao PDR
Activity 4: Develop and implement a groundwater management plan

Focus Task 3: Manage the use of groundwater
Activity 1: Monitor and inspect drilling or extraction of underground water nationwide
Activity 2: Compile a list of underground water drilling service providers nationwide

Activity 3: Monitor and evaluate groundwater use across the country.

- The Water and Water Resources Law, updated as Version No. 23 by the National Assembly on May 11, 2017, is composed of 14 sections and 103 articles. Articles 39, 40, 41 address groundwater management, covering water use at different scales, water use licenses (Article 42), suspension, change, and withdrawal of licenses (Article 40), groundwater (Article 45), goals for groundwater use (Article 46), the right to use underground water (Article 47), services related to water and water resources (Article 48), and drilling services for underground water (Article 50).
- The Environmental Protection Law, designated as No. 29/NPC and dated December 18, 2012, comprises 13 sections and 99 articles. Notably, it includes articles addressing groundwater management, such as Article 10, focusing on the impact on the social environment, Article 11, centering on the impact on the natural environment, and Article 14, specifically dedicated to environmental protection.
- The Fisheries Law, identified as No. 03/NPC and dated July 9, 2009, consists of 10 sections and 72 articles. Pertinently, it includes articles related to groundwater management, specifically Article 17 focusing on Fisheries survey and Article 20 detailing the Conditions for scientific research on fisheries.
- The Meteorology and Hydrology Law, identified as No. 068/SPO and dated November 13, 2017, is comprised of 11 sections. Notably, in Chapter 2, Article 69 focuses on Meteorological stations, while Article 30 emphasizes that Groundwater measuring points serve as locations to monitor and measure changes in the quantity and quality of groundwater.
- The Irrigation Law, identified as No. 26/NPC and dated December 14, 2012, includes Section IX, Article 79, and Article 20, which pertains to the Project survey-technical design for project construction. Additionally, Article 6 addresses the Use of underground water for rainwater irrigation, drip irrigation for economic crops, and planting grass for livestock in gardens and warehouses where there are no conditions for using surface water.
- The revised version of the Minerals Law, denoted as No. 063/SNP and dated November 03, 2017, encompasses XV sections and 136 articles. Notably, Article 25 addresses toxic areas in the first paragraph, and Section 97 specifically focuses on the development of sustainable mineral areas.
- The Water Supply Law (No. 04/SAP, dated July 9, 2009) comprises VIII sections and 77 articles, focusing on water supply. Article 18 highlights that water sources for production include surface water, underground water, spring water, and other documented sources, forming the basis for investing in effective and sustainable water infrastructure. Article 19 stresses the need for water supply businesses to protect and preserve water resources and the environment. Concessionaires, managers, entrepreneurs, individuals, and organizations must use water judiciously, implementing measures to minimize social and environmental impact. All entities are obliged to contribute to environmental protection by refraining from polluting or causing damage to water sources.
- The Agriculture Law (No. 01/98 National Assembly), dated October 10, 1998, consists of VIII sections and 85 articles. Notably, Chapter 2 focuses on Irrigation, with Article 21 specifying that pumping water involves bringing water from the surface or underground for agricultural production, using basic or modern equipment such as pumps.

- The Tourism Law (No. 32/NPC), dated July 24, 2013, encompasses XII sections and 103 articles. Specifically, Article 10 defines natural tourism resources, encompassing scenery, cliffs, caves, plateaus, high mountains, volcanoes, forests, vegetation, wild animals, insects, flowers, rivers, dales, beaches, ponds, swamps, waterfalls, rivers, hot springs, and other natural phenomena.
- The Revised Land Law (No. 14/NPC, dated June 21, 2019) comprises 15 sections and 188 articles. Notably, it addresses groundwater management in several articles, including: Article 45 (amended): Land near water, Article 46 (amended): Survey of land near water, Article 47 (new): Placing water area land use plan, Article 48 (new): Water area land protection, Article 49 (improved): Water area land use.
- The amended Law on Sanitation and Health Promotion (No. 28/SAP, dated November 22, 2019) comprises IX sections. Notably, Article 25 (Amendment) Paragraph 3 emphasizes that drinking water from various sources, including rainwater, well water, spring water, warm water, rivers, creeks, and streams, must undergo a process of water treatment or pathogen elimination.
- The Agreement on the use of water (No. 6118/Khs, November 29, 2022) encompasses IX sections and 87 articles. Its objective is to establish principles, regulations, and measures for the management, monitoring, and inspection of water and water resources. The agreement aims to ensure targeted, economical, efficient, and rational use of groundwater, while also promoting sustainable and green practices to meet various needs such as living, agricultural production, industry, transportation, sports, tourism, and other purposes, contributing to the socio-economic development of the nation.
- The National Environmental Standard (No. 81/Rev, dated February 21, 2017) is structured with 6 chapters and 18 articles. Article 11 specifically addresses groundwater quality standards, defining them as indicative values that establish the maximum allowable concentration of chemicals and impurities in groundwater. These values are set in a table that includes indicators, symbols, standard values, units, and analysis methods. The purpose of these standards is to ensure that groundwater quality does not cause harm to life, the health of people, animals, or the environment. The table establishes both general groundwater standards and specific groundwater standards for consumption.
- The Agreement Regarding the management of technical standards for the allocation of clean water in rural areas (No. 0738/ST; Dated May 4, 2017) is composed of 9 chapters and 32 articles. Notably, it addresses groundwater management through specific articles, including: Article 10: The standard of groundwater, Article 11: The standard of shallow well water system, Article 14: The standard of water protection, Article 15: The water distribution system to households

4. Expected monitoring items and purpose/usage of monitored data

The data on groundwater resources is very important and must be systematically managed and it is also requiring the study and collection of groundwater hydrogeological data, quantity, quality and use of groundwater as a basis for future management and the creation of groundwater management plans. The expected monitoring of the groundwater in Laos starts as follow:

- Data collection form created and sent to Provincial and district office of Natural resources and Environment

- Data collection form objective for collecting data and information on groundwater use by purpose as industrial sector, agriculture sector, household use
- There are totally 14 forms for existing groundwater use inventory

Future plan and policy for the monitoring system of groundwater and surface water will start as:

- Water use, Wastewater, and Reservoir management plan
- Legislation for determination of minimum flow. guidelines "Water use management,
- Three guidelines will be developed ad Wastewater management, and Reservoir management plan and one agreement for Determination of minimum flow.
- Three groundwater management plans for Vientiane Capital, Vientiane Province and Saravan Province will develop

5. Existing problems on groundwater management

- Limited of data and information on groundwater potential and demand on groundwater
- Government's staff lack of experiences, skills on groundwater monitoring and database making in both local level and national level as well
- The regulatory framework is being developed
- Limited of groundwater experts to support on data collection also develop well monitoring
- Financial aspect

6. Conclusion

In Laos, historically, 28% of the population lacked access to tap water, relying on untreated underground water sources. However, the increasing use of groundwater poses risks to its quantity and quality, with potential contamination by chloroform, nitrates, and arsenic. Groundwater serves as a crucial source, especially in rural and small-town areas distant from surface water sources. Risks arise from over-extraction and contamination due to a lack of community knowledge. As the demand for underground water rises, challenges in management emerge, including insufficient information, personnel limitations, and a lack of equipment. Despite overall good quality, localized risks exist near mining areas and industrial estates. Addressing these challenges requires systematic groundwater management with well-informed personnel, comprehensive plans, and updated legislation.

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Current monitoring system for groundwater in Malaysia and existing problems

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Abstract

The Department of Mineral and Geoscience Malaysia (JMG) is the primary agency responsible for groundwater-related affairs within the country. Demonstrating active engagement, JMG is dedicated to fulfilling international cooperation and obligations outlined in global frameworks such as the CCOP Geoinformation Sharing Infrastructure for East and Southeast Asia, particularly the CCOP-GSJ GSi Groundwater Project Phase IV. JMG has successfully implemented the Malaysia Geospatial Mineral and Geoscience Information System (MyGEMS), the national spatial data bank for comprehensively managing geoscience and mineral resource information. MyGEMS, aligned with stakeholder charters and prescribed acts like the Geological Survey Act 1974 [Act 129], aims to develop a comprehensive and integrated system encompassing all geoscience and mineral activities. This system ensures easily accessible and shareable geospatial products. Despite facing obstacles in groundwater monitoring progress, including Enabling Constraints, Fragmented Tools, and Fund Limitations, JMG has introduced innovative initiatives in line with the 12th Malaysia Plan. These initiatives are geared towards Water Sector Transformation Plan (WST 2040), emphasizing the mainstreaming of groundwater usage for both water security and economic growth. Integral to this transformation is incorporating IoT (Internet of Things) and Industry 4.0 (IR 4.0) technologies into the groundwater monitoring system, offering eight key advantages: real-time monitoring, enhanced data accuracy, and precision, cost-efficiency, remote accessibility, predictive analytics, seamless integration with other systems, environmental sustainability, and user-friendly interfaces. This strategic technology integration aligns with JMG's commitment to advancing groundwater monitoring capabilities to benefit Malaysia's sustainable development.

Keywords: groundwater, geoscience, Malaysia, Asia.

1. Introduction

The Department of Mineral and Geoscience Malaysia (JMG) is the lead agency responsible for addressing groundwater-related governance in Malaysia. Its scope encompasses groundwater exploration, tube well development, and the maintenance of a groundwater data inventory. Since 1986 (5th Malaysia Plan), JMG has successfully developed 614 monitoring tube wells (Figure 1) and actively monitors 526 wells as of the year 2022. Over the years, JMG has made strides in enhancing its capabilities, notably establishing the Malaysia Geospatial Mineral and Geoscience Information System (MyGEMS). This data inventory system operates as the national spatial data bank, pivotal in managing the country's geoscience and mineral resource information. Currently, JMG is engaged in the progressive implementation of the National Groundwater Mapping and Development Project, or PABT Project. The PABT Project's primary objective is to systematically map groundwater potential throughout the nation. Kedah has been identified as the pioneering state for this initiative, marking the commencement of the project's implementation (12th Malaysia Plan; 2021-2025).

A vital component of the Kedah PABT Project is establishing a state-of-the-art real-time groundwater monitoring system. This initiative aims to upgrade the existing manual approach currently in place. The plan will install real-time monitoring capabilities in ten newly constructed monitoring tube wells within Kedah state to kickstart this phase. These tube wells will be equipped with advanced technology, featuring four probes each and a solar-powered remote transmit unit. This setup enables the continuous and remote monitoring of groundwater conditions and data acquisition. The deployment of real-time monitoring not only enhances the efficiency of data collection but also provides a more accurate and timely assessment of groundwater dynamics. By implementing this modernized system, the Kedah PABT Project aims to elevate the capabilities of groundwater monitoring, contributing to a more comprehensive understanding of the state's groundwater resources and facilitating informed decision-making in water resource management.

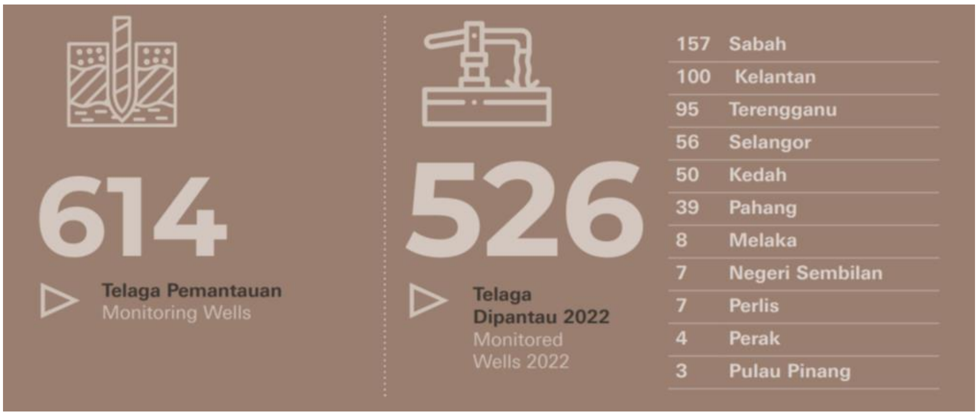


Fig. 1. Groundwater Monitoring Programme (JMG Annual Report, 2022)

JMG actively engages in and remains dedicated to meeting international cooperation and obligations outlined in global frameworks, such as the CCOP Geoinformation Sharing Infrastructure for East and Southeast Asia. JMG's commitment extends to the CCOP-GSJ GSi Groundwater Project Phase IV, a progressive initiative initiated by the Geological Survey of Japan (GSJ) in 2005. The GSJ has played a pivotal role in steering the project progressively through three phases: Phase I (2005-2008), Phase II (2009-2013), and Phase III (2014-2020).

In Phase I, from 2005 to 2008, selected CCOP Member Countries actively participated in the project, with a primary focus on developing a groundwater management and control database. Transitioning into Phase II (2009-2013), the project expanded its scope to include constructing and designing a comprehensive groundwater database—additionally, the initiative aimed to establish an Asian Standard for Hydrogeological maps. Throughout Phase II, challenges were addressed, leading to the identification of new objectives that subsequently shaped the project scope for Phase III.

In response to the evolving needs and challenges encountered during Phase II, Phase III (2014-2020) introduced an expanded database area, encompassing a broader range of member countries. Another key objective was the promotion of the CCOP, an open-source groundwater database. Figure 2 illustrates the comprehensive project scope for Phase III, emphasizing the commitment to enhancing regional cooperation and exchanging geoinformation within the CCOP-GSJ GSi Groundwater Project Phase IV framework.

Fig. 2. CCOP-GSJ GS*i* Groundwater Project Work Scope

2. Current status and issues

JMG continues to conduct groundwater monitoring manually, with a frequency of twice annually. Despite advancements in other aspects of groundwater management, the monitoring process still relies on periodic manual assessments.

In the context of the Kedah PABT Project, which has completed the construction of 14 new tube wells (Figure 3), a significant step forward is planned. Ten will be specifically chosen to serve as groundwater monitoring stations among these newly constructed tube wells. This strategic selection reflects an effort to transition towards a more systematic and continuous monitoring approach, moving beyond the traditional manual method (Figure 4).

By designating these ten tube wells as groundwater monitoring stations, the Kedah PABT Project aims to improve the efficiency and accuracy of data collection, laying the groundwork for a more comprehensive understanding of groundwater dynamics in the region. This represents a positive step towards modernizing groundwater monitoring practices within the framework of the broader project goals. Among issues encountered in manual monitoring, namely, (i) Enabling Constraints, (ii) Fund Limitations, and (iii) Fragmented Tools (Figure 5).

(i) **Enabling Constraint**

- *Description*: Lack of a dedicated monitoring personnel team resulting in a low data acquisition frequency.
- *Implication*: This may lead to incomplete or infrequent data collection, impacting the overall effectiveness of monitoring efforts.

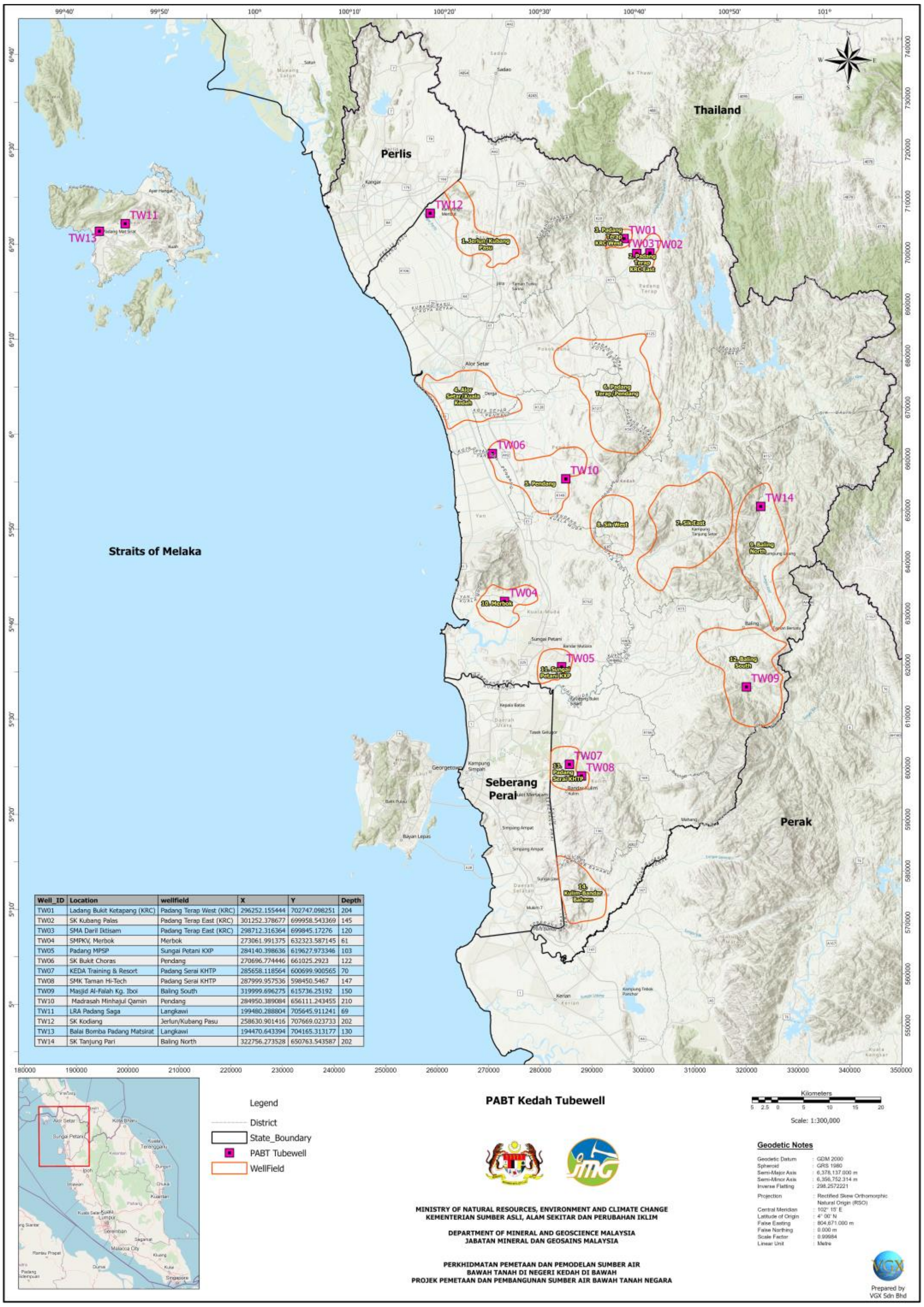
(ii) **Fund Limitations**

- *Description*: Insufficient funds for monitoring, data inventory, lab work, and tube well maintenance, making it difficult to achieve good quality and continuous data.
- *Implication*: Limited financial resources may hinder the ability to conduct necessary monitoring activities, affecting data quality and completeness.

(iii) **Fragmented Tools**

- *Description*: Inconsistency in coordination among branch offices and a lack of data maintenance were identified as factors contributing to disintegrated tools, slowing down the monitoring data collection progress.

- *Implication*: Lack coordination and maintenance can lead to inefficiencies, delays, and potentially inaccurate data, affecting the overall reliability of the monitoring process.



