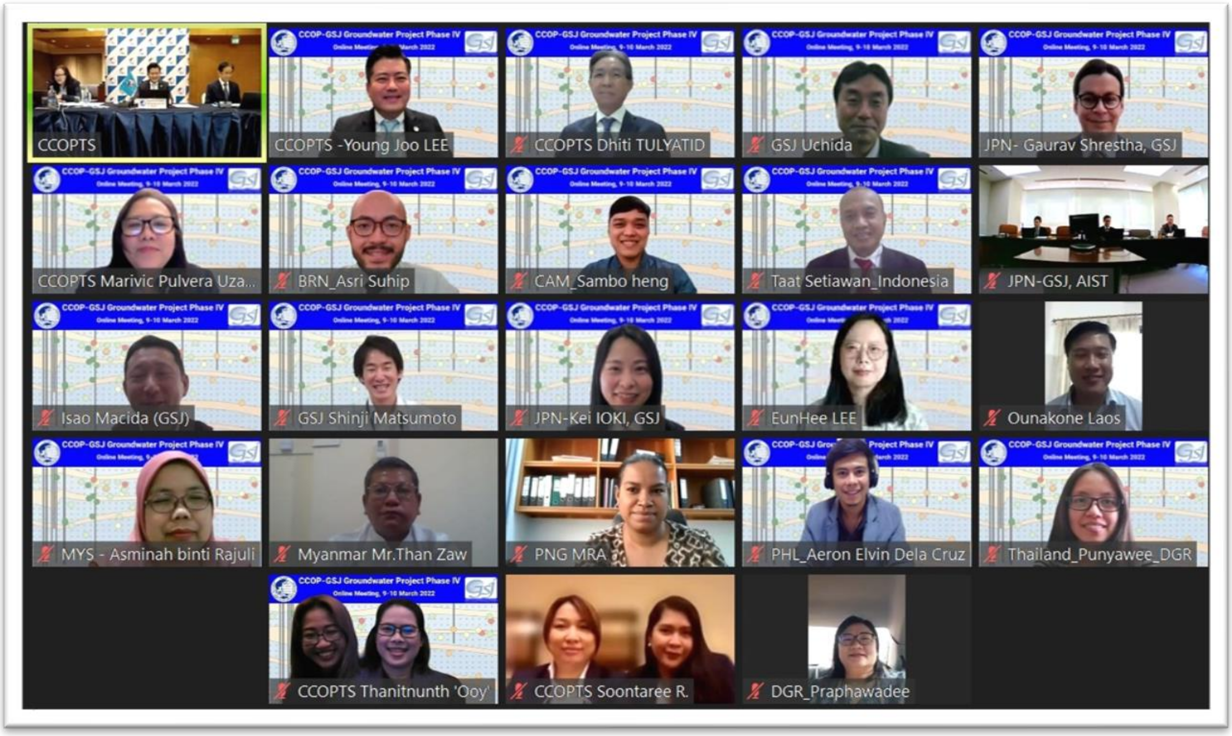
Report of the CCOP-GSJ
Groundwater Project Phase IV Meeting
9-10 March 2022 (Zoom Online Meeting)



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 20th 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 Groundwater Project Phase IV Meeting was held virtually using Zoom Meeting application on 9-10 March 2022. The meeting was hosted by CCOP and GSJ. It was attended by 26 participants from Brunei Darussalam, Cambodia, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand and the CCOP Technical Secretariat. In the meeting, participants confirmed the outcome of the CCOP-GSJ Groundwater Project Phase III and discussed the plans for the Phase IV.

Each CCOP member country made a presentation on the topic of "Current groundwater and surface water problems in one's country, and their possible solutions". All the participants discussed on the groundwater and surface water problems in each member countries and possible mitigation measures to solve them.

This publication compiles all the country reports presented in the CCOP-GSJ Groundwater Project Phase IV Meeting, 9-10 March 2022 (Zoom Online Meeting).

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

Published by:

Geological Survey of Japan (GSJ)
National Institute of Advanced Industrial Science and Technology (AIST)
AIST Central 7, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan
https://www.gsj.jp/

and

Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP)
CCOP Building, 75/10 Rama VI Road, Phayathai, Ratchathewi, Bangkok 10400, Thailand
https://www.ccop.or.th/

November 2022
ISBN978-4-9907680-5

Contents

II. The Minutes of the CCOP-GSJ Groundwater Project Phase IV Meeting

9-10 March 2022 (Zoom Online Meeting)

The CCOP-GSJ Groundwater Project Phase IV Meeting was held on 9-10 March 2022 via Zoom Meeting application. It was attended by 26 participants from Brunei Darussalam, Cambodia, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand and the CCOP Technical Secretariat (CCOPTS).

Dr. Young Joo Lee, CCOPTS Director welcomed all the participants and officially opened the virtual meeting.

Dr. Gaurav Shrestha, the GSJ Groundwater Project Phase IV Leader, presented the Past Achievements of CCOP-GSJ Groundwater Project & Review of Plan and Objective 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/groundwater/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 groundwater and surface water problems in one's country, and their possible solutions" were presented, and summarized below.

Country / Water Issues	Possible Solutions
Brunei Darussalam	
1) Insufficient water supply for rice farming	Groundwater extraction
2) Peat forest fire due to anthropogenic disturbances	Monitoring of groundwater level
3) Landslide occurrences	Landslide Hazard and Risk Mapping
	(Other solution) Soil investigation report digitization
Cambodia	
1) Annual shortage and extremely flooding	Modernization of the water management system, improve the irrigation system and increase storage
2) Over extraction and contamination of groundwater	
3) Overlapping and limited cooperation between relevant agencies and stakeholders at national and sub-national level	Improve coordinate and cooperate with relevant agencies and stakeholders to collect, share and upgrade data and related information.

Indonesia	
1) Excessive groundwater usage due to limited availability of surface water, both in quality and quantity, which is one of the causes of land subsidence in northern Java Island	Necessary to make derivative regulations for the management of integrated water resources.
2) Groundwater as well as surface water are subjected to a high pollution loads	Coordination between Ministries in water resources planning and between the Central and local governments need to be strengthened.
3) Decrease in groundwater level due to agricultural development	Institutions need to be strengthened to become as second echelon level that specifically manages groundwater and establishment of groundwater offices in several parts of Indonesia.
Japan	
1) Problem with surface water is renewal of old water supply system. High renewal fee.	Integration of water distribution system. Changing of the management system. Collaboration with private companies.
2) Problems of groundwater quality (pollutions) with high nitrate concentration. Decline of groundwater level	Enact of the basic law. Encourage of governance for groundwater resources by local governments.
Republic of Korea	
1) Groundwater depletion due to increasing demand particularly for agricultural activities.	Technology developments for securing large scale groundwater resources and optimum utilization to climate change
2) Groundwater quality deterioration by surface pollutants.	
Lao PDR	
1) Water quality, water shortage, human capacity, flood and drought, missing data.	Adoption of regulation on groundwater management. Development of groundwater management plan with 5 years action plan.
Malaysia	
1) Prolonged drought, water crisis, flooding	Groundwater exploration and development in water stress areas. Mapping of national groundwater exploration. Review of National Water Management Policy. Develop conjunctive water supply infrastructure.
Myanmar	
1) Shift of saline front towards upstream due to rising sea level and decreasing river flow in dry season.	Construction and upgrading dikes, island-round embankments and polders to prevent saline water intrusion

2) Saltwater intrusion to shallow aquifer. Contamination of ponds.	Hydrogeological study for feasibility of fresh deep confined aquifers in delta area
Papua New Guinea	
1) Contamination of shallow unconfined aquifers and surface water sources	Increment of rainwater harvesting tanks. More awareness programs on proper set up of villages.
2) Poor maintenance of shallow wells and borehole pumps	Proper training for maintenance of pumps within rural areas.
3) Tidal influence and saltwater intrusion	Improved and thorough mapping of freshwater zones for saline and tidal affected areas.
4) Low-yielding aquifers and overestimation of sustainable yield.	Proper and longer duration of pumping tests, and improved mapping.
Philippines	
1) Data gaps in groundwater quality data	Application of geospatial and statistical tool for data processing.
Thailand	
1) Risk of water shortage in dry season.	Preparation of relevant laws, policies and water resources management master plan. Groundwater Development: Groundwater distribution in the affected area.
2) Flood, drought, wastewater, saltwater intrusion, groundwater fluctuation, contaminated groundwater	Alleviating and solving drought and flooding problems. Groundwater conservation and restoration. Integrated Water Resources Management (IWRM)

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.

The participants requested to have more training sessions on the usage of GSi system. The Project Coordinator responded that there will be training session during project annual meetings. 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. It was also suggested that the function to upload/append/edit/delete CSV to the GSi system be more user friendly. The GSi system developer took note of the suggestion.

The next project meeting will be held within December 2022 and January 2023. It may be held either in Vietnam or Thailand. The CCOP Technical Secretariat will contact both countries for confirmation. Duration and schedule of the meeting with technical survey is as follows.

Duration (6 days including arrival and departure days).
Day1: Arrival in host country
Day2: Technical Groundwater Survey (where there are groundwater problems)
Day3: Meeting (Project updates & Country reports)
Day4: Meeting (GSi Training & Discussion)
Day5: Field Trip
Day6: Departure from host country to home country

Before the next meeting in December 2022 (or January 2023), the participants committed to populate the Groundwater Well Database in GSi Portal as follows.

Country	**Number of Well Data / Area**
Brunei Darussalam:	10 wells additional.
Cambodia:	
Indonesia:	50 more well data on Kalimantan Island.
Japan:	Akita Plain, Kinokawa.
Korea:	Update data.
Lao:	
Malaysia:	100 more data.
Myanmar:	Already uploaded 10 well data. 10 more data before next meeting.
Papua New Guinea	
Philippines:	Add 4 more provinces in Central Luzon, about 600 groundwater sources. Update existing data.
Thailand:	Will inform later.

If hydrogeological maps or relevant raster data are available, participants are encouraged to upload it in the GSi Groundwater Portal.

The meeting was officially closed by Dr. UCHIDA Youhei, Project Supervisor, and Dr. Young Joo Lee, CCOPTS Director.

Current groundwater and surface water problems in Brunei Darussalam, and their possible solutions

Muhammad Asri Akmal bin Haji Suhip[1] and Stefan Herwig Gödeke[2]

[1]Department of Technical Services, Public Works Department, Brunei Darussalam
[2]Geosciences Programme , Universiti Brunei Darussalam, Brunei Darussalam
E-mail: asri.suhip@pwd.gov.bn

Abstract

Water is one of the most used resources in Brunei Darussalam, typically it is used in large-scale industries such as oil and gas or for daily uses for drinking water. The country is located on the north-western coast of Borneo with a tropical climate having uniformly high temperatures along with rainfall occurring intermittently throughout the year with two dry and two wet seasons. The annual rainfall is typically high, with an average of over 2,800 mm throughout Brunei Darussalam and can occasionally exceed 4,000 mm further inland. Although there appears to be a sufficient amount of rainfall, several issues have been encountered primarily in agricultural areas due to scarcity of water resources in-between seasons. This has caused a strain on crop production leading to the creation of projects to tap into and explore additional groundwater resources. Groundwater studies are also an important component for risk and hazard mapping, as landslides are prevalent in the country commonly occurring when there are large volumetric or prolonged rainfall. With the increase of this research, it led to a cooperative interest in groundwater mapping using existing datasets aimed to focus on providing information for further sustainable developments in the country as well as to meet the objectives set for the country’s future.

Keywords: groundwater, hydrogeological map, resources, Asia, Brunei Darussalam

1. Introduction

Negara Brunei Darussalam is located on the north-western coast of the island of Borneo, between east longitudes 114° 23' and 1 15° 23' and between north latitudes 4° and 5° 5' sharing a border with the eastern Malaysian state of Sarawak shown in Fig. 1. The country has a total area of 5,765 km^2 which is divided into four districts namely Brunei-Muara, Tutong, Belait which makes up the mainland of the country and Temburong which was geographically separated by Limbang. However, since 2020, Temburong District has reconnected back to the rest of the country with the construction of a 30 km long Sultan Haji Omar Ali Saifuddien (SHOAS) Bridge built across Brunei Bay. The Temburong District is dominantly a pristine mountainous region that has a maximum elevation of 1,839 m located on Bukit Pagon. However, this region demonstrates a contrasting difference from the low-laying mainland which has an average height of 91 m. The current population of Brunei Darussalam according to the Department of Economic Planning and Statistics (2021) is 429,999 persons mostly living close to the coastal areas with a higher percentage in the Brunei-Muara District followed by the Belait district, Tutong district and lastly the Temburong district.

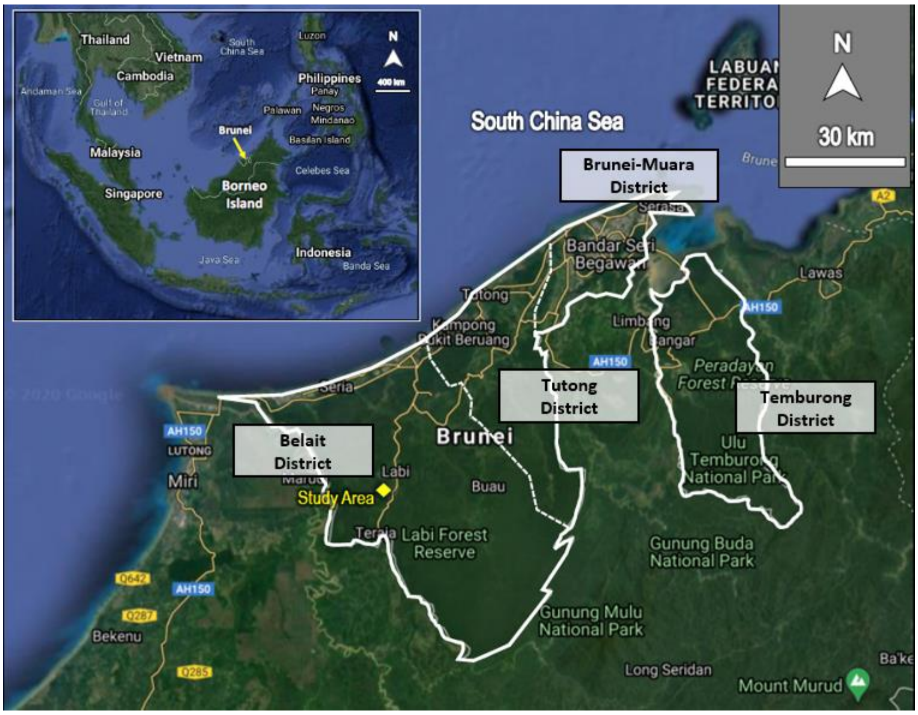


Fig. 1. Map of Brunei Darussalam (Obtained from Google Maps)

Brunei Darussalam has a tropical climate with uniformly high temperatures along with rainfall occurring intermittently throughout the year with two dry and two wet seasons. The climate is governed by the two monsoon winds generated by the low-pressure trough of the Inter-Tropical Convergence Zone (ITCZ) and trade winds.

The annual rainfall is typically high, with an average of over 2,800 mm throughout Brunei Darussalam and can occasionally exceed 4,000 mm further inland (Sandal, 1996). 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 seen in Fig. 2.

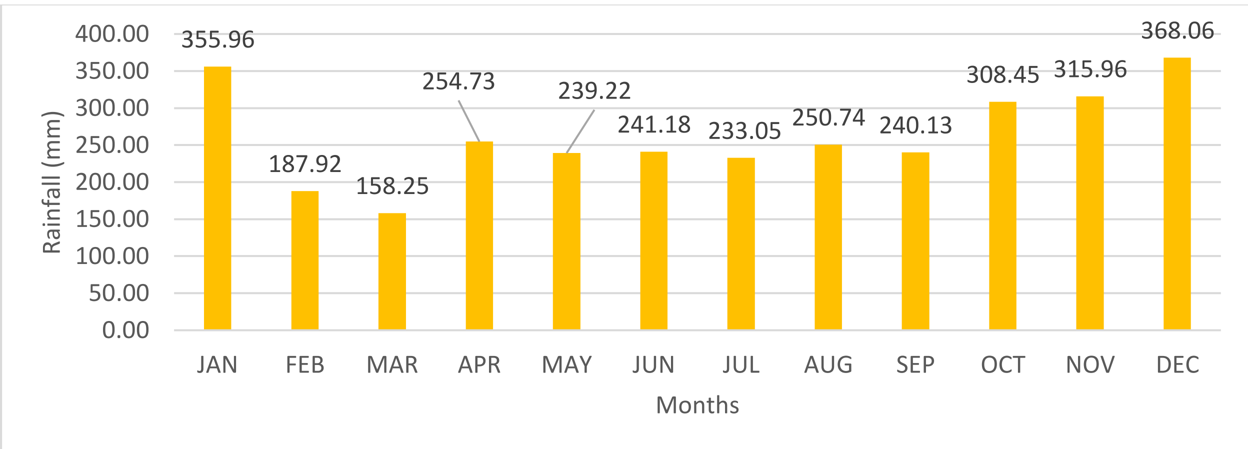


Fig. 2. Average monthly rainfall from 1998 - 2017 (Brunei Darussalam Meteorology Department, 2017)

1.2 Water supply in Brunei Darussalam

For the past several decades, 99.5 % of Brunei Darussalam's water supply originates from surface water whilst 0.5 % is from groundwater commonly used for the bottled water industry. Water is supplied from several water pumping stations (Fig. 3) as wells as dams which include Badas pumping station that exclusively supplies 69 million m^3/year towards the oil and gas industry (FAO, 2011) meanwhile the other locations Benutan dam and Mengkubau dam supplies both agriculture industry with water required to cover 3.6 million hectares/year as well as other uses which is estimated to be 23 million m^3/year or 350 liters/day per person. Water is also abstracted from the Tutong river with abstraction volumes shown in Fig. 4.

Fig. 3. (A) Badas pumping station, (B) Benutan dam and (C) Mengkubau dam

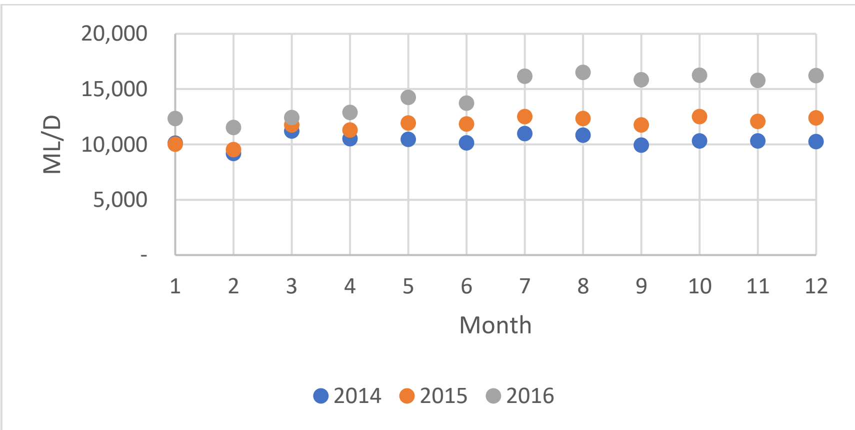


Fig. 4. Example of monthly abstraction from Sg. Tutong for the years 2014 to 2016 (Gödeke et al. 2020)

2. Current groundwater and surface water problems in Brunei Darussalam

2.1 Water supply insufficiency for rice farming

Rice is amongst the major crops that are grown in Brunei Darussalam covering around 852.97 hectares of land farmed in all districts however, 80 % of the rice is harvested in the Brunei-Muara district. In 2020, Brunei has successfully yielded 4000 metric tons of rice, the highest compared to previous years. Although the country's substantial yield, only 8.25 % of 30,517 metric tons is achieved to reach the nation's sufficiency in rice farming. One of the factors that caused this issue is the insufficient supply of water from the reservoirs, especially during the dry season as the industry heavily relies on surface water.

To maintain the supply, the Ministry of Primary Resources and Tourism (MPRT) has opened several governmental projects to attain more water by drilling groundwater wells that were initially surveyed using Vertical Electrical Sounding (VES) method to identify aquifers and locations with potential groundwater storage. The method estimates the variation in the ground's resistivity by injecting an artificially generated current through a set of electrodes into the underground medium and measuring the voltage differences at the potential electrodes (Telford et al, 1990; Binley et al, 2015). The resistivity can be determined from Ohm's law using the voltage differences for a known current and correcting the current geometrical pathway through the earth.

An example of a VES survey conducted on one of Brunei-Muara district's farm is shown in Fig. 5, the data shows the fourth layer to be a potential aquifer zone based on favorable resistivity contrasts and resistivity values of this layer ranging between 10 and 150 Ωm. This layer is observed at depths of about 30 to 60 m from the surface. In addition, the profile line is aligned with the flow direction of the nearby river within the area indicating this location can provide water supply to the rice farms.

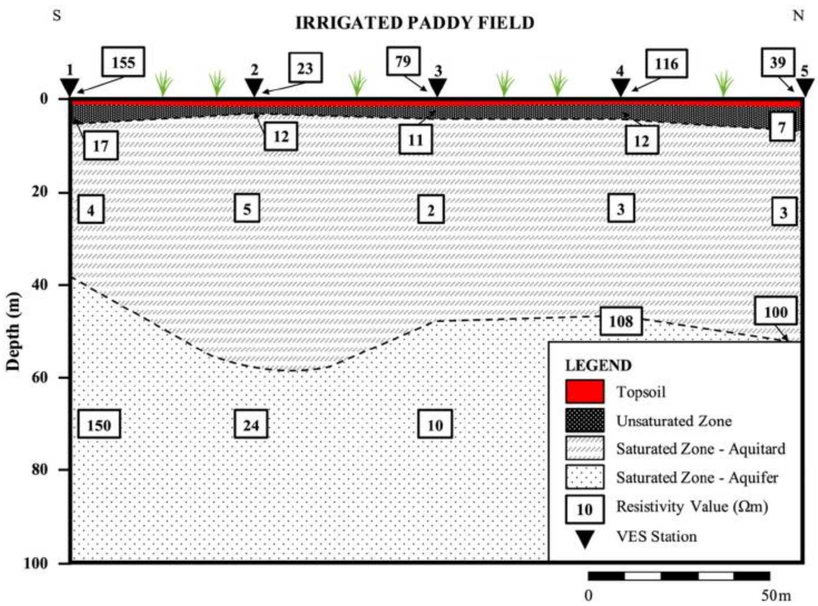


Fig. 5. Geoelectrical section of one of the rice fields in Brunei-Muara District (Azffri et al., 2022)

2.2 Peat Forest fire due to anthropogenic disturbances

Brunei Darussalam has been considered to have a sizable number of well-preserved peat deposits (Gandois et al., 2013) which cover around 18 % of the total land area, but from 1980 to 2000, it was observed that 5 % of the total peat swamp forest had been disturbed (Becek et al., 2008). One of the areas that has been affected by humans can be seen on a section of the largest peat dome in Brunei named Badas peat dome (Suhip et al., 2020) as expansion for urbanization increased. Due to the anthropogenic activities, alterations to the natural shape of the dome caused reduction in waterlogging and leading to yearly peat fire (Fig. 6) which has a potential to the release a large amount of greenhouse gasses stored in the peat deposits.

Fig. 6. Peat forest fire at the Badas Peat Dome

To identify potential areas susceptible to fires, Universiti Brunei Darussalam conducted several studies by using several piezometer monitoring wells together with topographic surveys, and rainfall intensity recordings installed on pristine and highly disturbed transects to assess the effects (Fig. 7).

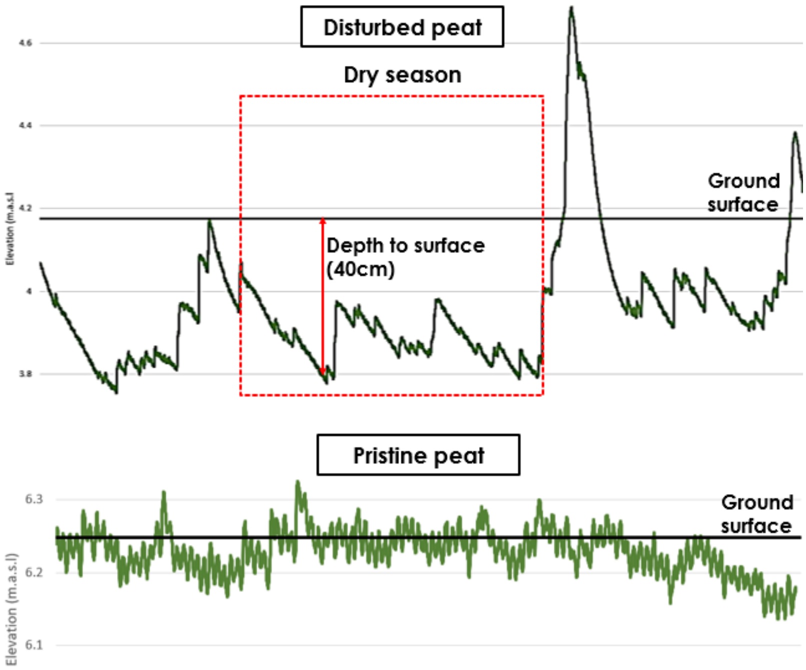


Fig. 7. Groundwater monitoring data

When the piezometer data was examined, significant differences between disturbed and pristine peat were found. For the disturbed peat, the graph shows undulatory groundwater fluctuations with deep drops of water level that can reach 40 cm beneath the surface especially during dry season. For the pristine peat the groundwater level is consistent throughout the survey period with minor fluctuations in water level. Fig. 7 also identifies potential fire risk periods.

2.3 Landslide hazard and risk mapping

Landslide occurrences are one of the most common geo-hazards in Brunei Darussalam. They are usually linked to several factors, such as prolonged or high intensity heavy rain, improper drainage and slope protection systems (Department of Technical Services, 2014; Jamalulail et al., 2021). Fig. 8 shows that the landslide occurrences are prevalent during the wet seasons which can happen frequently during the months of January and December which can be linked with the monthly rainfall data in Fig. 2.

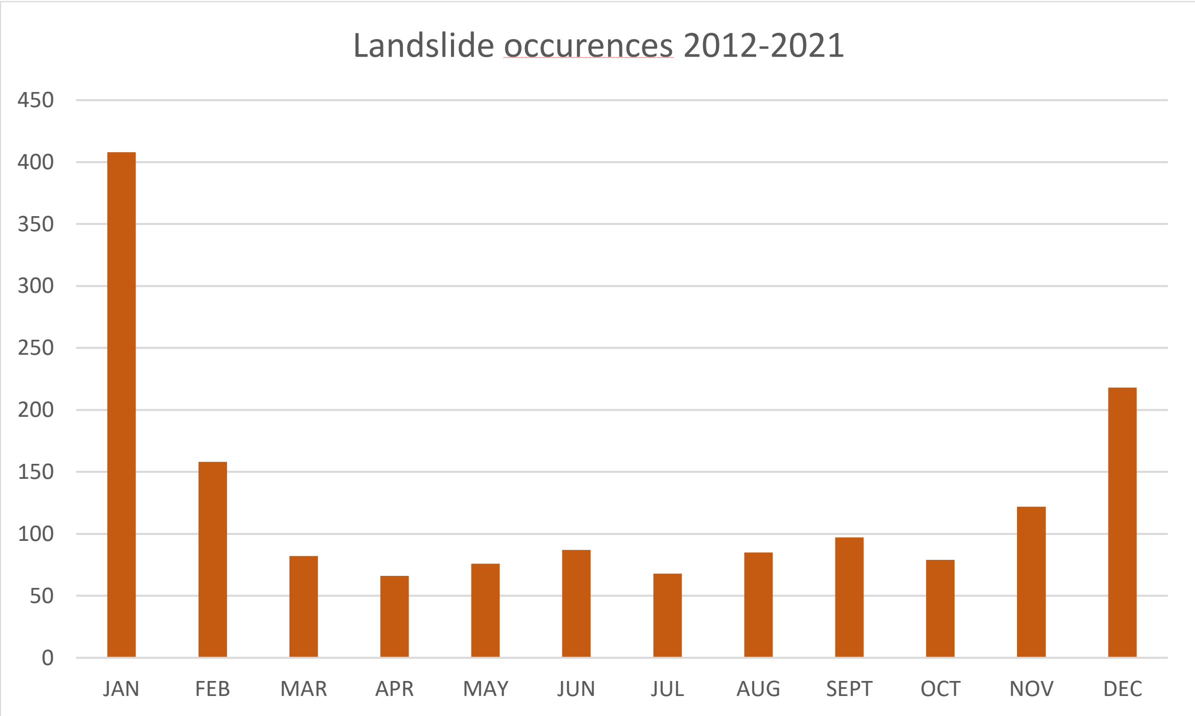


Fig. 8. Landslide occurrences in Brunei Darussalam from 2012-2021
(Department of Technical Services, 2022)

To examine further the public works department has taken initiative to conduct a landslide hazard and risk mapping study since 2014 using the Frequency ratio (FR) modeling method. This method is a combination of landslide distribution with an addition of several parameters influencing the landslides by using spatial analysis tool (Department of Technical Services, 2014).

The landslide distribution is a collection of landslide events that have occurred in all districts since 2008. The updated data shows 81 % of landslides occur in the Brunei-Muara district, 13 % in Tutong district, 3 % Belait District and 2 % in the Temburong District. LIDAR data and aerial photographs were also a major component in this study as they were utilized to obtain 13 different conditioning factors which were altitude, slope, aspect, curvature, Stream Power

Index (SPI), Topographic Wetness Index (TWI), Terrain Roughness Index (TRI), geology, Land Use and Land Cover (LULC), soil, distance from river, distance from roads and precipitation. The utilization of these data can be seen in Fig. 9, showing the steps in producing the risk and hazard map.

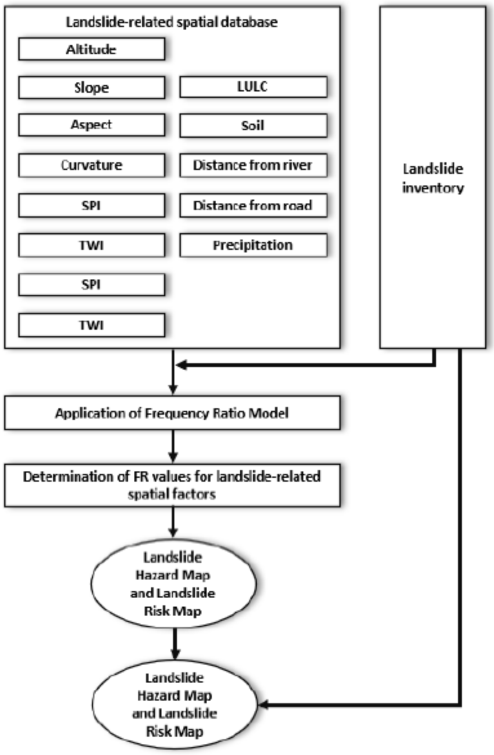


Fig. 9. Overall landslide hazard and risk mapping methodology (Department of Technical Services, 2014)

One of the locations that was studied using the FR method was in Kota Batu and Jalan Tutong. Once all the steps are applied the results showed a verification value of 86.4 % success rate and have shown hazards in the form of 5 different hazard and risk indices which are ‘very low’, ‘low’, ‘medium’, ‘high’ and ‘very high’ as shown in Fig. 10 producing a reliable risk and hazard map to delineate locations to be studied further with more details.

