Report of the CCOP-GSJ-DGR
Groundwater Project Phase III Meeting
13-15 February 2019, Chiang Mai, Thailand

Technical Report of the CCOP-GSJ Groundwater Project Phase III

COORDINATING COMMITTEE FOR GEOSCIENCE PROGRAMMES
IN EAST AND SOUTHEAST ASIA (CCOP)
in cooperation with
GEOLOGICAL SURVEY OF JAPAN (GSJ), AIST

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and
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Youhei Uchida (Chief Editor)

I. PREFACE

Groundwater is one of the limited natural resources on the earth. Mainly due to ignorance about its importance, humans have caused various groundwater issues by their activities especially in the late 20th century. Today, land subsidence, seawater intrusion, and groundwater pollution by toxic substances are serious problems everywhere in the world. The countries in the East and Southeast Asia also have faced many groundwater problems which need international cooperation to be solved. The CCOP-GSJ Groundwater Project was launched aiming to provide some solutions for groundwater management in the CCOP region.

The Groundwater Project Phase III started in February 2015 aiming at the development of groundwater database in the CCOP region and three groups, the DB Groups I and II, and the Public Policy Group were formed to promote the project smoothly.

The CCOP-GSJ-DGR Groundwater Project Phase III Meeting was held in Chiang Mai, Thailand on 13-15 February 2019. It was the final project meeting for the Phase III and attended by 27 participants from Cambodia, China, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, Mongolia, Myanmar, Philippines, Thailand, Vietnam and the CCOP Technical Secretariat. In the meeting, participants confirmed the progress of the project from March 2018 to February 2019, and discussed the outcome of the Phase III including the publication of this technical report (GW-9).

This "Technical Report on CCOP Groundwater Project Phase III" consists of the followings which the CCOP-GSJ-GA Groundwater Project Phase III Meeting in Bali, Indonesia, decided partially revised GW-7 and GW-8:

1. Report on the present status and future plan of hydrogeological maps in each country,

2. Explanation documents on the groundwater database of the country's capital city or representative area registered on the GSi Groundwater Portal by the DB Groups I and II.

3. Public policy for the groundwater observation system created/proposed/developed by the Public Policy Group.

Though the current problem varies from one country to another due to different hydrogeological and geographical settings, all the Member Countries should share the information to create a useful hydrogeological map in the CCOP region.

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

Youhei UCHIDA
Chief Editor

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

13-15 February 2019, Chiangmai, Thailand

The CCOP-GSJ-DGR Groundwater Project Phase III Meeting was held on 13-15 February 2019 in Chiangmai, Thailand. It was attended by 27 participants from Cambodia, China, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, Mongolia, Myanmar, Philippines, Thailand, Vietnam and the CCOP Technical Secretariat (CCOPTS).

The Opening Ceremony started with the Welcome Remarks delivered by **Dr Adichat Surinkum**, CCOPTS Director. The Opening Speech was made by **Dr. Youhei Uchida**, Groundwater Project Leader, Geological Survey of Japan (GSJ, AIST).

Dr. Youhei Uchida presented the progress of the Project from 4 March 2018 to 12 February 2019. During the period, the report of the CCOP-GSJ-MME Groundwater Project Phase III Meeting (GW-8) held on 5-7 March 2018 in Siem Reap, Cambodia has been published, and uploaded to the CCOP website, http://ccop.asia/pdf/publication/GW-8.pdf.

Dr. Uchida informed that the outcome of the CCOP-GSJ Groundwater Project Phase III includes publication of a technical report on CCOP Groundwater Project Phase III (GW-9) by the end of the project in 2019. The technical report will consist the following:

1. Report titled "Hydrogeological map –Present status and future plan-"
2. Explanation documents for the country's capital city or representative area in DB1& DB2
3. Public policy for Groundwater observation system in Public Policy Group

Dr. Gaurav Shrestha from GSJ reported on the status of the project's main objective of compiling groundwater data of CCOP Member Countries using Open Web GIS System. To date the following data are available from the GSi Groundwater Portal, https://ccop-gsi.org/gsi/groundwater/index.php.

Country	No. of GW Wells	Location
China	0	
Indonesia	292	Java Island, Sumatra Island
Japan	519	Kanto, Yamagata, Ishikari, Kumamoto, Nobi Plain, Sendai
Korea, RO	221	Whole Korea
Malaysia	21	Langat Basin, Sabah *(Coordinates to be corrected)*
Philippines	1,256	Luzon Island, Bohol, Camarines Norte, Pampanga, Pangasinan, Quezon, Zambales
Thailand	2,027	Chaophraya, Khonkean Province
Vietnam	147	Thanh Hoa, Ha Tinh, Quang Nam, Quang Ngai Provinces, Hanoi
Total	***4,483***	

Philippines has uploaded groundwater data (871 wells) to the GSi MGB (Philippines) portal, and will replace the current data at the GSi Groundwater Portal with this 871 wells data. Thailand will edit the data on Khonkaen province, and will have it re-uploaded to the GSi Groundwater Portal.

Dr. Youhei Uchida also reported on progress of the CCOP Groundwater Sub-Project: Development of Renewable Energy for Ground-Source Heat Pump System in CCOP Regions. Several countries such as Philippines, Thailand (DGR Regional Office in Lampang) and Vietnam (NAWAPI) expressed interest in hosting installation of GSHP system for studies.

Country reports on respective country's groundwater database in GSi system (DB1 & DB2) and "Draft of workplan for GW monitoring and GW management program" (Public Policy Group) including suggestions for the improvement of the GSi system and further related CCOP GW project.

Group discussions were held as follows.

DB1 & DB2 (Korea, Indonesia, China, Japan, Malaysia, Philippines, Thailand and Vietnam)

Cooperation with GSi National Compiler.

- Each country has its National compilers for the GSi system
- China will request the higher authority or institution to nominate the Chinese National compiler
- Some countries need to be re-nominated, and then CCOPTS need to send official letter to each country representative, and get the feedback.

Any problems with your database

- Some data need to be checked and corrected (Indonesia)
- Need to talk to National compiler and notify the Japanese GSi team, **Dr. Shrestha**.

Opinions, suggestions, recommendations for the improvement of groundwater portal

- Securing Data quality and reliability is important
- Layer adding (time series data, well design, etc) is possible, but each country has its own complicated and more developed information system. So, the simpler, the better, but the additional parameters or information to be included in GSi system will be discussed with GSi Japanese team.

Further related CCOP Groundwater project Phase IV

GSi system

- Needs strategy to maximize database utilization compared to other database systems. The GSi system must have its own characteristics and benefits
- Needs flexibility to allow data modification

Next project

- Database advancement
- Joint groundwater/cooperative projects to solve groundwater problems in CCOP region, and any interested countries are encouraged to participate in the project

Public Policy Group (CCOPTS- **Dr Dhiti Tulyatid**, Cambodia, Lao PDR, Mongolia Myanmar, PNG<absent>, Timor-Leste<absent>)

Existing Issues

- Cambodia: data are scattered; no nationwide framework for groundwater monitoring. Siem Reap province has their own monitoring system for temple conservation. One workshop had been organized for all stakeholders for groundwater monitoring.
- Lao PDR: department of water resources, and department of geology and minerals start to collect data and monitor groundwater with the newly installed 5 wells.
- Mongolia: similar problem to Cambodia. Mineral/Mining sector deals with ONLY hydrogeology (subsurface geological condition); water is under water authority.
- Myanmar: developing of groundwater law is ongoing process, and single framework to deal with groundwater monitoring. Up to now there are 25 wells already; 9 manual &16 automatic. Problems in auto-data sending.

Direction

- Difficult to change the Government hierarchy => Formulate a working team (task force:TF) with multi-stakeholders to collect and share groundwater data. The person in charge from MCs could play a role as the bridge among the TF.
- Start filling the existing data in the GSi format and upload to the GSi Groundwater Portal
- Expand the network and publish the data regularly to get the public awareness, and start approach local policy makers/government.
- Experience sharing among CCOP members

Requests

- More on-site trainings for groundwater monitoring at this early stage of groundwater monitoring. Provide more rooms/opportunity for field survey/monitoring exchange.
- Lao PDR request technical training for principle, monitoring and analysis.
- How to upload the data? It was agreed that the updated GW data format in excel file will be distributed to all participants, including the Public Policy Group (PPG). PPG will then use the input data in this excel file, and submit to respective GSi National Compiler with copy to CCOPTS and **Dr. Shrestha**.

All Member Countries requested for the continuity of the CCOP-GSJ Groundwater Project, and look forward to its next phase for the advancement of the groundwater database for the GSi Groundwater Portal as well as to joint groundwater/cooperative projects in solving groundwater problems in CCOP region.

Dr. Adichat Surinkum, CCOPTS Director, presented on the Groundwater activities in CCOP. He encouraged all the Member Countries' continuing support and cooperation in facilitating groundwater related activities in the region. The participants expressed hearty thanks and appreciation to **Dr. Adichat Surinkum** for his effective vigor leadership of the CCOPTS in coordinating activities not only in the groundwater sector but also in other fields of geoscience.

On the last day, a field trip to Mae Moh Mine in Lampang was organized.

This minutes is adopted as signed.

Cambodia

China

Indonesia

Japan

Republic of Korea

Lao PDR

Malaysia

Mongolia

Myanmar

Philippines

Thailand

Vietnam

CCOPTS

III-1
Outline of the CCOP Groundwater Project and Subproject for Application of Ground Source Heat Pump System

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Abstract

The CCOP-GSJ Groundwater Project Phase II (2009 – 2014) released hydro-geological maps that include the latest scientific information of the Chao-Phraya Plain, Thailand and the Red River Delta, Vietnam. The map gives various kinds of hydrogeological information in digital form, for example, water quality, temperature, flow condition, and water level. The Groundwater Project Phase III started in February 2015 also aiming at the development of groundwater database in the CCOP regions. In the Phase III, three groups, the DB Groups I and II and the Public Policy Group were formed to promote the project smoothly.

Another purpose of the Phase III is to contribute to energy saving and environmental protection in Southeast Asia, where these issues are a major matter of concern. Promotion of ground-source heat pump (GSHP) system is adopted in this phase, as the efficiency of a GSHP system, namely COP (thermal output/power input), is expected to be better than conventional air-source heat pumps even in tropic countries. Three GSHP systems have been installed on a trial basis: two in Thailand, at Chulalongkorn University and at Golden Jubilee National Geological Museum, and one at VIGMR in Vietnam. The CCOP groundwater database created in the Phase III will contribute not only to groundwater management but also to the development of the maps suitable for GSHP system in CCOP member countries.

Keywords: groundwater, database, renewable energy, GSHP system

1. Introduction

Groundwater is one of the limited natural resources on the earth. Due to poor awareness of its importance, the environment surrounding groundwater was significantly impaired by human activities especially in the late 20th century, causing many problems such as land subsidence, seawater intrusion, and groundwater pollution. East and Southeast Asian countries are also facing other groundwater issues which need international cooperation such as transboundary groundwater management.

The CCOP-GSJ Groundwater Project aims to release hydro-geological map including the latest scientific information for end users. Its final mission is to make an Asian standard of hydrological maps from CCOP.

The subproject entitled "Development of Renewable Energy for Ground-Source Heat Pump System (GSHP System) in CCOP Regions" started under the CCOP Groundwater Project in April 2013. The subproject utilizes groundwater temperature data of the CCOP hydrological map. In the subproject, a GSHP System was first installed at the premise of Chulalongkorn University (Thailand) under the cooperation between Chulalongkorn University, Akita University (Japan) and GSJ.

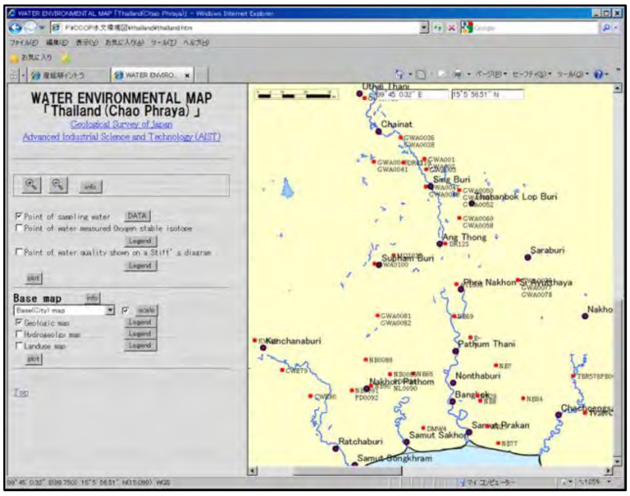

Fig. 1. Data areal Map of Chao Phraya Plain.

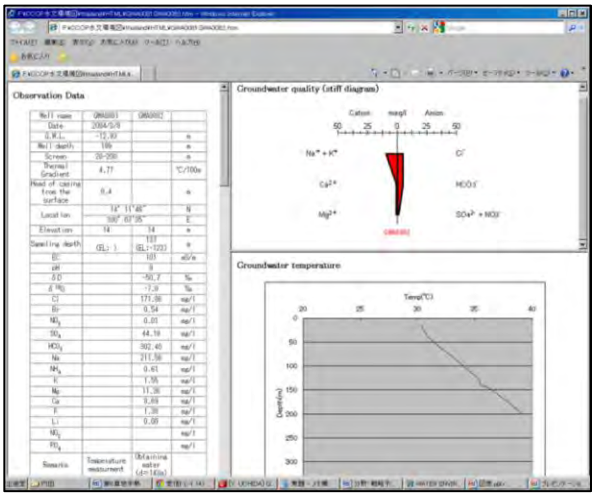

Fig. 2. Observation data window

2. CCOP-GSJ Groundwater project

The CCOP–GSJ Groundwater Project Phase II was carried out from October 2009 to March 2014. Its main theme was "renewal of the database for the hydro-geological map in the CCOP regions" and the purposes were;

1) To construct a database design,
2) To compile data of the Chao-Phraya Plain, Thailand and the Red River Delta, Vietnam, and
3) To create standards for hydrological maps in East and Southeast Asia.

GSJ and the Hydrological Mapping Working Group of the project conducted field works and hydrological analyses, and compiled groundwater data into a database. Data area map (Fig. 1) shows the location of observation points (right) which are chosen in the left sub-frame. Clicking an observation point on the map displays the observation data window as shown in Fig. 2. The location, well depth, screen depth, electric conductivity (EC), pH, and other water quality of the well are shown in the left frame, a stiff diagram of groundwater quality in the upper right, and groundwater temperature (temperature-depth profile) in the lower right.

This database consists of a map system files and simple Microsoft Excel tables, because most groundwater modeling programs such as MODFLOW, GMS and/or MT3D use Microsoft Excel files. The database is stored on a CD-ROM and is shared among the CCOP member countries.

The CCOP-GSJ Groundwater Project Phase III, whose main theme is "Renewal of database for the hydro-geological map in CCOP regions", was started in February 2015. In the Phase III, three groups were formed to promote the project smoothly: the DB Groups I and II to compile a Web based groundwater database, and the Public Policy Group to develop a draft public policy on GW observation system for efficient groundwater management in each country.

The groundwater database created in the Phase III was uploaded onto a new geoinformation system created by the CCOP Geoinformation Sharing Infrastructure for East and Southeast Asia (GSi) Project (Takarada and Bandibas, 2017). The main aims of the GSi project are to construct an open web-based database system using the world standard formats and GIS and to share various geoscientific information in the CCOP member countries through the system (Fig. 3).

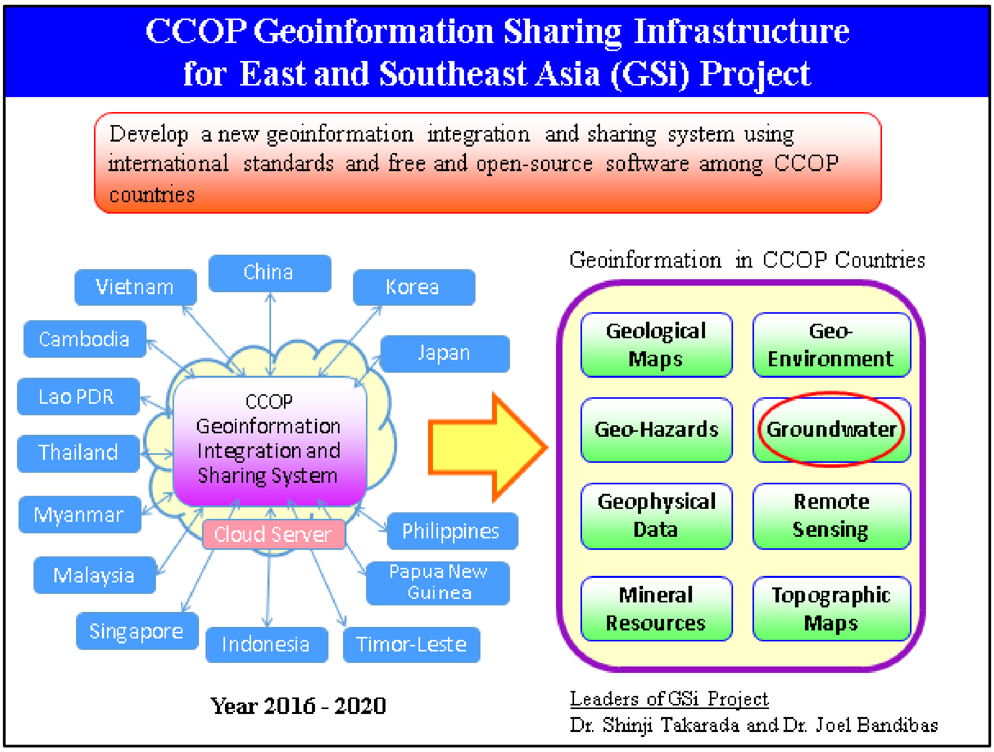

Fig. 3. Outline of CCOP Geoinformation Sharing Infrastructure for East and Southeast Asia Project (Takarada and Bandibas, 2017).

GSi system was officially released on 18th September 2018 and is accessible from "https://ccop-gsi.org/main/". The total number of 4,483 data which the member countries compiled and uploaded through the project are available from the GSi Groundwater Portal, https://ccop-gsi.org/gsi/groundwater/index.php" including compiled groundwater data of Japan, Thailand and Vietnam from the Groundwater Project Phase II (Fig. 4).

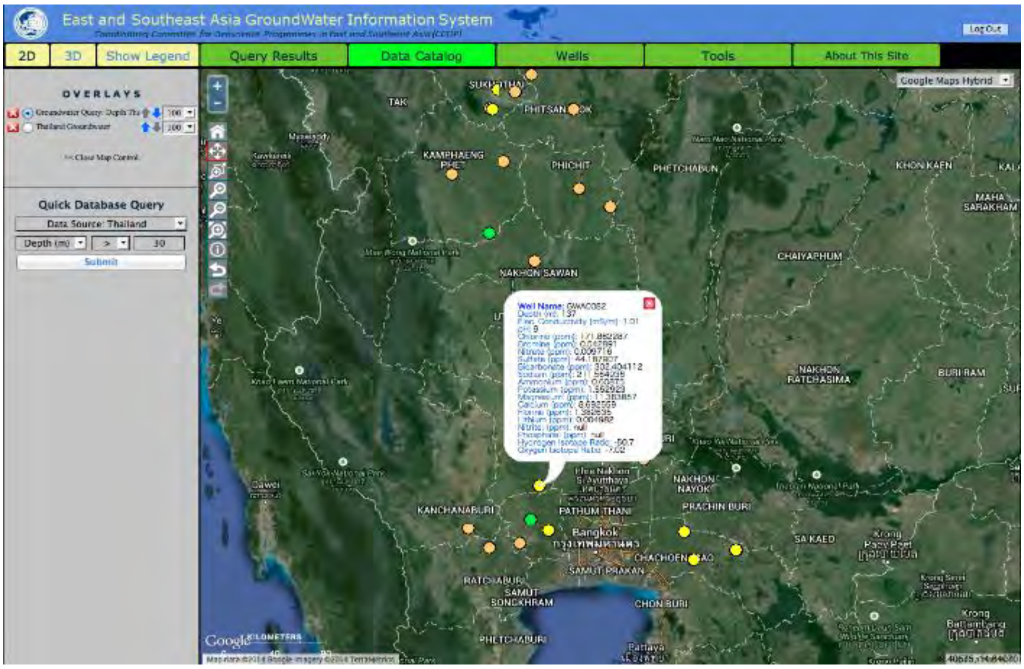

Fig. 4. CCOP Groundwater portal site on the GSi system.

3. Application of GSHP system

3.1. Experimental investigation of GSHP system for space cooling in Thailand and Vietnam

In Southeast Asia, where significant economic growth is expected this century, saving energy and protecting environment is a major matter of concern. GSHP System (Fig.5) is expected to be a promising approach to contribute to these issues, as its performance (COP, thermal output/power input) is better than conventional air-source heat pumps. The system has been introduced worldwide since the oil crisis in the 1970's, especially in the United States and North Europe. On the other hand, in Southeast Asia, the number of installed GSHP systems is very small.

Most of the major cities and towns in Southeast Asia develop on an alluvial plain or a basin, where the Quaternary system is relatively thick. The geological settings of Quaternary layers are usually considered not very suitable for GSHP because its thermal conductivity is lower than in Tertiary system and older sedimentary rocks. However, thanks to high hydraulic conductivity in Quaternary deposits, as well as abundant aquifers there, groundwater flow in the layers cause thermal advection which increases effective thermal conductivity. Making good use of groundwater flow is the key to successful operation of GSHP system in Southeast Asia.

The sub-project entitled “Development of Renewable Energy for Ground-Source Heat Pump System in the CCOP Regions” started in April 2013. Chulalongkorn University, Akita University and GSJ worked together in a cooperation program to install a GSHP system at Chulalongkorn University. Its objectives are as follows:

1) To demonstrate the benefits of installing a GSHP system in Bangkok City, Thailand,
2) To develop the adjustment technique for the GSHP system in tropical regions, and
3) To develop maps of areas suitable for GSHP system in Thailand reflecting large-scale

groundwater flow and a heat transport model.

Cooling efficiency of the GSHP system with two borehole heat exchangers was tested at Chulalongkorn University in February 2014. The measured data were compared with those of the existing air conditioner of similar capacity in the laboratory room. The result shows that the GSHP system can reduce the electricity consumption by 30% (Chokchai, 2016; Chokachai et al., 2018).

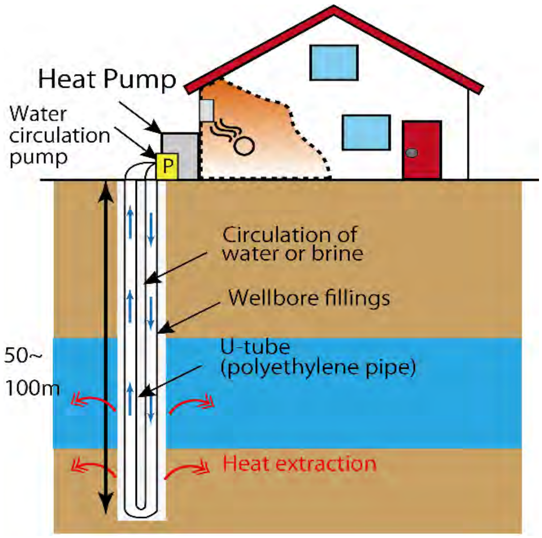

Fig. 5. Ground-Source Heat Pump System under cooling mode.

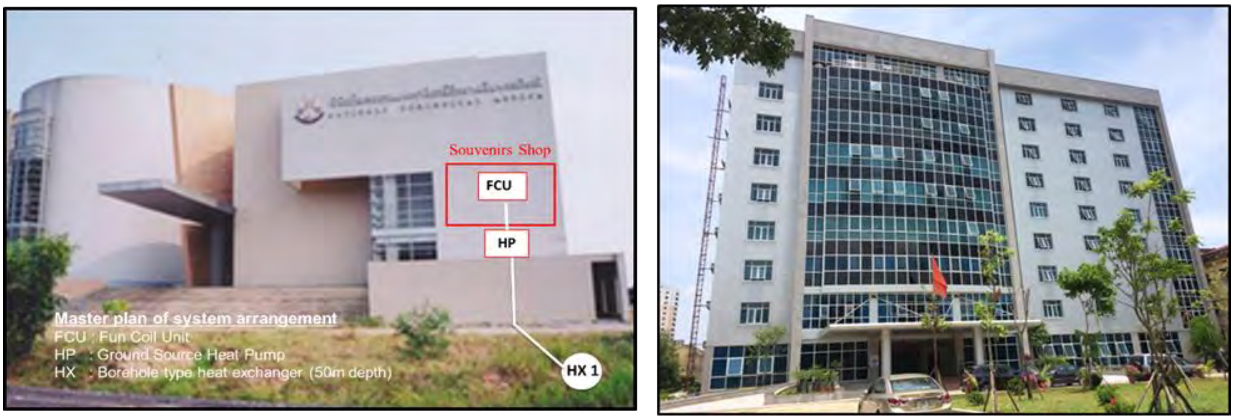

Fig. 6. Photos of Golden Jubilee National Geological Museum, Thailand (left) and Vietnam Institute of Geoscience and Mineral Resources, Vietnam (right).

The same type of GSHP system was installed at the Golden Jubilee National Geological Museum, Department of Mineral Resources (DMR), Pathumthani, Thailand in March 2015 and at the Vietnam Institute of Geoscience and Mineral Resources (VIGMR), Hanoi, Vietnam in October 2016, respectively (Fig. 6). As Hanoi City is situated in northern Vietnam, there are big advantages not only for cooling but also for heating (Yasukawa et al., 2009).

3.2. Thermal response test

Thermal conductivity is one of the inherent properties of the materials to conduct heat. It is used to characterize quantity of stable heat transfer. Apparent thermal conductivity, on the other hand, involves effect of thermal advection due to groundwater flow.

Thermal response test (TRT) is used to determine the subsurface and borehole thermal properties, which are needed to determine the size of the ground heat exchangers for GSHP systems. In the TRT, the temperatures of the water circulating in a closed loop and its flow rate are measured at the inlet and outlet of the borehole heat exchanger. The results are treated with analytical models to determine the subsurface apparent thermal conductivity and the borehole thermal resistance.

The TRT conducted at the test site of GSHP system at Chulalongkorn University in February 2018 shows that apparent thermal conductivity (λ) is 1.82 W/(m-K), which is larger than an average apparent thermal conductivity in Japan (1.2 - 1.4 W/(m-K)). The result suggests that there is a high potential of GSHP system there due to active groundwater flow (Fig. 7).

Fig. 7. Connecting the borehole heat exchanger of the GSHP system to the TRT instrument (left), and the TRT instrument made by Akita University (right)

Moreover, the TRT was conducted on the GSHP system installed at the Vietnam Institute of Geoscience and Mineral Resource (VIGMR), Hanoi to evaluate the apparent thermal conductivity of the ground on July 2018. The apparent thermal conductivity of the ground at the VIGMR was estimated about 1.5 W/(m-K) and proved to be big enough for the cooling and heating application of GSHP system in Hanoi.

4. Conclusions

The CCOP-GSJ Groundwater Project Phase II was carried out from October 2009 to March 2014 and the project compiled hydrological information on the Chao-Phraya Plain, Thailand and the Red River Delta, Vietnam. In the project, the standard design for hydrological maps in East and Southeast Asia was created. The CCOP-GSJ Groundwater Project Phase III started in February 2015, compiling the hydrological information in the CCOP member countries based on the design created in the Phase II. The groundwater database in the Phase III will be uploaded onto the GSi system.

Moreover, the subproject of the GSHP system in CCOP regions started in 2013 and three GSHP systems have been installed at Chulalongkorn University, Golden Jubilee National Geological Museum and Vietnam Institute of Geosciences and Mineral Resources. Cooling experiment of the GSHP system at Chulalongkorn University proved a high efficiency, reducing electricity consumption almost by 30%.

The CCOP groundwater database compiled in the Phase III will contribute not only to groundwater management but also to the development of the maps suitable for GSHP system in the CCOP member countries.

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III-2-(1)

The Current Developments of Arsenic Contamination in Kendal Province, Cambodia

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Ministry of Mines and Energy

1. Introduction

Cambodia's official name became the Kingdom of Cambodia in the 1990's. The Kingdom of Cambodia is located in Southeast Asia in the southwestern part of the Indo-Chinese peninsula. It lies between latitudes 10' and 15' North and longitudes 102' and 108' East in the Tropical North, and covers an area of 181,035 km². The Kingdom of Cambodia shares its 2,438 km border with Thailand, Laos PDR, and Vietnam (attached map). The maximum length of the country is approximately 580 km from east to west and 450 km from north to south and it has a total boundary of 2,600 km of which approximately 5/6 is land and 1/6 is a coastline. Approximately 86 % of the total land area lies within the Mekong Catchment (Mekong River Commission, 1998). Cambodia's climate is a part of Monsoon Asia and Tropical zone with pronounced wet and dry which divide in two seasons are dry season from November – April and Rain falls Mainly in May - October.

Fig.1. Map of Cambodia

2. History of Groundwater in Cambodia

In Cambodia, Groundwater have been investigated and exploited. In year 1958, on behalf of the United States Operation Mission (USOM) in Cambodia, it has been investigated by U.S. Geological Survey (USGS), R. V. Cushman. The main purpose could be for agriculture economic for irrigation was available during dry season from December to May. The result of this program had been collected for all the data needed and carried out for the groundwater used in the future.

During 1960-63, 1103 holes were drilled of which 795 of approximately 72 % productive wells at rates were ranging from 1.1 to 2,967 l/min. The productive wells ranged in depth from 2 to 209.4 m and were 23.2 m deep on the average.

Mr. Rasmussen studied the subsurface geology of Cambodia in considerable detail by examining drillings logs and constructing nine geologic cross sections. The principal aquifer tapped by drilled wells in Cambodia is the Old Alluvium. In many places, however, dug wells and a few shallow drilled wells obtain water from the young alluvium. Sandstone of the Indosinias formation yields moderate to small quantities of water to wells in a number of places. Also, numbers of wells tapping water-bearing basalt have a small to moderate yield.

3. Hydrogeological Characteristics and Groundwater-related Issues

- Strong geological control, with high arsenic almost always present in young alluvium (Fig. 2).
- Less risk for irrigation compared to drinking water, but needs to be considered.
- Poor quality groundwater can reduce crop yields and, in extreme cases, harm the soil chemistry and structure.

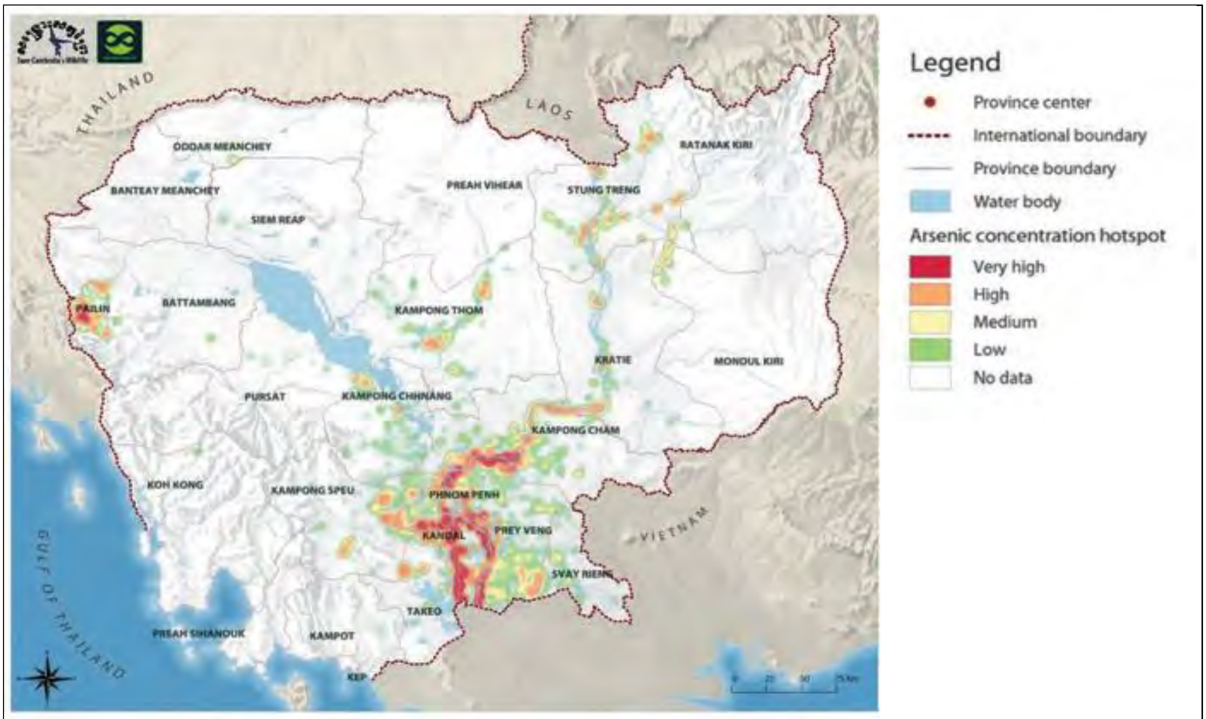

Fig. 2. Arsenic concentration hotspot map of Cambodia

3.1. Status of Groundwater Resources in Cambodia

- Groundwater is available almost everywhere in plain area except Dry-Zone in Central and Northwest region.
- Groundwater study is in progress (7 provinces out of 24 completed).
- Groundwater is major source for drinking water supply in Cambodia; 53 % of Cambodian households use groundwater sources during dry season.
- No data available for Groundwater Exploitation in Cambodia yet. About 270,000 tube-wells with hand pump are functioning for drinking water purpose.

3.2. Major issues and challenges that threaten groundwater resources

Groundwater quality problems include high arsenic and iron (Fe) contents in the Mekong and Tonle Sap River Basin (along the rivers). Saltwater intrudes from the sea in coastal areas (south-eastern provinces). Industrial zones are expanding in Cambodia and thus, causing potential groundwater contamination from untreated industrial waste. At present, groundwater is only used from small water supply communities but is trending toward greater industrial use and agricultural irrigation. Major threats from over-exploitation may occur without legal control from groundwater administrations. Groundwater management should be partially included in the water resource laws.

3.3. Potential consequences of groundwater issues

The health impact of arsenic contamination is of major consequence. Soils may be damaged from saltwater intrusion in coastal regions. In these areas, the groundwater tables are low and saltwater intrusion into these shallow aquifers could damage the soil quality. Groundwater is a major source of drinking water. If untreated industrial wastes are uncontrolled, the groundwater quality will deteriorate. The over-exploitation of groundwater could affect the environment and historical sites in Cambodia (therefore, the government should start to control groundwater development in Siem Reap region).

Two hundred manual rainfall stations are presents in Cambodia, approximately 10 of which are delivering continuous time-series data. One hundred twenty-seven hydrological stations are also present, 97 of which are water level stations.

4. Discovery of Arsenic in Cambodia

Arsenic (As) is a toxic metalloid element and it is well known that arsenic exposure causes lung and skin cancer, and birth defects. In the case of chronic poisoning, arsenic accumulated in hair, skin and nails, resulting in strong pigmentation of hands and feet (i.e., keratosis), high blood pressure, and cardiovascular, respiratory, endocrine, neurological and metabolic dysfunctions/disorders.

Naturally occurring arsenic was first confirmed in drinking water in Cambodia during the Cambodia Drinking Water Quality Assessment, conducted jointly by the Ministry of Rural Development (MRD) and the Ministry of Industry, Mines and Energy (MIME) between 1999 and 2000. This assessment screened approximately 94 urban and rural drinking water sources in 13 provinces for chemically hazardous elements and found elevated arsenic levels in approximately 11 per cent of the groundwater samples from 5 of the 13 studied, exceeding the WHO guideline value of 10 ppb.

In the present study, we investigated the potential arsenic exposure of Cambodia residents from their daily drinking water consumption. Groundwater samples were collected from some villages nearby Phnom Penh City in Kendal province, in the Mekong River basin of Cambodia.

4.1. General arsenic information from some villages nearby Phnom Penh City in Kendal province

As: metalloid group has many metallic properties and Inorganic arsenic forms

Arsenate-As (V): H_3AsO_4, $H_2AsO_4^{-}$, $HAsO_4^{2-}$, AsO_4^{3-}

Arsenate-As (III): H_3AsO_3, $H_2AsO_3^{-}$

4.2. Impacts of arsenic (As) on human health (Fig. 3)

- Chronic arsenic exposure (5-20 years)
- Non-cancer diseases: weak digestion, tired, neurasthenia, vascular, skin disorders
- Relative cancer diseases: gangrene, skin, lung, bladder and liver cancer

4.3. Arsenic contamination in Cambodia

Groundwater tube-wells: Main source of drinking water in Cambodia, especially in the rural area. In 2000, Identified arsenic concentrations above 100 µg/L (WHO drinking water guideline: 10 µg/L) in Cambodia through a small-scale drinking water quality screening in hand-pumped tube-wells.

4.4. Groundwater usage in the Kendal Province

About 1.3 million people have stopped using surface water or water from shallow dug wells due to bacterial diseases. Instead, it has become popular to pump groundwater using individual private tube-wells.

4.5. Exposure assessment

[Cumulative As intake (mg)]= [As level in groundwater (mg/L)] X [Period of exposure (year)] X [Ingestion rate of groundwater (365 days/year) X [Water consumption (2 L/day)]

As Exposure assessment

Relationship between arsenic concentrations, are in groundwater and cumulative arsenic intake in residents in the Kendal Province. Groundwater was considerably contaminated with As, Ba, Mn, Pb and Se. There were about 83 %, 52 %, 69 %, 48 % and 100 % of groundwater exceeded WHO drinking water guidelines for As, Ba, Mn, Pb and Se, respectively.

As (III) was found to be the dominant species in all of groundwater samples with high concentrations ranging from ND (in Don Sor (DS) village) to 1,334 µg/L (in Phum Thom (PT) village).

High arsenic concentrations (> 100 µg/L) were found along the Mekong River with young alluvium sediments. This indicates the strong geological control of groundwater arsenic in Kendal Province.

For the health risk assessment, Phum Thom village had the highest cumulative As ingestion, followed by Chorn Lork (CHL), Phum O Thom (POT), Tuo Tnoeut (TT), Don Sor (DS) and Po Pear Kher (PPK) villages.

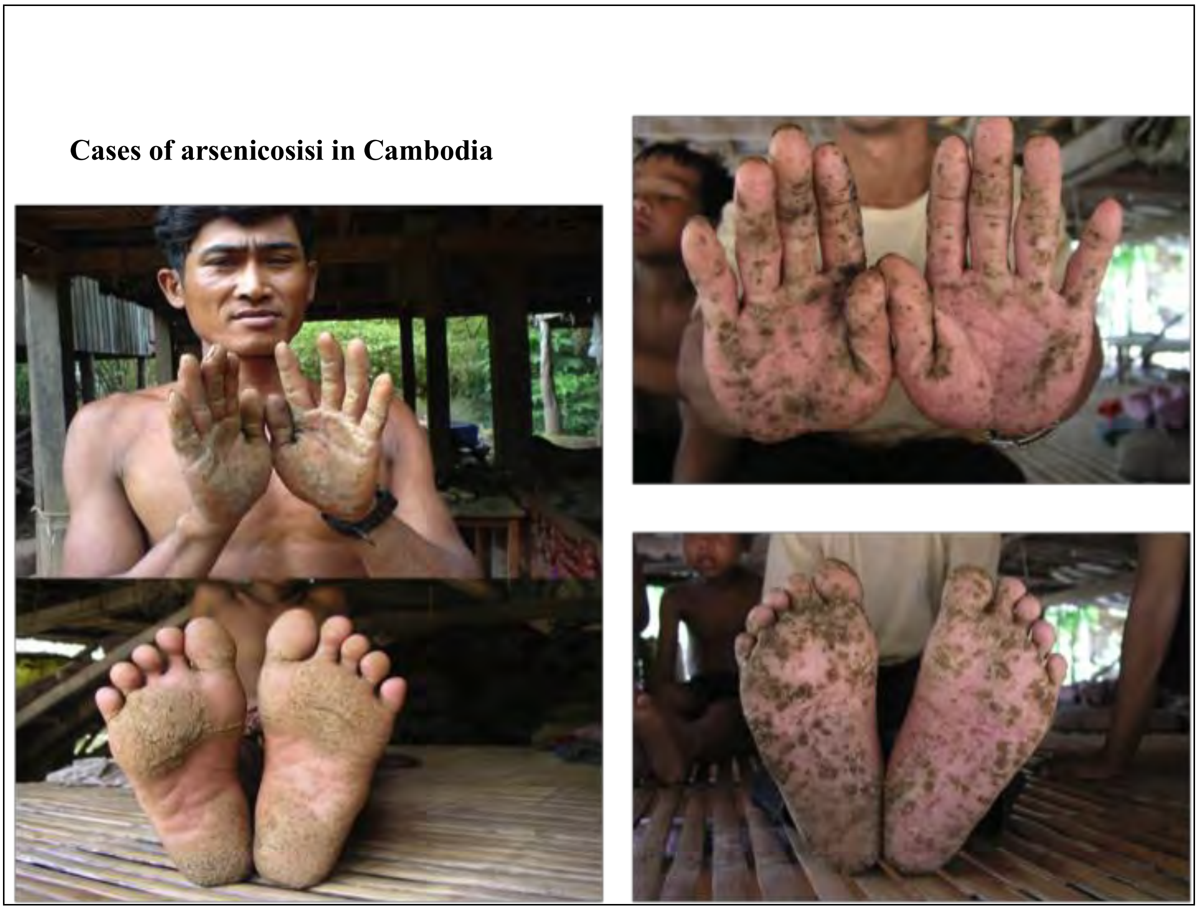

Fig.3. Impacts of **As** on human health

III-2-(2)
Hydrogeological mapping in China -Present status and future plan-

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Abstract

This paper briefly introduces the achievements of hydrogeological investigation and mapping in China in the past few decades. The hydrogeological survey in small scale, mainly in 1:200,000 scale has been completed through all the country. The groundwater resources were evaluated and the first round of regional investigation on groundwater pollution has been fulfilled. The National Groundwater Monitoring Project is carried out and the hydrogeological info-system has been recently developed. At present, China is carrying out a new stage of hydrogeological survey in 1:50,000 scale through using new technology and theory. Those efforts have played a vital role in supporting national economic and social development.

Keywords: groundwater, hydrogeological map, info-system, China

1. Introduction

The annual recharge for fresh groundwater is 884×10^9 m^3/a, accounting for about 31 % of water resources in China. From the 1950s to 1990s, a large number of hydrogeological investigation and evaluation has been carried out in China. The hydrogeological survey has covered 6.30×10^6 km^2 with a scale of 1:200,000 and 3.30×10^6 km^2 with a scale of 1:500,000 to 1:1,000,000. During this period, the hydrogeological survey of 1.30×10^6 km^2 areas for farming and animal husbandry in 1:100,000 scale has also been completed. Since 1999, the hydrogeological and environmental survey of the original basin with 2.20×10^6 km^2 areas in 1:250,000 scale has been completed, and in concentrated poverty-stricken region and ecologically fragile region in 1:50,000 scale has also been completed, covering 0.40×10^6 km^2 areas. Moreover, the regional groundwater pollution investigation with 4.40×10^6 km^2 areas in 1:250,000 scale has been fulfilled with a space database created. Based on investigation, the total quantity, expected exploitable quantity and current exploited quantity of groundwater in China and the catchments under investigation have been evaluated. Besides, the groundwater resources were evaluated in 1983, and it was evaluated once more in 2000 based on new investigated data. The results show that the whole groundwater resources is 923.5×10^9 m^3/a. Since 1950s, China began to carry out the groundwater monitoring. And China launched the National Groundwater Monitoring Project (NGMP) in 2015. These works have played a vital role in supporting national economic and social development.

2. Recent groundwater data and hydrogeological mapping in China

2.1 Overview

Over the past few decades, on the basis of various types of hydrogeological surveys, a large number of relevant data have been obtained and a large number of hydrogeological maps have been compiled and published.

In 1950s, China published the first national hydrogeological zoning map in 1:3,000,000 scale. In the early 1960s, many regional hydrogeological maps in smaller scale were compiled and published, including the series of Songliao Plain hydrogeological maps and Huang-Huai-Hai Plain hydrogeological maps in 1:1,000,000 scale, which included hydrogeological maps, groundwater chemical maps, farmland water supply hydrogeological maps and quaternary geological maps, etc. This is the first batch of small scale hydrogeological maps in China. In the late 1970s, "the People's Republic of China Hydrogeological Atlas" were published. The album includes the national map series, regional map series and provincial map series, which basically reflected the China's main achievements in hydrogeological maps during the past three decades. In the middle of 1980s, the China hydrogeological map and China groundwater distribution map in 1:4,000,000 scale were finished. And Environmental Geological Map of the Yangtze River Basin, Northwest region environmental geological map and other regional maps were completed.

2.2 Hydrogeological Mapping（1:200,000）

Over the past few decades, the maps of 1:200,000 hydrogeological survey were the most influential hydrogeological products. It was gradually carried out according to international standard format with a nationwide plan. In order to unify the working methods, the Specification for hydrogeological survey and mapping in 1:200,000 scale were compiled and published on the basis of summing up foreign advanced methods and domestic reality. In addition to the standard synthetic hydrogeological map, the products still include text reports and other ancillary maps, such as quaternary geological map, geomorphic map, water quality map and so on.

Since 1999, CGS began to construct the national hydrogeological space database which was mainly based on the the products of 1:200,000 regional hydrogeological survey. China Institute of Geol-Environmental Monitoring (CIGEM) organized the development of hydrogeological space database standards and work guidelines. By 2006, about 1148 sheets of the standard synthetic hydrogeological maps (Fig. 1) and many other hydrogeological maps were digitized and synthesized in the database. The information of the data covered 9.60 million km^2 and more than 40 major cities.