Well_ID	Location	wellfield	X	Y	Depth
TW01	Ladang Bukit Ketapang (KRC)	Padang Terap West (KRC)	296252.155444	702747.098251	204
TW02	SK Kubang Palas	Padang Terap East (KRC)	301252.378677	699958.543369	145
TW03	SMA Daril Iktisam	Padang Terap East (KRC)	298712.316364	699845.17276	120
TW04	SMPKV, Merbok	Merbok	273061.991375	632323.587145	61
TW05	Padang MPSP	Sungai Petani KXP	284140.398636	619627.973346	103
TW06	SK Bukit Choras	Pendang	270696.774446	661025.2923	122
TW07	KEDA Training & Resort	Padang Serai KHTP	285658.118564	600699.900565	70
TW08	SMK Taman Hi-Tech	Padang Serai KHTP	287999.957536	598450.5467	147
TW09	Masjid Al-Falah Kg. Iboi	Baling South	319999.696275	615736.25192	150
TW10	Madrasah Minhajul Qamin	Pendang	284950.389084	656111.243455	210
TW11	LRA Padang Saga	Langkawi	199480.288804	705645.911241	69
TW12	SK Kodiang	Jerlun/Kubang Pasu	258630.901416	707669.023733	202
TW13	Balai Bomba Padang Matsirat	Langkawi	194470.643394	704165.313177	130
TW14	SK Tanjung Pari	Baling North	322756.273528	650763.543587	202

Fig. 3. PABT Propose Monitoring Tube Well (Selective) Location in Kedah, Malaysia

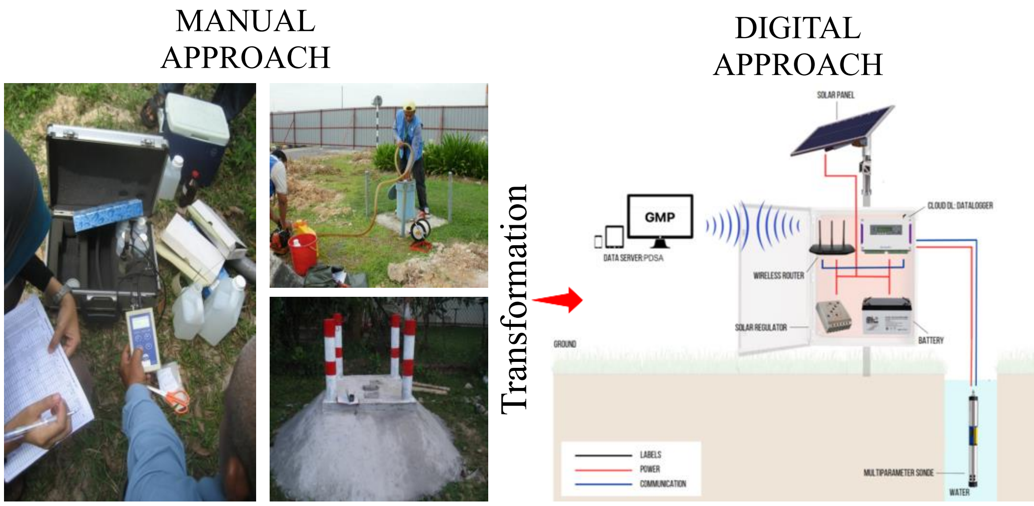


Fig. 4. JMG's groundwater monitoring system transformation

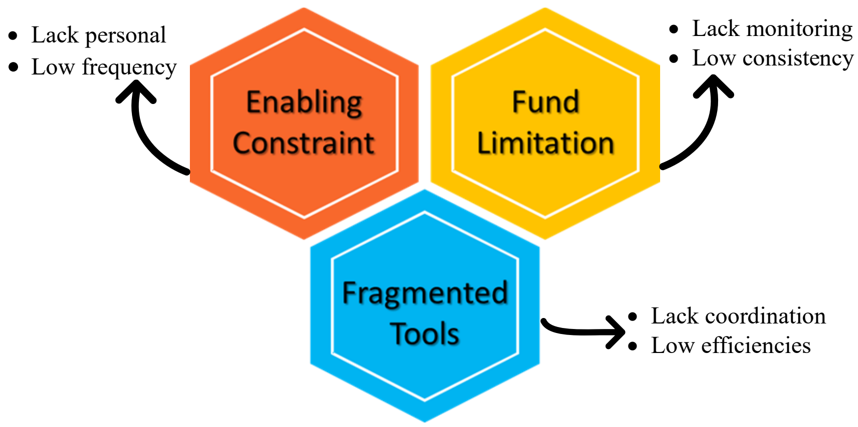


Fig. 5. Groundwater monitoring issues; Enabling Constraint, Fund Limitation and Fragmented Tools

3. Improvement initiative for groundwater monitoring

JMG understands that there is a need to overcome the issues and ensure the monitoring work is continuously done, which will benefit all (Figure 6). Therefore, JMG has outlined a few new initiatives to resolve the issues, that are also in line with the 12th Malaysia Plan pursuant to the transformation of the water sector through mainstreaming groundwater usage for water security and economic growth.

Improves Groundwater Monitoring Tools (framework and network)

Good and comprehensive groundwater monitoring leads to effective groundwater management and water security sustainability. JMG's current groundwater monitoring network must be more cohesive and well-coordinated. The current monitoring framework is manually conducted with low frequency and needs more improvements. Hence, JMG will propose setting up a National Groundwater Monitoring System (NaGMiS), an integrated groundwater monitoring network that collaborates with relevant agencies, providing more groundwater data collection and comprehensive data coverage. As a start, PABT Kedah will commence installing ten groundwater stations equipped with state-of-the-art real-time groundwater monitoring systems. Apart from that, progressively channeling the groundwater data to the current national database system (MyGEMS) will be carried out for an integrated groundwater evaluation and management for risk assessment. These efforts and initiatives will definitely strengthen and enhance the monitoring tools to be more effective and efficient, subsequently in line with the national Water Sector Transformation Plan (WST 2040).

Promotes State-of-The-Art Enabling Approach

Promoting state-of-the-art technology, such as IoT (Internet of Things) and Industry 4.0 (IR 4.0) technologies, in groundwater monitoring is crucial for enhancing the effectiveness of monitoring efforts. The traditional manual approaches are no longer suitable due to their limitations, which often result in poor outcomes in monitoring works. There are several potential outcomes incorporating advanced technologies, namely:

1. **Real-time Monitoring:**
    - IoT devices can provide real-time data, allowing continuous monitoring of groundwater conditions. It enables prompt detection of any changes or anomalies, facilitating timely responses to potential issues.
2. **Data Accuracy and Precision:**
    - Automated sensors and devices offer higher accuracy and precision in data collection compared to manual methods. It ensures that the information obtained is reliable and can be used for more accurate assessments.
3. **Cost-Efficiency:**
    - While there might be an initial investment in setting up IoT and IR 4.0 technologies, the long-term benefits often outweigh the costs. Automated systems can reduce the need for frequent manual interventions, leading to cost savings over time.
4. **Remote Accessibility:**
    - IoT devices allow remote monitoring, providing access to groundwater data anywhere. It is especially valuable for large-scale monitoring projects or areas that are difficult to access, as it reduces the need for physical presence on-site.
5. **Predictive Analytics:**
    - Advanced technologies enable the use of predictive analytics, allowing for the identification of patterns and trends in groundwater behavior. It helps in forecasting potential issues and proactively prevent or mitigate them.
6. **Integration with Other Systems:**
    - IoT and IR 4.0 technologies can be integrated with other systems, such as GIS (Geographic Information System) or data visualization platforms. This integration enhances the overall monitoring capabilities and facilitates comprehensive data analysis.
7. **Environmental Sustainability:**
    - Implementing modern technologies often leads to more efficient resource utilization; which in turn, contributes to environmental sustainability by minimizing unnecessary resource consumption and reducing the ecological footprint of monitoring activities.

8. **User-Friendly Interfaces:**
    - The interfaces of IoT devices are often designed to be user-friendly, making it easier for operators to manage and interpret data. This accessibility can empower experts and non-experts to make informed decisions based on the collected information.

In conclusion, adopting state-of-the-art technologies in groundwater monitoring, such as IoT and IR 4.0, is essential for improving monitoring practices' effectiveness, efficiency, and sustainability. This shift allows for a more proactive and data-driven approach, ultimately leading to better-informed decision-making in groundwater management.

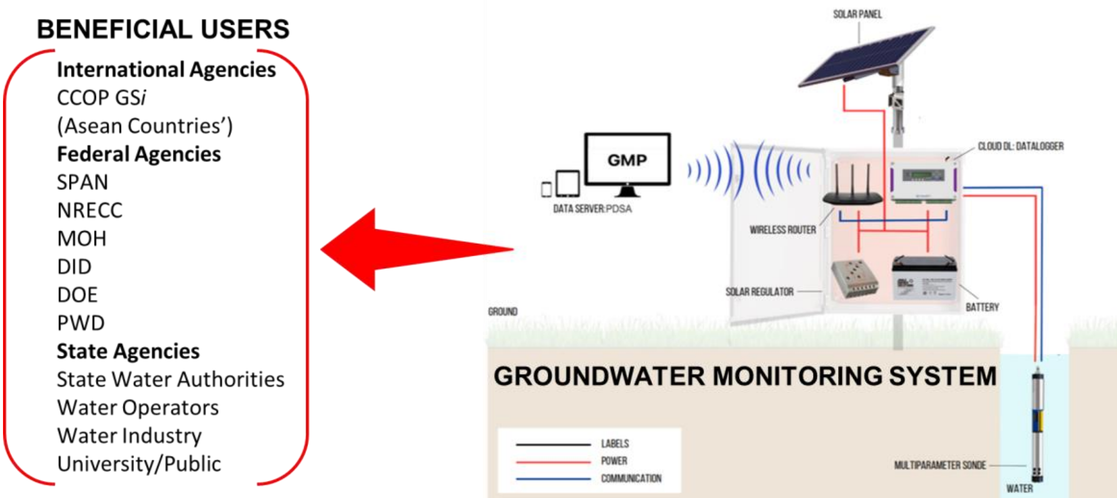


Fig. 6. Recommendations On Tool Framework and Network Improvement for Groundwater Monitoring System

4. Conclusions

In conclusion, the Department of Mineral and Geoscience Malaysia (JMG) is the lead agency responsible for groundwater matters in Malaysia. Actively engaging in international cooperation, JMG adheres to global frameworks like CCOP-GSJ GSi Groundwater Project Phase IV. Notably, JMG has successfully established the Malaysia Geospatial Mineral and Geoscience Information System (MyGEMS), a national spatial data bank facilitating the management of geological and mineral resource information. Despite facing challenges such as Enabling Constraints, Fragmented Tools, and Fund Limitations hindering groundwater monitoring, JMG is proactively addressing these issues through new initiatives aligned with the 12th Malaysia Plan. Moreover, incorporating IoT and IR 4.0 technologies into the groundwater monitoring system brings eight key advantages, including real-time monitoring, enhanced data accuracy, cost-efficiency, remote accessibility, predictive analytics, integration capabilities, environmental sustainability, and user-friendly interfaces. This strategic approach aligns with the broader goal of water sector transformation, emphasizing groundwater usage for water security and economic growth in Malaysia.

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Ongoing plan and policy for the monitoring system of groundwater and surface water in Mongolia, and problems to establish the system

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Abstract

Mongolia is a landlocked country in north-central Asia, adjacent to China to the south and Russia to the north. Mongolia lies on a high plateau surrounded by mountain ridges, in the transition zone between the Siberian taiga and the dry steppes and semideserts of central Asia. The mean annual precipitation in Mongolia is about 200 mm, ranging from less than 50 mm in the Gobi Desert region to about 400 mm in the mountainous regions in the north. Surface water has unevenly distributed throughout the country. Surface water constitutes the majority of the water resource. The hydrogeological mapping and detailed studies of groundwater have not relatively well conducted compared to the territory. There are surface water and groundwater monitoring networks present in Mongolia. However, the monitoring data are not available to public, some of the data has been categorized as confidential. Therefore, these data are not stored in integrated system and not well organized. There is a vital need to disclose these materials to the public, improve the monitoring systems, create integrated database system.

1. Ongoing plan and policy for the monitoring system of groundwater and surface water

1.1 Current conditions of water monitoring related regulations

There are mandatory laws and regulations for water monitoring throughout Mongolia which regulation of the needs and requirements of the water monitoring program has begun to be reflected in the legislation of Mongolia. All citizens, enterprises and institutions must comply with these laws. Environmental and water monitoring requirements are set forth in the Environmental Impact Assessment and Water Laws and their related regulations. All citizens, enterprises and institutions must comply with these laws. These regulations are contained in the following laws:

- Environmental Protection Law
- Law on water
- Law on Environmental Impact Assessment
- Law on Minerals
- Law on water, climate and environmental monitoring

1.2 National institutions responsible for water monitoring

The following main institutions responsible for water monitoring are operating in Mongolia. It includes:

- The Ministry of Environment and Tourism (MOET) is the central government agency responsible for the development and implementation of water management policies in a broader context or to ensure sustainable water management. In addition, according to the Law on Environmental Impact Assessment (2012), the Ministry of Education and Culture reviews and approves environmental management plans for all mining projects, heavy industrial projects, and other major projects.

Many governmental bodies related to water by some of their role, and activities.

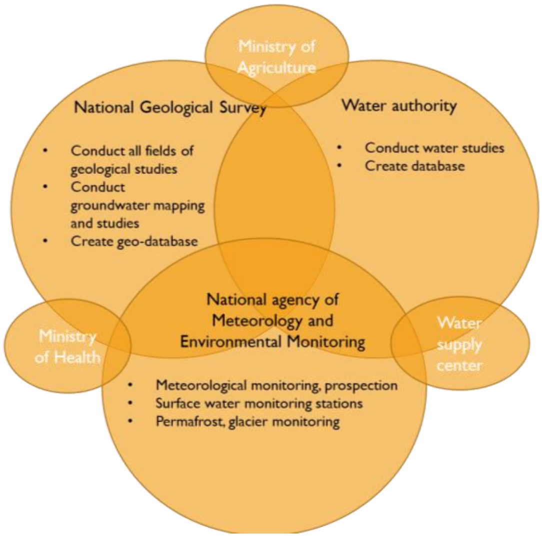

Fig. 1. Schema of water related stakeholders

- The Water Basin Administration (WABA) is responsible for developing and implementing the water management plan for the basin, as well as accounting for water resources.

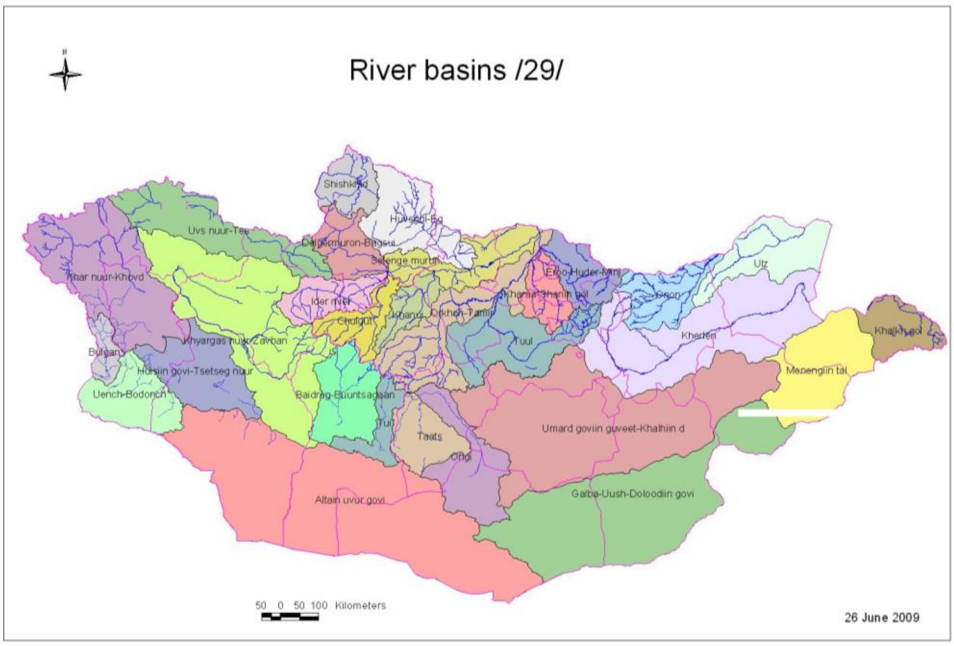

Fig. 2. River basins map of Mongolia

Provincial Environment Departments are responsible for reviewing and approving Environmental Management Plans (including environmental monitoring plans) developed and submitted by projects.

• The General Department of Professional Inspection is the main organization to ensure the implementation of the law, including the implementation of the Environmental Management Plan.

- Department of Meteorology and Environmental Analysis is responsible for the surface water level monitoring network.

The main task of the state-owned enterprise "Mongolian Water" is water monitoring and analysis, including water inventory, water monitoring and analysis, and development of water measurement procedures.

2. Expected monitoring items and purpose/ usage of monitored data

2.1 Current monitoring items

According to the Water Act, water users of more than 50 cubic meters per day are required to have an internal water monitoring plan.

The groundwater monitoring database is developed to contain the following types of data:

- Groundwater level, pressure, temperature, hardness, total dissolved solids and conductivity in time series;
- Geological data
- Hydrogeological data, such as depth to water surface, as static data;
- Construction data, such as casing, piezometer, and borehole development photos, as static, one-time entry;
- Type of equipment, such as pumping equipment and records, as static, one-time entry;
- Geophysical data, including surface and borehole measurements, as static, one-time entry.