3. Possible solutions to manage problems related to water resources

Public Works Department’s Geotechnical, Geological and Research Section, Department of Technical Services is currently conducting digitization of geotechnical reports obtained from soil investigation projects (SI) that were performed according to British Code BS 5930:2015+A1:2020. These types of projects are one of the work scopes of the department primarily to assist government-led projects in terms of foundation advice. The report usually consists of physical testing that includes the coordinates of projects, borehole information, soil/rock sampling (undisturbed & disturbed), standard penetration tests, water level measurement and rock coring as well as laboratory testing such as moisture content, bulk & dry density, Atterberg limits, sieve analysis, 1D consolidation test, chemical testing (pH) value, salinity, total sulphate, organic matter, chloride contents and unconfined compressive strength.

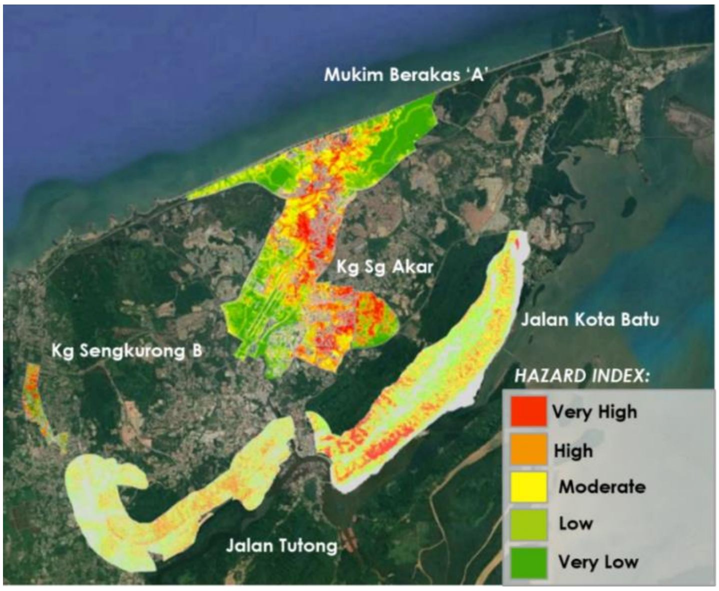


Fig. 10. Landslide hazard map of Brunei and Muara District (Department of Technical Services, 2020(2))

Up until 2022, 745 soil investigation reports comprising 4,356 borehole logs have been digitized. Thus about 76.25 % of the borehole logs from 1967 until present have been converted into digitized formats. The work is expected to be completed by the end of 2022.

Digitizing these sets of data is a cost effective and useful way to provide vital preliminary information using the ArcGIS software by creating several maps such as soil maps shown on Fig. 11. The interpolated data provide interpretations of different types of soil within the requested area including the hardness of the soil to locate the target depth to install the foundation.

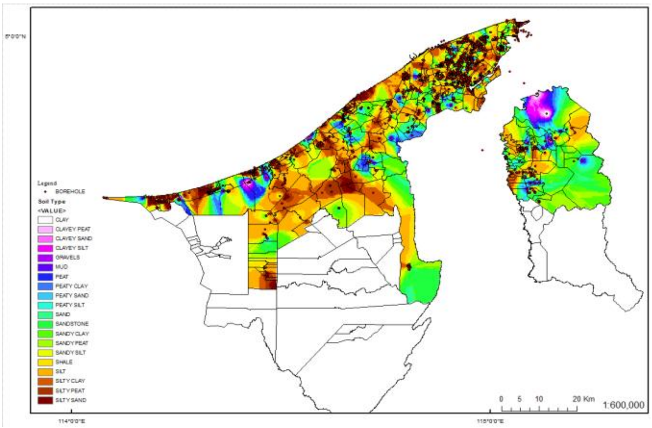


Fig. 11. Topsoil map of Brunei Darussalam with 18 soil classification (Department of Technical Services, 2021)

With the success of the digitization method, this department has also started to store groundwater data as interest in groundwater maps increased. Several institutions such as Universiti Brunei Darussalam are also involved in this project as collaboration in data sharing to improve the reliability of the data with real time groundwater monitoring. An example of the map is found in Fig.12 showing the potential groundwater level in one of the precincts in Brunei Darussalam.

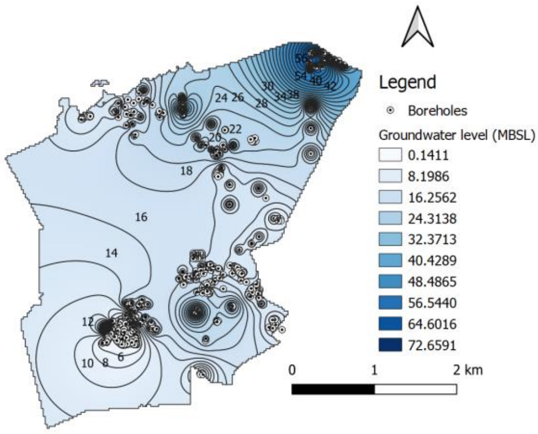


Fig. 12. Groundwater contour map of Mukim Gadong A (Department of Technical Services, 2022)

4. Conclusions

In conclusion, based on the evidences several issues on groundwater are beginning to rise in Brunei Darussalam causing environment impacts as well as an effect on several sectors such as agriculture. However, multiple organizations have started to be involved in the mitigation in reducing the impacts such as using groundwater surveys to find the depth of potential aquifers, perform monitoring to identify fire risks zones and mapping to identify locations that has a potential risk from landslides. With increasing number of collaboration initiatives with different organizations more information can be disseminated to increase the information capacity providing an early step in improvement and management of the water resources in Brunei Darussalam.

References

Azffri, S. L., Azaman, A., Sukri, R. S., Jaafar, S. M., Ibrahim, M. F., Schirmer, M. and Gödeke, S. H. (2022) Soil and Groundwater Investigation for Sustainable Agricultural Development: A Case Study from Brunei Darussalam. *Sustainability*, **14(3)**, 1388, MDPI AG. Retrieved from http://dx.doi.org/10.3390/su14031388

Becek, K. and Odihi, J.O. (2008) Identification and assessment of factors affecting forest depletion in Brunei Darussalam. *In* The International Archives of the Photogrammetry, *Remote Sensing and Spatial Information Sciences*, XXXVII, Part B2, Beijing.

Binley, A. (2015) Tools and techniques: Electrical methods. *In* Treatise on Geophysics, 2nd ed.; Gerald, S., Ed.; Elsevier: Oxford, UK, 11, 233–259.

Brunei Darussalam Meteorology Department (2017) Rainfall Statistics by Brunei Meteorology Department, Brunei Darussalam.

Department of Technical Services (2014) The overall landslide hazard and risk mapping methodology.

Department of Technical Services (2020) Topsoil map of Brunei Darussalam with 18 soil classification.

Department of Technical Services (2020(2)) Landslide Hazard and Risk Mapping of Mukim Berakas 'A', Brunei Darussalam.

Department of Technical Services (2021) Soil Investigation analysis and mapping, Brunei Darussalam

Department of Technical Services (2022) Landslide Inventory Mapping, Brunei Darussalam.

Food and Agriculture Organisation of the United Nations (2011) AQUASTAT Country Profile - Brunei Darussalam; FAO: Rome, Italy, pp. 8.

Gandois, L., Cobb, A. R., Hei, I. C., Lim, L. B. L., Salim, K. A. and Harvey, C. F. (2013) Impact of deforestation on solid and dissolved organic matter characteristics of tropical peat forests:

implications for carbon release. *Biogeochemistry*, **114(1-3)**, 183–199. doi:10.1007/s10533-012-9799-8.

Gödeke, S.H., Malik, O.A., Lai, D.T.C., Bretzler, A., Schirmer, M. and Mansor, N.H., (2020) Water quality investigation in Brunei Darussalam: investigation of the influence of climate change. *Environ. Earth Sci.*, **79**. https://doi.org/10.1007/s12665-020-09157-2.

Jamalulail, S. N. R., Sahari, S. and Shah, A. A (2021) Preliminary analysis of landslide hazard in Brunei Darussalam, Southeast Asia. *Environmental Earth Science*. https://doi.org/10.1007/s12665-021-09815-z.

Sandal, S.T. (1996) The Geology and Hydrocarbon Resources of Negara Brunei Darussalam, Brunei Shell Petroleum Company: Bandar Seri Begawan, Brunei, 1996, pp. 243.

Suhip, M. A. A. B. H, Gödeke, S. H, Cobb, A. R, and Sukri, R. S. (2020) Seismic refraction study, single well test and physical core analysis of anthropogenic degraded Peat at the Badas Peat Dome, Brunei Darussalam. *Eng Geol*, 273:105689.

Telford,W.M., Geldart, L.P and Sheriff, R.E. (1990) Applied Geophysics, Cambridge University Press, Cambridge, UK, pp. 770.

Current groundwater and surface water problems in Indonesia, and their possible solutions

Taat Setiawan[1], Wahyudin[1], Budi Joko Purnomo[1], and Fajar Dwinanto[1]

[1]Center for Groundwater and Environmental Geology, Geological Agency, Ministry of Energy and Mineral Resources, Republic of Indonesia
e-mail: taat.setiawan@esdm.go.id

Abstract

Water demand in Indonesia is increasing rapidly, projected to increase by around 31 % in the period 2015 - 2045. Until now, groundwater is still a priority to meet domestic clean water needs, which is around 46 % in 2019. Some of the reasons include the lack of access to piped clean water supply, low surface water storage capacity, and high surface water pollution load. This causes groundwater in quantity to continue to degrade, and it is even suspected to be one of the causes of land subsidence in northern Java Island which lasts between 1 - 20 cm per year. Currently, horizontal water resource management is given different responsibilities between groundwater and surface water. Surface water is managed by the Ministry of Public Works and Housing based on river basins territory (RBT), while groundwater by the Ministry of Energy and Mineral Resources is based on groundwater basins (GWB). Law No. 17 of 2017 mandates the management of water resources based on RBT by taking into account the interrelationships of surface water and groundwater by prioritizing the utilization of surface water. This presents its challenges in integrating water resources management which requires a complex set of considerations to determine appropriate actions against water resource degradation. Groundwater problems are still complicated, some of which is the absence of more technical water resources management regulations, differences in the basis of water resources management become a separate problem because the GWB boundaries in many cases are very much different from the RBT boundaries, as well as limited human resources and financing in groundwater management. In addition, most of the use of groundwater for irrigation is unlicensed so that it cannot be monitored, and the preparation of spatial plans has not considered groundwater conditions as an important factor. Several solutions are needed to overcome the problems of water resource management in Indonesia. Derivative regulations for integrated water resource management should be issued soon and more coordination between relevant agencies in water resources planning is needed to identify areas where surface water needs to be prioritized over groundwater use. Groundwater management institutions need to be strengthened to the second echelon level and the establishment of groundwater offices in several parts of Indonesia. Evaluation of the water balance is very necessary, especially in groundwater recharge areas and damaged groundwater discharge areas as a basis for prioritizing surface water use. The GWB boundaries need to be re-delineated by looking at the groundwater potential of non-GWB areas, to reduce the gap between GWB and RBT boundaries. The addition of water storage capacity in the upstream area which is also a groundwater recharge area is needed to increase water security. A sustainable spatial planning process that accommodates river basin planning and groundwater conservation zones. The last is to reduce pollution of water resources in an integrated manner and to accelerate the provision of clean water that is inclusive, sustainable, and efficient for all Indonesian people.

Keywords: water resources, river basin territory, groundwater basin, Indonesia

1. Introduction

The need for water in Indonesia is increasing rapidly. GWSP (2021) reports that water demand is projected to increase by around 31 % in 2015 - 2045. Water demand for industrial purposes will increase fourfold, from 9 billion m^3 to 36 billion m^3, while irrigation/ agriculture will increase by around 10 %, from 177 billion m^3 to 196 billion m^3. Until now, groundwater is still a priority to meet domestic clean water needs, which is around 46 % in 2019 (Fig. 1). The lack of access to piped clean water supplies is suspected to be the cause of the problem that groundwater remains a priority for clean water sources in addition to the very high load of surface water pollution. Groundwater in quantity also continues to be degraded due to excessive pumping. This is even suspected to be one of the causes of land subsidence in the northern part of Java Island which lasts between 1 to 20 cm per year, even Jakarta as the nation's capital is dubbed the 'sunken city' (Andreas et al., 2018). However, this research has not been able to explain how big the proportion of groundwater extraction is to land subsidence and is still being debated among related experts.

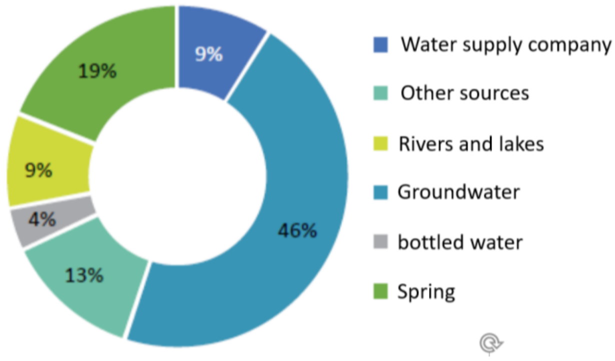


Fig. 1. Water sources for domestic needs in 2019 (GWSP, 2021)

Horizontal water resource management is given different responsibilities between groundwater and surface water management. The responsibility for surface water management is given to the Ministry of Public Works and Housing base of River Basin Territory (RBT), while groundwater to the Ministry of Energy and Mineral Resources base of Groundwater Basin (GWB). Indonesia has 421 GWB and based on Law no. 17 of 2019 concerning water resources, 74 % of the groundwater management area is carried out by the Central Government in this case the Ministry of Energy and Mineral Resources (Fig. 2). For surface water in Indonesia, there are around 8,000 watersheds and more than 5,700 rivers grouped into 128 RBT (Fig. 3). Based on Law No. 17 of 2019 concerning Water Resources, it is explained that the management of water resources is based on RBT by taking into account the relationship between the use of surface water and groundwater by prioritizing the utilization of surface water. This of course presents its challenges in integrating water resources management which requires a series of complex considerations in the utilization of water resources, as well as to determine appropriate actions against the degradation of water resources both in quality and quantity.

2. Current groundwater and surface water problems in Indonesia

One of the causes of excessive use of groundwater is the limited availability of surface water in both quality and quantity. Surface water storage capacity is still very low, which is only 1 % of the total available water resources, and it is still not managed properly (GWSP, 2021). Surface water has high seasonal variability both in quality and quantity, so this is a separate obstacle to the gap between water supply and water demand. The most visible is the high load of surface water pollution. GWSP (2021) reports that more than half of rivers in Indonesia are polluted, especially in Java and Sumatra (Fig. 4) and about 93 % of urban and industrial wastewater is discharged without going through a treatment process and into the water system.

As a result, this water source cannot be used for various purposes, except for the relatively high cost of sanitation.

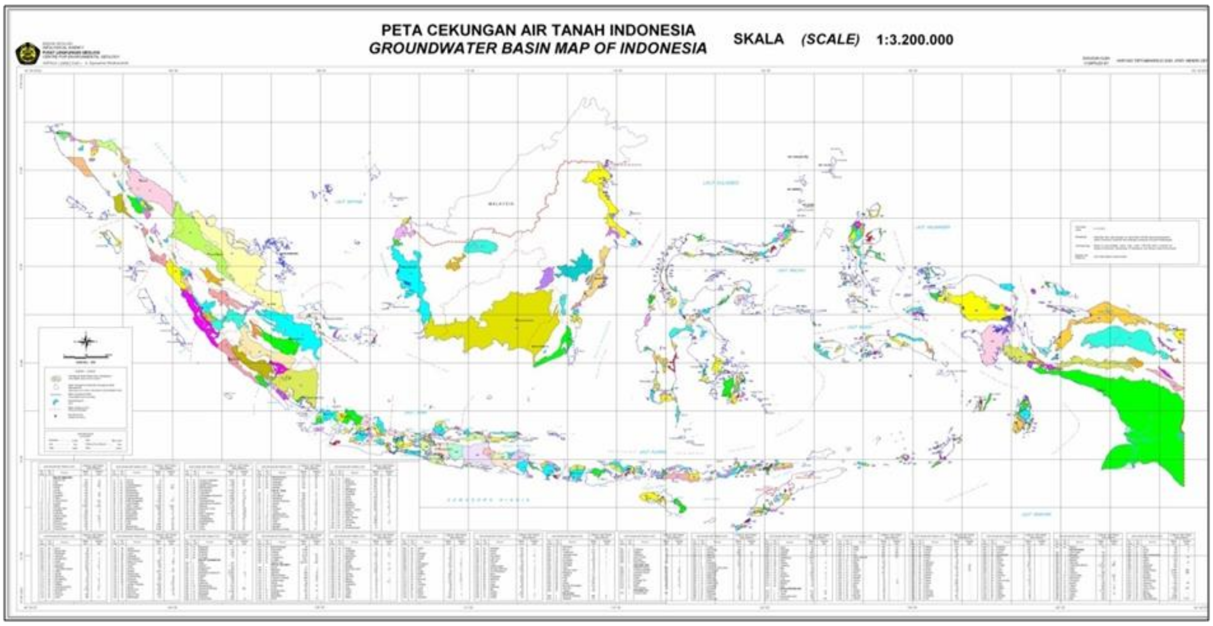


Fig. 2. Groundwater basin map of Indonesia

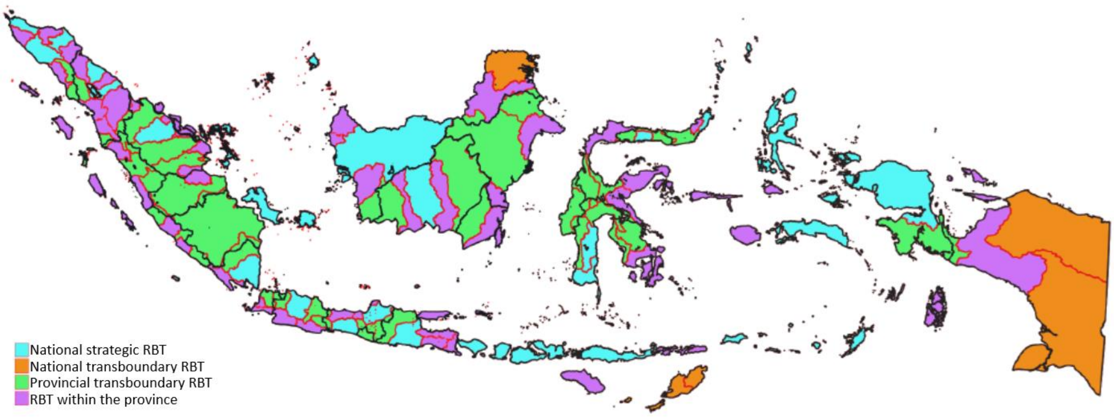


Fig. 3. River basin territory of Indonesia

Groundwater also experiences a relatively high pollution load, especially in unconfined aquifer systems, although it is not as severe as surface water. This is mainly related to the exposure of groundwater by domestic waste that contaminates the unconfined aquifer system (Lasagna et al., 2016). Compressed groundwater is also starting to be polluted due to excessive pumping. As an example of unconfined groundwater in the urban area of the Citarum River Basin, Bandung City, unconfined groundwater pollution was identified from the nitrate and ammonium content (Rusydi et al., 2017). Research conducted by Taufiq et al. (2019) showed that nitrate in unconfined groundwater had infiltrated into confined groundwater, namely in areas that experienced a deep piezometric decrease due to excessive extraction of confined groundwater.

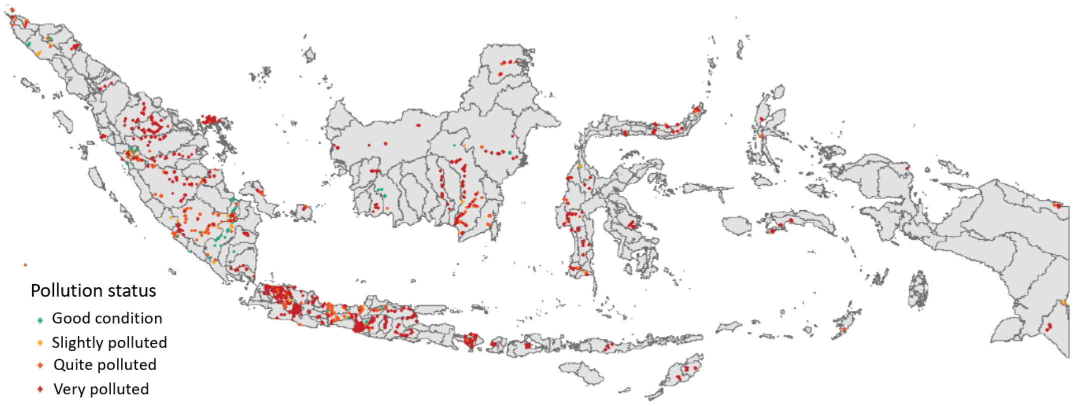


Fig. 4. The status of surface water pollution in Indonesia (GWSP, 2021)

Groundwater damage quantitatively is also seen in most groundwater basins in Indonesia, which is characterized by a decrease in the groundwater level by more than 80 % from its original condition. Some of these groundwater basins include the Jakarta GWB, Bandung-Soreang GWB, Serang-Tangerang GWB, Semarang-Demak GWB and Palangkaraya-Banjarmasin GWB (Fig. 5). Groundwater degradation was also identified in agricultural areas, where drilled wells for irrigation purposes did not carry out the licensing process or submit reports to the Ministry of Energy and Mineral Resources. This of course makes it difficult to monitor, especially the development of groundwater for agricultural irrigation tends to ignore the potential availability of groundwater. For example, in the northern part of Madiun City, the groundwater level has decreased to 20 m in 10 years.

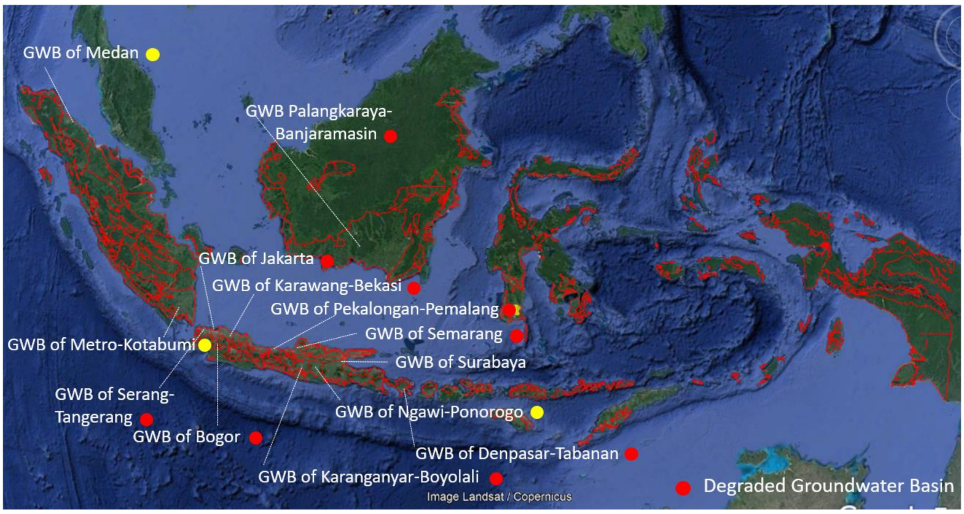


Fig. 5. Status of groundwater basin conditions in several locations in Indonesia

In the planning of spatial and regional development, groundwater conditions have not been fully considered. Some areas with damaged groundwater conditions are used as industrial development areas, groundwater recharge areas are developed for an urban area. The management of springs that are genetically included in the groundwater section does not involve the Ministry of Energy and Mineral Resources as the groundwater manager.

Regarding legal and institutional aspects, until now there are still water resources management problems that must be addressed immediately. The lack of technical regulations for water resources management raises doubts for most groundwater management institutions in the regions to carry out a series of policies. For example, regarding licensing for groundwater utilization and how to prioritize the use of surface water over groundwater, the mechanism has not yet been regulated between institutions or ministries managing water resources. The difference in the management basis between groundwater and surface water is a problem in itself, the boundaries of the groundwater basin (GWB) are in many cases very different from the boundaries of the river basin territory (RBT). Of course, this will require a lot of coordination, both horizontally and vertically between institutions. The last one is groundwater management, although it is managed by the Ministry of Energy and Mineral Resources, the technical implementation is only carried out by the Groundwater Working Group (echelon 3 levels), under the Center for Groundwater and Environmental Geology, Geological Agency. This has an impact on the lack of human resources and funding, one of which results in the unavailability of a comprehensive groundwater conservation map, and the updating of this map has not gone well in GWB priority.

3. Possible solutions to manage problems related to water resources

With the issuance of Law No. 17 of 2019 concerning Water Resources, groundwater must be an integral part of the management of water resources in a river area. This presents its challenges with how to integrate groundwater management based on groundwater basins with surface water based on river basins. To overcome these problems and the problem of water resources in general in Indonesia, it is necessary to carry out several solutions, both legal and institutional aspects as well as technical aspects. Regarding legal and institutional aspects, the first is that derivative or technical regulations need to be made immediately for the integrated management of surface water and groundwater in all groundwater basins and river areas. The two water resources are integrated into a system (Younger, 2007; Hiscok, 2014), which is called a single unit of water resources (Winter et al., 1999). In a groundwater basin, the two types of water resources interact with each other, especially in the groundwater recharge area. In these areas, water security is crucial because it has a high vulnerability in both quantity and quality.

The second is that more coordination between the Ministry of Public Works and Housing and the Ministry of Energy and Mineral Resources is needed in water resource planning to identify areas where surface water needs to be prioritized over groundwater use. This is especially true for groundwater recharge areas and groundwater discharge areas that have been damaged because these areas have relatively low water security. The third, coordination between the central government and local governments needs to be strengthened, especially in the areas of licensing and supervision. Local governments need to increase their commitment to implementing national-level plans. The integration of water resources management is also carried out at the level of coordination between institutions. Groundwater licensing is carried out after coordinating with the local surface water manager so that groundwater use can be carried out after it is stated that the availability of surface water is inadequate. To strengthen integrated river basin territory management, it is necessary to take steps to strengthen the coordination mechanism of the National Water Resources Council in all stakeholder institutions. Coordination, synchronization, and cooperation between water resources stakeholder institutions are followed by the development of an integrated water resources database and information system. The fourth, specifically for groundwater management, institutions need to be strengthened to become a second echelon level that specifically manages groundwater and the establishment of groundwater centers in several parts of Indonesia.

Fig. 6. The extent of the Central Government's authority in groundwater management and the planned location of the Groundwater Center

Solutions related to technical aspects include the first is an evaluation of the water balance to determine the potential for groundwater and surface water, especially in groundwater recharge areas as the basis for meeting clean water needs in areas that are vulnerable to water security. The second is the evaluation of the boundaries of the groundwater basin, especially the delineation of the boundaries of the groundwater recharge area by reviewing the non-groundwater basin areas to be included in the groundwater recharge area. This will minimize the boundary difference between the groundwater basin and the watershed. The third is the construction of water storage facilities (dams, reservoirs, etc.) in the upstream areas which are also groundwater recharge areas. In addition to being used as a water resource, it can also increase the capacity of groundwater recharge. Rivers, lakes, reservoirs, and groundwater should be managed in an integrated manner because they are intrinsically connected to a system, especially in upstream areas. Incorporating these lakes and groundwater into reservoirs can lead to more integrated systems and increased water security. The fourth is integrated cross-sectoral spring management, including how to implement appropriate spring conservation efforts to meet the need for clean water in groundwater recharge areas. The fifth is that a forward-looking spatial planning process can be considered which includes not only existing river basin planning instruments (patterns and plans), but also groundwater basin conservation zones that regulate groundwater protection and utilization zones. The sixth is to significantly reduce water pollution by improving wastewater treatment (municipal, industrial, and mining), reducing the spread of water pollution from agriculture and aquaculture, strengthening water pollution control. The last is to accelerate the provision of clean water that is inclusive, sustainable, and efficient for all Indonesians.

4. Conclusions

Water demand in Indonesia is increasing rapidly and groundwater is still a priority to meet domestic clean water needs. Some of the causes include the lack of access to piped clean water supplies, low surface water storage capacity, and polluted surface water. Law No. 17 of 2019 mandates the management of water resources based on river basin territory by taking into account the interrelationships of surface water and groundwater by prioritizing the utilization of surface water. Groundwater problems are still complicated, some of which are the absence of more technical regulations for water resources management, differences in the basis for water resource management, and limited human resources and funding for groundwater management. Several solutions are needed to overcome water resource management problems; the issuance of derivative regulations for integrated water resource management, greater coordination between water resource management institutions, evaluation of the water balance, delineation of GWB boundaries, enhancement of water storage capacity, as well as reducing pollution of water resources and accelerating the provision of clean water.

References

Ministry of Energy and Mineral Resources (2017) Regulation of Minister of Energy and Mineral Resources No. 2 of 2017 concerning Groundwater Basin.

Law No. 17 of 2019 concerning Water Resources

Andreas, H., Hasanuddin Z. A., Irwan G., Teguh P. S., Dina A. S. and Dhota P. (2018) Insight into the Correlation between Land Subsidence and the Floods in Regions of Indonesia. *In* Natural Hazards - Risk Assessment and Vulnerability Reduction, edited by José Simão Antunes Do Carmo, IntechOpen.

GWSP (2021) Indonesia Visi 2045 Menuju Ketahanan Air, Global Water Security and Sanitation Partnership, World Bank Group.

Hiscok, K.M., Bense V.F. (2014), *Hydrogeology: Principles and Practice*, 2nd Edition, Wiley-Blackwell.

Lasagna, M., Domenico, de Luca, A. and Franchino, E. (2016) Nitrate contamination of groundwater in the western Po Plain (Italy): the effects of groundwater and surface water interactions. *Environmental Earth Sciences*, **75(240)**, https://doi.org/10.1007/s12665-015-5039-6.