The national hydrogeological space database achieves resource sharing and plays a multi-purpose, all-round role. It provides a great deal of hydrogeological information services for land development, agricultural planning, urban development, water conservancy construction, geological environment protection and new rural construction.

2.3 Hydrogeological Mapping（1:50,000）

In order to meet the needs of economic and social development and ecological civilization construction, CGS has also carried out a higher precision hydrogeological survey (1:50,000). In recent years, the hydrogeological survey in 1:50,000 scale turns into comprehensive survey which pays equal emphasis on resources and ecological environment compared with the traditional single groundwater resources survey.

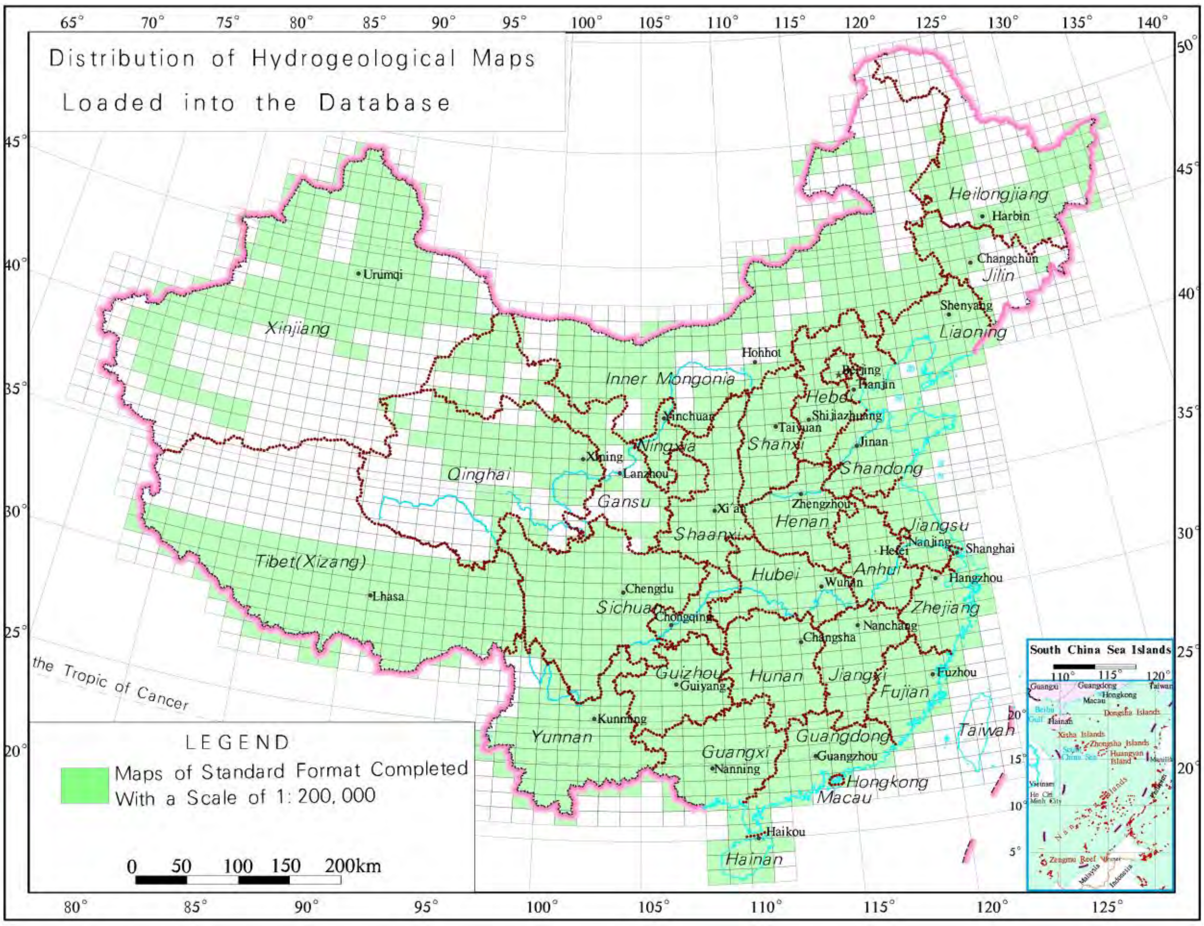

Fig. 1. National Hydrogeological Map Database (scale of 1:200,000)

The new 1:50,000 hydrogeological survey takes groundwater system theory as the guiding ideology, emphasizing the application of new technology and new methods. Firstly, a "survey, mapping and database" trinity of the technical standard system for hydrogeological survey has been constructed. Secondly, it emphasizes on needs-oriented research. That is, the mapping should follow the procedures of "analysis of existing information, pre-mapping, targeted work and compilation of reports and mappings". It was planned according to the whole drainage basin and carried out with standard sheet. Thirdly, it uses many key technologies such as multi-type remote sensing data interpretation, aviation and ground hydrogeophysical prospecting, automated real-time monitoring, three-dimensional simulation and so on. The whole hydrogeological survey process information is recorded in computer.

A series of maps should be compiled according to the hydrogeological survey results. There are some maps which must be compiled by standard sheet style, such as the workload map and the hydrogeological map (including the hydrogeological profile and the manual of the map). There are some maps which should be compiled by the whole groundwater system, such as hydrogeological map (including the hydrogeological profile), map of groundwater resources, map of groundwater environment, zoning map of groundwater utilization and protection and the written report. There are also pieces of maps that are compiled according to actual needs by the whole groundwater system, such as groundwater exploitation potential map, hydrogeochemical map of groundwater, groundwater quality map, map of buried depth groundwater, groundwater level contour map, groundwater level variation map, groundwater antifouling performance map, three-dimensional hydrogeological structure map, aeration zone structure map and so on. And there are still a few maps that are compiled by administrative area. In short, the series of maps include not only professional maps but also applied maps.

As for the new standard hydrogeological map, the layout of it is further optimized. It includes main maps, hydrogeological column, legend, hydrogeological cross section and some mosaic maps. The main map highlights the hydrogeological features. The hydrogeological column highlights the division of water-bearing formation and its productivity grade. The mosaic maps highlights the three-dimensional expression and the groundwater system concept. The hydrogeological cross section mainly reflects the aquifer structure, hydrogeological parameters, groundwater recharge characteristics, groundwater flow system and so on.

3. Hydrological survey and groundwater monitoring for database / hydrogeological map

A hydro-geological info-system has been recently developed to manage the historical indexes, raw data, achievements, summary and resulting maps of hydrogeological survey already carried out in administrative regions, drainage areas, plains/basins or standard-division map range(1:50,000 ~ 1:1,000,000). Served as a beta version, the info-system is now shared online for some public organizations.

With an annual data storage of 342,000 records from 1980s to 2015, China's national groundwater monitoring data including 172,200 groundwater-level data records, 93,900 groundwater-quality data records are managed in the above info-system. These data are mainly manufactured from 1820 National-level monitoring wells all over China, among which 914 wells are for porous-phreatic aquifer, 572 for porous-confined aquifer, 85 for fissured aquifer and 249 for karst aquifer. However, most of them (1461) are manual observation wells, and the rest 359 are auto-observation wells; the majority (1370) of them runs in very good condition.

As mentioned above, the national hydrogeological space database (with a scale of 1:200,000) constructed since 1999 has already been loaded into the Hydro-geological Info-System, mainly including 1017 sheets of the standard synthetic hydrogeological maps. The new 1:50,000 hydrogeological survey plan since 2016 might produce 100-200 result maps per year. These maps might also be loaded into INFO-SYS. The nationwide hydrogeological maps with different scales from 1:3,000,000 to 1:14,000,000 have been achieved during various historical periods, and these digitized results of which might be managed in the INFO-SYSTEM too.

4. Future plan of hydrological mapping in China

Since 2014, CGS has formulated "Nine Programs" to meet the requirements of "five service" Among them, the Fourth Program is the Program of Geo-disaster Prevention and Geoenvironment Protection. There are several subprograms under it. It includes four subjects related to hydrogeological mapping, namely survey of hydrogeology and environmental geology in the ecological fragile areas and indigent areas, survey of the hydrogeological environment in the karst areas, groundwater quality investigation for main aquifers and the National Groundwater Monitoring Project.

In the next five years, CGS plans to carry out the hydrogeological survey of 30,000 km^2 areas in 1:50,000 scale every year, which covers the 14 concentrated poverty-stricken region and ecologically fragile areas. And about 110 exploration wells will be constructed every year, which can supply enough safe water resources for 800,000 people. A new phase of groundwater quality investigation for main aquifers is started. To 2020, the groundwater quality of 19 main aquifers covering about 1.0×10^6 km^2 in the east and west China will be investigated. To 2017, about 2502 groundwater automatic monitoring sites will be constructed. The first phase of the National Groundwater Monitoring Project construction will be finished.

5. Conclusions

The Chinese government attaches great importance to water resources management. Over the past few decades, a great deal of hydrogeological investigations and mapping were carried out, which has provided an important supporting role for the economic and social development. The maps of 1:200,000 hydrogeological survey were the most influential hydrogeological products. A hydrogeological info-system has been recently developed. All the hydrogeological data from survey and monitoring are synthesized into the info-system. During these years, CGS focuses on the new 1:50,000 hydrogeological survey applying new technology and theory. CGS is willing to strengthen international cooperation and jointly promote the technical methods of hydrogeological survey.

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III-2-(3)
Hydrogeological mapping in Indonesia -Present status and future plan-

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Abstract

Groundwater mapping is a part of the first step in the groundwater management in Indonesia, though the map also can be used for other purposes, e.g., regional planning. The history of hydrogeological mapping in Indonesia was started in 1972 by cooperation with the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Germany through a project of German Hydrogeological Advisory Group (CTA-40). The project produced hydrogeological map scale of 1:250,000, focused on Java Island. After reformation era since 1998, following the decentralization system, the responsibility of groundwater mapping in Indonesia was split between central government and local government. Central government was responsible to produce hydrogeological map scale of 1:250,000 and local governments producing maps scale of 1:100,000 or larger (Law number 22 years 1999 and Government Regulation number 25 year 2000). Until 2016, central government (Center for Groundwater and Environmental Geology, Geological Agency of Indonesia) has finished hydrogeological mapping scale of 1:250,000 in all area of Indonesia, split into 266 sheets. Technically the map is created by, first, data compilation, followed by fieldworks, and finished with studio works. The compiled data including several thematic maps, i.e., geological map, topographic map, geomorphology map, land use, landsat, and rainfall map. Meanwhile, measurement of groundwater quantity and quality, including water sampling are accomplished in the fieldwork. Current government issued one map policy in order to provide semi-detail map with a scale of 1:50,000 to support local and regional development planning, regulated in Presidential Decree number 9 years 2016. In this program, Center for Groundwater and Environmental Geology is responsible to provide hydrogeological map scale of 1:100,000. The program was started by finishing hydrogeological map in 17 provinces and the rest of 17 provinces will be finished in 2017. More detail hydrogeological maps, i.e., with a scale of 1:50,000, are planned to be finished in the upcoming years. The hydrogeological maps, together with other detail thematic maps, will be compiled in a database system, managed by Badan Informasi Geospasial-BIG (Geospatial Agency of Indonesia).

Keywords: Hydrogeology, map, groundwater, Indonesia

Introduction

Hydrogeological mapping is a part of the groundwater management in Indonesia. In the perspective of groundwater management, the map is used as basic information to determine the potential groundwater resource and groundwater basin mapping. Basically the map is produced by a series of activities, started by compilation of groundwater-related data, field-work, data analyses, and finished by drafting a hydrogeological map. In addition for groundwater management purpose, the map is also widely used for regional landuse planning.

Hydrogeological mapping program in Indonesia has a long history, started in c.a. 1972. In the beginning, the mapping program was done in cooperation with Bundesanstalt für Geowissenschaften und Rohstoffe (BGR). Indonesia government and BGR created a project, called as German Hydrogeological Advisory Group (CTA-40). The project produced hydrogeological map scale of 1:250,000 with a main focus on Java Island, which is the central of government, economy, and population in Indonesia. Afterward, by following the procedure established in the CTA-40 project, Center for Groundwater and Environmental Geology (CGEG) has continued the mapping program throughout the Indonesian territory, though the progress relatively slow, i.e., by only in average five hydrogeological map scale of 1:250,000 per annual.

After reformation era, since 1998, the political system in Indonesia was changed radically, from centralized government to decentralization system. The political system has an impact to the hydrogeological mapping program in Indonesia. The mapping responsibility was shared between central and local (provincial and residential/city) government. The former responsible for hydrogeological map scale of 1:250,000 or smaller and the later for scale of 1:100,000 or larger (Law number 22 year 1999 and Government Regulation number 25 year 2000). However, in order to standardize the hydrogeological map scale of 1:100,000 produced by local government, central government (in this case CGEG) had to establish a technical standard for hydrogeological mapping scale of 1:100,000.

In this paper, hydrogeological mapping program in Indonesia, the history, current status, and future plan are briefly explained. It is aimed to share the experience of Indonesia in establishing hydrogeological maps among hydrogeologist society in CCOP member countries. The large area and complex geological conditions in Indonesia are quite big challenges for Geological Agency of Indonesia to establish high quality hydrogeological maps, though the responsibility has been shared with local government.

Recent groundwater data and hydrogeological map in Indonesia

In a brief, it can be reported that up to 2016, central government of Indonesia (CGEG, Geological Agency) has finished the hydrogeological map scale of 1:250,000 for all areas of Indonesia. In total, the map is split into 266 sheets, which was created started from Java Island and finished in Papua Island. The Java Island is the most developed major island, in contrast the Papua Island is the most least developed major island, hence respectively was selected as starting and finishing points. In spite of the hydrogeological mapping has been finished, however the publication status of the maps are vary, hence not all of the maps can be accessed online. The overall publication status of the hydrogeological map in Indonesia is presented in Table 1 and Figure 1.

Table 1. The status of hydrogeological map scale of 1:250,000 in Indonesia until 2016.

Map Status	Number of Mapping Sheet
Open Map	33 sheets
Published Map	44 sheets
Digital Published Map	96 sheets
Digitizing process	93 sheets
TOTAL	266 sheets

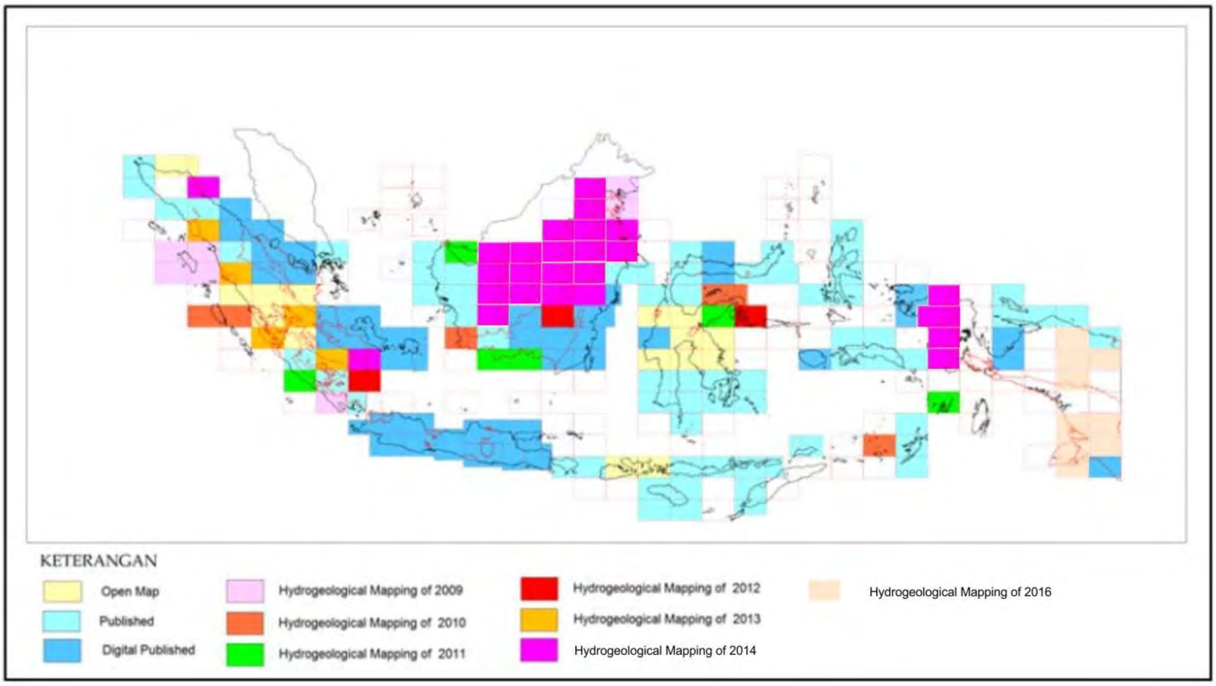

Fig. 1. The status of hydrogeological map scale of 1:250,000 in Indonesia until 2016 presented in a different color.

Technically, the hydrogeological mapping scale of 1:250,000 in Indonesia is performed by following the procedure explained in Struckmeier and Marget (1995). The map is produced by a series of phases that can be described in a flowchart diagram in Figure 2. The procedure is started by groundwater-related data compilation, consisting of several data and/or maps, i.e., topography, landuse, landsat imagery, aerial photography, geology, groundwater wells, geophysical sounding, and rainfall.

The compilation of these data, then followed by a fieldwork with main activities including groundwater table mapping, groundwater sample collection, wells and springs data, and hydrostratigraphy boundaries mapping. The secondary maps/data then compiled with resulting data from the fieldwork activities to create a hydrogeological map. The next procedure is publication process, started by hardcopy printing and digitizing the map, that will be published in both hardcopy and digital form.

Meanwhile, the hydrogeological map scale of 1:100,000 in Indonesia is made based on the handbook of drafting hydrogeological map scale of 1:100,000 by Soekiban, S. (2001). The procedure of this hydrogeological mapping in general is similar with the procedure for hydrogeological mapping scale of 1:250,000, in which the procedure basically is split into four main activities, i.e., secondary data compilation, fieldwork/groundcheck, map drafting, and finished with printing and publication.

In contrast with the hydrogeological mapping program for scale of 1:250,000 that need relatively a long time to finish for all Indonesia area, the hydrogeological map scale of 1:100,000 is relatively fast by mapping acceleration. This is triggered by One Map Policy in Indonesia established in 2016 by Presidential Decree number 9 Year of 2016. The policy aims to provide a single map that will be used as a basic for national development and land use planning. In case of the hydrogeological map, central government (i.e., CGEG, Geological

Agency of Indonesia) is obligated to provide detail hydrogeological map up to scale of 1:50,000. Following the policy, CGEG, Geological Agency of Indonesia, finished hydrogeological mapping scale of 1:100,000 in 17 provinces located on Java Island, Kalimantan Island, Bali Island, and Bangka-Belitung Island. The rest 17 provinces are planned to be finished in 2017. The finished hydrogeological map will be compiled in a One Map database system by Badan Informasi Geospasial-BIG (Geospatial Agency of Indonesia-GAI).

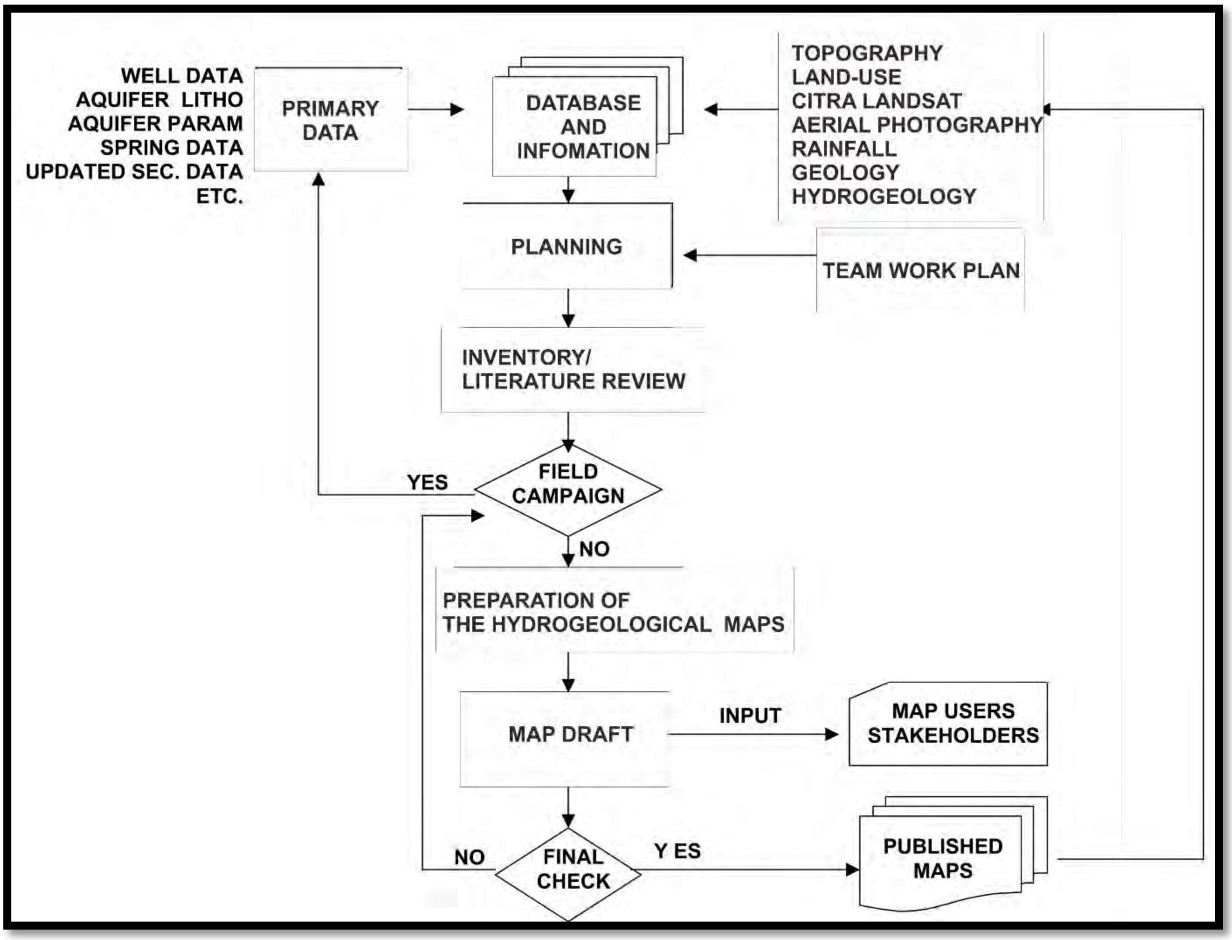

Fig. 2. The flowchart of hydrogeological mapping scale of 1:250,000 in Indonesia.

The hydrogeological map scale of 1:100,000 basically is a preliminary map, created based on hydrogeological map scale of 1:250,000 and geological map scale of 1:100,000 from Center for Geological Survey, Geological Agency. The sheets split system is following the topographic map from GAI. The quality of the hydrogeological map is reviewed by ground check campaign in the following years.

Overall the status of hydrogeological map scale of 1:100,000 in Indonesia until present (2017) is presented in Table 2 and Figure 3.

Table 2. The status of Hydrogeological map scale 1:100,000 until 2017.

Map Status	Number of Mapping Province
Finished Map	17 Province
Unfinished Map	17 Province
TOTAL	34 Province

Fig. 3. The status of hidrogeological map scale of 1:100,000 until 2017.

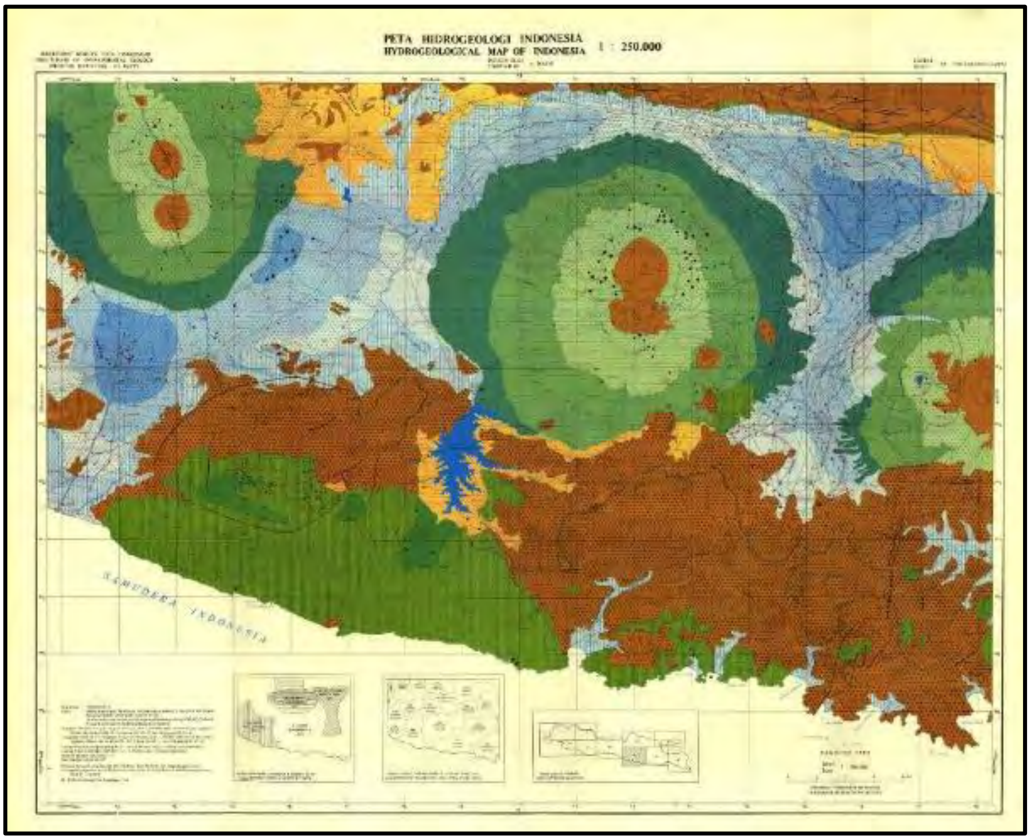

Fig. 4. Example of the hydrogeological map scale of 1: 250,000

Both hydrogeological map with the scale of 1:250,000 and 1:100,000 provide four main hydrogeological information, lithology composition, permeability, groundwater occurrence, and aquifer productivity. Based on the groundwater occurrence, the hydrogeological system can be classified into three: 1) aquifer with intergranular flow, 2) aquifer with fissure and intergranular flow, and 3) aquifer with fissure, fracture. While the aquifer productivity can be grouped into five: 1) highly productive aquifer, 2) productive aquifer, 3) moderately productive aquifer, 4) poor productive aquifer, and 5) without exploitable groundwater area.

Take examples of hydrogeological map scale of 1:250,000 sheet of Yogyakarta (Figure 4) and scale of 1:100,000 sheet of Karawang (Figure 5). The type of aquifers, groundwater occurrence, and aquifer productivity can be explained as follow:

a. Intergranular aquifers

- dark blue colour ( ):

  Extensive and highly productive aquifers with transmissivity of moderate to high, piezometric head close to land surface, and wells yield above 10 L/s.

- light blue colour ( ):

  Extensive and productive aquifers, with moderate transmissivity, piezometric head close to land surface, and wells yield generally 5 to 10 L/s.

- Bright blue colour ( ):

  Moderately productive aquifer, with low to moderate transmissivity, groundwater table close to land surface to >10 m depth, and wells generally yield <5 L/s.

- Striped light blue colour ( ):

  Locally, moderate productive aquifer, generally has thin aquifer layer with low transmissivity, wells generally yield 5 L/s.

b. Fissures and interstices aquifers

- dark green colour ( ):

  Extensive and highly productive aquifers with wide range of transmissivity and water table, wells generally yield >5 L/s.

- light green colour ( ):

  Extensive and moderate productive aquifers with wide range of transmissivity, deep water table, and wells generally yield <5 L/s.

- bright green colour ( ):

  Locally productive aquifers, with wide range of transmissivity, deep water table, and low wells yield.

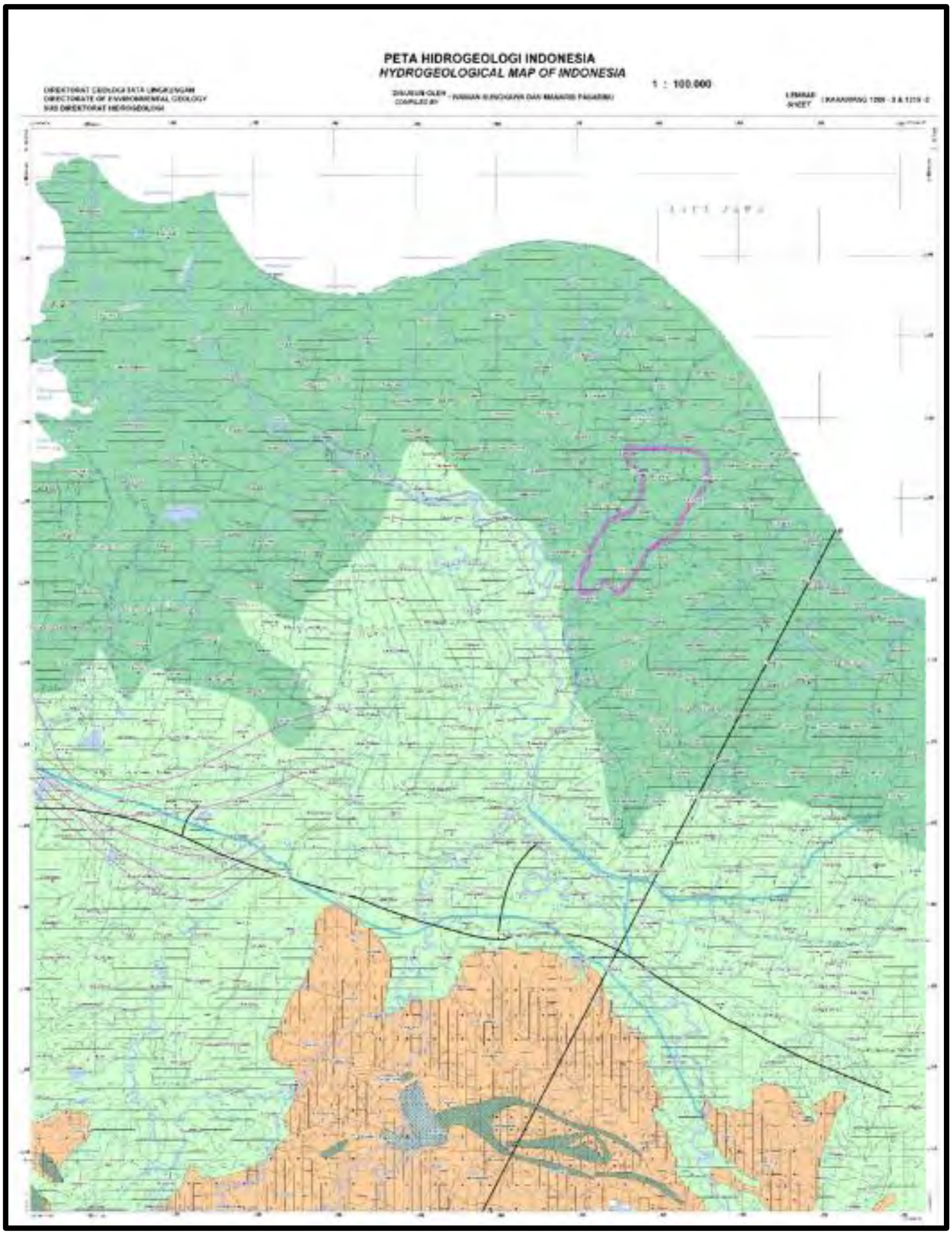

Fig. 5. An example of hydrogeological map scale of 1: 100,000 i.e., Karawang sheet.

c. Fissures, fractures and channels aquifers

- yellowish green colour ( ):

  Highly productive aquifers, with relatively shallow water table; well yields very in favourable sites may exceed 10 L/s.

- light yellowish green colour ( ):

  Moderately productive aquifers, with deep water table, wide range of springs and wells discharge.

d. Fissures or porous aquifers with poor productivity and un-exploitable groundwater areas

- light brown colour ( ):

  Poorly productive aquifers, with low to moderate transmissivity, locally have significance spring/well yield.

- The dark brown colour ( ):

  Regions without exploitable groundwater.

Hydrogeological maps in Indonesia are available in both hardcopy and digital files, in JPG and SHP form. All of the resulting map will be digitized and provided online in a database system made by the Indonesian Geospatial Agency (http://tanahair.indonesia.go.id).

Hydrological survey and groundwater monitoring for database or hydrogeological map

a. Type of hydrogeological survey

Center for Groundwater and Environmental Geology conducts four main survey activities, based on the resulting product. The surveys include 1) Hydrogeological Mapping, 2) Potential groundwater basin map, 3) Groundwater basin conservation map, and 4) Exploration drilling of groundwater. The first to third programs can be mentioned as a series program, started by hydrogeological mapping that will be used for groundwater basin delineation. The resulting groundwater basin map then will be used as a base to conduct groundwater basin potential mapping. This program focuses on aquifer configuration determination, aquifer parameter measurement, groundwater quality, and groundwater potential discharge for each aquifer. The map is applied for groundwater utilization planning in a groundwater basin. Meanwhile, to control groundwater abstraction in a groundwater basin for conservation purposes, groundwater conservation mapping is conducted. The conservation zone basically determined based on two criteria, i.e., groundwater piezometric head and groundwater quality. Groundwater abstraction in a groundwater basin causing groundwater drawdown that has to be controlled. In Indonesia, it is regulated that the safe level of groundwater drawdown is less than 40 %. The conservation map will be applied to control groundwater abstraction by issuing technical recommendation that consist two mains technical control: abstracted aquifer layer (deep) and well discharge.

Primary data in the field work obtained by several activities, such as rock observation to determine hydro-stratigraphy unit boundary, piezimetric head mapping, groundwater sampling, pumping test, geophysical measurement, infiltration test, and groundwater quality measurement. The exploration drilling program was mostly conducted in clean water scarcity areas, which are still widely distributed throughout Indonesia. The exploration well will be developed as production well, if the exploration results a potential aquifer for groundwater abstraction.

Fig. 6. Exploration drilling and well logging activities.

b. Groundwater monitoring program

Generally, two main programs establish to monitor the groundwater condition in a basin in Indonesia: 1) periodic updating the groundwater control and 2) establishing a monitoring wells network. The former is done every 3 to 5 years depend on the intensity of groundwater abstraction in a basin. In an urban area, for an instance in the Jakarta basin, the groundwater conservation map is updated every 3 years. The updated conservation map is applied to regulate groundwater abstraction by issuing technical recommendation and groundwater production permit. The groundwater condition in a basin is evaluated based on two parameters, i.e., 1) groundwater table drawdown and 2) groundwater quality, which is presented as a matrix in Figure 7. The second parameter only applied in basins that connected directly to sea, hence only using total dissolved solid (TDS) and electric conductivity (EC). The parameter is used because over abstraction of groundwater in coastal areas will induces seawater intrusion.

The second monitoring tool, which is establishing groundwater monitoring wells network, is a working progress. Up to 2016, Geological Agency of Indonesia has installed 35 monitoring wells on Java Island consist of 33 for groundwater table drawdown record and two special for groundwater quality. These 35 monitoring wells are distributed in 10 groundwater basin. In 2017, it is planned to install additional three monitoring wells in the Jakarta basin. This basin currently becomes a hot spot of land subsidence problem in Indonesia, which was assumed mostly due to over abstraction of groundwater. The numbers of monitoring wells above were the only wells developed by Geological Agency of Indonesia. In fact there are many more monitoring wells developed by local government and private sector. For example, in Jakarta basin more than 100 monitoring wells exist. The private sector also has contribution in developing monitoring wells because it is regulated that an industry with more than three production wells has to install monitoring wells. All of the existing monitoring wells will be integrated in a web database system, called as *Sistem Informasi Sumur Pantau* (SISP v.1) which in English means information system of monitoring wells.

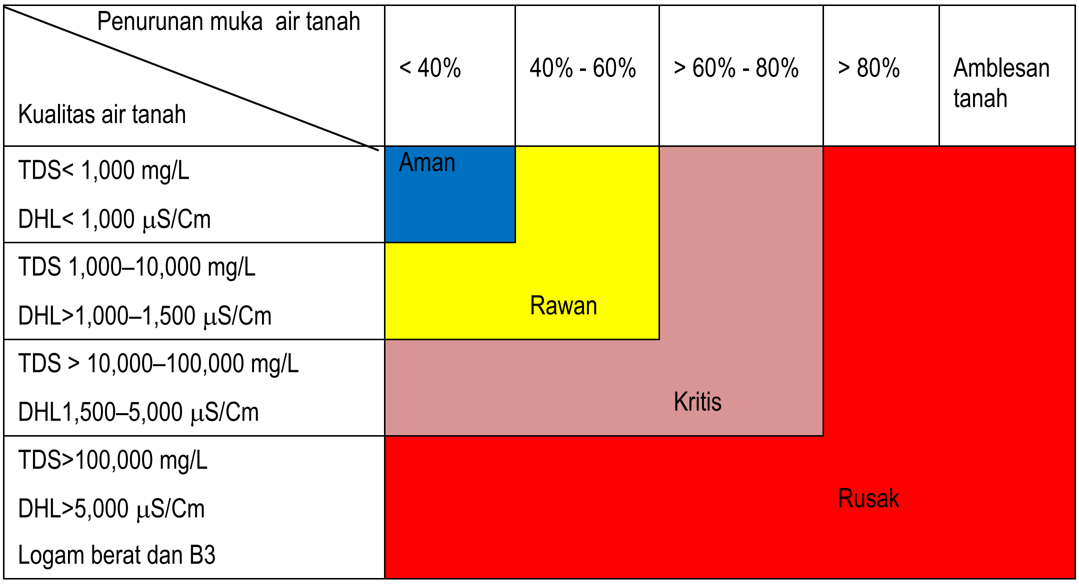

Fig.7. Matrix of groundwater condition classification based on piezometric head drawdown and groundwater quality.

Fig. 8. The location of groundwater monitoring wells on Java.

Future plan of hydrogeological map in Indonesia

Future plans for hydrogeological mapping in Indonesia can be divided into two phases short-term plan and a long-term plan. Short-term plans are 1) finishing the hydrogeological mapping scale of 1:100,000 for the rest 17 provinces and 2) ground checking for the preliminary hydrogeological maps finished in 2016. Meanwhile, the long term plans are creating larger scale hydrogeological map (e.g., scale of 1:50,000) and also creating detail hydrogeological map in areas with intensive groundwater abstraction. In parallel, an online groundwater database system is established hence the maps can be accessed by all stakeholders related to groundwater.

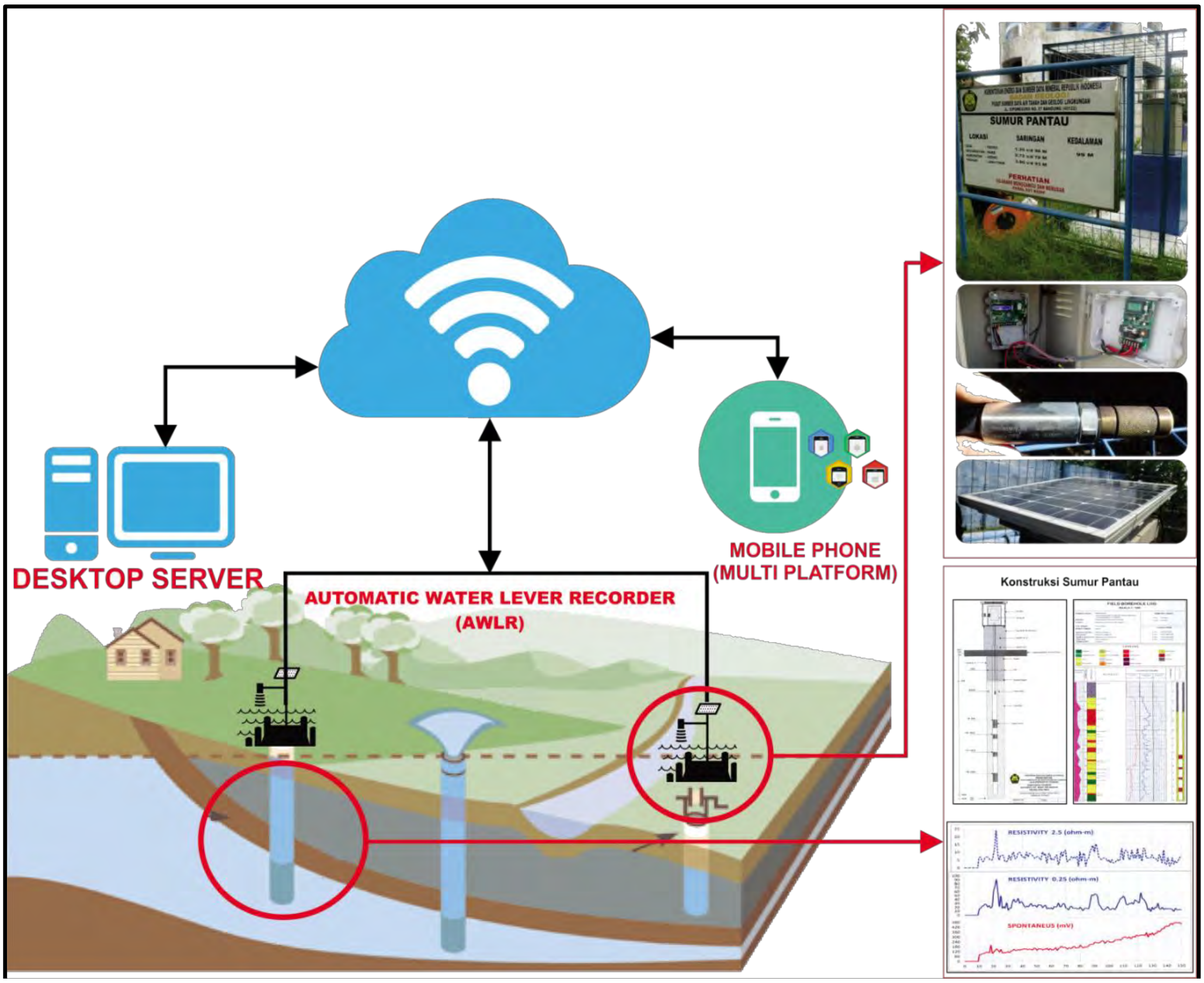

Fig. 9. Web base telemetric information system of the groundwater monitoring wells network.

Fig. 10. Maintenance activities of groundwater monitoring wells.

Conclusions

Hydrogeological mapping program in Indonesia is started in 1972, by developing hydrogeological maps scale of 1:250,000. The program at least experienced three milestones, i.e., the beginning phase in 1972, post reformation era in 1998, and current administration (since 2015). At present, the hydrogeological mapping scale of 1:250,000 has been finished, with total map sheets of 266. In 2016, due to One Map Policy program, Geological Agency of Indonesia accelerated the hydrogeological mapping program with larger scale, i.e., 1:100,000, in which the preliminary maps are finished for 17 provinces. The rest 17 provinces will be finished in 2017. Beside hydrogeological mapping program, in order to conserve the groundwater resources in Indonesia, two main programs are implemented continuously, i.e., 1) updating the map of groundwater conservation periodically and 2) establishing networks of groundwater monitoring wells.

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III-2-(4)
Hydrogeological map in Japan -Present status and future plan-

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Abstract

In Japan, the Water Cycle Act was established on March 3, 2014 and administered on July 7, 2014. This act is aimed to maintain a healthy water cycle by promoting comprehensive and unified measures. The healthy water cycle means that water evaporates, precipitates, flows as groundwater and river, and drifts to the sea. During this process, the role of water to human activity and environmental conservation is retained appropriately. In order to maintain the healthy water cycle, groundwater resources must be managed and used properly. It is also important to comprehend not only groundwater storage but also the whole flow system.

In Geological Survey of Japan (GSJ), “Japan Hydrogeological Map” series for 41 areas had been published, illustrating the groundwater storage. Contents of this series was revised and new series of “Water Environment Map” including groundwater was edited and published with emphasis on flow and quality.

In the past studies related to groundwater flow, dissolved components of groundwater, environmental isotopes, temperature etc. have been used as tracers. However, since each tracer has different characteristics, using them in combination can connect to highly accurate studies rather than using the tracers individually. Authors are using this “Multi Tracer” method to compile Water Environment Maps. Water Environment Maps are published in CD-ROM format, which consists of various data such as groundwater level, general water quality, oxygen and hydrogen stable isotopic ratios, subsurface temperature distribution etc. Until now, maps of Sendai Plain, Akita Plain, Kanto Plain, Nobi Plain, Chikushi Plain, Yamagata Basin, Kumamoto, Ishikari Plain, Mt. Fuji, altogether 9 areas were prepared. As a future work, water environment maps of major areas of Japan such as Osaka Plain, Niigata Plain etc. will be published.

Keywords: groundwater, hydrogeological map, water environment map, Japan

1. Introduction

Water environment map is one of the geoscientific maps that has been edited and published by Groundwater Research Group of Geological Survey of Japan (GSJ). GSJ had published “Japan Hydrogeological Map” series illustrating the groundwater storage of 41 areas. Contents of this series were revised and a new series of “Water Environment Map” including groundwater has been edited and published with emphasis on flow and quality. Water environment map and its related results are published in CD under the trend of space saving and computerization. Since No. 1 issue (Sendai Plain, 2004) was published, discussions on groundwater publicity became active in Japan, and problems related to water also changed rapidly. On the other hand, water environment maps from No. 1 to No. 5 (Chikushi Plain) mainly consisted of results of groundwater quality analysis and subsurface temperature measurements conducted by different individuals in charge, and it was found that contents of the instruction manual were different for each map. In addition, many opinions and requests were received from users and experts regarding the description items and data representation methods of the maps. In order to respond to this kind of situation, our Groundwater Research Group reviewed the editing policy of the water environment map, and set common items in the maps starting from No. 6 (Yamagata Basin, 2010). The current water environment maps are mainly prepared to contribute to groundwater and shallow geothermal use of the area. Maps prepared with this purpose are considered to be an essential basic data for discussing groundwater and shallow geothermal resources in plains and basins throughout Japan.