- CTD Diver
- Mini Diver
- Diver DXT
- Direct read cable
- Gate M

Photo 1 Groundwater monitoring (equipment)

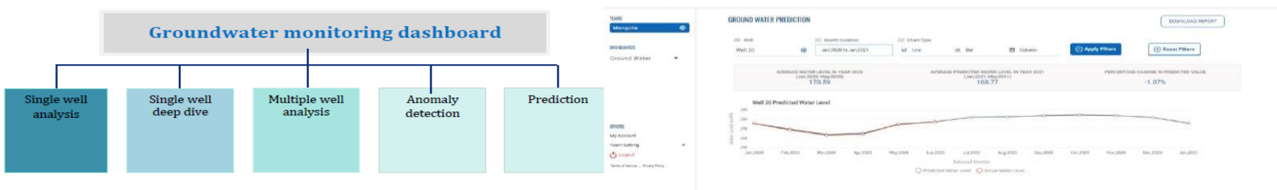

Fig. 3. The overlook of system in www.groundwater.mn (Water Authority (2012))

Photo 2 Groundwater monitoring (installation)

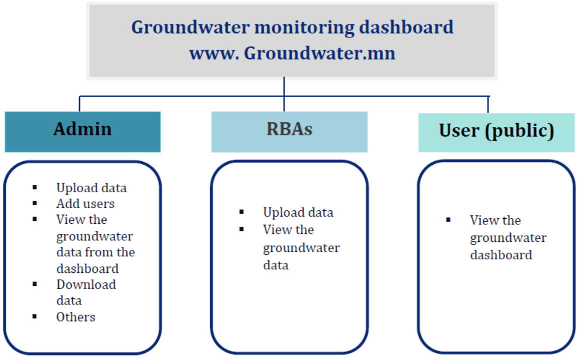

Fig. 1. Groundwater monitoring dashboard

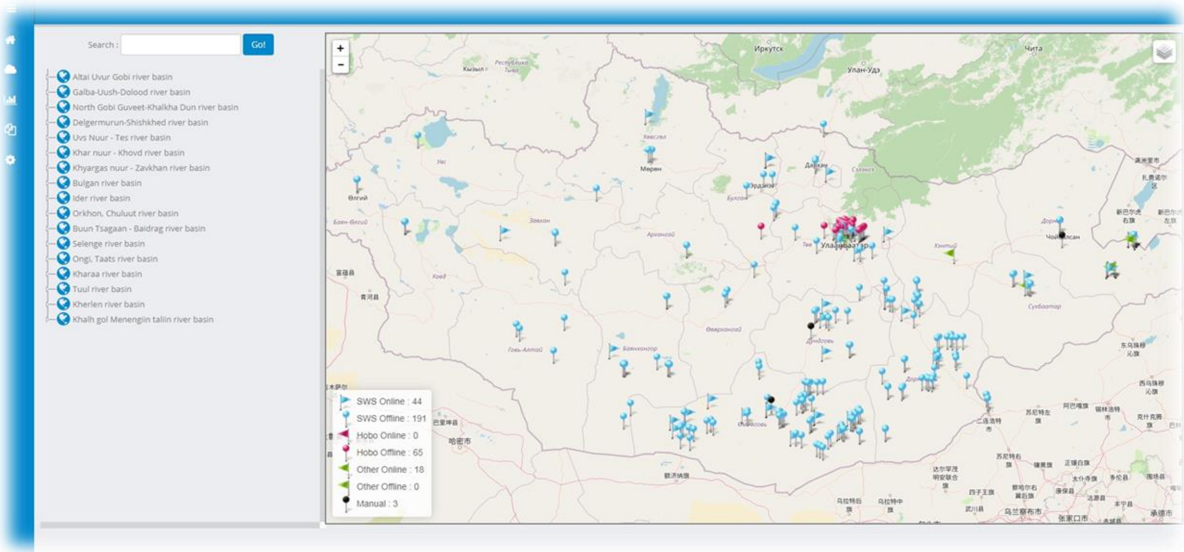

Fig. 2. Location map of Groundwater monitoring wells

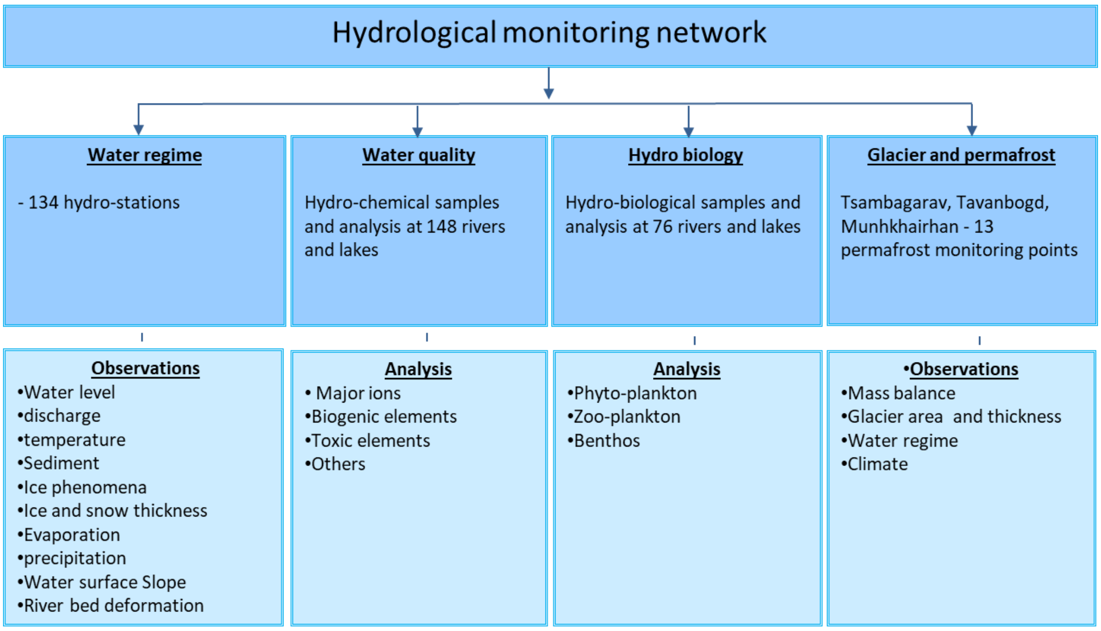

Fig. 6. Hydrological monitoring network

2.2 Water use and management are future challenges

Factors influencing future water demand in Mongolia. Agriculture has traditionally been the major water user in the Mongolia region. Increased water demand from planned natural resource development projects and current mining expansion is expected to further strain Mongolia's water resources in the near future. The average annual temperature in Mongolia increased by 2^0C between 1940 and 2008. Winter temperatures increased more than summer temperatures and increased more in mountainous areas than in plains and valleys. During the above period, the average annual rainfall in Mongolia decreased by 10%. The number of dried-up water points, rivers and streams is increasing.

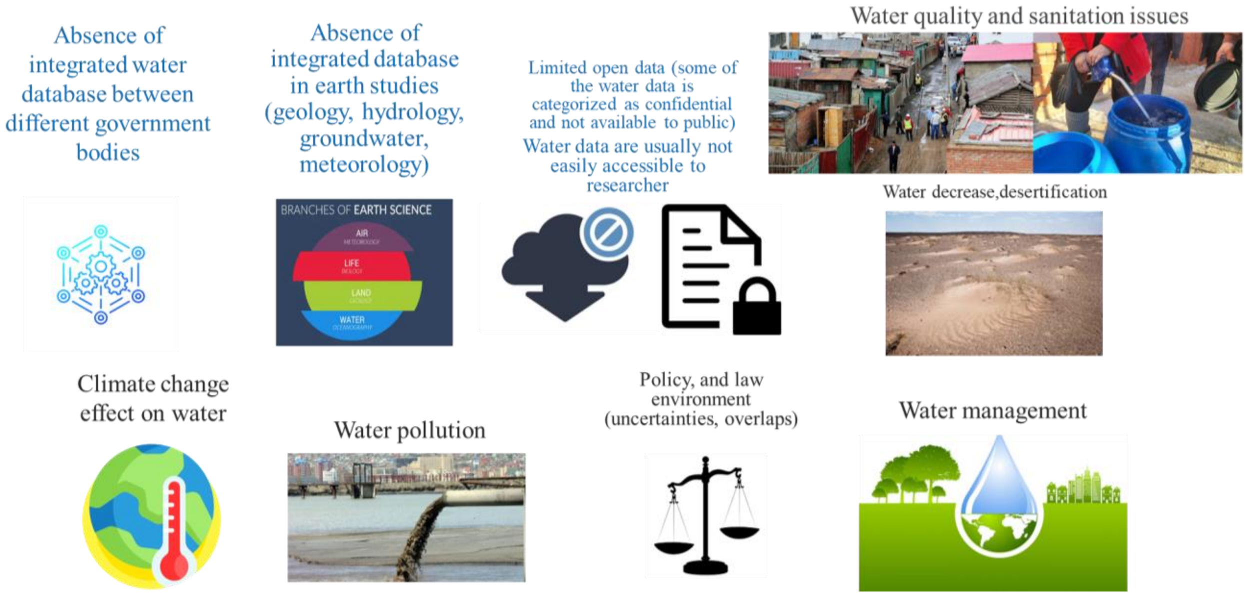

Fig. 7. Current issues in Mongolian water monitoring

2.3 Monitored data collection and usage

The results and data of water monitoring measurements are recorded in their internal domain systems of each institute.

- Groundwater monitoring system (Water Authority, River Basin Administrations): internal domain
- Environmental database (Ministry of Environment and Tourism): https://www.eic.mn/
- Geo database (NGS): https://geosystem.mris.mn/ (Internal)
- Independent databases of mining companies, private entities
- CCOP Geoscience Data Repository - http://49.247.131.15:58080/index.do (planning to upload water sample laboratory results)
- CCOP groundwater data portal - https://ccop-gsi.org/gsi/groundwater/index.php

3. Existing problems to establish the monitoring system

Water monitoring is an important way to ensure to be shared the information between stakeholders and their participation who is directly or indirectly affected by any water related project.

Stakeholder engagement is not an easy process, but it ultimately has the benefit of greater efficiency for the project and the affected parties. For this, it is necessary to plan the process of involving the parties in advance in accordance with the project goals and implement it as a part of the activities of the organization.

4. Conclusions

According to the Water Act, water users of more than 50 cubic meters per day are required to have an internal water monitoring plan and a qualified water management. Environmental monitoring is important for understanding the natural conditions of water monitoring parameters and determining the causes and effects of changes in monitoring parameters. Water monitoring is also an important way to build trust and engagement among stakeholders.

The hydrogeological mapping and detailed studies of groundwater have not been relatively well conducted compared to the territory. There are surface water and groundwater monitoring networks present in Mongolia.

However, the monitoring data is not available to the public, some of the data has been categorized as confidential. Therefore, these data are not stored in the integrated system and not well organized. There is a vital need to disclose these materials to the public, improve the monitoring systems, create an integrated database system.

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Future plan and management of groundwater and surface water in Myanmar

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Abstract

Myanmar is said to be a water rich country. But the spatial distribution of the water resources throughout the country and also the temporal distribution throughout the year is very different, and the water scarcity is encountered in some regions on some parts of the year. Although Delta area gets abundant precipitation on monsoon season, fresh water is insufficient in dry season. Almost all of the population in the area wholly relies on rainwater collecting ponds and tanks for drinking and domestic usage. Shallow tube-wells can be found in some favorable areas. Rising temperature due to Global Climate Change higher the evaporation rate. Existing domestic water supply ponds and tanks are not enough to meet the demand. Saline front (Salinity Line) is progressive moving towards upstream due to the rising of sea level and decreasing river flow in the dry season. Saltwater intrusion to shallow aquifer is more severe and saline water intrusion is closer to the ground level as the water table is rising up. Construction of dikes, island-round embankments and polders has been done to prevent intrusion of saline water into the paddy fields in the delta area. Upgrading and maintenance of these infrastructures is needed to fit the requirements. According to tectonic processes and geological setting of the delta area fresh water hold deep confined aquifer can be seated under the saline alluvium. So hydrogeological study for feasibility of fresh deep confined aquifers in delta area should be carried out as a way. Effective rainwater harvesting facilities for the household level is a way to solve the problems of drinking requirement of the delta area. For the sustainable utilization of fresh water resources in the delta area, all feasible measures must be conducted and ensure the safe and fresh water requirements of future generations. The total of (30) groundwater monitoring wells were sunk along the Central Cenozoic Belt of Myanmar even though there is still needing technical and financial assistant for installation of real time data sending and receiving system. The basin level detail development plan is needed and important for the sustainable development of water resources in the country.

Keywords: groundwater monitoring well, global climate change, saltwater intrusion

1. Introduction

Myanmar is a low water stress country according to its geographical position which favor to obtain sufficient monsoon rainfall in delta and hilly areas. Even in the central Myanmar which is known as dry zone, pre and post monsoon rainfall by the tropical storms during the dry seasons. Four major rivers and their tributaries are also fulfilled the water requirements throughout the country. So, traditionally, Myanmar people have very less concerns on water.

But the progressively increasing water demand due to population growth, urbanization and industrialization alarms the water scarcity problems. Cooperation with the international communities also changes the perspective of the stakeholders and enhance the awareness on the water management and conservation of natural resources.

Globally, climate change strongly influences freshwater supply and demand. Over the last half century, the temperature is rising ~1°C globally and it has directly impacted the freshwater supply through the amplification of precipitation extremes, more frequent and pronounced floods and droughts, increasing evapotranspiration rates, rising sea levels, and changing precipitation and melt water regimes.

The impacts of climate change on the quantity and quality of water resources will result in the opportunities, risks and challenges on irrigation and domestic water supply systems. Development and management of water resources will be the fast action to be taken for adaptation and mitigation of climate change.

2. Status of water resources and usage

2.1 Potential

Myanmar has three different seasons; monsoon, winter and summer, and it gets most of the rainfall in monsoon season. It obtains wide range of average annual rainfall, below 750 mm to 500 mm depending on geographical condition. The average annual rainfall of different geographical regions can be found as follows.

1) South & West Coastal Strip - 5000 mm
2) Delta - 2000 - 3000 mm
3) North & Eastern Hilly Region - 1250 - 3000 mm
4) Central Myanmar - below 750 mm

Based on the hydrological condition, Myanmar can be divided into eight major basins. The annual surface and groundwater potential of eight major basins are estimated as shown in the following table. It has 1082 km^3/yr. of surface water potential and 495 km^3/yr. of groundwater potential annually.

Table 1. Water resources potential of Myanmar

Sr.	River Basin Number	Name of Principal River Basin	Catchment area for each stretch (thousand sq.km)	Average estimated annual surface water(km^3)	Estimated groundwater Potential (km^3)
1	I	Chindwin River	115.30	141.293	57.578
2.	II	Upper Ayeyarwady River (up to its confluence with Chindwin)	193.30	227.920	92.599
3.	III	Lower Ayeyarwady River (From confluence with Chindwin to its mouth)	95.60	85.80	153.249
4.	IV	Sittoung River	48.10	81.148	28.402
5.	V	Rivers in Rakhine State	58.30	139.245	41.774
6.	VI	Rivers in Taninthari Division	40.60	130.927	39.278
7.	VII	Thanlwin River (From Myanmar boundary To its mouth)	158.00	257.918	74.779
8.	VIII	Mekong River (within Myanmar Territory)	28.60	17.634	7.054
		TOTAL	**737.80**	**1081.885**	**494.713**

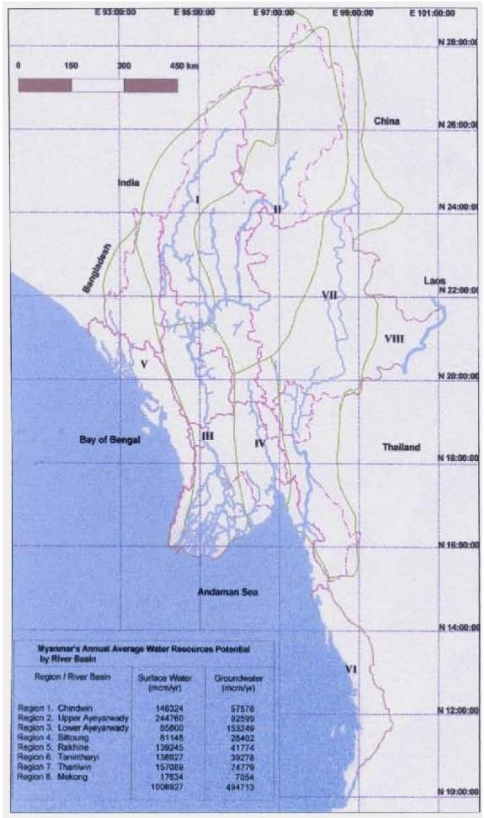


Fig. 1. River Basins Map of Myanmar

2.2 Water usage

Domestic water supply, Irrigation, industries are main users and the amount of water consumed by different sectors can be seen as follows.

		Surface Water		Groundwater		Total	
1)	Domestic	1.15	(3%)	2.55	(68%)	3.7	(8%)
2)	Industrial	1.17	(3%)	0.33	(9%)	1.5	(3%)
3)	Irrigation	41.97	(94%)	0.85	(23%)	42.82	(89%)
	Total	**44.29**		**3.73**		**48.02**	

(Unit in million acre-ft.)

Of the total water withdraws, around 89% is for agriculture, 8% for municipalities, and 3% for industry (ADB, 2013). This is a higher agricultural average than for Asia as a whole, reflecting the lower level of industrialization and urbanization in Myanmar. Approximately 91% of Myanmar's total water withdrawal comes from surface water, and 9% from groundwater (ADB, 2017). Myanmar currently uses less than 5% of the renewable water resource available to it.

3. Water resources management and conservation

3.1 Myanmar national water policy

In Myanmar, different government, non-government agencies and private firms are engaged in water sector. They are on the way with their own vision, perspective and responsibility.

With the aim to unify the perspectives and allocate the water rights for the different sectors under the Integrated Water Resources Management, IWRM, National Water Resources Committee (NWRC) was formed in 2013 as the National Apex Body for Water Resources Management in Myanmar. It is the highest level and the most responsible committee in the water sector. The committee adopted Myanmar National Water Policy, MNWP in February 2014.

The MNWP encompass from the formation water framework directive, allocation of water resources, adaptation to climate change, enhancing water available to use, demand management and water use efficiency, water pricing, conservation of river corridors, water bodies and infrastructures, management of flood, drought and extreme weather events, water supply and sanitation to institutional arrangement, trans boundary rivers and international cooperation, organizing database and information system, research and capacity development, and implementation of the water policy. The policy laid down the foundation to strengthen the institutional and legal framework for the IWRM.

3.2 Surface water management

Evaluation of surface water resources and development of surface water storage facilities had been started from Myanmar King Dynasty era. Surface storage facilities include dams, weirs, reservoirs and ponds. Most of them are constructed for irrigation, some are used for domestic water supply and managed by township committees and village communities. Totally, 660 numbers of dams, weirs and reservoirs, and 210 Pump Stations so far had been constructed for irrigation by Irrigation and Water Utilization Management Department (IWUMD).

Evaluation and monitoring of precipitation and other meteorological parameters by 31 weather stations throughout the country. These stations are operated by the Department of Meteorology and Hydrology (DMH). As an international cooperation, DMH installed 10 surface water monitoring stations under the Mekong-Lancang project.

Fig. 2. DMH surface water monitoring stations

For the dams, reservoirs, weirs and their catchment areas, precipitation, surface inflows and storage volume are monitored by Irrigation and Water Utilization Management Department's own stations. Monitoring on salinity of major rivers in delta area is also carried out to study the saline waterfront changes and degree of saltwater intrusion. Due to the high intensity of rainfall in delta area, the area wholly relies on rain water collection ponds for their drinking and domestic usage and river water for irrigation.

Ayeyarwaddy delta is popular for its heavy paddy cultivation, and it is called as **"Myanmar's Sapar gyi" "Myanmar's granary of paddy"**. Rising temperature due to Global Climate Change higher the evaporation rate. Existing domestic water supply ponds and tanks are not enough to meet the demand. Rising Sea Level will also affect the saltwater intrusion which is progressively more towards the upstream. Saltwater intrusion may be a major problem for delta areas to monitor and mitigate for the protection of the granary of paddy. Mangroves are natural cover for storm wind and water. Embankment along the islands, dykes and sluice gates are made to protect from sea water intrusion.

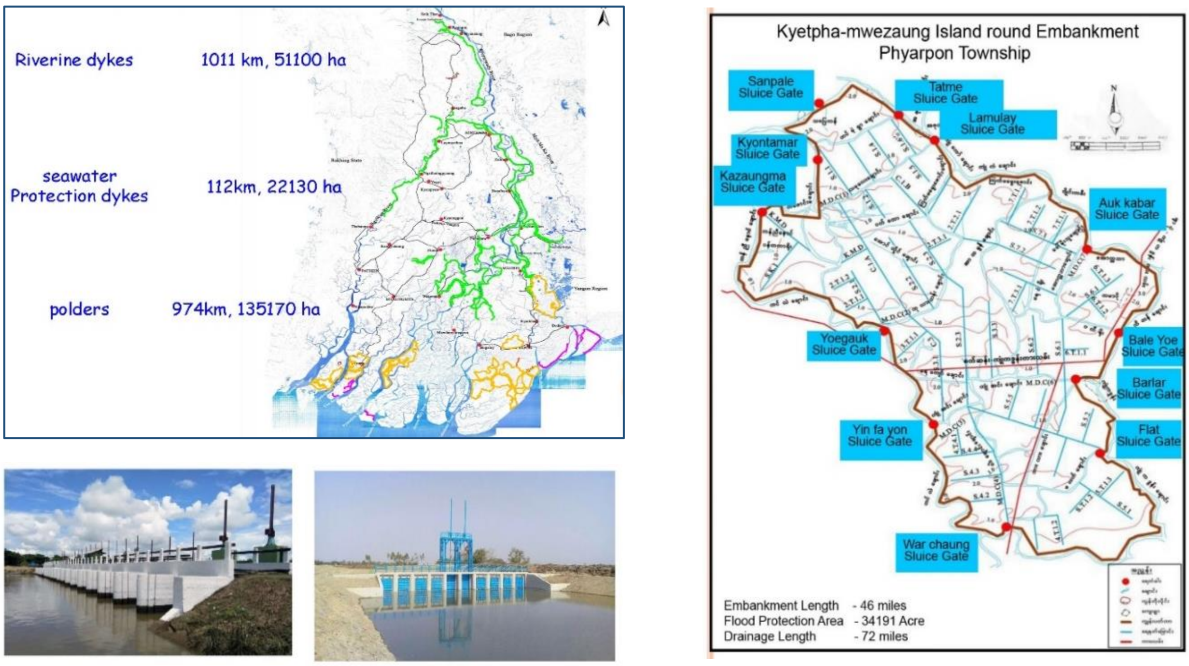


Fig. 3. Sea water protection dykes and polders in Ayeyarwaddy Delta

Myanmar has been continuously implementing the surface water development to meet the water demand which is progressively increase with population growth. Improving ponds and reservoirs to enhance rainwater harvesting.