Rusydi, A. F., Naily, W., & Lestiana, H. (2015) Pencemaran Limbah Domestik Dan Pertanian Terhadap Airtanah Bebas Di Kabupaten Bandung. *Jurnal RISET Geologi Dan Pertambangan*, **25(2)**, 87, https://doi.org/10.14203/risetgeotam2015.v25.201.

Taufiq, A., Effendi, A. J., Iskandar, I., Hosono, T., & Hutasoit, L. M. (2019) Controlling factors and driving mechanisms of nitrate contamination in groundwater system of Bandung Basin, Indonesia, deduced by combined use of stable isotope ratios, CFC age dating, and socioeconomic parameters. *Water Research*, **148**, 292–305, https://doi.org/10.1016/j.watres.2018.10.049

Winter, T. C., Harvey, J. W., Franke, O. L., & Alley, W. M. (1999) Groundwater and surface water. *A single resource. USGS Circular*, **1139**.

Younger, P.L. (2007) *Groundwater in the Environment, An Introduction*, Blackwell Publishing, USA.

Current groundwater and surface water problems in Japan, and their possible solutions

MACHIDA Isao [1]

[1]Groundwater Research Group, Geological Survey of Japan, AIST, Japan
e-mail: i-machida@aist.go.jp

Abstract

The total usage of river water and groundwater in Japan is 70.2 and 8.8 billion m^3/year, respectively. Construction on water supply systems began in the 1950s and is ongoing. Tap water is drinkable throughout whole country, with water supply being accessible to 98 % of the population today. However, the current water supply system has to be replaced with the huge total costs. Various efforts are being made to reduce costs by local governments. Regarding the groundwater, poorly enforced laws such as groundwater protection zones allow to cause qualitative and qualitative potential risks. For our solution, the Basic Law on the Water Cycle was enacted in 2014. Although the new law does not address penalties, but local governments can construct suitable local ordinances based on this law.

Keywords: replacement of water supply systems, efforts by local governments, groundwater protection zones, the Basic law on the Water Cycle

1. Introduction

The 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.

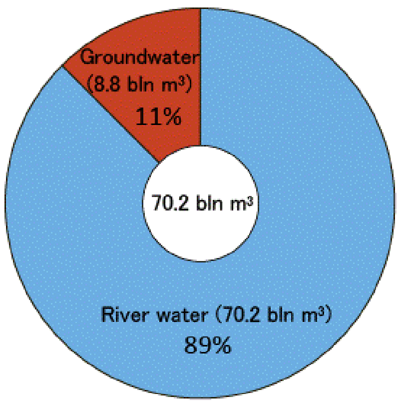


Fig. 1. The annual percentage usage of river water and groundwater in Japan (MLIT, 2021)

2. Surface water

Good quality river water is based on the abundant rainfall (1700 mm/y; global average of 970 mm/y) and steep topography along the rivers (Fig. 2). Figure 3 shows the water quality of the Tone River, which is one of the longest rivers in Japan. The electric conductivities in the river were under 100 µS/cm upstream, increasing to approximately 300 µS/cm downstream. The good quality river water flowing downstream makes river water the primary water source in Japan.

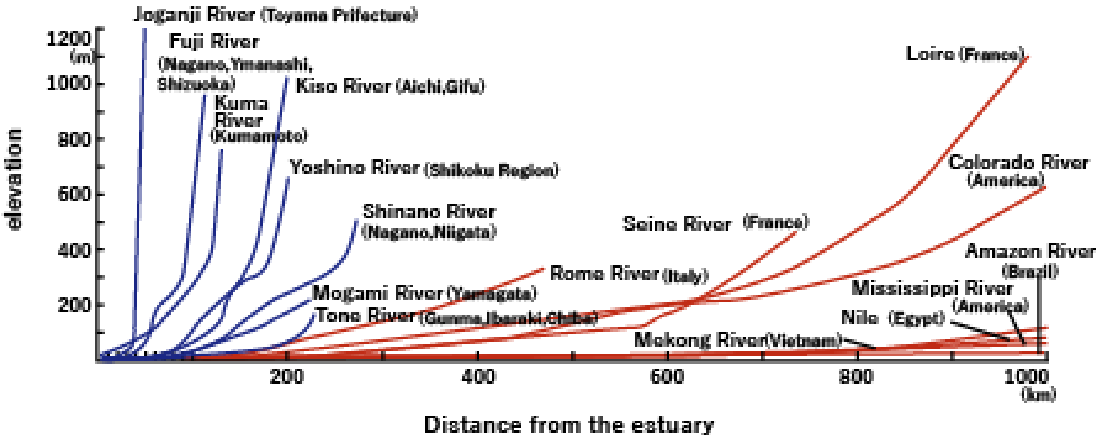


Fig. 2. Gradient of representative rivers (Mantoku, 2020)

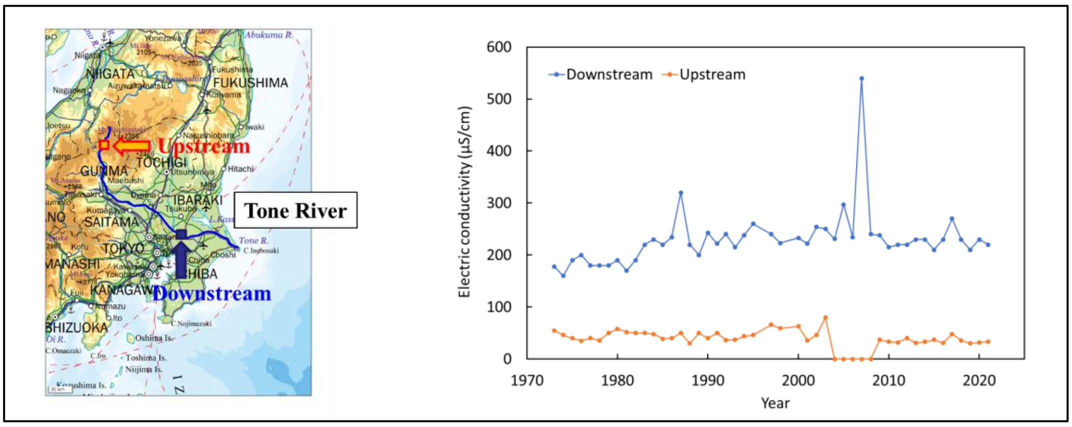


Fig. 3. Comparison of electric conductivities in the Tone River (Data from MLIT, 2022)

3. Problems and solutions for surface water

Tap water is drinkable throughout Japan, with water supply being accessible to 98 % of the population. However, there are several issues with maintaining a constant water supply. Construction on water supply systems began in the 1950s and is ongoing. Considering that the legal life span of water pipes is approximately 40 years, the current pipes have to be replaced. Unfortunately, the total cost of replacing the water pipes is estimated to exceed \$10 billion annually (MHLW, 2019). In Japan, each city independently runs a water distribution facility, with some cities integrating with neighboring cities to reduce costs. In addition, the Miyagi Prefecture started collaborating with private companies to help run water intake and supply systems (Fig. 4). This new method is called “concession”, whereby a private business operator is given the right to operate the facility while the public entity owns the property. In the Miyagi Prefecture, the Metawater Consortium (Metawater Co. Ltd., Veolia-Jenets K.K., and Hitachi Ltd., to name a few) was selected as the operator at the end of 2021 (Miyagi Prefecture Government, 2021).

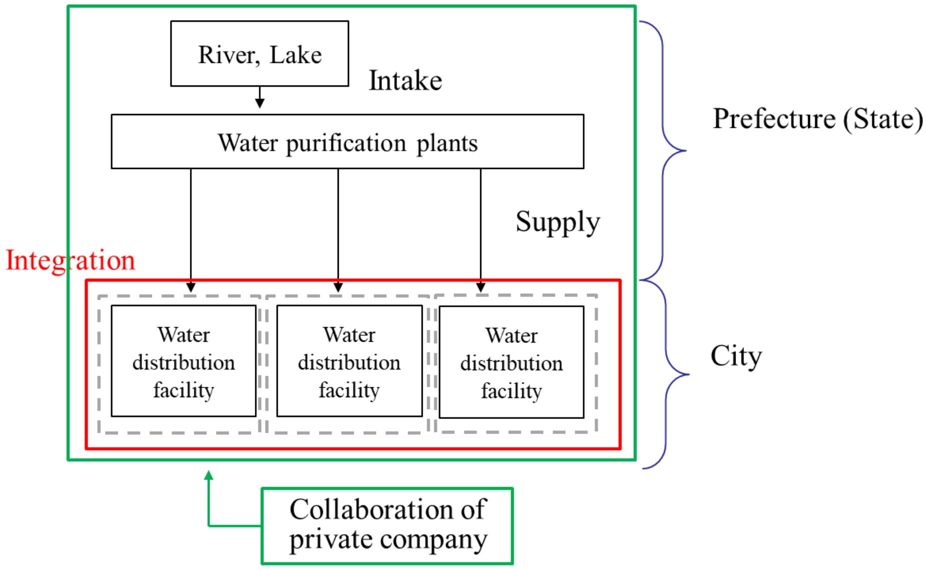


Fig. 4. Solutions for reducing costs to manage the water supply system

4. Groundwater

When groundwater is safe to drink, Japanese people prefer to drink groundwater rather than tap water as it is more natural. Qualitative analysis of groundwater showed that there was a high NO_3^- concentration (Fig. 5). The Ministry of the Environment investigates whether NO_3^- concentration in the groundwater exceeds the environmental standard. If the concentration of nitrate-nitrogen is 9.9 mg/L, it is considered “under the environmental standard”. Without analysis of the water, potential risks may be overlooked.

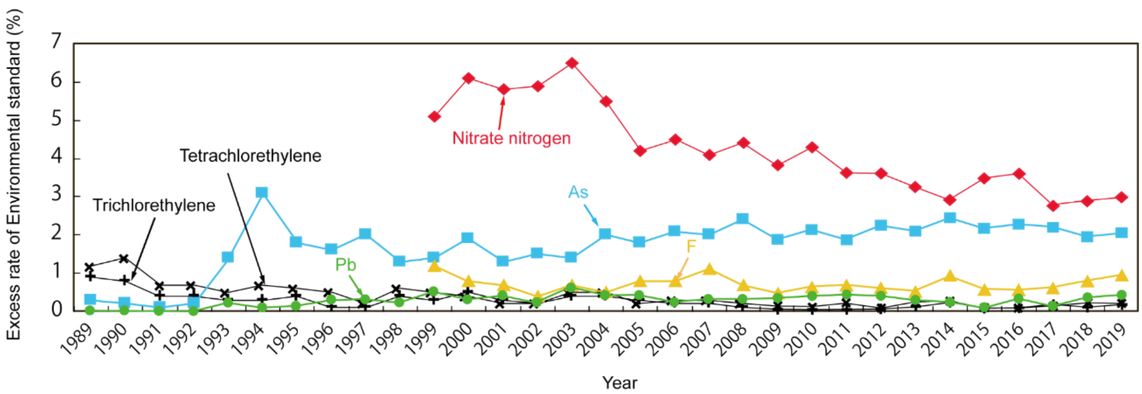


Fig. 5. Percentage exceeding environmental standard (10 mg/L of NO_3-N; Ministry of the Environment, 2021)

Potential risks may occur due to poorly enforced laws such as groundwater protection zones (Fig. 6). In some countries where groundwater is treated as public water, laws limit the use of the land around the water source. In Germany, for example, the catchment area (zone III) prevents the use of diffuse sources (ex. fertilizer) and resistant materials to protect the groundwater quality for drinking. There are no limitations corresponding to zone III in Japan, thereby making it difficult to prevent groundwater pollution.

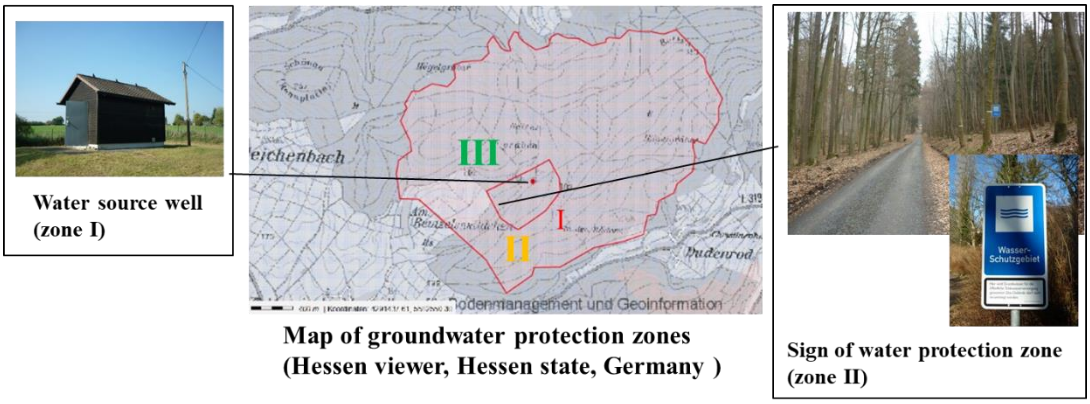


Fig. 6. Groundwater protection zones in Germany (Machida et al., 2015)

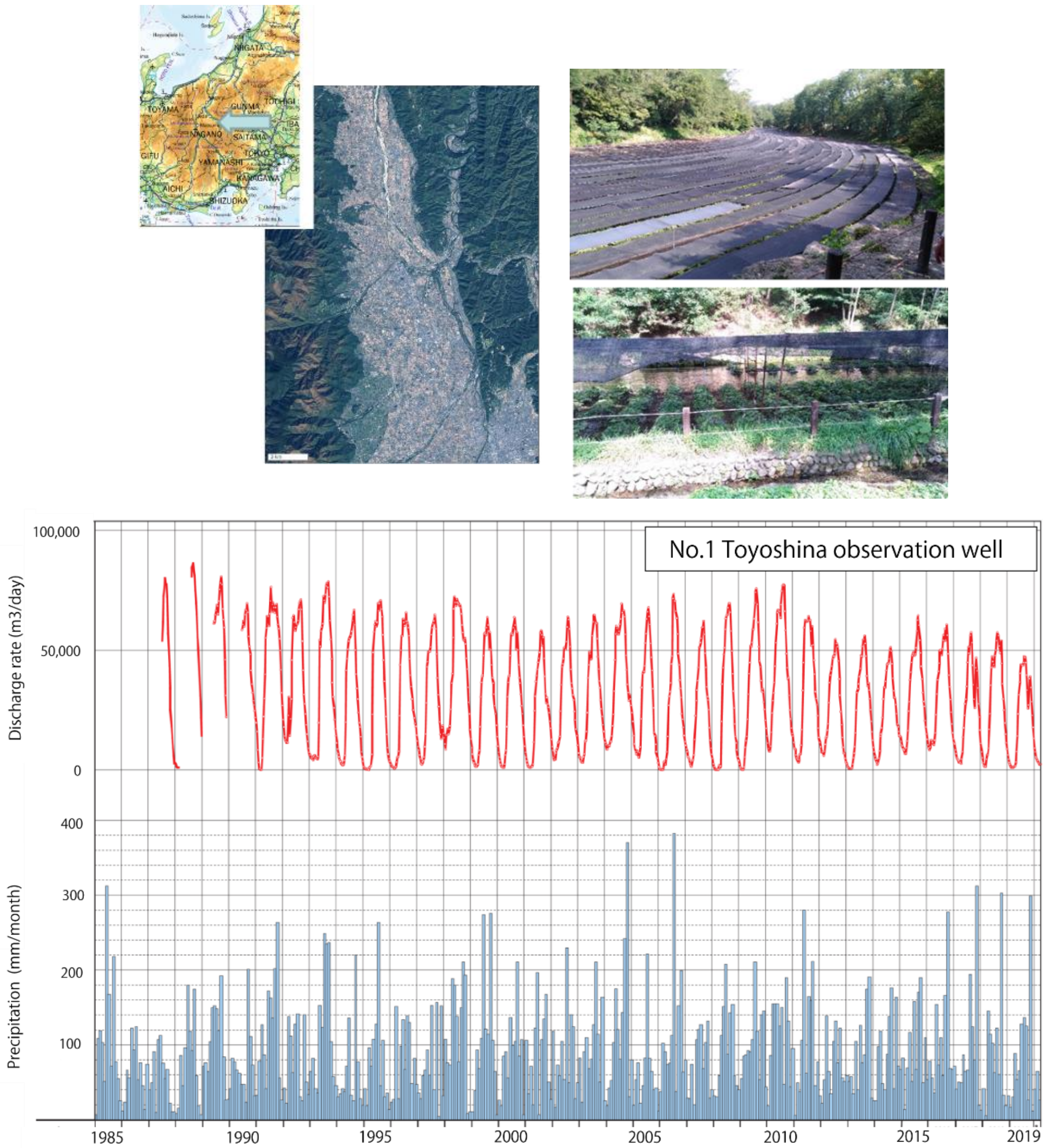


Fig. 7. Decreasing of discharge of springs (Azumino City, 2019)

In addition to qualitative factors, quantitative factors may influence groundwater resource.

Figure 7 shows an example of the wasabi gardens in Azumino City, Nagano Prefecture. The wasabi gardens require vast amounts of groundwater which is discharged via springs. The wasabi gardens are crucial for both local industries and tourism, however the water volumes in springs are decreasing annually. The primary reasons for the decrease in recharge water is the change in the use of the land and a decrease in paddy fields (Yamamoto, 2020). Furthermore, a large beverage factory was built in the basin; although it is important for the local economy, it pumps a lot of groundwater, ultimately affecting the discharge from the springs. This issue may potentially cause a conflict in the future.

5. Solution for groundwater problems

A new law, the Basic Law on the Water Cycle, was enacted in 2014 to promote sustainable groundwater usage. According to this law, groundwater is the “common property of local citizens”. This law does not address penalties but ensures that the groundwater property is owned by the people and not by individuals. The law also ensures that a sound water cycle is maintained. The lack of penalties may render the law ineffective. However, local governments can construct suitable local ordinances based on this law, as the hydrogeological conditions differ locally.

6. Conclusions

In this report, salient issues regarding surface water and groundwater, such as the aging of water supply facilities, poor rules on diffuse sources for groundwater pollution, and their solutions were addressed. In addition to these efforts, information needs to be disseminated publicly so that people become more knowledgeable about water resources and constraints. The GSi system, introduced in the meeting, aims to invoke public interest in sustainable groundwater use.

References

Azumino City (2020) Reiwa gan nendo Azumino shinai chikasuii tou kansoku chousa kekka (Observations of groundwater level in Azumino City, 2019), Azumino City, www.city.azumino.nagano.jp/uploaded/attachment/42883.pdf.

Machida, I., Rumohr, S., Hartwig, C., Orth, K., Schyett, T. (2015) Groundwater management in Hessen, Germany. *Journal of Groundwater Hydrology*, **57(3)**, 307–315. (in Japanese with English abstract).

Mantoku, A. (2020) Dishasaigai kara Fujigawa wo mamoru. *Kensetsu graph*, **2**, 2020, www.jiti.co.jp/graph/page2002/0218k/index.htm

MHLW (2019) Saikin no Suidou Gyousei no Doukou ni tsuite (Recent trend of administration for water), Ministry of Health, Labour and Welfare.

MLIT (2021) Reiwa 3 Nihon no Mizushigen no Genjo (Water resources in Japan, 2021), Ministry of Land, Infrastructure, Transport and Tourism, www.mlit.go.jp/mizukokudo/mizsei/mizukokudo_mizsei_tk2_000028.html.

MLIT (2022) Water information system, Ministry of Land, Infrastructure, Transport and Tourism, www1.river.go.jp/.

Ministry of the Environment (2021) Reiwa gan nendo Chikasui Suisitsu Sokutei Kekka (Measurements of groundwater qualities, 2019).

Miyagi Prefecture Government (2021) Miyagi gata Kanri Unei Housiki ni kansuru Jigyou Setsumeikai Siryo (Explanatory meeting for PFI Miyagi Method), www.pref.miyagi.jp/documents/4455/813982.pdf.

Yamamoto, A. (2020) An example of consensus building on groundwater governance in Azumino City, Nagano Prefecture. *Journal of Groundwater Hydrology*, **62(2)**, 183–189. (in Japanese)

Current groundwater and surface water problems in Republic of Korea, and their possible solutions

Eunhee Lee[1] and Seongkyun Kim[1]

[1]Korea Institute of Geoscience and Mineral Resources, Republic of Korea
e-mail:eunheelee@kigam.re.kr

Abstract

In Republic of Korea (ROK), five main groundwater monitoring networks are under the operation by different authorities for the national monitoring of groundwater resource and quality. These database (DB) include data from 661 national groundwater monitoring stations, 140 national groundwater pollution monitoring network, 181 seawater intrusion monitoring wells, 521 rural groundwater monitoring wells, 2,021 provincial monitoring wells, and 2,495 subsidiary groundwater monitoring wells as of 2019. Additionally, Ministry of Environment (ME) in Republic of Korea has regularly examined national groundwater quality from 2,872 groundwater monitoring station as of 2019. As a result of reform of national water governance in ROK, parts of these networks (NGMN and GQMN) have been integrated, which has enabled easier access and integrated management of the national groundwater DB. In connection of these groundwater monitoring networks, KIGAM is currently developing a groundwater database of integrated information system. This new database contains data from the existing monitoring network, as well as a variety of data measured by our researchers. Under the framework of KIGAM's international collaboration strategy, KIGAM, together with CCOP, has started a new groundwater project for transboundary management in Mekong River countries, aiming at establishing transboundary groundwater monitoring network in GMS.

Keywords: groundwater, hydrogeological map, Republic of Korea (ROK)

1. Introduction

In Korea, there are several main groundwater monitoring networks including National Groundwater Monitoring Network (NGMN), Groundwater Quality Monitoring Network (GQMN), Seawater Intrusion Monitoring Network (SIMN), Rural Groundwater Monitoring Network (RGMN), and Supplementary Groundwater Monitoring Network (SGMN). These networks had been operated by different authorities for different purposes. As the outcomes of ROK government's recent efforts to integrate different water structures and to maximize the administrative efficiency of water management, parts of these networks (NGMN and GQMN) have been integrated and managed by Ministry of Environment (ME).

In connection of these groundwater monitoring networks, KIGAM is currently developing a groundwater database of integrated information system. This new database contains data from the existing monitoring network, as well as a variety of data measured by our researchers.

2. Current groundwater and surface water problems in Republic of Korea

The NGMN, the primary groundwater monitoring network in Korea, has completed the establishment of 661 groundwater observation stations throughout the country in accordance with Article 17 of the Groundwater Act and the Basic Plan for National Groundwater Management, and plans to install 324 stations by 2030 (Fig. 1a). The monitoring networks in

ROK are divided by major watershed regions, including the Han-gang, Nakdong-gang, Geum-gang, Seomjin-gang, Youngsan-gang, and Jeju. The NGMN aims to provide basic data necessary for the water resources management and pollution control by continuously monitoring groundwater level and quality. Groundwater level, temperature and electrical conductivity (EC) are automatically measured at 1 hour intervals. Groundwater quality is measured twice a year for all monitoring wells.

The GQMN is operated by the Ministry of Environment under Article 18 of the Groundwater Act and Article 9 of Enforcement Rule Regarding Groundwater Quality Conservation. The GQMN has a total of 140 groundwater monitoring station in 2019 (ME, 2020) (Fig.1c). The data are available to the public via a website (www.sgis.nier.go.kr) managed by the National Institute of Environmental Research or K-Water (www.gims.go.kr). Besides GQMN, Ministry of Environment has conducted annual national groundwater quality survey from the 2,872 monitoring station nationwide (Fig. 1c). The RGMN and SIMN, operated by the Korea Rural Corporation, were developed (1) to evaluate the status of groundwater level and water quality in areas of concern in rural areas, (2) to investigate the impact of seawater infiltration in coastal areas and islands, (3) and to prevent water depletion and degradation in agricultural land.

As stated, each groundwater network in ROK has been managed by different authorities, thus there were difficulties to integrate information from each network. After the reform of the national water act in ROK, however, parts of these DB has been integrated, which has enabled easier access and integrated management of the national groundwater DB. In addition to integrated water management, systematic approaches, such as new water quality goals for managing the total water pollution load management system, expanded waterworks facilities, disaster prevention and conflict management to combat inequity, are taken to ensure national water security (ME, 2020).

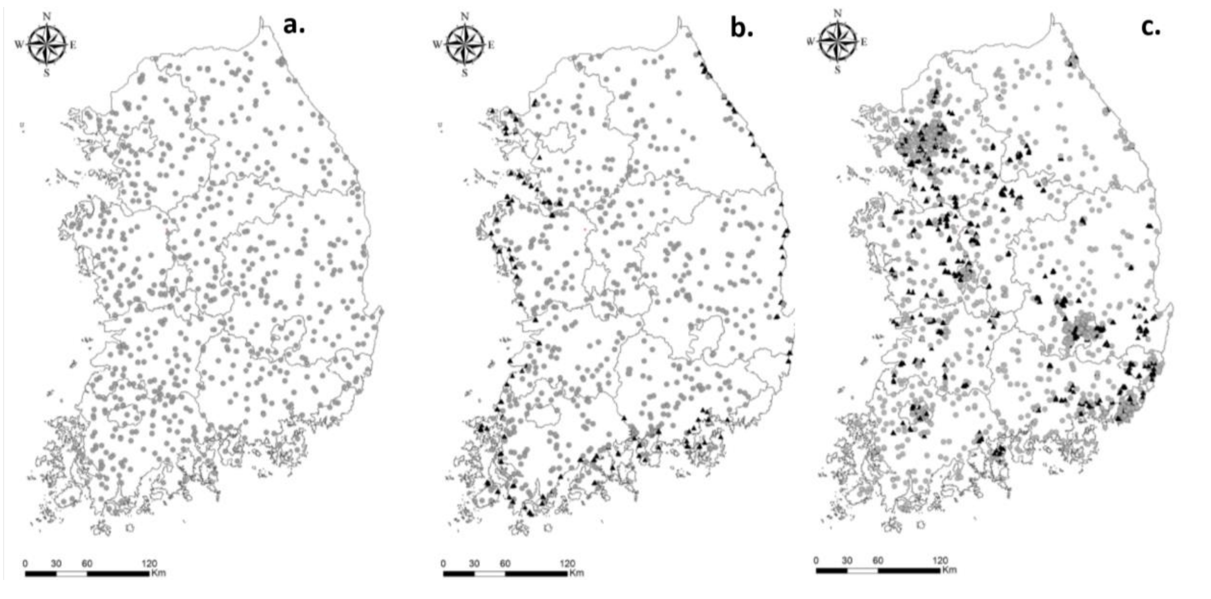


Fig. 1. Examples of national groundwater monitoring network in mainland of ROK as of 2019. a: NGMN, b: RMNG and SIMN, c: GQMN

ROK's groundwater monitoring database are increasingly covering most of the country's territory, but there are several missing networks particularly for small islands and mountainous areas. Accordingly, government is continuously expanding these network to sufficiently cover and better evaluate national groundwater resource status.

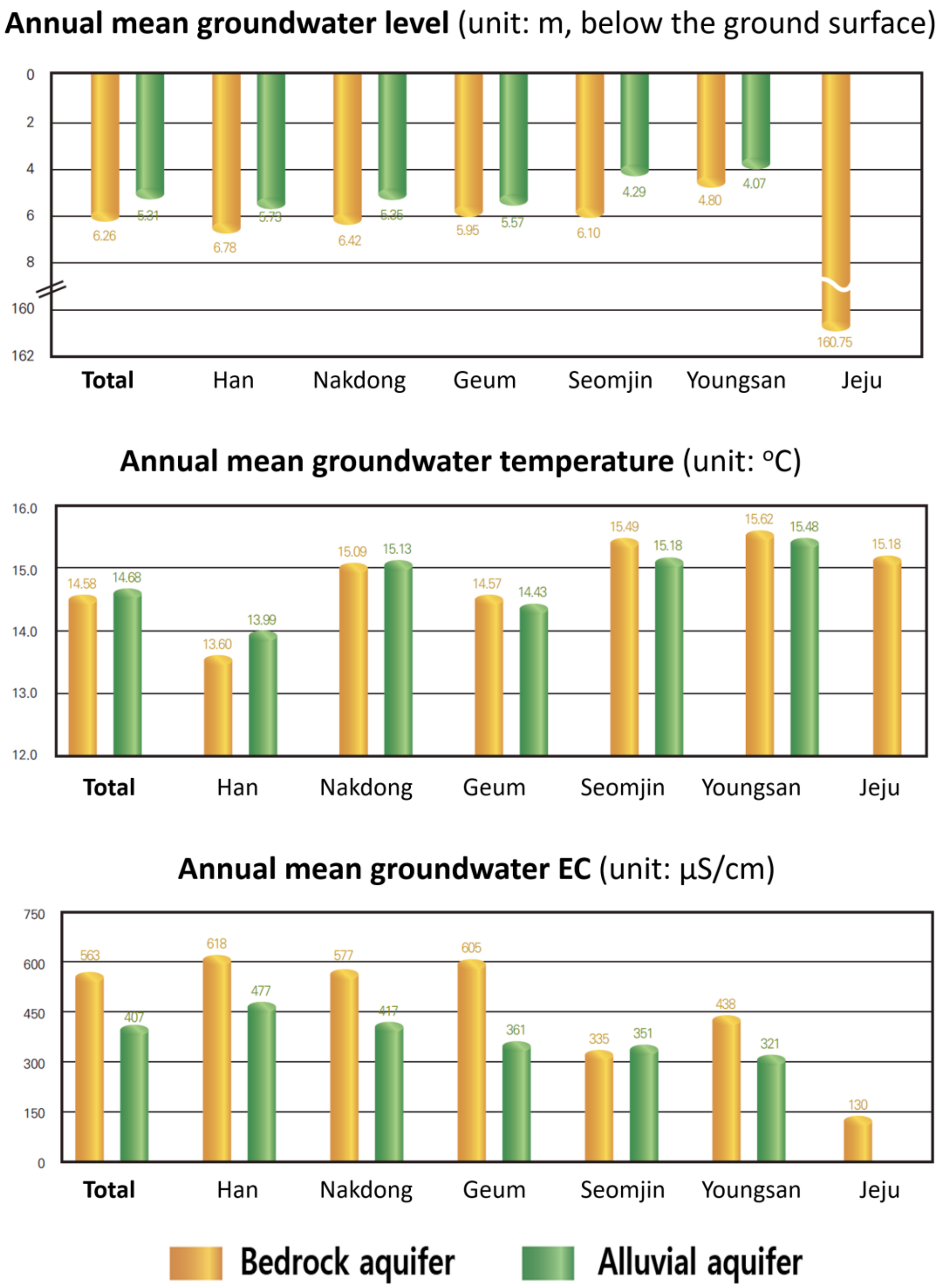


Fig. 2. Overview of groundwater observation data as of 2019 by region (ME, 2020).