2. Recent groundwater data and hydrogeological map in Japan

Since the publication of No. 1 Japan hydrogeological map and explanatory manual of Kiso River, Yahagi River and Toyo River basins (Murakami and Takei, 1961) in 1961, the hydrogeological maps were published for 37 years up to No. 41 of Amagi Island in Kagoshima Prefecture (Noma and Goto, 1998). In the hydrogeological map, topography, surface geology, columnar diagram, quantity of water production (available quantity), groundwater potential, aquifer classification and hydrogeological base, information on surface and spring water, general water quality are mentioned emphatically. One of the features of this map is that available quantity of water, aquifer classification and hydrogeological base are particularly focused.

As a continuation of Japan hydrogeological map, the first issue of water environment map No.1 (Sendai Plain) was published in 2004. Major changes from Japan hydrogeological map are 1) CD is used instead of paper based maps, 2) Entire basin or plain is taken as a study area, 3) Latest water quality and water temperature data measured in the actual field are presented, 4) Whole process of study from data acquisition method to investigation results are presented. At the time of production of No. 6 (Yamagata Basin, 2010), editing policy was revised, and common editing items were set in the subsequent water environment map series (Fig. 1). After No. 6, the water environment map was defined as “Map based on qualitative and quantitative study and editing of water environment focusing on groundwater, in order to contribute to use of groundwater and shallow geothermal area” and the contents were fundamentally revised. (Machida, 2010). Thereafter, water environment maps of three areas No. 7 (Kumamoto Plain), No. 8 (Ishikari Plain), No. 9 (Fuji-san) have been published complying with the editing items of Fig. 1 (Fig. 2).

As water environment maps are provided in electronic media, users can operate the side menus on the computer monitor to obtain the displayed hydrologic information (Fig. 3). Main information is shown on the map screen and related details are described in the attached explanatory manual (Machida et al., 2014).

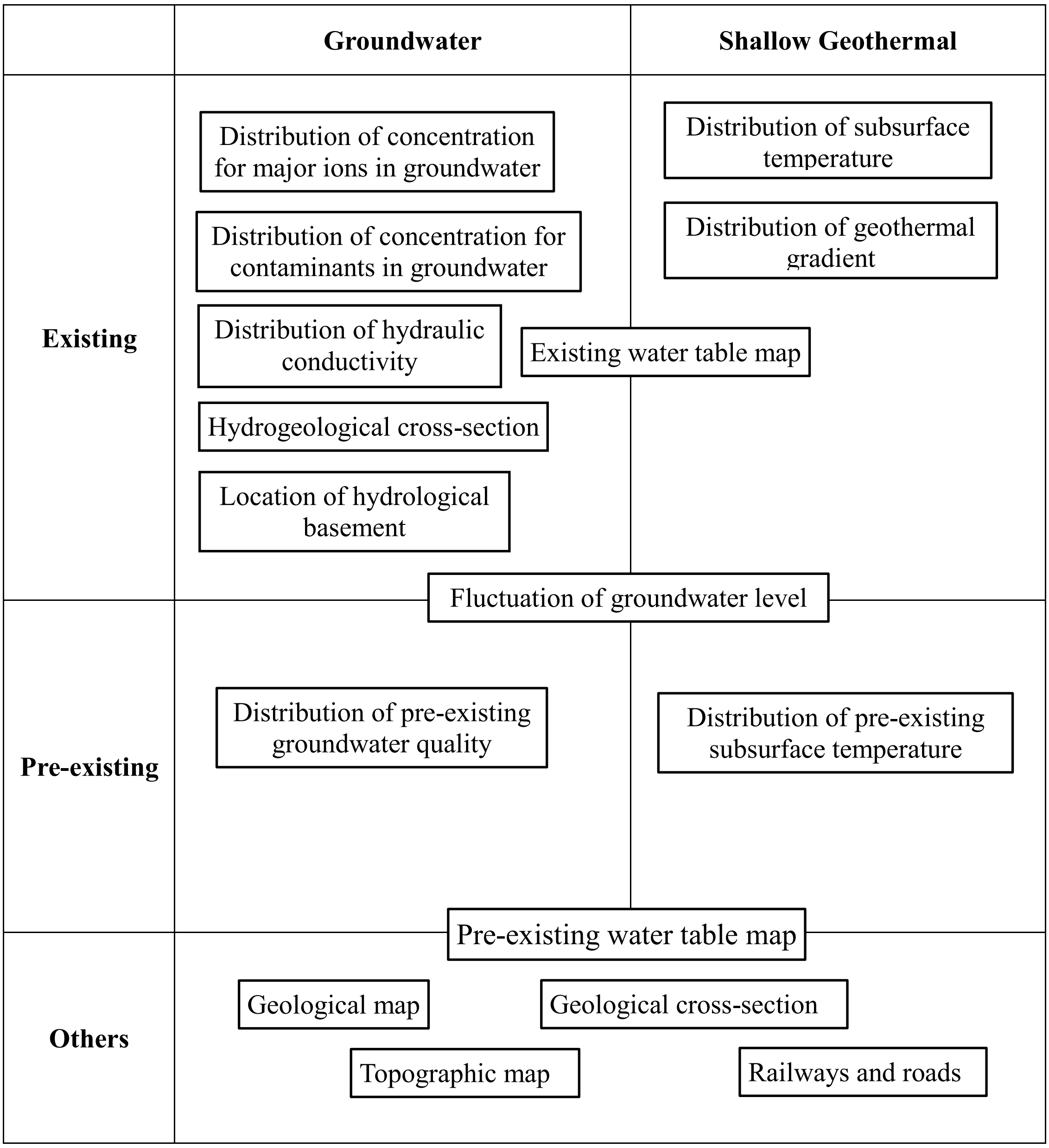
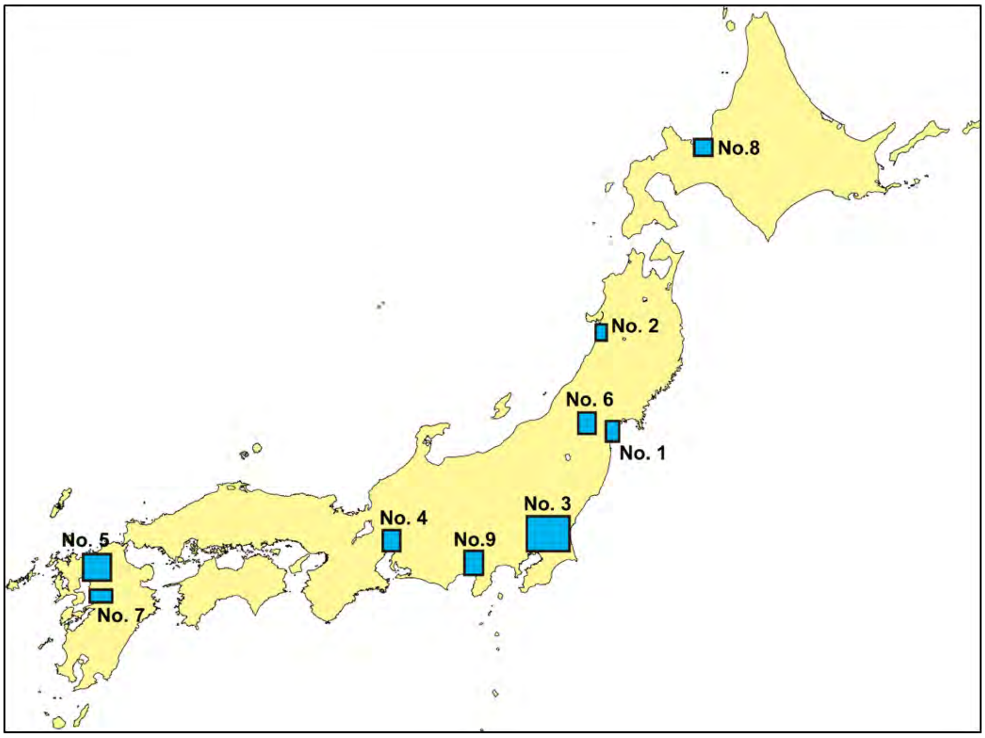


Fig. 1. Main editing items of water environment map



No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9
Sendai	Akita	Kanto	Nobi	Chikushi	Yamagata	Kumamoto	Ishikari	Fujisan (Shizuoka)

Fig. 2. Area of water environment maps in Japan

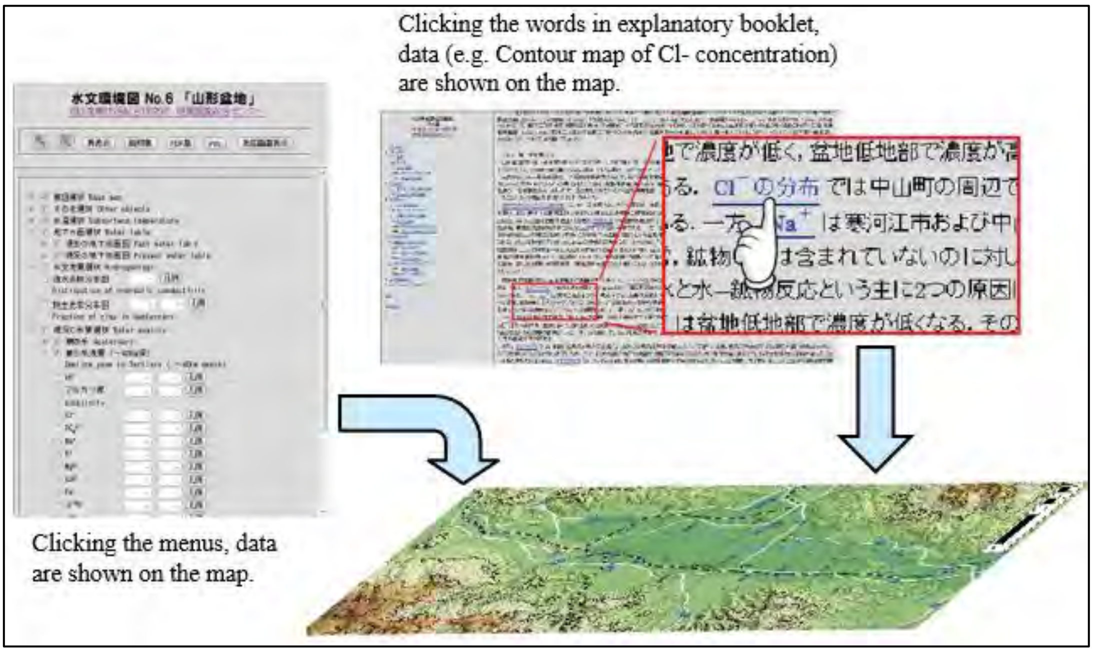


Fig. 3. Explanatory booklet and map in the water environment map in Japan

3. Hydrological survey and groundwater monitoring for database / hydrogeological map

There are many observation wells in Japan which are used for monitoring groundwater level and land subsidence (Photo 1, left). Each observation site has two or three nested observation wells, and these wells are designed for single screen well. Each screen depth is set at the different aquifer; therefore we can get three-dimensional distribution of hydraulic head and groundwater qualities. Moreover, we measured groundwater temperature at 2 m intervals in those observation wells. The precision of thermometer which we used is 0.01 degree C (Photo 1, right).

It is known that subsurface temperature distribution is generally affected not only by thermal conduction but also by advection owing to groundwater flow (Uchida et al., 2003). The effect of thermal advection is especially large in shallow sedimentary layer with high groundwater flux.

Groundwater temperature measured in an observation well is assumed to be identical to subsurface temperature, because there exists thermal equilibrium between the water in a borehole and its surrounding subsurface layers. Temperature profiles are one-dimensional sequential data arrays so that aerially distributed temperature profiles provide three-dimensional subsurface information. Fig. 4 shows groundwater flow system and subsurface thermal regime (modified form Domenico and Palciauskas, 1973). If there is no groundwater flow or static groundwater condition (Fig.4a), subsurface thermal regime is governed only by thermal conduction and subsurface temperature gradient is constant (Fig. 4b). When a simple regional groundwater flow system due to topographic driving (Fig. 4c) is assumed, thermal regime will be disturbed by thermal advection owing to groundwater flow (Fig. 4d). In the groundwater recharge area, subsurface temperatures and gradients are lower than that of under static groundwater condition (Fig. 4b). In the discharge area, on the other hand, temperatures and gradients are larger than that of under static condition.

Photo 1. Observation well for monitoring of groundwater level and land subsidence in Japan (left), digital thermistor with 300m cables (right), respectively.

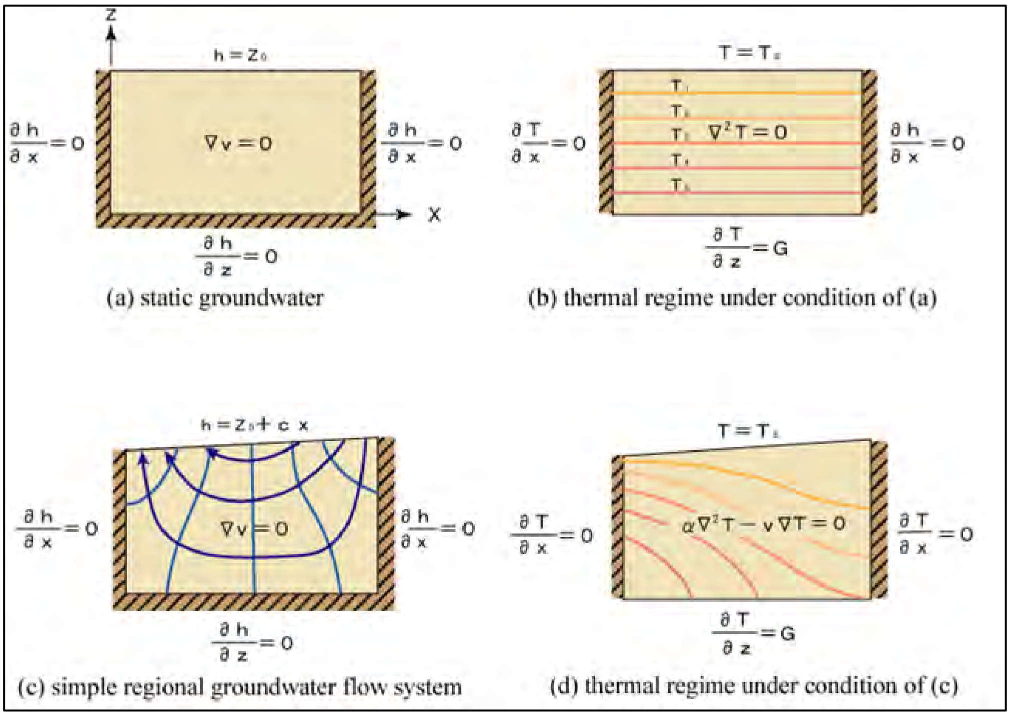


Fig. 4. Groundwater flow system and subsurface temperature distribution (modified from Domenico and Palciauskas, 1973)

4. Future plan of hydrogeological map in Japan

Water environment maps have been published in CD format till now. However, this method cannot cope with the change of Operating System (OS) of Computer repeatedly and sometimes there is a problem that the CD cannot be browsed depending on the version of OS. Further, to provide database of water environment map continuously, addition of new data (database update) is required. Therefore, from No. 10 series (Osaka Plain) currently being edited, publication through internet is considered. In addition, there is a problem with the speed of publication.

In Japan, water resources like rivers and canals are the common properties of citizens, and the public use of water is regulated by a law. On the other hand, groundwater was used to be legally treated as a private property and the owner of the land was free to use the groundwater. Then, Basic Water Circulation Law enforced in July 2014 prompted comprehensive and unified promotion of measures concerning water circulation to maintain sound water circulation. In the Basic Water Circulation Law, groundwater is a concept of "shared property of the community", and it became necessary for local residents to properly manage and utilize groundwater resources.

In this way, the social situation surrounding the groundwater in Japan is rapidly changing. For this reason, the need for publications of basic data such as water environment map is expected to increase in the future, as the understanding of groundwater is becoming increasingly necessary. However, the current method takes more than 3 years to prepare and edit the map of on area. Despite the lack of man power in our group, cooperation with local research institutes and universities should be strengthened in order to shorten the time for preparing and editing the water environment maps.

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III-2-(5)

Hydrogeological map - Present status and future plan in Korea

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Abstract

Hydrogeological map has been published as a part of basic groundwater survey since 1997 in Korea. The basic groundwater survey is classified as the regional and local survey based on survey areas, purposes, and applications. The products of the surveys are 1: 250,000 scale hydrogeological map in the regional surveys, and 1:50,000 administrative (city or county) hydrogeological map in the local surveys. The groundwater data from the surveys are collected and managed in the National Groundwater Information Center, and they provide the data to the public in website (www.gims.go.kr).

Keywords: groundwater, hydrogeological map, Korea

Introduction

Hydrogeological maps represent the conditions of the occurrence and distribution of groundwater. Based on the scale of the maps, they can be classified as small-scale hydrogeological map (smaller than 1:500,000), medium-scale hydrogeological map (1:200,000-1:100,000), large-scale hydrogeological map (larger than 1:50,000). Hydrogeological maps usually have an appended explanatory text with a description of the region's hydrogeological conditions. There are also maps that divide an area into hydrogeological zones, hydrochemical maps, and maps indicating the reserves of underground waters (Freeze and Cherry, 1979; www.encyclopedia.com). Hydrogeological maps have been produced as a part of the basic groundwater survey in Korea.

Basic groundwater survey in Korea

Basic groundwater survey project in Korea (Figure 1) is an investigation for groundwater occurrence, exploitation, usage, water quality in a region, which has started since 1997. The investigations include various field surveys such as geological, geophysical, and drilling surveys, and laboratory analyses. Hydrogeological map is the product of the project, and it provides a summarized interpretation of the topographic, geologic, hydrologic, geochemical, and water resource data available in an area.

The basic groundwater survey project has a legal basis in the Groundwater Law in Korea which has been established in 1993. Groundwater law Act 5 and Enforcement Ordinance Act 2 state that government should carry out comprehensive groundwater investigation on each district in order to get the information of groundwater exploitation, use, water quality, and manage groundwater efficiently both in quantity and quality. The law also has the clause to establish the National Basic Groundwater Management Plan to give directions and make the detailed plans for the project. The target area for the project is the whole area of Korea, which is divided as 4 large river regions, and 165 cities or counties (MOLT, 2015).

The surveys in Korea are classified as the regional and local survey. The regional survey is accomplished for the purpose of groundwater management on each basin unit. The basin units are Han-gang, Nakdong-gang, Keum-gang, and Youngsan-gang regions. The "gang" means "river" in Korean. The surveys are mainly composed of existing data collection and analyses and complementary field surveys. It takes 2 or 3 years to finish the survey on each basin. The product of the regional survey is 1:250,000 hydrogeological map.

The local survey is conducted to provide the information and give a reference for groundwater development, and help permission process, and establish a local groundwater management planning. The surveys are accomplished in a city or county unit under the implementation plan of the National Basic Management Plan. It usually takes 2 years to finish the survey on each area. The product of the local survey is 1:50,000 hydrogeological map.

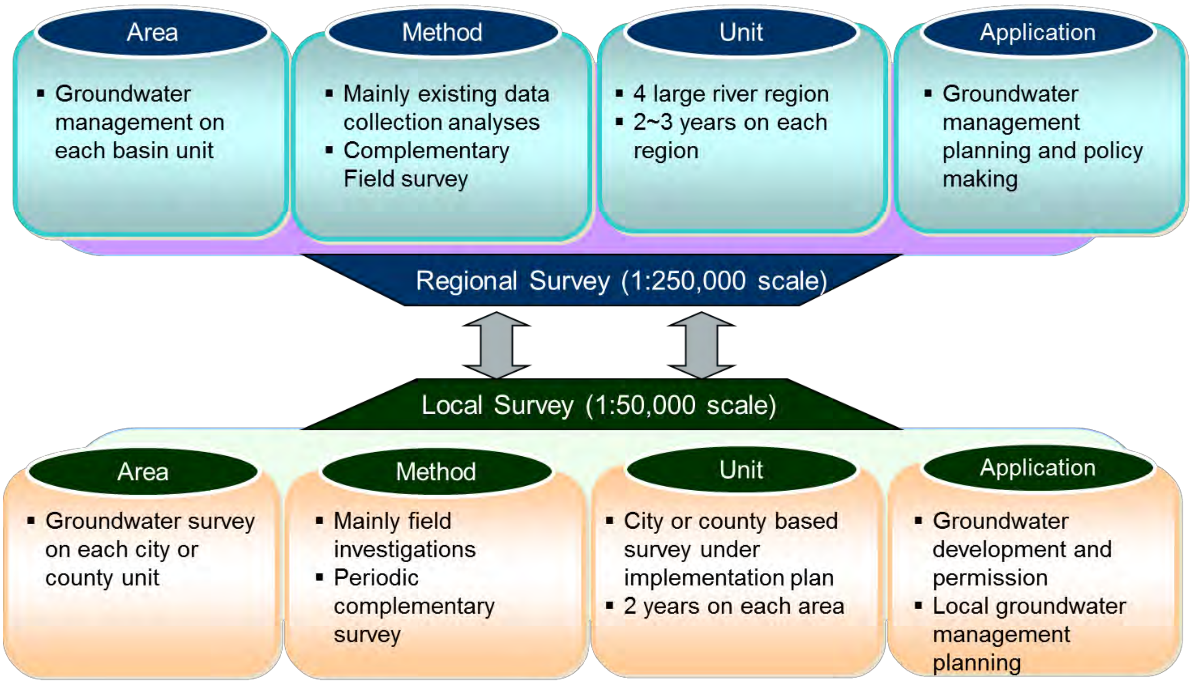

Fig. 1. Basic groundwater surveys in Korea

The priority survey areas are selected according to needs for groundwater protection and development. High groundwater use areas relative to sustainable groundwater yields, vulnerable areas to groundwater contamination, drought prone or water shortage areas, poor water system areas, poor water quality areas are the prior survey areas to be performed. The priority and orders of the surveys are specified in the National Basic Groundwater Management Plan.

There are some official institutes to conduct the basic groundwater survey project, which are K-water, KIGAM (Korea Institute of Geoscience and Mineral Resources), KICT (Korea Institute of Civil Engineering and Building Technology), KEC (Korea Environment Corporation), KRCC (Korea Rural Community Corporation), and KORES (Korea Resources Corporation). The Ministry of Land and Transport in Korea is the main authority to take charge of the project.

Current status and future plan of hydrogeological mapping in Korea

The regional surveys in the whole country (Figure 2) were finished in 2006. The surveys have started from the area of Youngsan-gang in 1997, and Nakdong-gang in 1999, Keum-gang in 2001, and Hang-gang in 2004. The surveys are composed of data collection, analyses of groundwater contamination and depletion, and field surveys such as geophysical surveys, groundwater level and quality monitoring, water quality analyses, and so on. To produce the hydrogeological map on each region, hydrogeological units (HGUs) and some aquifers are classified. And, groundwater recharge and potential groundwater yield are evaluated. The hydrogeological map from the survey is produced in 1:250,000 scale, which can be used for planning of groundwater development and utilization in the 4 river basin regions.

The local surveys (Figure 2) were completed in 115 districts among the total 165 districts, and 16 districts are being done as of 2017. Then, 34 districts remain to be surveyed in the future. The government has the plan to finish the project by 2021. After that, complementary surveys will be scheduled from the beginning of the old surveyed areas. The product of the local survey is the 1:50,000 hydrogeological map. The surveys are composed of the preliminary and detailed field surveys, and comprehensive analyses. In the preliminary survey, existent data collection, topographic/geological survey and hydrologic analyses are performed. In the detailed field surveys, the wells and facilities, potential contamination sources are investigated, and monitoring for groundwater levels and quality, surface water flow and quality were practiced, and laboratory works including chemical analyses for water, soil, and rock samples also are accomplished. Geophysical survey and well logging with drilling works are executed to characterize the aquifers, followed by aquifer testing. After the preliminary and the detailed field survey, hydrogeological units and characterizations, aquifer classifications and flow system analyses and groundwater resource evaluations including water budget and recharge, and groundwater management planning are conducted in the comprehensive analyses.

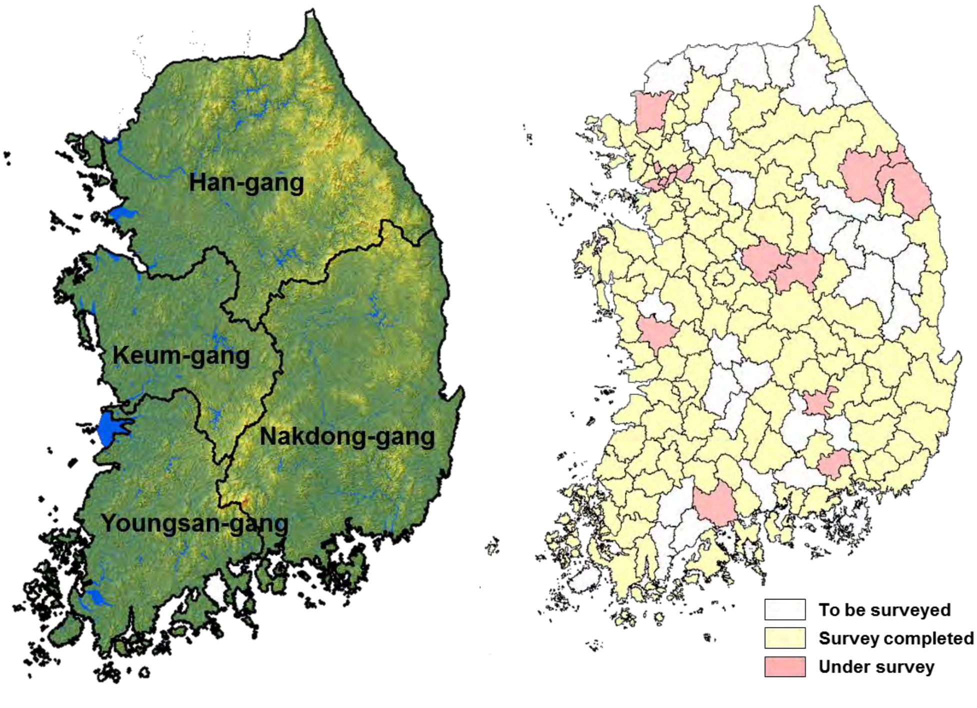

Fig. 2. The status of the regional (left) and local (right) groundwater surveys in Korea

Data management and service

The Ministry of Land and Transportation has prepared guidelines for hydrogeological mapping and the basic groundwater survey in 1998, which is a kind of manual for the works. Afterward, several corrections and supplements were made, and the latest version was published in 2015. The guidelines prescribe the production and management for hydrogeological map and groundwater data from the basic groundwater survey. The guidelines provide the criteria for the production of the hydrogeological maps, which are paper or digital format. At present, 6 maps which are hydrogeologic map, groundwater quality map, groundwater flow system map, groundwater contamination vulnerability map, depth to groundwater map, and lineament map, are published.

Various and lots of data from the basic groundwater survey including the reports have to be reviewed and evaluated, and corrections and complementary actions will be made if the error and faults are discovered. These procedures are under the supervision of the Ministry of Land and Transport.

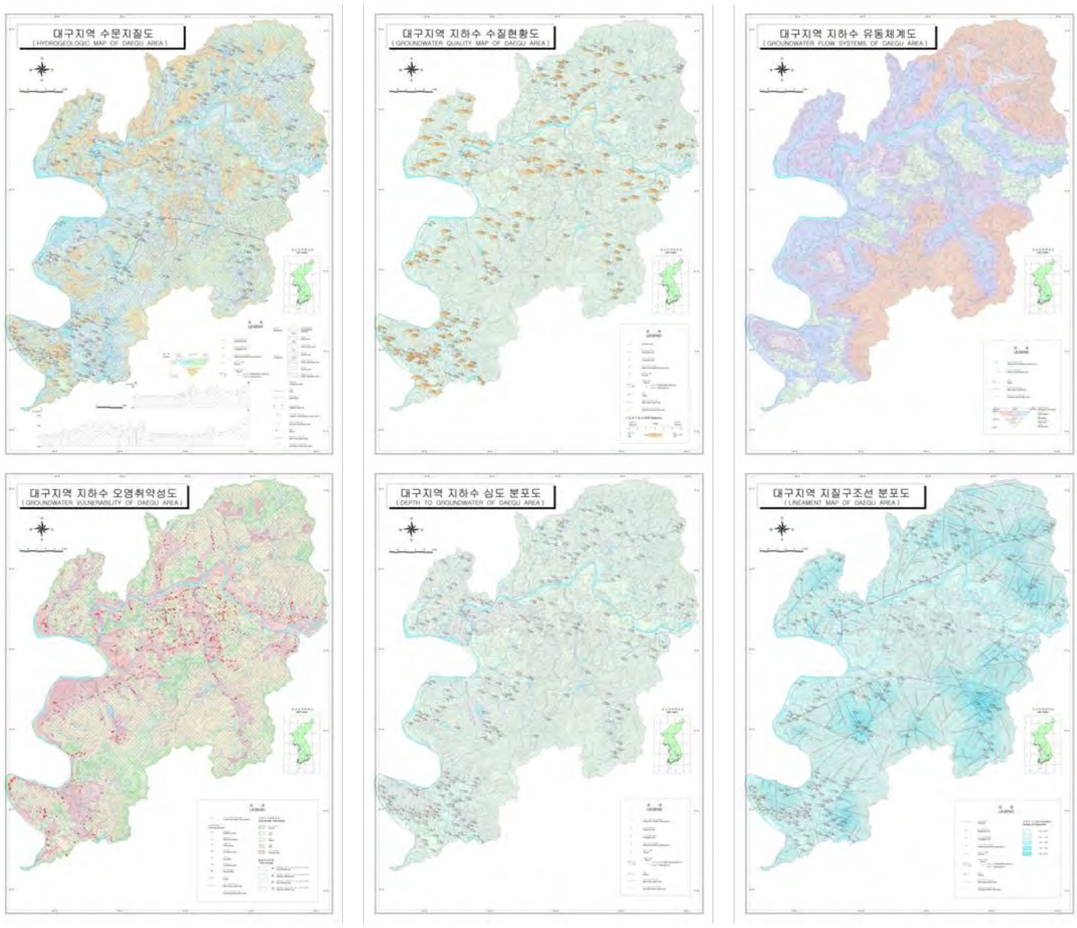

Fig. 3. The product maps of the basic groundwater survey in Korea

The data produced from the basic groundwater surveys (Figure 3) basically are transferred to the National Groundwater Information Center (http://www.gims.go.kr). The Center has the responsibility to manage the data and provide services for government and public institutes, specialized organizations, private companies and the public (Figure 4).

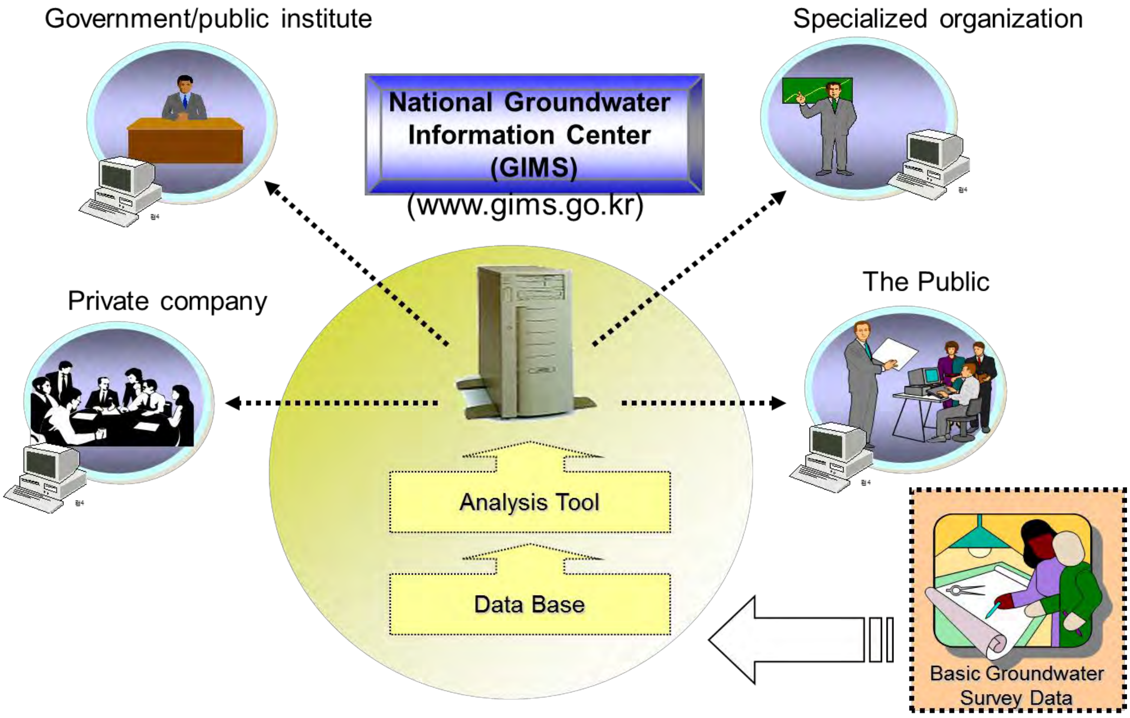

Fig. 4. The data management and service

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III-2-(6)
Groundwater Management in Lao PDR

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1. Background

Lao PDR located in a central position in the Southeast Asian Region. There is approximate total population of 6.5 million (2012) and total area of 236,800 km^2. Most of area is around 90 percent of the country is within in the Mekong basin, accounting for approximately 35 percent of the total area of Mekong river basin.

Lao PDR is the land of water resources, with average annual rainfall is over 1,900 mm or 462 km^3, beside that 80 percent of surface water availability occurs in rainy season, while only 20 percent is available in the dry season. Lao PDR contribute about 35 percent runoff to Mekong River. The Mekong river flows through 1,898 Km of Lao PDR with 13 tributaries, and the average annual flow is approximately 8,500 km^3 per second *(draft of National Water Strategy 2020 and 5 years action plan 2011-2015, MoNRE, 2011).*

Lao PDs aveR harage surface water 332.5 km^3 and is equivalent to more than 55,000 m^3 annual per capita, the highest in Asia. However, utilization of water for development of the country is still limited, equivalent to 2.8 percent of annual surface water *(draft of National Water Strategy 2020 and 5 years action plan 2011-2015, MoNRE, 2011).*

Groundwater information is limited in the country. Groundwater is an important source of drinking water and use water for rural people and less in city, particularly in plateaus located far from surface water such as the South and the West of Champasack province, Xe Bang Hieng and Xe Don Plateaus. In addition, monitoring and evaluation activities on quantity and quality of groundwater have not yet carried out systematically and regularly *(draft of National Water Strategy 2020 and 5 years action plan 2011-2015, MoNRE, 2011)*

2. Groundwater Management in Laos

1) Institutional Framework

The Department of Water Resources, abbreviated as "DWR" is one of department under Ministry of Natural Resources (MoNRE). DWR is a new establishes organization from 2011 until present, which restructure from Water Resources Coordination Committee Secretariat in 2008 (MoNRE, 2011).

The mandate of DWR is mainly responsible for surface and groundwater management which is in line with Integrated Water Resources Management principal through-out the country.

Some duty of DWR that focus on groundwater is to develop the mechanism in management, utilization and development of groundwater in collaborated with line agencies/ stakeholders; to develop mechanism in management and monitoring the surface and groundwater quality in collaboration with related agencies; and to study and propose an issuance of permission for surface water and groundwater resources use and development (DWR, 2011).

Department of Water Resources is mainly responsible for groundwater management together in cooperation with Natural Resources and Environment Institute for groundwater analysis, Department of Geology for geology assessment and Department of Methodology and Hydrology for groundwater flow assessment (MoNRE, 2011). Moreover, the other agencies in different ministry such as National Center for Environmental Health and Water Supply, Ministry of Public Health and Department of Water Supply also has mandate related to groundwater in different aspect.

Ministry of Natural Resources and Environment with a technical line in local level called Provincial of Natural Resources and Environment and District of Natural Resources and Environment and Community volunteer in village level is seriously working on groundwater data collection in order to prepare and support for sustainable groundwater management. In recently, there is existing list of coordinators for groundwater work in provincial and district level which is a good significance for further groundwater management (List of Coordinators for Integrated Water Resources Management in Lao PDR, DWR 2013).

2) Groundwater use

According to the National Implementation Plan for Clean Water Supply and Sanitation in Rural Area*, (Ministry of Public Health,2012)*, It is estimated that 80 % of the rural population use groundwater for their domestic use. And the Department of National Statistic showed that sources of water use for groundwater are from Borehole 13.3 % and from Dug Well 17.8 % in the whole country.

The number of usage groundwater for water supply is increased compare to year 1994-2009 there is 29 boreholes used for water supply production; it is approximately 5,000 m^3/day of groundwater produce water supply and can be used only 1,103 m^3/day. In 2012 Department of Water Supply plan to extend to 59 boreholes using for water supply production in the country *(Department of Water Supply, 2011).*

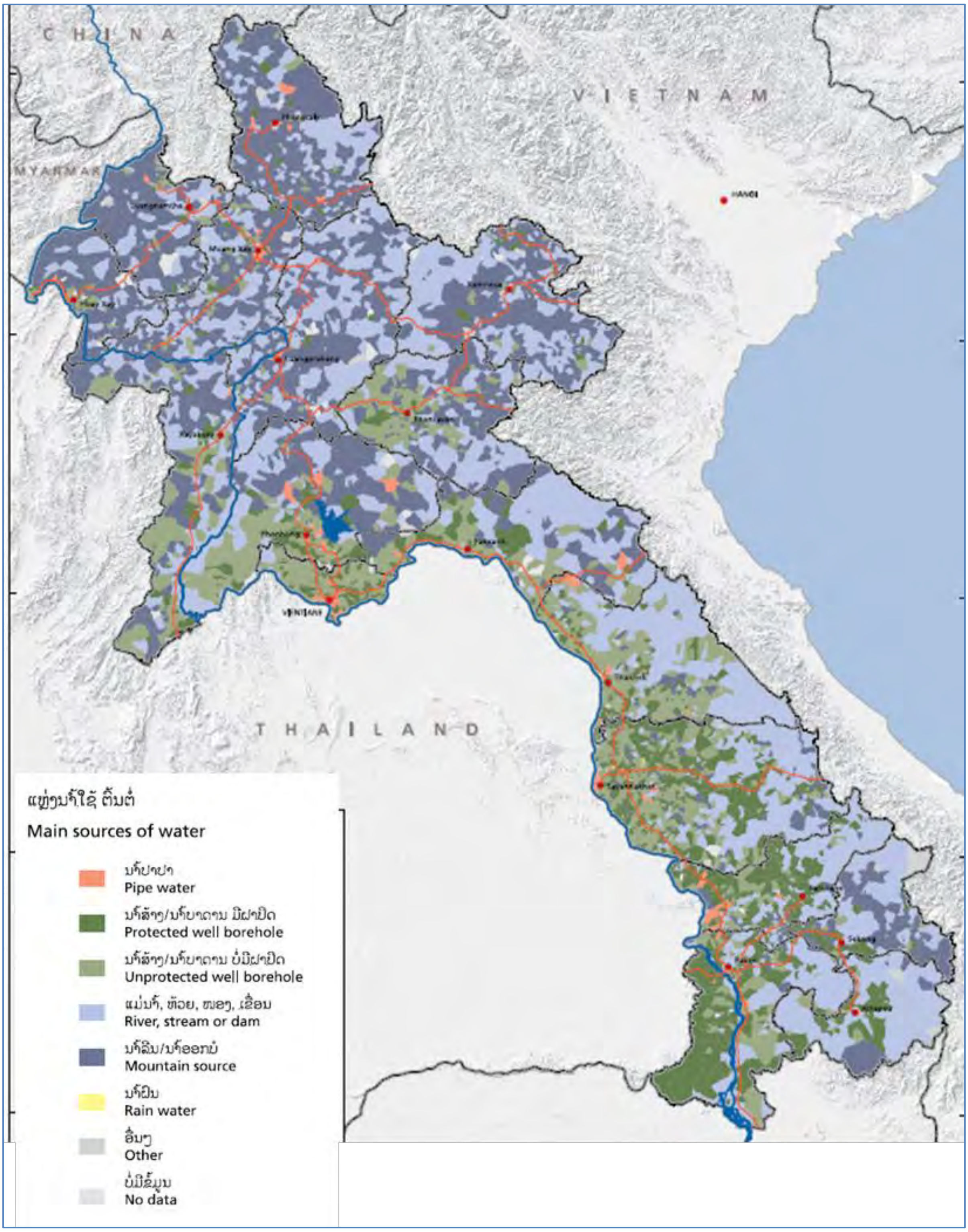
The existed using of 100 liters per capita per day, we can estimate that around 90 million cubic meters per year using groundwater in the country *(Stakeholder Assessment Working Paper by GHD supported by ADB, Nov 2013).*

3. Pilot activities

3-1 Background and location

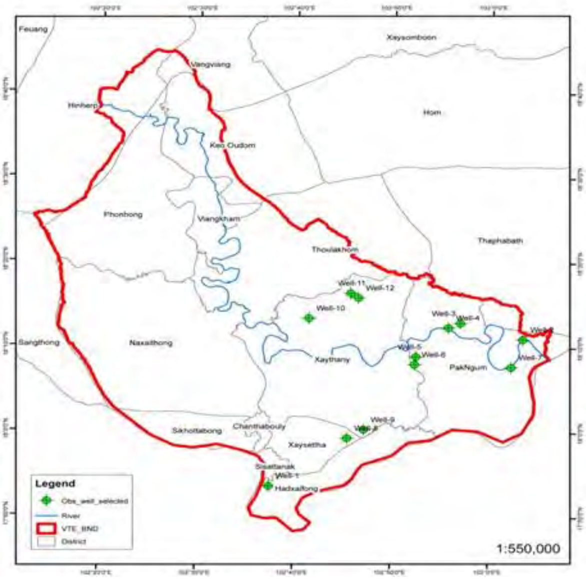
The Vientiane Plains have higher numbers, indicating greater priority, which is influenced by population pressure and generally favorable hydrogeological conditions (Stakeholder Assessment Working Paper by GHD supported by ADB, Nov 2013).

As mention earlier, the information of groundwater is limited especially the technical information. Therefore, we start up to do data collection in four districts in Vientiance Plains as Phonehong, Keoudom, Viengkham and toulakom districts.



Map 1. Sources of water use in Lao PDR (Stakeholder Assessment Working Paper by GHD supported by ADB, Nov 2013).

Map 2. Location map of the 30 wells measured SWL



Map 3. Well selected Map

3-2 Social and Economic

The area of In 4 districts is 2,432 km^2, there is 161,433 people in total with 80,372 are woman. There are 144 families and 31,905 households. There are three major ethnic groups existed in local community, the Lao Loum is the biggest group,

Economic of these areas is developing. There is school, gas station in and a health care center and also organizations as government office, hospital, restaurant, hotel and guesthouse. Average income for these areas is 1247 USD/person/year.

3-3 Groundwater use

People depend on the groundwater for domestic use and for agriculture activity. The agriculture activity was doing for the whole year which some use the water from irrigation (surface water) cannel and some are from boreholes and dug wells *(Marleen Van, A 2013).*

Every family has their own wells mostly for domestic and agriculture use. Some family have two wells/boreholes or more (for who's has bigger agriculture land) for domestic and for garden. However, there is no data on the groundwater quantity consumption available in the village.

There is no big borehole present. to irrigate the land and distribute the water, the farmers use buckets, sprinklers or dig canals. There are no tubes on the ground to carry the water *(Marleen Van, A 2013).*

According to the village head and framer report that in last five years the water quality was in good condition and there has been enough water. Just the year 2013 is appears to be a water shortage *(Village head, 2013).*

3-4 Ground Water Management in project site

Ground Water Profile is a report which summary data and information about Groundwater specific for 4 districts. Quality and quantity of ground water in Vientiane plant collected and expressed in this report.

Regulation for groundwater management is drafting the objective for sustainable us of groundwater by noticed and guild people in project site how to use, drilling and protection.

Some tool is create for rising awareness as poster to express important of groundwater, brochure for sharing data and information also newspaper objective for involve people in groundwater management and protection.

4. Groundwater Regulation Framework

As mention the key organisation responsible for groundwater management was new established. Therefore the regulation framework is being developing. Below is introduced the policy and legislation related to groundwater management.

4-1 Draft National Water Strategy 2020 and 5 Year Action Plan

Department of Water Resources, MoNRE with cooperation with line

Agencies is developing the National Water Strategy 2020 and 5 Year Action Plan(2011-2015). The strategy covers of twelve programmes beside that the programme 4 is directly focus on Groundwater Management, the twelve programmes are:

- Program 1. Institutional Strengthening & Coordination;
- Program 2. Legislation, Plans and Implementation;
- Program 3. River Basin and Sub-RBs WR Planning;
- Program 4. Groundwater Management;
- Program 5. Data Collection and Analysis;
- Program 6. Water Allocation;
- Program 7. Protection of Water Quality and Ecosystems;
- Program 8. Wetland Management;
- Program 9. Flood and Drought Management;
- Program 10. Management of WR Risk & CC Adaptation;
- Program 11. Financial Aspects of IWRM;
- Program 12. Awareness, Participation & Capt. Building

The programme 4.Groundwater Management under the strategy is composed of two actions. Action 1, formulate and implement regulations and groundwater management planning, and action 2, strengthen groundwater management capacity *(draft of National Water Strategy 2020 and 5 years action plan 2011-2015, MoNRE, 2011).*

4-2 National Groundwater Action Plan

The National Groundwater Action Plan is drafted by MoNRE. The Action Plan is develop base on the real need situation which cover the category of Institutional Settings; Regulatory Framework; Groundwater Management and Strategic Planning; and category of User involvement. In each category there are different support tasks to achieve the action plan.