For the Ayeyarwady Integrated River Basin Management (AIRBM) Project, The Ayeyarwady State of the Basin Assessment (SOBA) was conducted in 2017. It studied eight thematic areas; 1) Surface Water resources & use, 2) Water Pollution, 3) Groundwater resources & use, 4) Geomorphology & Sediments, 5) Fisheries & Aquaculture, 6) Biodiversity, 7) Socio-Economic Development, including demographics, sectorial development and macro-economics, and 8) Community Perspectives. Along the Ayeyarwaddy River, sixteen low head dams have been planned to construct for flood protection and river training.

The flow volume of the Ayeyarwaddy River has high difference between monsoon and dry seasons. Flood is very common in monsoon, and erosion, deposition and meandering along the river course is very high. It affects transportation and also the pump irrigation stations along the river course.

Melting of snow cap in the upstream of Ayeyarwaddy River is one of the sources of base flow. Climate change will affect the base flow. The low head dam along the river will help to mitigate the impact of climate change. IWUMD also planned new 77 pump irrigation projects along Chindwin and Ayeyarwaddy Rivers in line with construction of low head dams.

3.3 Groundwater management

Approximately 9 % of Myanmar's total water withdrawal comes from groundwater (ADB, 2017). The largest consumer of groundwater is domestic water supply. Except groundwater unfeasible areas in hilly and delta areas, almost all settlements depend on groundwater for drinking water. IWUMD alone had constructed (39796) tube-wells for domestic water supply and (25338) tube-wells for irrigation water supply. Other government and non-government agencies and private sectors are also involved in groundwater extraction. Most of the households in urban areas wish to use water from their own tube-well. There is no comprehensive legal mechanism to control groundwater extraction. The ground-water law is only under processing. Groundwater is a hidden natural resource. The evaluation and management is more complicated than that of surface water.

3.3.1 Hydrogeological study

Hydrogeological study is needed to evaluate the quality and quantity of groundwater resources. Hydrogeological studies have been made for the following areas.

1. Dry Zone, Central Myanmar
2. Eastern Highland Area
3. Kawthmu-Kungyangon Area

Hydrogeological study in Dry Zone (CDZ) and Eastern Highland areas are done with the assistance of Australian Water Partnership (AWP). Report for the CDZ had been successfully publish in both English and native Myanmar Language in 2017 and 2018, but only the draft report was completed for the Eastern Highland. Hydrogeological study for the whole Ayeyarwaddy delta area was planned to conduct with AWP, but can only completed for the Kawthmu-Kungyangon Area as a part of the delta area with IWUMD's own capacity.

3.3.2 Groundwater monitoring

To address above mention problems, IWUMD initiate the pilot groundwater monitoring in Myanmar. It has started by installing groundwater monitoring devices on nine existing tube-wells in dry zone in 2016-17, and then sixteen stations in 2017-18 and another five more station in 2018-19 fiscal years. Totally (30) monitoring stations were constructed by IWUMD. But, due to technical and communication failure, automatic data transmission and receiving system cannot be done yet. IWUMD also planned to construct 121 monitoring stations in cooperation with Korea Rural community Cooperation (KRC) by the assistance of Ministry of Agriculture, Food and Rural Affair (MAFRA), Korean Government.

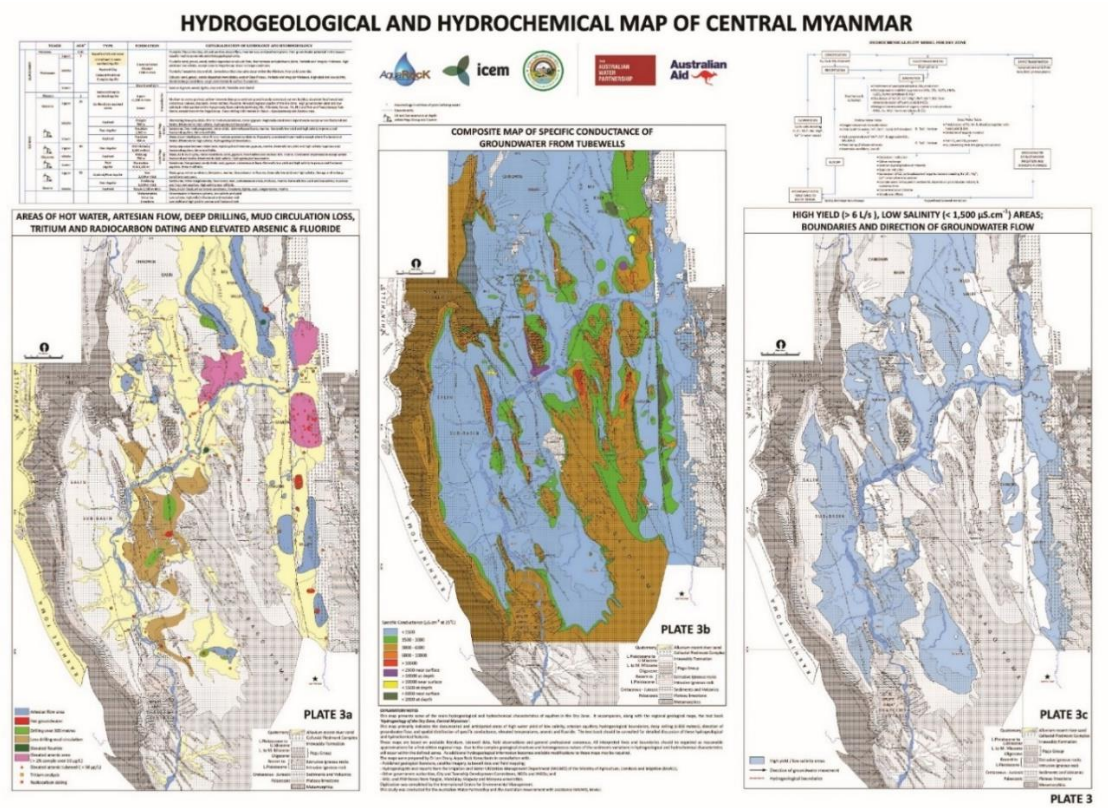
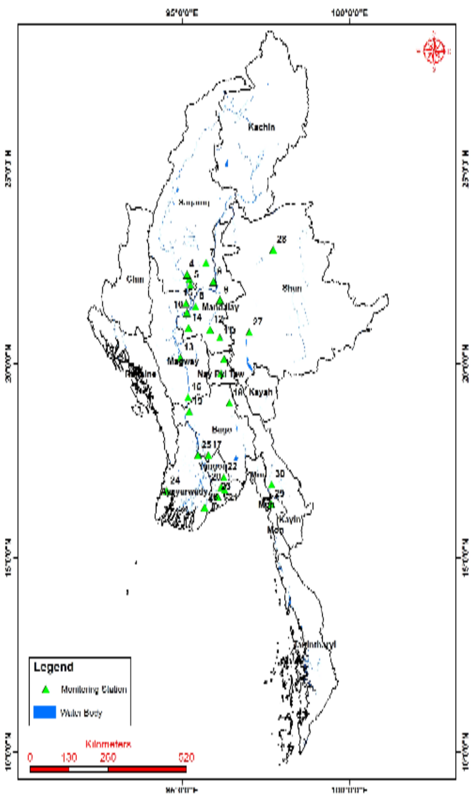


Fig. 4. Hydrogeological and hydrochemical Map of Central Myanmar



Sr	Well_No	State and Region	Township	Station_Location	Depth (ft)	SWL (ft)
1	Npt-1	Naypyitaw	Zabuthiri	IWUMD Office	370	25
2	Npt-2	Naypyitaw	Takkone	Shaukkon	215	0
3	Sgg-1	Sagaing	Monywa	Monywa Office	135	101
4	Sgg-2	Monywa	Budalin	Cycle(1) Well No(1/28)	300	82
5	Sgg-3	Monywa	Chaung Oo	Cycle(4) Well No(4/4)	295	30
6	Sgg-4	Yinmabin	Yinmabin	Near Myitta Pond	300	0
7	Sgg-5	Sagaing	Shwebo	IWUMD Office	700	32
8	Mdy-1	Mandalay	Myingyan	Myingyan Office	200	103
9	Mdy-2	Mandalay	Kyauk Se	Kyauk Se Office	60	1
10	Mdy-3	Myingyan	Taungtha	Kyawzi Pump Station	390	90
11	Mdy-4	Meiktila	Pyawbwe	Htanaungpinwine Monastery	500	10
12	Mdy-5	Meiktila	Meiktila	IWUMD Service Housing	410	28
13	Mgy-1	Magway	Magway	Magway Office	200	51
14	Mgy-2	Magway	Minbu	Minbu Office	275	124
15	Mgy-3	Pakokku	Pakokku	IWUMD Office	255	16
16	Mgy-4	Thayet	Aunglan	Duyingabo Pump Station	210	23
17	Bgo-1	Bago	Bago	Thayarwaddy Office	120	27
18	Bgo-2	Taungngu	Taungngu	IWUMD Office	370	7
19	Bgo-3	Pyay	Pyay	IWUMD Office	450	7
20	Ygn-1	Yangon	Yangon	Yangon Office	300	48
21	Ygn-2	Yangon (S)	Thanlyin	IWUMD Office	300	28
22	Ygn-3	Yangon(N)	Hlegu	Ngamoeyeik Pump Station	247	11
23	Ygn-4	Yangon	Kawhmu	Magyikan Village	500	13
24	Ayar-1	Ayarwaddy	Ayarwaddy	Pathein Office	240	11
25	Ayar-2	Hinthada	Hinthada	IWUMD Office	300	5
26	Ayar-3	Phyarpon	Phyarpon	IWUMD Office	435	6
27	Shn-1	Shan(S)	Taunggyi	IWUMD Office	550	70
28	Shn-2	Shan(N)	Lashio	IWUMD Office	400	60
29	Mon-1	Mon	mawlamyine	mawlamyine Office	180	44
30	Kyn-1	Kayin	Hpa an	IWUMD Office	140	10

Fig. 5. Location of pilot groundwater monitoring stations in Myanmar

3.3.3 Artificial groundwater recharge

For the sustainable utilization of groundwater, it is needed to maintain and develop the quantity and quality of groundwater resources. In this regard, IWUMD starts the pilot artificial groundwater recharge initiatives in 2020. Totally 9 artificial groundwater re-charge facilities have been constructed in Sagaing Region, Mon and Shan States, and two facilities are constructing in Sittwe, Rakhine State.

The above eleven groundwater recharge facilities are only conducted as a pilot project to take awareness on groundwater recharge. For the implementation of effective groundwater recharge, hydrogeological framework of each and every groundwater basin must be identified, groundwater balance must be estimated, and quantity and quality of groundwater must be monitored. And also all stakeholders including local community must be cooperated.

Fig. 6. Photographs of artificial groundwater recharge well in Mawlamyine, Mon State

4. Future plan

The followings are the future plan of water resources managements in Myanmar-

a. Preparation of river basin-wise water resources development plan
b. Strengthening of cooperation and coordination among the water related agencies, departments and organizations in country
c. Accelerate to groundwater management works
d. Accelerate to surface water management works

5. Conclusion

Climate change can cause severe saltwater intrusion in the delta area. Construction and Upgrading Dikes, Island-Round Embankments and Polders to prevent intrusion of saline water. Alternative ways must be found to fulfill the demands of safe drinking water such as improving rainwater harvesting facilities. Basin level water resources development master plan is needed. Groundwater monitoring network is important for long term sustainable development of groundwater resource in the country. It is important to launch the systematic centralized groundwater database system for the country. Hydrogeological study for feasibility of fresh deep confined aquifers in delta area need to extend. It is important to make capacity building in water resources management sector in the country.

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Future plan and policy for the monitoring system of groundwater in Papua New Guinea, and problems to establish the system

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Abstract

Papua New Guinea currently do not have any properly established groundwater monitoring system in place. This may be due to a lack of collaboration between important stakeholders concerned with groundwater resources and its development within the country. For a monitoring system to be established, other factors may need to be considered as well, mostly socio-economic factors and identifying which government entity will be in charge of managing these data.

Groundwater quality data is the main data set that needs to be monitored, including water level fluctuations to confirm if respective groundwater resources are sufficient and suitable for water supply purposes, especially for domestic use. Data currently captured in the groundwater database is mostly from historical data from old reports, hence, a proper groundwater monitoring system is necessary, and vital, which will aid in keeping more up-to-date data. Further discussions between government and private stakeholders will be needed to initiate the establishment of a proper groundwater monitoring system so that data captured and recorded is more systematic.

Keywords: groundwater, database, PNG.

1. Introduction

At present, Papua New Guinea (PNG) does not have a properly established groundwater monitoring system in place. Before the establishment of the Mineral Resources Authority (MRA), borehole drilling was carried out by the Geological Survey's Drilling Section under the Department of Minerals & Energy, hence, sufficient data was recorded under the Geological Survey. The drilling section eventually ceased to operate, hence, creating a gap for borehole data collection. With the inception of the MRA, and the introduction of private drilling companies in the country which are usually contracted to carry out most of the groundwater borehole drilling, most data sets are not reported back to the Geological Survey Division (GSD) of the MRA.

Adding onto this, the original groundwater database which was kept under the Department's Geological Survey Division was lost during the transition from the Department to the establishment of the MRA. This gave rise to the need for a new database to be set up where data is been collected from old groundwater reports from the Geological Survey library of the MRA; this is an existing project still in progress.

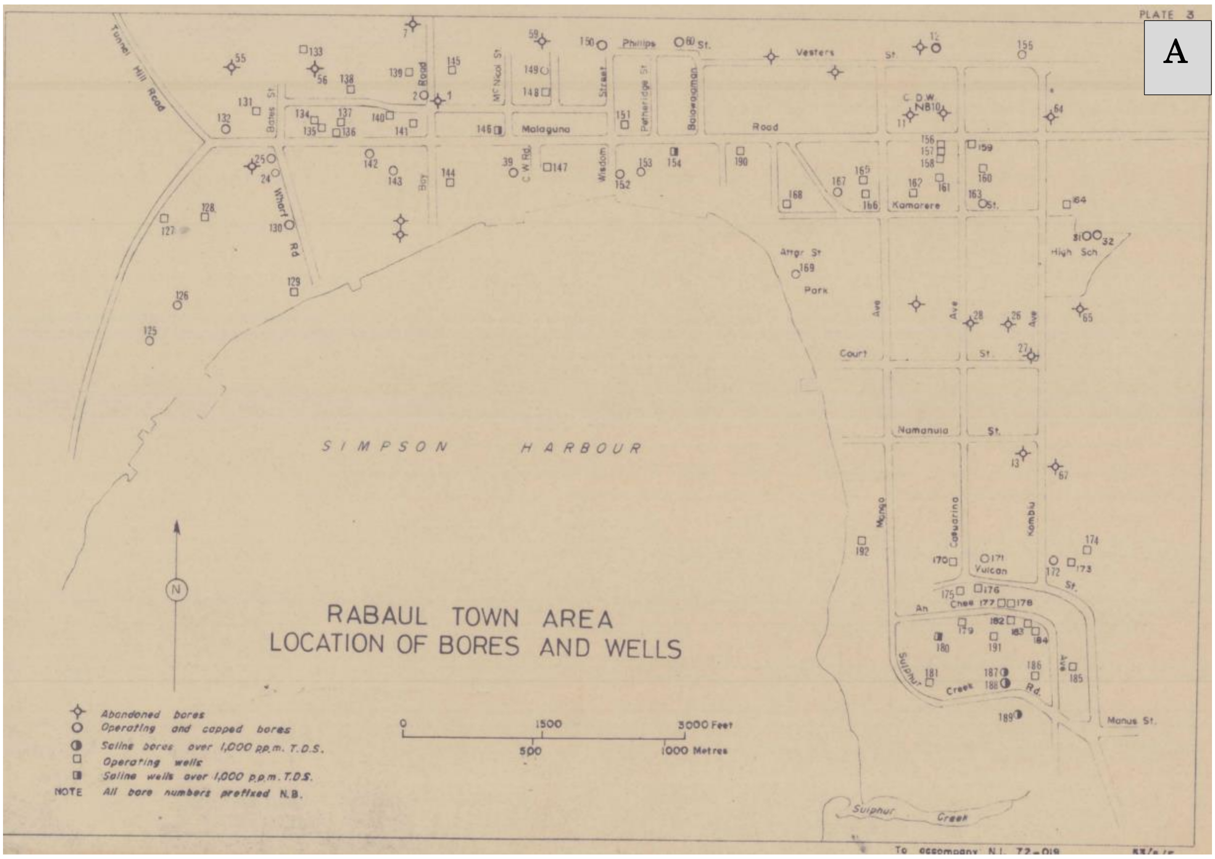
The main aim of this report is to outline and identify the main problems that may be encountered in establishing a groundwater monitoring system, and the potential plan for this monitoring system in PNG.

2. Existing problems to establish the groundwater monitoring system in PNG

Three main problems were identified regarding the establishment of a groundwater monitoring system in PNG:

1. Most bores are privately owned, either by customary landowners, or within company premises.
2. There is no proper Water Resources Department or Bureau to monitor and manage these data.
3. There is no proper collaboration between government departments involved in water resources-related projects, and other private companies.

Currently, bore data is being collated from old reports from the Geological Survey internal library. The location of many boreholes reported is unknown, and where locations are known, proper permission is needed to access the bore site to collect the necessary data. From the reports sited to date, no exact location coordinates are provided, however, sketch maps of the bore locations are provided (Figure 1). Collecting the geographic location of the bores is one part of this project, however, the main challenge in this project would be going on site to confirm the location and other necessary data, including water quality and pump test information. Moreover, regular updates need to be made on these data in order to keep the data valid.