As stated, each groundwater network in ROK has managed by different authorities, thus there were difficulties to integrate information from each network. After the reform of the national water act in ROK, however, parts of these DB has been integrated, which has enabled easier access and integrated management of the national groundwater DB. In addition to integrated water management, systematic approaches, such as new water quality goals for managing the total water pollution load management system, expanded waterworks facilities, disaster prevention and conflict management to combat inequity, are taken to ensure national water security (ME, 2020). Major groundwater level monitoring networks in ROK such as NGMN, RMNG and SIMN are providing real-time groundwater monitoring data through the automatic groundwater monitoring and IOT-based data distribution system. Institutions in the country are increasingly applying various data-prediction methodology such as Deep Learning for detecting observation errors and filling out missing dataset. However, parts of these network (SGMN) still includes considerable level of low-quality data.

Major groundwater related issue in ROK includes groundwater-depletion in some agricultural area. For example, intensive amount of groundwater is currently used for greenhouse heating in agricultural area, resulting in serious groundwater depletion. Increasing vulnerability of groundwater resources by climate change is another major concerns. In terms of groundwater quality, the national statistics suggests about 9.8 % of groundwater in ROK exceeded its contamination standards (Table 1). Major groundwater contamination sources includes, pH, total coliform, nitrate, and chloride.

Table 1. Number of samples exceeded by contamination standards as of 2019 (ME 2020).

Number of samples	7085
Exceeded number of samples	696
Exceeded ratio (%)	9.8
Exceeded number of parameters	759
pH	234
Total coliform group	190
Nitrate	97
Chloride ion	108
Cadmium	1
Arsenic	70
Cyanide	0
Mercury	1
Organophosphorus pesticide (Diazinon)	5
Phenol	17
Lead	2
Hexavalent chromium	2
TCE	22
PCE	6
1,1,1-TCE	3
Toluene	0
Ethylbenzene	0
Xylene	4

3. Possible solutions to manage problems related to water resources

In ROK, the government reorganized the national water management system into an integrated structure under the Ministry of Environment. Such reform allowed water-related institutions could better establish integrated water management strategies. In accordance with the government's effort, research institutions and academia have provided scientific In addition to integrated water management, government has put increasing effort to manage water quality, by managing the total water pollution load management system.

KIGAM has continuously supported the government's groundwater management strategy through the development of new core technologies or provision of science-based evidences. As an example, KIGAM has developed the groundwater potential map of ROK in a basin scale, by reclassifying hydrogeological units based on the 2,699 data of specific capacity and 2,948 data of transmissivity for bedrock aquifers and delineating the groundwater potential zone. In terms of groundwater monitoring network, KIGAM together with CCOP have started a new groundwater project for transboundary management in Mekong River countries. The objective of this project is to establish transboundary groundwater monitoring network in GMS. Until 2024, five to ten groundwater monitoring stations will be installed along the Mekong River. For each monitoring station, the automatic groundwater monitoring data collection and transmission system will be mounted and the collected dataset will be shared with open access database (DB) portal, which will allow water managers and water experts in GMS can monitor groundwater level and assess its interaction with Mekong River.

4. Conclusions

In Korea, there are six main groundwater monitoring networks including National Groundwater Monitoring Network (NGMN), Groundwater Quality Monitoring Network (GQMN), Seawater Intrusion Monitoring Network (SIMN), Rural Groundwater Monitoring Network (RGMN), Provincial and Subsidiary Groundwater Monitoring Network (SGMN). These network had been operated by different authorities of ROK. As the outcomes of ROK government's recent efforts to integrate different water structures and to maximize the administrative efficiency of water management, parts of these networks (NGMN and GQMN) have been integrated, which has enabled easier access and integrated management of the national groundwater DB. In connection of these groundwater monitoring networks, KIGAM is currently developing a groundwater database of integrated information system. This new database contains data from the existing monitoring network, as well as a variety of data measured by our researchers. Under the framework of KIGAM's international collaboration strategy, KIGAM together with CCOP have started a new groundwater project for transboundary management in Mekong River countries, aiming at establishing transboundary groundwater monitoring network in GMS. Until 2024, five to ten groundwater monitoring stations will be installed along the Mekong River. For each monitoring station, the automatic groundwater monitoring data collection and transmission system will be mounted and the collected dataset will be shared with open access database (DB) portal, which will allow water managers and water experts in GMS can monitor groundwater level and assess its interaction with Mekong River.

References

Ministry of Environment (ME) (2020) Groundwater Monitoring Annual Report of 2019.

Current groundwater problems and their possible solutions in Savannakhet Province, Lao PDR

Ounakone Xayviliya[1]

[1]Groundwater Management Division, Department of Water Resources, MoNRE, Lao PDR
e-mail: ounakone@gmail.com

Abstract

Groundwater is important source for social-economic development of Savannakhet Province. Almost 15 districts in Savannakhet Province use groundwater for domestic and small factories' purpose. Kaysorn Phomvihan Capital city is social-economic development area by the high number of population and the increasing of number of factories effected to the increasing of water use. Outoumphone is also the priority area for social economic development in Savannakhet Province, due to location and resources attractive to the developer for investment regarding to industry and factories. Water shortage is occurring in this area. Groundwater is the main source of water use covering 70 % and to be increased by the increasing number of population and economic development. Champhone District is agriculture area therefore water shortage also occurs in dry season and soil salt is the main issue for this area. It affects groundwater quality in some villages. This issue has been studied by many researchers, but it is not yet solved and no clear information about which water table has salt water and how many villages are impacted from this issue. Sustainable usage of groundwater is an important objective. Groundwater management plan is method for its management. Beside that data and information gathering, and registration of water user and developer are needed for groundwater management in this pilot project area.

Keywords: groundwater, hydrogeological map, Lao PDR

1. Introduction

Savannakhet Province is located in the south-central part of Lao PDR, about 469 km from Vientiane Capital, lying at 105 ° 46 '48' 'East and 16 ° 32' 24 '' with an area of 2,177,400 hectares. The west is bordering the Kingdom of Thailand with a length of 152 km, the southern by Saravane Province with a length of 259 km. It is 122 km long to the east of Vietnam and 314 km long, to Khammouane Province.

Savannakhet Province consists of 14 districts and 1 city divided into two major areas: the plains cover 59 % and the plateau covers 41 % (divided by elevation from the sea level). Kaisone Phomvihan City, which is at an altitude of 140 to 200 m above sea level, covers 1,053,903 hectares. The plateau covers five districts such as Nong, Sepon, Vilabouly, Phin, and Tha Pang Thong, with an altitude of 200 m above sea level, covering an area of 1,123,497 hectares.

Savannakhet is a province with great potential for natural resources and many major rivers are flowing through it such as Xe Bang Hieng and Xe Bang Nuan. Therefore, Savannakhet Province has the potential to develop water resources that are conducive to socio-economic development, such as the construction of irrigation systems and hydropower. Over the past 20 years (2000 - 2019) the water resources in the province have changed due to climate change. Therefore, every year there are problems with a shortage of water and floods. Especially in the year 2019 - 2020, Savannakhet Province is affected by floods along the Xebanghieng, Xesamsoi, Xechamphone and Selenong rivers, which has caused considerable economic damage.

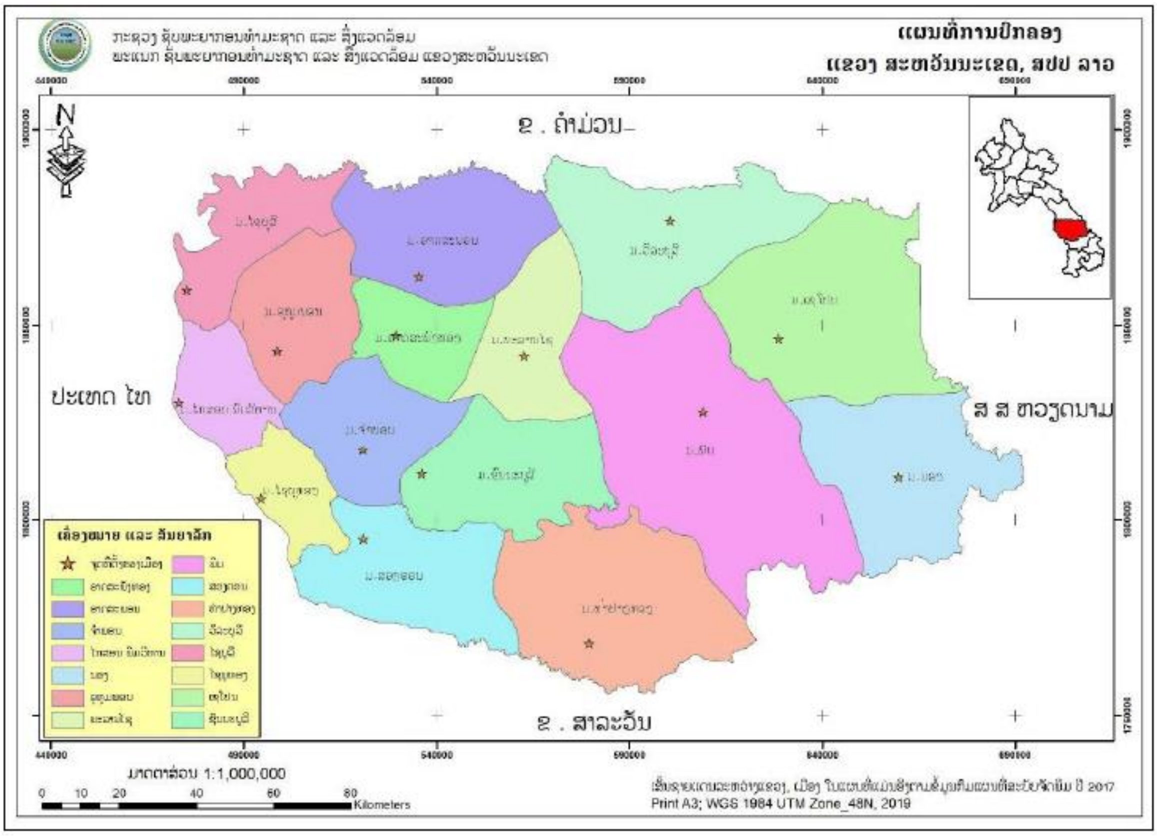


Fig. 1. Map of Savannakhet province
(Source: Information from the Department of Natural Resources and Environment, Savannakhet Province)

In terms of groundwater, in recent years groundwater has been used in small quantities, but in the current situation due to climate change, groundwater resources have been changed. Use of groundwater is increasing and groundwater is used for daily living, especially in the kitchen and garden areas. However, the use of groundwater for agricultural and industrial purposes is still limited. To ensure the potential for increased groundwater use in the future, it is necessary to have a groundwater management plan as a tool to manage groundwater use for maximum efficiency and sustainability. The plan must identify problems and issues related to groundwater, groundwater management work, and detailed activities to help solve those issues.

2. Current groundwater problems in Savannakhet Province, Lao PDR

Savannakhet Province contains many groups of rocks such as Alluvial deposits, Basement rocks, Karstic rock, Schist rock, Mesozoic sedimentary rocks, Paleozoic sedimentary rocks, and Volcanic rocks. Details of each rock group are shown in the geological map of Savannakhet Province (Fig. 3) and geological characteristics of rocks and soils are illustrated in figures 4, 5, and 6.

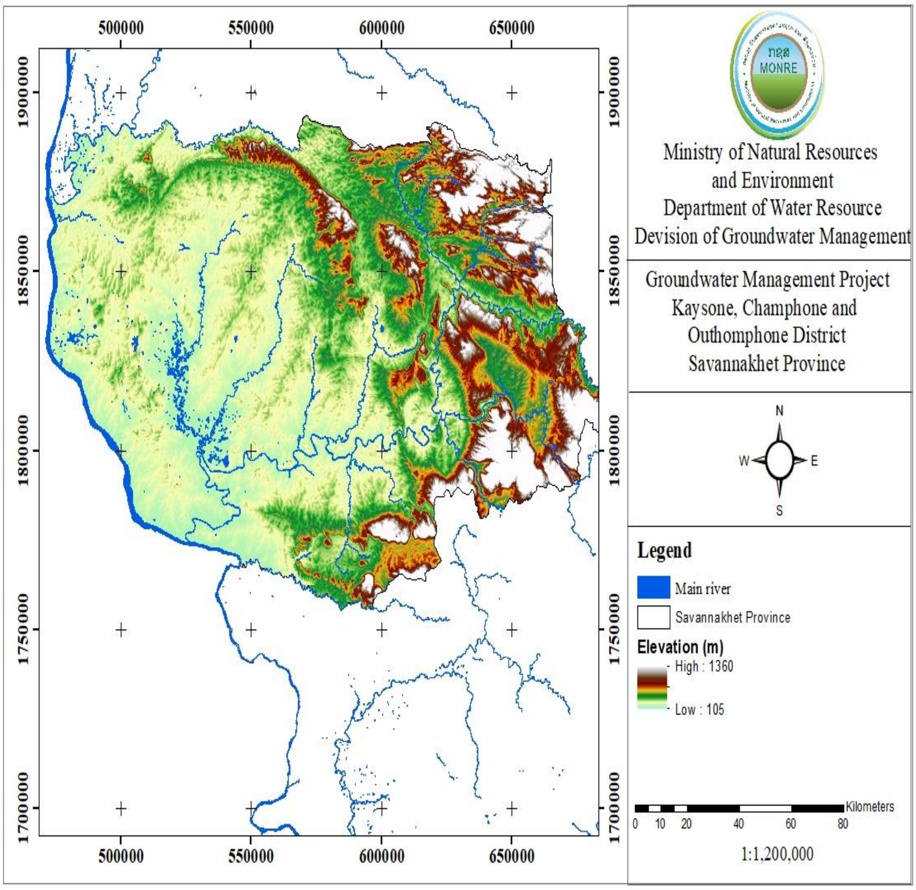


Fig. 2. Landscape slope map of Savannakhet Province
(Source: Department of Mapping)

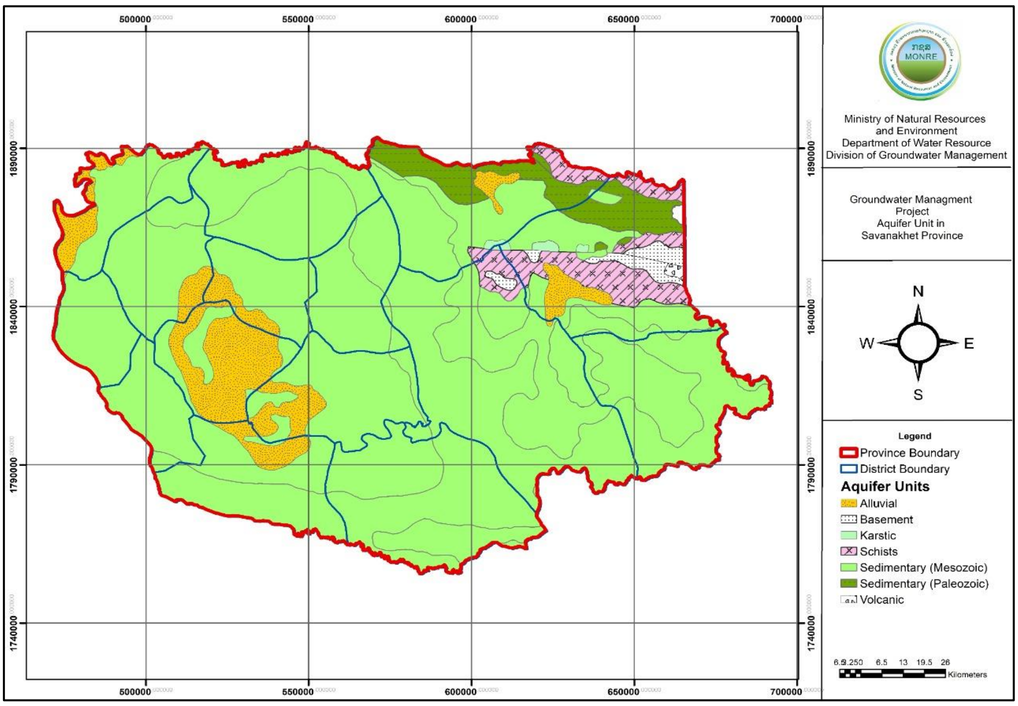


Fig. 3. Geological map of Savannakhet Province

1. Alluvial deposit: This area contains sorts of sediments of gravels, sands, silts, and clays.
2. Karstic and Basement rocks: The area contains mostly limestone.
3. Schist rock: It contains rock units of schist, mudstone, wackes, arenite, limestone, and marble.
4. Mesozoic sedimentary rocks: The area is composed of sandstone, clays, mudstone, rock salt of halite, and gypsum.
5. Paleozoic sedimentary rocks: It is an area mostly composed of sandstone, siltstone, and shale.
6. Volcanic rocks: This area contains granite, migmatite, and tonalite.

The geological characteristics of soil and rock layers of Kaisone District, Savannakhet Province can be observed from geological cross-sections 1 and 2. Based on the data shown in the geological cross-sections; three geological layers were found such as sandy clay and silty sand, sandstone and rock salt. The thickness of sandy clay and silty sand layers ranges from 6 - 12 m, the thickness of sandstone varies from 5 - 56 m, and the layer of rock salt has its thickness ranging from 16 - 40 m (Fig. 4).

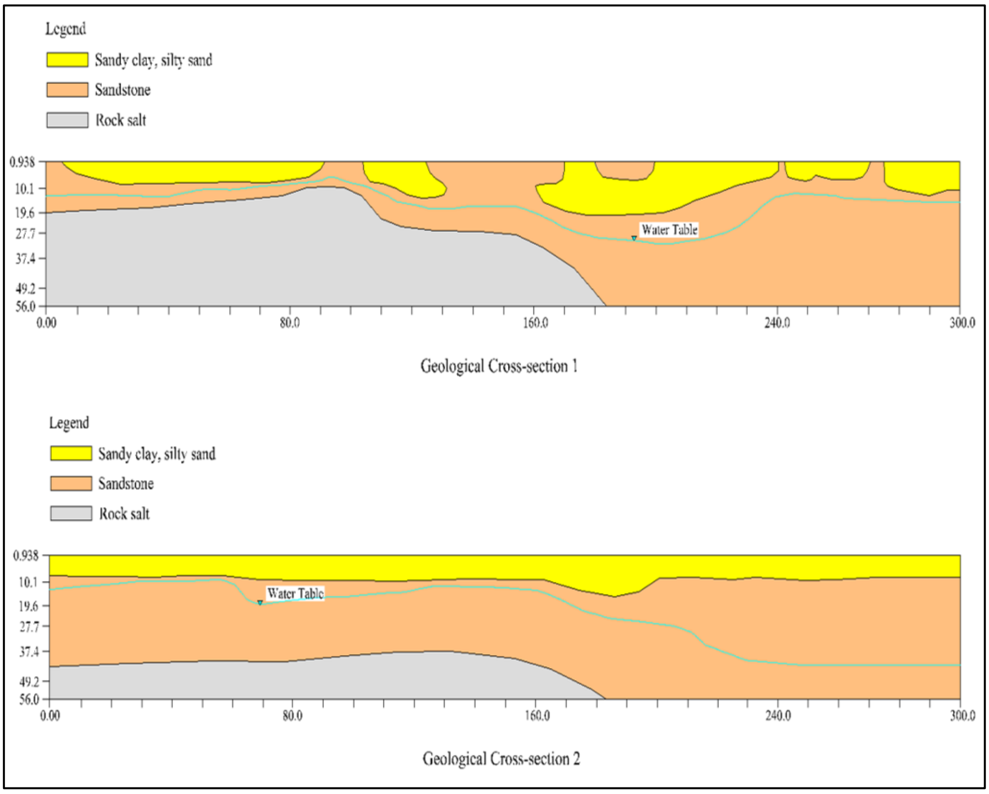


Fig. 4. Geological characteristics of soil and rock layers of Kaisone District (Source: Geological Survey of Water Resources Department)

The geological characteristics of the soil and rock layers of Outhomphone District, Savannakhet Province can be obtained from geological cross-sections 3 and 4. From the data shown in the cross-sections, two geological layers were observed, consisting of the layer of sandy clay and silty sand and fine sand, and the layer of sandstone. The thickness of sandy clay and silty sand and fine sand ranges from 6 - 16 m, while the thickness of the sandstone layer varies from 5 - 56 m (Fig. 5).

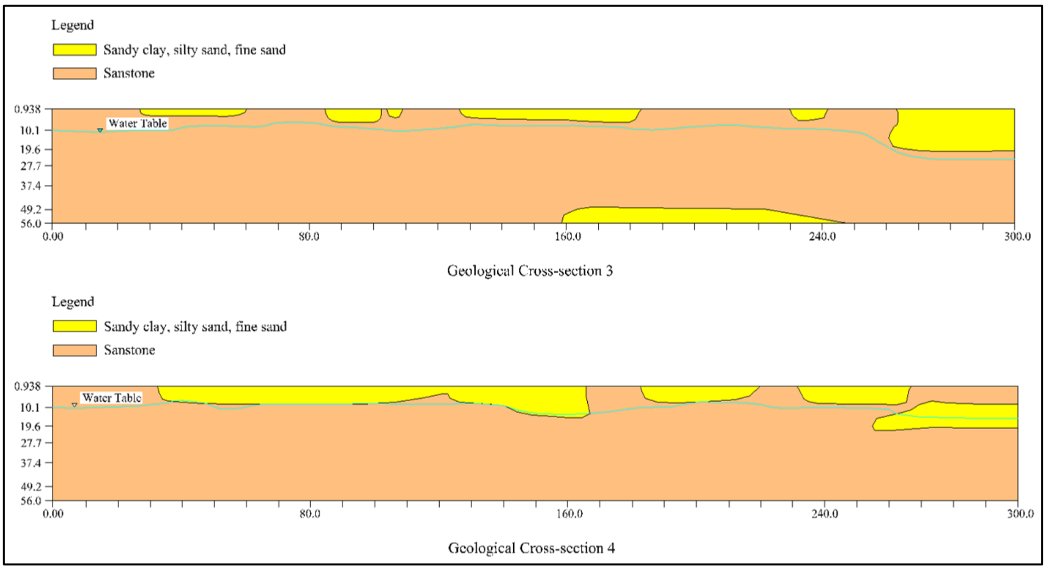


Fig. 5. Geological characteristics of soil and rock layers of Outhomphone District (Source: Geological Survey of Water Resources Department)

The geological characteristics of the soil and rock layers of Champhone District, Savannakhet Province can be observed from the geological cross-sections 5 and 6. Based on the data shown in the geological cross-sections; three geological layers were found, including sandy clay with gravel, sandy clay, and rock salt. The thickness of sandy clay with gravel layers ranges from 5 - 15 m, the thickness of sandy clay varies from 3 - 56 m, and the layer of rock salt has its thickness ranging from 20 - 52 m. Based on the geological drilling data and geophysical survey results, the depth of the groundwater level was found at 4 - 15 m (Fig. 6).

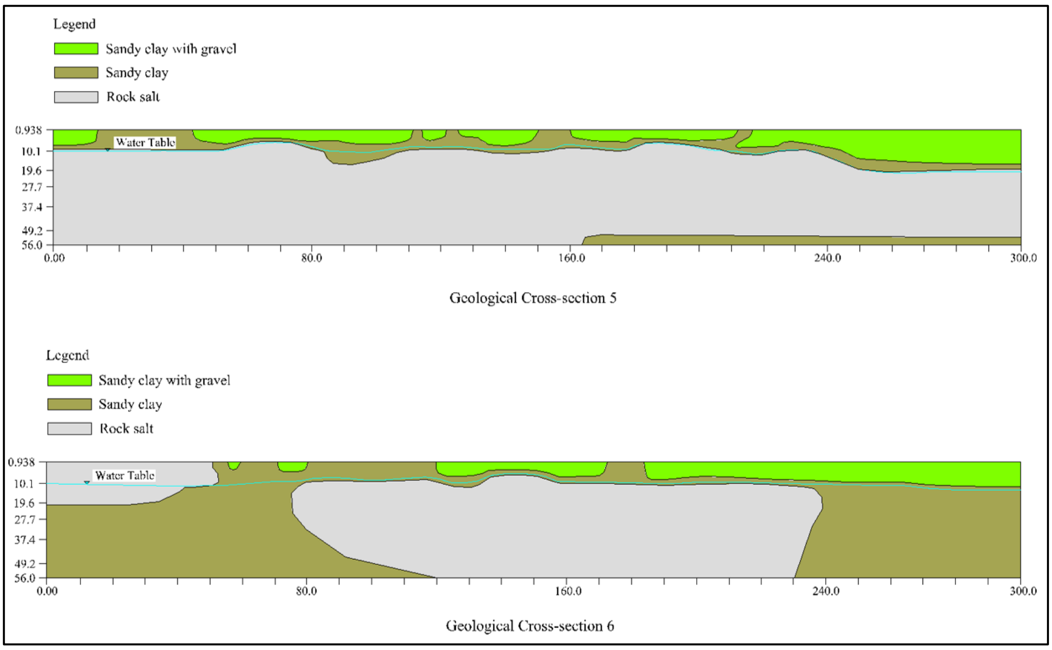


Fig. 6. Geological characteristics of the soil and rock layers of Champhone District (Source: Geological Survey of Water Resources Department)

2.1. Hydraulic conductivity values of groundwater

According to the data obtained from the Division of Geophysics, Department of Geophysics, National University, the hydraulic conductivity values of rocks and soils are shown in Table 1.

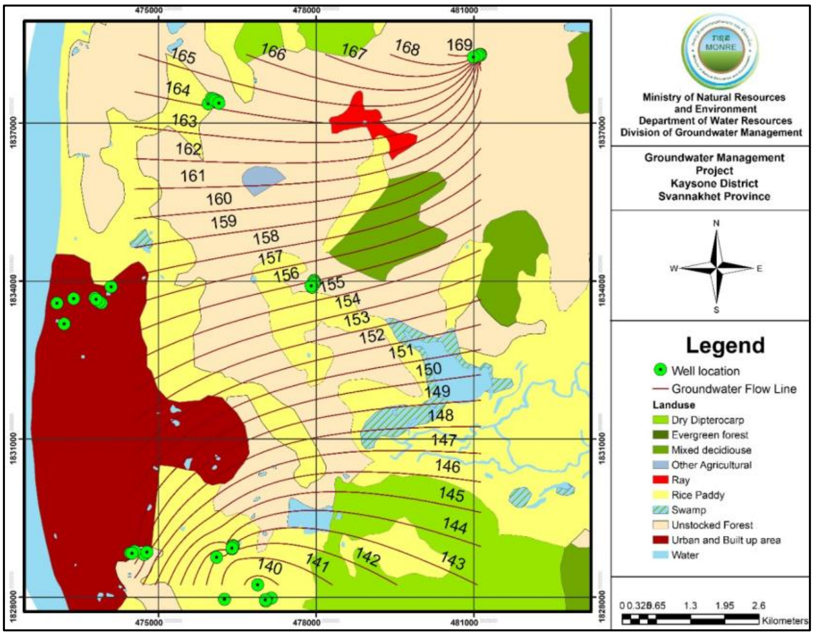
Table 1. Specific electrical resistance of groundwater

No.	Area	Groundwater Level (m)	Geological Characteristics (Rock and Soil Layers)
1	Outhoumphone District, Savannakhet Province	30 - 50	Layers of coarse-grained and fine-grained sands, some of which is saline water to a depth of more than 45 m below the ground surface
2	Atsaphone District, Savannakhet Province	9 - 16	Layers of fine-grained sandstone and siltstone, the hydraulic conductivity value is not more than 3 m^3/h, the depth of water table is at 9-16 m, the mud layer is found at some depths of 15-50 m.
3	Nong District, Savannakhet Province	12 - 30	The area of high ground underlain by hard sandstone layer, the hydraulic conductivity value is approximately 2.5-5 m^3/h

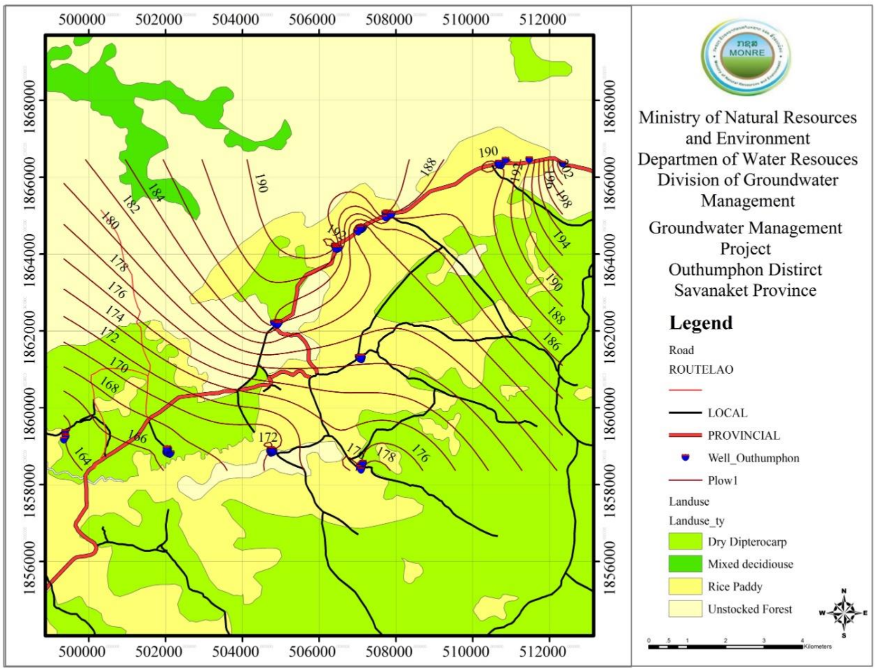
(Source: Division of Geophysics, Department of Geophysics, National University)

2.2. Flow direction of groundwater

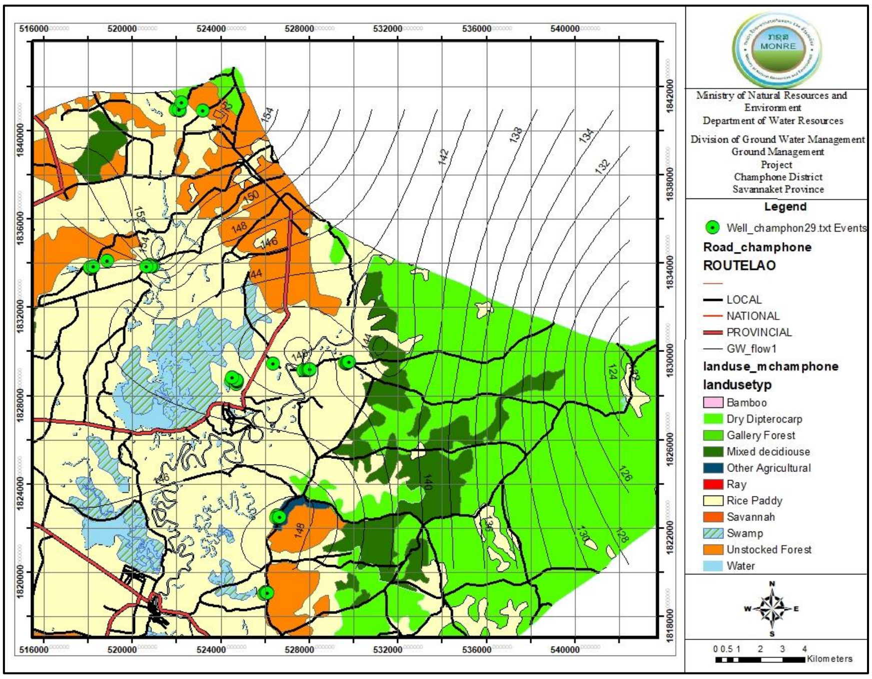
In groundwater quantity and quality management, the flow direction of groundwater is one of the criteria that helps to identify the flow path through which groundwater flows. Therefore, based on the groundwater survey in 2020, it can be seen that the groundwater flow in Savannakhet Province is from the southeast to the west of the province, where the groundwater flows to the Mekong River adjacent to the west of the province. It is as shown in the Fig. 7.