4-3 Water Resources Law

The water and water resources law were approved in 1996. The MoNRE seek the important necessary to update/revise in order to sustainable water resources management in the country. The water and water resources law is revised in to new Law call ‘’Water Resources Law” that consists of Fifteen Part, Eighty-Eight Article.

The Part Four is call ‘’Use, Protection and Monitoring of Groundwater”. Under this part there are 4 articles support as show below:

- **Article 1.** Use of Groundwater;
- **Article 2.** Community management of groundwater;
- **Article 3.** Groundwater Drilling regulations;
- **Article 4.** Groundwater monitoring and protection

4-4 Regulation on Groundwater Management

The Groundwater Management Regulation is drafting. This regulation objective to groundwater management by giving permit for Ground water use and drilling

5. Groundwater Management Challenges

The groundwater management in Lao PDR was recognized to take serious during restructured of Ministry of Natural Resources and Environment in 2011. The challenges of groundwater management described below:

1. New Institutional setting both national and local;
2. There is misunderstand of some organization/groundwater developer to the groundwater’ mandate institutional;
3. Lack of capacity building both national and local;
4. The staffs lack of experiences, skills and backgrounds on groundwater management at technical line in local level and somehow found in national level as well;
5. The regulation framework is being develop and some groundwater policies is not appeared yet;
6. Lack of groundwater expert to advise the implement of groundwater management throughout the country;
7. Lack of data and information on groundwater used and development and some were separately kept.
8. Lack of financial supported on groundwater management.

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III-2-(7)

Hydrogeological Map of Malaysia -Present status and future plan-

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Abstract

The hydrogeological map of Malaysia has been useful in that it has contributed significantly towards the understanding of the general features and characteristics of groundwater occurrences in Malaysia. It serves as a valuable source of information to government agencies, private sectors and interested parties involved in groundwater investigations and has been utilised as a reference for the preparation, planning and implementation of subsequent hydrogeological programmes. The hydrogeological map was published in 2008 by Minerals and Geoscience Department of Malaysia (JMGM) on a scale of 1:500,000. The main component used in producing this map was lithological map and groundwater database information known as *Hidrodat*. The *Hidrodat* compiles data such as a hydrogeological data, water quality and geological information from borehole logging as well as the data gathered from Groundwater Monitoring Programme. In line with the implementation of 11th Malaysia Plan (2016-2020), JMGM has been given a task to investigate groundwater potential through Groundwater Development Project at Water Stressed Area and River Basin Study to evaluate and establish accurate groundwater reserves in this country. As a result of this investigation, more data will be collected and several potential water-bearing zones can be identified. Thus, with the collected data, database and hydrogeological thematic maps, a new improvised hydrogeological map can be developed for use in development plans for groundwater exploitation in a more efficient and effective manner.

1. Introduction

Groundwater is in high demand in Malaysia where surface water supply is inadequate. It had become a highly researched topic especially during water crisis in drought period and being suggested as an alternative source to surface water. Prolonged seasonal droughts and severe pollution of rivers have imposed a heavy constraint on the surface water supply causing alternative water resources to be in high demand. Recent study had mentioned that the demand for water (surface and groundwater) in Malaysia has been projected to increase by 63 % from year 2000 to 2050. Therefore, producing a hydrogeological map is very important and useful for future groundwater development and management by related agencies in Malaysia, where it offers a much faster process with lesser cost. With more hydrogeological activities being implemented, more data can be captured so that the hydrogeological map can be improvised and be more accurate in the future.

The hydrogeological maps are available in a larger scale as per states of Malaysia, which is prepared by JMGM state offices. Hydrogeological map of each state will be combined to produce a hydrogeological map of Peninsular Malaysia, Sabah and Sarawak.

2. Hydrogeological map of Malaysia and recent groundwater data

2.1. Hydrogeological map of Malaysia

The hydrogeological map of the Peninsular Malaysia on a scale of 1:500,000 was first published in 1975 by Geological Survey of Malaysia. The map was compiled by Chong Foo Shin and Dieter Pfeiffer based on consideration of four main aspects, namely:

i) Lithology: this was based to a large extent on the geological map of the country, published by the Geological Survey in 1973. Consideration was given to the lithological difference and areal distribution of the main rock types.

ii) Structural/Tectonic elements: consideration was given to the occurrence and degree of fracturing, jointing and other factors that contribute to secondary porosity in the rock formation.

iii) Topography: consideration was given to its influence on the flow of groundwater.

iv) Borehole and well data.

Based on the previous map, the hydrogeological map of Malaysia has been updated and improvised from time to time throughout the year to the latest hydrogeological map, which was published in 2008 on the scale of 1:500,000 by using Arc GIS 9.3. Basically, the baseline of groundwater potential zone was delineated based on surface lithological mapping data from Geological Map of Malaysia published in 2005. Other than that, the existing data from the database (*Hidrodat*) was one of the main components used in producing this map. *Hidrodat* is a computer aided database system being adopted for use to store, retrieve, analyse and manage hydrogeological data. In designing the database structure, considerations are given to characteristics of well/borehole and other related hydrogeological data and groundwater quality. This information are being utilised to identify the groundwater potential and for sustainable groundwater resources management.

The groundwater potential zone in the map has been updated based on the latest information of the rock type from bore hole logging and pumping test data as well as water quality analyses. Based on an existing database and recent studies, the distribution of groundwater potential in Malaysia can be generalised as below:

2.2. Peninsular Malaysia

The distribution of groundwater potential in Peninsular Malaysia can be generalised into four main groups:

a) Aquifers in alluvial deposits

Aquifers in alluvium deposits occur along the coastal zones of Malaysia and are made up of quaternary deposits consisting of gravel, sand, silt and clay. Along the east coast of Peninsular Malaysia (Kelantan, Terengganu and Pahang) and south of Selangor (around Teluk Datok), highly productive aquifers can be found especially in areas where sand and gravel made up a 20m thick of aquifer. In the district of Pasir Mas in Northern Kelantan, it showed a gradual thickening of the sediments from about 25 m in the south to more than 150m in Tumpat area. Generally, the Kelantan and Terengganu alluvium aquifers can yield per well more 100 m^3/hr.

b) Limestone/carbonate Rock Aquifers

This type of aquifer is made up of carbonate rocks (limestone and marble) and is mainly found in the states of Perak, Perlis, Kedah and Selangor. In Perak, limestone outcrops are exposed within the center part of the state around Ipoh, Kampar and Batu Gajah. In Royal Perak Golf Club (Kinta Valley), an 8 inch diameter tube well was constructed which yields 32 m^3/hr.

In central part of Perlis, high potential aquifers are located on limestone areas adjacent to Malaysia - Thailand border, such as Paya Kerchut, Arau and Kg. Bonggol Sena which yield from 67-117 m^3/hr.

c) Aquifers in sedimentary/metamorphic rocks

These aquifers are present in the fractured sandstone, quartzite, shale, conglomerate, schists and slate. These type of aquifers can be found in the state of Kedah, Negeri Sembilan, Johor and Selangor of the Peninsular Malaysia. Fractured sedimentary rock, their metamorphic equivalent and volcanic rock aquifers can yield up to 30 m^3/hour. In phyllite/schists, yields are comparatively high ranging from 20.0 - 40.0 m^3/hour.

In 1999, studies on groundwater potential were carried out in the District of Kuala Muda and Padang Terap, Kedah. The results showed that there were groundwater resources potential in hard rock formation located within Mahang Formation in Kuala Muda area, which consists of slate and graphitic schist and Semanggol Formation, which consists of interbedded metasandstone and metaargillite with minor conglomerate in Padang Terap area. Both areas can give an average yield of 22 m^3/hr/well. The water quality is good and suitable for domestic purposes except for iron (Fe) and manganese (Mn) which exceeded the standard value recommended by World Health Organisation (WHO). Nevertheless, the content of Fe and Mn could be reduced to the acceptable level through the treatment methods such as aeration, precipitation or filtration.

d) Aquifers in igneous rocks and volcanic rocks

Granitic rocks are found in the west, forming parts of the Main Range and generally extend from north to south. Fractures within crystalline rocks and associated rocks form this type of aquifer. These aquifers are found in the states of Johor, Selangor, Melaka, Negeri Sembilan and Kedah. Yields are comparatively low ranging from 5.0 -12.0 m^3/hr. In the district of Kota Tinggi (Johor), the fractured aquifer gives a yield of 10 m^3/hr whereas, in the district of Alor Gajah (Melaka) it gives a yield of 4 m^3/hr only.

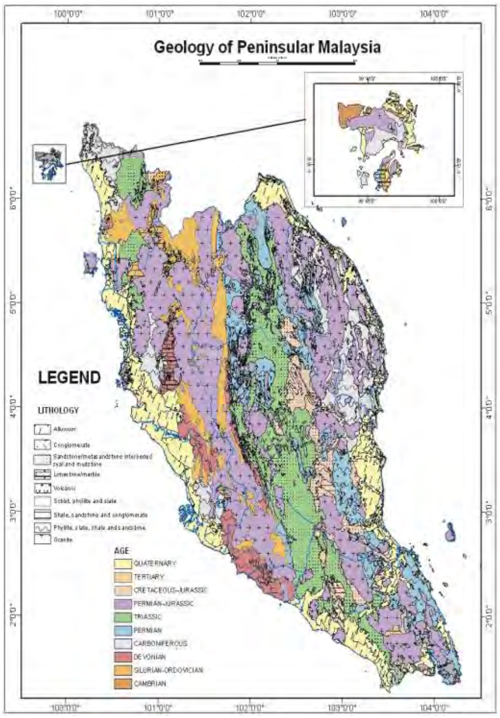

Fig. 1. Geological map of Peninsular Malaysia

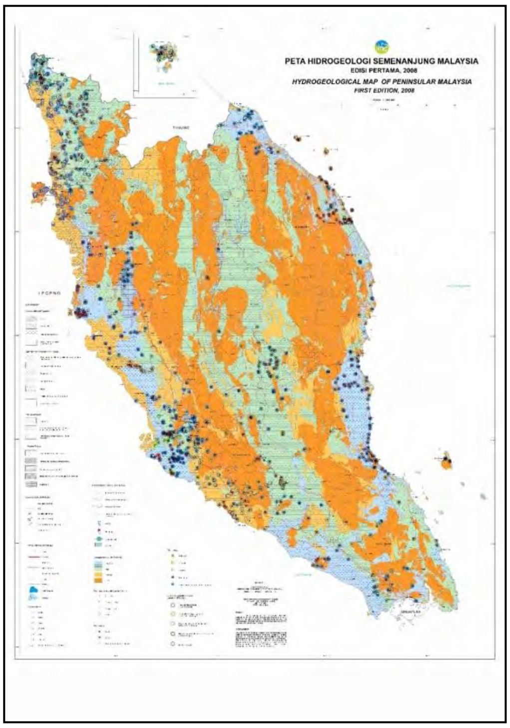

Fig. 2. Hydrogeological map of Peninsular Malaysia

2.3. Sabah

In Sabah, over three quarters of the State are underlain by sedimentary and volcanogenic-sedimentary rocks. The most productive aquifer is at the Sandakan Formation (thick-bedded sandstone) that underlies part of the Sandakan district in the east coast of Sabah. The other potential aquifers are at the Belait Formation (at the southwest coast and in Labuan) and the Crocker Formation, which are extensively faulted and fractured. Quaternary and Recent Alluvium, which cover the coastal areas give small but sufficient yield for the isolated villages.

2.4. Sarawak

Hydrogeologically, Sarawak can be divided into three distinct regions – West Sarawak, Central North Sarawak and the coastal alluvium plains. Generally, the aquifers in Sarawak can be classified into three categories: shallow aquifers (sand, gravel and peat), deep aquifers in sedimentary basins and deep aquifers in fractured hard rocks.

2.5. Recent Groundwater Data

In the 10th Malaysia Plan (2011 – 2015), JMGM had completed groundwater investigations for the assessment of groundwater potential and to provide clean drinking water to the water-constrained areas. A total of 33 exploration wells were drilled, nine (9) monitoring wells were constructed and 30 production wells were successfully developed as water resources in 2015. Besides this, a total of 19 production wells were constructed under the Disaster Relief Project to provide water for clean-up purposes due to flood disaster occurred in late 2014 till early 2015 at the east coast of Peninsular Malaysia. Other than that, JMGM had also liaised with the Department of Environment Malaysia to construct tube wells to combat and prevent peat fires, which commonly occur during the seasonal dry spells.

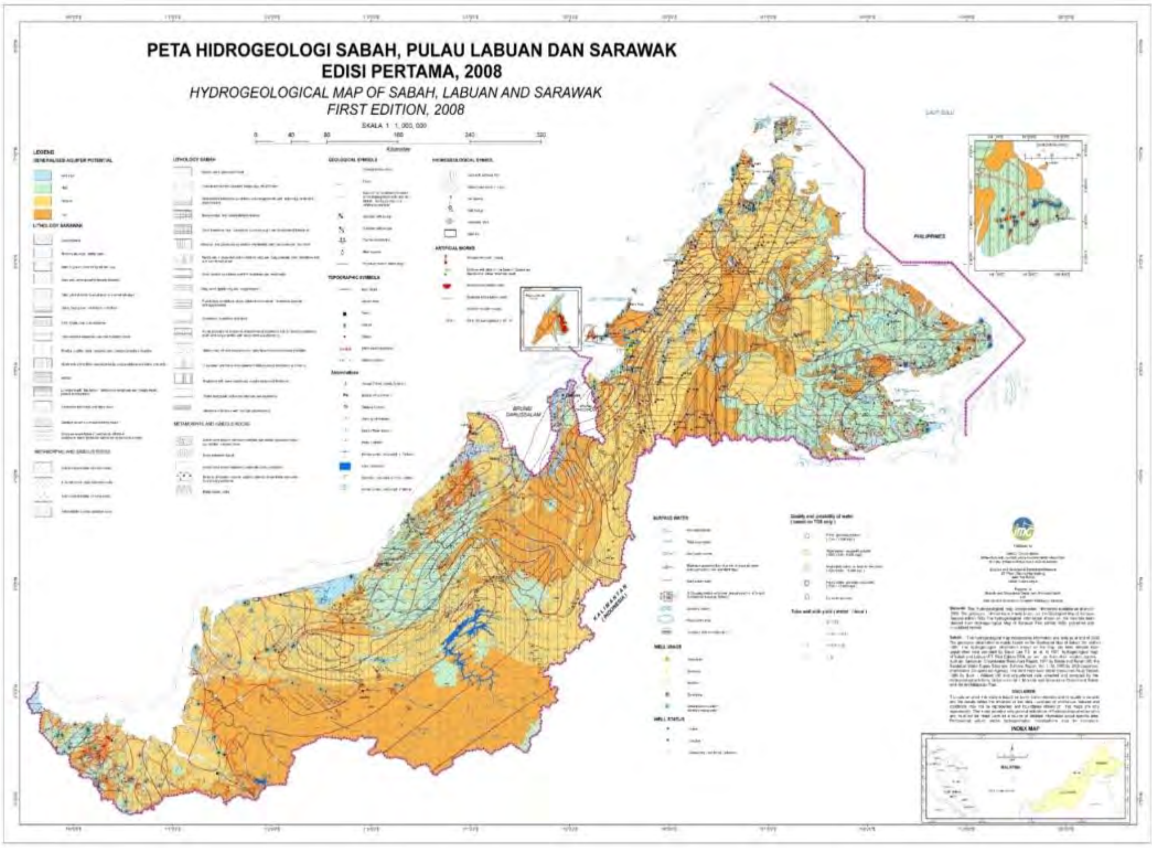

Fig. 3. Hydrogeological map of Sabah and Sarawak

The information obtained from these groundwater related works, which involve drilling, borehole logging, pumping test, geophysical survey and water quality analyses, more data can be included into the existing map. With these data, the hydrogeological map of Malaysia would be more informative and accurate in line with current demands. Table 1 shows the wells that have been successfully constructed in 2015:

Table 1. Wells Information

State	Location	No. of well	Depth(m)	Yield(m^3/h)
Kedah	Sik	1	63	51.6
	Pendang	1	102	12.20
Selangor	Banting	1	60	60
	Kuala Langat Selatan	1	72	60
Negeri Sembilan	Gemencheh	1	113	9
Kelantan	Bachok	1	60	>90
	Lojing	1	130	4.5
Johor	Mersing	1	104	27
Sabah	Tuaran	5	8-10	7 (average)

Based on the successful achievement of the 10th Malaysia Plan Project, Minerals and Geoscience Department (JMGM) has been entrusted by the government of Malaysia to conduct and manage groundwater development projects in the 11th Malaysia Plan (2016-2020). These projects are:

i) to provide clean water for the people in water stressed areas, which is facing shortage of water supply and also for the water treatment plants if necessary,

ii) to estimate the groundwater reserves in five (5) river basins; Selangor River Basin in Selangor, Pahang River Basin in Pahang, Kuala Muda River Basin in Kedah, Miri -Baram River Basin in Sarawak and Kedamaian -Tempasuk River Basin in Sabah,

ii) to carry out periodic groundwater monitoring for the purpose of evaluating the quantity, quality, land subsidence and contamination, so that groundwater protection zone can be established to avoid destruction and contamination of aquifers.

Apart from the projects listed above, a study to identify boundary of salt water intrusion zone along the coastline is also carried out. The output of the study can be used as a guide in future water resources planning along the coastline.

3. Groundwater Monitoring

Initially, groundwater monitoring activities have been undertaken by the Geological Survey Department of Malaysia in selected areas since 1989, as part of a long term programme to detect changes to the hydrogeological regime. Monitoring well networks have been established in the alluvial aquifer system in the coastal areas of north Kelantan and east Pahang. The networks were designed and built to monitor the groundwater regime such as the Sungai Kelantan delta in north Kelantan. The programme was expanded to include areas where active groundwater pumping has been carried out by state water supply authority, such as in Terengganu, Pahang, Kedah and Perlis. Monitorings were carried out by using existing JKR/JBA wells and supplemented by JMG's own wells wherever possible. For example, in Kuantan-Pekan-Rompin area, the exploration wells constructed during Regional Hydrogeological Studies by JMG were used as monitoring wells. Monitoring well sites were targeted at areas that are potentially vulnerable to contamination such as at the industrial, rural, urban/suburban, agricultural, golf courses and landfills area.

Presently, groundwater monitoring activities are being carried out throughout the year as part of the JMG’s effort to monitor the trends in groundwater level, the state of groundwater quality, evaluating the impact of groundwater abstractions, checking compliance with standards, determining suitability for specific uses, preventing saltwater intrusion, tracing movement of contamination within the aquifer and to enable sustainable use and long term planning in relation to groundwater resource. The monitoring activities are being carried out twice a year. In 2015, a total of 396 wells were monitored.

4. Future plan of hydrogeological map of Malaysia

Presently, the hydrogeological map of Malaysia, which was published in 2008 is being used as a reference for all concerned purposes. However, there is a hiatus of data input since 2009 up till now. To produce a more informative and impressive hydrogeological map of Malaysia, recent and latest data should be included into the map. Data from the various projects of groundwater studies under the Malaysia Plan Development Projects carried out by JMGM could be utilised to further enhance the quality of the said map.

From the projects and studies carried out, more geological and hydrogeological data can be captured and the map can be improvised. Amongst the improvisation that should be done are:

i) converting the existing water table/potentiometric surface data to the reference datum (above mean sea level) for water table/potentiometric surface mapping (contouring). These contours will visualize the groundwater flow.

ii) groundwater salinity mapping for particular aquifer where Total Dissolved Solids (TDS) are commonly used (in ppm). The map will show the boundary between the freshwater and saltwater zone at the interface.

iii) delineating the aquifer potential zone based on the latest lithological information obtained from borehole logging so that the aquifer potential zone can be mapped precisely.

5. Conclusion

JMGM is the lead agency entrusted with the responsibility to undertake exploration and evaluation of groundwater resource potential and characterization of aquifer systems. It has also undertook groundwater monitoring works involving routine measurement and surveillance of groundwater levels, groundwater quality and land subsidence in the major groundwater basins in the country. In line with the implementation of groundwater development project in the 11^{th} Malaysia Plan (2016-2020) by JMGM, more hydrogeological data can be collected and included into the present hydrogeological map. Not only from JMG's department, data from other government agencies and private sectors will also be used to produce a more meaningful and an impressive hydrogeological map of Malaysia. Thus, with the available data collected, systematic database and hydrogeological thematic maps, a new improvised hydrogeological map of Malaysia can be developed for use in the development plan for groundwater exploitation in an efficient and effective manner.

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III-2-(8)
Present Status of Hydrogeological Mapping in Myanmar

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Abstract

There is no detail hydrogeological map in Myanmar which covered the whole country. Groundwater related departments and agencies that are mainly use as reference on the Geological Map of Myanmar, edited and compiled by Myanmar Geosciences Society in 2014 scaling 1:1000000. There are some detailed regional geological maps available for referencing in groundwater exploration purposes at Universities' Thesis and research. But the detail Hydrogeological map is available which covered some parts of the country especially for the Central Dry Zone of Myanmar and administratively include the parts of Sagaing, Mandalay and Magway Regions. This map presents some of the main hydrogeological and hydrochemical characteristics of aquifers in the Central Dry Zone of Myanmar. The compilation of this map was carried out by Australian hydrogeologist, Dr. L. W. Drury, Project Manager, village water supply project in consultation with hydrogeologists from the Rural Water Supply Division, Agriculture Mechanization Department and the Irrigation Department; both are under the Ministry of Agriculture and Forests at the past time. The map was printed in August, 1986. All interpreted lines and boundaries showing in the map have been based on available literature, tube well data and field evidences; however, the degree of estimation involved is such that the position of lines and boundaries should be regarded as a good approximation. As additional Hydrogeological information becomes available, the modifications to this given data may be necessary. Recently, the final filed checking and editing on previous hydrogeological and hydrochemical map of Central Dry Zone of Myanmar is in progress collaboration with Dr. L. W. Drury, Australian hydrogeologist and hydrogeologists from Irrigation and Water Utilization Management Department. The extension of detail hydrogeological mapping for the whole country is urgently needed for future groundwater development in Myanmar.

Keywords: groundwater, hydrogeological map, Myanmar, hydrochemical characteristics

1. Introduction

1.1 Land area and boundary

Myanmar is located between 9˙ 32' and 28˙ 31' North Latitude and 92˙ 10' and 101˙ 10' East Longitude. The total land area is about 676,557 km^3. Myanmar is bordering with China in the north, Thailand and Laos PDR in the east, India and Bangladesh in the west and Thailand in the south. It is characterized by mountain ranges in the north, east and west and a long coastal strip in the south and west.

Fig.1. Location Map of Myanmar

1.2 Population

The population of Myanmar is estimated at 51.486 million in 2014 and the 70 % of them are residing in rural area. According to 2014 census, the population increasing rate is about 0.89 % and the average population density of the country is 76 persons per square kilometer.

1.3 Climate and rainfall

Myanmar has three distinct seasons. The cold season starts from November to end of January; dry season starts from February to April followed by the wet season. Myanmar receives its annual rain mainly from south-west monsoon from mid of May to mid of October. The rainfall intensity, pattern and rainy duration are varied depending on the locality and elevation of the region. Rainfall receives 2,030 mm to 3,050 mm in the deltaic area, 2,030 mm to 3,810 mm in the north, about 1,500 to 2,000 mm in eastern hilly region, rising to 5,080 mm in the coastal regions of Rakhine and Taninthayi and only 760 mm in the central dry zone. And incidentally such localities experience temperature of 40 ˚C during summer, and dropping to 10˚C to 16˚C in some hilly regions.

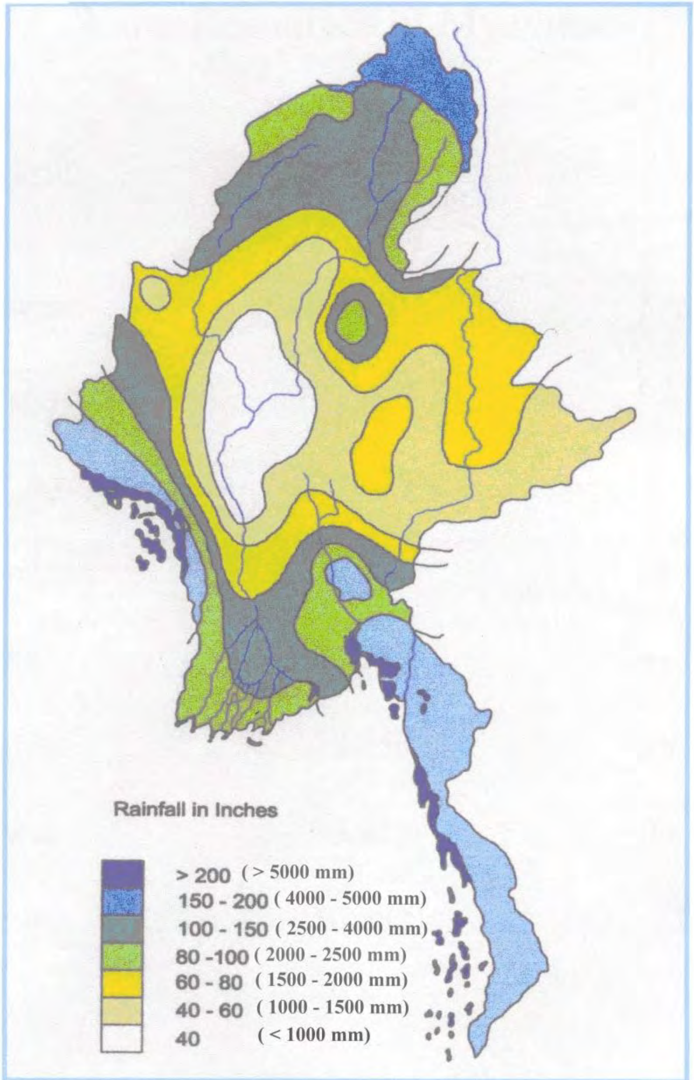

Fig.2. Annual Rainfall Map of Myanmar

2. Recent groundwater data and hydrogeological mapping in Myanmar

2.1 Water Resources Potential

Among the water resources rich countries, Myanmar could still be classified as low water stress country. There are four major river systems, namely, the Ayeyarwaddy, the Thanlwin, the Chindwin and the Sittoung. Moreover there are some river systems in Rakhine State and Thanintharyi Region. These river systems contribute for the surface water resources of the country. Due to physiographic condition of the country, there are eight major river basins can be classified and those cover about 90% of the country's territory. Total surface water and groundwater potential of Myanmar are estimated about 1, 082 km^3 and 495 km^3 per year respectively.

Fig.3. River Basin Map of Myanmar

Table 1. Myanmar's annual average water resources potential by river basin

Sr.	River Basin Number	Name of Principal River Basin	Catchment area for each stretch (thousand sq.km)	Average estimated annual surface water(km^3)	Estimated groundwater Potential (km^3)
1	I	Chindwin River	115.3	141.293	57.578
2	II	Upper Ayeyarwady River (up to its confluence with Chindwin)	193.3	227.92	92.599
3	III	Lower Ayeyarwady River (From confluence with Chindwin to its mouth)	95.6	85.8	153.249
4	IV	Sittoung River	48.1	81.148	28.402
5	V	Rivers in Rakhine State	58.3	139.245	41.774
6	VI	Rivers in Taninthari Division	40.6	130.927	39.278
7	VII	Thanlwin River (From Myanmar boundary To its mouth)	158	257.918	74.779
8	VIII	Mekong River (within Myanmar Territory)	28.6	17.634	7.054
TOTAL			**737.8**	**1081.885**	**494.713**

2.2 Geological Map of Myanmar

The updated geological map of Myanmar was compiled by Myanmar Geosciences Society in 2014. The Scale of Map is 1:2,250,000.

2.3 Hydrogeological and Hydrochemical Map of Central Dry Zone of Myanmar

It accompanies along with the regional geological map, the unpublished text book entitled "an Assessment of the Hydrogeology and Hydrochemistry in the Dry Zone, Central Burma". Primarily this map indicates specific conductance, yield and direction of groundwater flow of the major aquifer systems. Generalizations are necessary where multiple aquifer systems of variable aquifer hydraulic characteristics or salinity are intersected. Also indicated are areas of artesian flow, zones where loss of drilling mud circulation during tube well construction may occur, Hydrogeological boundaries, occurrence of high temperature groundwater and average annual rainfall. For elaboration of these features the text book should be consulted.

All interpreted lines and boundaries have been based on available literature, tubewell data and field evidence; however, the degree of estimation involved is such that the position of lines and boundaries should be regarded as a good approximation. As additional Hydrogeological information becomes available modifications to this given data may be necessary.

The compilation of this map was carried out by Dr. L.W. Drury, Project Manager, village water supply project in consultation with hydrogeologists from the Rural Water Supply Division, Agriculture Mechanization Department and the Irrigation Department, both of the Ministry of Agriculture and Forests in August, 1986. The assistance and co-operation of the National Water Committee, Working Groundwater Committee, University of Yangon, University of Mandalay, Department of Geological Survey and Mineral Exploration and Department of Applied Geology, Yangon University.

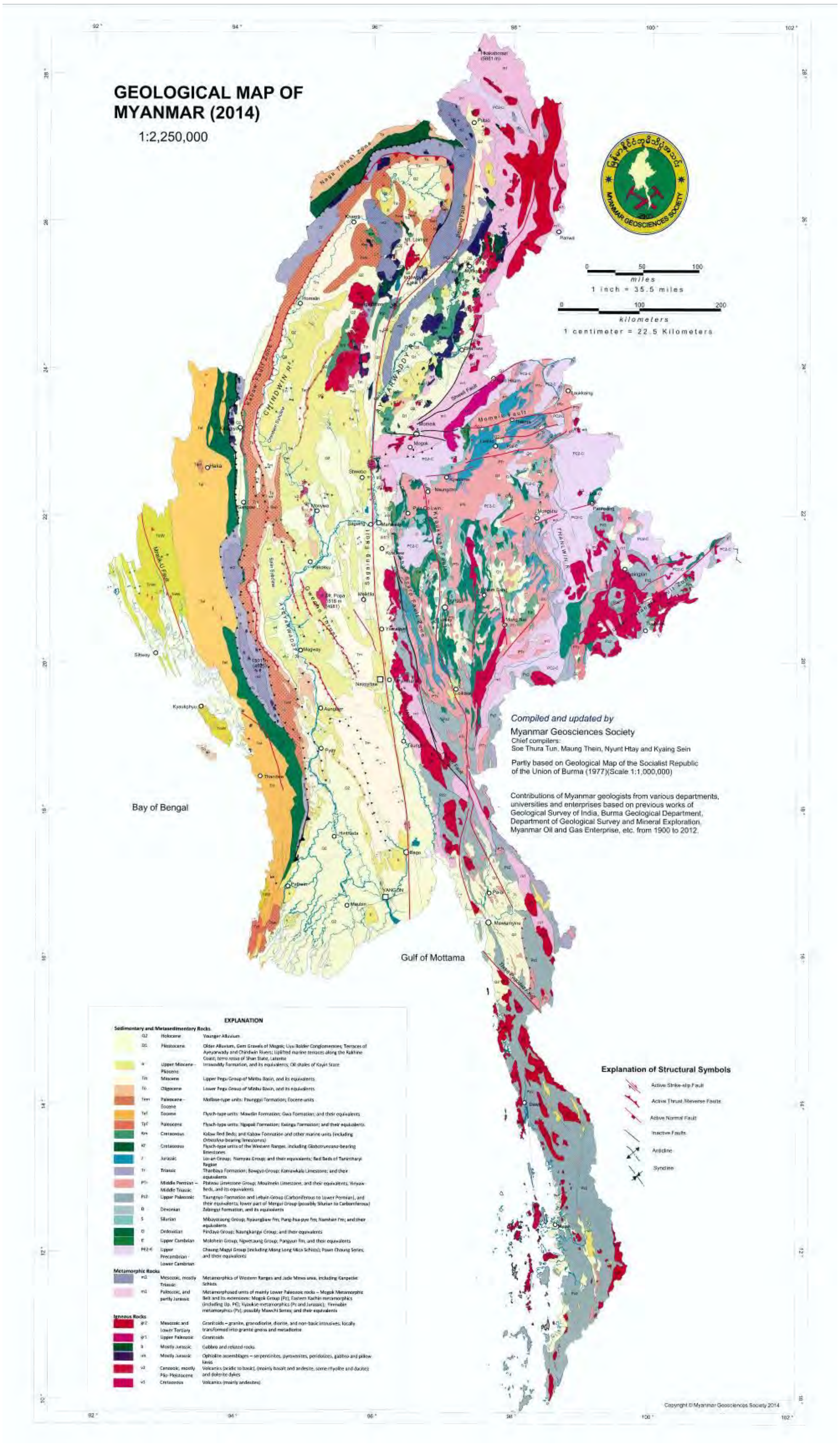

Fig. 4. Geological Map of Myanmar

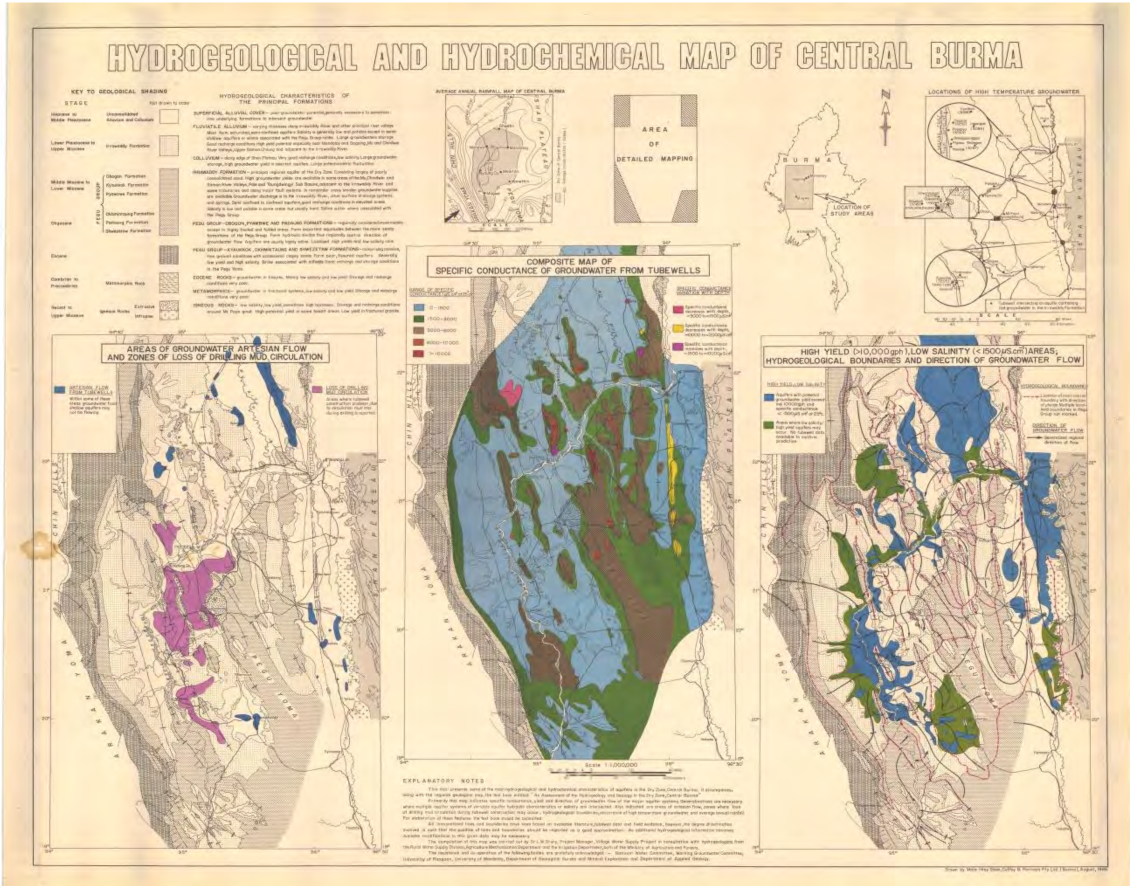

Fig. 5. Hydrogeoloigcal and Hydrochemical Map of Central Burma

3. Hydrogeological Survey and Groundwater Monitoring in Myanmar

3.1 Hydrogeological Survey

There are two major groundwater related departments in Myanmar namely, Irrigation and Water Utilization Management Department (IWUMD) and Department of Rural Development (DRD). Both departments are under the Ministry of Agriculture, Livestock and Irrigation. The main responsibilities of those departments are groundwater investigation, exploration and groundwater management works.

The following methods are use in hydrogeological surveying;

- Surface geophysical investigation by resistivity method
- Test well drilling
- Sub-surface geophysical bore hole logging method is used for aquifer setting in water well construction works
- Pumping test investigation is performed in the necessary areas to know aquifer parameters
- Water quality analysis in the laboratory was carried out by department's own laboratory
- Hydrogoelogical mapping using GIS is also applied in some project area.
- Updating of Hydrogeological and Hydrochemical Map of Central Dry Zone of Myanmar collaboration with Australian Water Partnership (AWP) and it is now in progress.

Fig. 6. Surface Geophysical Surveying using SAS 1000 Terrameter

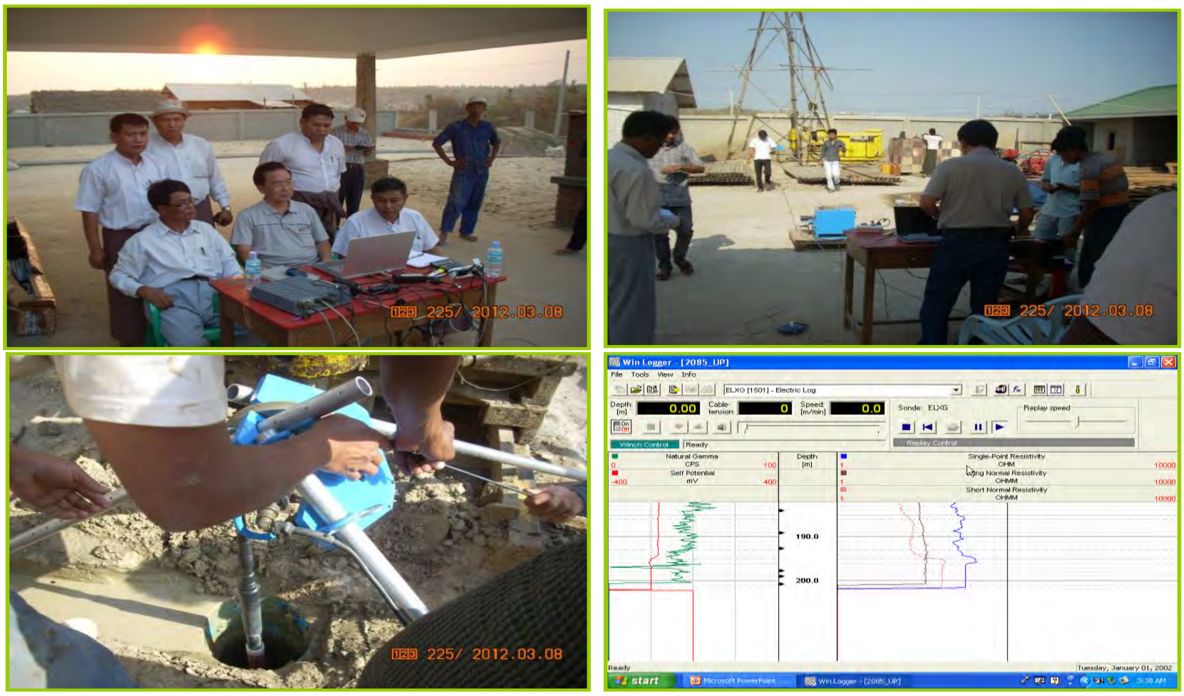

Fig. 7. Geophysical bore hole logging at water well drilling site

Fig. 8. Water Well Drilling Site (flowing tubewell at Sagaing Region)

Fig. 9. Water Quality Testing Laboratory

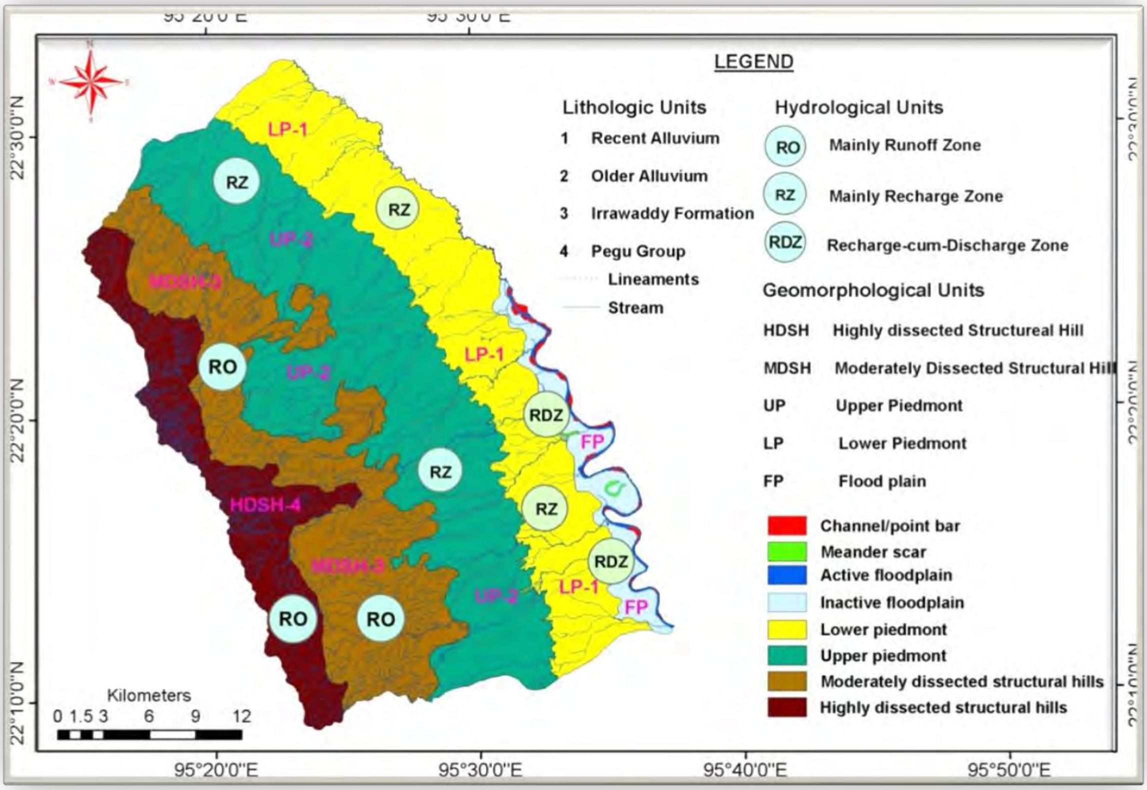

Fig. 10. GIS Mappping

3.2 Groundwater Monitoring Stations

Recently, the total of 8 groundwater monitoring stations are establishing in progress by government own budget. But there is no remote access facilities can installed because of budget limitation. The Solinst level logger of Canadian origin will installed in each stations. The main objectives of establishment of groundwater monitoring stations are;

- Data support to systematic groundwater management plan
- To know seasonal and annual groundwater table fluctuation
- To know the water quality changes in term of EC
- To prevent over exploitation of groundwater
- Linkage to regional and global groundwater monitoring networks

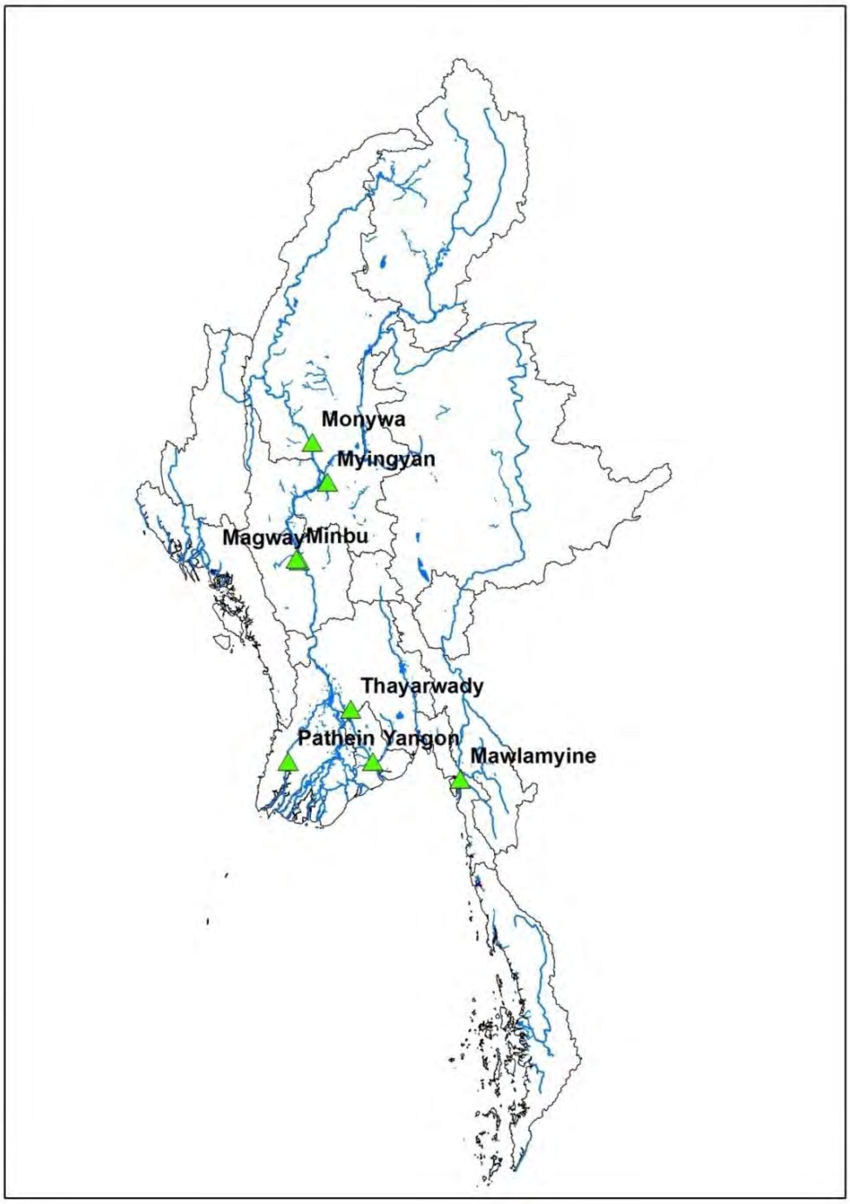

Fig. 11. Location map of groundwater monitoring stations in Myanmar (in progress)

4. Future Plan of Hydrogeological Mapping in Myanmar

- The updating and modification of previous printed hydrogeological mapping in Central Dry Zone collaboration with International Water Management Institute (IWMI) and Australian Water Partnership (AWP).
- The detail hydrogeological mapping for the whole country will extend based on the financial availability.
- Need technical and financial assistances for establishment of groundwater balance model for the country.
- The country is stilled need capacity building in application of GIS and Remote Sensing in detail hydrogeological mapping process.