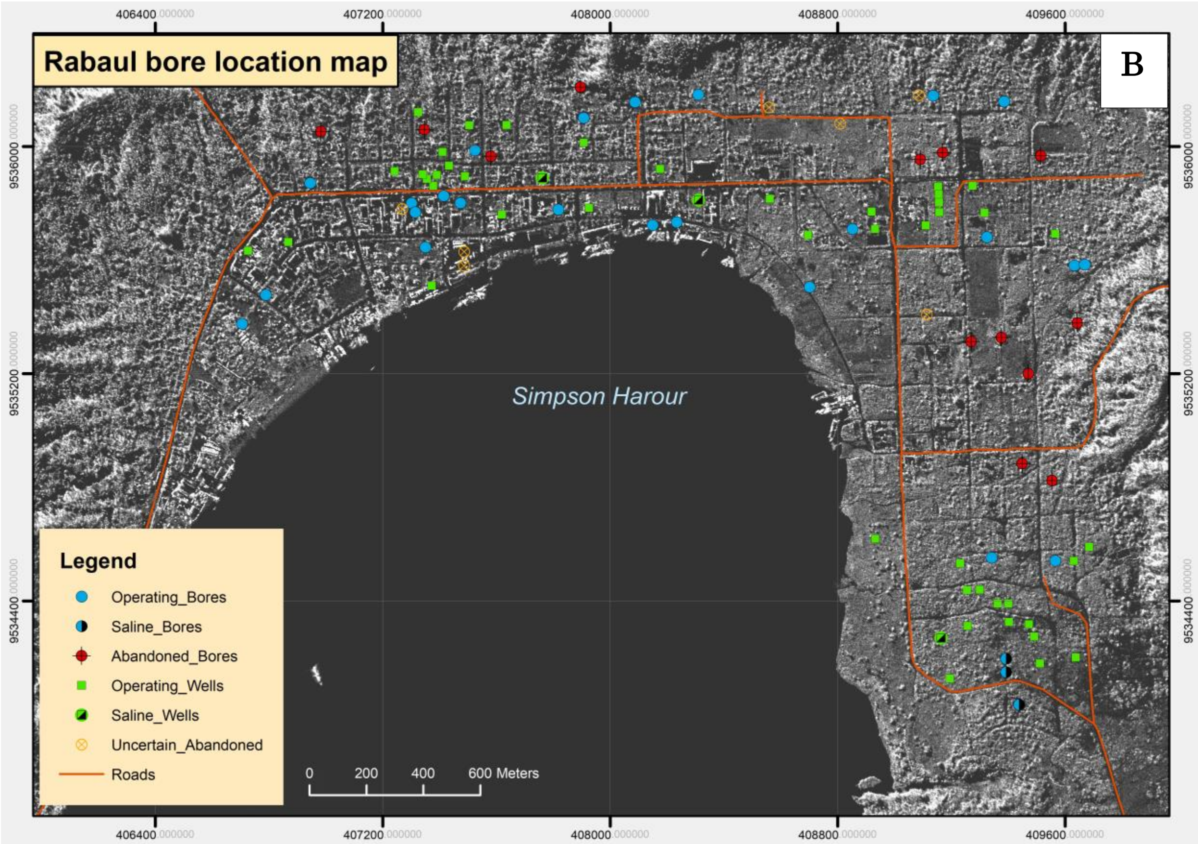


Fig. 1. A) Example of a sketch map of borehole locations of Rabaul Town, East New Britain Province (Pounder, 1972), **B)** and the estimated plotted bore locations on a simplified map

Currently, there is no proper Water Resources Department or Bureau to monitor and manage these data. According to PNG legislation, *"Division 4, Sections 88-94"* of the Environment Act 2000 confirms that *'water investigation'* permits are to be obtained through application to the Conservation and Environment Protection Authority (CEPA) which includes any investigation relating to water resources, pumping tests, test-drilling, and collection of soil or geological samples in the target site (Independent State of Papua New Guinea, 2000). The *Act* also states that any water investigation permit holder is required to furnish a report to the Director of CEPA of the investigations of water resources to provide details of hydrological, geographical, geological and geophysical information collected. Data from these reports are to be compiled by the Director (CEPA) for purposes relating to the conservation of water resources and administration of the *Act*.

Management of water resources data, therefore, falls under the mandate of the CEPA, however, currently the Hydrogeology Section under the Geological Survey under MRA is unaware of the status of the compilation and management of these water resources data.

Proper collaboration between government departments involved in water resources-related projects is lacking. Major stakeholders concerned with water resources-related projects in the country include:

- Conservation and Environment Project Authority (CEPA).
- MRA-Geological Survey Division Hydrogeology Section.

- Water PNG Limited.
- And major drilling companies.

The Hydrogeology Section under MRA-GSD are part of the Geoscience for humanity arm of MRA. This section focuses on carrying out groundwater investigations (Figure 2) in selected areas within the country to help identify groundwater sources that may be used for rural and/or urban water supply purposes. Data is also collected for database compilation within the GSD, both from ongoing projects, and mostly from historical data captured in old reports from the MRA Geological Survey library.

Fig. 2. Photographs showing usual site inspection of bores and shallow wells during groundwater investigations

Water PNG Limited focus on the planning, designing, constructing, and managing of water supply and sewerage services throughout PNG. These includes bore water supply around several towns and districts in the country.

Drilling companies are usually contracted to do bore water drilling for private and government clients, however, most of the data is not reported back to MRA Hydrogeology Section for entry into the database. Discussions with a drilling company, namely Central Drillers (currently non-existent) resulted in an agreement where their borehole pumping test data was provided to the Hydrogeology Section. These data, however, is missing spatial reference information, hence, location of the bores is unknown, even if the pumping test data are available.

3. Future / Ongoing plan and policy for the monitoring system of groundwater in PNG

Collating of groundwater historical data from old reports from the MRA library is ongoing, as part of the PNG groundwater database project. Data has already been collected for:

- Port Moresby (capital city) and surrounding areas (Figure 3).
- East New Britain Province (Rabaul and Kokopo).
- Lae, Morobe Province (ongoing).
- And Central Province (mostly Rigo District).

Port Moresby was the only area that was further surveyed to confirm the location coordinates and status of these historical bores (Fig. 4).

Registered No / Well ID	Location	Easting (mE)	Northing (mN)	Elev. (m)	Total Depth (m)	Groundwater Level (m)	S.W.L (m)	Supply (m3/hr)	Salinity (p.p.m)	Lab Test	Pump Test	Year
P31	Sir John Guise Stadium	520195	8956520	57.0	20.7	17.1	13.7	2.7		No	Yes	1965
P102	Laloki Psychiatric Hospital	524578	8965024	27.0	30.5		3.0	2.4	558.0	Yes	Yes	1968
P119	Transitmix Quarry	525127	8960809	45.0	18.3	10.7	7.0	1.8	557.0	Yes	Yes	1971
P129	Eleven Mile - Brown River Road	524628	8962525	33.5	7.3		6.7		367.0	Yes	No	1971
P178	Laloki Psychiatric Hospital	524664	8965035	33.0	24.2	18.3	3.7	2.0	477.0	Yes	Yes	1971
P200	Laloki Psychiatric Hospital	524604	8965176	32.0	22.2	13.7	2.4	2.0	481.0	Yes	Yes	1971
P241	Jacksons Airport	523082	8956490	53	14.3	8.5	5.5	1.4		No	Yes	
P291	POM Golf Course	521475	8957982	47.0	18.9	2.7	4.9			No	Yes	1973
P342	Bomana Seminary	528205	8961108	40.0	11.0	1.9	1.3			No	Yes	1978
NCD 4	D.O.W Training Centre - Boroko	521421	8954232		16.6	4.3		0.61 l/sec		No	Yes	1983
NCD 7	Milan Investments - Hohola	520138	8955438		28.0	4.9	8.2	0.8 l/sec	225.0	Yes	Yes	1988
NCD 8	Gordons International School	521697	8955091		17.7	5.5		0.63 l/sec		No	Yes	1979
NCD 10	University of PNG (DMK)	518873	8960208		14.0	1.9		0.8 l/sec	187.0	Yes	Yes	1985
NCD 15	Nebire Quarry	524194	8962525	50.0	9.0	2.7		0.76 l/sec		Yes	Yes	1980
NCD 20	Sports Oval - Hohola	519250	8955148		16.0	3.1		1.08 l/sec		No	Yes	1988
NCD 22	Sir John Guise Stadium	520195	8956520	57.0	31.0	13.9	0.7	0.94 l/sec		Yes	Yes	1988
NCD 23	Airways Hotel - 7 Mile	523816	8955067	89.0	30.0	12.5		0.4 l/sec		No	Yes	1988
NCD 25	Police College (New)	526849	8962246	36.0	15.0	7.2		1.1 l/sec		No	Yes	1988

Fig. 3. Example of the type of data collected for the PNG groundwater database, under the Hydrogeology Section, MRA-GSD

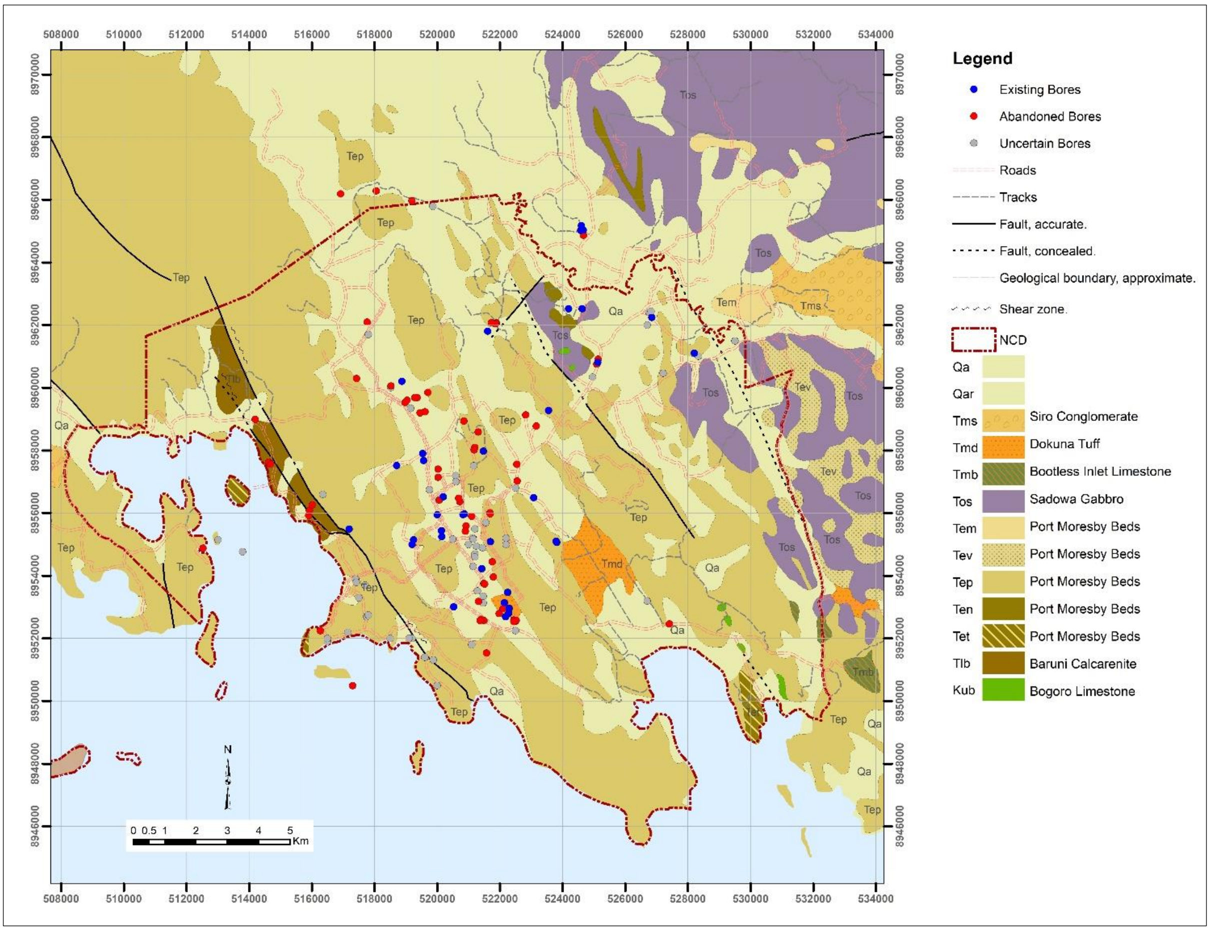


Fig. 4. Bore location map of Port Moresby, National Capital District (NCD) and surrounding areas

All other areas have not been further surveyed for bore locations, however, a bore location map was generated for East New Britain's Rabaul and Kokopo Towns. These are mostly extracted from sketch maps from old reports (Figure 1).

As advised by Water PNG Limited, bore water supply systems are currently operational in the following areas:

- West New Britain Province – Kimber Town.
- Morobe Province – Lae Town.
- Eastern Highlands Province – Kainantu Town.
- And partially in MilneBay Province – Alotau.

For every production bore, a monitoring bore is usually constructed to monitor water level fluctuations and aquifer performance. In the absence of a monitoring bore, the production bore flow rates is monitored. Where necessary, remedial action such as water rationing is carried out to maintain the water supply. Drilling is currently underway in other selected areas in the country, managed by Water PNG Ltd.

The way going forward would be to have further discussions between the MRA Hydrogeology Section, the Conservation and Environment Protection Authority, Water PNG Ltd, and major drilling companies engaged in water-resources projects. Upon discussions, a more systematic approach can be established on how to manage the groundwater resources data for the country's groundwater database.

4. Expected monitoring items and purpose/ usage of monitored data

The main aspects of groundwater data which is critical and need regular monitoring include:

- Groundwater quality.
- Water level fluctuations.
- Bore performance from flow rates.

Groundwater quality data must be monitored more regularly as it will determine the portability and safe use of this water before domestic use. Other aspects such as water level fluctuations and bore performance may be monitored, but less frequently compared to water quality.

It may be necessary to engage an accredited water testing laboratory to carry out regular analysis of monitored samples which will help maintain validity and consistency in the analysis results. Monitoring is important as this will help identify whether additional bores are required to supply the community, especially where there is an increase in population, or where there is extreme weather and climatic changes. Monitoring instruments such as dip meter, data logger, water sampling kit or in-situ water testing probe should be used to collect the needed data to update the database. A proper system can be established where these data from the borehole owners can be supplied to CEPA and passed to the Hydrogeology Section of MRA, however, this can be done only after further discussions between these stakeholders is done.

5. Conclusions

Although there is no proper monitoring system in place for PNG, this can be established through proper collaboration between major stakeholders concerned with water resources development in the country, especially for groundwater. Proper collaborations between MRA-GSD Hydrogeology Section, CEPA, Water PNG, major private drilling companies, and any other stakeholders may help establish a groundwater monitoring system that can give up-to-date data on our groundwater resources. This will provide a more systematic approach to keeping records and managing groundwater data of the country.

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Current groundwater monitoring system in the Philippines and existing issues

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Abstract

The Philippines has abundant surface and groundwater resources with an estimated potential of 125 million cubic meters (MCM) per year (86%) and 20 MCM per year (14%) respectively. Despite the groundwater's lower availability compared to surface water, it serves as the backbone of the domestic and industrial water supply systems of the Philippines. It supplies most of the requirements of 1,634 Local Government Units and the needs of economic and industrial zones. However, this resource is susceptible to the effects of climate change. The Philippines established a system of groundwater monitoring to ensure the sustainability of the resource for its increasing population and to support economic growth.

Monitoring is managed by a cluster of agencies and institutions whose focus depends on their respective functional mandates. Among those, the Mines and Geosciences Bureau (MGB) collects and analyzes data and generates groundwater maps while the National Water Resources Board (NWRB) is in charge of coordination and regulation.

In order to enhance monitoring, a Memorandum of Agreement was signed in 2014 between NWRB, the Local Water Utilities Administration, and the Department of Interior and Local Government to generate a listing of water providers and several parameters that must be annually updated.

Effective groundwater monitoring is hampered by the country's archipelagic conditions, variability of terrain, incomplete national groundwater assessment, decentralized and limited coordination among multiple designated agencies, and limited monitoring capacity of agencies and water supply providers.

Monitoring could be enhanced through institutional strengthening at the agency and water supply provider level, stricter implementation of monitoring requirements, and analysis of monitoring results at the watershed level. In accordance with their mandate, MGB is in a position to consolidate and analyze the data through collaborative projects with NWRB that will enhance groundwater monitoring in the Philippines.

Keywords: groundwater, monitoring, Philippines

1. Introduction

The Philippines has abundant surface and groundwater resources with an estimated respective annual potential of 125 million cubic meters (MCM) and 20 MCM, respectively (**Table 1**).

Table 1. Water Resources Potential of the Philippines

Water Resources Region		**Groundwater Potential**	**Surface Water Potential**	**Total Water Resources Potential**	**% Groundwater Potential to Total Potential**
I	Ilocos	1,148	3,250	4,398	26.10
II	Cagayan Valley	2,825	8,510	11,335	24.92
III	Central Luzon	1,721	7,890	9,611	17.91
IV	Southern Tagalog	1,410	6,370	7,780	18.12
V	Bicol	1,085	3,060	4,145	26.18
VI	Western Visayas	1,144	14,200	15,344	7.46
VII	Central Visayas	879	2,060	2,939	29.91
VIII	Eastern Visayas	2,557	9,350	11,907	21.47
IX	Western Mindanao	1,082	12,100	13,182	8.21
X	Northern Mindanao	2,116	29,000	31,116	6.80
XI	South-eastern Mindanao	2,375	1,300	13,675	17.37
XII	Southern Mindanao	1,758	18,700	20,458	8.59
Total		**20,100**	**125,790**	**145,890**	**13.78**

Adapted from “Philippines Environment Monitor” by World Bank, 2003

Surface water resources are manifested in 421 principal river basins of which 18 are considered major. Usage of surface water includes irrigation, hydropower generation, and domestic supply for major cities notably Metro Manila, Tacloban City, and Zamboanga City.

Despite its relatively lower abundance compared to surface water, groundwater serves as the backbone of the domestic water supply system of most of the 1,634 Local Government Units (LGUs) in the Philippines. It is tapped through wells and springs by the different water users and supply providers which include water districts, LGU-run utilities, community-based organizations, and private utilities, among others. It is also used by major economic zones and industrial establishments to sustain their operations, as well as by farmers in the irrigation of selected agricultural areas.

2. Current monitoring system of groundwater in the Philippines

Management of the country's water resources is performed by a cluster of 31 government agencies headed by the National Economic and Development Authority (NEDA) on policy and by the National Water Resources Board (NWRB) on coordination and regulation. As shown in Fig. 1, the sector has been divided into 12 major functions: (1) Water Quality and Sanitation, (2) Watershed Management, (3) Integrated Area Development, (4) Data Collection, (5) Research, (6) Cloud Seeding, (7) Water Supply, (8) Irrigation, (9) Hydro-power, (10) Flood Management, (11) Ports and Navigation, and (12) Fisheries and Navigation. Each function is assigned to a group of agencies that perform their tasks in accordance with their respective mandates.

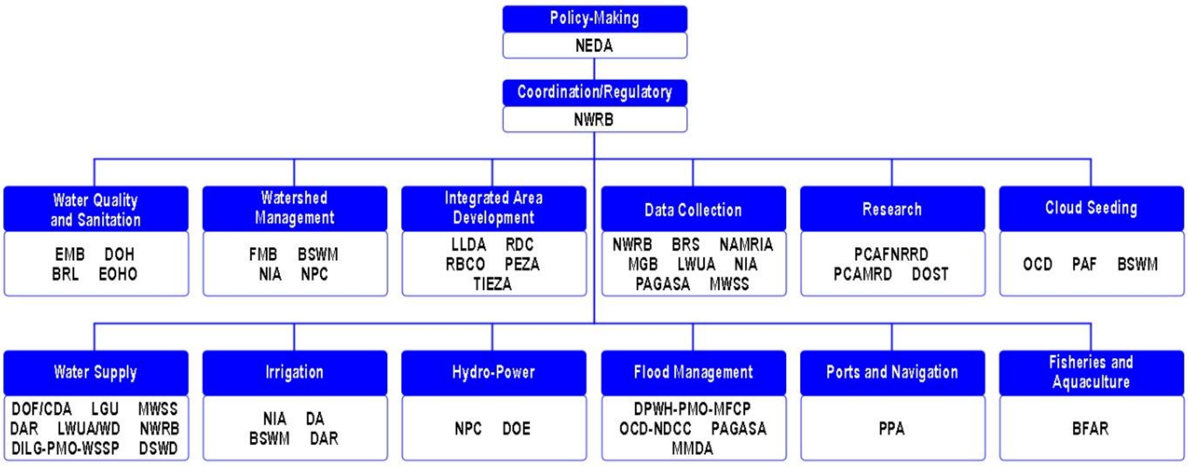

Fig. 1. Functional Chart of Water-related Agencies in the Philippines (Adapted from "Philippine Water Supply and Sanitation Master Plan 2019-2030" by NEDA, 2021)

Among these functions, water quality and sanitation, data collection, and water supply cover the aspect of groundwater monitoring.