A. Kaisone District, 39 wells



B. Outhoumphone District, 86 wells



C. Champhone District, 86 wells

Fig. 7. Groundwater flow map of Kaisone, Outhomphone, and Champhone Districts

2.3 Quantity of groundwater

Groundwater recharge in the study area is derived from rainwater because rainwater is one of the main sources of groundwater. Therefore, when water infiltrates into the ground, the rate of groundwater recharge increases. To know the groundwater recharge rate, the concept of the water cycle can be applied. Groundwater recharge can be calculated as follows.

1. Evaporation is calculated based on the annual rainfall and average temperature using the following equation and the results of the evaporation analysis are 1028.67 mm / year.
2. Runoff is the result of excessive rainfall. The method of calculating the total surface runoff is using data on average temperature, annual rainfall, and catchment area. The total runoff can be calculated using the water balance method to calculate groundwater recharge in the study area, and it is calculated to be 184.19 mm/year.
3. Groundwater recharge: From the above assessment, the average groundwater recharge value is 310.45 mm/year.

The groundwater volume/quantity can be estimated as follows: (1) the average groundwater recharge is 310.45 mm, (2) the study area covers 21,774 km^2. The analysis will consider climate and land-use change, which could reduce groundwater volume by 1 % per year. Therefore, the results of the analysis of all water resources are shown in Table 2.

Table 2. Groundwater volume of aquifers

Year	Groundwater Recharge (mm/year)	Area of Savannakhet Province (ha)	Groundwater Volume (Million m^3/year)
2021	307,35	2.177.400	6.759,74
2022	304,27	2.177.400	6.692,14
2023	301,23	2.177.400	6.625,22
2024	298,22	2.177.400	6.558,97
2025	295,23	2.177.400	6.493,38
2026	292,28	2.177.400	6.428,44
2027	289,36	2.177.400	6.364,16
2028	286,47	2.177.400	6.300,52
2029	283,60	2.177.400	6.237,51
2030	280,77	2.177.400	6.175,14

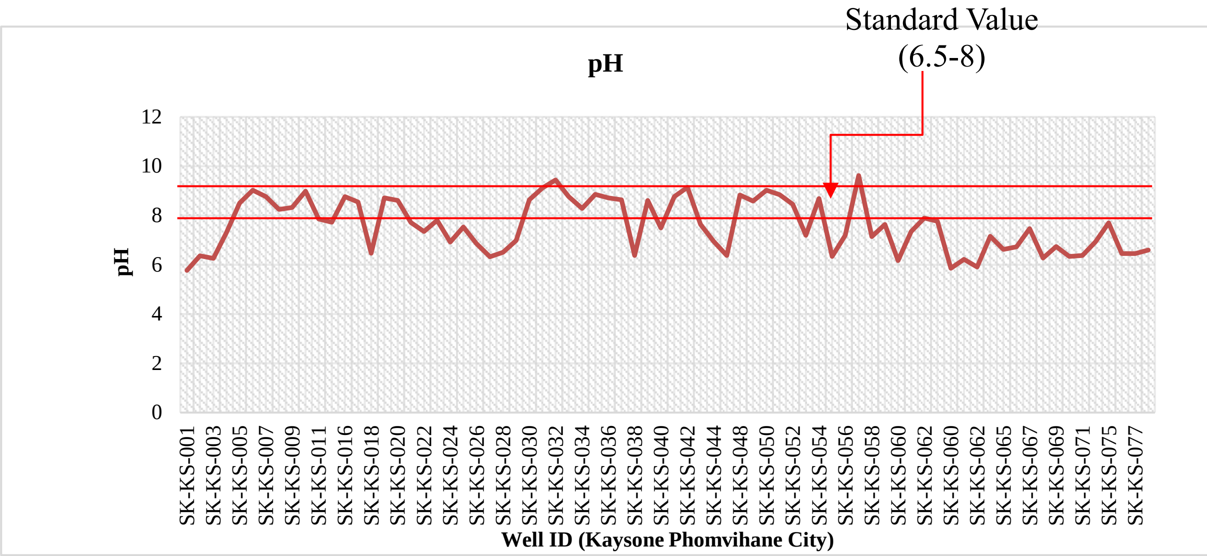
(Rainfall data from the Department of Meteorology and Hydrology are used to calculate groundwater recharge)

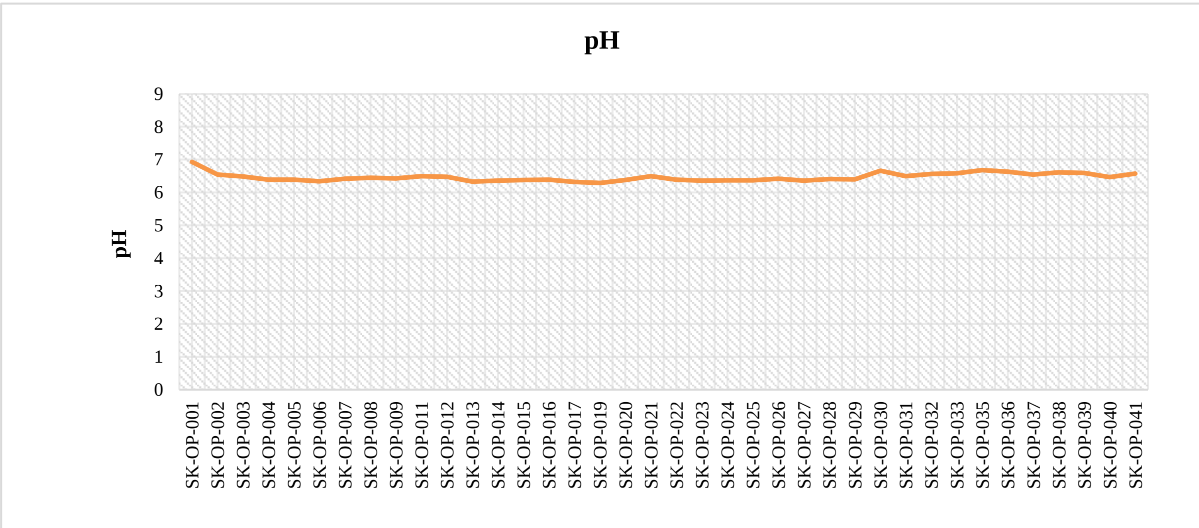
2.4 Groundwater quality

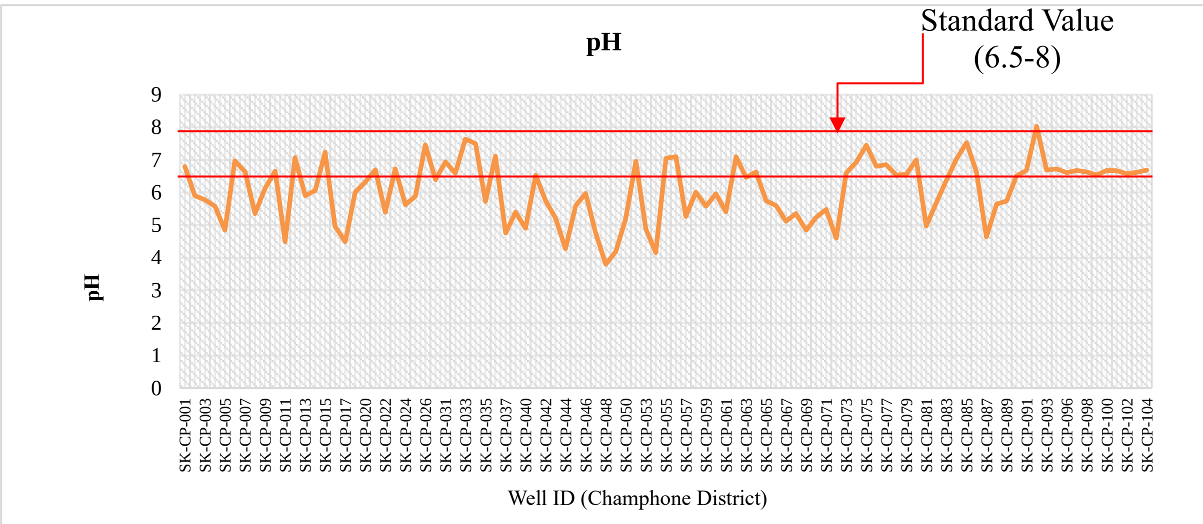
Groundwater quality in Savannakhet Province as a whole is good, but there are still some areas with saline and alkaline problems. The results of water quality analyses in three districts, including Kaisone Phomvihane City, Outhoumphone District, and Champhone District (2020) are as follows:

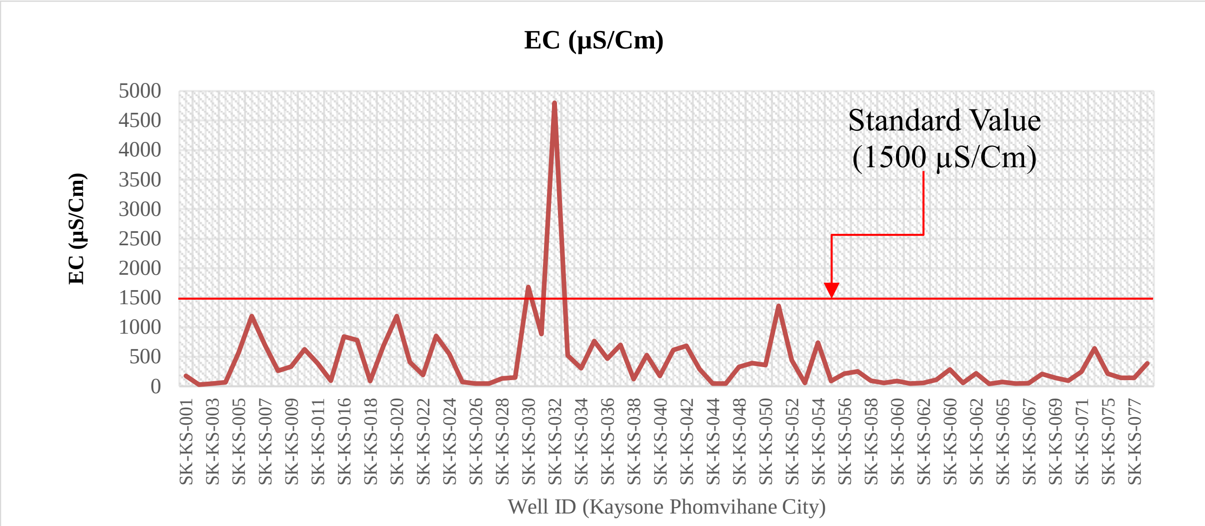
- As a result of the pH change, the pH value increased from 5.59 - 9.44. Thus, it may be affected by CO_2 removal, in effect, reducing the acidity of the water. Thus, the pH of the water sample as per the guidelines of the National Environmental Standards pH (6.5 - 8.5), is in an alkaline state.
- Water-soluble solid (TDS) is 1 - 2450 ppm, the results show the higher values and are above the standard value (250 ppm). It may be due to increased temperature or excessive nutrients (25.52 - 28.05 ^{o}C). Hence the increased pH level and TDS results indicate that groundwater may be saline. The salinity concentration, on the other hand, is 1-2450 ppm, so groundwater

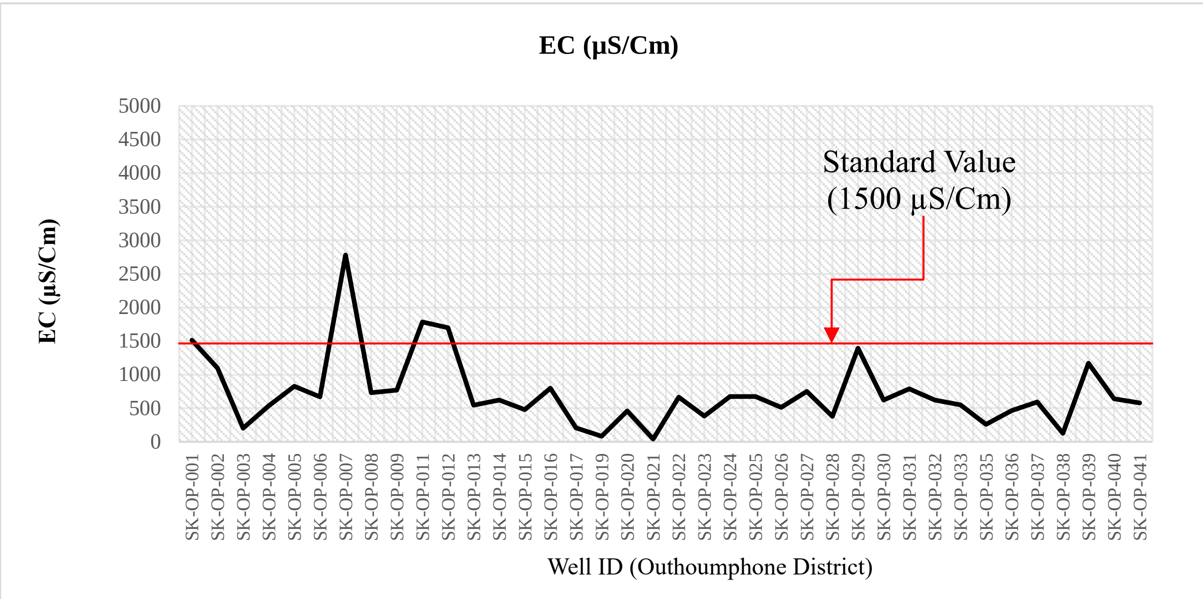
conditions in Kaisone Phomvihane City tend to be saline.

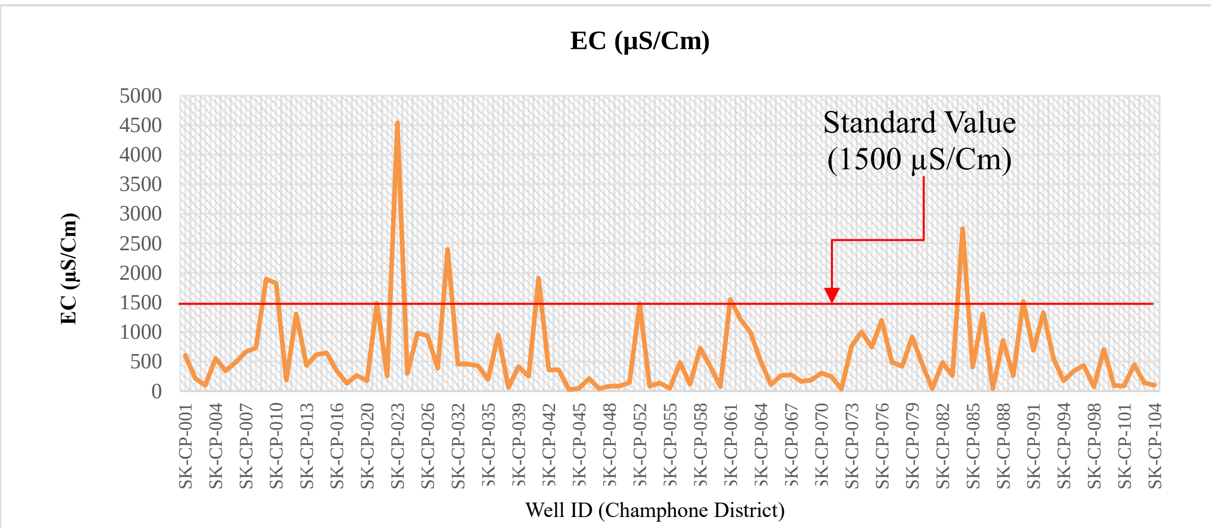







EC (µS/Cm)
EC (µS/Cm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Standard Value
(1500 µS/Cm)
SK-KS-001
SK-KS-003
SK-KS-005
SK-KS-007
SK-KS-009
SK-KS-011
SK-KS-016
SK-KS-018
SK-KS-020
SK-KS-022
SK-KS-024
SK-KS-026
SK-KS-028
SK-KS-030
SK-KS-032
SK-KS-034
SK-KS-036
SK-KS-038
SK-KS-040
SK-KS-042
SK-KS-044
SK-KS-048
SK-KS-050
SK-KS-052
SK-KS-054
SK-KS-056
SK-KS-058
SK-KS-060
SK-KS-062
SK-KS-060
SK-KS-062
SK-KS-065
SK-KS-067
SK-KS-069
SK-KS-071
SK-KS-075
SK-KS-077
Well ID (Kaysone Phomvihane City)


EC (µS/Cm)
EC (µS/Cm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Standard Value
(1500 µS/Cm)
SK-OP-001
SK-OP-002
SK-OP-003
SK-OP-004
SK-OP-005
SK-OP-006
SK-OP-007
SK-OP-008
SK-OP-009
SK-OP-011
SK-OP-012
SK-OP-013
SK-OP-014
SK-OP-015
SK-OP-016
SK-OP-017
SK-OP-019
SK-OP-020
SK-OP-021
SK-OP-022
SK-OP-023
SK-OP-024
SK-OP-025
SK-OP-026
SK-OP-027
SK-OP-028
SK-OP-029
SK-OP-030
SK-OP-031
SK-OP-032
SK-OP-033
SK-OP-035
SK-OP-036
SK-OP-037
SK-OP-038
SK-OP-039
SK-OP-040
SK-OP-041
Well ID (Outhoumphone District)


EC (µS/Cm)
EC (µS/Cm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Standard Value
(1500 µS/Cm)
SK-CP-001
SK-CP-004
SK-CP-007
SK-CP-010
SK-CP-013
SK-CP-016
SK-CP-020
SK-CP-023
SK-CP-026
SK-CP-032
SK-CP-035
SK-CP-039
SK-CP-042
SK-CP-045
SK-CP-048
SK-CP-052
SK-CP-055
SK-CP-058
SK-CP-061
SK-CP-064
SK-CP-067
SK-CP-070
SK-CP-073
SK-CP-076
SK-CP-079
SK-CP-082
SK-CP-085
SK-CP-088
SK-CP-091
SK-CP-094
SK-CP-098
SK-CP-101
SK-CP-104
Well ID (Champhone District)

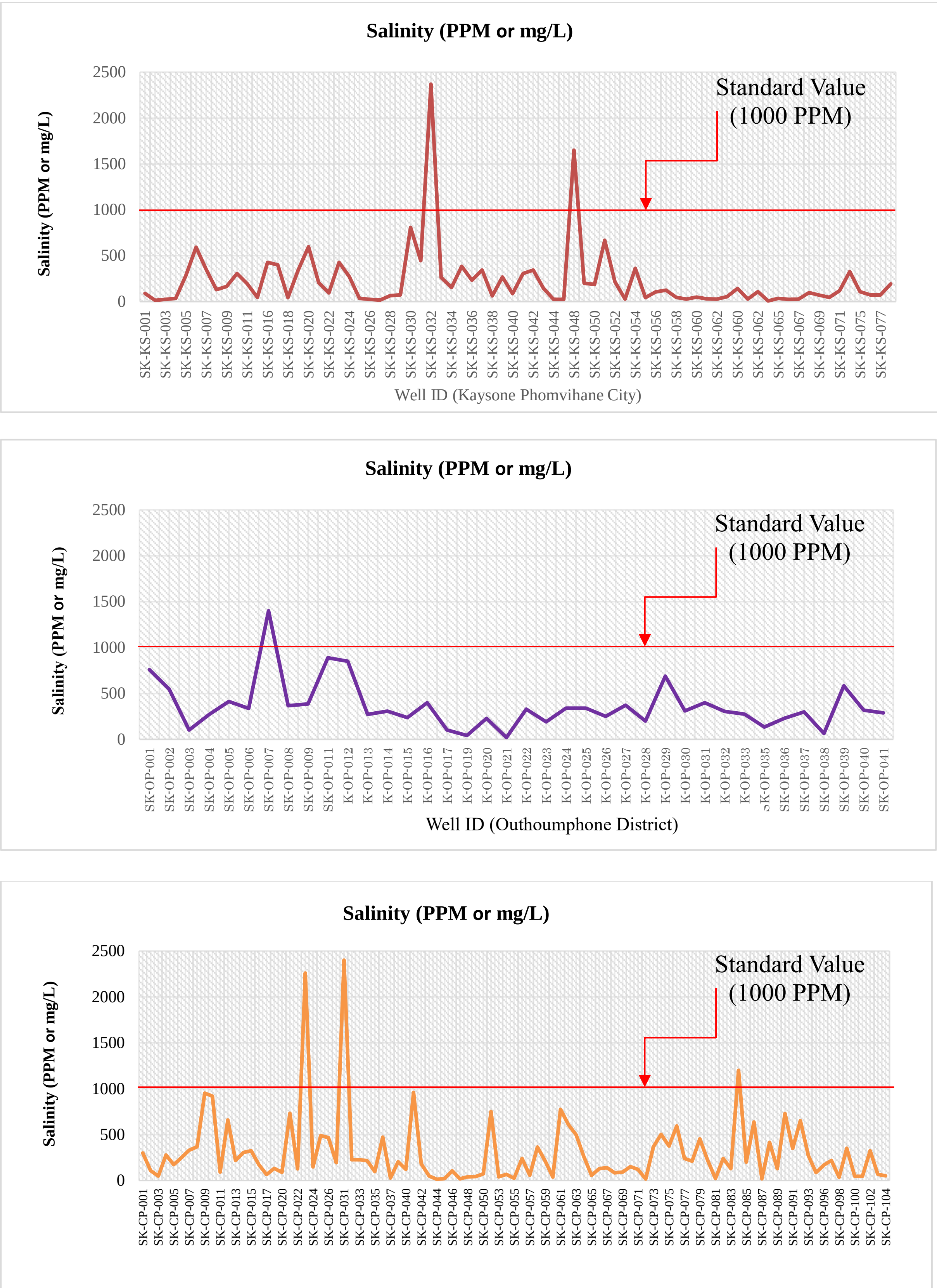


Fig. 8. Groundwater quality in Savannakhet Province

3. Possible solutions to manage problems related to groundwater

3.1 Strengthening and promoting participation in groundwater management

- Strengthening groundwater management mechanisms and personnel
- Capacity building on technical skills on groundwater management to staff in the field of water resources on groundwater management periodically
- Establish a coordination mechanism to share knowledge, information and lessons learned on groundwater management in the field of natural resources and environment, and between the relevant sectors at the central and local levels
- Fund raising for groundwater management from national and international organizations
- Promoting participation and awareness-raising in groundwater management
- Promote community participation and gender equality in groundwater management
- Disseminate laws and regulations to developers and raise public awareness, understanding and contribution to groundwater management
- Assessing the implementation and involvement of groundwater management

3.2 Gathering data and information, and creating a groundwater database

- Survey and collect data and information on the quantity and quality of groundwater also do the inventory on groundwater boreholes, areas at risk of quantity and quality of groundwater, as well as areas at risk of water scarcity.
- Collect and compile second-hand information such as reports, research papers, socio-economic development plans, water use plans for each sector, and others.
- Gather and compile the operators who provide drilling services or groundwater drilling services to support groundwater management, issuance of drilling licenses, drilling services or groundwater drilling services and issuance of groundwater use licenses.
- Establish observation wells and install the rocker to measure groundwater level and quality in areas deemed necessary.
- Periodically monitor and collect information on groundwater levels and quality

3.3 Groundwater rehabilitation, protection and development by Encourage and promote the protection of groundwater resources and groundwater wells

- Identify protected areas and groundwater reserves, such as reserves for groundwater use, groundwater reserves for biodiversity, water pollution risk areas, and groundwater reserves to accommodate water shortages.
- Develop regulations or guidelines for the protection of groundwater and groundwater reserves.
- Promote the establishment of community groundwater user and protection groups
- Encourage and promote the rehabilitation, improvement, and construction of groundwater wells in communities and areas with water shortages.
- Promote the most efficient and beneficial use of groundwater.
- Create activities to rehabilitate and protect the environment and Rivers around groundwater sources and groundwater wells in each village.
- Promote the establishment of a village fund for groundwater protection.

4. Conclusions

Groundwater problems are occurring in Savanakhet Province and in need to be solved.

Management activities are in line with the state of water resources in the province. Therefore, data and information on groundater are missing such as information on the water balance and groundwater demand. The data show that the amount of groundwater in Savanakhet Province is sufficient to meet the demand for groundwater each year.

From the above mentioned points and potentials, although the amount of groundwater is sufficient to meet the needs of groundwater use, there are still many issues with groundwater that need to be addressed and improved, such as water quality problems, soil degradation, and landuse change. Therefore, it is necessary to have a detailed plan for groundwater management. The groundwater management plan of Savannakhet Province has been approved but it needs the financial support to implement its 5 years action plan.

- This shows that the amount of groundwater in the province is balanced or sufficient to meet the demand for groundwater each year.
- The groundwater management is for 5 years (2021-2025) management which include 3 plans, with 5 expectations and 21 activities, and it request the support to achieve the indicators of the plan.
- Groundwater management agreement was adopted and it enhanced stakeholder involvement in implementation of groundwater management. Therefore, this agreement has to be updated and in harmony to current country and also provincial situations.
- These successful it come from the advice of leaders of MoNRE and provincial also the team capabilities or a particular team member, and the best coordination and collaborate from the related agencies especially PoNRE and DoNRE of Savanakhet Province.

References

Department of Water resources (2022) Groundwater Management Plan for Savanakhet Province, MoNRE.

Current groundwater and surface water problems in Malaysia, and their possible solutions

Asminah Rajuli[1]

[1]Department of Mineral and Geoscience, Malaysia
e-mail: asminah@jmg.gov.my

Abstract

Malaysia is a country located entirely in the equatorial zone with warm and humid climate throughout the year and receives high annual rainfall with an average of 2,500 mm. As a result, Malaysia is blessed with abundant surface and groundwater resources. In Malaysia, public water supply depends entirely on surface water resources with less than 3 % of groundwater is being utilised.

Although the country has abundant of surface water resources, ironically water shortage problem is not new in the country. This is mainly due to the decreasing water level in dams during drought seasons. At some point in dry seasons, water in dams will drop to the critical water level; thus, the dams could only survive for a short period of time if the drought continues. This problem occurs almost every year. Surface water is very sensitive to climate and environmental changes; thus, depending solely on it for water supply resources could lead to water crisis problems in the country. Historically, various environmental threats against surface water had also created water security issues. In contrast, groundwater is a natural water resource which is more resilient to climate and environmental changes and able to accommodate a continuous water supply throughout the year.

In Malaysia, groundwater is often overlooked and it is only highlighted during critical time, especially during drought season. With all the issues, it is high time for the country to consider the usage of groundwater as part of the main water resources to ensure the continuity of water supply to the public. The focus should be given to increase groundwater usage as public water supply up to thirty percent by 2040 as part of National Water Management Policy. The best method to implement this policy is through the conjunctive use of surface water and groundwater. Both resources can be utilised through effective coordination management to complement each other and thus, optimised the water supply system. Few strategic plans that have been outlined to implement the policy. For instance, conduct groundwater explorations and developments in water stress areas, increase the coverage area of national hydrogeological mapping, strengthen groundwater governance, and develop conjunctive water supply infrastructures such as underground dams, managed aquifer recharge and riverbank filtration.

Keywords: groundwater, conjunctive use, public water supply

1. Introduction

Groundwater is a natural water resource with unique characteristics that make it suitable to be developed as water supply. Groundwater is resilient to the drought because it reacts very slowly to the changes of dry and wet season and therefore, it able to accommodate a continuous water supply. In the sequence of hydrological drought, groundwater is the last to react to the drought conditions and usually it occurs several months or even years after meteorological drought. The occurrence of groundwater beneath of the soil layer makes it less expose to the risk of contamination.

Malaysia is a country located entirely in the equatorial zone with warm and humid climate throughout the year and receives a high annual rainfall with an average of 2,500mm. In JICA study, 1982 shows that Peninsular Malaysia is capable of producing 16.7 million cubic meters of groundwater per day. Although Malaysia has a lot of groundwater storage, less than 3 % of the resources is being utilised as a clean water supply. Currently, the water supply from groundwater is only about 300 million litre per day (MLD) which is very small compared to the surface water that supply about 16,900 MLD. Kelantan which is located at the east coast of Peninsular Malaysia is the only state that utilised a huge amount of groundwater. The groundwater contributes to 63 % of the water supply in this state.

2. Current groundwater and surface water problems in Malaysia

Although the country has abundance of surface water, yet we are still facing a shortage water supply problem. In the event of drought season, the water level in several dams reduced to a critical level and can only survive for a short period of time if the drought continues. This problem occurs every year since we depend almost entirely on surface water as a source of water supply. In addition, surface water nowadays is exposed to various threats and issues such as drought, the effects of global climate change and uncontrolled development that led to the water crisis. The phenomenon of global warming has resulted in strong El Nino and leads to dry weather and prolonged drought. Several series of El Nino Episodes which struck us into water crisis has occurred in between 1991 to 2016 that burdens the nation. In 1991, the Durian Tunggal Dam in Malacca had dried up due to El Nino phenomenon thus affected 300,000 people. Until now, water rationing takes place every year, especially when the drought season struck thus affecting life and economy especially in the areas with high population density such as Selangor and Kuala Lumpur. Besides, uncontrolled development that is increasing every year contributes to the water crisis. The destruction of hills and forests in catchment area has caused a decreasing of water level and water quality of the river which is the main source of water supply. Heavy run off in the disturbed forest area has also led to the soil erosion resulting in high turbidity and sedimentation, thus reducing the river capacity. In addition, rapid growth population in a big city resulting high water demand leading to the underestimation of the water supply. Based on these factors, it is clear that surface water is very sensitive to the changes in the environment and is easily disrupted, causing a water crisis problem.