5. Conclusion

Myanmar National Water Resources Committee (NWRC) was formed in 2013. It is on the highest level and the most responsible committee in the water sector of the country. The committee adopted "Myanmar Water Resources Policy" in February, 2014. Myanmar still needs to get the technical assistance from regional organizations. The detail hydrogeological mapping for the whole country is urgently needed for the sustainable development of groundwater resources in Myanmar. The limited financial and technical measures are the main constraints for mapping. Even though, the country himself is trying to develop in the all sector of the natural resources. Myanmar would like to cooperate in the trans-boundary aquifer mapping with bordering countries.

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III-2-(9)
Hydrogeological map of Papua New Guinea -Present status and future plan-

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Abstract

Groundwater in Papua New Guinea (PNG) may be categorized into five broad hydrogeological units which comprise of the bedrock formations, volcanic rocks, karst limestones, coastal sediments, and unconsolidated sediments. The bedrock formations include metamorphic, intrusive igneous and sedimentary rocks which form the mountain region that runs northwest-southeast in the center of the mainland of PNG. Of the five units, most water bores in PNG are developed from the unconsolidated sediments.

Utilization of groundwater is increasing, hence the need for more quality groundwater data is essential as this will contribute to a better understanding of the groundwater resource and how it behaves. Collection of such data may also aid in creating groundwater maps which is also vital for a better understanding of the groundwater resource, and may be beneficial in future groundwater investigations.

A groundwater monitoring system would be most vital in keeping record of the changes in groundwater behavior and groundwater quality. However, at present, there is no monitoring system in place in PNG; irrespective of this, field visits are carried out to various borehole sites to confirm the current status of boreholes, whether operational or abandoned within the capital of PNG, Port Moresby.

Collection of groundwater data for Port Moresby has already commenced, and most data have been acquired from previous groundwater reports of the area, and the same method will be carried out for other provinces of PNG once the final database has been created. Updated data which will require field tests on the existing operational bores, is necessary for this project, however.

Keywords: PNG, groundwater, groundwater potential map, groundwater data.

1. Introduction

Papua New Guinea (PNG) is situated between the latitudes 1^0S and 12^0S and longitudes 141^0E and 156° E. The capital city, Port Moresby is situated at 9° S and 147° E. Papua New Guinea comprises the eastern half of the main island of New Guinea and groups of small islands. The main island of PNG shares a border with Indonesia to the west.

Groundwater in PNG may be found in five broad hydrogeological units and consist of the bedrock formations, volcanic rocks, karst limestones, coastal sediments, and unconsolidated sediments. In the past, groundwater was utilized mainly for domestic purposes in urban and rural areas and occasionally for agricultural and industrial purposes. At present, demand for groundwater as a source of reliable portable water in rural communities has increased, and the agricultural and industrial sectors are becoming more aware of the potential for its utilization.

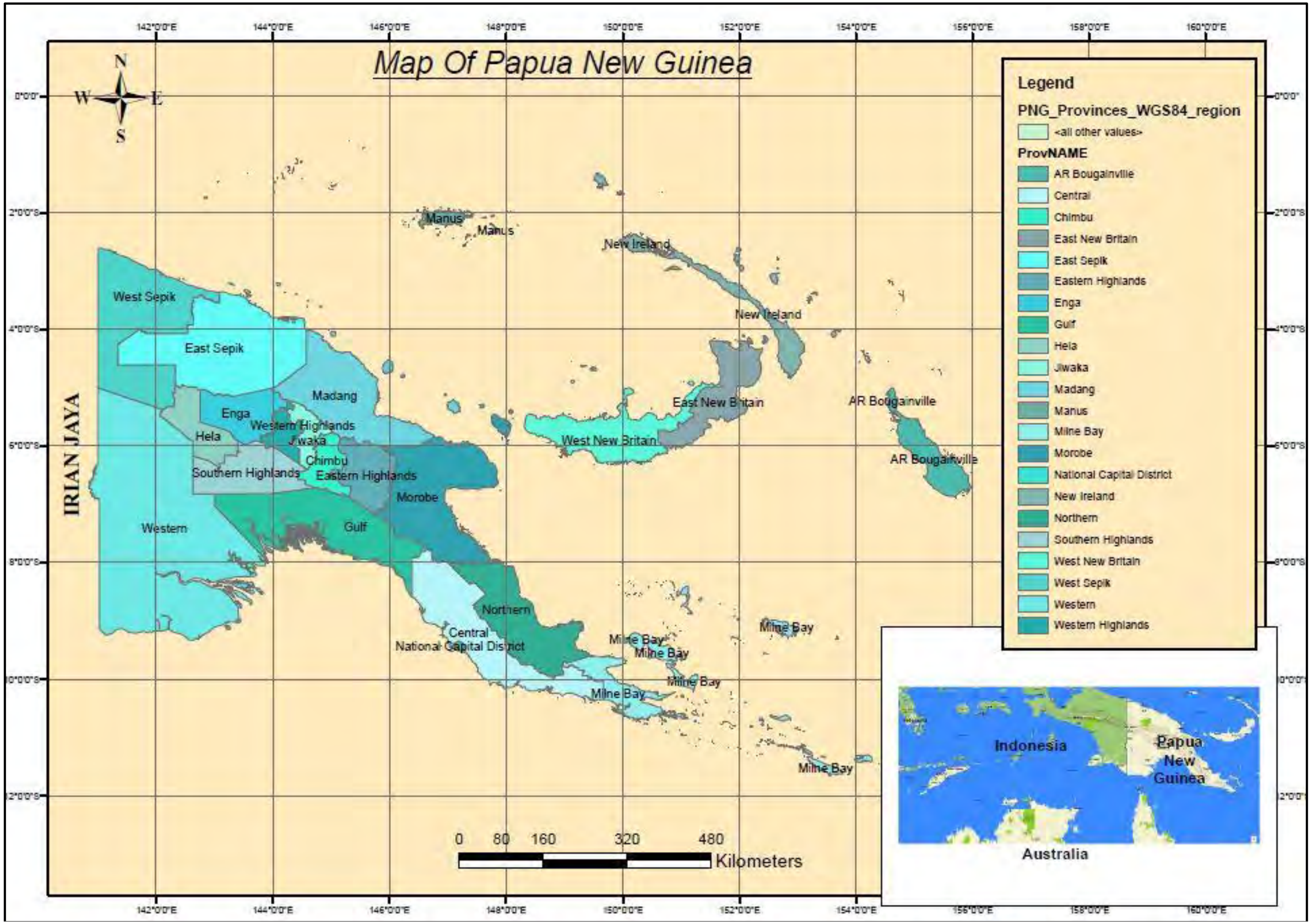

Fig. 1. Location map of Papua New Guinea (Fabila, 2017)

As the utilization of groundwater is increasing, the need for groundwater data is getting more significant as this may contribute to a better understanding of the groundwater resources in the country. It is essential that groundwater data should be collated and recorded into a database, so that the groundwater resource can be more easily understood and developed. Collection of important groundwater data may help in creating groundwater maps which will give a better understanding of this valuable resource, and will assist in future groundwater investigations.

2. Recent Groundwater Data And Hydrogeological Map in Papua New Guinea

2.1. Recent Groundwater Data

Groundwater data collection for a new groundwater database commenced in the year 2016, where reports of the capital city of Papua New Guinea, Port Moresby, were reviewed and hydrogeological data was collated. Approximately 190 boreholes were identified from these reports and were tabulated into an excel spreadsheet database; a few of the boreholes had duplicate records in one or two reports.

A city-wide site survey was undertaken throughout Port Moresby City to locate the boreholes, and to confirm the status of each borehole, whether they were still operational or abandoned. Majority of the boreholes were abandoned, while only a few (less than 25 %) were found to be operational. A number of boreholes that were recently constructed were also visited and recorded into the database. A representation of the database spreadsheet is presented in Table.1 below. The field visits to locate and confirm existence of the boreholes is continuing at present.

A similar hydrogeological investigation is being conducted for Kokopo Town in East New Britain Province. The investigation commenced in April 2016 and will continue for the rest of 2017.

2.2. Hydrogeological Map in Papua New Guinea

Groundwater in PNG may be classified into five broad hydrogeological units and consists of:

1. Bedrock formations.
2. Volcanic rocks.
3. Karst limestones.
4. Coastal sediments.
5. Unconsolidated sediments.

2.2.1. Bedrock Formations

These formations generally consist of metamorphic, intrusive igneous and sedimentary rocks that form the basement of the central ranges of the mainland of Papua New Guinea and some of the smaller islands to the east. Groundwater within these rocks is available in open joints and fractures, however, characteristically they have low primary porosity and permeability, hence are considered to have relatively low groundwater potential, although some sandstone formations may form porous rock aquifers. Most areas underlain by these rocks are mountainous and sparsely populated; hence demand for groundwater is minor. Only in the past 20 years, drilling in bedrock formations around Port Moresby and the then Misima Mine have indicated that groundwater potential of bedrock formations can be important.

Table 1. General view of the general information on the borehole data collected from previous reports

Report No.	Registered No / Well ID	Location	Easting (mE)	Northing (mN)	Elev. (m)	Total Depth (m)	Groundwater Level (m)	S.W.L (m)	Supply (m3/hr)	Salinity (p.p.m)	Lab Test	Pump Test	Year	Remarks
1972/243	P116	University of PNG	518981	8959529		18.3					No	No		Abandoned - insufficient supply
1972/243	P117	Wards Strip - Telikom Rumana	520027	8957146		21.3	6.1			564.0	Yes	No	1967	Abandoned
1972/243	P118	Wards Strip - NSO	520028	8957405		16.1	7.6				No	No		Abandoned
1972/243	P119	Transitmix Quarry	525127	8960809	45.0	18.3	10.7	7.0	1.8	557.0	Yes	Yes	1971	Electric Pump - existing
1972/243	P120	Transitmix Quarry	525136	8960913		14.9		11.9	0.1		No	Yes		Abandoned
1972/243	P124	Boroko Sports Oval	522282	8952801		10.7					No	No		Abandoned
1972/243	P125	Boroko (Bava Street)	522184	8952695		13.7	8.2	8.8		C12100	No	No		Abandoned - saline
1972/243	P126	Baruni Village	514629	8957625		12.8		7.6			No	No		Abandoned - caving
1972/243	P127	Baruni Village	514618	8957627		13.7					No	No		Abandoned
1972/243	P128	Baruni Village	514679	8957568		0.6					No	No		Abandoned
1972/243	P129	Eleven Mile - Brown River Road	524628	8962525	33.5	7.3		6.7		367.0	Yes	No	1971	Electric Pump - Existing
?	P135	Pari Village				13.8					No	No	1957	Abandoned
1972/243	P178	Laloki Psychiatric Hospital	524664	8965035	33.0	24.2	18.3	3.7	2.0	477.0	Yes	Yes	1971	Electric Pump - Existing
1972/243	P200	Laloki Psychiatric Hospital	524604	8965176	32.0	22.2	13.7	2.4	2.0	481.0	Yes	Yes	1971	Electric Pump - Existing
1972/243	P213	Ten Mile Quarry	525096	8960756		18.3	10.7	7.6			No	No		Abandoned
?	P215	Napa Napa	512529	8954881		18.3					No	No	1967	Abandoned
?	P221	Austin Crossing	527409	8952461		12.2	2.4				No	No	1971	Abandoned
?	P231	Tanubada				18.3	0.9	5.8			Yes	Yes	1971	
1972/243	P237	Moitaka Wild Life Laboratory			40.0	19.8			0.4	729.0	Yes	Yes	1971	Abandoned - insufficient supply
1972/243	P238	Moitaka	522827	8959132	30.0	9.1					No	No		Abandoned - dry; covered by development
1972/243	P239	Makana School				12.2					No	No		Abandoned - insufficient supply
1972/243	P240	Moitaka	523163	8958778	26.0	10.7					No	No		Abandoned - Covered by development
1972/243	P241	Jacksons Airport	523082	8956490	53	14.3	8.5	5.5	1.4		No	Yes		Monitored bore
1972/243	P256	Laloki Valley - Telecom Relay Station				13.8	4.3	4.3		463.0	Yes	No	1972	
1972/243	P259	Moitaka	520935	8965223		14.3	7.6	5.2	3.6		No	Yes		
1972/243	P260	Moitaka	519861	8965793		9.8	7.6	4.0			No	No		
1972/243	P261	Laloki Valley - United Church Training Farm	?							343.0	Yes	No	1972	
1972/243	P262	Gumine Squatters Camp, Rigo Road	?							606.0	Yes	No	1971	Dugwell
1972/243	P263	Gordons - Environmental Health Services	?							746.0	Yes	No	1971	Dugwell - demonstration
?	P291	POM Golf Course	521475	8957982	47.0	18.9	2.7	4.9			No	Yes	1973	Monitored borehole
?	P292	POM Golf Course	520854	8958937		9.1				422.0	Yes	No		abandoned
?	P293	POM Golf Course	521200	8958096		12.2					No	No		abandoned
?	P294	POM Golf Course	521311	8958590	50.0	13.4	2.1	1.2			No	Yes		POM Golf Course - abandoned
?	P295	New Show Grounds	521178	8958022	43.0	12.8	4.6			490.0	Yes	Yes	1973	Abandoned - golf course pond
?	P335	Son Mig Brewery - POM	51446	8952287		90.0	4.3	18.7			No	Yes		Abandoned
?	P340	Baruni Atlas Still Mill	514192	8958994		27.0	0.2				No	No	1978	Abandoned - windmill
?	P342	Bomana Seminary	528205	8961108	40.0	11.0	1.9	1.3			No	Yes	1978	Electric Pump - existing (previosuly windmill)
?	P343	Tanubada Dairy				21.7					No	No	1978	Abandoned
?	P344	Tanubada Dairy				19.0	3.7	5.1	9.7		No	Yes	1978	
?	P345	Gordons International School	521690	8956012		18.5	5.5	11.0			Yes	Yes	1979	Abandoned - check IEA on 3254088

2.2.2 Volcanic Rocks

The volcanic deposits consist mostly of andesitic and basaltic lavas and pyroclastics. They occur in most parts of PNG, however occupy a relatively small total area. Massive lava flows are generally poor aquifers, but where dissected by closely spaced joints, occurrence of large quantities of groundwater is possible. Other potential aquifers consist of slightly to moderately weathered, brecciated lava flows, interbedded pyroclastics, reworked pumiceous tuffs and buried alluvium. Perched groundwater exists where buried soils and fine grained tuffs with very low permeability act as a confining bed and forms barriers to groundwater movement.

The most intensely developed volcanic aquifer underlies the township of Rabaul, which is located on the floor of a caldera. This aquifer consists of volcanic debris which mainly comprise of reworked pumiceous tuff (Jacobson et al, 1974). Around the Kokopo area, the aquifer/ water bearing formation is from the ash beds which extend from the Rabaul caldera, and are thicker near the caldera (~5,000 m) and thin out further away, with an approximate thickness of 1,000 m around the Kokopo area (Water Board PNG, 1996).

Groundwater springs are most common on volcanic islands and forms a significant proportion of the villages water supplies for Bougainville, New Ireland and New Britain provinces.

2.2.3 Karst Limestone

Karstic limestone landforms in PNG are extensive. Most of these areas consist of caves and sinkholes, and despite a high annual rainfall, a minimal number of surface drainages exist. These areas have high groundwater potential, however not many of the known boreholes or dug wells tap into the karst limestone aquifer. Yields are not known for the few boreholes that tap into this aquifer. Spring development, on the other hand, is more common and is used as a source of water supply.

2.2.4 Coastal Sediments

Parallel to the coast line around the main land of PNG, coastal sediments are widely developed along a narrow strip, and extend up to several hundred meters inland. This hydrogeological unit comprises of two main lithologies: raised coral limestone (locally known as karanas) and alluvial and detrital sediments including gravel, sand and mud. Further inland, the unit grades into karst limestone or unconsolidated sediments.

Solution cavities occur in the raised coral limestones and is usually loosely cemented resulting in high porosity and permeability. Generally, the water table in low-lying islands and coastal plains is only a few meters above mean sea level, which results in a relatively shallow fresh water/ salt water interface.

Since many towns and villages are located on the coast, the demand for good clean water supplies is quite high. Groundwater has the potential to supply this demand; however, groundwater development must be closely supervised by a groundwater specialist in order to preserve the fresh water/ salt water balance.

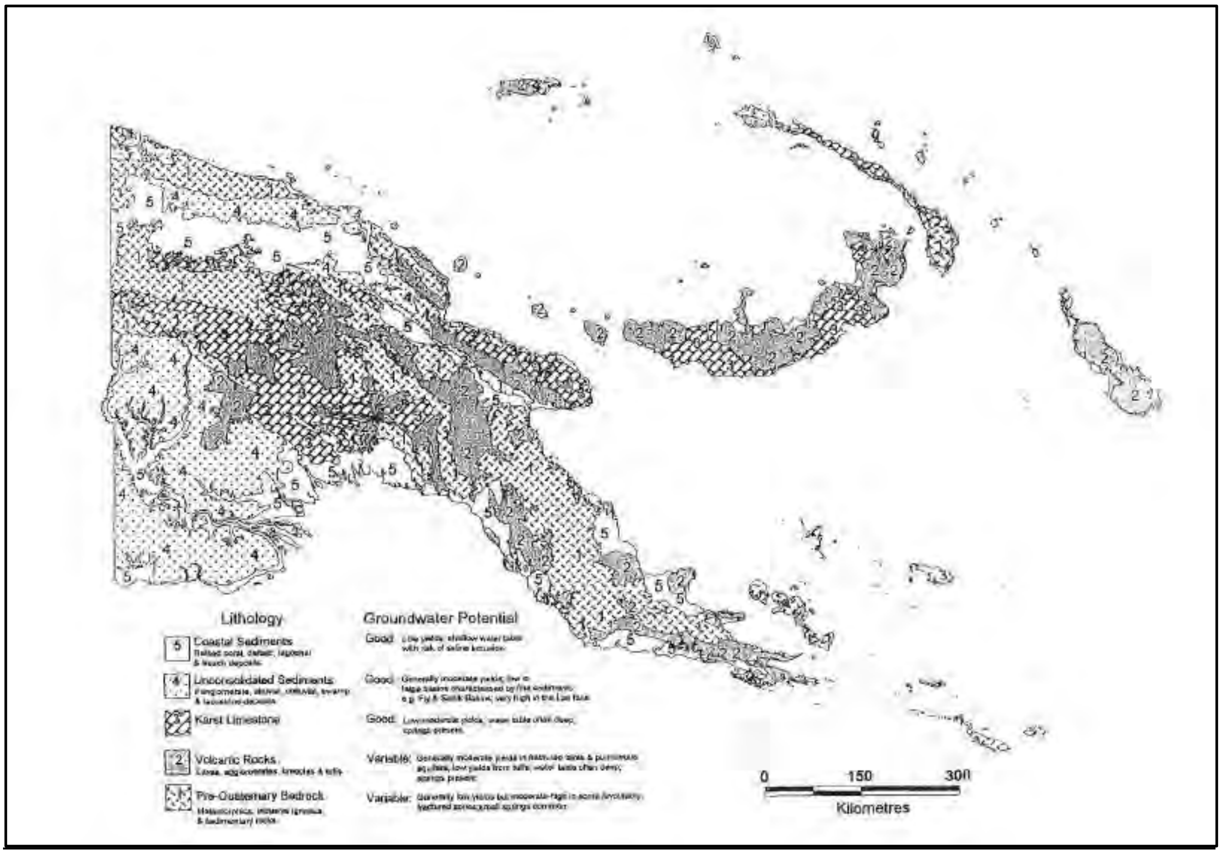

Fig. 2. Previous groundwater potential map of Papua New Guinea (Egara, 1999).

2.2.5 Unconsolidated Sediments

Most water bores developed in PNG are located in this hydrogeological unit, which consist mostly of alluvial, lacustrine and fan deposits within valleys and depressions. Alluvium within the larger basins consists principally of silt and sand with some gravel, while smaller mountain-rimmed basins are predominantly composed of coarse gravels or lacustrine muds. Sand aquifers provide clean water from the larger basins, while sand and gravel aquifers provide water in the smaller basins.

Thickness of the sediments in these major basins and tectonic depressions is unknown, however is considerable. These sediments are considered to have good groundwater potential; therefore, most water bores developed in PNG are from this unit.

2.2.6 Current Status of Groundwater Potential Map of PNG

At present, a new groundwater potential map for Papua New Guinea is been digitized in order to update the previous existing map. The groundwater potential boundaries indicated in the new map (Fig. 3) are generally based on the geological maps of Papua New Guinea. Using the various lithologies of different areas on the 1:250,000 scale maps of Papua New Guinea, these geological units are grouped into seven categories: 1. Quaternary Alluvial Deposits, 2. Unconsolidated Sediments, 3. Lacustrine/ Lagoonal sediments, 4. Limestone, 5. Sedimentary Rocks, 6. Volcanic Rocks, and 7. Metamorphic Rocks. This classification is derived from the earlier groundwater potential map, but is broadened to these seven categories.

As the different map sheets of Papua New Guinea are currently been updated through ongoing mapping projects throughout PNG, the current groundwater potential map of PNG may also undergo few alterations. The revised geological maps of PNG are currently been updated to a scale of 1:100,000, hence, these maps will be used to revise the current groundwater map. From the current progress of the map, figure 3 displays what has been digitized so far.

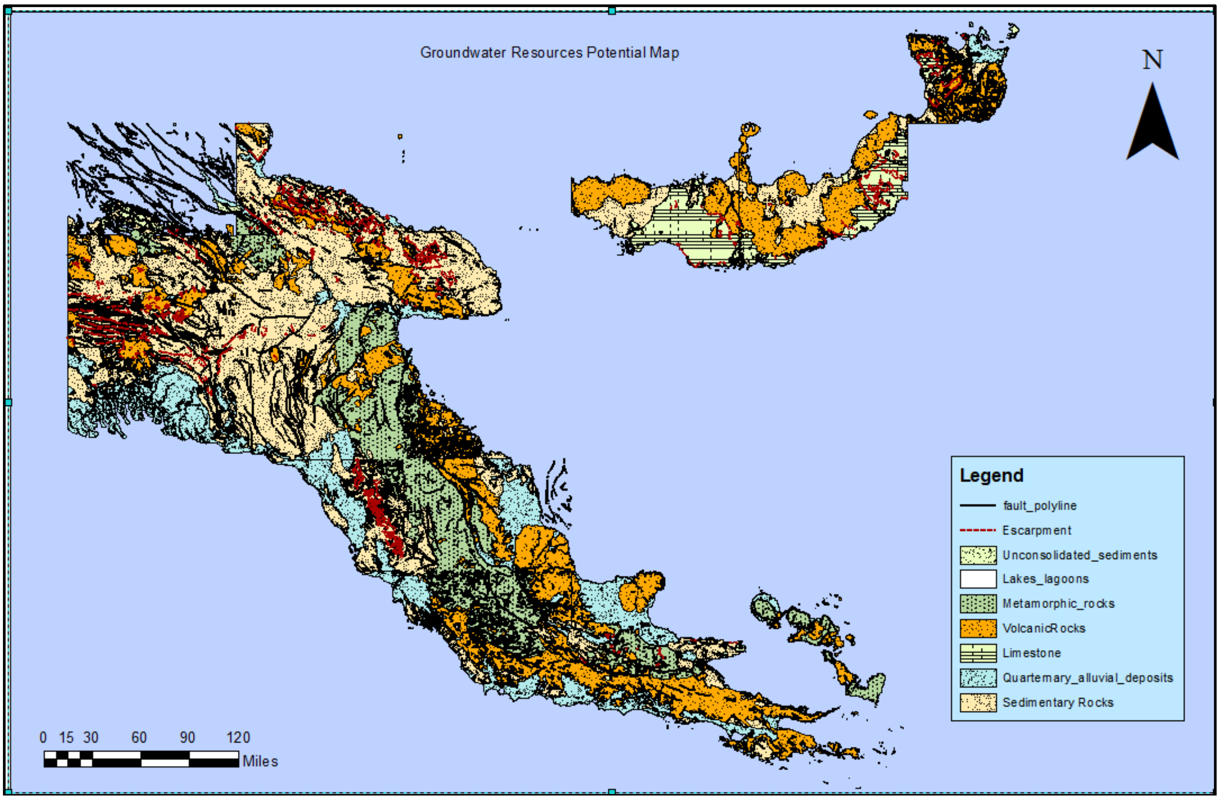

Fig. 3. Present groundwater potential map of Papua New Guinea (Kuman, 2017)

3. Hydrological survey and groundwater monitoring for database/ hydrogeological map

At present, no monitoring system is in place to monitor groundwater data; however, within the past year, few groundwater investigations were carried out within the country. These included groundwater investigations in the Saivara and Buswara area of Nine Mile, National Capital District, groundwater investigations for Kokopo Town, groundwater investigations for Edai Town, Boera, just on the outskirts of Port Moresby City, and resistivity sounding for the Emirau Island Project, New Ireland Province. Recommendations were made for the Saivara investigations, while drilling for the Edai Town water supply was completed in early February 2017. Work on the Kokopo groundwater project will continue for the rest of 2017. From these investigations, groundwater data will be collected and added into the database.

4. Future plan of hydrogeological map in Papua New Guinea

Data collection for groundwater in all the provinces of Papua New Guinea will continue. As stated, data for Port Moresby area has been collected and currently, database software is being used to create a specific database template for the data to be imported. Continuation of data collection is currently ongoing for Kokopo Town. Data collection for other provinces may follow subsequently. Other necessary tests will be carried out on existing boreholes, to confirm important groundwater parameters such as water level, groundwater quality, production and yield of the well etc.

Once more data is collected; the groundwater map will be further updated with additional information such as the water quality, depth to water table, lithological log to confirm aquifer formation and other necessary information. From this information, it is proposed that a more defined map of the different groundwater basins in PNG may be mapped out, i.e. by referring to the lithology of the aquifer formation which each bore is sourcing water from.

5. Conclusions

Groundwater data is very critical as it will provide important information that can further help develop the groundwater resource in PNG. Hence, collation of groundwater data is important, and this project in turn, will help contribute to a more defined groundwater potential map for the country. PNG has a high potential for developing its vast groundwater resources, however, lack of good quality data is a hindrance in the utilization and management of the groundwater resources in PNG

At present, old reports are been used to collate data, and only once there is enough funding available, further field tests can be carried out to collect more updated data of the groundwater resource.

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III-2-(10)
Hydrogeological Map of the Philippines -Present status and future plan-

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Abstract

The Hydrogeological/Groundwater Availability Map of the Philippines provides emphasis on the hydrogeological features in regional scale. It offers information on the extent and characteristics of the aquifers, which is based on the integrated analysis of geology, structural geology, geomorphology, climatology, and hydrology. The water-bearing capacities of different lithologic units were used as a basis for characterization of the groundwater availability (i.e. extensive/highly productive aquifers, fairly productive aquifer, less productive aquifers, and rocks with limited or low potential capacity to produce water) of the entire Philippine Archipelago. Since the early 1960's, published and unpublished hydrogeological studies were conducted to present maps at the scale of 1:250,000 or greater covering specific sites, municipalities, islands, provinces and regions. The Hydrogeology and Environmental Geology Section (HEGS) of the Lands Geological Survey Division of the MGB compiled and prepared the 1:2,500,000 hydrogeological map based on the internationally accepted UNESCO/IAH Legend. The Groundwater Availability Map of the Philippines was published in 1982 and included in Geology of Philippines (Volume 2) by MGB.

The General Hydrogeological Map of the Philippines was digitized/vectorized to have a fast and easy way of data sharing in Geographic Information System (GIS) format. Furthermore, some groundwater data (e.g., well and spring data) of Luzon are already available in excel and GIS format (i.e., shapefiles) and continuously being populated. The HEGSs of central and regional offices are currently conducting hydrogeological fieldworks at 1:250,000 and 1:50,000 scales. These activities aim to provide information on the availability and suitability of the groundwater in provincial and municipal levels. The available more detailed and updated hydrogeological maps of Luzon were also compiled, digitized/vectorized and presented in this paper.

Keywords: groundwater, hydrogeological map, Luzon, Philippines

1. Introduction

Since the early 1960's, published and unpublished hydrogeological studies were conducted to present maps at the scale of 1:250,000 or greater covering specific sites, municipalities, islands, provinces and regions. The surface water and groundwater data were acquired from different agencies in the Philippines, such as the Hydrology Division of the Department of Public Works and Highways; the National Irrigation Administration; and Local Water Utilities Administration. The Philippine Atmospheric Geophysical and Astronomical Administration provided the climate data. The Hydrogeology and Environmental Geology Section (HEGS) of the Lands Geological Survey Division of the MGB compiled and prepared the 1:2,500,000 hydrogeological map based on the internationally accepted UNESCO/IAH Legend. The Groundwater Availability Map of the Philippines was published in 1982 and included in Geology of Philippines (Volume 2) by MGB. It was digitized/vectorized for a fast and easy way of data sharing in Geographic Information System (GIS) format (Figure 1). To have a more detailed and systematic approach regarding the groundwater availability map of the Philippines, the HEGS of MGB is continuously conducting hydrogeological fieldworks at 1:250,000 and 1:50,000 scales. This paper mainly focused on the preparation and presentation of the Hydrogeological Map of the Luzon, including its adjacent islands, and the recent available groundwater data.

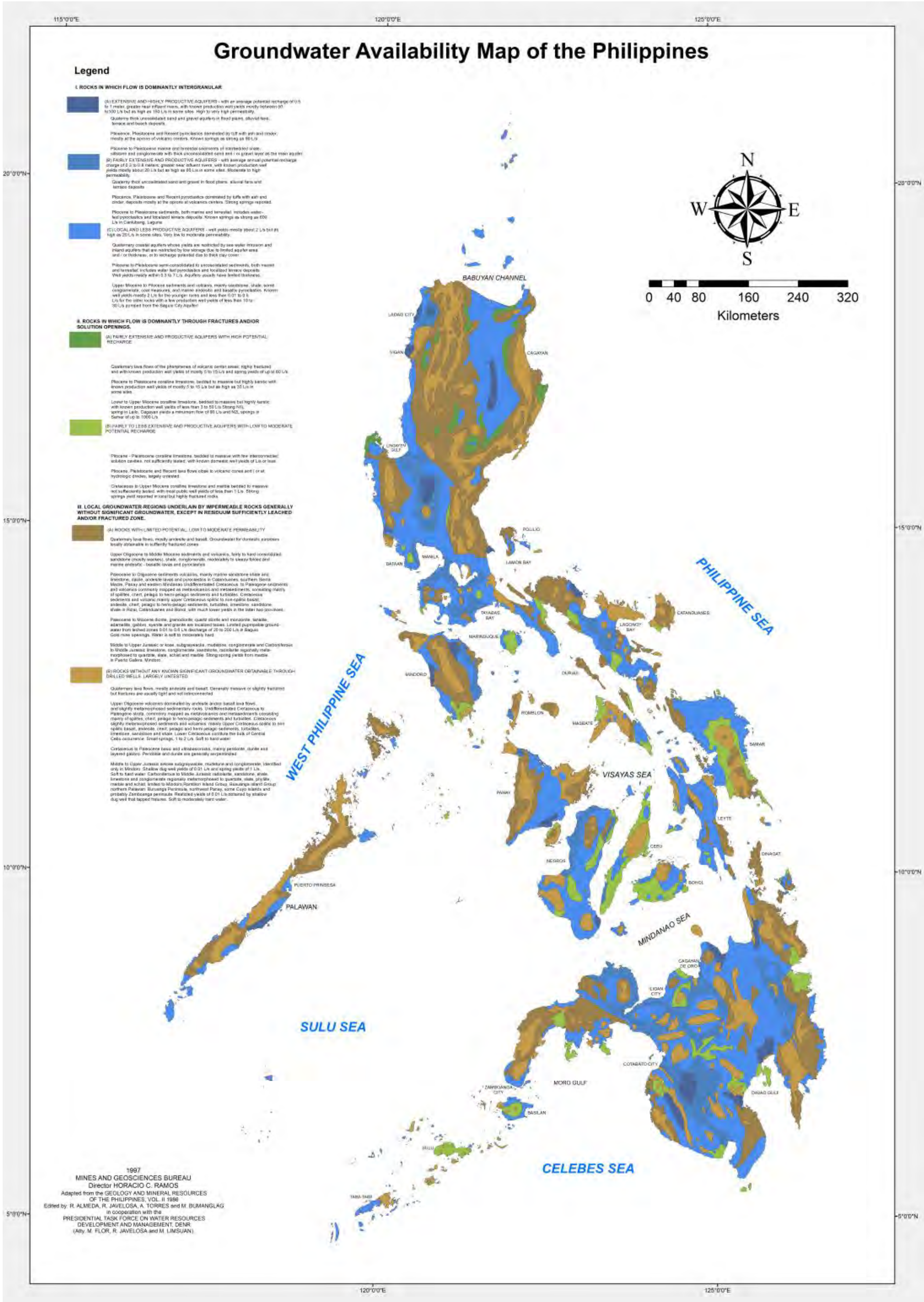

Fig. 1. Groundwater availability map of the Philippines.

Based on the previous and recent studies of the MGB, forty-seven (47) percent of the Luzon land area (around 53,000 sq km) is underlain by unconsolidated and semi-consolidated clastic sedimentary deposits. These areas are considered as hydrogeological units in which the groundwater flow is dominantly intergranular. The total area underlain by recent unconsolidated deposits is about twenty-three thousand (23,000) sq km. The unconfined alluvial aquifers in the lowlands are usually easily saturated while the elevated semi-consolidated clastic rock formations (i.e., sandstone, conglomerate, shale, pyroclastics) require more water and longer time to attain optimum saturation due to a thicker unsaturated zone. Limestone deposits characterized the eight (8) percent of the land area of Luzon. This constitutes about nine thousand (9,000) sq km of rock units in which the groundwater flow is through solution channels. The limestone rock formations usually discharge huge volume of groundwater through spring outlets. Lastly, around forty-five (45) percent or fifty thousand (50,000) sq km the total land area of the Luzon Island is considered as hydrogeological units without significantly primary interconnected porosity. It manifested that groundwater availability in these areas is only limited to the leached and fractured zones of the rock formations.

Groundwater Regions in Luzon

The Luzon Island may be divided into upland, lowland, limestone and Quaternary volcanic groundwater regions. The following data were adopted from the previous works of the MGB. The upland regions are mostly occupied by Paleozoic to Middle Miocene crystalline igneous and metamorphic rocks and well consolidated sedimentary rocks. The lowland regions are mostly marine and terrestrial sedimentary and pyroclastic rocks underlain by Upper Miocene to Pliocene marine sedimentary and volcanic rocks. The limestone formations are composed of coralline to marly, with local occurrences of coquina deposits; the reef limestones were generally noted at the fringes of the sedimentary basins of Cretaceous to Recent age. Quaternary volcanic groundwater basins in Luzon were characterized by the volcanic belts of Bataan-Zambales, Batangas-Cavite-Laguna-Rizal, and Bicol Peninsula.

The rock units in the upland regions are normally impermeable to moderately permeable where the economically pumpable groundwater is localized to weathered, leached and fractured, sheared or jointed zones. Variable yields were obtained, with a maximum of value of 0.3 l/sec, based on the shallow dug wells and deep drilled tube wells. Wells drilled along fault zones are reported to yield 0.3 to 5.5 l/sec. A 150 m deep well underlain by leached Middle Miocene sandstone aquifer in Baguio City was test pumped at 32 l/sec with a drawdown of 20 m after 24 hours withdrawal. The underground workings of the Baguio City mining district were reported to have a yield of about 22 to 330 l/sec.

For the lowland regions, the valleys are covered with lenses and layers of irregular coastal, river, outwash and talus deposits of silt, sand, gravel and clay. These deposits were estimated to have a maximum thickness of about 200 meters. The main lowland basins are in north Luzon, central Luzon, and Bicol Peninsula. The production from the unconsolidated aquifers is mostly within 2.5 to 72 l/sec. On the other hand, the yields obtained from the loosely to poorly consolidated Pleistocene aquifers of sandstone and conglomerate are about 2.5 to 72 l/sec. The Pliocene and Upper Miocene sandstone and conglomerate are commonly tight when cemented with clayey to silty material. The coarse sandstone and conglomerate with a yield of about 11 l/sec are considered as fair sources of groundwater. The Upper Miocene to

Pliocene shale, siltstone, fine sandstone and other tight sandstones act either as aquitards or as lower confining formations for the younger aquifers.

The significant sources of pumpable groundwater in limestone regions are the Miocene to Pleistocene formations. Generally, the water is stored in solution-enlarged fracture and bedding openings that allow rainwater percolation through sinkholes and crevices. Only the youngest, poorly cemented limestone is known to contain significant interconnected porosity with a yield of 0.3 to 0.5 l/sec. Calcarenite, calcareous sandstones and conglomerate underlying the limestone is the common source of pumpable water at the rate of 0.5 l/sec. Water is considered as confined to semiconfined in these areas. The water supply wells in the limestone portions of the Baguio City were tested with known operating yields of over 2.5 to 55.5 l/sec. One to ten percent of limestone watershed was considered as sinkhole catchment area and almost all limestone formations are characterized by underground streams.

The volcanic cones and plains of the Quaternary volcanic regions are underlain by intercalated lava, agglomerates, ash flows and pyroclastics. The upper 100 to 150 meters of the Bataan volcanic belt was strongly pumped and yielded around 14 to 64 l/sec. Other volcanic basins in Luzon yielded about 2.5 to 25 l/sec only. The evapotranspiration from the quaternary volcanic watersheds averages from 0.8 to over 1 meter since these regions are partly to densely forested.

2. Recent groundwater data and hydrogeological map of Luzon

The Hydrogeology and Environmental Geology Sections (HEGSs) of MGB Central Office and Regional Offices are continuously conducting groundwater resources assessment at 1:250,000 and 1:50,000 scales to provide information on the availability and suitability of the groundwater in provincial and municipal levels. Some groundwater data (e.g., well and spring data) of Luzon are currently being populated and updated in excel and GIS format (i.e., shapefiles) but not all CCOP parameters are available. The representative groundwater data of the Province of Zambales were shown in Table 1.

Table 1. An example of groundwater data in Luzon.

Date	Wellname	Lat.	Lon.	Elevation	Depth	EC	pH	D	18O	Cl	Br	NO3	SO4	HCO3	Na	NH4	K	Mg	Ca	F	Li	NO2	PO4	anion	cation	Balance
7/27/2015	ZM-MBP-71	15.04583	120.1245	53	51	61.6	7.8			28.15			6	226.55	24.76		5.4	17.16	41.79							
7/27/2015	ZM-MBP-72	15.06064	120.1015	46	9	90.3	7.3			36.29			54	267.5	18.52		6.84	8.89	23.15							
7/27/2015	ZM-MBP-73	15.05764	120.0717	15	6	48.9	6.8			10.64			95	62.78	6.04		7.64	1.96	4.34							

Aside from the conversion of the 1:2,500,000 scale Hydrogeological Map of the Philippines into Geographic Information System (GIS), the available more detailed and updated hydrogeological maps of Luzon were also compiled and digitized/vectorized Figure 2. The Hydrogeological Map of Luzon was also prepared based on the UNESCO/IAH Legend (1970) classification of the hydrogeological units to conform to the international standards. The grouping generally depends on the type and age of geological formations since groundwater movement through interstices in the soil and rocks is governed by the rock's permeability. The hydrogeological units representing the geology and lithology that underlain the Luzon Island were briefly presented in this section. Based on the occurrence and movement of groundwater, the three major hydrogeological groups are (1) rocks in which flow is dominantly intergranular (2) rocks in which flow is through fracture and/or solution openings and (3) rocks with local or no groundwater. Each group is further subdivided into sub-hydrogeological units based on the extent and productivity of the formations and on the degree of cementation, consolidation, and fracturing of the rocks which indirectly controls their permeabilities.

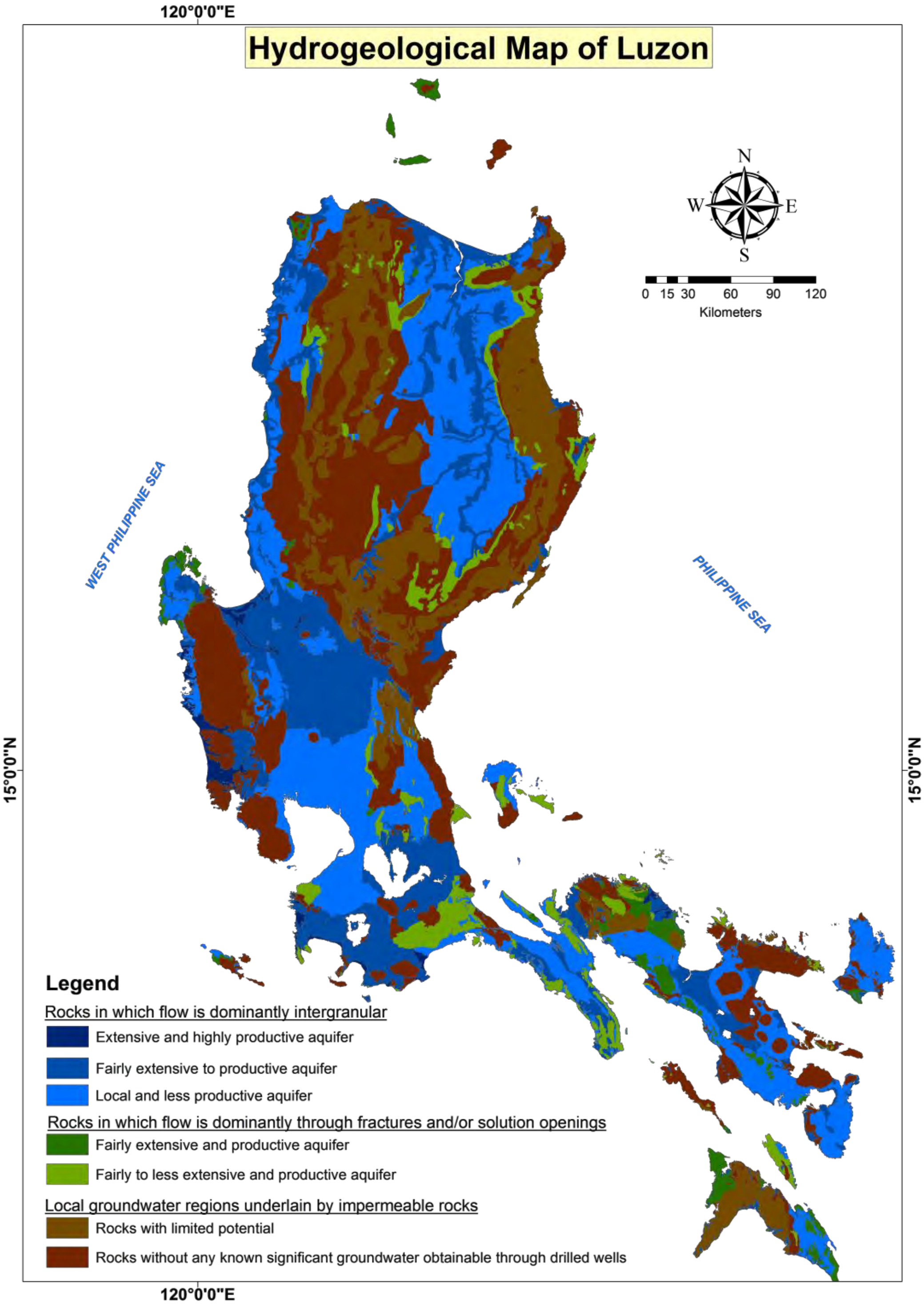

Fig. 2. Hydrogeological Map of Luzon and its adjacent islands.

The rock units in which groundwater flow is dominantly intergranular generally consist of granular deposits wherein groundwater occurs and moves through pore openings between individual grains and to a small extent, through fractures. The most important formations are the unconsolidated deposits that contain extensive and thick, medium to coarse-grained sand and gravel and the semi-consolidated but thick deposits of coarse sandstone and conglomerate. Some pyroclastics composed dominantly of tuff with ash and cinder deposits were also included. Some examples of areas in Luzon with extensive and highly productive aquifers are Ilocos Norte coastal plain (sand dune deposits), Central Luzon Plain, northeastern Cagayan and the Bicol River Basin. The fairly extensive and productive aquifers are characterized by the aquifers in areas of Cagayan, Agno, Pampanga and Bicol Basins, Laguna, Rizal, Cavite, Bulacan, Bataan, Batangas, and Quezon. Lastly, the rock units with local and less productive aquifers are the Quaternary alluvial and coastal sandy deposits, coral reefs, pyroclastic and clastic rocks and Oligocene to Pliocene sedimentary formations that are intercalated with volcanic flows and pyroclastics in some areas. Sedimentary rocks include mudstone, shale, marl, calcarenite, sandstone and conglomerate.