Monitoring of the groundwater resources in the Philippines is embodied under key standards, laws, decrees, and administrative orders which have been formulated over the past 60 years. **Table 2** presents the features of these legal instruments and their relevance to groundwater monitoring.

These legal instruments reduced the agencies actually tasked with groundwater monitoring to four (4) agencies: NWRB, DOH, DENR, and LWUA. Under the guidance of these agencies, actual monitoring in the field is performed by the major drinking water service provider (**Table 3**). All levels of water supply systems are included.

Table 2. Features of Legal Instruments with Respect to Groundwater Monitoring

Legal Instruments	Features Related to Groundwater Monitoring
1963 - Philippine National Standards for Drinking Water (PNSDW) (Modified in 1978, 1993, 2007, and 2017)	Establishment of the PNSDW, the water quality standards which must be satisfied prior to usage and distribution of groundwater
1967 - Water Code of the Philippines	Regulation of groundwater extraction through a permitting and monitoring system
1973 - Presidential Decree 198: Provincial Water Utilities Act	Creation of the Local Water Utilities Administration (LWUA) which requires all water districts to submit monthly reports on the production, water levels, and potability of water from their respective wells and springs and annual reports on the physicochemical properties of these sources
1975 - Code on Sanitation of the Philippines	Prescription of standards for the bacteriological and chemical examination of water and for the evaluation of drinking water in accordance with the PNSDW
1978 - Presidential Decree 1586	Creation of the Philippine Environmental Impact Statement System which requires all establishments that have been issued Environmental Compliance Certificates (ECCs) by the Department of Environment and Natural Resources (DENR) to regularly submit self-monitoring reports on water extraction and quality
2004 - Philippine Clean Water Act	Promotion of the protection of different water resources from pollutants brought by industries and commercial establishments and agriculture
2014 - Department of Health (DOH) Administrative Order 2014-0027	Development of the National Policy on Water Safety Plan (WSP) for all Drinking Water Service Providers which requires all drinking water service providers to develop and implement their respective WSPs
2022 - Joint Administrative Order No. 2022-0002	Creation of Guidelines on Establishing Local Drinking Water Quality Surveillance (LDWQS) Program which provides instructions for the establishment of LDWQS programs in each LGU through the creation of the Local Drinking Water Quality Monitoring Committee for the use of all LGUs and the national and regional offices of the DOH and the Department of the Interior and Local Government (DILG)

3. Monitoring items, purpose/usage of monitored data, and database (data management)

The NWRB coordinates and regulates water activities in the country. It monitors the extraction of groundwater based on the permits it issues for the operation of the wells and springs of the water service providers. It also conducts regular measurements of water level and water quality in selected wells located in water-stressed watersheds.

Table 3. Water Supply Systems and Corresponding Drinking Water Service Providers

Water Supply System	Drinking Water Service Provider
Level 3	Water District
	Rural Waterworks and Sanitation Association
	Local Government Unit
	Barangay Waterworks and Sanitation Association
	Special Economic Zone drinking water provider
	Metropolitan Waterworks and Sewerage System and concessionaires
	Water service cooperative
	Homeowners Association/Subdivision developer
	Other recognized drinking-water service provider
Level 2	Rural Waterworks and Sanitation Association
	Local Government Unit
	Barangay Waterworks and Sanitation Association
	Water service cooperative
	Other recognized drinking-water service provider
Level 1	Barangay Waterworks and Sanitation Association
	Water service cooperative
	Other recognized drinking-water service provider

NWRB spearheaded the setting up of the Listahang Tubig or Water Register in 2014 through a Memorandum of Agreement with the DILG and LWUA. Listahang Tubig is a survey of all the water service providers in the country that regularly provide information on the location, production, and quality of water sources utilized by the providers.

The DOH monitors the quality of the water distributed by the water service providers through reports of tests from its accredited laboratories.

The DENR, through the Environmental Management Bureau (EMB), monitors the submission of reports from establishments that were issued ECCs. The report covers production, water levels, potability, and physicochemical properties of water from the wells of the said establishments.

LWUA requires all water districts to submit monthly reports on the production, water levels, and potability of water from their respective wells and springs and annual reports on the physicochemical properties of these sources.

In Metro Manila, the Metropolitan Waterworks and Sewerage System (MWSS) through its concessionaires, monitors the production, water levels, and quality of its wells which are operated to augment the output of its major surface water source, the Angat Dam.

The objectives of the monitoring agencies vary in accordance with their respective mandates. NWRB aims to control extraction within the limits set in the water permits. Its Listahang Tubig program aims to create a database of all water service providers which contains location, source type (deep well, spring, surface water, others), production, water level (static and pumping), hours of operation, and well design (depth, diameter, pump setting). Measurements are to be performed monthly and submitted quarterly. The database would be updated annually.

DENR aims to ensure that the aquifer tapped by the wells is not contaminated by the potential waste that will be generated by the establishments with ECCs and that the extraction is within the permitted production capacity of the wells.

LWUA and MWSS have similar objectives in their monitoring programs - ascertain that groundwater extraction falls within the limits determined in feasibility studies, by NWRB, and in the design of the well fields of water districts and concessionaires; and ensure that the water delivered to consumers meets the PNSDW.

4. Existing problems and future tasks

A groundwater monitoring system is considered effective if it satisfies the following conditions:

- It uses reliable and accurate equipment that is calibrated and maintained regularly;
- It monitors points within the target aquifers;
- It monitors water sources that are measured at the appropriate frequency and consistency;
- It is stored in a database that is supported by necessary infrastructure;
- It has a database that is easily accessible to key stakeholders and in digital format; and
- It has a database that can generate reports and make comparisons with established standards that are easy to understand.

In general, the Philippines, through selected agencies has attained a certain level of monitoring which covers the major water service providers. In order to satisfy the aforementioned criteria, the Philippines will need to resolve the following technical and institutional issues:

1. Aquifers tapped by wells and springs have not been adequately characterized in terms of origin, spatial distribution, geometry, and hydraulic properties. Accordingly, the parameters being regularly monitored such as production, water quality, and water level cannot be correlated and evaluated.

2. Current monitoring systems do not point to the corresponding watershed where the tapped springs and wells are located. The watershed, as one of the basic hydrologic units, is not being utilized in the existing groundwater-related activities which include monitoring. The monitoring systems also fail to make the most out of data from the currently available 1:250,000 national groundwater assessment data which could provide guidance in the analysis of the observed production rates of the groundwater sources.

3. While each agency maintains a record of the monitoring data they have gathered, there is no centralized database that will standardize the inputs. Without this, the presentation of data among the various agencies will remain inconsistent with each other and will cause difficulty in correlation and analysis.

4. Interagency access to the currently existing databases of the different agencies has not been established. The absence of interoperability translates to difficulty in the sharing of data and the conduct of meaningful analyses.

5. Overall coordination in groundwater monitoring among NWRB, LWUA, DENR, and DOH is absent. Each agency operates its monitoring program based on its own mandates. For instance, DOH requires potability tests of drinking water sources while NWRB covers the production of water resources.

The government has already begun taking steps to address identified issues that plague the water sector. It has initiated the creation of a super body called the Department of Water Resources (DWR) that will harmonize the functions of the 31 agencies involved in the water sector. The creation of the DWR will address the current fragmented condition of the water sector. It was proposed to be in charge of the overall policy-making, planning, and management of water resources which includes monitoring. This is a huge undertaking that seems to be further down the roadmap for the water sector.

Within DENR, the Water Resources Management Office, a smaller, transitional body, was recently created through Executive Order No. 22 It is tasked to lay the groundwork prior to the establishment of the DWR. It will be in charge of implementing the Integrated Water Resources Management which is a response to current environmental challenges. This plan will be implemented to manage water resources through a joint government effort engaging various sectors.

Both efforts are seen to address the prevailing issues that hamper groundwater monitoring through various collaborative work.

One of the line bureaus of DENR, the Mines and Geosciences Bureau (MGB) has been conducting groundwater studies through research and analysis of secondary data, field surveys, characterization of the hydrogeology of the study areas, and vulnerability assessment throughout the country.

In the process of conducting its Groundwater Resource and Vulnerability Assessment Program, MGB partially uses data obtained from selected agencies. Given these potential linkages, national coverage through regional offices, and geological expertise, the MGB is in a position to initiate the incorporation of the data of various agencies and situate them within currently available geologic data and basic hydrogeological frameworks (i.e. watershed).

In fact, MGB has already developed a database that includes parameters that are currently being gathered by the other agencies.

In order to develop this potential for unification, it needs to strengthen linkages with other players in the water sector through collaborative projects and capacity-building activities. These efforts will pave the way for the eventual integration of groundwater monitoring in the Philippines.

MGBWaterSo	Date of In-situ Testing	Temperature	pH	Electrical Conductivity	Total Dissolved Solids	Salinity
BUL-AEDC-14	10/4/2017	30.0	8.1	416	247	0.2
BUL-AEDC-15	10/4/2017	29.5	8.3	765	458	0.3
BUL-AEDC-16	10/4/2017	30.8	8.2	320	187	0.1
BUL-AEDC-17	10/4/2017	29.9	8.2	726	431	0.3
BUL-AEDC-18	10/4/2017	29.5	8.1	900	539	0.4
BUL-AEDC-19	10/4/2017	30.4	8.0	806	475	0.4
BUL-AEDC-20	10/4/2017	30.9	8.1	391	229	0.2
BUL-AEDC-21	10/4/2017	28.9	8.2	1282	775	0.6
BUL-AEDC-22	10/4/2017	29.7	7.6	774	1058	0.8
BUL-AEDC-23	10/4/2017	30.2	7.8	1108	655	0.5
BUL-AEDC-24	10/9/2017	30.2	9.0	787	465	0.4
BUL-AEDC-25	10/9/2017	30.8	9.0	622	364	0.3
BUL-AEDC-26	10/9/2017	31.3	8.8	1264	733	0.6
BUL-LOB-10	9/28/2017	29.5	8.8	2310	1381	1.1
BUL-LOB-11	9/28/2017	30.6	9.4	824	482	0.4
BUL-LOB-12	9/29/2017	28.2	7.9	479	293	0.2

MGBWaterSo	Lithology	Geologic Formation	Aquifer Type
AMFC-WELL-254	Tuff	Guadalupe Formation	Unconfined
AMFC-WELL-302	Alluvium	Quaternary Alluvium	Unconfined
AMFC-WELL-131	Tuff	Laguna Formation	Unconfined
AMFC-WELL-234	Alluvium	Quaternary Alluvium	Unconfined
AMFC-WELL-319	Alluvium	Quaternary Alluvium	Unconfined
AMFC-WELL-255	Tuff	Guadalupe Formation	Unconfined
AMFC-WELL-256	Tuff	Guadalupe Formation	Unconfined
AMFC-WELL-230	Alluvium	Quaternary Alluvium	Unconfined
AMFC-WELL-50	Tuff	Taal Tuff	Unconfined
AMFC-WELL-229	Alluvium	Quaternary Alluvium	Unconfined
AMFC-WELL-122	Tuff	Laguna Formation	Unconfined
AMFC-WELL-293	Alluvium	Quaternary Alluvium	Unconfined
AMFC-WELL-72	Tuff	Taal Tuff	Unconfined
AMFC-WELL-75	Tuff	Taal Tuff	Unconfined
AMFC-WELL-74	Tuff	Taal Tuff	Unconfined
AMFC-WELL-77	Tuff	Taal Tuff	Unconfined

MGBWaterSo	Water Source Type	Well Depth	Static or Piezometric Water Level	MainUsage	Owner
CSB-MLG-12	Deep Well	42	14	Drinking	Barangay
CSB-MLG-10	Deep Well	80	18	Drinking	Lgu
CSB-RXS-11	Artesian (Flowing) Deep Well	23	12	Drinking	Sonia Martinez
AMO-RXS-03	Shallow Well	9	9	Drinking	Barangay
CSB-RXS-13	Shallow Well	18	12	Drinking	Eduardo Cabotaje
AMO-RXS-08	Deep Well	80	9	Drinking	Barangay
AMO-RXS-04	Shallow Well	15	6	Drinking	Ramil Ronquillo
CSB-RXS-14	Shallow Well	12	6	Domestic	Benjamin Ampaya
AMO-RXS-01	Shallow Well	16	1	Drinking	Wilfredo Narito
AMO-RXS-07	Deep Well	30	3	Domestic	Barangay
AMO-RXS-02	Shallow Well	12	12	Domestic	Barangay
MNM-TUG-109	Dug Well	14	8	Domestic	Mauricia Tumbali
MNM-TUG-98	Shallow Well	15	12	Domestic	Mario Lasam
MNM-TUG-112	Dug Well	16	11	Domestic	Edward Calimag
MNM-TUG-75	Dug Well	12	9	Domestic	Barangay
MNM-TUG-102	Shallow Well	13	9	Domestic	Barangay

MGBWaterSo	Cu	Pb	Zn	Cd	Fe	Ni	Mn	Cr	As
BUL-MAC-01	<0.05	<0.05	4.39	<0.01	1.18	<0.05	0.47	<0.05	<0.05
BUL-MAC-03	0.06	<0.05	0.07	<0.01	0.30	<0.05	0.14	<0.05	<0.05
BUL-MAC-06	<0.05	<0.05	<0.05	<0.01	0.07	<0.05	0.07	<0.05	<0.05
BUL-MAC-09	<0.05	<0.05	<0.05	<0.01	0.11	<0.05	0.09	<0.05	<0.05
BUL-MPB-30	<0.05	<0.05	<0.05	0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-MAC-10	<0.05	<0.05	<0.05	<0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-MAC-09	<0.05	<0.05	<0.05	<0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-MPB-32	<0.05	<0.05	<0.05	<0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-VAL-28	<0.05	0.06	0.97	<0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-MPB-25	<0.05	<0.05	<0.05	0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-VAL-07	<0.05	<0.05	<0.05	<0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-MBP-07	<0.05	<0.05	<0.05	<0.01	0.83	<0.05	0.19	<0.05	<0.05
BUL-MPB-24	<0.05	<0.05	<0.05	<0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-LOB-04	<0.05	<0.05	1.24	<0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-MPB-34	<0.05	<0.05	<0.05	<0.01	0.00	<0.05	0.00	<0.05	<0.05
BUL-MPB-24	<0.05	<0.05	<0.05	<0.01	0.07	<0.05	0.21	<0.05	<0.05

Fig. 2. Mines and Geosciences Bureau Groundwater Database

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Current monitoring system of groundwater in Thailand and existing problems

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Abstract

Currently, there are 1,943 groundwater monitoring wells in Thailand. The aim is to monitor both groundwater quantity and quality on a large scale covering 27 groundwater basins and 460 groundwater monitoring wells for the risk areas of contamination. There are 3 methods to measure groundwater levels such as by using electric dipper, automatic recorders, and real-time measurement with the installed network. The data are stored in the database system of Thailand Groundwater Monitoring System (TGMS). In addition, an analysis of groundwater quality for physical and chemical parameters is conducted once a year. The analysis of heavy metals and Volatile Organic Compounds (VOCs) is performed where are a risk of groundwater contamination. The data on groundwater levels and quality are stored in TGMS. In general, groundwater quality in Thailand is the standard, except for groundwater quality in some parts of the country such as Si Sa Kat Province, Northeastern Thailand. Freshwater in aquifers has a higher salinity than the previous. Consequently, the groundwater quality has been changed to brackish and saline due to the up-coning of saltwater into freshwater in the upper aquifer. In the coastal areas, saltwater intrusion increases to the shallow aquifers less than 50 meters. Moreover, most groundwater contamination problems are due to human activities. Contaminated groundwater resources are polluted by heavy metals and VOCs the values are higher than the groundwater standard for consumption by the Ministry of Natural Resources and Environment in landfills and industrial waste disposal areas where are Chachoengsao Province, Phetchabun Province, Phetchaburi Province.

Keywords: Groundwater monitoring wells, Groundwater contamination, Saltwater intrusion

1. Introduction

The groundwater quantity situation in Thailand has not changed too much except for the central region. However, the water level in the aquifer did not exceed 50 meters depth decreased significantly. In 2017 - 2021, there was an average decrease in water levels more than 2 meters/year for the groundwater crisis zone covering 7 provinces such as Bangkok, Samut Prakan, Pathum Thani, Nonthaburi, Samut Sakhon, Phra Nakhon Si Ayutthaya, and Nakhon Pathom. The zone found that the water level at a depth not exceeding 150 meters has recovered and is relatively stable, and the level is 15-20 meters from the surface. In some areas in the Phra Nakhon Si Ayutthaya Province, the aquifer was more than 150 meters deep, and water levels decreased by more than 2 meters/year. In 2021, the quality situation was found that it was generally within standard criteria while in some areas in Phra Nakhon Si Ayutthaya Province, the aquifer was more than 150 meters depth. Water level tended to decrease by more than 2 meters/year. In 2021, it was found that groundwater quality was generally within standard criteria.

Groundwater resources can be used for consumption according to the Groundwater Act of 1977, some areas in the northeastern region were over-pumping. The quality of the shallow aquifer was fresh which above had changed to brackish-salty as a result of saltwater intrusion.

Moreover, the coastal area connected to the Gulf of Thailand and the Songkhla Lake found that the quality in some areas had changed from fresh to brackish-salty and tended to expand into the land. Furthermore, the industrial and electronic waste disposal sites and some community landfill areas detected that the water quality had high heavy metals and volatile organic compounds that exceeded groundwater quality standards for consumption.

2. Current monitoring system of groundwater in Thailand

The groundwater situation in Thailand was analyzed from data on changes in groundwater quality and water level. There are 1,173 groundwater monitoring network stations with 1,943 monitoring wells covering 27 groundwater basins (Fig. 1).

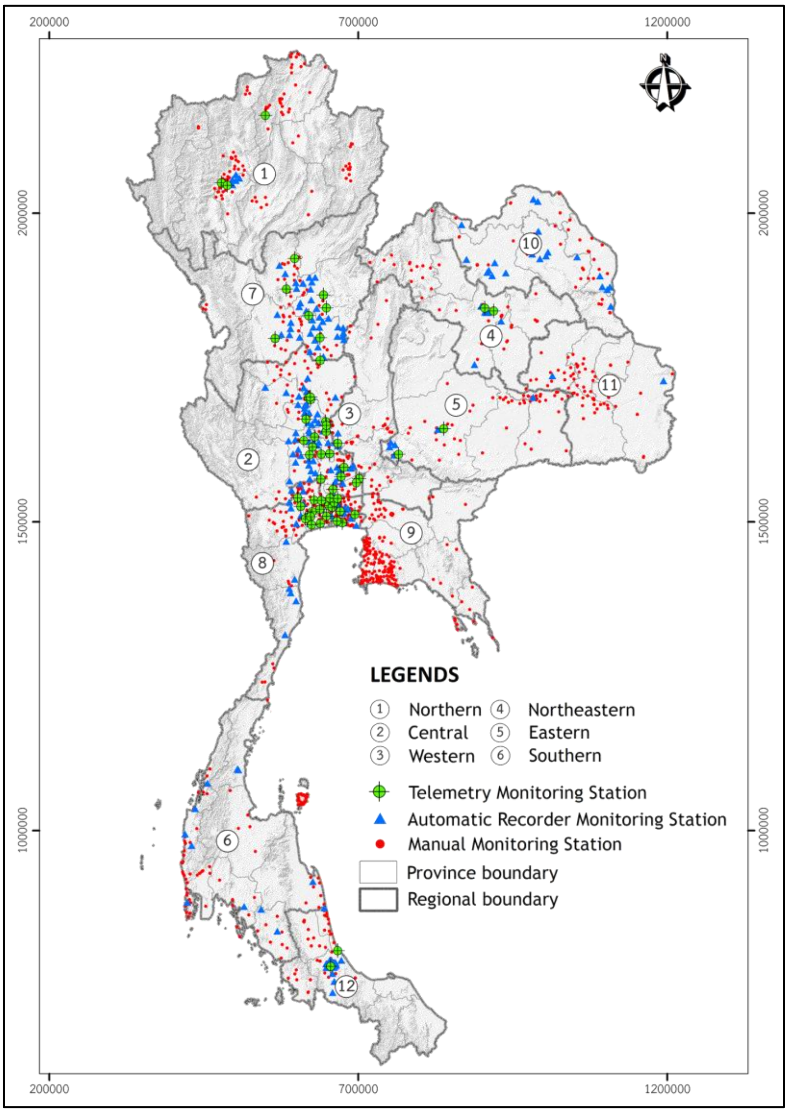

Fig. 1. Monitoring network in Thailand

The criteria for selection of monitoring wells site are as follows:

(1) Number of monitoring wells in the present.
(2) Land uses.
(3) Groundwater development and groundwater consumption.