In Malaysia, groundwater is often overlooked and is only highlighted during critical time especially in the drought season. This is because groundwater is an invisible source and most of the people do not realize the importance of groundwater as a source of clean water. Groundwater is usually depicted as insufficient water resources to be developed as a public water supply. The cost to develop groundwater is often described high as compared to the surface water. Furthermore, most people believe that huge amount of groundwater abstraction could lead to subsidence and environmental destruction. To date, the use of groundwater as water supply is only concentrated in rural areas and for the use of local communities with a small capacity with (less than 1 MLD). With all the issues of surface water, hence it is time to consider the usage of groundwater and the importance of groundwater exploration to ensure the continuity of water supply to the people.

3. Possible solutions to manage problems related to water resources

The experience of water crisis over the last decade should be a basis to introduce immediate water policies to balance surface water and groundwater in order to ensure the security and sustainability of water in this country. The focus should be given to increase groundwater usage as public water supply as part of National Water Management Policy. The best method to implement this policy is through the conjunctive use of surface water and groundwater which is the most effective strategy to increase the capacity of water supply throughout the country. The conjunctive use of surface water and groundwater refers to the usage of both resources through effective coordination management to complement each other and would then optimize the water supply system.

The strategic plan to encourage the conjunctive use of groundwater and surface water is in line with the national water roadmap known as Water Sector Transformation 2040 (WST 2040) which main agenda is to increase groundwater usage up to 30 % by 2040. Among the strategic plans that have been outlined to implement the agenda is to conduct groundwater explorations and developments in water stress areas, increase the coverage area of national hydrogeological mapping, strengthen groundwater governance and develop conjunctive water supply infrastructures.

Most of the remote area in this country do not have good public water supply due to high piping costs. This kind of area is known as water stress area where water supply problems need to be addressed immediately. In such areas, groundwater exploration and development will be conducted through the construction of groundwater well and basic water treatment system to provide water supply for the small communities such as school and long house. The cost to develop groundwater well and the treatment system in remote area is cheaper and faster compare to the development of surface water infrastructure.

The coverage of groundwater exploration mapping in Malaysia is considered low especially in Sabah and Sarawak. One of the aspirations of the WST 2040 agenda is to increase groundwater exploration mapping coverage to 70 % by 2040. Based on the mapping information, the thematic maps such as National Groundwater Profile and National Groundwater Index will be produced that will be the reference for policy maker to make decisions in national water management planning.

Over the years, the water management policy is managed separately between the federal and state governments. In addition, there are various government agencies involved in the management of water resources separately. Therefore, there is a need to review the laws and regulations and coordinate among agencies involved in water resources management to ensure sustainable management of water resources including groundwater. Generally, surface water and groundwater have an interaction in terms of quantity and quality and should be utilized together through the development of conjunctive water supply infrastructure. There are many ways to develop conjunctive water supply infrastructure such as underground dam, artificial recharge storage and riverbank filtration. The construction of underground dams allows water to be stored and impounded as soon as entering the aquifer. In addition, some underground dams are designed to control saltwater intrusion into aquifers. The water storage in an aquifer can be optimized in a several ways such as Managed Aquifer Recharge, MAR which refers to purposeful recharge of water to aquifers for subsequent recovery or environmental benefit. Common MAR infrastructures are recharge well, gabion well and bench terracing. Riverbank filtration, RBF is a popular infrastructure in conjunctive use of surface water and groundwater and has been widely practiced in Kelantan. The capacity and quality of surface water and groundwater can be improved by RBF system before being supplied to the consumer.

4. Conclusions

Groundwater is a main natural resource which has multiple advantages that can be exploited as a source of public water supply. The water managers should take an initiative to increase the capacity of groundwater as a source of water supply to avoid fully dependence on surface water which had caused problems of water crisis every year especially during the dry season. To achieve the aspiration of using groundwater as a part of public water supply, the conjunctive use of surface water and groundwater for the purpose of water supply must be carried out under the Water Sector Transformation 2040, WST 2040 agenda. The availability of comprehensive groundwater information, and the involvement and cooperation of all agencies related to water management is very important to achieve sustainable water management for both of groundwater and surface water resources.

References

Andrea, S. (2013) Conjunctive Use of Surface Water and Groundwater. *Groundwater Journal-Vol III*

Hanapiah, M. N. (2012) Dasar Sumber Air Negara, *Jabatan Pengairan Dan Saliran Malaysia.*

Keiji, S. (2002) The Study on the Sustainable Groundwater Resources and Environmental Management for the Langat Basin in Malaysia, Japan International Cooperation Agency and Mineral and Geoscience Department.

Yamada, T. (1993) Construction of Underground Dams on Miyakojima. *The Dam Digest,* **580**, 81-95, The Japan Dam Foundation. (in Japanese).

Wan M. Z. (2014) Innovation in Water Supply Industry. *Air Kelantan Sdn. Bhd.*

Current groundwater and surface water problems in Myanmar and their possible solutions - Saltwater Intrusion in Delta Area, Myanmar -

Than Zaw[1] and Aung Khaing Moe[1]

[1]Irrigation and Water Utilization Management Department,
Ministry of Agriculture, Livestock and Irrigation, Myanmar

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 region 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 rely 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. Some tanks and ponds are contaminated. Saltwater intrusion is not only a problem for the drinking water of the delta area, but also for the lives of the whole country as the delta area is a granary of the country. 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 freshwater resources in the delta area, all feasible measures must be conducted and ensure the safe and freshwater requirements of future generation.

Keywords: saltwater intrusion, groundwater, surface water, delta area, Myanmar

1. Introduction

Myanmar is being well known as a low water stress country. It gets more than 3000 mm rainfall every year. But the spatial and temporal distribution of the rainfall varies greatly throughout country. Almost all precipitation is obtained in monsoon season and there is no or very little rain in winter and summer seasons. The frequency and intensity of rainfall in delta area is significantly higher than that of central dry zone.

The delta area can be divided into four depend on their location and occurrence (Fig.1).

1) Rakhine delta
2) Ayeyarwaddy Delta
3) Bago-Sittaung Delta
4) Thanlwin Delta

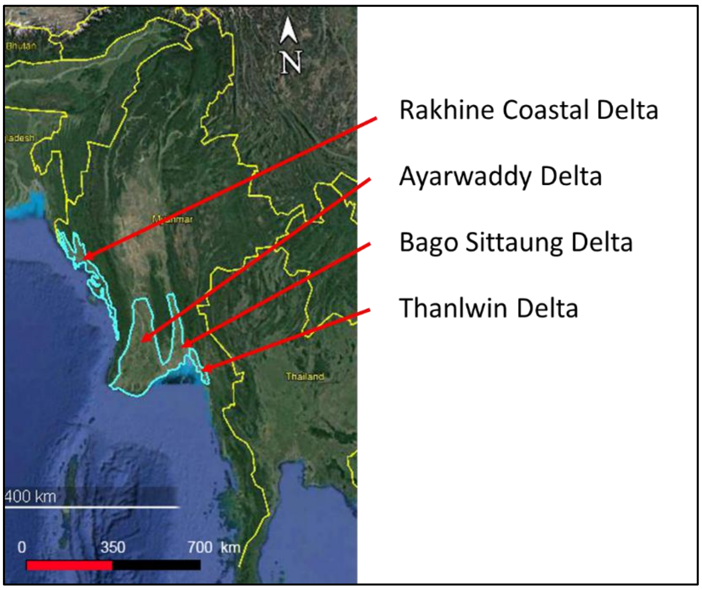


Fig. 1. Delta areas of Myanmar

Among these four deltas, Ayarwaddy Delta is the largest, it extends from the mouth of the Yangon River in the east to the Mawtinsun, the southern extreme of Rakhine Yoma Ranges in the west. Ayarwaddy Delta is popular for its heavy paddy cultivation, and it is called as "Myanmar's Sapar gyi" "Myanmar's granary of paddy". Mangroves are natural cover for storm wind and water. Embankment along the islands, dikes and sluice gates are made to protect from sea water intrusion.

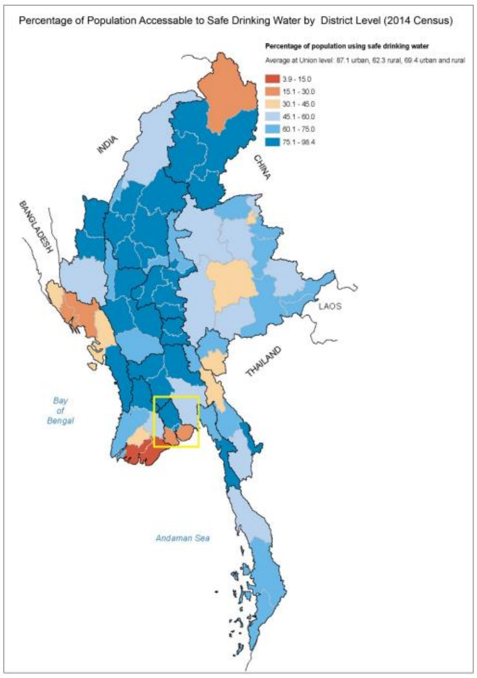


Fig. 2. Percentage of population accessible to safe drinking water

Due to the high intensity of rainfall in delta area, the population in these areas wholly rely on rainwater collection ponds for their drinking and domestic usage. 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.

According to the Population Census 2014 data, the percentage of households which can access to safe drinking water is less than 40 percent in the Rakhine and Ayarwaddy Delta including Southern District of Yangon Region, the former Capital of Myanmar (Fig.2).

Drinking water facilities in these areas are not safe and also not sufficient for the population for the whole year. Water shortage happens in dry season every year (from February to May). It becomes more common in recent years.

Rising sea level will also affect the salt water intrusion. Saline water intrusion into the rivers and streams is progressively more towards the upstream. Salt water intrusion into the shallow aquifer also becomes more severe.

2. Current groundwater and surface water problems in Myanmar

Myanmar has many challenges in surface and groundwater sector. Sustainable utilization through evaluation, monitoring and conservation is stay needed for both surface and groundwater. Among these challenges the saline water intrusion in the delta areas is a significant one and more severe with the climate change.

- Saline front (Salinity Line) is progressive moving towards upstream due to the rising of sea level and decreasing river flow in dry season (Fig. 3).
- Saltwater intrusion to shallow aquifer.
- Saline water intrusion is closer to the ground level as the Water Table is rising up. Some tanks and ponds are contaminated

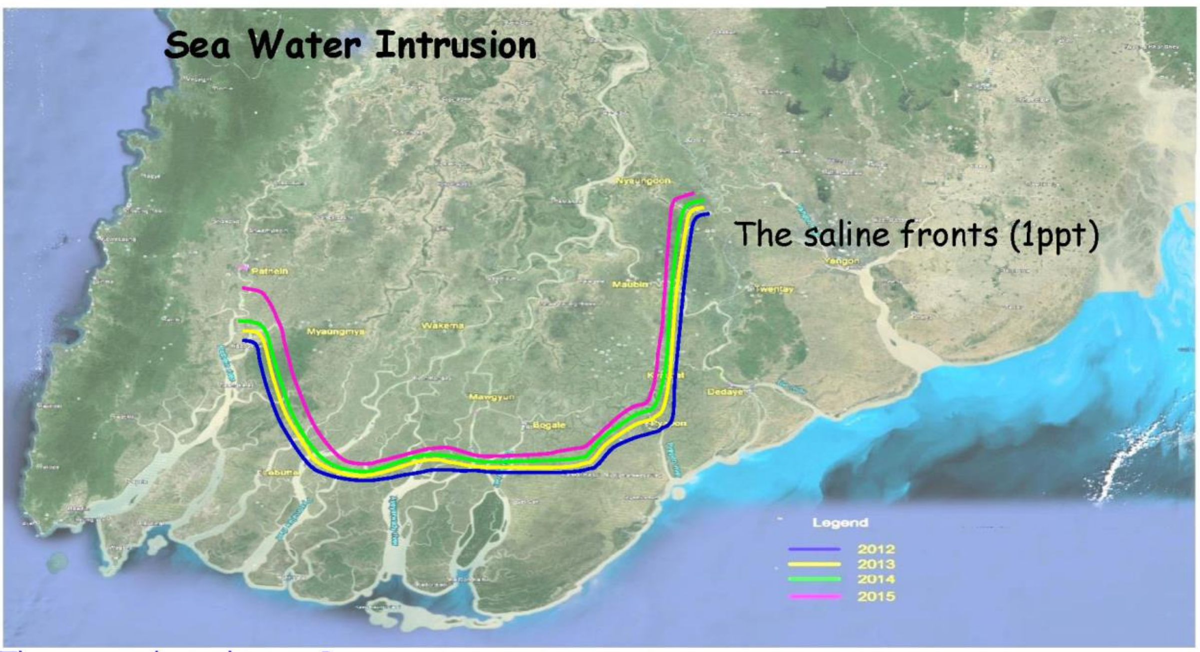


Fig. 3. Saline front line progressively moving towards upstream in Ayarwaddy Delta
(Source: www.gwp.org/globalassets/global/gwp-sas_images/gwp-sas-in-action/ldai/disaster-risks-in-ayd-deltairri-and-flood-protection30-5-2017.pdf)

In 2018, Irrigation and Water Utilization Management Department, IWUMD conducted a survey on the status of domestic water facilities in Kawhmu, Kungyangone, Twunte and Dala townships which is located in the eastern most part of the Ayeyarwaddy Delta. Totally 138 water samples from selected shallow tube-wells, dug wells and ponds were collected in the survey (Table 1). 53 samples the EC value greater than 1500 micromho/cm (Table 2).

Table 1. Water samples collected

Township	Tank	Dug Well	Tube Well	Total
Kawhmu	3	4	48	55
Kungyankon		6	29	35
Twunte	1		33	34
Dala	1		13	14
Total	5	10	123	138

Table 2. Samples with EC >1500 micromho/cm

Township	Tank	Dug Well	Tube Well	Total
Kawhmu	1		13	14
Kungyankon		1	14	15
Twunte			12	12
Dala			12	12
Total	1	1	51	53

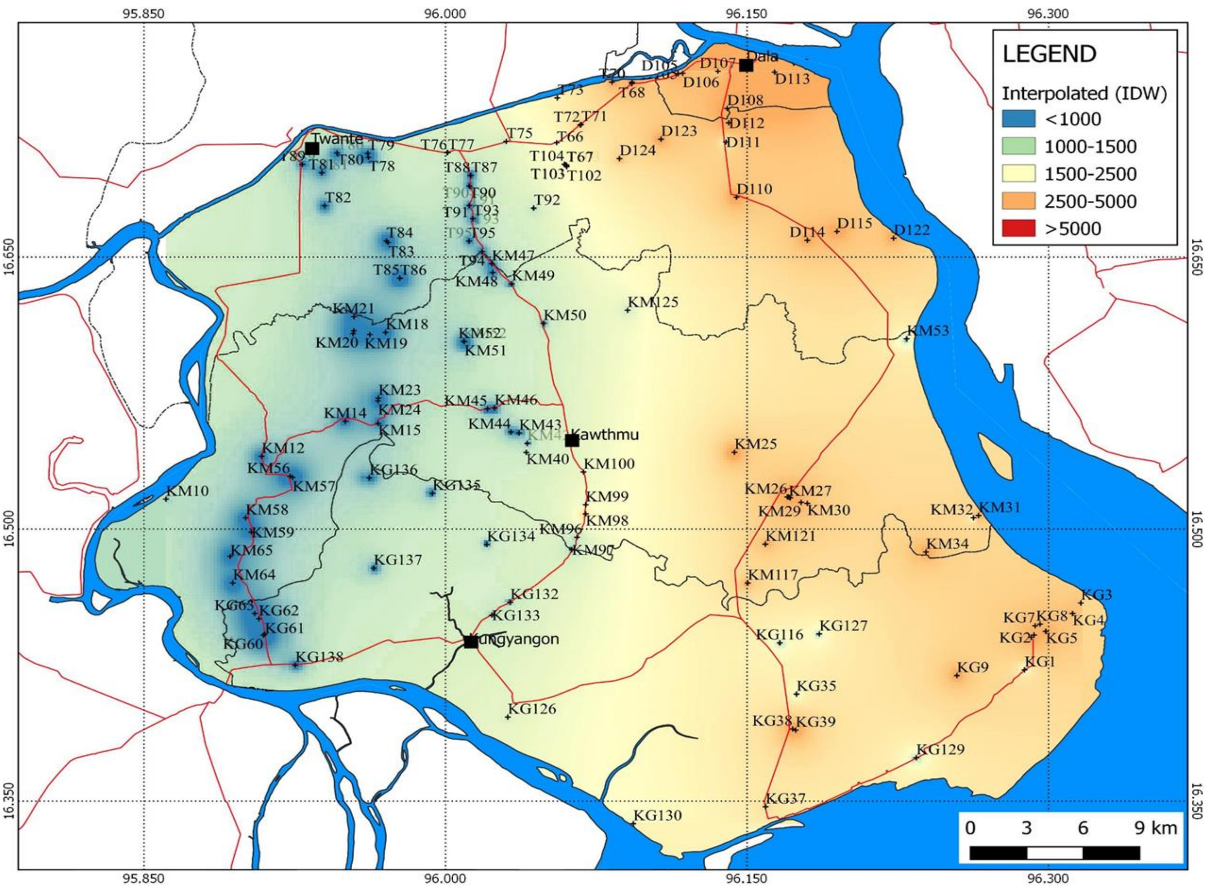


Fig. 4. Map showing the electrical conductance, EC of shallow aquifer in Kawhmu-Kungyangon, Twunte-Dala Area

The study found that the shallow aquifer is totally saline in eastern alluvial plain and some ponds and dug wells are also contaminated with saline water (Fig. 4). It shows that the saline water interface is closed to the ground level.

3. Possible solutions to manage problems related to water resources

In the Ayeyarwaddy Delta area island-round embankments, dikes and polders had been constructed to prevent saline water intruded with tide (Table 3, Fig. 5). River dikes were constructed along the Ayeyarwady River, Sittaung River and Ngawun River since 19th century.

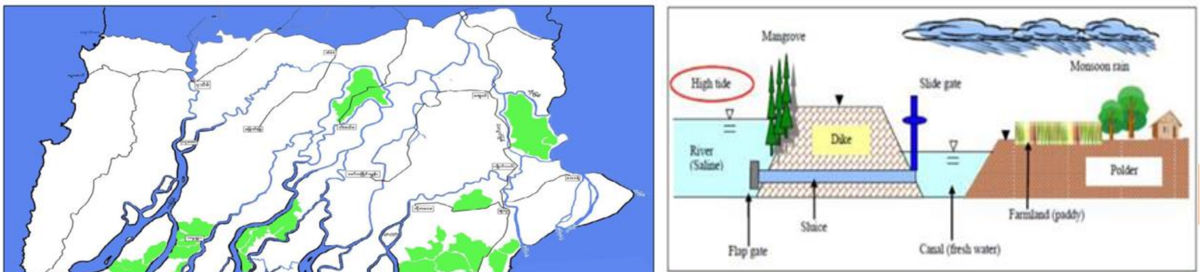
The major river dikes, western Ayeyarwady Embankments, eastern Ayeyarwady Embankments, Ngawun Embankments, Sittaung Embankments and Bago Embankments, and these were constructed between 1860s and 1880s.

The British engineers designed, constructed the urban dikes along the Ayeyarwady and Ngawun rivers, during colonial era. Urban dikes were also constructed continuously in town area along the Ayeyarwady and Ngawun rivers. Dikes were reconstructed and improved from time to time as the river regime is changing yearly.

Table 3. Dikes constructed for flood protection and sea water intrusion by IWUMD

Sr. no.	State/Region	Flood Protection			Sea water Protection			Total			Remark
		no.	Length (mile)	Protected Area (acre)	no.	Length (mile)	Protected Area (acre)	no.	Length (mile)	Protected Area (acre)	
1	Kayin	2	1.360	2372	-	-	-	2	1.360	2372	
2	Sagaing	6	49.090	42146	-	-	-	6	49.090	42146	
3	Tanintharyi	-	-	-	14	54.320	10754	14	54.320	10754	
4	Bago	39	387.400	515907	-	-	-	39	387.400	515907	
5	Magway	1	1.500	1160	-	-	-	1	1.500	1160	
6	Mandalay	2	10.989	5649	-	-	-	2	10.989	5649	
7	Naypyidaw	5	17.040	16956	-	-	-	5	17.040	16956	
8	Mon	-	-	-	18	50.190	20536	18	50.190	20536	
9	Rakhine	-	-	-	32	207.890	79584	32	207.890	79584	
10	Yangon	19	101.280	78481	22	234.050	203489	41	335.330	281970	
11	Shan	1	41.000	-	-	-	-	1	41.000	-	
12	Ayeyarwady	29	733.535	1356101	35	583.400	339177	64	1316.935	1695278	
		104	**1343.194**	**2018772**	**121**	**1129.850**	**653540**	**225**	**2473.044**	**2672312**	

Totally 35 dikes had been constructed to protect 339,177 acres of land from sea water intrusion in Ayeyarwaddy Delta (Table 3).



Phase	polders (No)	Length (Km)	Sluice (No)	Drainage (km)	Beneficial area (ha)	Phase	Commencement	Completion
I	11	643.2	65	664	82983	I	August, 1976	June, 1985
II	4	393.6	84	430.4	76497	II	July, 1978	April, 1990

Fig. 5. Location and schematic diagram of polders in Ayeyarwaddy Delta

Historically, only few tube-wells are drilled in the delta area. The oldest tube-well of Myanmar which was drilled in 1889 in Dala Township by E.Solomon and Sons, for the Bombay Burma Trading Company Ltd. This 75 mm diameter tube-well was sunk up to 53 m but abandoned due to saline water being encountered. During 2015 – 2017, fresh water was obtained from 700 ft depth tube-wells in Phyarpon and Ma-u-pin townships (Fig. 6). Some tube-wells are closed to coastal line.

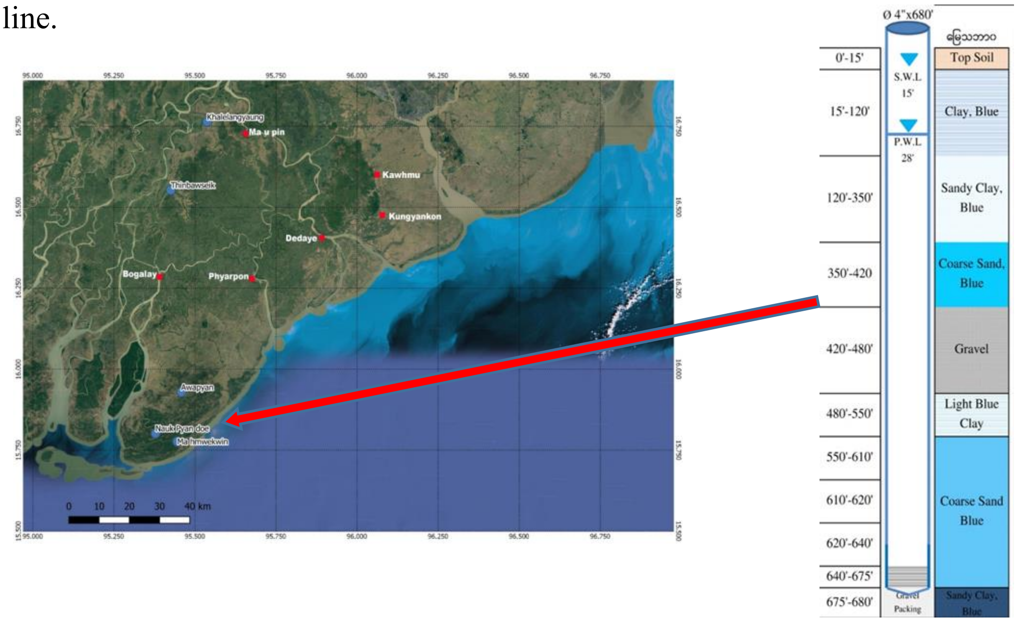


Fig. 6. Location and lithologic log of tube-well in Nauk-Pyan-doe village, Phyarpon Township

The evidence found from these tube-wells encourage to conduct a hydrogeological study to find out the feasibility of confined fresh groundwater aquifer in Kawhmu-kungyangon-Twunte-Dala area, eastern marginal part of the Ayeyarwaddy Delta. Geophysical investigation and test well drilling had been done in this study (Fig. 8).

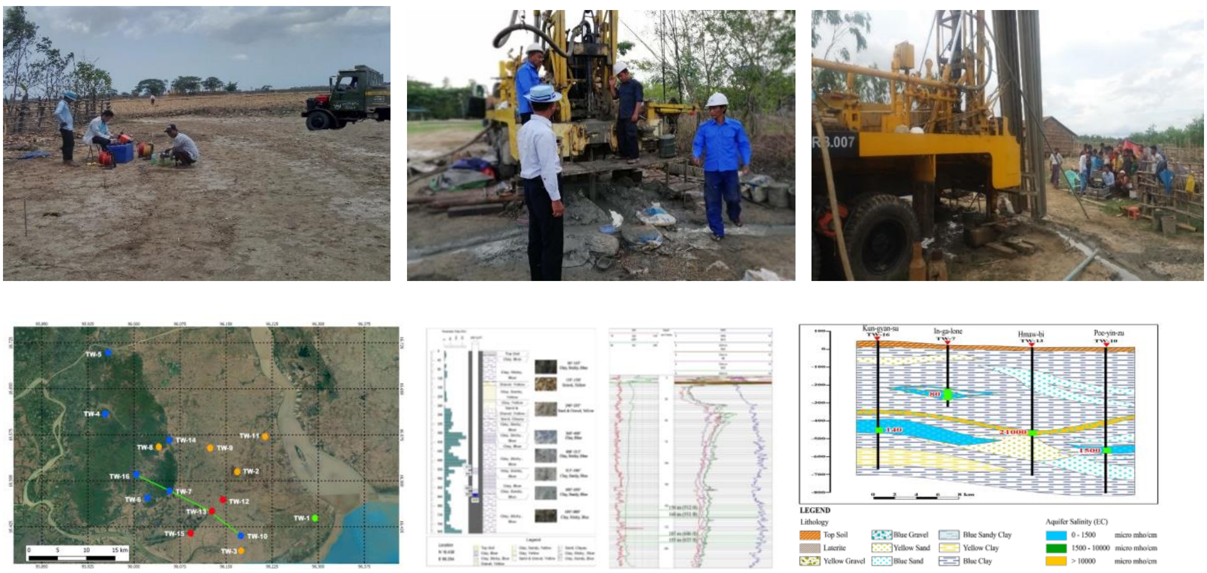


Fig. 8. Geophysical investigation and test-well drilling in Kawhmu-Kungyangon-Twunte-Dala Area

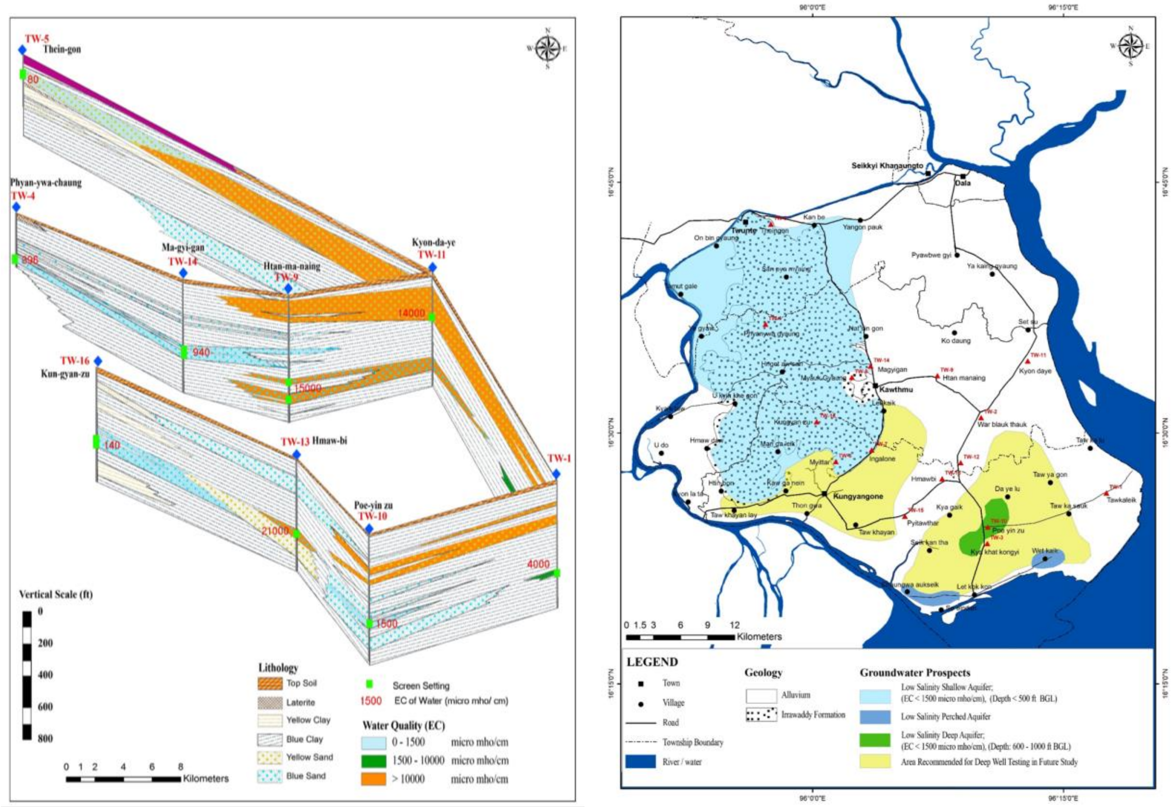


Fig. 9. Identified groundwater prospect areas by hydrogeological study

As the hydrogeological study indicate the existence of confined fresh aquifer in the delta area, groundwater utilization can be a measure to fulfill the freshwater demand (Fig. 9). More detail study may be needed for the sustainable utilization of groundwater.

4. Conclusions

Population growth will increase the water demand and the climate change will severe the saltwater intrusion. Detail study and monitoring on the intensity and extent of the saltwater intrusion is necessary to alarm the depth of the hazard. To reduce the impact of saltwater intrusion, maintenance and upgrading the preventive infrastructures must be done. Alternative ways must be found to fulfill the demands of safe drinking water.