In the Luzon Island, the sufficiently studied area that represents the groundwater that moves mainly through fractures, fissures, crushed zones, and solution-enlarged openings is the Baguio city. The more productive formations are the moderately to highly karstic limestone and the fairly fractured volcanic rocks. The volcanic cones in Mts. Banahaw, Makiling and San Cristobal in Laguna are highly fractured with springs discharging 50 l/s or more. The wells in these areas yielded over 120 l/s. The aquifers with lower groundwater potential include Cretaceous to Pleistocene limestone formations in Luzon.

The group of rocks with local or no groundwater is typically composed of impermeable rocks such that potential groundwater flow is restricted to the residuum, leached mantle, and few interconnected fracture and fissure openings with discharge points. In general, potential groundwater is strongest in forested watersheds, where rainwater is trapped and discharge as groundwater runoff or baseflow to streams. These rocks are usually not exploited. Impermeable rocks include Pliocene to Quaternary andesite and basalt at the volcanic centers; Oligocene to Miocene volcanics and well-cemented marine sedimentary rocks; slightly metamorphosed (both regional and local) Cretaceous to Oligocene spilitic volcanics that include andesite and basaltic flows and marine sedimentary rocks consisting of graywacke, shale, conglomerate, and limestone. Their common hydrogeological properties are poor permeability and superficial or shallow groundwater which is almost wholly discharged to surface drainage during the rainy season.

The favorable groundwater basins are underlain by Quaternary alluvial deposits, loosely to poorly consolidated marine and terrestrial sandstone, shale, local conglomerate horizons, basal conglomerate and pyroclastic deposits with minor intercalated flows. These basins are in northeast Luzon, Central Luzon, Laguna Lake basin, Cavite-Batangas-Laguna basin and southeast Luzon. Fractured zones in the cordilleras are significant sources of groundwater to mining operations. The limestone basins are not sufficiently tested except in the three cities previously mentioned. The annual spring yield of over one billion cubic meters is an indication of the pumpable groundwater prospects in the limestone formations.

3. Hydrological survey and groundwater monitoring for database / hydrogeological map

After the conduct of hydrogeological surveys, all available water-related information pertaining to individual inventoried wells/springs were organized and systematically encoded in an MGB established database. The locations of the wells in terms of the coordinates (latitude and longitude) were taken using a Global Positioning System (GPS). Relevant information includes ground elevation of wells and depth to groundwater; these data were utilized to establish groundwater contour map. Other important information for each well/spring include groundwater level (i.e., SWL, PWL), discharge (volume of water extractable/or flowing out per unit of time), water usage, owner, year constructed, etc. In-situ water quality tests are also being conducted parallel to the well inventory activity. The physical parameters that were measured on site include temperature, pH, Total Dissolve Solid (TDS), ORP, conductivity, turbidity, dissolved oxygen, and salinity; these data are being encoded in a water quality database. In situ sampling provides readily available values to initially assess the water quality in an area. Aside from the result of in-situ tests, the results of the laboratory analysis of collected groundwater samples were included in the water quality database. These data were used to assess the potability of groundwater by comparing them with the Philippine Standard for Drinking Water. The groundwater chemistry information that were included in the database are cations (e.g., Na^+, K^+) anions (e.g., Cl^-, $SO4^-$) and other trace elements (e.g., Cu, Pb). Not all of the inventoried well were subjected to a laboratory analysis for the groundwater chemistry. Some groundwater sources were only in-situ tested for physical parameters (e.g., temperature, pH, Total Dissolve Solid (TDS), ORP, conductivity, turbidity, salinity). The excel format that is currently being adopted by the MGB for the groundwater database is presented in table 2. More detailed hydrogeological maps with the location of the inventoried wells were also prepared per province; the Hydrogeological Map of the Province of Pangasinan is shown in figure 3 for example.

The characterization of the water-bearing formations at depths was also assessed with the conduct and interpretation of the Vertical Electrical Sounding (VES) data. The processed and interpreted VES data present several distinct lithologic/resistivity layers based on deduced georesistivity value coupled by calibration from existing well data information. Each interpreted VES, with their corresponding resistivity value, thickness, and depth, were tabulated is a separate database. The locations of the VES point in terms of the coordinates (latitude and longitude) were also taken using a Global Positioning System (GPS). All in all, the geo-resistivity database present identified possible aquifer at individual VES point with their respective location, thickness, and depth from the ground level.

To have an overview of the groundwater occurrences in Luzon Island, recent and old reports were summarized in this section. The upper 100 to 200 meters of the various formations were mainly developed for groundwater abstraction. The Quaternary alluvial deposits of large valleys, basins and coastal plains; Quaternary volcanic cones and plains; Quaternary marine and terrestrial sandstone-conglomerate-shale deposits; Early Miocene to Pleistocene coralline limestone formations; Upper Miocene to Pliocene coarse sandstone, conglomerate and pyroclastics; and heavily fractured fault zones of impervious rock formations are considered as the groundwater reservoirs in Luzon Island. In addition, free flowing artesian conditions are known in all the Pliocene to Pleistocene marine sedimentary basins and Quaternary volcanic basins. Loose and unconsolidated alluvial deposits are the aquifers that were easy to replenish during the rainy season.

Table 2. The template of MGB for groundwater database.

DATE	LOCATION							
	PROVINCE	MUNICIPALITY	BRGY	LATITUDE (DegDec)	LONGITUDE (DegDec)	LATITUDE (DMS)	LONGITUDE (DMS)	GEOGRAPHIC COORDINATE SYSTEM
08-12-16	Negros Occidental	ESCALANTE	BALINTAWAK	10.8518	123.5028	10° 51' 6.42" N	123° 30' 10.02" E	GCS_Luzon_1911
08-12-16	Negros Occidental	ESCALANTE	BALINTAWAK	10.84827	123.5006	10° 50' 53.65" N	123° 30' 2.36" E	GCS_Luzon_1911
08-12-16	Negros Occidental	CALATRAVA	TIGBAO	10.67175	123.4874	10° 40' 18.99" N	123° 29' 14.10" E	GCS_Luzon_1911

WELL/SPRING DATA											
WELL NO./ID	OWNER	USAGE	TYPE	YEAR CONSTRUCTED	WELL DEPTH (m)	ELEV (masl)	DEPTH TO GW (mbgl)	WATER TABLE ELEVATION (mbgl)	DISCHARGE (l/s)	LITHOLOGY	SAMPLE TAKEN?
NOC-MAC-2	Communal	Domestic	DUG WELL	1995	7	34.88	5.1	29.78		SANDSTONE	N
NOC-MAC-3	Water District	Commercial	TUBE WELL	1900	15	33.65	8	25.69		SANDSTONE	Y
NOC-MAC-4	Water District	Commercial	SPRING	1985	0	32.59	0	32.59	1	LIMESTONE	Y

PHYSICAL PARAMETERS (INSITU TESTS)							
TEMP	pH	Orp Mv	EC (ms/cm)	Turbidity(NTU)	DO (mg/l)	TDS (g/l)	Salinity (ppt)
31.45	6	-15	0.861	22.3	3.8	0.551	0.4
30.69	7	-121	0.965	4.16	10.4	0.617	0.5
30.19	7	330	0.652	1.75	4.91	0.417	0.3

GROUNDWATER CHEMISTRY INFORMATION										
pH*	Alkalinity* as CaCO3 (mg/L)	HCO3-* as CaCO3 (mg/L)	Cl- (mg/L)	SO4-2 (mg/L)	TSS* (mg/L)	TDS* (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
6.8	134.54	164.14	13	8.44	180	210	24.76	0.71	63.95	16.74
6.4	27.72	33.81	32.74	11.73	17	177	19.18	2.47	39.63	14.63
5.6	10.39	12.68	12.52	5.56	85	60.5	26.41	2.12	41.73	14.35

The generalized groundwater quality of Luzon was presented based on the compiled old and recent reports of MGB. Acceptable physical and chemical quality for human consumption was interpreted for groundwater that was pumped from the Quaternary clastic and pyroclastic rocks, sand and gravel deposits. On the other hand, the Pliocene and older marine sedimentary rocks generally contain higher concentrations of dissolved solids. All marine sedimentary formations are normally salty at depths that exceed 1,000 meters and unconfined and low pressure confined water is underlain by saline water at the coastal zones. High physical and chemical qualities, with acidic pH (6 to 6.5), were generally observed in groundwater from crystalline rocks. The aquifers that were characterized as former swamps, marshes, and forest lands have methane gas emanations like the free flowing wells in Eastern Bulacan, Victoria, Laguna, and Tarlac. The shallow unconfined aquifers are commonly easily contaminated while the deep confined artesian waters are generally free from bacteria and other harmful organisms. For the chemical parameters, very hard to excessively hard water (i.e., 200 to 375 ppm $CaCO_3$) was noted in the water wells underlain by reef limestones and calcarenites while less hard water was generally observed in spring waters. High chloride concentrations are commonly obtained from very well confined formations that are not sufficiently flushed. The highly oxidized aquifers or recharge sources generally have very high concentrations of iron (Fe^{2+}) that settles out as a red precipitate. Iron concentrations are commonly reported in groundwater obtained from former swamp or marshland areas.

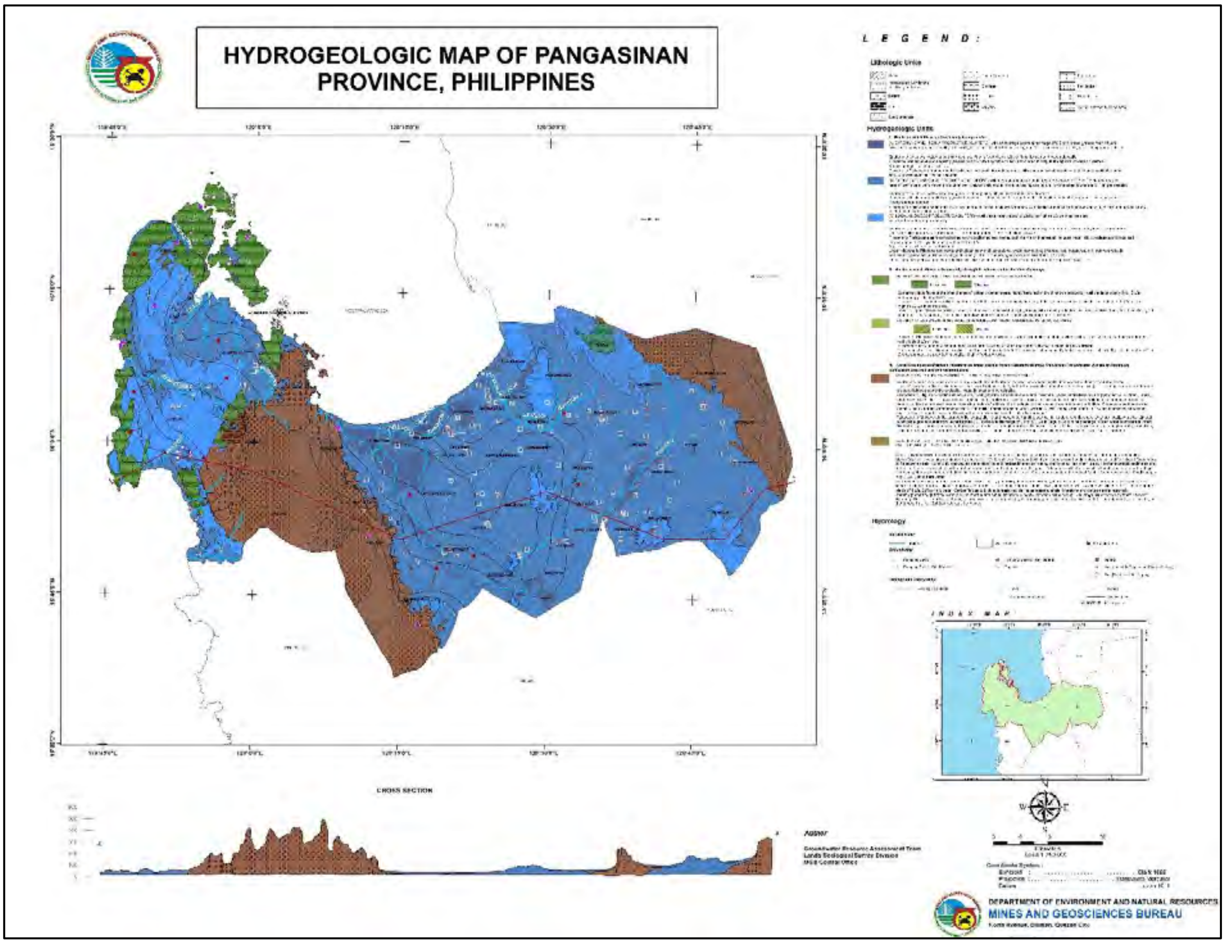

Fig. 3. Sample layout of the Hydrogeological Map of Pangasinan Province.

4. Future plans for the hydrological map of the Philippines

After the digitization/vectorization of the 1:2,500,000 scale General Hydrogeological Map of the Philippines and the initial compilation and collation of the groundwater data (e.g., well and spring data) of Luzon, future activities were aligned for the provision of information on the availability and suitability of the groundwater in local levels (i.e., municipal, provincial). The future plans for the hydrogeological map of the Philippines are the continuation of the detailed (1:250,000 and 1:50,000) hydrogeological assessment for provincial and municipal levels, the completion of the Luzon groundwater database, the updating of the Hydrogeological Map of Luzon, the generation of the Hydrogeological Map of Visayas Island Group, the implementation of stable isotope (δD and $\delta^{18}O$) analysis for groundwater studies and the conduct of groundwater vulnerability assessment for the publication of the national groundwater vulnerability map.

5. Conclusions

The past and present hydrogeological studies, together with the future plans, in the Philippines presented important notions. The following conclusions can be made from these concepts.

1. The Groundwater Availability / Hydrogeological Map of the Philippines is available in GIS format (i.e., shapefiles) for sharing purposes.

2. The Groundwater Data of Luzon (e.g., well and spring data) are already available in excel and GIS format (i.e., shapefiles) but currently being populated.

3. On-site hydrogeological training (e.g., detailed groundwater assessment, hydrochemistry, water isotopes, and vulnerability mapping) for technical personnel are needed for proper and uniform implementation of the project.

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III-2-(11)
Hydrogeological map of Thailand -Present status and future plan-

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Abstract

Thailand's use of groundwater has increased significantly over recent decade due to population and economic growth. As surface water supplied are insufficient to meet demands, groundwater development as a substitute for surface water or conjunctive use between groundwater and surface water is needed.

Groundwater map and hydrogeological map are the important tools for groundwater development. The effective development for groundwater requires the accurate, detailed and updated map databases. Department of Groundwater Resources (DGR), Ministry of Natural Resources and Environment, Thailand developed groundwater map and hydrogeological map at a scale of 1:100,000 in period between 1989 and 2001. However, the groundwater resources databases used in the maps do not have enough detailed information. As a result, DGR has carried out "The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1:50,000" since 2008. The project aims to create 800 Groundwater map sheets and 800 Hydrogeological map sheets covering the whole country. The project will be completed 48 percents and 100 percents of the country's area by 2017 and 2020, respectively.

Groundwater map at a scale of 1:50,000 is designed for non-technical users and shows groundwater resources information up to the village level. It can be used for effective groundwater well site selection and drilling according to groundwater potential (quality and quantity) information. Groundwater map can also be used together with surface water data for water resources planning. In addition, hydrogeological map at a scale of 1:50,000 is a helpful primary data sources for technical users since it does not show only groundwater resources information but also aquifer hydraulic properties and characteristics. As a result, it is appropriate for using in research projects and studies.

Keywords: groundwater, hydrogeological map, Thailand

1. Introduction

Department of Groundwater Resources (DGR) is a government agency of Thailand which has the missions to develop and manage groundwater resources for optimal efficiency. One of its responsibilities is to prepare the accurate and up-to-date databases needed to create groundwater and hydrogeological maps for each groundwater basin throughout the country. The maps are used as an important tool for development and management of groundwater resources to the public.

The original groundwater and hydrogeological databases developed before the year of 2000 were used to create provincial groundwater and hydrogeological maps at a scale of 1:100,000. However, since the databases did not have enough detailed information in the local scale as village and sub-district areas, suitable site selection and drilling for groundwater wells as well as groundwater management were challenged. Later, groundwater and hydrogeological information have increased and improved substantially due to several advanced researches and studies. Also, drilling and construction of new groundwater wells conducted by DGR, local administrations, and other agencies not only provide groundwater supply but also more groundwater and hydrogeological information.

Thus, DGR has established "The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1:50,000". The project's objectives are to study and explore groundwater and hydrological characteristics in the local scale, and create databases and detailed groundwater and hydrogeological maps at the scale of 1:50,000 covering the whole country.

2. Recent groundwater data and hydrogeological map in Thailand

In 2002, DGR established Thailand's hydrogeological and groundwater databases which were named as "PASUTARA Database". PASUTARA Database has been continuously added the information of soil and rock layer, groundwater well location and depth, drilled log, geophysical log, casing program, static water level, and groundwater quality, etc. DGR used PASUTARA Database and groundwater paper and digital maps at a scale of 1:100,000 to create Hydrogeological Geographic Information System (HYGIS). HYGIS combines with the geographic program for inputting data, displaying maps and storing data. It is easy to install and use. Also, HYGIS contains more kinds of hydrogeological and groundwater data than PASUTARA database, for example, aquifer type, geological structure and hydrogeologic cross section.

DGR has been carried out "The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1: 50,000". Hydrogeological and groundwater maps at a scale of 1:50,000 has been created by improving groundwater map, hydrogeological map and HYGIS, making geographic input data to be changeable, and putting more effective metadata for data references. The target is to create 800 map sheets covering the areas of whole country. In 2008, the project started in Nan province, the Northern Thailand, for 23 map sheets. The project was conducted in the Upper Chao Phraya groundwater basin for 77 map sheets between 2010 and 2011, the Upper Khorat Plateau for 82 map sheets, the Central Khorat Plateau for 90 map sheets, and Phetchaburi - Prachuab Khiri Khan groundwater basin for 21 map sheets between 2012 and 2015. The project in the Lower Khorat Plateau for 87 map sheets is ongoing and will be finished by 2017. DGR will create the total of 380 map sheets or 48 percents of the target by 2017.

3. Hydrological survey and groundwater monitoring for database / hydrogeological map

The detailed Groundwater and Hydrogeological maps at a scale 1:50,000 were established following the standard of International Associate of Hydrogeologists (IAH). They were designed simply so that technical and non - technical users such as engineer, local administrator, economist, and farmer can understand easily. To develop the maps, DGR studies, collects, evaluates and analyzes different types of groundwater and hydrogeological input data. The groundwater and hydrogeological mapping framework is shown in Figure 2.

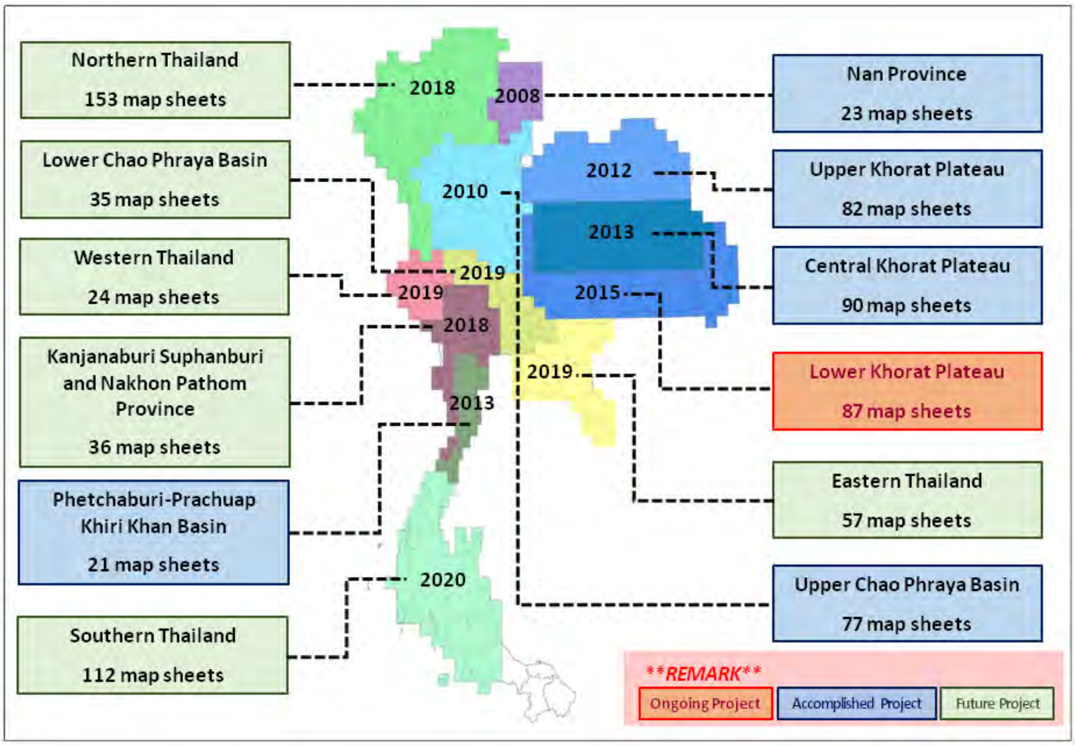

Fig. 1. The Project of Detailed Groundwater and Hydrogeological Mapping at a scale of 1:50,000 in Thailand.

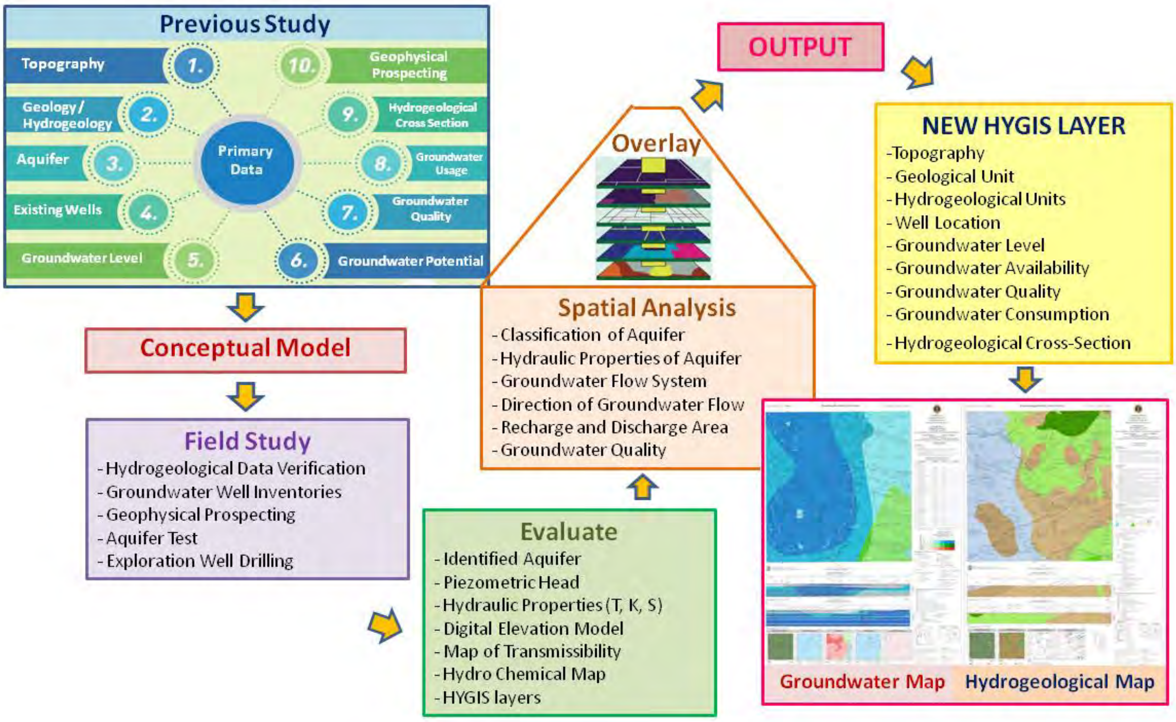

Fig. 2. The groundwater and hydrogeological mapping framework

For the step of data study, several types of data were obtained from the previous study and stored as groundwater and hydrogeological databases. DGR had three main databases named PASUTARA, Groundwater Control and Legislation Information System (GLC) and Hydrogeological Geographic Information System (HYGIS) as the following.

Firstly, PASUTARA Database stores all information of groundwater wells including general well data such as drilling data, well location and number, well depth, well yield and groundwater level. The data of wells properties as chemical analysis, lithologic log, pumping test, geophysics and maintenance are also kept.

Secondly, Groundwater Control and Legislation Information System or GCL GLC stored database related to groundwater control and groundwater act such as application for license to use groundwater and operate well drilling.

Thirdly, Hydrogeological Geographic Information System or HYGIS is the Geographic Information System (GIS) that DGR applied for stored and displayed provincial groundwater map at a scale of 1:100,000. There are eight main data layers as primary data, aquifer type, wells location, groundwater level, groundwater potential, groundwater quality, groundwater usage and geologic cross-section.

4. Future plan of hydrological map in Thailand

The future activities are to complete detailed hydrogeological and groundwater maps at a scale of 1:50,000 for the remaining 52 percents of the target map sheets or 420 map sheets so that they cover all the country's areas. In 2018 the project will be implemented in Northern Thailand for 153 map sheets, Kanjanaburi, Suphanburi and Nakhon Pathom Province for 36 map sheets. Also, in 2019, it will be conducted in Lower Chao Phraya groundwater basin for 35 map sheets, Eastern Thailand for 57 map sheets, and Western Thailand for 24 map sheets. In 2020, the project will be conducted in Southern Thailand (shown in Future 1).

Besides, DGR has endeavored to add more information in the maps in order to improve detailed hydrogeological and groundwater maps at a scale of 1:50,000, and make different forms of sources data consistent.

Additionally, to elaborate the project of detailed hydrogeological and groundwater maps at a scale of 1:50,000, DGR was recently launched "The Project of Training the Local Administrators on Using Detailed Groundwater Mapping at a Scale of 1:50,000 for the Control of Groundwater Well Drilling". The local administrators have duties to develop groundwater in areas of responsibilities, for example, to allow of groundwater well drilling and providing the correct information, recommendations or suggestions on groundwater uses.
Since the detailed groundwater map at a scale of 1:50,000 is a helpful tool for groundwater development in the local areas, the project which aims to provide the knowledge and understanding on the groundwater map to the local administrators was initiated. This also supports the effective groundwater management in the local areas.

5. Conclusions

DGR has carried out “The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1:50,000” which will generate 800 groundwater map sheets and 800 hydrogeological map sheets covering the whole country. The maps can provide the groundwater and hydrological information in the local scale as village and sub-district areas. The project was already completed in some areas of Thailand as the Upper Chao Phraya groundwater basin, the Upper Khorat Plateau, the Central Khorat Plateau, Nan Province and Phetchaburi - Prachuab Khiri Khan groundwater basin. Also, the project is ongoing in the Lower Khorat Plateau and will be finished by 2017. Besides, by 2020, the project will be completed in Northern Thailand, Kanjanaburi Province, Suphanburi Province, Nakhon Pathom Province, the Lower Chao Phraya groundwater basin, Eastern Thailand, Western Thailand, and Southern Thailand.

In addition, DGR was recently launched “The Project of Training the Local Administrators on Using Detailed Groundwater Mapping at a Scale of 1:50,000 for the Control of Groundwater Well Drilling”. The project objective is to provide the knowledge and understanding on the map to the local administrators who are responsible for developing water sources for public consumption in areas of responsibilities.

“The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1:50,000” and “The Project of Training the Local Administrators on Using Detailed Groundwater Mapping at a Scale of 1:50,000 for the Control of Groundwater Well Drilling” purpose to provide more accuracy of research results and effective groundwater development and management in the local areas. The maps are useful not only for DGR which has been continuously carried out the groundwater researches and several groundwater development projects but also researches, students, pubic and non-public organizations.

III-2-(12)
Hydrogeological map -Present status and future plan of Vietnam-

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Abstract

Hydrogeological maps are compiled on the basis of hydrogeological and groundwater surveying as well geological and tectonic charecterictis; they also reflect the interrelationship of geological structure, terrain, and groundwater. These maps contain a lager amount of data on hydrogeological conditions and groundwater. For nearly a century, many hydrogeological maps with different scales have been established, from 1:25,000 to 1:1,000,000, under different tasks and followed various legend principles and models which met the requirements of socio-economic development and national security. To meet the needs of socio-economic development and national security, this report will propose and orient for establishing hydrogeological maps as following: 1) Editing and adding new data to the previous hydrogeological map in the relation with meteorology, hydrology data, and human activities; and reflecting the dynamic characteristic of groundwater.; 2) Paying attention to the local characteristics of mountainous, midland, and plain areas when editing hydrogeological maps for different provinces; 3) Carrying out investigations and surveys will be considered as an urgent task to establish hydrogeological maps for the continental shelf and exclusive economic zones of Vietnam; 4) Establishing electronic hydrogeological maps.

Keywords: groundwater, hydrogeological map, Vietnam

1. Introduction

Hydrogeological maps show groundwater studying, survey and investigation results. They reflect to correlation between the elements: Groundwater (distribution, quality and quantity); geology (structure, stratigraphy, lithology...), topography (altitude, degree of segments, hydrological networks...) and artificial elements affected to groundwater (groundwater pumping, construction of reservoirs, discharge of pollutants ...). Therefore, hydrogeological maps are considered useful basis documents in socio-economic development planning, security and defense protection for any nations, locals (provinces), and utilization and protection of groundwater resources. These maps are compiled at various scales from small-scale (smaller than 1:500,000), medium-scale (1:250,000-1:50,000), to large-scale (large than 1:25,000) depending on information sources of land, mineral, and others. Therefore, up to now, the compilation of hydrogeological maps is varied according to the various principles and annotated models dependent to the requirements of relevant users in Vietnam.

2. Groundwater resources in Vietnam

For more than half a century through the hydrogeological investigation, exploration, and groundwater exploitation, the people have collected a huge amount of information on groundwater and hydrogeology. This report has been currently consisting of various agencies, reliability levels are quite different in which mainly from the National Center for Water Resources Planning and Investigation, Department of Water Resources Management that under the Ministry of Natural Resources and Environment, companies of water supply in some provinces (Ha Noi Water Supply Company which has the largest exploitation of groundwater), Center for Rural Water Supply and Environmental Sanitation and some research institutes, universities in the country. Unfortunately, the bad conditions for storing and preserving data on water resources results from the lack of information on groundwater due to information obtained from results of investigation and groundwater exploration and exploitation has been done since before 1990 which is seriously damaged. Especially the types of maps and drawings and their restoration are limited.

2.1. Hydrological investigation and surveys

Hydrological investigation and surveys have been conducted over the whole country and a number of f main islands with varying degrees, so currently hydrogeologists have information database for the assessment of hydrogeological features in Vietnam and hydrogeologicial features of 63 provinces including remote and isolated areas. Of which, in the Northern Delta and the Southern Delta, the Central Highlands and some coastal plains, some areas were formerly considered industrial development zones such as coal mines of Quang Ninh, Thai Nguyen and others have been carried out sooner and more comprehensively. In recent years, this work has been extended to remote areas to serve the socio-economic plan of the territory and ethnic minorities in mountainous areas in the locals clean water also is disposed of. From 2007 to present the Government project "Investigation and assessment of groundwater in the midland and mountainous areas of the North" has been implemented and resulted a comprehensive report and submitted for appraisal and approval of the results at 15 provinces with area of 118,722 km^2, which is an important area for national defense, security, politics, and socio-economy. This project marks the way of surveying and assessment from serving water resources management in combination with the rehabilitation of source of groundwater exploitation and use. The project has reviewed groundwater resources of 15 provinces and preliminary estimated the area of 8/15 provinces. During this period, hydrogeologic investigation was conducted in key economic areas in the Mekong Delta to evaluate the groundwater resources as approved with a survey area of 12,698 km^2 and to serve as a basis for water resources management and planning. The project of “Water Resources Survey and Assessment in Capital Region” was implemented the whole administrative boundary of Hanoi Capital and seven provinces: Vinh Phuc, Hung Yen, Hoa Binh, Bac Ninh, Hai Duong, Ha Nam and Hoa Binh with a natural area of about 13,436 km^2, in which preliminary investigation and assessment of groundwater resources with an area of 8,090 km^2.

Investigation and assessment of groundwater resources have been implemented under the following themes:

- The project “Surveying and searching for clean water sources for cancer villages in Vietnam;

- The project “Investigation, assessment and determination of restricted areas, restricted areas for groundwater exploitation” has also been implemented by many provinces.

- Investigation of hot thermal water resources in the whole country and potential assessments for rehabilitation, treatment, tourism and geothermal exploration.

However, we have over one million square kilometers of the continental shelf, the exclusive economic zone at sea, of which there are many valuable natural resources such as oil, gas and other minerals as well as huge marine resources. Hydrological investigation and surveys are not almost interested in and there is no minimum information even though we have hundreds of deep holes in 1,500 m depth, exploration and exploitation of oil and gas proceeded over more than half last century.

Search for groundwater implemented 92 tasks in the areas with a total area of 45,000 km^2, groundwater sources was detected and evaluated with total exploitation reserve of B 104,428 m^3/day and level C1 1,186,991 m^3/day and C2 11,366,465 m^3/day (in Soviet Union type). Searching areas have delineated and their depth of aquifers will be explored for groundwater extraction. To accomplish these tasks, thousands of boreholes of pumping test; analyze the basic parameters of the chemical composition of water samples. At the same time, other information related to hydrogeology is collected.

The depth of boreholes limited, exploitation and use mainly concerned; the survey area is not inter-regional so water resources planning and management will not meet the requirements of.

- Groundwater exploration implemented 46 groundwater exploration tasks with more than 7,000 km^2 in 20 provinces/towns. This exploitation characterized the aquifers properties; preliminary exploration with reserves of level A is 922,787 m^3 /day, B 1,043,892 m^3/day, C1 1,359,301 m^3/day and C2 4,136,707 m^3/day. To accomplish this task, hundreds of boreholes will be drilled and hydrogeological test (pumping test) with high reliability; and analyze the chemical parameters for assessing the water quality. In addition, other information related to hydrogeology and water collected. These results are detailed and reliable, have been directly used in the design and construction of water plants in key socio-economic areas.

2.2. Groundwater monitoring:

The territory of Vietnam has 7 hydrogeological zones (Zones where have different aquifers) but groundwater monitoring networks have constructed 5 zones. The station density, wells in the zones are almost sparse and many areas have not been invested monitoring stations yet (North Central and South Central Coast).

The ground water monitoring well density in the Northern delta is 1 well/ 80 km^2, the southern Delta is about 1 well/280 km^2 and the Central Highlands is 1 well/260 km^2.

The monitoring networks constructed and operated in three regions (Northern delta, the Mekong Delta, and the Central Highlands) from 1988 to 1995 and is currently in the process of completion with the total is 638 works

In 2009, 26 groundwater monitoring networks in the North Central Coast and 26 networks in the South Central Coast were established with total of 92 works. Results of groundwater works are shown in Table 1.

2.3. Groundwater exploitation

Currently, the groundwater exploitation in the territory of Vietnam has been very popular with different modes: large-scale industrial exploitation with wells or borehole with the capacity of each cluster of borehole is 10,000 m^3/day, actually in Ha Noi, hundreds of wells have been drilled in the 300 mm diameter range; wells or clusters of well of 1,000-10,000 m^3/day. These well clusters also drilled hundreds of boreholes; individual wells are less than 1,000 m^3/day; exploitation from small diameter boreholes currently for rural water supply including hundreds of thousands of boreholes in the country; exploitation from the wells in the countryside and the drain away, in the central and mountainous areas. In order to exploit more than one water type with purpose of water supply, thousands of water samples were collected and analyzed chemical composition for assessing and inspecting the water quality.

Table 1. Status of groundwater monitoring works

No	Region (Constructional year)	Main aquifer	Available works	Works according to Decision 16	Obtained percentage
1	Northern Delta (1988)	Holocene (qh), Pleistocene (qp)	206	315	65%
2	North Central (2010)	Holocene (qh) and Pleistocene (qp)	46	96	27%
3	South Central Coast (2010)	Holocene (qh) and Pleistocene (qp)	46	92	30%
4	Highland (1990)	Quaternary, eruption of basal and Neogene	212	275	77%
5	Southern (2010)	Quaternary (3 levels) and Neogene (2 levels)	220	336	65%
Total			**730**	**1247**	**58%**

In addition to the collected information from the surveys, exploration of groundwater monitoring for the purpose of water supply as mentioned above, in fact, information for the hydrogeologic surveys and groundwater carried out during the prospection and exploration of minerals, including oil and gas; building irrigation reservoirs and hydropower; building works on the surface and ground; environmental investigation and assessment; defense works; traffic and many other types of works. Thousands of boreholes were drilled and analyzed chemical components for thousands of groundwater samples.

2.4. Scientific research projects on hydrogeology at various levels.

The groundwater resource information has collected from Ministry level or localities. This information is usually kept at the Ministry of Science and Technology; Ministry of Natural Resources and Environment, research institutes such as Institute of Geology, Geography of Vietnam Academy of Science and Technology; Vietnam Institute of Geosciences of the Ministry of Natural Resources and Environment, some universities such as University of Mining and Geology, University of Science of Vietnam national university and provinces.

In summary, over the past several years, the amount of collected information that related to hydrogeology and groundwater is available to serve hydrogeological map. However, as mentioned above, this information has some of the following shortcomings:

- The information is scattered many places such as Ministries, Departments, Companies, business, enterprises, military units... and no one can understand and where they fully stored

- The information does not follow the uniform standard, so it is very limited when exploited and used even collecting more on reliability of information and the ability to check the classification is also extremely difficulty.

- The documents carried out from 1990 and earlier due to typing, printing technology, and maintenance work is limited, currently, many documents have been old, the ability to recover them too difficult for using, especially maps and drawings.

- The documents did not show the areas in the Vietnam territory, they only focus on the key areas and mainly serve the demand for water supply so they focus more in the delta and some large cities such as Hanoi, Hochiminh City, Hon Gai-Cam Pha, the Northern Delta, the Southern Delta, Central High and and some Central coastal areas such as Thanh Hoa and Vinh provinces. The information is very limited in the mountain, island and coastal areas; In particular, the coast shelf and the exclusive economic zone of the sea (about 1,000,000 km^2) are almost white although we had been searching, exploring and exploiting oil and gas for decades.

3. Hydrogeological map now and orient to future

3.1. Current hydrogeological map

As noted, over the past two-thirds centuries, the investigations of hydrogeology have collected a big amount of hydrogeological and groundwater information for hydrogeological mapping. In fact, almost all hydrogeological investigation, groundwater exploration and exploration, and some hydrogeological surveys for different purposes have made hydrogeological maps.

Currently, there are available many types of maps in the country and they divided in different ways.

3.1.1. According to the tasks

Hydrogeological maps were made under the "hydrogeological mapping" tasks, and "hydrogeological mapping" options implemented by the geological Sector.

When other tasks such as groundwater search, exploration, mineral deposits, urban areas, surveys for the construction of water reservoirs, hydrogeological maps were followed. These maps have large scale of 1:50,000, 1:25,000 to 1:5,000 and not small except in the case of hydrogeological surveys for reservoirs

Hydrogeological maps are compiled from the synthesis of collected documents on hydrogeological, groundwater, and related documents for hydrogeological assessment of a large regions or provinces. These maps are made according to scientific research projects in the state level, a provincial level which ha small and medium scale (from 1:250,000 to 1:1,000,000 and smaller).

3.1.2. According to the formed principles and the map legend model were divided into the following groups

Hydrogeological maps were formed by the stratigraphic principle of the hydrogeological and almost hydrogeological maps were formed before the 1990s and in accordance with this principle, including hydrogeological maps developed by "hydrogeological mapping tasks” and hydrogeological maps were made for different purposes and scientific research project and its legend model by the former Soviet Union; except for the hydrogeological maps that made by the Atlas 1:3,000,000 in accordance with the formation principle.

According to this principle, the hydrogeological strata are realized as the same muck with of hydrogeology (permeability, water-bearing, an abundance of water, etc.), located in succession on the cross section, distributed in available geological structures. For small-scale maps, hydrogeological maps are hydrogeological partitions which are based on geological structures of areas.

The hydrogeological map with the scale of 1:500,000 in Vietnam was announced by Hong Phu in 1983. This map formed 24 hydrogeological units in the Vietnam (3 porous aquifer units in quaternary sediments, 2 porous aquifer units in Neogenesis sediments, 2 fractured rock aquifer units in basalt rock and 17 fractured rock aquifer units, and karst fractures in hard rocks). And the country has many hydrogeological regions

Hydrogeological map 1:1,000,000 was established by Socialist Republic of Vietnam in accordance with the scientific research project "Groundwater of Vietnam Socialist Republic" was owned in 1985 by Vu Ngoc Ky who divided Vietnam's territory into 17 sub-regions into 6 hydrogeological regions and 28 hydrogeological units.

For large and medium scale maps, they are no zoned schemes as 19 hydrogeological maps 1: 200,000 on 236,340 km^2, almost they occupied the area of territory (except some areas have no implementation in the mountainous regions of Viet Bac, Northern West, North Central and Northern Highlands), they delineated the distribution range, defined the overview water content and water complexes in the surveyed areas; assessed the groundwater potential (C2 reserve is 12,428,967 m^3/day), characteristic of ground water quality in the mapping areas, is the basis for water resources investigation and planning by region.

Hydrogeological maps were made on the groundwater principle and under the UNESCO noted model. Almost Hydrogeological maps almost were formed since 1990 and in accordance with the principle and legend model.

Up to now, 34 hydrogeological maps have been made with the scale of 1:50,000 and 1:25,000 and 2 projects of hydrogeological mapping with scale of 1:50.000 implemented to make the maps in the area of 58,911 km^2, accounting more than 17 % of the territory, distributed scattered in key socio-economic regions such as the northeastern economic region, the industrial zone in the midland of the North, Northern Delta, the North Central Plains, the central border gate economic zone, the coastal economic zone in the South Central region in the Central Highlands, economic zone in the South East and some urban areas in the Mekong Delta. With a total area of 46,666 km^2, these maps delineated the scope and assessment of the water characteristics, the level of groundwater of the layers, the structure of the water rocked soil; Total groundwater reserves are investigated and assessed level A is 172,345 m^3/day, level B is 160,631 m^3/day, level C1 is 458,619 m^3/day and level C2 is 8,059,213 m^3/day. Identify for the distribution rules of chemical species and groundwater quality in the surveyed areas.

3.1.3. Regarding the contents of the hydrogeological map current whether formed under any principle, tasks must show the following basic factors

- The spatial distribution of water - bearing unit;

- Some characteristic of quantities such as discharge, specific borehole yield, conductivity K or transmissivity K of water rocked soil in surveying works;

- Some of the characteristic of quantities in water units such as mineralization, major water chemical types in water units;

- Some basic geological factors (strata, tectonic fault, etc.); Some for feature terrain and hydrological networks;

- Some hydrogeological researches (borehole experiment, hydrogeological monitoring borehole); Some artificial works have a strong impact on groundwater (groundwater exploitation works, mining zones, large reservoirs).

However, the methods of reflecting the characteristic quantities for the above parameters differ from the formed principles and the intention of the map authors.

3.1.4. Results and meaning of the hydrogeological map that has been formed

Hydrogeological maps have been formed with small scale (1:50,000 - 1:1,000,000) and have been generalized to hydrogeology and groundwater in Vietnam territory, they toward hydrogeology survey, investigation, groundwater resources assessment, the planning on exploitation, resources using and protection of territorial for the country's socio-economic development planning and orientations, and the large territories such as Northwest, North East, Northern Delta, Southern Plains, Central Highlands, Central Coast.

Medium and large-scale hydrogeological maps have identified hydrogeological units, areas where groundwater extraction are feasible, in terms of quality and quantity, and to be protected at different levels as well as properly identify the requirements for groundwater exploitation and other economic activities to ensure sustainable development in the provinces and economic regions.

3.1.5. The existence of the formed hydrogeological maps

- The continental shelf and exclusive economic zone on the sea where big economic potential not only marine resources but mineral resources as oil, gas and other minerals including the submarine resources are almost unspecified at the state level, so now the area is still no maps, even at small scale.

- The drawback of these maps is that many areas of intermittent investigation, the contents of the map sheets do not have the same principles; the depth of investigation limited to water "meaningful" objects is a big difference in each locality; when a link to unified hydrogeological characteristics meets many difficulties.

- Due to the water agglutination on the surface and groundwater has not been paid enough attention and groundwater has not been properly paid attention, so the hydrogeological maps have not clearly mentioned their relationship

- Medium and large scale hydrogeological maps have been formed in particular or the hydrogeological investigation in general in the two-third of last century focused on water supply and partly on groundwater resources protection in some specific areas.

- Groundwater is a dynamic element (while geologic, terrain is static compared to groundwater) they change very strongly not only effects of natural factors but also due to human activities, Therefore current hydrogeological maps did not reflect clearly and adequately. Current hydrogeological maps are static maps while human activities are dynamic.

As it is known that the hydrogeological map is in the field of basic investigation, it can serve a variety of purposes and reflects the close relationship between geological, terrain, groundwater and factors affecting to the ground water (meteorology, hydrology and especially human economic activities are strongly impact and lead to the degradation of groundwater source it means it take thousands of years or million years to form). Therefore, for the formed hydrogeological maps it should pay attention to the above characteristics for each specific object.

In our country, the hydrogeological map is recently no longer an independent field but has joined the Meteorological and Hydrographic Sector to create a new field of "Water Resources" to easily integrate into the world. However, it should be noted that except for "Water Resources" the establishment of maps current existing agencies still requires the establishment of more hydrogeological maps with different scales and the hydrogeological maps should have more necessary information to serve better not only water resources but also other purposes. We would suggest some of the following orientations for these issues in the coming years. (2025-2030).