(4) Risk of groundwater contamination.
(5) Risk of geohazard affected groundwater resources.
(6) Transboundary aquifer of the ASEAN.

3. Monitoring items, purpose/ usage of monitored data and database (data management)

Water sampling has been collected according to the parameters. Normally, physical and chemical composition and heavy metals analysis are collected once a year. In the areas at risk of contamination, they are collected 1-2 times per year. Water samples to analyze volatile organic compounds are collected 1-2 times per year (Fig. 2).

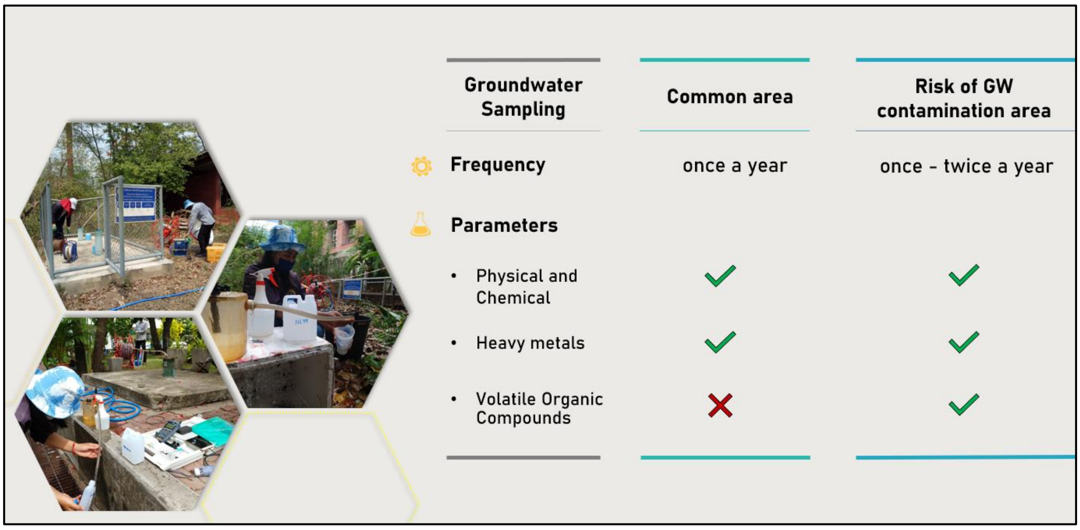

Fig. 2. Groundwater level sampling

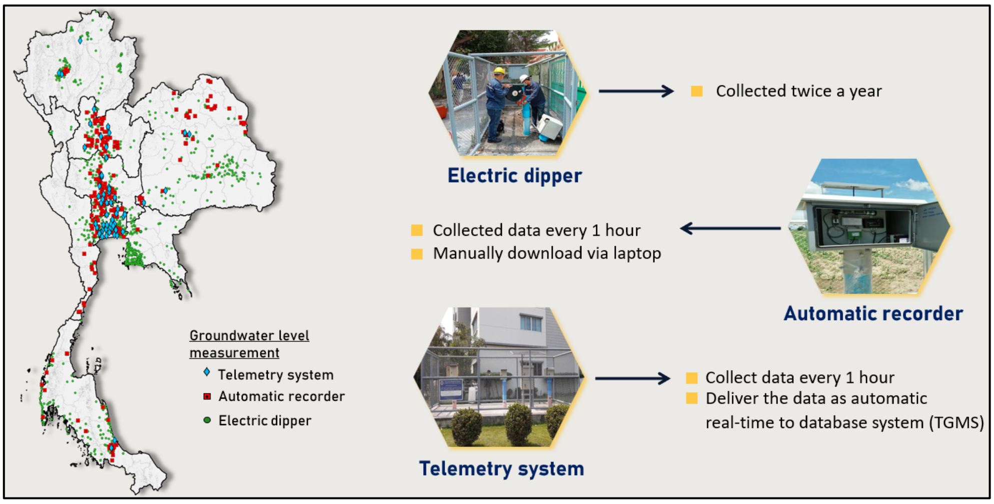

Fig. 3. Water level measurement

There are 3 methods to measure groundwater levels such as by using electric dipper, automatic recorders, and real-time measurement with the installed network (Fig. 3). Water level measurement using an electric dipper is collected twice a year. As for the automatic recorder of water level measurement, it is recorded every hour, and the data is downloaded using a laptop. Telemetric water level measurements are taken every hour, and the data was automatically recorded in real-time to a database system called "Thailand Groundwater Monitoring System (TGMS)" (Fig. 4). Fig. 5 shows the overview of groundwater data management in Thailand mentioned above.

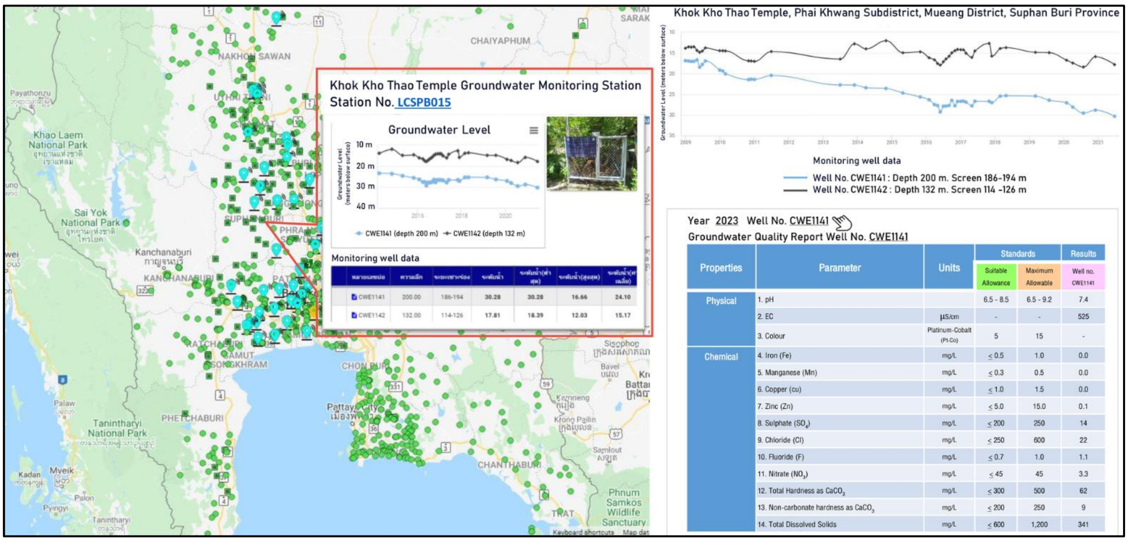

Fig. 4. Thailand Groundwater Monitoring System (TGMS)

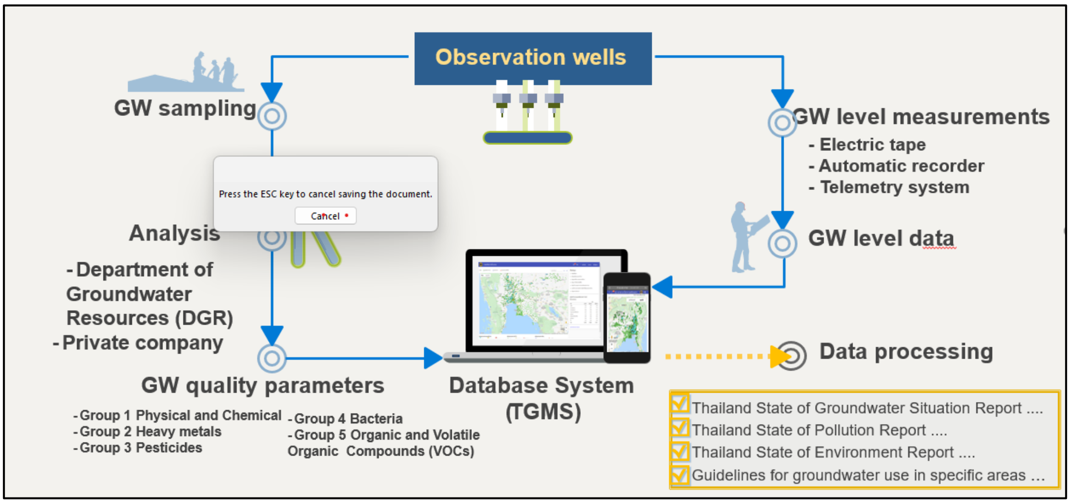

Fig 5. Overview of groundwater data management

4. Existing problems and future tasks

There are groundwater existing problems (Fig 6) such as

1. Floods and Droughts due to Climate change recur every year.
2. Saltwater up-coning in the Si Sa Kat Province, and some parts of the North-Eastern Part of Thailand.

3. Contaminated Groundwater from the illegal dumping sites.
4. Saltwater intrusion due to over-pumping groundwater near the coastal area.

Possibly future tasks are as follows:
1. Assessment of groundwater quality in landfill disposal sites for monitoring, and surveillance of groundwater contamination.
2. Groundwater contamination and integrated remediation schemes.
3. Update groundwater laws to be up to date.
4. Well preparation of groundwater resources management master plan.

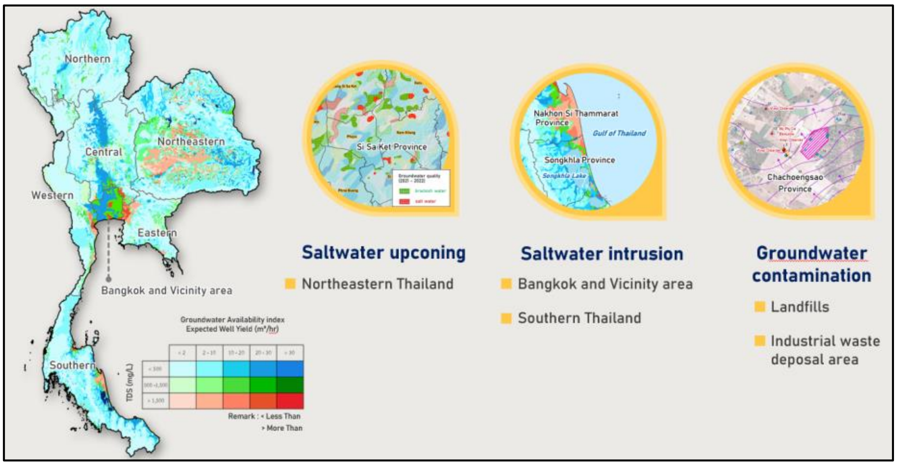

Fig. 6. Groundwater existing problems

5. Conclusions

Groundwater monitoring stations have been installed from the past until the present. To continuously monitor the groundwater quality and quantity, and to protect the groundwater resources are from being affected by the external environment, whether it be human actions. To protect and preserve quality groundwater for drinking and sustainable usage, as well as bringing in groundwater laws to control the amount of groundwater usage so that it does not imbalance and cause long-term impacts on the aquifer. Because if it is affected cause damage toxic contaminants flow into groundwater resources. This will remediate difficulty and the costs are quite high, complicated, and take a long time to be successful whether or not. However, groundwater resources must be managed sustainably by the cooperation of all sectors to integrate the groundwater resources management service plan efficiently and effectively.

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Current monitoring system of groundwater and surface water in Viet Nam, and existing problems

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Abstract

The water resource observation network is a component of the environmental resource observation network. Information on monitoring of water resources is increasingly important and is invested by the Government of Vietnam and annually provides funding to maintain monitoring. The national water resources monitoring network managed by the Ministry of Natural Resources and Environment includes 805 groundwater resources monitoring works and 6 surface water resource monitoring stations nationwide.

The network's monitoring database for many years has been applied by agencies from the central to local levels to the work of calculating water resources, as a basis for building planning, allocating and managing resources. national resources. In terms of monitoring, the continuity of the database over time is an important basis for assessing trends, forecasting and warning of water resources, helping state management agencies to have infrastructure. manage, allocate, exploit and use water resources rationally and sustainably, contributing to the socio-economic development of the country. Therefore, it can be affirmed that a water resource monitoring is a necessary task that must be carried out regularly and the management and operation of the system must ensure the authenticity, objectivity, and important factors. must track whether the requirements of the output header are met. Every year, it is adjusted to ensure faster, more accurate information and a variety of products for announcements, forecasts and warnings to gradually meet information requirements for state management. on water resources.

Some existing problems need to be resolved, including: The monitoring network has only been built in some key economic regions; equipment, monitoring methods are not synchronized on the entire network; no professional data management and evaluation software; sharing monitoring, warning and forecasting information has many limitations in the form of information sharing and receiving.

Keywords: monitoring system, groundwater, surface water, Vietnam

1. Introduction

The water resources observation network encompasses both surface water and groundwater monitoring components. Operational since April 2011, six surface water monitoring stations are currently active in the Highland and Coastal area of South of Centre regions. There are 415 stations with 805 monitoring works of groundwater resources monitoring network, strategically located in the Red River Delta, North of Centre, Highland, Coastal area of South of Centre and Mekong River Delta regions of Vietnam.

Over the years, the network's comprehensive databases have served a multitude of purposes, supporting local utilization methods and computational analyses essential for national water resource management. The continuity of these databases is paramount for evaluating trends, making forecasts, and issuing timely warnings related to water resources. This ongoing effort aids state management agencies in efficiently overseeing water resources, allocating their exploitation, and ensuring sustainable and rational usage, thereby contributing significantly to the socio-economic development of the country.

Regular water resources monitoring is deemed an indispensable task, requiring consistent attention. The management and operation of the system are designed to uphold authenticity, objectivity, and adherence to required standards in observational elements. To meet the dynamic information needs of water resources management, content options and annual implementation strategies are subject to adjustments. Recent modifications focus on enhancing information delivery speed and accuracy, alongside the development of a diverse array of notification, forecast, and warning bulletin products, gradually aligning with the evolving information demands crucial for serving state water resource management needs.

2. Current monitoring system of groundwater and surface water in Vietnam

2.1. Current monitoring system of surface water

The purpose of these observation stations is to assess both the quantity and quality of surface water. This assessment serves as a foundation for effective planning and exploitation of water resources, as well as an early warning system for potential water pollution within the river basin. Observation parameters are categorized as follows: (i) Water quantity assessment includes water level (H), water flow (Q), and suspended matter content (ρ). (ii) Water quality assessment involves multiple groups: Group I (pH, temperature); Group III (As, Cd, Pb, Cr_6, Cu, Zn, Hg); Group IV (DO, BOD_5, COD, $N\text{-}NH_4$, $N\text{-}NO_3$, $N\text{-}NO_2$, $P\text{-}PO_4$); and Group V (Coliform, E. coli) for the 2 regions such as: Coastal area of South of Centre region and Highland region (see the zoning the water resources monitoring network in Vietnam figure below).

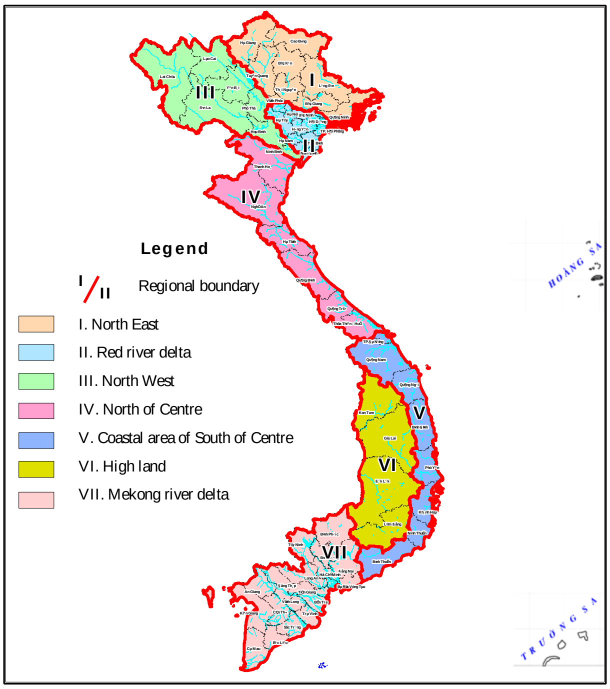

Fig. 1. Zoning the water resources monitoring network in Vietnam

2.1.1. The Coastal area of South of Centre region

Surface water monitoring is conducted at two stations in the South Central Coast region: Phu Ninh and An Thanh. Phu Ninh Station, situated in the Tam Ky river basin, is located on the right bank of the Yen Thuan river in village I, Tam Son commune, Nui Thanh district, Quang Nam province. This station monitors both the quantity and quality of wastewater entering Phu Ninh lake. The station modified its water level measurement line in 2018, relocating it approximately 2 km upstream to mitigate the effects of high water levels in Phu Ninh Lake. The measurement protocol for water level, water flow, suspended matter content, and environmental sampling varies between seasons: During the dry season, factors are surveyed approximately 2 km upstream from the designated water level. In flood seasons, flow monitoring and suspended matter content sampling occur at the designated level, located in front of the station, along with consideration of other critical upstream factors.

An Thanh Station, located in the Ky Lo river basin, stands on the left bank of the Ky Lo river in Phu My village, An Dan commune, Tuy An district, Phu Yen province. This station measures water levels, flow, and suspended matter content, with its measurement line presently positioned to account for the impact of glass dams approximately 1 km downstream.

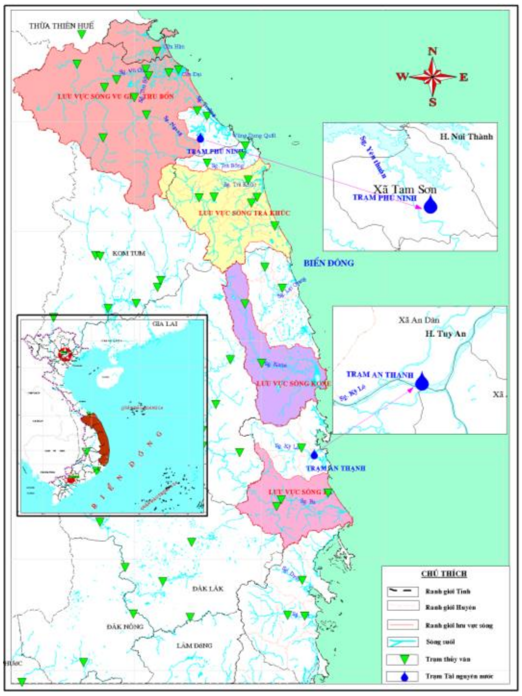

Fig. 2. Diagram of the network of surface water resources monitoring stations in the Coastal area of South of Centre region

2.1.2. The Highland region

In this area, there are currently four surface water resource monitoring stations established in 2008. Ya Yun Ha Station: This station is situated on one of the three main river branches within the Ba River basin in Gia Lai province. It was constructed on the right bank of the Ya Yun River, located in Chep village, A Yun commune, Chu Se district. The primary water level measurement route coincides with the flow measurement route, situated approximately 180 meters upstream from the station route.