References

IWUMD (2017) Disaster Risks in Ayeyarwaddy Delta, Irrigation and flood Protection, gwp.org/global assets, 30-5-2017.

Aung Khaing Moe (2020) Hydrogeological Study of Delta Area: Kawhmu, Kungyangon, Twunte, Dala Township. *IWUMD Interdepartmental Paper*, 23-12-2020.

Current groundwater and surface water problems in Papua New Guinea and their possible solutions

Dorcas Fabila[1]

[1]Geological Survey Division,
Mineral Resources Authority, Papua New Guinea
e-mail: dfabila@mra.gov.pg

Abstract

Papua New Guinea currently source water from both groundwater and surface water sources, however, there are certain problems that are still encountered from these water sources. The main problem affecting rural community water supply is contamination, especially to surface water sources as most rural communities collect water directly from the source. Poor set up of villages resulting in pit latrines located anywhere within some villages increases contamination risks to both shallow groundwater sources, and surface water. Other problems encountered within both rural and urban communities include poor maintenance of pumps, tidal influence and saltwater intrusion, low-yielding aquifers and overestimation of sustainable yield.

Possible solutions to alleviate these water problems include increasing of rainwater catchment systems, proper technical training for maintaining and repairing of pumps, proper thorough mapping of freshwater zones, proper awareness programs for village set up, and proper long-term pumping tests for improved calculation of sustainable yield.

Keywords: aquifer, groundwater, water, contamination, borehole, well.

1. Introduction

The main water sources used within Papua New Guinea (PNG) include both groundwater and surface water. Surface water sources include streams, rivers, creeks, lakes, ponds, estuaries and swamps, while groundwater sources include freshwater from confined and unconfined aquifers.

According to the Pacific Community, Water, Sanitation Program website (2007), only 20 % of PNG's rural population have access to an improved water supply system which comprise of public standpipes, boreholes, and protected wells or springs. Majority of the population within rural areas collect water directly from the water source. Water supply services within the urban areas of PNG are managed by Water PNG Limited, previously known as PNG Waterboard. As stated by the Pacific Community, Water, Sanitation Program, 91 % of PNG's urban population have access to treated and reticulated water, however, only 60 % of these households get piped water directly into their houses.

The current sources of water do encounter problems, which may be solved in finding possible solutions, therefore, this report outlines some of the main problems encountered, including possible solutions to these water problems within PNG.

2. Current groundwater and surface water problems in Papua New Guinea

While groundwater may be one of the safest sources of water, there are certain problems that have been observed during site groundwater investigations, which are outlined below; this also includes problems observed in surface water sources.

i. Contamination of shallow unconfined aquifers and surface water sources

Majority of the population within rural areas depend on surface water, and in areas that have favorable aquifer conditions, shallow wells are constructed. Due to lack of knowledge of groundwater resources, a lot of rural communities do not have a proper village set up, resulting in pit latrines (pit toilets) been set up anywhere within the village. This poses a contamination risk to shallow groundwater aquifers, as well as surface water such as rivers or streams since local alluvial aquifers are usually connected to the adjacent surface water bodies. According to local villagers within the South Fly District, World Vision Papua New Guinea carried out awareness programs within the South Fly District to address such sanitation and hygiene issues under the Water, Sanitation and Hygiene (WASH) program. Few other selected provinces have been identified under the World Vision WASH program to carry out similar awareness programs. One of the main issues addressed to the rural communities was to relocate all pit latrines (pit toilets) away from current water sources.

Fig. 1. Examples of untreated river water (left) and creek water (right) used within villages in the South Fly District, Western Province, PNG

Adding onto this, it has been observed that many villages dig shallow hand wells which are unlined with no proper cover, therefore, the water becomes contaminated from surface run off during periods of high rainfall and flooding.

Surface water bodies are also prone to contamination due to both human and animal activities. During periods of high rainfall, there is an increase in surface run off where animal waste may be washed down into the river systems or any surface water body, resulting in contamination. This is common within rural areas, however, due to the lack of groundwater sources in certain areas, the communities are forced to use this surface water sources regardless of its poor state. Since most surface water is not treated, this poses a health risk for these rural communities.

ii. Maintenance of shallow well and borehole pumps

Within certain rural areas of PNG, donor funding organizations construct shallow boreholes and wells, usually fitted with a hand pump or submersible pump. Although this is a good approach to solving water scarcity issues within these rural areas, there is no proper knowledge on maintaining the pumps, hence, the pumps become dysfunctional only after few years of operating.

Fig. 2. Examples of shallow unlined wells in Western Province, susceptible to contamination

From these observations, it is clear that proper training is needed for local people within these areas in order to maintain the pumping equipment, and hence, have a sustainable water source. A shallow borehole constructed by the Japan International Cooperation Agency in 2001 within a village in the South Fly District was maintained for the past twenty-one (21) years, from 2001-2021 since it was maintained by a caretaker.

Fig. 3. A dysfunctional hand pump (left) and a currently functioning hand pump with the caretaker (right) in Giringarede village, South Fly District, Western Province

iii. Tidal influence and saltwater intrusion

Saltwater intrusion has always been a problem for areas located within close proximity to the coastline. This may be due to over-pumping of the freshwater zone due to a thin lens of freshwater sitting on top of the saltwater interface. This has been previously reported for areas such as East New Britain Province northeast of PNG (Pounder, 1972), and for coastal villages within the Western Province of PNG, South Fly District.

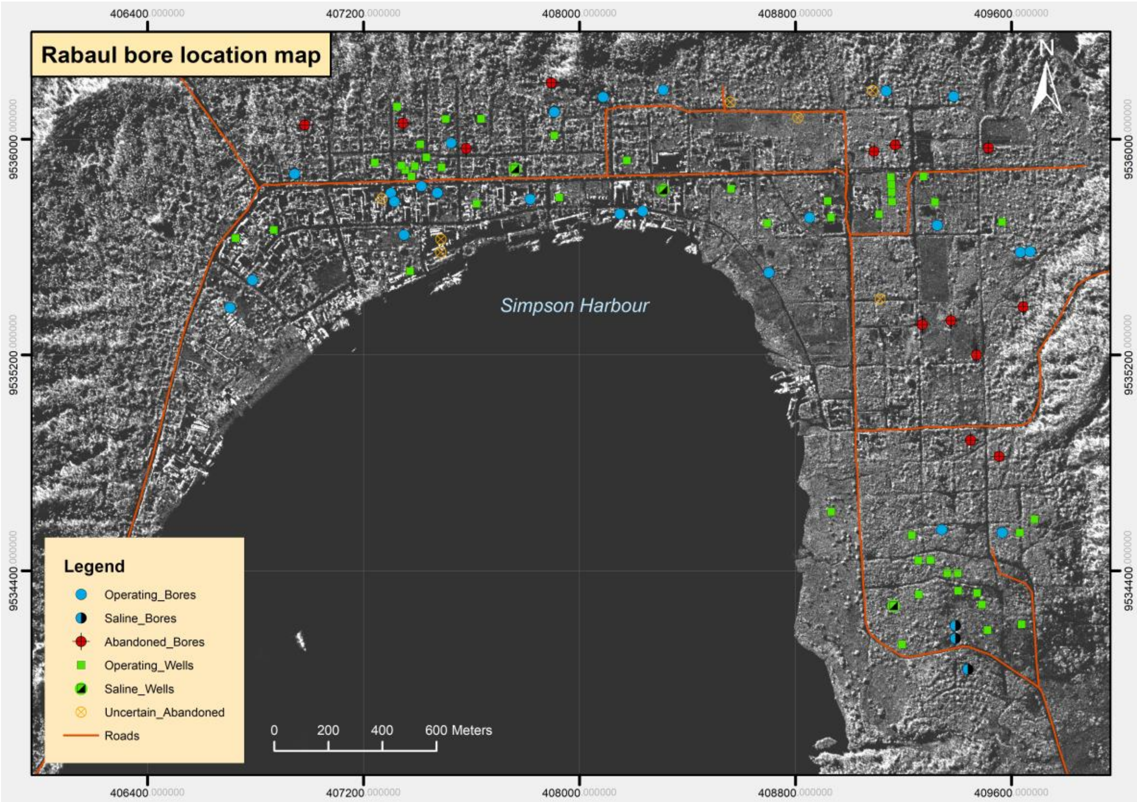


Fig. 4. Borehole location map (estimated) extracted from an old report by Pounder (1972) of Rabaul, East New Britain Province indicating some saline bores and wells

Fig. 5. Shallow wells, lined (A) and unlined (B) that experience saltwater intrusion due to close proximity to the coastline; South Fly District, Western Province.

In a recent site investigation within the Western Province, local people in villages near to the river mouths and estuary zone advised that tidal influence affected their water quality as water from their wells tasted salty during high tide events. One of the river villages visited was Kunini, which is approximately 10 km up the Binaturi River; this village experiences saltwater intrusion during high tide events, therefore, villagers usually fetch water directly from the river during low tide, when tidal influence is negligible. However, for villages nearer to the river mouth, all water sources taste salty throughout the year. Due to this, rainwater catchment tanks are one of the main water supply sources been currently used within such communities.

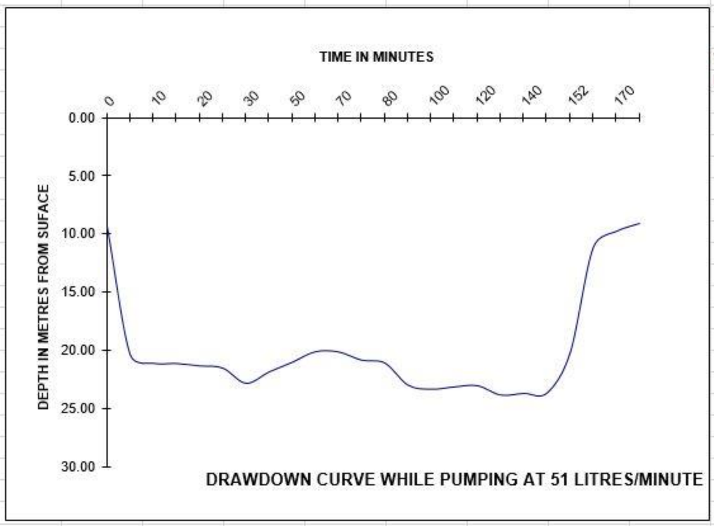
iv. Low-yielding aquifers

Different types of aquifers exist within PNG, which include pre-Quaternary bedrock aquifers, volcanic rock aquifers, karst limestone aquifers, coastal sediments and unconsolidated sediments (Jacobson and Kidd, 1974). Of these aquifers, alluvial aquifers typically produce more water, while on the other hand, the efficiency of the bedrock aquifers depend largely on structural factors such as faulting and fracturing. Some geological formations which undergo fracturing, however, do not have a high fracture intensity and connectivity result in low yields.

The Sadowa Gabbro aquifer within PNG's capital city, Port Moresby and the surrounding areas is an example of such an aquifer where yield is low due to low fracture intensity and connectivity. An old report by Harris and Jacobson (1972) confirmed the low yields of the Sadowa Gabbro aquifer through a city-wide groundwater survey.

Adding onto this, the sustainable yield of boreholes within an aquifer is at times overestimated due to a short-term pumping test, which does not properly reflect the long term efficiency of the borehole and aquifer. As a result, production bores tend to deplete faster than expected.

TIME	WATER DEPTH
0.00	9.30
5.00	20.39
10.00	21.12
15.00	21.14
20.00	21.34
25.00	21.53
30.00	22.84
40.00	21.86
50.00	21.03
60.00	20.12
70.00	20.14
75.00	20.85
80.00	21.10
90.00	23.00
100.00	23.35
110.00	23.15
120.00	23.05
130.00	23.85
140.00	23.71
150.00	23.68
151.50	20.23
160.00	11.14
170.00	9.76
180.00	9.08



Water table: 9.30 Metres
Bore Depth: 30 Metres

Results: The Bore pump discharge rate was set at 51 litres per minute, the pump was set just above the screen at 28 meters
Total water discharged during the test was 8,160 liters.The bore will produce at this rate 72,000 liters per 24 Hr day

Fig. 6. Graphical results of a short-term pumping test carried out by Central Drillers over a 3-hour period (constant discharge test).

3. Possible solutions to manage problems related to water resources

From the main groundwater and surface water problems discussed above, the following present the possible solutions to address these water problems.

i. Increase rainwater catchment tanks

In order to avoid rural communities been exposed to water borne diseases due to consumption of contaminated surface or groundwater sources, it would be more safe to increase the number of rainwater catchment tanks. This may be able to provide sufficient water to the rural communities throughout the wet season, and the dry season, but more so, this water will be fresh and free from contamination.

Fig. 6. Rainwater catchment tanks connected to tap outlets in a village in Western Province.

ii. More awareness on proper set up of village

In order to avoid contamination to shallow aquifers and surface water bodies, there needs to be more proper awareness to local rural communities of how to do a proper village set up. Such set up will locate pit latrines away from any surface water sources, and also downhill, ideally 50-100 m from any shallow well or boreholes constructed. This can be achieved with the help of local leaders who can manage these changes to carry out proper village set up in order to avoid contamination to water sources.

iii. Proper training for maintenance of pumps

In order to have a sustainable ground water supply through shallow wells or boreholes, maintaining the pumps is very important. Although water may still be available within wells and boreholes, it won't serve its purpose if the pump is dysfunctional. Therefore, proper technical training is needed to train local men on how to properly maintain the pump or carry out repair. Another possible option would be for the donor funding organizations to purchase spare parts of these pumps, therefore, making it more efficient for repair of the pumps when the pumps become faulty.

iv. Improve mapping of freshwater zones

Fractured rock aquifers may not always be productive in different target points where boreholes or shallow wells are sunk. While one location may give sufficient water, another location within the same fractured rock aquifer may yield less. To avoid such low yields, an improved and more thorough mapping needs to be carried out in order to properly map out structural areas near faults where fracturing will be more intense. Adding on to this, during the drilling stage, it would be more efficient if the boreholes are drilled to deeper depths (more than 50 m) in order to increase the storage capacity of the borehole, as well as increasing the number of fractures feeding water into the borehole. This was observed in a recent drilling project in the Goldie Barracks just outside of Port Moresby, where a shallower well (less than 50 m) yielded less compared to that of a deeper well (nearing 100 m) which showed signs of producing more water.

Proper mapping can also be carried out within the coastal areas which are affected by saline intrusion and tidal influence. This may help reveal previously undetected freshwater zones in these coastal areas, and may properly delineate the freshwater-saltwater interface. In this way, the thicker zones of freshwater can be used as target points for borehole drilling or installation of shallow wells. Within rural areas, it would be advisable to use hand pumps, which can manage the abstraction rates of the freshwater, and therefore, avoid saline intrusion.

v. Improve pumping test duration

In order to avoid miscalculation of the sustainable yield of a production borehole, it is highly recommended that pumping tests be carried out over longer periods. The usual standard pumping test duration usually include 24 hours, 48 hours, or 72 hours continuous pumping tests, depending on the population and demand within the given target areas.

4. Conclusions

Papua New Guinea currently sources water from both groundwater and surface water, however, certain problems are still encountered from these sources. These problems as discussed, may be alleviated through a number of better approaches in terms of avoiding contamination to water sources, proper and thorough mapping of freshwater zones, proper technical training of pumps, and proper estimation of sustainable yields of wells and boreholes. By using different approaches to address these problems, more safe and sustainable water supply systems can be achieved, especially within the rural areas where proper water supply systems are lacking.

References

Pacific Community, Water, Sanitation Program (2007) Papua New Guinea, Status of water resources. SPC Water, Sanitation and Hygiene: Papua New Guinea (www.pacificwater.org)

Pounder, G, M. (1972) Summary of groundwater data, Rabaul, East New Britain, Geological Survey of Papua New Guinea, Note on Investigation 72-019.

Harris, J. and Jacobson, G. (1972) Port Moresby Urban Geology, Geological Survey of Papua New Guinea, Memoir 1.

Jacobson, G. and Kidd, C. H. (1974) Groundwater in Papua New Guinea, Geological Survey of Papua New Guinea, Report 74/16.

Current groundwater problems in the Philippines and their possible solutions: Application of Preliminary Geospatial and Statistical Assessment to enhance Groundwater Quality data

Aeron Elvin C. Dela Cruz[1], Edrian M. Tubalado [1], Marnette B. Puthenpurekal [1] and Nerielyn G. Inducta[1]

[1]Mines and Geosciences Bureau, Department of Environmental and Natural Resources, Philippines
e-mail: hegs@mgb.gov.ph, eyronelbin@gmail.com

Abstract

Groundwater Resources and Vulnerability Assessment Program is one of the major ongoing programs of the Mines and Geosciences Bureau (MGB). One of its objectives is to generate a database containing critical information on groundwater quantity and quality in all provinces of the country. Results of the 1:250,000-scale assessment completed over the period 2015-2018 were made available to stakeholders responsible for water resources management and development. Highlighting the significant contribution of this undertaking, various improvements on data quality has been undertaken to further enhance its applicability, particularly in groundwater monitoring. The present study aims to improve data quality on groundwater parameters using spatial and statistical techniques to aid in the groundwater database management. A total of 25,605 groundwater sources were surveyed nationwide and water from each point sources were analyzed for the five (5) physical parameters – Temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), pH, and Salinity. It was estimated that 39 % of the database is incomplete, and the identified gaps in groundwater parametric data, therefore, were filled by interpolation using the Inverse Distance Weighting (IDW) method to create a preliminary statistical evaluation of water potability. Evaluation of the result was based using the Philippine National Standard for Drinking Water (PNSDW) and the United States Geological Survey (USGS) parameters for saline water. Results show that temperature values for various wells and springs in the country range from 10 ºC to 35 ºC, while the EC recorded values range from 8 to 5,829 µS/cm. It was further evaluated that 16 % and 19 % of the data on TDS and pH, respectively, are outside the permissible limit set in the PNSDW. With respect to Salinity, 97 % of the groundwater sources has a value of <1000 ppm which is categorized as fresh based on the USGS guidelines. The results revealed that the majority of groundwater sources in the country has water parameter concentration within the allowable limits considering the application of the resolution of interpolation and statistics. These findings demonstrate that IDW and preliminary statistical evaluation produces reliable estimates for improving groundwater data quality. The MGB's conduct of the detailed 1:50,000-scale assessment will serve to validate the result of this study.

Keywords: Inverse Distance Weighting, electrical conductivity, total dissolved solids, pH, salinity

1. Introduction

The importance of groundwater as a resource can never be underestimated especially with the continued threat to quality as a result of growing population and climate change impacts. The resource has increasingly become susceptible to pollution due to various causes and therefore, efforts to protect and properly manage it must be increased. Understanding the general condition of groundwater quality and the management of existing database is one of the many ways to guide all stakeholders to manage this critical resource collectively and wisely.

While there has already been a good number of information generated on water quality, issues have been identified particularly on data gaps that deter generating a complete picture of the general groundwater quality status (Fig. 1). The application of preliminary geospatial and statistical assessment was made to enhance the existing water quality database, and it made use of collected data obtained during the period 2015–2018 from all provinces in the country. In particular, the assessment and evaluation were focused on the physical water characteristics obtained employing in-situ water quality testing, and this includes water parameters such as temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity.

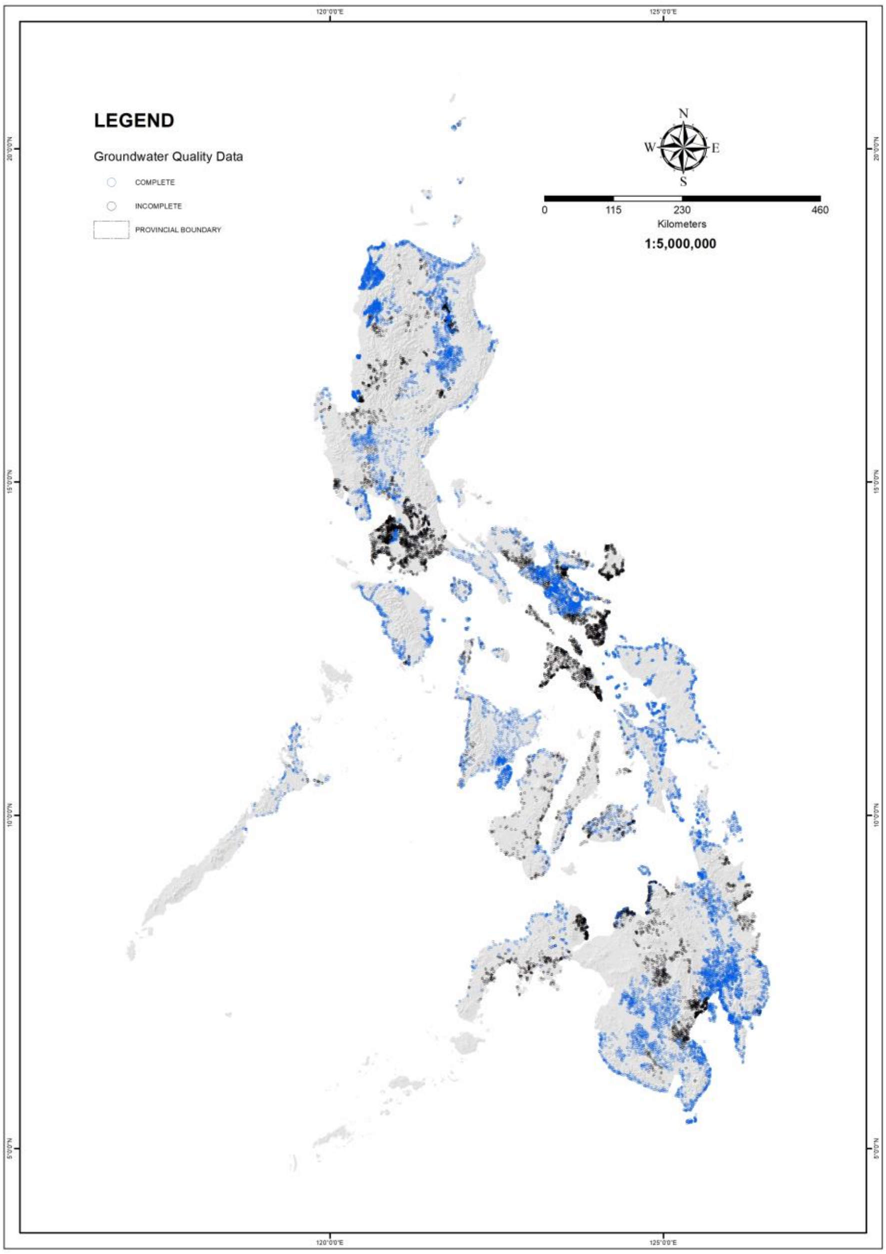


Fig. 1. Location Map of Groundwater Sources in the Philippines

The analysis via the use of interpolation had certain limitations, to wit:

1. Groundwater quality assessment was based on the results of 1:250,000-scale in-situ

measurements of physical parameters, suggesting a more regional scale and coverage;

2. It made use of historical data that may no longer represent recent water quality scenario; and
3. IDW was the only interpolation method used to evaluate and analyzed the incomplete parametric data.

Notwithstanding the above, the groundwater physical parameters of the country were adequately processed based on the available data. The process flow reflecting the detailed methodology and IDW interpolation tool in ArcGIS 10.7.1 are shown in Figures 2 and 3.

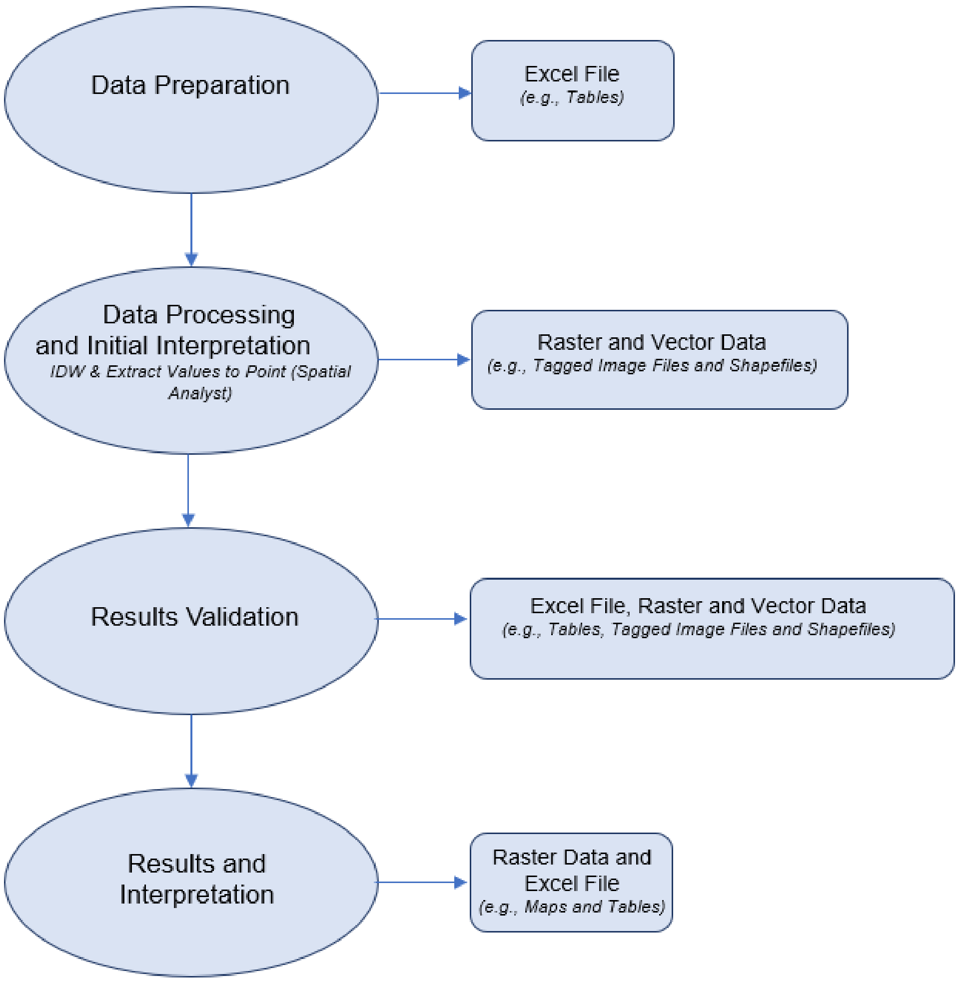


Fig. 2. Flowchart depicting the methodology for geospatial and statistical analysis of the present study

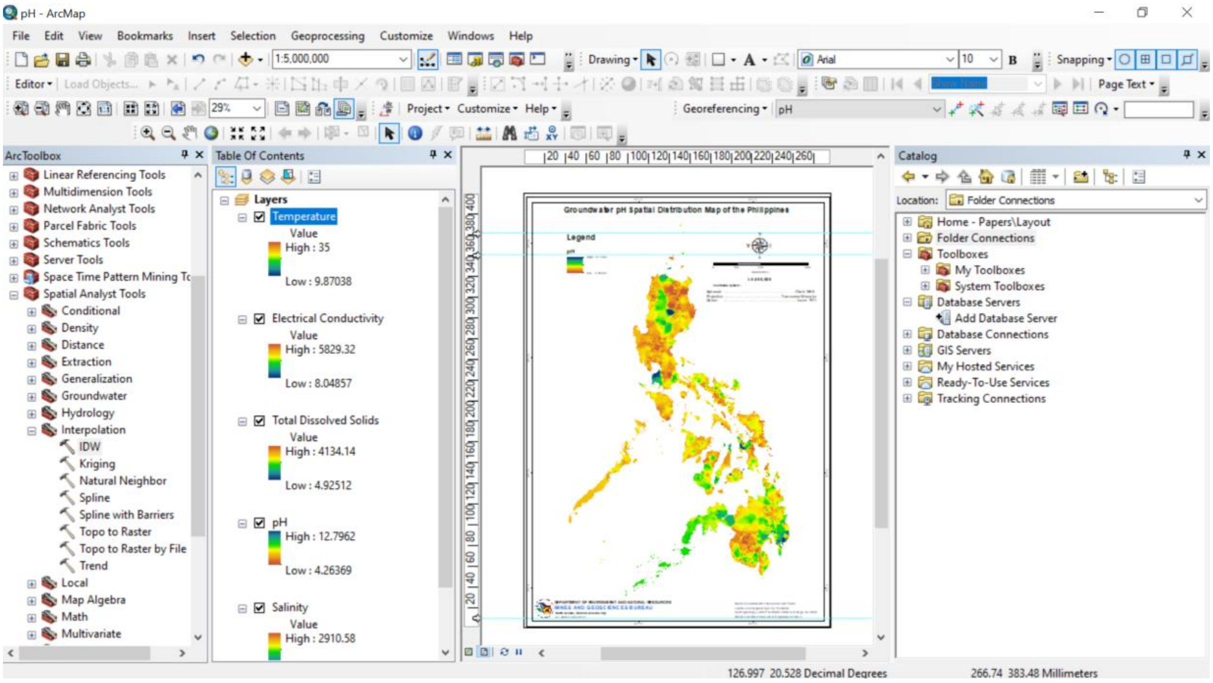


Fig. 3. Photo showing the IDW spatial analyst interpolation tool in ArcGIS 10.7.1

IDW Interpolation

IDW method of the spatial analyst extension in the ArcGIS 10.7.1 was used in generating the groundwater quality parameter maps within the country. It assumes that data points that are close to one another are more alike than those that are farther apart. The measured data points closest to the prediction location have more influence on the predicted value than those farther away. IDW also assumes that each measured point has a local influence and diminishes with distance. It gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance, thus the name inverse distance weighted (ESRI, 2019).

The IDW method was used to interpolate surfaces at available data points. As a result, the groundwater quality maps were created by overlaying the interpolated raster. These maps depict the spatial distribution and were created to highlight variations in groundwater parameter concentrations in all of the provinces throughout the country.

2. Current groundwater problems in Philippines

Data collection is an important and primary part of a research work because it improves efficiency and eliminate uncertainty. While information gathering is basic and is an integral part of the scope of work in research, data processing can still be a challenge particularly when handling large amount of data. It can even be more tedious if database is not enough and lacking, that it may require considerable effort and time to secure additional data. Specific challenges also arise from the fact that information come from various sources with different data collectors (e.g. both from the Central and Regional Offices), and possibly with different issue/s in acquisition. It becomes common, therefore, when data is incomplete when needed. Moreover, there is also issue on incompatibility when it comes to data format and software, as well as non-uniformity in the units of measurement, which requires additional work to keep them unified. To address these issues, it is essential to carry out data validation before proceeding with data processing. This will make sure that differences are corrected, and data reliability is assured before proper assessment is made. In this study, efforts have been exerted to make certain gaps (i.e. water quality data) were identified as the methodology progresses (Fig. 4).