Editing and supplementing of hydrogeological maps with scales of 1:200,000 and 1:50,000 that previously established according to the stratigraphic principle:

a. Information on groundwater changes, namely the specific quantitative of water level fluctuations (water level max, min in many years) in the groundwater monitoring station;

b. The basins of the main channel and the hydrological measuring stations and the rainfall measuring stations to control available basins and with water level parameters, the annual average smallest and largest discharge in hydrological stations, average – smallest – largest annual precipitation in many years at rain fall measuring stations.

c. The addition of artificial works that impact to groundwater such as reservoirs, ground water extraction clusters, mineral exploitation areas, and special land using conversion areas from tillage to industrial and urban land. (because these areas will be limited the amount of water percolation to add to the groundwater, and at the same time in these areas, the people constructed works on surface and underground and they strongly impact on the permeability of the muck under the foundations of the construction works, therefore greatly affect the assessment of groundwater reserves.

Hydrological mapping or water resources mapping for provinces or major river basins with a scale of 1:250,000 and for midland, mountainous areas or localities; the scale of 1:50,000 for the plains. When making these maps, we should pay attention to the following characteristics:

* For the midland and mountain, water-bearing rock and paleo type rock directly exposed or only covered by a thin coating of weathered products, rainwater will be directly absorbed and added to groundwater; In the dry season, groundwater supply water to rivers and streams, so lower water of rivers is also groundwater flow, moreover when assessing the water resources of a basin it must not to count twice.

* For Northern Delta and some coastal plains in central of Vietnam, due to the dam system to prevent the river water overflowing on the surface of the delta for hundreds of years, in fact, the delta is divided into puddle, so the impact of flow to the groundwater only available in the riverside. Hydrogeological maps have reflected those characteristics so that when assessing groundwater reserves are reliable data.

* For the Southern delta in the flood season, currently floodwater from upstream flooded all over the plain, at which time rain does not play an important role for groundwater. Hydrogeological maps must reflect those issues.

* For our country, there are two dry and rainy seasons each year. In the dry season, the amount of surface water added to groundwater is mainly irrigation water; so hydrogeological maps should also reflect those characteristics.

Hydrogeographic mapping of the continental shelf and exclusive economic zone is now considered an urgent task as it is too late for a country with more than 1,000,000 km^2 of the continental shelf and exclusive economic zone and more than 3,200 km of coastline and more than thousands of large and small islands. The hydrogeographic mapping of the continental shelf and the exclusive economic zone not only has economic implications but also contributes to the establishment of territorial sovereignty and territorial waters of Vietnam.

For hydrogeographic mapping of the continental shelf and the exclusive economic zone, there are some advantages and disadvantages. The current difficulties include:

- Shortage of staffs of marine hydrogeology and it is necessary for urgent training in the country as well as overseas training (the former Soviet Union has had such problems since 1950 -1960 of the last century and the Republic of the Russian Federation is still a country with strength in marine hydrogeology but Vietnam University of Mining and Geology is the only place to train staffs of marine hydrogeology with undergraduate, masters and doctoral degrees but have not yet formed marine hydrogeology courses)

- Equipment, as well as manpower and organizations are necessary for marine hydrogeology survey and investigation is almost nothing in the agencies on water resources hydrogeological investigation

However, we also have some advantages that are:

- Over the past half century, the oil and gas industry has surveyed thousands of square kilometers on the continental shelf; Exploratory, searching, and exploitation of oil and gas with maximum depths both on land and sea with hundreds of boreholes, taking and analyzing thousands of samples of muck, analyzing the chemical composition of water in the aquifers, and geophysical measurements of thousands of meters of boreholes. This huge volume of material is good for hydrogeological mapping in the continental shelf. In the coming years, we should be linked to discover benefits to the country. On the other hand, in our country, the research on the geological structure of the continental shelf has also accumulated a large amount of necessary information and has been widely published in scientific journals in the country as well as abroad. These documents are a good basis for the development of marine hydrographic maps.

- In recent twenty years, marine geological research has certain results as well as advantages for marine hydrogeological mapping in our country.

- In recent years due to the fact of operation, petroleum geologists have been interested in water in the oil and gas fields which is also a favorable factor in linking to the development of hydrogeological maps in the continental shelf.

- New technologies such as remote sensing technology, especially in lightweight flying equipment, localization technology searching points, information technology are also key factors for the construction of hydrogeological maps in the continental shelf.

In order to meet the requirements of marine hydrogeology research and the hydrogeological mapping of continental shelf and exclusive economic zone, it is necessary to improve the specialists, equipment development, and especially international cooperation, especially in countries with the same sea and high-tech countries on related issues.

Digitizing hydrogeological maps and GIS Integration

At present, the volume of information on groundwater as well as water resources is very large and it fluctuated over time. Moreover, the impact of the economy on water resources in general and on groundwater, in particular, is more and more intense and complex. Hydrological mapping is usually limited to reflecting dynamic information and adding new survey points, such as information on water level changes, the total mineralization content of groundwater at groundwater hydrodynamics monitoring stations, hydrological stations or rainfall at rain gauges, exploitation discharge in groundwater exploitation works on the maps. Electronic hydrogeological maps overcame those difficulties...

4. Conclusion

For more than half a century, in Vietnam, various types of maps have been made in different proportions, depending on the purpose of use. However, before 1990, the hydrogeological maps have been made according to hydrogeological stratigraphic principles. and the legend model of the hydrogeological maps created by the Soviet Union. Since 1990, the hydrogeological maps have been mainly made under the principle of the existence of groundwater and the legend model of UNESCO.

At present, the amount of hydrogeological and groundwater information, including dynamic monitoring data is very large, which must be used and considered as a task to make hydrogeological maps with a different scale.

The hydrogeological mapping in the continental shelf and the marine exclusive economic zone is an urgent need, despite many difficulties, it has many favorable conditions so it needs to be implemented quickly and these maps mainly make under the hydrogeological stratigraphic principle

With the available amount of information currently along with the rapid development of information technology, the current hydrogeological maps must be made into electronic maps to meet a variety of purposes in using of hydrogeological maps.

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III-3-(1)
Utilization and Management of the Groundwater Resources in North China Plain, China

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Abstract

This paper introduces the situation of groundwater in the North China Plain. The North China Plain is one of the most important political and economic areas. The North China Plain is a large Mesozoic-Cenozoic sedimentary basin. The municipal, agricultural and industrial water supplies are highly dependent on groundwater resources that mainly found in the Quaternary aquifers. Because of the long-time overexploitation, wetland shrinks, groundwater level continuously decreases, saline water intrudes and land subsidence even found in some areas. At the same time, the same areas of groundwater have been polluted. In order to better use and protection of water resources, the hydrogeology survey for different purposes with different accuracy has carried out by China Geological Survey. The groundwater water quality and water level monitoring system and the database have been established and improved. Meanwhile, various groundwater protection measures have been carried out, such as groundwater exploitation control, pollution control, monitoring, groundwater recharge, agricultural water saving irrigation etc. Especially the South-to-North Water Diversion Project will help to reduce the groundwater exploitation. Through kinds of management measures, the groundwater environment would be effectively improved.

Keywords: groundwater, hydrogeological, management, North China Plain, China

1. Introduction

The North China Plain (NCP) is located in the eastern part of China between 112°30′-119°30′ east longitude and 34°46′-40°25′ north latitude. It is on the west of Bohai Sea, east of Taihang Mountains, south of Yanshan Mountains and north to the Yellow River. It covers Beijing Municipality, Tianjin Municipality, the whole plain of Hebei Province and the plain north of the Yellow River in Henan Province and Shandong Province, with an area of 139,238 km^2, where 19 prefecture-level cities and 227 county-level administrative units are distributed (Meng Shuhua, 2011).

The overall topography of the North China Plain slopes towards the Bohai Bay from north, west and south. The elevation in the piedmont is generally between 80-100m, which changes to 30-50 m in the central plain and reduce to 0-5 m in the coastal plain (Fig. 1)(Liu J., 2011). The North China Plain is semiarid monsoon climate in warm temperate zone on the east coast of Eurasia. The average annual precipitation is generally 500-600 mm and 600-700 mm in coastal area, slightly more. Because of the rainy shadow effect and north sinking airstream, the average annual precipitation in the central plain is less than 500 mm, and the total annual precipitation concentrated in the summer monsoon months (July to September). Therefore, water resource is important and limited in the North China Plain (Kendy E., 2011). The plain is flat with numerous rivers and lakes, convenient transportation and developed economy. It is one of the most populated and developed region in China and is the cultivation center of wheat and maize. The North China Plain is the center of China's politic, economy and culture since ancient times. Capital Beijing and municipality Tianjin and Hebei Province capital Shijiazhuang are located in the region, while Shandong Province Jinan and Henan Province

Zhengzhou are located at the region border. Its population and cultivated area account for about one fifth of China. According to the National Statistical Yearbook data, the total population of the entire district was 125.99 million in 2004 (Wu Aimin, 2010), accounting for 9.2 % of the national total. The GDP supported by groundwater was 1,560.8 billion RMB in 2003, and it quickly increased to 3,758.5 billion RMB in 2011 (Liu min, 2017).

Groundwater is the main water source in the North China Plain. Over the past 60 years, groundwater has played an important supporting role in the agricultural and industrial development of the North China Plain.

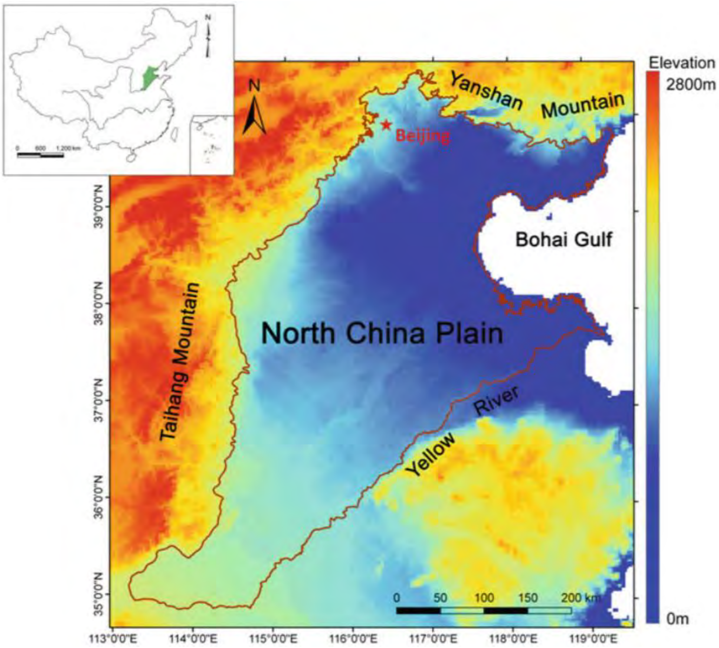

Fig. 1. Location of the North China Plain (Liu J., 2011)

2. Geology and Hydrogeology in North China Plain

The North China Plain is a large Mesozoic-Cenozoic sedimentary basin in the tectonic subdivision of the North China prospective platform in the tectonic division. The lower base of the North China Plain consists of a complex set of metamorphic rocks formed by folding and metamorphism of the Archean and Paleoproterozoic Archean. The upper part of the Neoproterozoic, the Paleoproterozoic and Cenozoic sediments composed of two sets. The area of Upper Ordovician to Lower Carboniferous is generally missing (Zhang Zhaoji, 2009).

North China Plain widely distributed pore water in loose rock. The aquifer lithology is pebbles, coarse sand, medium fine sand in piedmont plain and medium fine sand, fine sand, silty sand in the central plain, silty sand, silt in the coastal plain (Fig. 2) (Qian Yong, 2014). The North China Plain Quaternary groundwater system consists of seven secondary groundwater systems. Quaternary aquifer is usually divided into four aquifers, which basically correspond to the Quaternary Holocene and the upper, middle and lower Pleistocene. The depth of bottom plate of first aquifer group is 40-60 m, and it’s phreatic; the second aquifer group floor depth is 120-170 m, micro confined water, which basically integrates with the upper layer due to human mixed mining, commonly known as "shallow groundwater "; the third aquifer depth is 250-350 m, and the fourth is 550-650 m (Fig. 3). These two confined layers are deep and are commonly known as" deep groundwater"(Wu Aimin, 2010). The second and third layers are main exploitation layers in this region (Zhang Zhaoji, 2012). Groundwater is the main water supply in the North China Plain.

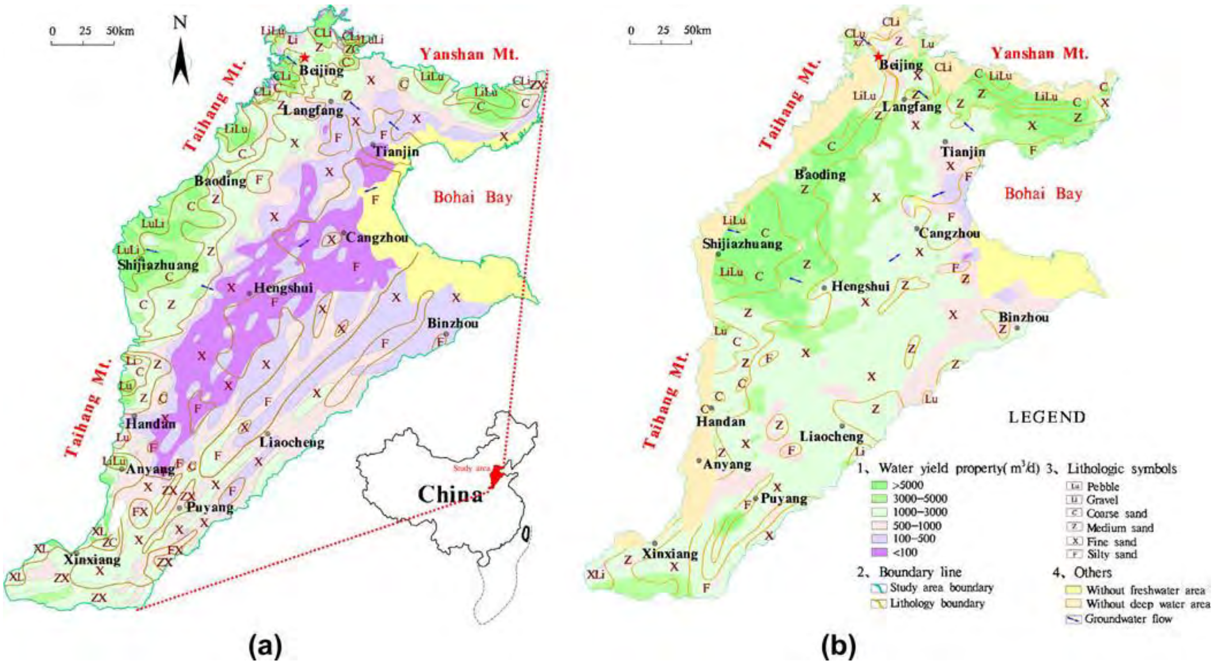

Fig.2. Hydrogeologica map of shallow aquifers (a) and deep aquifers (b)in the North China Plain (Xing Lina, 2013)

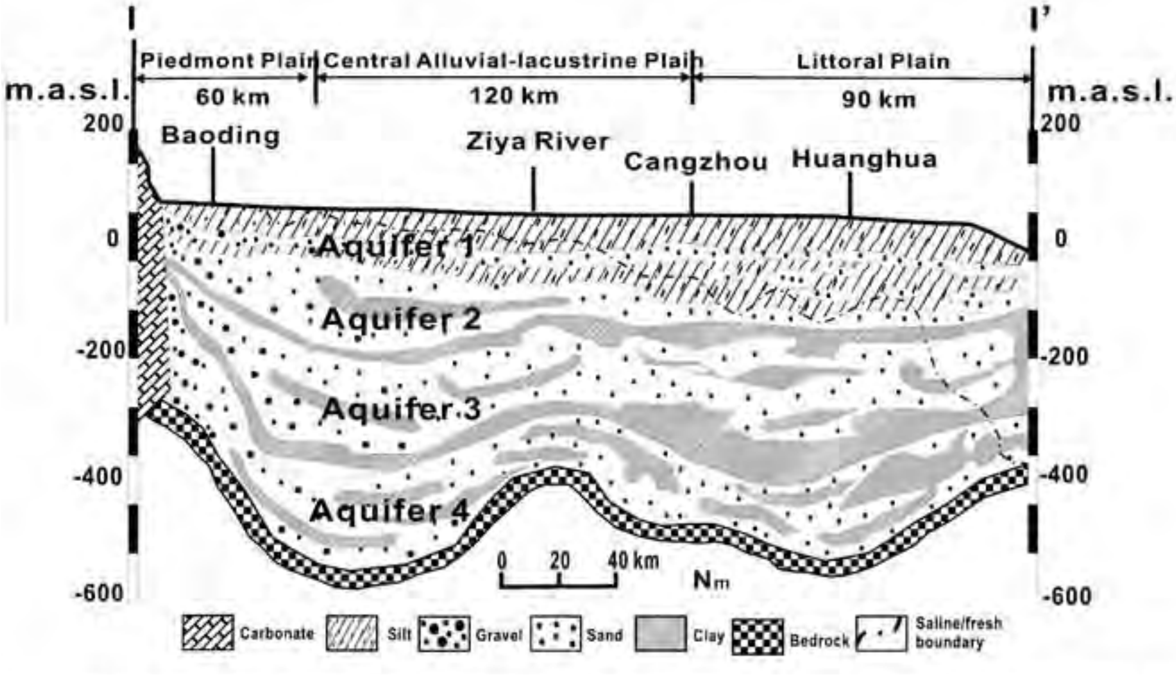

Fig. 3. Hydrogeological cross section from the piedmont Baoding to Cangzhou. The Quaternary aquifers are divided into four groups name as Aquifer 1-4. The boundary between shallow saline water and deep freshwater is marked as a dashed line. (Li Xiaoqian, 2012)

The groundwater recharge mainly includes precipitation infiltration, lateral inflow, irrigation infiltration and river infiltration, among which the precipitation infiltration is one of the main recharge of groundwater, and the irrigation, is the main driving force of vertical recharge. The recharge volume increases with the increase of irrigation (Lu X., 2011). Groundwater exploitation has become the main groundwater discharge in the North China Plain, including agricultural, domestic and industrial exploitation and a small amount of ecological water. Shallow exploitation is mainly concentrated in the piedmont zone, while deep mining mainly concentrated in the central plains of Hebei Province. The exploitation of groundwater in the North China Plain in 2002 and 2003 was 211.16×10^8 m^3, 199.22×10^8 m^3 respectively, among which, the exploitation shallow groundwater was 180.79×10^8 m^3 and 166.39×10^8 m^3, and the exploitation of deep groundwater was 30.37×10^8 m^3 and 32.83×10^8 m^3. Shao Jingli, used precipitation and rivers information of years, evaluated the annual average groundwater recharge rate based on water balance analysis, which is 256.68×10^8 m^3/a, and the annual average recharge modulus is 18.47×10^4 $m^3/(km^2\cdot a)$, the precipitation infiltration rate is 179.70×10^8 m^3/a, accounting for 70.00 % of the total supply. Using the model, the total safe yield of groundwater in the North China Plain is calculated to be 213.49×10^8 m^3/a, among which, shallow aquifers safe yield is 191.65×10^8 m^3/a, and average exploitation modulus is 13.79×10^4 $m^3/(km^2\cdot a)$; Deep aquifers safe yield is 22.64×10^8 m^3/a, and average exploitation modulus is 1.93×10^4 $m^3/(km^2\cdot a)$ (Shao Jingli, 2009).

Since late 1970s, increasing water demands associated with rapid urban development and expansion of irrigated land have led to overexploitation of both surface and groundwater resources, and the annual exploitation of shallow aquifers increased significantly. In 2000, approximately 74% of the annual water supply comes from groundwater pumping (Liu J., 2011). For recent 50 years, groundwater plays an important supporting role in the development of industry and agriculture in the North China Plain (Zhang Zhaoji, 2009). Because of the long-time overexploitation and the interception by reservoirs upstream, most of the river channels in the North China Plain are perennially drying up, wetland shrinks, groundwater level continuously decreases, saline water intrudes and land subsidence even found in some areas (Liu Changming, 2001). These resource and environmental problems have seriously affected the safety of water supply in the region (Xia Jun, 2002). Therefore, the deficit between the growing water demands and the finite water supply will become more and more acute. The aquifers in the North China Plain have become one of the most overexploitation areas in the world (Liu J., 2001).

In the North China Plain, both deep and shallow groundwater is universally overexploited. Fig. 4 shows that depth of deep and shallow groundwater in the North China Plain. As can be seen, the equivalent water depth of the Circum-Bohai-Sea Large Depression Zone has exceeded 100 m, while this value was negative before the 1970s (China Geological Survey 2009). The exploitation rate was exceeding the precipitation recharge rate which caused the groundwater level declined in different special scales. Exploitation was the main factor for groundwater dynamic while precipitation was the limiting factor for groundwater renewability (Li Xue, 2013). In some areas, groundwater level has gradually recovered at present.

In the past, the shallow groundwater generally recharge from deep groundwater. However, the deep groundwater recharge from shallow groundwater in many areas now (Shao J., 2013). At the same time, the changes of conditions of hydrologic cycle make the chemical characteristics of shallow groundwater tends to be complex, especially in the central plain, which change from the early HCO_3-SO_4, Cl-SO_4 and SO_4-Cl mixed type to HCO_3-SO_4, HCO_3-Cl, Cl-SO_4, SO_4-Cl, SO_4, Cl-SO_4 and SO_4-Cl. The area of Cl and Cl-SO_4 type in phreatic water is greatly reduced. Groundwater tends to desalination, and the hydrochemical type transfers into HCO_3 or SO_4 type (Shi Jiansheng, 2014). Seawater intrusion occurs in some coastal areas.

With the intensification of human activities, the increase of the improper disposal of oil pollution, city garbage and sewage production, a large number of pesticides and fertilizers used in agricultural production while environmental protection legislation and management is relatively backward, groundwater pollution has become increasingly serious. Zhang Zhaoji evaluated the groundwater contamination condition of the North China Plain with the Single Factor Standard Index Method. Results show that the contamination is mainly point pollution and there are many pollution indicators like three nitrogen, heavy metal and organic pollutants. 35.47 % samples have been contaminated by human activities, mainly slightly contamination. Deep groundwater is better than shallow groundwater and uncontaminated deep groundwater, uncontaminated samples accounts for 87.14 % (Zhang Zhaoji, 2012). Besides, high fluoride groundwater occurs in the flow-through and discharge areas of NCP, while high iodine groundwater is mainly observed at coastal area of NCP (Li Junxia, 2017).

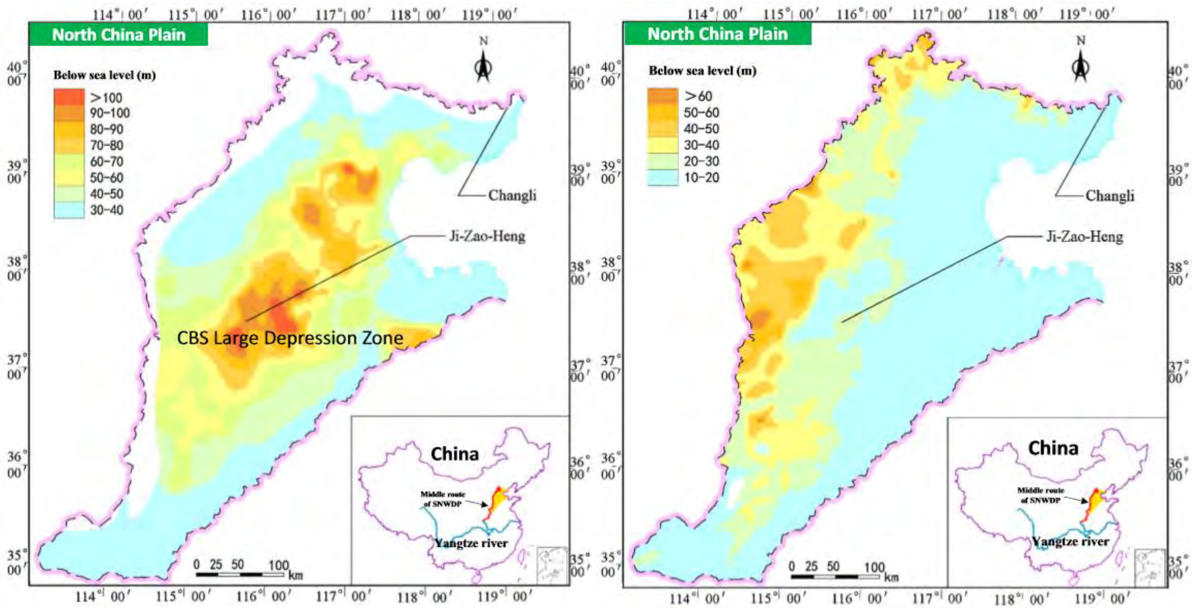

Fig.4. Depth of deep groundwater (left figure) and shallow groundwater in the North China Plain in China (Colored area shows the Cirum-Bohai-Sea (CBS) large depression zone. Data were collected in 2014. Shang Yizi, 2016)

3. Hydrological database in North China Plain

3.1 Groundwater monitoring and database

The North China Plain is one of the first areas in China to carry out groundwater monitoring, and it is also a relatively perfect area for monitoring network. Before 2014, the departments of land and resources had formed a groundwater monitoring network consisting of more than 100 national monitoring sites and over 4,000 provincial and municipal groundwater monitoring points.

Table 1. Monitoring points in the Huang-Huai-Hai Plain of National Groundwater Monitoring Project (*www.cigem.cgs.gov.cn*)

Sum	Newly designed monitoring point		Upgraded monitoring point	
	MWR	MLR	MWR	MLR
5,845	2,536	1,590	927	792

In 2015, a new *"National Groundwater Monitoring Project"* of China is implemented by the Ministry of Land and Resources (MLR) and the Ministry of Water Resources (MWR). The China Geological Survey (CGS) is responsible for part of the construction of MLR. The main objective of this project is to construct a comprehensive monitoring network covering the 16 dominant plains/basins in China. Total 20,401 monitoring wells are schemed, among which 10,103 wells are implemented by CGS. The Huang-Huai-Hai Plain where North China Plain is located is one of 16 Plains/basins, there are 5,845 Monitoring points that constituted of 4,126 newly designed and 1,719 should be upgraded from the available old wells (Table 1, *www.cigem.cgs.gov.cn*). By now, the most of the monitoring sites have been completed. The focal monitoring areas include the groundwater pollution areas, the areas with environmental geological problems caused by human activities, the groundwater sources, urban areas, railway and subsidence areas.

As described in the China Country Report in GW5-2015，There are two main monitoring database running to satisfy the demand for Data storage, analysis and releasing for groundwater monitoring in China. The original database for all China groundwater monitoring, ran under MS-DOS in 1990's. All-China groundwater monitoring Database have developed to being a flexible Windows tools for daily data processing. This database holds 5 normative tables to record general wells condition, water level, water quality, water temperature and pump discharge respectively. Function modules such as data importing, data check, statistical analysis, reports generating, water quality assessment, curve plotting and yearbook (annual) exporting are included in this database system. Another database had been taken into consideration as one of the main tasks for the project "Investigation and evaluation of Groundwater dynamics for Plains-of-North-China". This improved database holds 19 relational tables to deal with complex data structure, to store mass data based on SQL SEVER 2000. The database not only have the capacity to store and deal with all-China national-level groundwater monitoring datum, but also support real-time data gathering from the auto-monitoring/ transmission wells.

At present, in order to adapt to the national groundwater monitoring project and new requirements, new groundwater database is being upgraded and developed.

3.2 Geological cloud and database

"*Geological Cloud*" is developed by China Geological Survey, presided over a set of comprehensive geological information service system, using the classic four layers of cloud architecture, integrates the geological investigation, business management, data sharing and public service four subsystems. For the public, the cloud provides multi-class geological information products, such as to view the public version of geological map, remote sensing database, working degree, drilling data, geological literature, geological popular science, etc. For geological survey and technical personnel, the cloud provides cloud environment intelligent geological survey work platform. For the manager of geological investigation, the cloud provides "one-stop" integrated service cloud environment management and decision support. For all kinds of geological survey professionals, it provides basic geology, mineral geology, hydrogeology, environmental geology, marine geology and other specialized data sharing services (*http://geocloud.cgs.gov.cn*).

In addition, the MWR monthly publishes groundwater dynamic report, which includes the changes of groundwater level in the north China plain (as Huang-Huai-Hai Plain, *www.hydroinfo.gov.cn*).

The project "*Investigation and Assessment of Sustainable Utilization of Groundwater Resources in the North China Plain*" is sponsored by the China Geological Survey between 2003 and 2005. The project had established "*NCP Geodatabase*" containing data of hydrogeological drilling, groundwater level, groundwater exploitation, and groundwater chemical information. In addition, the three dimensional numerical groundwater model of NCP was established by Feflow and GMS software. The groundwater evolution trend with different conditions, the South-to-North Water Diversion Project especially, have predicted by the model. In addition, the regional investigation on groundwater pollution by CGS in

1:250,000 scale had been fulfilled with a spatial database, the hydrogeological survey in 1:50,000 scale by CGS has also been implemented. These data and information would be retrieved in the *Geological Cloud*, and obtained through application and authorization.

3.3 Groundwater level and water quality in North China Plain

Based on the monitoring data of 1,467 monitoring wells in North China Plain in June 2019, the average depth of groundwater level in North China Plain was 7.88 m. Compared with the same period last year, the stability zone of groundwater depth accounted for 40%, the increased zone accounted for 49 %, and the increase was generally less than 2 m. However, in some parts of the western and southern of plain, such as Shijiazhuang, southeastern Baoding, Kaifeng and Heze cities, the increase was more than 2 m. The decreased zone accounted for 11 %, and the reduction range was generally less than 2 m except Beijing and Northwest Baoding, etc. In general, the depth of groundwater level in the plain increased gradually from east to west. The groundwater depth in the eastern plain area was about 1-12 m. Meanwhile, the groundwater depth in the central and western plain was 20-50 m, such as northern part of Beijing, Tangshan, Baoding, Shijiazhuang, Xingtai and Handan in Hebei Province, the depth of groundwater level, and some areas was more than 50 m *(http://www.mwr.gov.cn,* Monthly report of groundwater regime of ministry of water resources of China in June 2019).

Based on 4,384 samples of shallow groundwater in North China Plain collected from October to December in 2006-2009, groundwater quality gradually deteriorated from piedmont plain to central plain and coastal plain. Among all shallow groundwater sample points, samples of type I to III which divide according to *Standard for Groundwater Quality* of China accounted for 22 %, type IV accounted for 57 %. Among 1,679 samples of deep groundwater, type I to III accounted for 26 %, type IV accounted for 23 % and the type V accounted for 51 % (Fei Yuhong, 2014). The main over-standard components included nitrate, nitrite, ammonia, heavy metals, etc (Wang Xuan, 2016, Wang Shiqin, 2018).

4. Groundwater Management in North China Plain

4.1 Laws and Regulations

The laws about groundwater management include "*Water Law of the People's Republic of China*", "*Law of the People's Republic of China on the prevention and control of water pollution*". The regulations about groundwater management include "*Regulations on the administration of water collection permits and water resources fees*" and local government regulations, such as "*Regulations on the administration of groundwater in Hebei Province*". Currently, "*Groundwater Management Regulations*" which specifically for groundwater management has been enacted (Exposure draft, *www.mwr.gov.cn*) and will be enforced follow in China.

4.2 Organization

In China, the groundwater management is mainly carried out by the departments of MWR, including the management of groundwater exploitation license, hydraulic engineering and so on. The groundwater pollution control is mainly carried out by the departments of Ministry of Environmental Protection. The groundwater management with mineral properties, such as geothermal water and mineral water, is carried out by the departments of MLR. At the same time, the MLR is responsible for the management of hydrogeological exploration and evaluation, monitoring and Supervise development to prevent excessive groundwater exploitation and pollution. The China Geological Survey of MLR is responsible for the investigation, monitoring and evaluation of groundwater. In the cross content of groundwater management, the two departments will solve the problem.

In order to better development and protection of groundwater in the North China Plain, a series of measures have been implemented, such as the groundwater water level and water quality monitoring, reduced and limited of the groundwater exploitation, pollution control, multi-headwater jointed dispatch, groundwater artificial recharge, water source protection, agricultural water saving irrigation and so on.

4.3 Comprehensive Management for Groundwater Over-exploitation

The groundwater over-exploitation has resulted in a series of geological and environmental problems such as land subsidence and wetland shrinking and drying-up. The Chinese government has paid high attention on groundwater resources protection. In 2014, a pilot project of comprehensive management for groundwater over-exploitation has been initiated in Hebei Province in the North China Plain.

The Chinese government has implemented a series of management measures, which mainly include: demarcation of groundwater over-exploitation zones - restricted zones - prohibited zones, Shutdown some exploitation wells, developing water-saving agriculture, changing the type of agricultural planting and implementing the fallow program (Liu Di, 2018), implementation of diversion project, raising public awareness of water. Through that management, about 1.52 billion m^3 groundwater of agricultural exploitation had been reduced. In the test areas, the shallow groundwater depth decrease rate has been slowed down, and the deep groundwater depth of 60 % area shows a recovery trend (Ma Lei, 2017).

4.4 The South-to-North Water Diversion Project

The *South-to-North Water Diversion Project* is a major strategic infrastructure aimed at alleviation severe water shortages in Northern China, optimizing the allocation of water resources, and improving the ecological environment. The East Route Project and Middle Route Project could mainly provide water for North China Plain that not only supplies water to urban cities, but also replenishes natural lakes and rivers. An accumulated 1.48×10^{10} m^3 and 1.3×10^{10} m^3 water will be diverted annually by the East Route and Middle Route respectively (Office of the South-to-North Water Diversion Project Construction Committee, 2016). Phase I of the Middle Route Project has diverted more than 1.08×10^{10} m^3 of water since December 12, 2014 to 2017 (www.nsbd.gov.cn). The project will help to reduce the groundwater exploitation and recover the groundwater level.

5. Conclusions

The North China Plain covers Beijing Municipality, Tianjin Municipality, the whole plain of Hebei Province and the plain north of the Yellow River in Henan Province and Shandong Province. It is one of the biggest plains in China, where municipal, agricultural and industrial water supplies are highly dependent on groundwater resources.

The North China Plain accessible groundwater mainly occurred in the Quaternary sediment aquifers. From the top to the bottom, sediments can be divided into shallow and deep aquifers as four aquifer groups. Shallow exploitation is mainly concentrated in the piedmont zone, while deep mining mainly concentrated in the central plains of Hebei Province. The groundwater exploitation volume in the North China Plain in 2003 was 199.22×10^8 m^3, among which, shallow groundwater exploitation volume was 166.39×10^8 m^3, and deep groundwater exploitation volume 32.83×10^8 m^3. Both deep and shallow groundwater is universally overexploited. Because of groundwater level continuously decreases, saline water intrudes and land subsidence even found in some areas. The contamination of groundwater is mainly point pollution and there are many pollution indicators like three nitrogen, heavy metal and organic pollutants. 35.47 % samples have been contaminated by human activities, mainly slightly contamination. Deep groundwater is better than shallow groundwater and uncontaminated deep groundwater, uncontaminated samples accounts for 87.14 %.

In order to better use and protection of water resources, the groundwater monitoring system and data base have been established. The North China Plain is one of the first areas in China to carry out groundwater monitoring, and it is also a relatively perfect area for monitoring network. Geological Cloud and NCP Database have been developed by China Geological Survey.

Based on the laws and regulations, the groundwater management is mainly carried out by the departments of MWR，the departments of Ministry of Environmental Protection, and the departments of MLR. The China Geological Survey is responsible for the investigation, monitoring and evaluation of groundwater.

In order to better development and protection of groundwater in the North China Plain, a series of measures have been implemented, such as the groundwater water level and water quality monitoring, reduced and limited of the groundwater exploitation, pollution control, multi-headwater jointed dispatch, groundwater artificial recharge, water source protection, changing the type of agricultural planting and implementing the fallow program, and so on. Especially the South-to-North Water Diversion Project will help to reduce the groundwater exploitation. Through the above management measures, the groundwater environment would be effectively improved.

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III-3-(2)

Jakarta Groundwater Basin, Indonesia

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Abstract

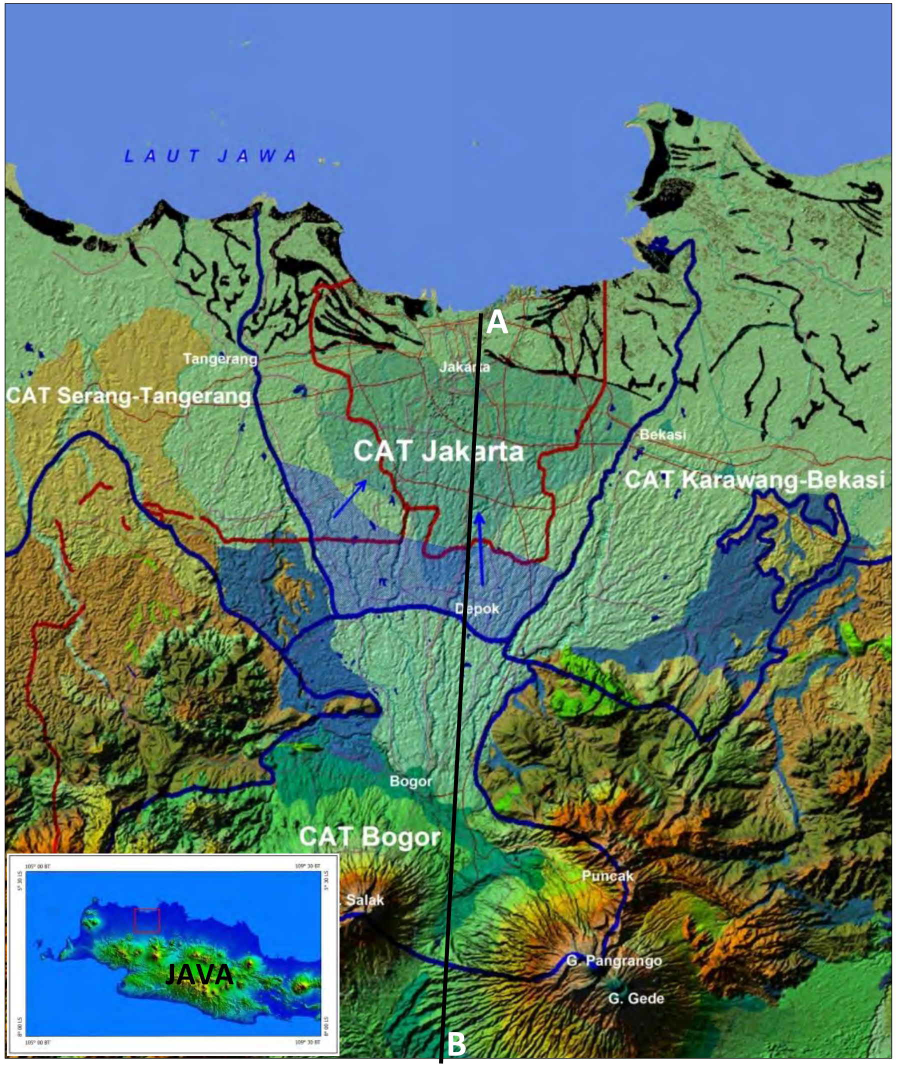
This paper describes the geology, hydrogeology, groundwater condition, and groundwater management in the Jakarta groundwater basin. The basin is an inter-provincial basin consisting of marine and non-marine deposits and bounded by the Java Sea in the north, by an influent stream in the east and west, and by basement undulation in the south. Poor municipal water network is causing over abstraction of groundwater in some areas, which leads to seawater intrusion and land subsidence. The water level recorded a drastic drop during the early 1980's. Since then, the water level has been dropping slowly up to present. Salty water from a confined aquifer reached far into the land and severe land subsidence by up to 12 cm/year is proceeding in north Jakarta, especially in Muara Angke. The management of the basin is shared between the central and provincial governments: the former publishes the conservation map and issues technical recommendation for production wells, whereas the provincial government issues wells registration. In order to improve the monitoring of groundwater condition, a master plan to network the (existing) monitoring wells is being developed, followed by the systematic installation of additional wells. The government is also conducting an action to fight against illegal wells.

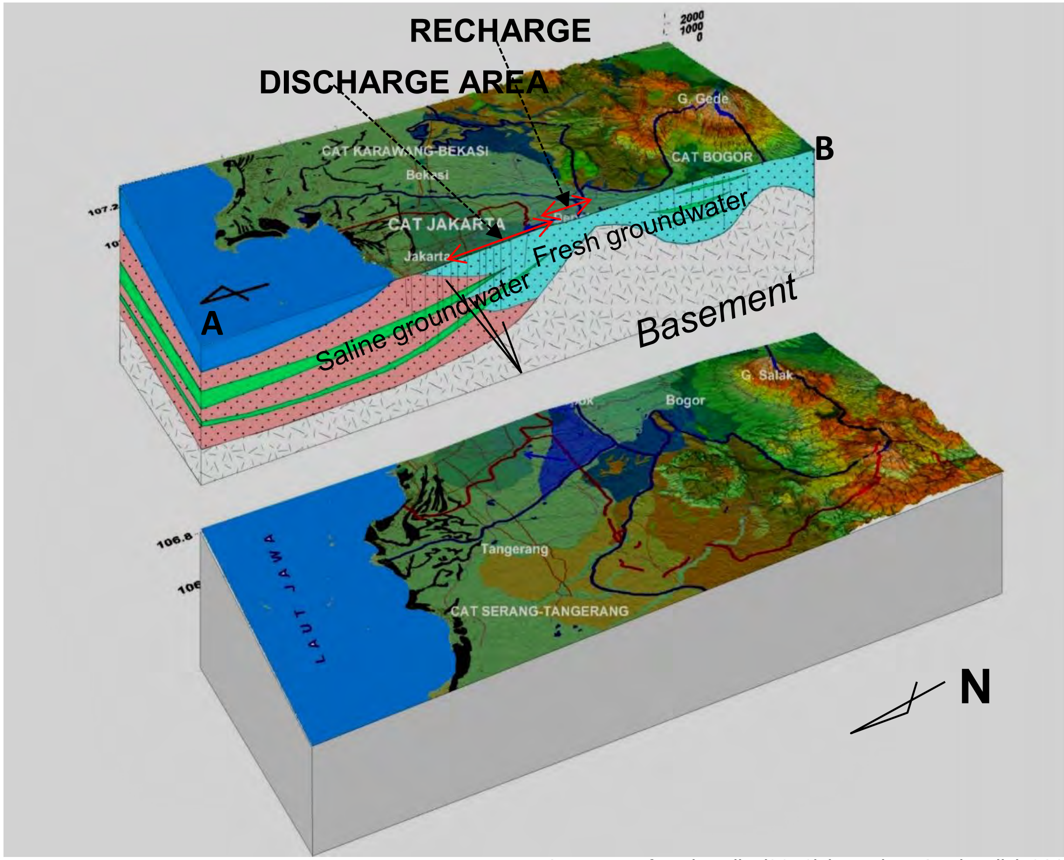
Keywords: groundwater, Jakarta, basin, management

1. Introduction

Jakarta as the capital city of Indonesia has been for a long time becoming a hot spot of its groundwater and related problems. With a population of c.a. 10.17 million in 2015 (BPS, 2016), Jakarta is considered as a megacities, equal with other big cities in Asia, e.g., Delhi, Bangkok, Manila, Tianjin (Onodera et al., 2008). In this kind of city, without sufficient municipal water network coverage, groundwater normally will be the main source of water supply. Over abstraction of has been identified triggering land subsidence and, in coastal cities, also seawater intrusion (Abidin et al., 2010; Huang et al., 2012; Murdohardono and Sudarsono, 1998; Onodera et al., 2008; Phien-wej et al., 2006; Suripin, 2005; Zhu et al., 2015). Recently, groundwater degradation in Jakarta becoming a hot issue, due to big flooding evens occured at some strategic areas, e.g., Monas, Bundaran Hotel Indonesia, and recently Kemang. The flood has been associated with land subsidence due to over abstraction of groundwater. Data from Jakarta provincial administration reported that in 2011 water demand in Jakarta reached 846 billion m^3, and only 35.2 % covered by municipal water network, hence the rest, 64.8 %, obtained from groundwater. From the number of 64.8 %, only 9.3 % were registered, hence troublesome for such a management effort. Recent flooding events in some strategic areas in Jakarta, has been associated with groundwater abstraction.

This paper explains the configuration of Jakarta groundwater basin, its geological setting, hydrogeological condition, and the management practices. Groundwater management aimed to maintain the sustainability of groundwater to support environment and community.