Duc Xuyen Station situated in the Serepok River basin, this station was built on the right bank of the Krong No River in Phi Dih Ja B village, Krong No commune, Lak district, Dak Lak province. The primary water level measurement route aligns with the flow measurement route and monitoring takes place directly in front of the station.

Dai Ninh Station is located in the Dong Nai River basin, this station stands on the right bank of the Da Nhim River in Phu Hoa village, Phu Hoi commune, Duc Trong district, Lam Dong province. The basic water level measurement route is constructed approximately 100 meters downstream of the station, where monitoring is carried out. Water Flow Measurement Route: During the dry season, measurements are taken with a flowmeter (LTK), synchronized with the water level measurement route. Additionally, an automatic ADCP machine measures the flow approximately 80 meters upstream of the base water level to ensure safety due to the presence of a large waterfall downstream of the baseline.

Cat Tien Station is positioned in the Dong Nai River basin, this station is built on the left bank of the Dong Nai River in village I, Phu My commune, Cat Tien district, Lam Dong province. Similar to other stations, the primary water level measurement route coincides with the flow measurement route, and monitoring is conducted at a location in front of the station.

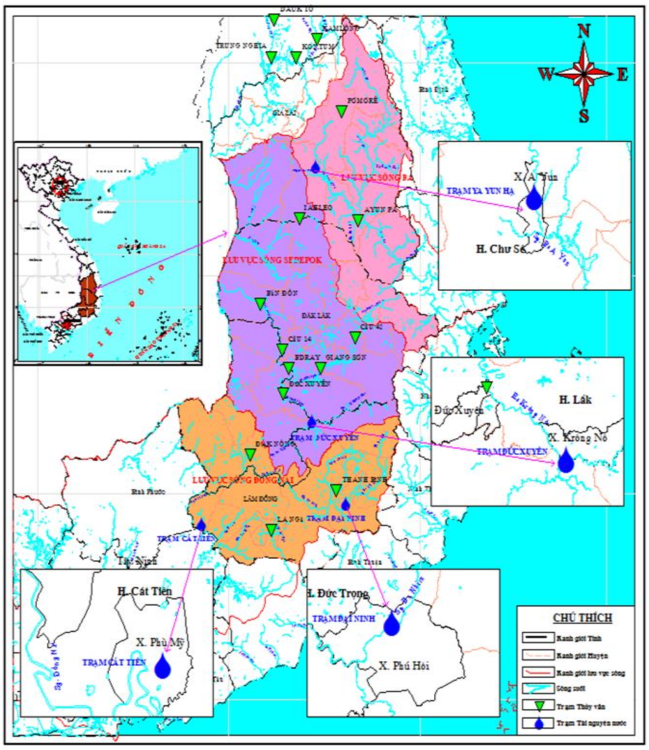

Fig. 3. Diagram of the network of surface water resources monitoring stations in the High land region

2.2. Groundwater monitoring system

Regarding Water Level Monitoring: (i) The monitoring regime is categorized based on factors influencing groundwater levels and is divided into two primary groups: those impacted by natural factors within natural dynamic areas and those affected by water exploitation in the destructive dynamic zone. (ii) Monitoring Frequency: During the rainy season, measurements are conducted 10 times per month, while in the dry season, the frequency is reduced to 5 times per month. The dry season spans from November to April, whereas the rainy season covers May to October. Notably, for provinces extending from Ha Tinh to Thua Thien Hue (North of Centre region) and the South Central Coast region, the dry season spans from January to August, with the rainy season occurring from September to December. (iii) Monitoring Methods: Three primary methods are employed: automatic, semi-automatic recording, and manual methods.

Regarding Water Quality Collection and Analysis to monitor changes in groundwater's chemical components over time, evaluating current water quality status and trends in aquifer water quality changes. Four types of samples are collected and analyzed: comprehensive, iron, trace, and contaminated, depending on each project's requirements.

Sampling Volume Calculation Conditions: (i) Comprehensive samples are obtained from all primary aquifers used for exploitation. (ii) Iron samples are extracted at comprehensive sampling sites (except for saltwater monitoring sites with TDS values exceeding 3g/l). (iii) Micronutrient samples are collected from the main exploitation layers and the upper aquifer of the area. Microsamples are not taken from structures containing saltwater (TDS>3g/l). and (iv) Contamination samples are gathered in urban or residential areas with high levels of nitrogen compounds in groundwater. Only one sample is collected within a monitoring route, avoiding contaminated samples in constructions with saltwater (TDS>3g/l).

2.2.1. The Red River Delta region

The Red River Delta observation network comprises a total of 89 monitoring stations, with 156 groundwater observation works. Among these, there are 64 monitoring works in the Holocene aquifer, 77 in the Pleistocene aquifer, 9 in the Neogene aquifer, 3 in the Triassic aquifer, 2 in the Carbon aquifer, Permian, and 1 in the Ordovician-Silurian aquifer. Concerning observation methods, the entire region utilizes 42 manual observation works, 11 automatic observation sites that transmit data, and 103 semi-automatic observation works.

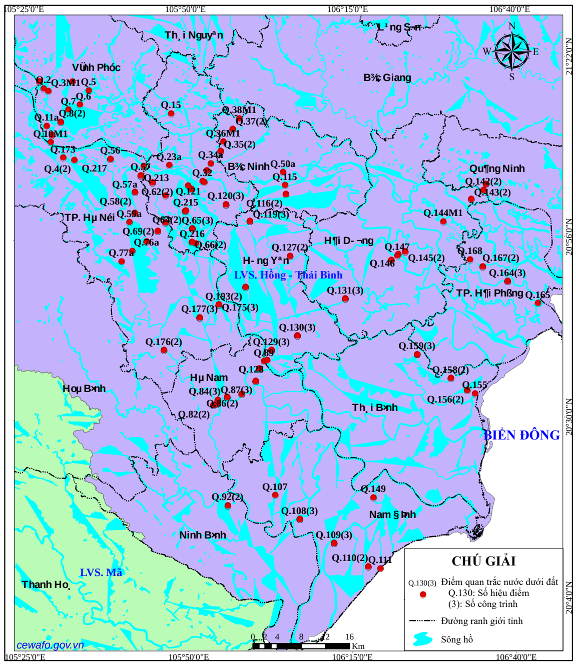

Fig. 4. Diagram illustrating the water monitoring network in the Red River Delta

2.2.2. The North of Centre region

The monitoring network in the North of Centre region encompasses a total of 96 monitoring stations with 167 monitoring works spread across the provinces of Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang Tri, and Thua Thien Hue. Among these sites, there are 66 monitoring works for the Holocene aquifer, 71 for the Pleistocene aquifer, 7 for the Neogene aquifer, 2 for monitoring the basalt water layer, 9 for fissure aquifer projects in terrigenous sediments, 4 for monitoring the fissure-karst water layer of Carbon-Permian carbonate sediments, 1 for the fissure aquifer structure of lower Carboniferous terrigenous sediments, 6 for monitoring the fissure water layer of the lower Devonian terrigenous sediments, and 1 project to monitor the fissure water layer of the upper Ordovician-Silurian metamorphic sediments.

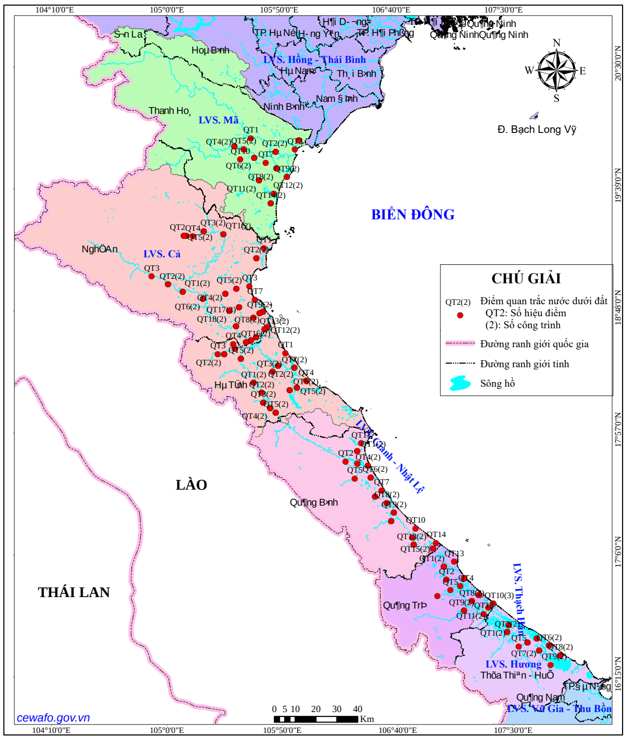

Fig. 5. Diagram of the groundwater resources monitoring network in the North of Centre region

2.2.3. The Coastal area of South of Centre region

The monitoring network here comprises a total of 41 works, divided between two stations: Quang Da (Quang Nam - Da Nang) and Quang Ngai. These facilities encompass 23 monitoring works for the Holocene aquifer, 10 works for the Pleistocene aquifer, 4 monitoring works dedicated to aquifers, fissures, and reservoirs of Neogene sedimentary lagoon formations, 1 work for monitoring the Cambrian-Ordovician metamorphic water layer, along with 2 works for monitoring Proterozoic-Paleozoic magma intrusive fissure aquifers, and 1 work specifically for monitoring Pliocene Basalt eruptive fissure aquifers.

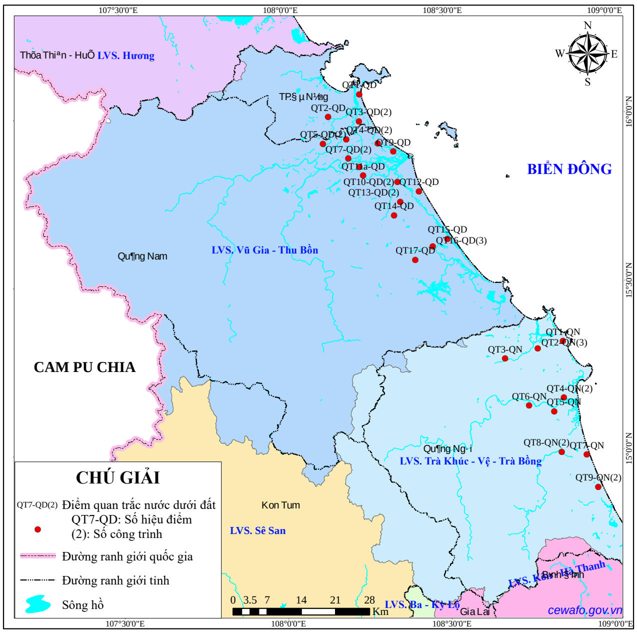

Fig. 1. Diagram of the groundwater resources monitoring network in the Coastal area of South of Centre region

2.2.4. The High land region

The High land monitoring network comprises a total of 118 stations and 138 groundwater monitoring works. These include 25 monitoring works for modern alluvial porous aquifers, 21 works dedicated to Middle Pleistocene Basalt eruptive fissure aquifers, 59 works for monitoring lower Pliocene-Pleistocene basalt eruptions in aquifers, 18 works focused on monitoring water layers, cracks, and seams within Neogene sedimentary lake and lagoon formations, 1 work for monitoring terrigenous crevasse aquifers and Upper Jurassic-Cretaceous eruptive formations, 10 works for Lower-Middle Jurassic sedimentary fissure aquifers, along with 1 work for monitoring magma-intrusive fissure aquifers and 3 works dedicated to the Arkei-Sialua metamorphic aquifers.

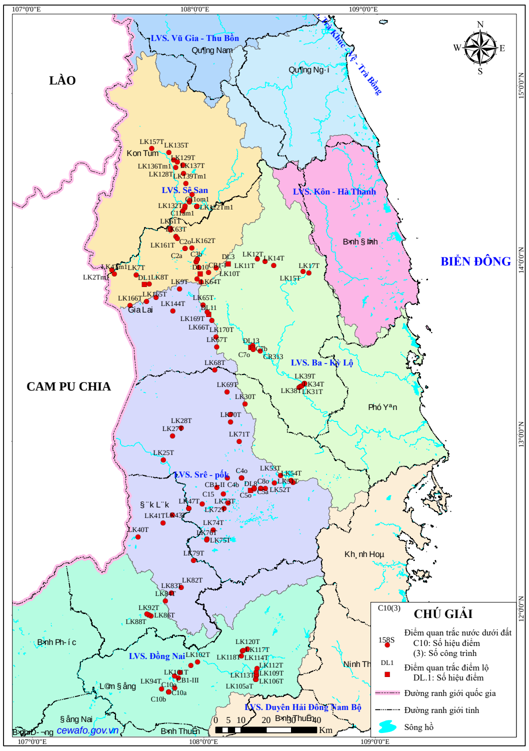

Fig. 2. Diagram of the groundwater resources monitoring network in the high land region

2.2.5. The Mekong River Delta region

The Mekong River Delta region monitoring network has a total of 303 groundwater monitoring works. Among them, there are 34 Holocene aquifer monitoring works, 144 Pleistocene aquifer monitoring, 92 in Pliocene aquifer monitoring projects, 26 Miocene aquifer monitoring projects; and 2 monitoring works for fissure aquifers in Mesozoic terrigenous sediments and 5 monitoring works for fissure aquifers in Cenozoic basalt rocks.

Fig. 3. Diagram of the groundwater resources monitoring network in the Mekong River Delta region

3. Monitoring items, purpose/ usage of monitored data and database (data management)

Upon collection, the monitoring data undergoes correction, error evaluation, and subsequent utilization in forecasting and issuing water resource warnings. The water resource forecasting process involves multiple steps aimed at predicting and conveying information concerning the status, quality, and potential hazards associated with water resources. Below is an overview of the typical process related to water resource forecasting news:

Data Collection: Gathering a wide range of data is crucial. This includes historical records of water levels, flows, rainfall, and temperature from monitoring data, as well as relevant satellite hydrological and environmental data obtained from monitoring stations, satellites, weather forecasts, and other sources.

Analysis and Modeling: Analyzing the collected data using hydrological modeling and statistical techniques aids in comprehending past patterns and forecasting future trends. These models simulate the movement of water through watersheds, rivers, and aquifers, considering various factors like precipitation, evaporation, soil type, and land use. The MIKE model suite and the MO decision support system.

Forecast Creation: The Water Resources Forecasting and Warning Center, generates forecasts based on analyzed data and models. This includes predictions regarding water levels, river flows, droughts, floods, and potential water quality issues.

Risk Assessment: Assessing potential risks and vulnerabilities related to water resources, such as droughts, floods, pollution, or water scarcity. This step involves evaluating the anticipated impact of forecasted conditions on communities, agriculture, ecosystems, and infrastructure.

Communications and Reporting: The forecast information in an accessible and easy-to-understand format, typically through newsletters submitted for approval before release to policymakers, resource management units (e.g., Department of Natural Resources and Environment of the provinces, Department of Water Resources Management, Department of Agriculture and Rural Development), the public, and relevant stakeholders. Reports, visualizations, and articles are commonly used to disseminate this information.

Early Warning System: Establishing an early warning system based on forecasted data to alert authorities and communities about potential water-related dangers, enabling proactive measures to minimize risks.

Policy and Decision Making: Management units utilize forecast information for policy decisions, such as water allocation, conservation strategies, infrastructure development, and emergency response planning.

In the field of news reporting consistently receives feedback, questions, and supports informative and easily comprehensible news, often disseminated through websites, emails, seminars, and other channels, aiming to enhance awareness, inform, and educate individuals and communities about water-related challenges and opportunities.

In the realm of news reporting, the process involves transforming these forecasted insights into informative and understandable news pieces, often disseminated through various media channels to raise awareness, inform, and guide individuals and communities regarding water-related challenges and opportunities.

4. Existing problems and future tasks

The operational effectiveness of monitoring systems in various sectors, such as environmental, scientific, or industrial domains, can face multiple challenges that impede their efficiency. Among the prevalent issues encountered are equipment malfunctions, data inaccuracies, limited coverage, communication constraints, and susceptibility to environmental interferences. Equipment malfunctioning or breakdowns often disrupt data collection, while inaccuracies may stem from sensor errors, calibration issues, or external interferences, resulting in unreliable data. Moreover, insufficient monitoring coverage in certain areas leads to information gaps, hindering comprehensive analyses. Communication hurdles and connectivity issues further hamper real-time data transmission and inter-station communication, affecting system responsiveness. Additionally, environmental factors or human activities pose risks by encroaching upon monitoring sites, potentially compromising equipment accuracy and reliability.

Addressing these challenges demands a multi-faceted approach. Regular maintenance schedules are essential to ensure equipment undergoes routine servicing, calibration, and prompt repairs. Implementing stringent data quality checks and validation procedures helps detect and rectify inaccuracies, ensuring data integrity. Expanding the monitoring network by setting up additional stations improves coverage in areas lacking sufficient data. Upgrading communication infrastructure and employing redundant channels bolster seamless data transmission and station connectivity. Protective measures around monitoring sites safeguard equipment from environmental interferences or human encroachment. Additionally, providing comprehensive training to personnel responsible for monitoring enhances their proficiency in equipment management and data handling. Furthermore, technological advancements and sensor upgrades can significantly enhance the precision and efficiency of the monitoring system. Collaboration with relevant agencies, institutions, or stakeholders fosters resource sharing and expertise exchange, augmenting the overall effectiveness of the monitoring infrastructure.

In the realm of groundwater and water resources monitoring, a notable inadequacy emerges specifically concerning the availability of monitoring wells in the Northwest and Northeast regions. These areas notably suffer from a scarcity of fully established monitoring wells, a critical component for comprehensive data collection and analysis essential to comprehend groundwater dynamics, quality, and sustainability. The absence of such monitoring infrastructure significantly limits access to vital information regarding groundwater levels, flow patterns, and potential contaminants. This deficiency poses challenges in accurately assessing aquifer conditions and compromises the ability to predict and effectively address groundwater-related issues. Consequently, this gap impedes the formulation of informed policies, sustainable resource management strategies, and the implementation of proactive measures to conserve and protect groundwater reservoirs in these regions. Rectifying the shortage of monitoring wells is imperative to enhance the understanding and management of groundwater resources in the Northwest and Northeast regions, demanding urgent attention and investment in establishing a comprehensive network of wells. The robust monitoring system, aligned with the directives of Decision 432 spanning the period 2021-2030, involves the government's approval for constructing new monitoring stations in areas lacking both surface and groundwater. Table 1 Show the number of new construction initiatives during the period 2025-2030. Furthermore, the integration of water resources monitoring networks with environmental monitoring has also gained government approval, aiming to augment information and data availability for integrated water resources management.

Table 1. Catalog of proposed new construction initiatives during the period 2025-2030.

Region	Period 2023-2025	Period 2026-2030
Northwest		33
Red River Delta		56
South Central region		81
Highlands	67	
Southern		80

5. Conclusions

In conclusion, mitigating the challenges faced by monitoring systems requires a holistic strategy encompassing equipment maintenance, data quality assurance, network expansion, technological advancements, and collaborative efforts. Implementing these solutions contributes to maintaining the reliability, accuracy, and functionality of monitoring systems across academic, scientific, and operational domains.

References

National Centre for Water Resources Planning and Investigation in Vietnam (2022) Assessment of the National Water Resources Monitoring Network's Performance.