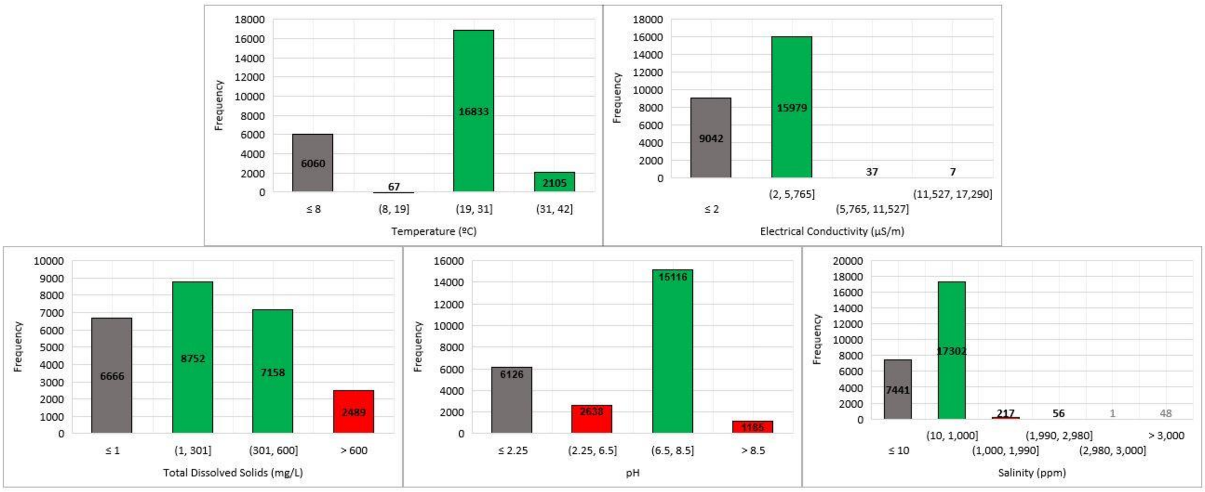


Fig. 4. Histograms showing the frequency of incomplete (gray bars) and complete data (red and green bars) for each parameter

3. Possible solutions to manage problems related to groundwater resources

Groundwater quality in the country is determined based on the PNSDW and USGS parameters for saline water as a basis (Tables 1 and 2). In situ testing of water quality was conducted in all springs and/or wells inventoried. Physical parameters such as pH, temperature, electrical conductivity and total dissolved solids (TDS) of the groundwater were measured with the use of water quality test kits (e.g., Hach, Oyster, SmarTROLL and Hanna Instrument).

Table 1. Standard Values for Physical Quality of PNSDW

Parameter	Maximum allowable Level
TDS, mg/L	600
pH	6.5 – 8.5

Table 2. USGS Parameters for Saline Water

Salinity (ppm)	Quality
< 1,000	Fresh Water
1000 – 3,000	Slightly saline water
3,000 – 10,000	Moderately saline water
10,000 – 35,000	Highly saline water

Gathered data represent points on the map and need to be interpolated in order to generate values for the entire study area. The resulting data must then be extracted from the raster using the Extract Values to Points tool. The tool will take the points generated and the IDW raster as input. The resulting feature class will have values assigned to each parameter. Values from the extracted raster were used to generate histograms for each parameter as shown in Fig. 5.

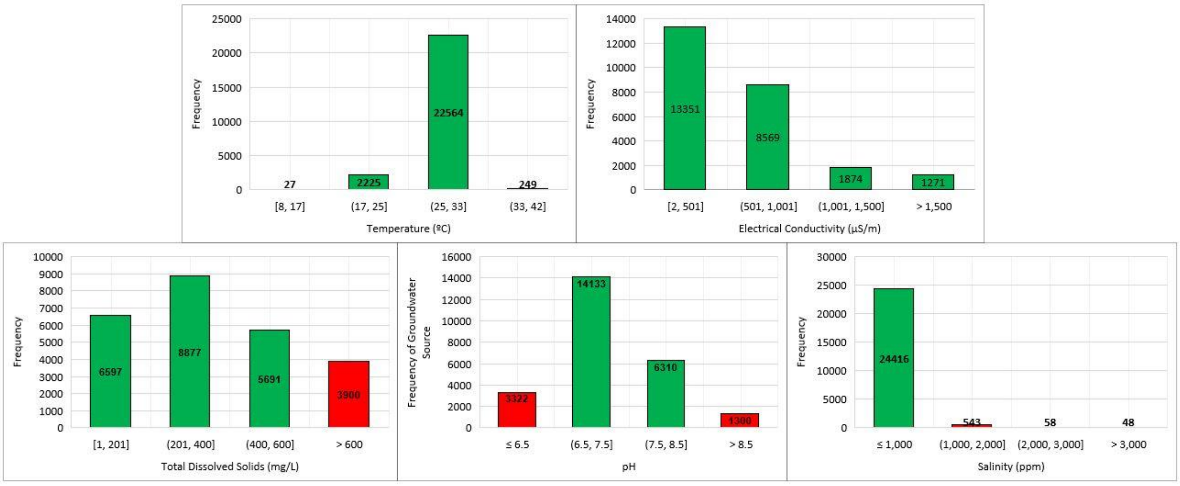


Fig. 5. Histogram displaying the frequency of interpolated values for each physical parameter. For TDS, pH and Salinity, the green bar represents the groundwater sources within the permissible limit, and the red bar represents outside the permissible limit

Temperature

Temperature of groundwater sources in the country ranges from 9.87 °C to 35 °C. On average, groundwater temperature in the area measures approximately 28.12 °C.

Electrical Conductivity

Another parameter used to determine the water quality is the electrical conductivity defined as the ability of the water to pass an electric current. Electrical conductivity is affected primarily by the amount of total dissolved solids present in the sample. Higher conductivity rate can indicate high amounts of total dissolved solids in the water.

Electrical conductivity measured in the water sources range from 8 to 5829.32 µS/cm. Average values were calculated to be 608.02 µS/cm. In general, groundwater sources in the area have low conductivity.

Total Dissolved Solids

Total Dissolved Solids (TDS) refer to the amount of dissolved ions in the water. Acceptable values of TDS shall not exceed 600 mg/L according to the PNSDW. TDS measurements in all groundwater sources in the area are below the set limit. TDS ranges from 4.93 to 4134.14 mg/L. Fifty (50) out of 81 provinces of the country have the highest TDS values.

pH

pH values of groundwater sources measure from 4.26 to 12.80. Most groundwater sources in the area are within the normal pH range (6.5-8.5) set by the PNSDW. Only five thousand eight hundred sixty-nine (5,869) out of 25,065 springs/wells are out of the acceptable range. These acidic and basic groundwater sources with pH ranging from 4.26 to 6.4, and 8.60 to 12.80, respectively, are located in the country.

Salinity

Salinity values of the country, range from 10 to 2910.58 ppm with an average of 304.72 ppm. Based on the USGS parameters for saline water, country's groundwater is classified as fresh water. Only 649 (3 %) out of 25,605 are considered as slightly to moderately saline water.

Various groundwater quality maps were created utilizing interpolated groundwater quality data points by using ArcMap GIS software as shown in the Fig. 6.

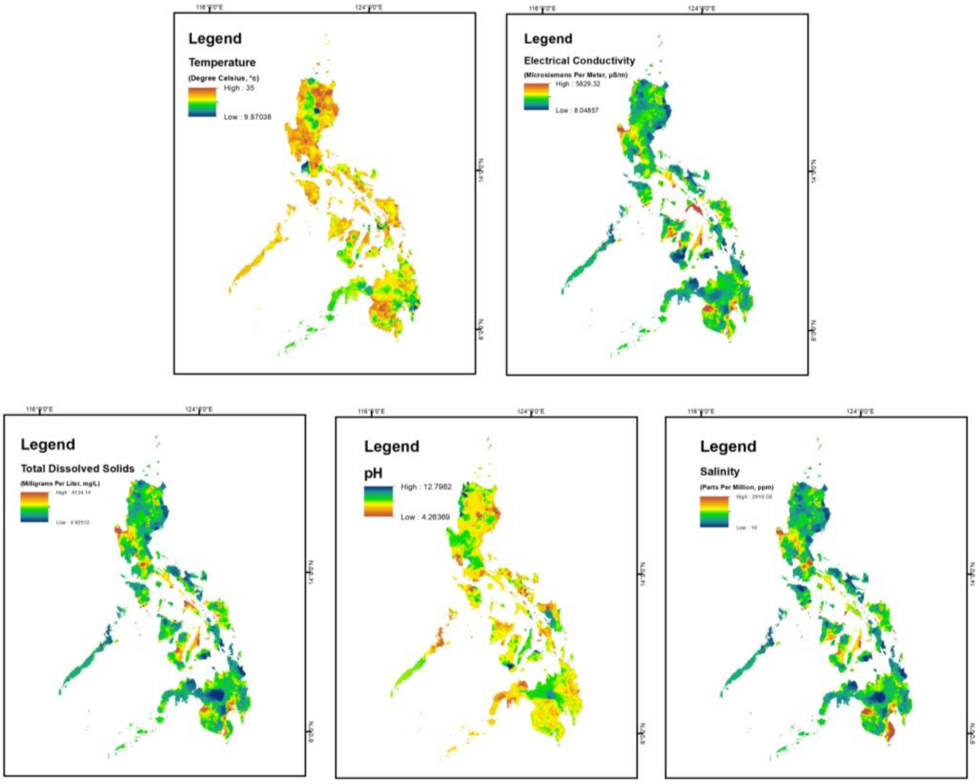


Fig. 6. Groundwater Parameter Distribution Maps of the Philippines

The results of the groundwater quality data are presented statistically in the form of minimum, maximum, and mean. Descriptive analysis of the physical parameters of twenty-five thousand sixty-five (25,065) groundwater sources is presented in the table below.

Table 3. Descriptive Statistics of Groundwater Sources in the Philippines

	Minimum	Maximum	Mean
Temperature, °C	9.87	35	28.12
Electrical Conductivity, µS/cm	8	5829.32	608.02
pH	4.26	12.8	7.24
Total Dissolved Solids, mg/L	4.93	4134.14	401.98
Salinity, ppm	10	2910.58	304.72

4. Conclusions

Geospatial and statistical techniques produce reliable estimates for improving groundwater data quality at 1:250,000-scale. The IDW interpolation method was utilized for its ability to accurately produce the interpolated surfaces of the five (5) physical parameters. In this study, the interpolation method was tested for effectiveness in determining the distribution of raster values for each parametric data. Statistical analyses using tables and distribution curves (e.g, histogram, excel) were used to enhance the ability to analyze large amounts of groundwater quality data.

The spatial distribution of groundwater quality throughout the country revealed that most of the parametric data show safety for human consumption. Most groundwater sources are within the normal pH range (6.5-8.5) and permissible limit of TDS set by the PNSDW. Salinity values are low, and majority are within the freshwater limit based on the USGS parameters for saline water.

Furthermore, the preliminary results of this study will be validated by the ongoing detailed 1:50,000-scale assessment of MGB.

References

Mines and Geosciences Bureau (2015-2018), Philippines, Groundwater Resource Assessment of the Provinces in the Philippines.

Department of Health (2017), Philippines, Administrative Order No. 2017-0010 Subject: Philippines National Standard for Drinking Water.

United States Geological Survey, accessed February and March 2022, https://www.usgs.gov/special-topics/water-science-school/science/saline-water-and-salinity.

Environmental Systems Research Institute accessed March 2022, ArcGIS Desktop, ArcMap, https://desktop.arcgis.com/en/arcmap/10.7/extensions/geostatistical-analyst/how-inverse-distance-weighted-interpolation-works.htm.

Current groundwater and surface water problems in Thailand, and their possible solutions

Praphawadee Otarawanna[1]

[1]Department of Groundwater Resources, Bangkok, 10900, Thailand
e-mail: praphawadee@hotmail.com

Abstract

In the past 10 years, it was found that the average rainfall tended to decrease with the highest volume in 2017. The southern west coast had the highest rainfall of 2,498.5 mm, followed by the Eastern, Northeastern, North, and Central region respectively. The volume of runoff in Thailand in all 25 river basins (2018 - 2019) had an average annual natural runoff of 197,321 million cubic meters, which was lower than 14.22% in 2017 - 2018.

Current groundwater and surface water problems in Thailand, there are water shortages in some areas where water is not accessible, and flood problems due to climate change. The situation of water resources tends to increase the demand for water continuously. The amount of water in large reservoirs has decreased causing impacts on the agricultural sector and the community. In preparation for dealing with issues that occur every year, the Department of Groundwater Resources (DGR) is responsible directly for solving problems of drought and repeated flooding such as the development of groundwater resources to be used throughout all affected areas. In addition, the problem of changes in groundwater levels is not only the saltwater intrusion because of over pumping excess safe yield near the coastal area or the area that is the boundary between freshwater and saltwater, but also contaminated groundwater are from smuggling industrial wastes, illegal landfills and so on. Therefore, the participation of all stakeholders in water resources management, especially water user groups such as farmers and villagers, requires a network of local water users as well as laws enforcement to regulate the use of groundwater.

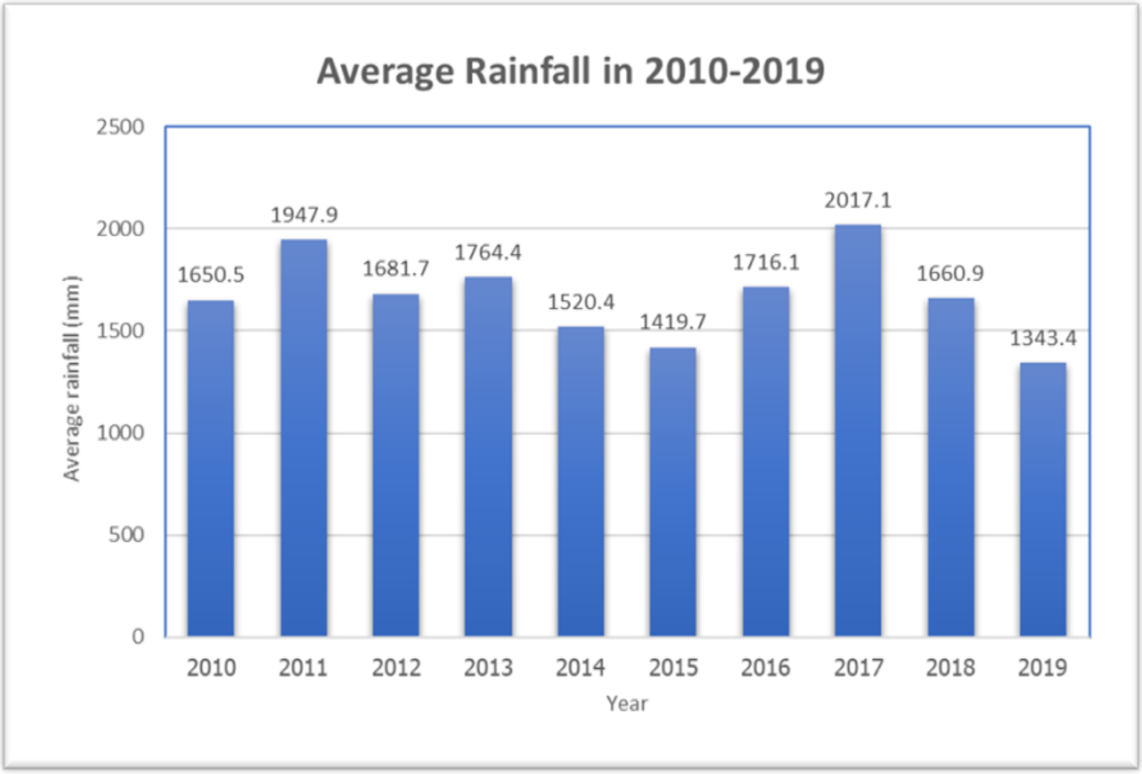
Keywords: Contaminated groundwater, Saltwater intrusion, Water resources management.

1. Introduction

In 2019, Thailand has average rainfall 1,343.4 mm (Fig. 1), which is below normal or 30 years average rainfall, representing 15.39 %, a decrease from 2018 with an average rainfall of 1,660.9 mm. The past 10 years, it was found that the average rainfall tends to decrease with the highest volume in 2017. The southern west coast has the highest rainfall of 2498.5 mm, followed by the eastern region, Northeastern, North and Central respectively.

The volume of runoff in Thailand (Table 1) in all 25 river basins (2017 - 2019) has an average annual natural runoff 197,320.92 million cubic meter, which is lower than 14.22 % in 2017-2018. Figure 2 shows areas at risk of water shortage in the dry season during 2019-2020.

There are 5 river basin groups such as the Chao Phraya Yai River Basin group, the Northeast Region River Basin group, the West Region River Basin group, the East Region River Basin group and the South Region River Basin Group (Fig. 2). From the forecast of areas at risk of water shortage in the drought season 2019/2020 by monitoring the situation, accumulated rainfall (May-September 2019) and water forecast can be used in medium-sized reservoirs and large areas in the 5 river basin groups of the country, found that Thailand has accumulated rainfall of 407 to 4,670 mm. The symbol indicates the difference in color. Purple is the highest value (> 4,000 mm) to pink is the lower value (401 - 600 mm).



The Meteorological Department (2019)

Fig. 1. Average rainfall in 2010 - 2019

Table 1. Volume of runoff in Thailand classified by region (2017 - 2019)

Region	Basin area (km^3)	Year	
		2017/2018	2018/2019
North	128,448.00	41,661.01	35,715.50
North-East	176,602.00	54,741.39	42,989.80
Central	98,473.00	36,936.23	32,834.91
East	36,438.00	24,433.49	22,098.08
South	71,401.00	72,269.64	63,682.63
Total	**511,362.00**	**230,041.76**	**197,320.92**

The Royal Irrigation Department (2019)

Triangle symbols represent large reservoirs which have different percentage of water usage by different color from lower value (red 0 - 15%), and the highest value (green 60 - 100 %). Red spots represent medium sized reservoir that has water content less than 30 percent of the capacity. The Chao Phraya Yai River Basin group is the largest agricultural area in Thailand (orange zone).

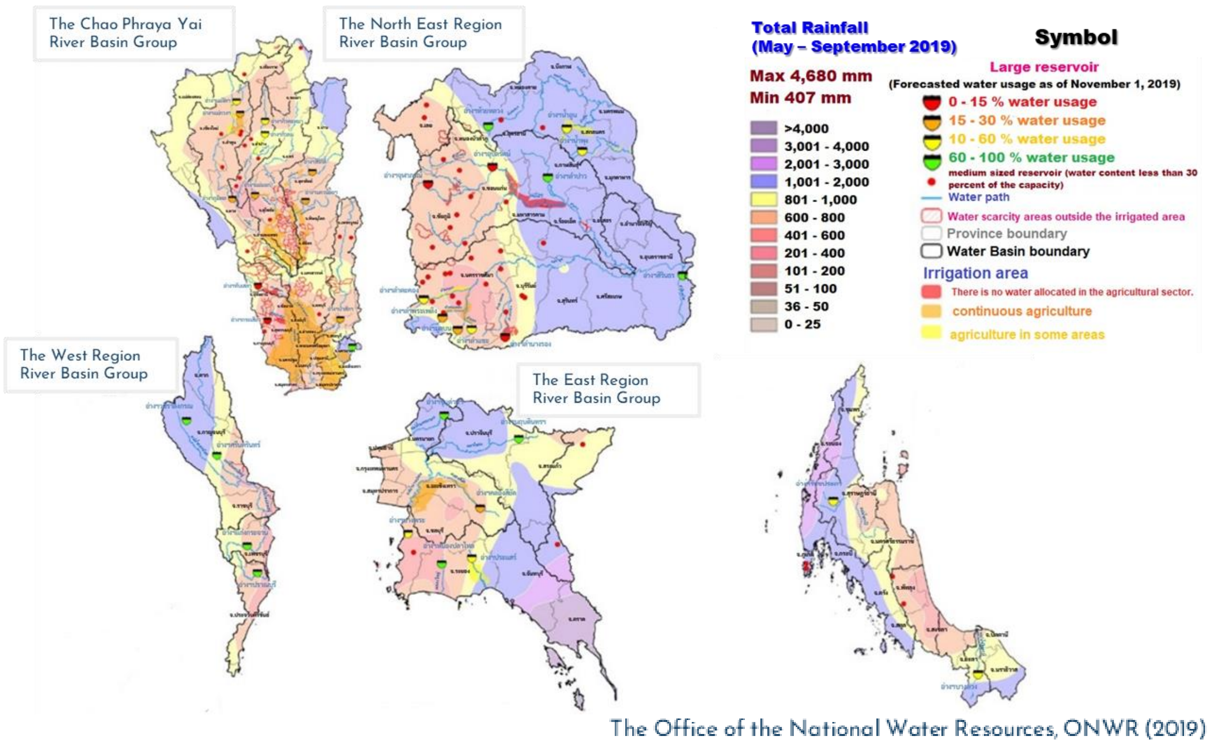


Fig 2. Areas at risk of water shortage in the dry season (2019-2020)

For the situation of 35 large reservoirs as of November 1, 2019, using the operating criteria. Reservoir (Rule Curve) found that there is a large reservoir with low water content being the lowest water storage reservoir operating criteria (Lower Rule Curve) at 15 sites. 8 of which are in the Chao Phraya Yai River Basin, namely Bhumibol Reservoir, Mae Kuang Udom Thara Reservoir, Ki Walom Reservoir Mae Mok Reservoir, Sirikit Reservoir, Pa Sak Cholasit Reservoir, Thap Salao Reservoir and Kra Siew Reservoir. The Northeastern River Basin’s 5 areas are Chulabhorn Reservoir, Ubonrat Reservoir, Lam Phra Ploeng Reservoir, Lam Sae Reservoir and Lam Nang Rong Reservoir. In the Eastern Basin, one of which is Khlong Si Yat Reservoir and one southern watershed group, namely Bang Lang Reservoir (The Office of the National Water Resources Agency, 2020).

In 2019, groundwater resources in the country from the data of 1,162 observation wells, 2,098 wells distributed in 27 groundwater basins, the total amount of groundwater stored in the country is 1,137,587 million cubic meter per year. 45,386 million cubic meter per year is the amount of groundwater that can be taken and used safely, which accounted for 3.99 % of the volume. All groundwater that is stored at the central region has the highest amount of water stored, accounted for 38.31 % of the amount of groundwater stored all. For the water supply situation, the overall groundwater level did not change much. It was found that the groundwater level is shallow, the depth does not exceed 50 m in the central region. There is a change in relation to the amount of rainfall.

Groundwater level tends to decrease and in the groundwater crisis area (Bangkok and its vicinity). It was found that the level of groundwater in the aquifers with a depth of less than 150 m in the area of Nonthaburi Province, Pathum Thani, Bangkok and Samut Prakan tend to be quite stable while the groundwater level in the groundwater slope with a depth of more than 150 m in the area of Nakhon Pathom, Samut Sakhon and Phra Nakhon Si Ayutthaya tends to decrease.

Table 2 shows that the number of groundwater wells and the amount of groundwater usage by the licensed private sector. The use of groundwater in Thailand for private wells that have been applied for permission to use in 2019, it was found that there is a total of 64,946 wells (December 2019), with the total volume of groundwater according to permits, 58,955,846 m^3, using groundwater for most business accounted for 57.75 %. All of them are licensed, followed by agriculture and consumer goods accounted for 24.40 % and 17.85 % of the total groundwater all according to the license, respectively. In this regard, the actual amount of groundwater used includes 11,666,911 m^3, by using groundwater for most business accounted for 87.30 % of the total volume of groundwater, followed by agriculture and consumer accounted for 9.96 % and 2.74 %.

Table 2. Number of groundwater wells and amount of groundwater use by the licensed private sector

Water Usage	Number of wells	Amount of groundwater (Permission)		The actual amount of groundwater used	
		Amount of groundwater (M^3)	%	Amount of groundwater (M^3)	%
Household / Consumer	18,055	10,522,780	17.85	319,256	2.74
Agriculture	21,733	14,384,584	24.40	1,162,428	9.96
Business / Services	25,157	34,048,482	57.75	10,185,227	87.30
Total	**64,945**	**58,955,846**	**100.00**	**11,666,911**	**100.00**

2. Current groundwater and surface water problems in Thailand

Current surface water and groundwater problems in Thailand are as follows.

1. Flood and drought due to Climate change recur every year
2. Wastewater from houses, industrial plants, and other human activities
3. Contaminated groundwater from the illegal dumping sites
4. Saltwater intrusion due to over pumping groundwater near the coastal area or within Northeastern part of Thailand
5. Groundwater fluctuation, decreasing of groundwater levels in some areas where groundwater is over pumping

The overall groundwater level has not changed much. However, there are water resources problems that occur such as water shortage, flooding, wastewater and salt water, which are caused by the amount of water, not enough or too much rain, encroachment on watershed forest areas and public water sources, increasing population, expansion of urban community's economic area, development of industrial area, expansion of special tourism, planting not suitable for soil and water conditions, construction of water barriers, emissions into rivers and canals, and lack of reservoirs.

Sufficient cost water and management of different water resources in each watershed area has had a broad impact, including flood and drought situations that occur regularly in many areas affecting the economy, society and people as can be seen from areas damaged by floods and droughts in Thailand. Table 3 shows the area of flood, drought and economic corridor in Thailand (2019), in total 322.44 million rai, categorized areas according to the severity of the crisis are 4 areas as below.

(1) Severe crisis areas 75.92 million rai or 23.55 %
(2) Medium-critical area, 46.20 million rai or 14.33 %
(3) Low-critical area, 34.08 million rai or 10.57 %
(4) Non-critical area, 166.24 million rai or 51.5 %

Table 3. Area of flood, drought, and economic corridor in Thailand (2019)

Region	Flood, Drought, and Economic Corridor				
	Severe	Moderate	Low	Non-critical area	Total
North	19.76	11.72	7.20	68.80	107.48
Central	15.45	8.96	4.90	21.05	50.36
East	8.44	0.41	0.81	5.06	14.72
North - East	28.00	23.80	20.08	33.04	104.92
South	2.64	0.89	0.91	27.05	31.49
Southern Border	1.63	0.42	0.18	11.24	13.47
Total	**75.92**	**46.20**	**34.08**	**166.24**	**322.44**
%	**23.55**	**14.33**	**10.57**	**51.55**	**100.00**

Unit: Million Rai
1 Acre = 2.53 Rai

Department of Water Resources (2020)

3. Possible solutions to manage problems related to water resources

Possible solutions are listed below.

1. Preparation of relevant laws and policies
2. Water resources management master plan
3. Alleviating and solving drought and flooding problems
4. Distribute groundwater to the people in the affected area
5. Groundwater conservation and restoration
6. Integrated Water Resources Management (IWRM)

4. Conclusions

The situation of water resources tends to increase the demand for water continuously. From 2010 - 2020, it was found that there was a problem of drought during the dry season due to decreased rainfall. The amount of water in large reservoirs has reduced. It was causing impacts on the agricultural sector and the community. Fig. 3 summarizes the overview, what happens, what the problem is and how to solve problems by using the diagram as shown below. Therefore, the participation of all stakeholders in water resources management, especially water user groups such as farmers and villagers, requires a network of local water users as well as laws enforcement to regulate the use of groundwater.

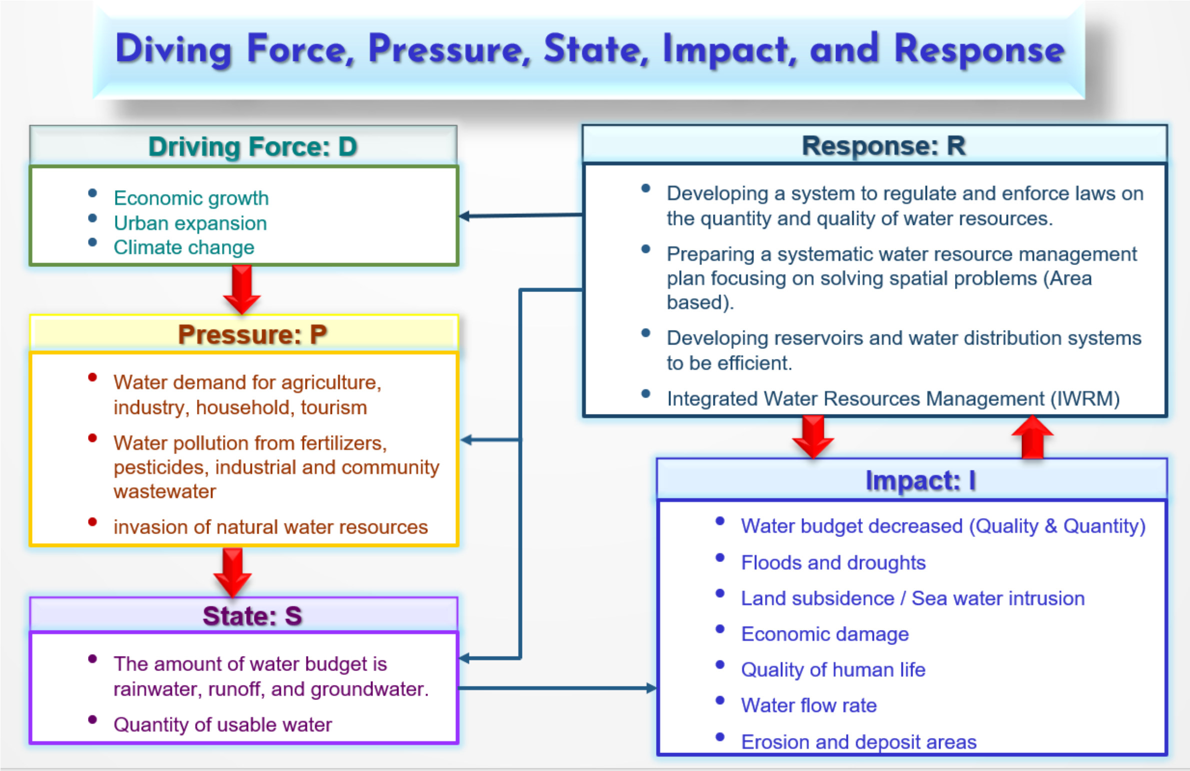


Fig 3. Summarizes the overview by using the diagram of driving force, pressure, state, impact, and response diagram

References

The Office of National Water Resources, Environmental Policy and Planning, 2017 - 2021, Water Resources. *Environmental Quality Situation Report*.

Department of Groundwater Resources Website, http://www.dgr.go.th/th/home

The Meteorological Department, 2019

The Royal Irrigation Department, 2019

Department of Water Resources, 2020