Courtesy of Wahyudin (2010) based on Soekardi (1982)

Fig. 1. Boundaries configuration of the Jakarta groundwater basin

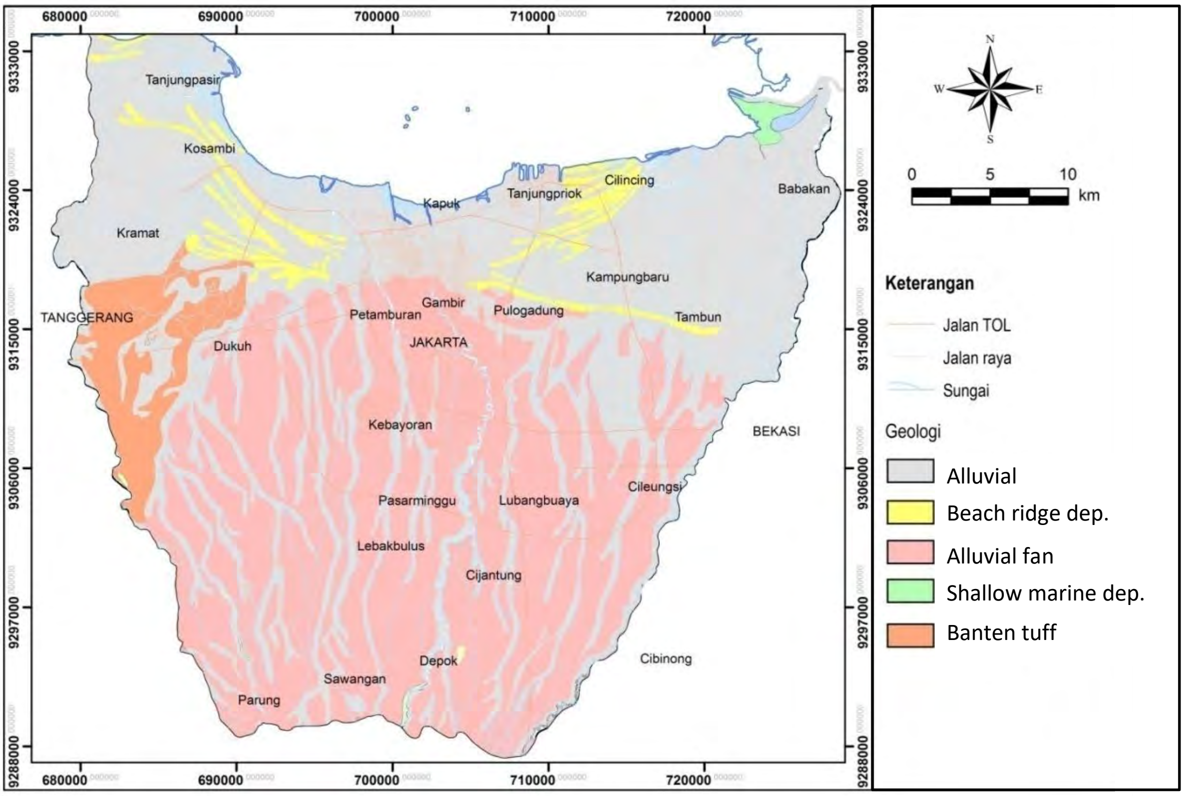


Fig. 2. Geological map of the Jakarta Groundwater basin (Turkandi, et.al., 1992)

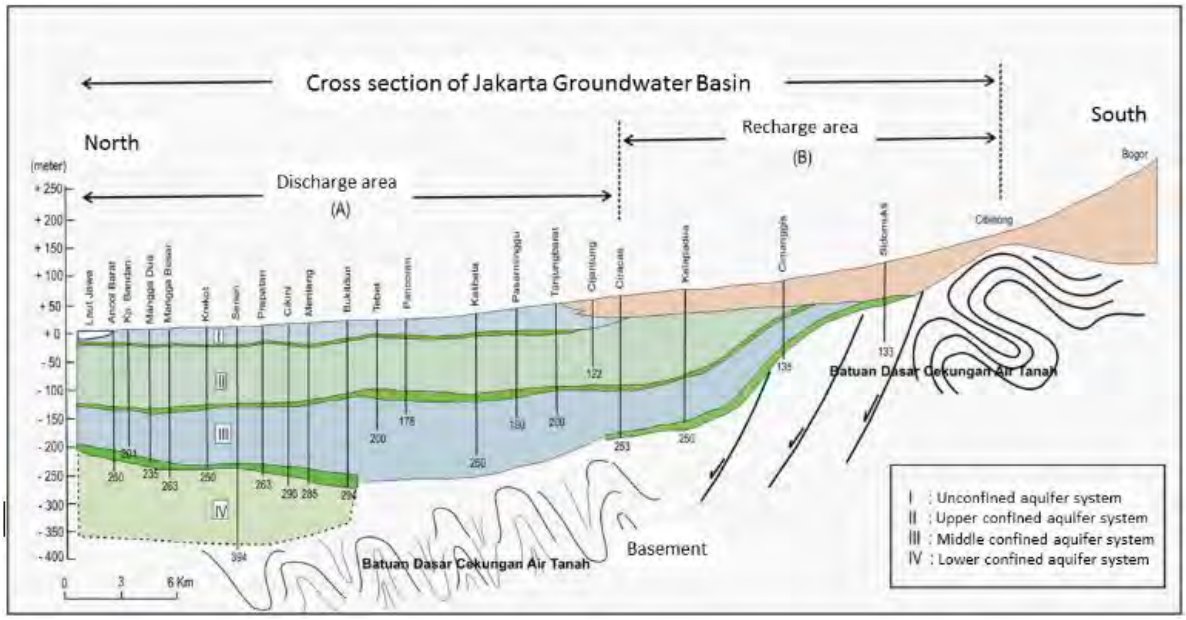


Fig. 3. The aquifer configuration of Jakarta basin modified from Soekardi (1982)

2. Geology and Hydrogeology in Jakarta, Indonesia

Jakarta groundwater basin is located at 106° 36' 32,54" - 107° 04' 04,78" E and 06° 00' 43,50" - 06° 26' 58,23" S (Fig. 1). The basin boundaries consist of three types, i.e., 1) external-head control (Java Sea) in the north, 2) influent stream in the east (Bekasi River) and the west (Cisadane River), 3) no-flow boundaries by basement outcrop at the upstream part of the Bekasi River and Cisadane River, and 4) basement undulation in Depok area in the south. According to these boundaries, Jakarta groundwater basin covers three provincial territories, i.e., DKI Jakarta, Jawa Barat and Banten, hence classified as inter-provincial basin. The basement of Jakarta basin are impermeable Miocene sedimentary rocks at c.a. 300 m depth, outcropped in the southwestern, southern, and southeastern boundaries of the basin (Soefner et al., 1986).

In more regional perspective, Jakarta groundwater basin is a part of the Northwest Java basin, specifically in Ciputat sub-basin (Patmosukismo and Yahya, 1974). The rocks formation in Jakarta, from old to young, composed by Bojongmanik and Jatiluhur Formation, Parigi Formation, Subang Formation, Parigi Formation, Basalt from Gunung Dago, Genteng Formation, Kaliwungu Formation, Serpong Formation, Citalang Formation, Banten Tuff and Quaternary Volcanic Deposit (Achdan and Sudana, 1992; Fachri et al., 2002; Turkandi et al., 1992). The basin consists of Pliocene marine deposits and Quaternary fan-deltaic sediments (Djaeni et al., 1986) (Fig. 2). The general stratigraphic unit filled the basin from bottom to the top are Pleistocene marine and non-marine deposits, a Late Pleistocene volcanic fan deposit and Holocene marine and floodplain deposits (JWRMS, 1994). The Pleistocene sediments is considered forming a single layer aquifer of the lower confined aquifer (JWRMS, 1994; Maathuis and Yong, 1994; Soefner et al., 1986). Moechtar et al. (2003) divided the deposits into three depositional environments, i.e., 1) onland deposits (paleochannel and floodbasin), 2) transition deposits (marsh), and 3) linierclastic deposits (beach-ridges-nearshore-offshore). The on land and linier clastic deposits characterized by coarse to fine grain materials, while the transition deposits is dominated by clay and organic materials. The thickness of the deposit filled the Jakarta basin is predicted up to 300 m (Geyh and Sofner, 1989). Assumed that the basin is only consist of Quaternary materials, micropaleontology analysis by Delinom et al. (2009) found that the basement depth only up to c.a. 200 meter below sea level (mbsl).

The aquifer configuration of Jakarta basin, firstly proposed by Soekardi (1982), consists of a relatively thin unconfined aquifer and three thick confined aquifers (Fig. 3). The bottom of the unconfined aquifer is up to 40 mbsl. The upper confined aquifer ranged from 40 to 140 mbsl, middle confined aquifer from 140 to 250 mbsl, and lower confined aquifer > 250 mbsl. Djaeni et al. (1986) predicted that the aquifer layer composed by sandy material is only thin, i.e., 1 to 5 m thick. The thin sandy layer intercalated by predominantly silt and clay materials. The hydraulic property of those layers, regionally, was considered homogeneous but anisotropic, hence grouped as an aquifer layer (Djaeni et al., 1986; Schmidt et al., 1988).

3. Hydrological database in Jakarta

Jakarta groundwater basin has been continuously managed for a long time, started by deep drilling in c.a. 1900's (Schmidt, 2004). However, excessive groundwater abstraction is considered started up in around 1950. Since then, the piezometric head of the confined aquifer drop gradually, and rapidly post 1970 (Djaeni et al., 1986). In 1900's the level of water head was reported at 5 to 15 m above sea level (masl) and close to 0 masl in 1970, dropped continually up to 10 to 30 mbsl in 1985. In spite of the effort in controlling groundwater abstraction, it seems that the drop of water level is still ongoing up to present, as indicated in several monitoring wells installed in Jakarta. For instances, monitoring wells of

Porisgaga recorded a water level at 18 mbsl in 1982 and dropped to 46 mbsl in 1994 for the upper confined aquifer (Fig. 4). Groundwater condition for middle confined aquifer indicated much better than the upper confined aquifer, in which monitoring wells for this aquifer at KBN Marunda (North Jakarta) showed that water level only dropped by c.a. 4 m during 2003 to 2013 (Tirtomihardjo and Setiawan, 2013).

Expansion of municipal water network coverage in Jakarta until 2017 indicated a slow progress or might be in a stagnant condition. Therefore, groundwater is still being use as the main source of water needs. Jakarta administration reported a total of 4144 active production wells in Jakarta that abstracted groundwater by c.a. 4,67 billion m^3 in a month (Fig. 5 and Table 1).

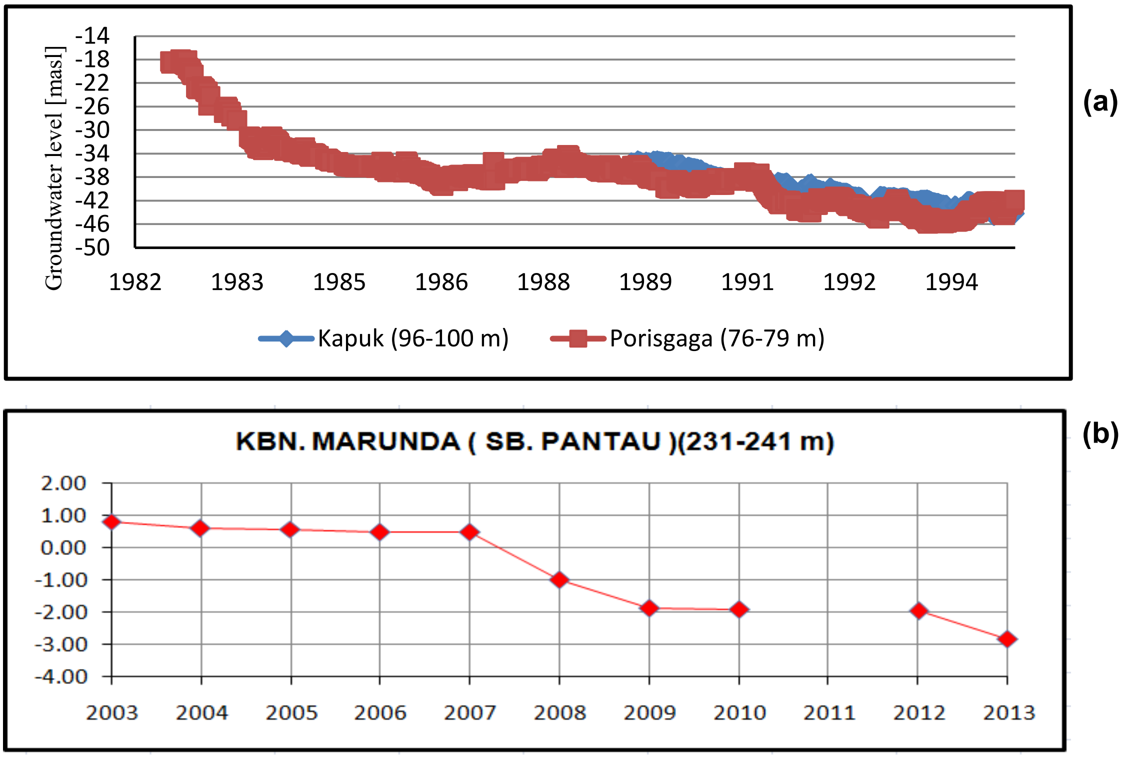


Fig. 4. a) Groundwater level of upper confined aquifer recorded from monitoring wells of Kapuk and Porisga. During 1980's water level dropped rapidly; b) Groundwater level of middle confined aquifer recorded from monitoring wells of KBN Marunda.

Table 1. Active deep wells and the production in Jakarta in 2017

Administration area	Active Deep Wells	Production (m^3/month)
North Jakarta	337	231,852
East Jakarta	842	637,160
Central Jakarta	625	322,987
South Jakarta	1630	2,471,079
West Jakarta	710	1,014,078
Total	**4144**	**4,677,156**

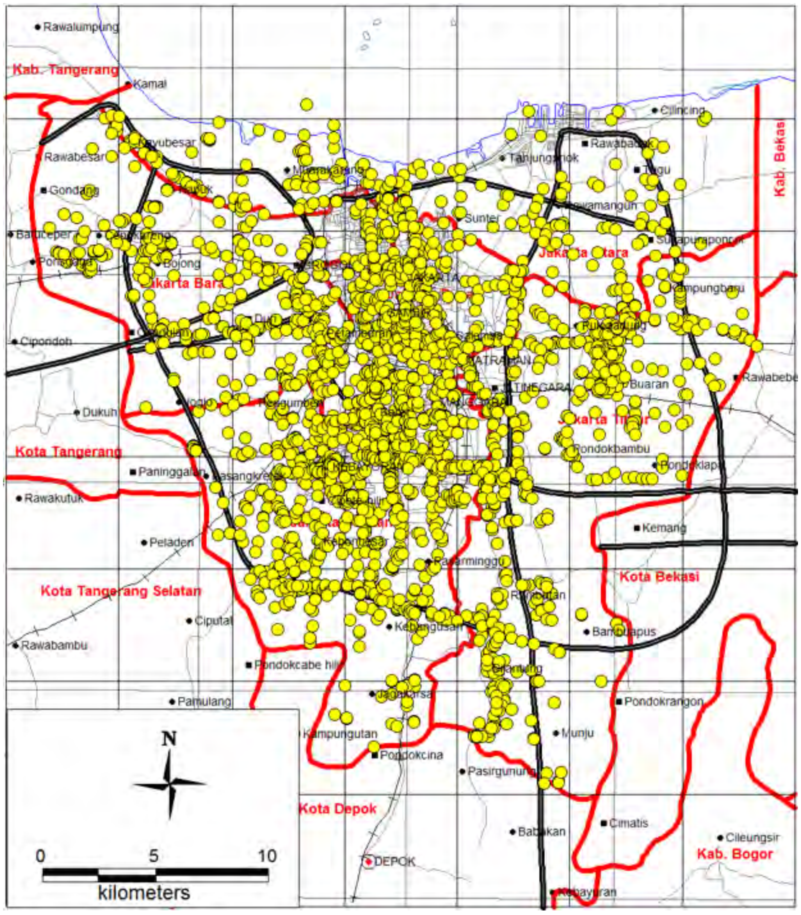


Fig. 5. Distribution of deep production wells in Jakarta

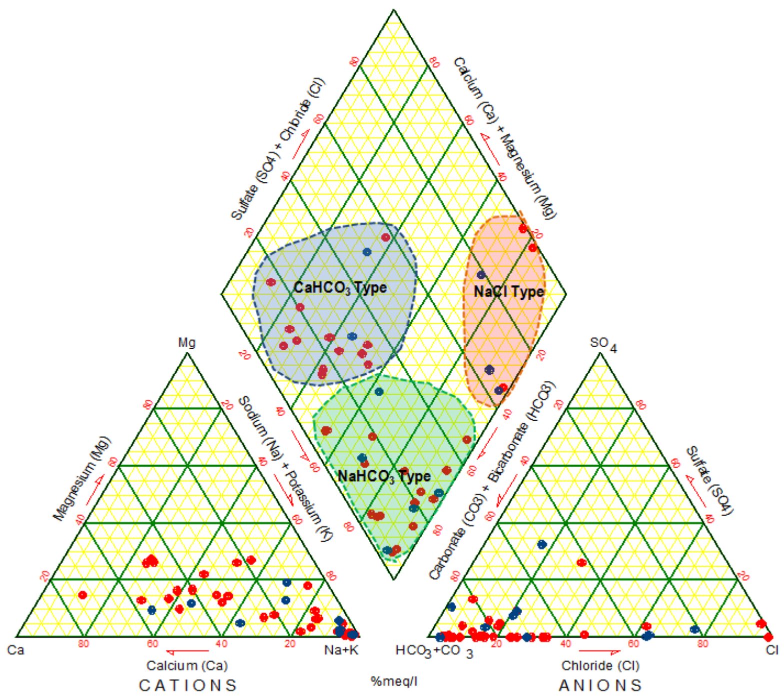


Fig. 6. Groundwater facies of the confined aquifer (Setiawan et al., 2014)

Groundwater quality in Jakarta basin is also monitored continually, considering that groundwater in the basin directly flowing to sea; hence over abstraction potentially induce seawater intrusion. Seawater intrusion in confined aquifer has been reported in 1979 by Hehanusa (Hehanusa, 1979), followed by Djaeni et al. (1986) that found the intrusion spread up to 6 km from coastline. Recent study, Setiawan et al. (2014) indicated that salty water in the upper confined aquifer distributed up to 3 km landward, and up to 9 km for middle and lower confined aquifers. Groundwater sampling campaign in 2017 also indicated that for the confined aquifer, $NaHCO_3$ groundwater has distributed far away to the land (Fig. 6).

Over abstraction of groundwater especially in North Jakarta has been considered triggering land subsidence; hence it has been continually monitored. Land subsidence is well correlated with groundwater abstraction, in which areas with highest level of groundwater drop, the ground level severe land subsidence. Measurement in 2017 noted the level of land subsidence up to 12 cm/annual in Muara Angke (Fig. 7).

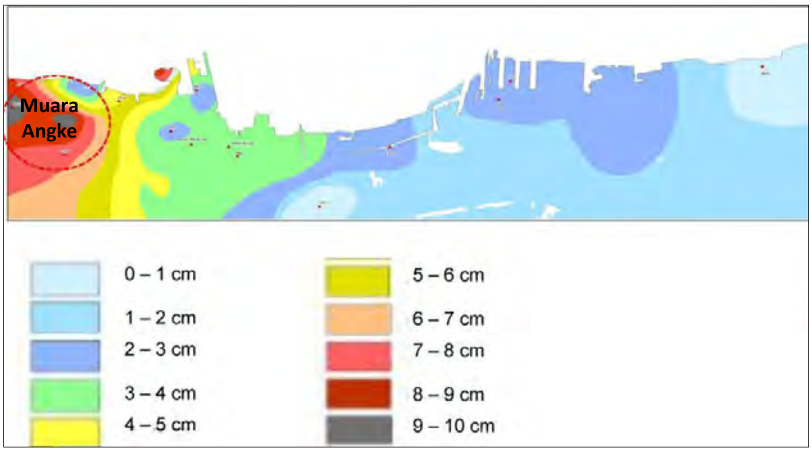


Fig. 7. The level of land subsidence in northern Jakarta

4. Groundwater Management in Jakarta

Jakarta groundwater basin is an inter-provincial basin, therefore by law the management responsibility is shared between central government (i.e. Geological Agency) and Administration of Jakarta province. Central government is responsible in establishing groundwater conservation map that will be used to issue technical recomendation. Based on this technical recommendation, provincial administration issues groundwater wells registration. Groundwater basin with excessive groundwater abstraction like Jakarta, conservation map is updated every 4-5 years. The last conservation map of Jakarta was published in 2013 (Fig. 8) and at the moment is on going progress to be updated. The map created based on the observation data from monitoring wells and routine sampling campaign. The later is still conducted due to insufficient number and distribution of the monitoring wells in Jakarta. Currrently, active monitoring wells in Jakarta are only 22 units. Therefore, in the upcoming years it is planned to install more monitoring wells, for example in 2018 will be installed 6 monitoring wells. In order to have a better monitoring system, at the moment is being design a master plan of monitoring wells in Jakarta. The strategic role of Jakarta and its complex groundwater management problem made the central goverment giving a special treatment to Jakarta basin by establishing an office located in Jakarta since 2013, called as Office of Groundwater Conservation, with a main task to estabished a well practice of groundwater conservation in Jakarta. Starting in this year, provincial governmet supported by Geological Agency is conducting an action against illegal wells, basically by using a simple method, calculating water balance in selected buildings.

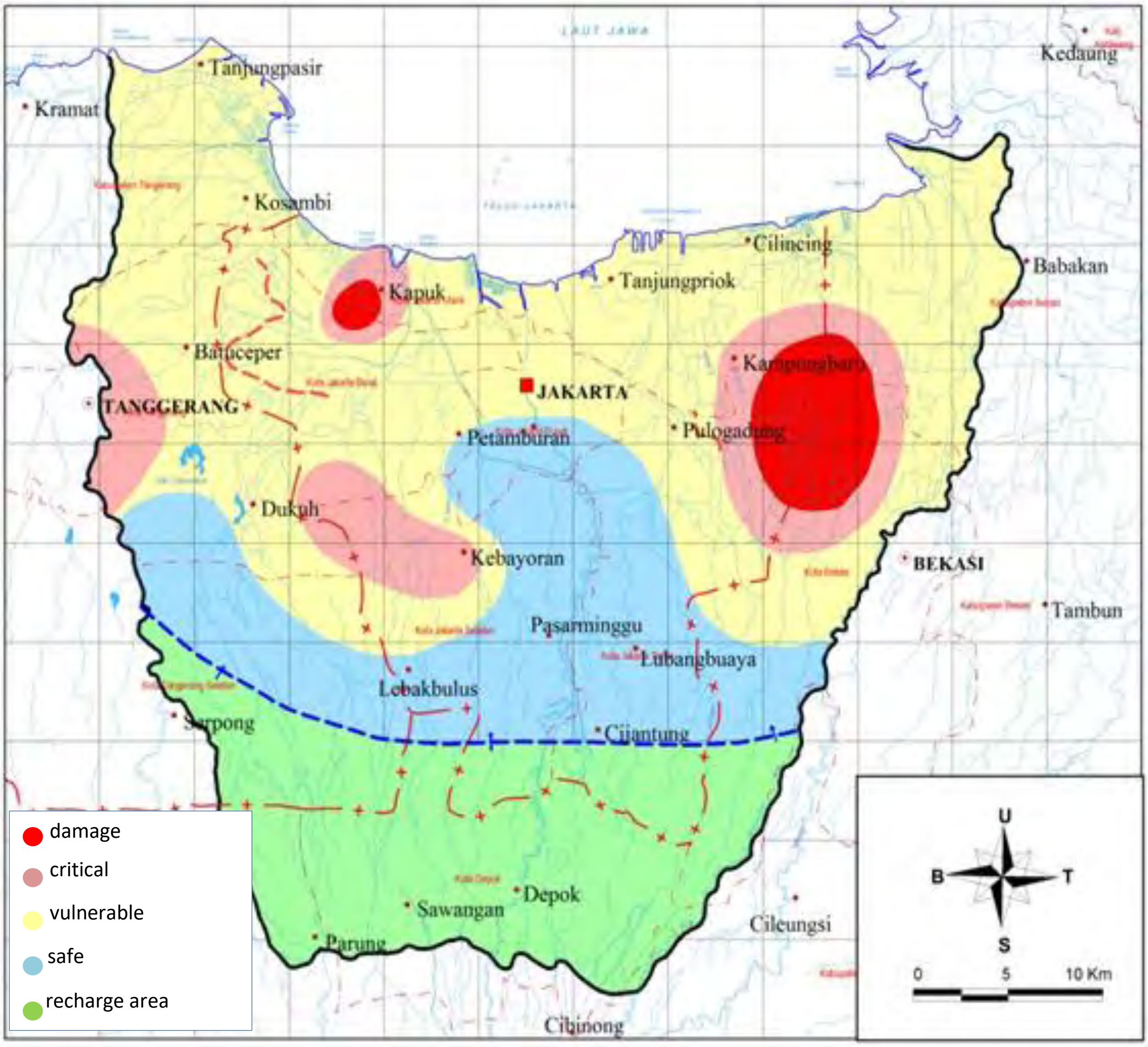


Fig. 8. Groundwater conservation map in Jakarta published in 2013

5. Conclusions

Several conclusions based on the data of groundwater condition and management in Jakarta are:

- Jakarta groundwater basin facing severe problem of over abstraction caused by insufficient municipal water network and illegal water wells,
- over abstraction of groundwater has induced further impact of land subsidence and seawater intrusion,
- routine observation of groundwater quantity and quality as well as its land subsidence impact is conducted to control further groundwater problem,
- management of groundwater in Jakarta is shared between central and provincial government. An action to control illegal wells is being conducted in this year.

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III-3-(3)
Groundwater Database -Kanto Plain, Japan-

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Abstract

Kanto Plain is the largest plain in Japan and there are many large cities such as Metropolis of Tokyo. Groundwater in the Kanto Plain has been used since 20^{th} century. There are some existing studies of groundwater flow system in the Kanto Plain, but all of studies is limited in the local parts of the Kanto Plain, not the whole area of it. The purpose of this study was to clarify the regional groundwater flow system of the Kanto plain from the distribution of hydraulic heads and subsurface temperature.

Keywords: Kanto Plain, groundwater, hydrogeological map, Japan

1. Introduction

One of the main tasks of the Groundwater Research Group, Geological Survey of Japan, AIST is to publish a series of hydro-environmental map. In this map series, we especially attempt to apply multi-tracer technique to analyze regional groundwater flow systems. The technique is based on the data combination of groundwater level, water chemistry (quality), stable isotopes and subsurface ground temperature as tracers. Although each tracer has both advantages and disadvantages in water flow analysis, application of multiple tracers may compensate disadvantages of each tracer.

Kanto Plain is the largest plain in Japan and there are many large cities such as Metropolis of Tokyo. Groundwater in the Kanto Plain has been used since 20th century. There are some studies of groundwater flow system in the Kanto Plain, but all of studies is limited in the local parts of the Kanto Plain, not the whole area of it. This report is based on previous studies (Miyakoshi et al., 2003; Geological Survey of Japan, AIST, 2005) that were conducted to clarify the regional groundwater flow system of the Kanto plain from the distribution of hydraulic heads and subsurface temperature.

2. Geology and Hydrogeology in Kanto Plain, Japan

The Kanto Plain is the largest plain in Japan (about 15,000 km^2, Fig. 1), and it is surrounded by the Tanzawa Mountains, the Kanto Mountains, the Ashio Mountains and the Yamizo Mountains. The topography of the plain is classified into three types, lowlands along the river, uplands and hills located in border of the plain. The Kanto plain consists of the sedimentary layers which is more than 3,000 m in thickness (Suzuki, 1996). The sedimentary layers are classified into three groups: Shimousa group, Kazusa group and Miura group. The Shimousa group and upper part of the Kazusa group are the most useful aquifer in the plain. It is difficult to delineate the boundary between the Shimousa group and the Kazusa group, using their geological feature (Suzuki, 1996).

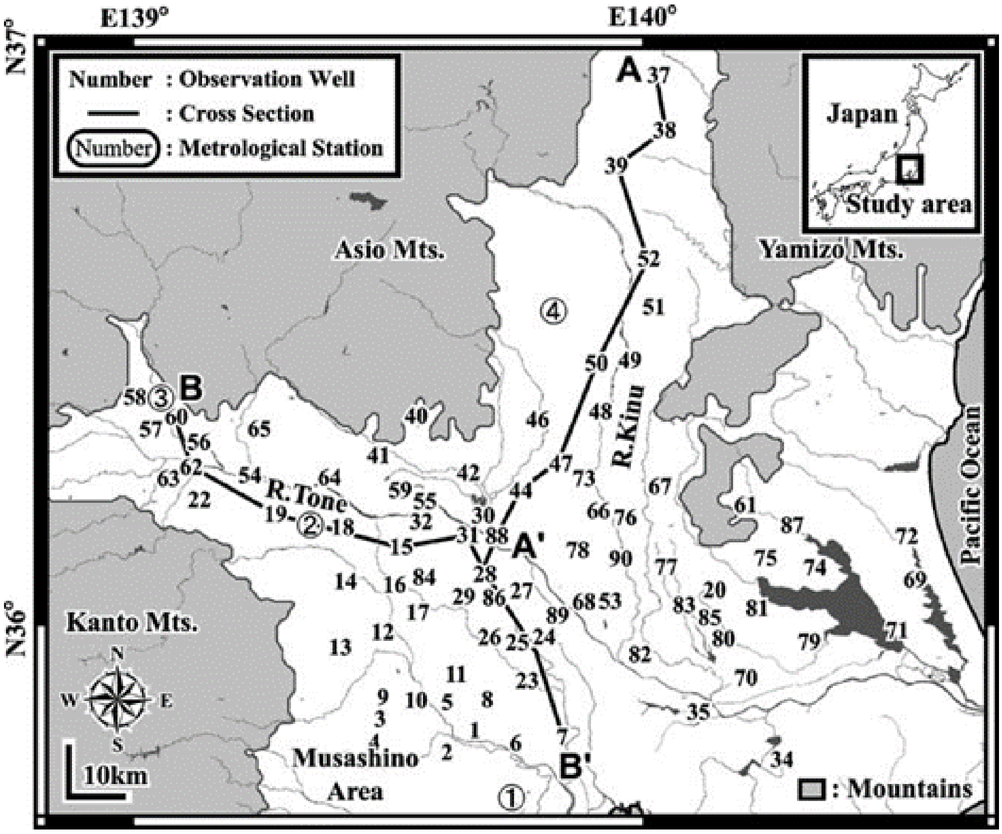

Fig. 1. Location Map of the study area and distribution of observation wells.

The average of geothermal gradient shows about 2.0-2.5 ℃/100 m in the plain, up to 300 m deep (maximum about 500 m deep), from the geothermal map of Japan (Yano et al., 1999).

3. Hydrological database in Kanto Plain

3.1. Groundwater flow system and their subsurface thermal regime

It is known that subsurface temperature distribution is generally affected not only by thermal conduction but also by advection owing to groundwater flow (Uchida et al., 2003). The effect of thermal advection is especially large in shallow sedimentary layer with high groundwater flux.

Groundwater temperature measured in an observation well is assumed to be identical to subsurface temperature, because there exists thermal equilibrium between the water in a borehole and its surrounding subsurface layers. Temperature profiles are one-dimensional sequential data arrays. Therefore, areally distributed temperature profiles provide three-dimensional subsurface information. Fig. 2 shows groundwater flow system and subsurface thermal regime (modified from Domenico and Palciauskas, 1973). If there is no groundwater flow or static groundwater condition (Fig.2a), subsurface thermal regime is governed only by thermal conduction and subsurface temperature gradient is constant (Fig. 2b). When a simple regional groundwater flow system due to topographic driving (Fig. 2c) is assumed, thermal regime will be disturbed by thermal advection owing to groundwater flow (Fig. 2d). In the groundwater recharge area, subsurface temperatures and gradients are lower

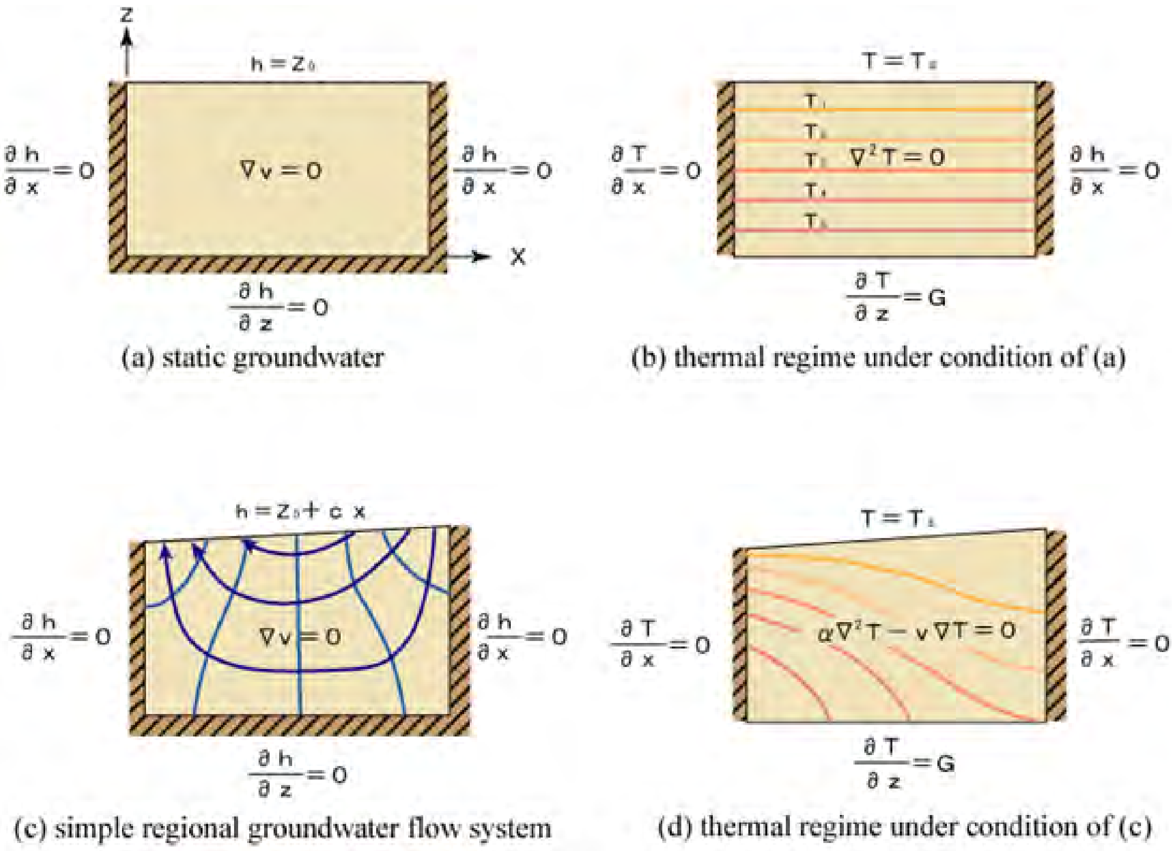

Fig. 2. Subsurface thermal regime affected by a groundwater flow system. (modified Domenico and Palciauskas, 1973). (a) static groundwater, (b) thermal regime under condition of (a), (c) simple regional groundwater flow system, (d) thermal regime under condition of (c)

than that of under static groundwater condition (Fig. 2b). In the discharge area, on the other hand, temperatures and gradients are larger than that of under static condition.

3.2. Measurement methods

In this study, subsurface temperature and hydraulic head were measured in observation wells used for monitoring groundwater level and ground subsidence. The depths of observation wells are between 30 and 600 m.

Measurements were carried out from October 14, 1999 to November 20, 2000. Subsurface temperature was measured with thermistor thermometer (resolution is 0.01 ℃). Temperature was measured every 2 m depth intervals up to 300 m depth, and measured every 5 m depth intervals for the depth deeper than 300 m. Well diameters are less than 20 cm (mostly about 15 cm). Taniguchi (1987) analyzed free thermal convection in wells and concluded that the temperature profile, which is measured in the wells, were stable and could represent the subsurface.

3.3 Observation Results

Fig. 3a and b show vertical 2-D distribution of hydraulic heads along the Kinu river (A–A') and the Tone river (B–B'), respectively. Hydraulic heads are high in the surroundings of the plain such as hills or highlands, and low in the lowlands which are located along the river. Hydraulic heads gradually decrease from highlands to lowlands. Especially, in the lowlands located in central part of the plain, hydraulic heads are anomalously low. There were a lot of

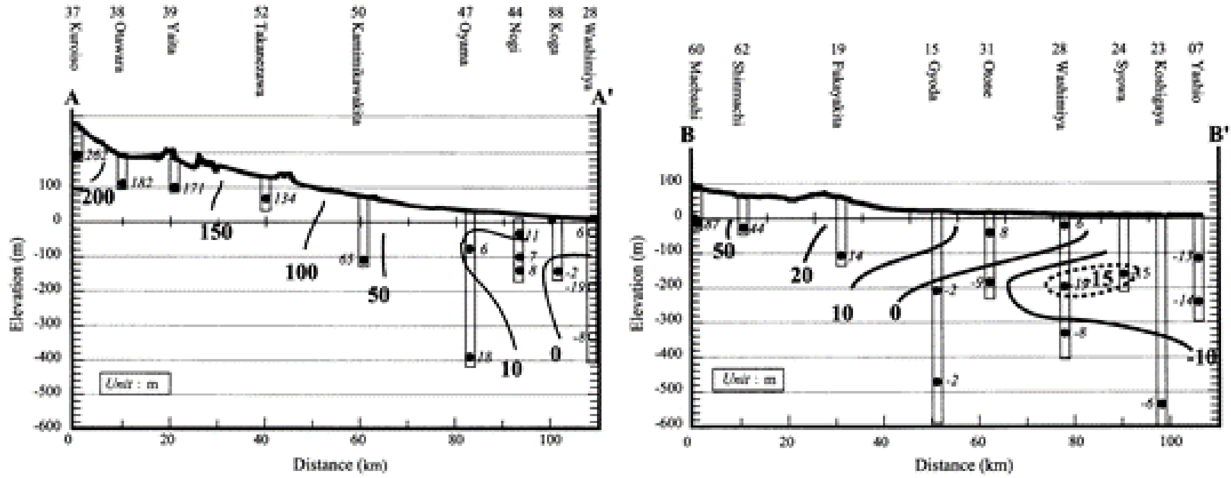

Fig. 3. Vertical distribution of hydraulic heads in cross section along (a) A–A', (b) B–B' in Fig. 1. Italic number shows the hydraulic head at the screen.

artesian wells in the central part of the plain before 1970 (Kino, 1970). At present, there are very few artesian wells in this area, because of effects of pumping (Tochigi Prefecture, Japan, 1999; Saitama Prefecture, Japan, 1999). These distributions show the existence of groundwater flow system. Groundwater gets recharged in hills and highlands and discharged at lowlands.

Fig. 4a and b show 2-D vertical distribution of subsurface temperature along same sections, respectively. Subsurface temperature is low in the surroundings of the plain such as hills and highlands, and high in lowlands.

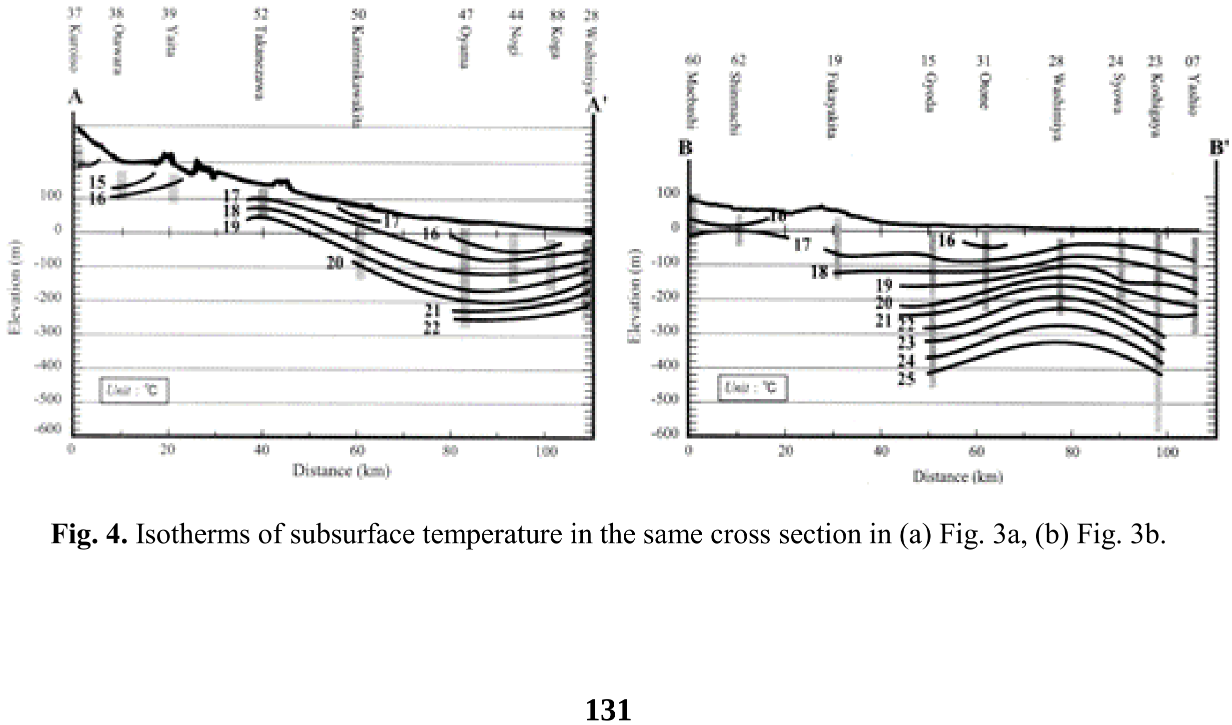

Fig. 4. Isotherms of subsurface temperature in the same cross section in (a) Fig. 3a, (b) Fig. 3b.

Fig. 5 shows horizontal distribution of subsurface temperature at an elevation of 50 m above sea level. Areas with high temperature are located on lowlands along the Tone River (about 18℃), the Kinu River (about 18 ℃) and the central part of the plain (17.0‐17.5 ℃). On the contrary, areas with relatively low temperature are located on hills and highlands that are high topographic areas (15.0‐16.5 ℃).

3.4. Discussion

Groundwater levels and temperature–depth profiles were measured at 88 observation wells in the Kanto Plain, East Japan. From observation results, subsurface temperature distribution in the Kanto Plain is assumed to be strongly affected by thermal advection due to groundwater flow, which has regional difference between high temperature area and low temperature area (Fig. 4 and Fig. 5). The high temperature area located in lowlands around the Kinu, Tone Rivers and central part of the Kanto Plain. The low temperature area, on the other hand, located in hills and highlands surrounding the Kanto Plain. Considering from observed distribution of hydraulic heads (Fig. 3a and 3b) and subsurface temperatures (Fig. 4a and 4b), two local groundwater flow systems which discharge to the Tone River in Gunma Prefecture and to the Kinu River in Tochigi Prefecture, and one regional groundwater flow system which recharges in the peripheral area of the plain and discharges to central part of the plain are estimated.

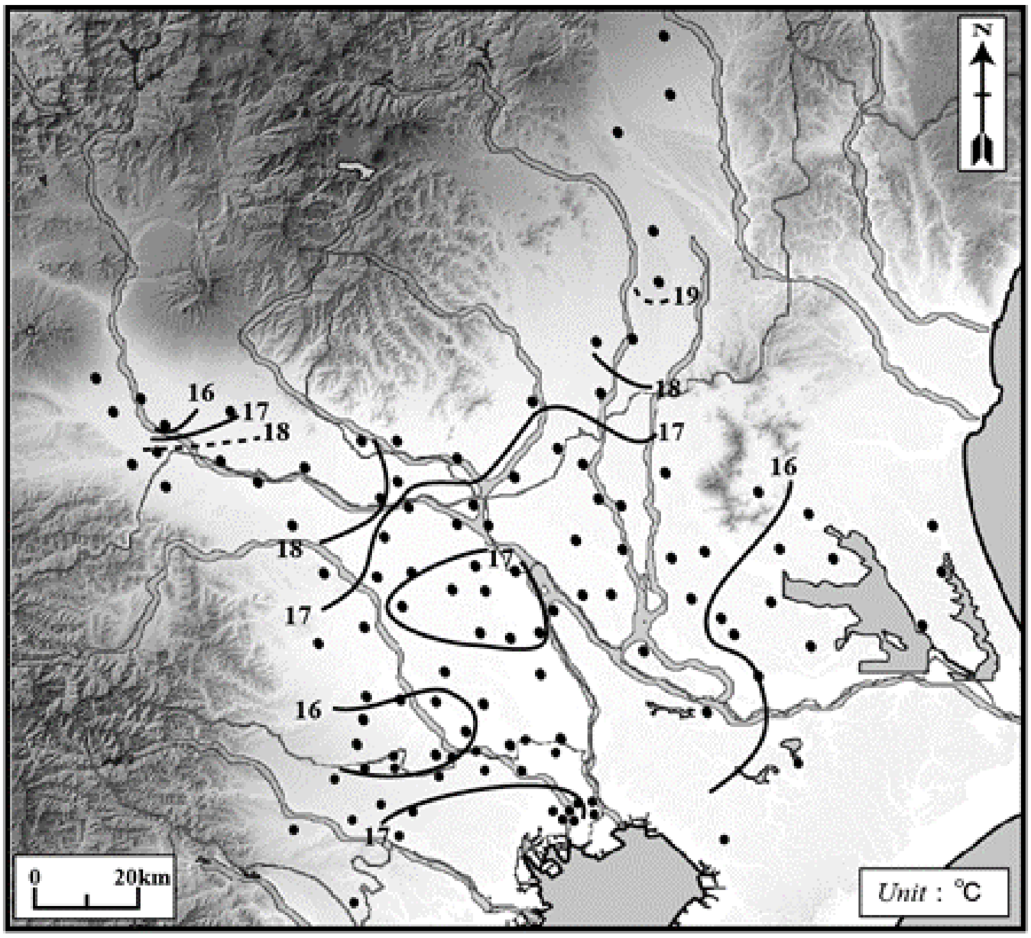

Fig. 5. Isotherms of subsurface temperature at 50 m below sea level.

4. Groundwater Management in Japan

Since late 19th century, Japan had been trying to accomplish economic growth, especially, in the field of industry and agriculture. The economic growth was mainly supported by groundwater. As the result of over pumping, groundwater level has gradually decreased and land subsidence has occurred in the main industrial regions such as Tokyo and Osaka. During the World War II, groundwater level rapidly recovered and land subsidence temporarily stopped due to decrease of groundwater withdrawal.

After the war, economy of Japan grew remarkably and groundwater was withdrawn improperly. The newly constructed industries along the seaside needed groundwater in large amount and withdrawn it more than recharge. Severe land subsidence and sea water intrusion occurred in almost all the seaside industrial regions in Japan as shown in Fig.6.

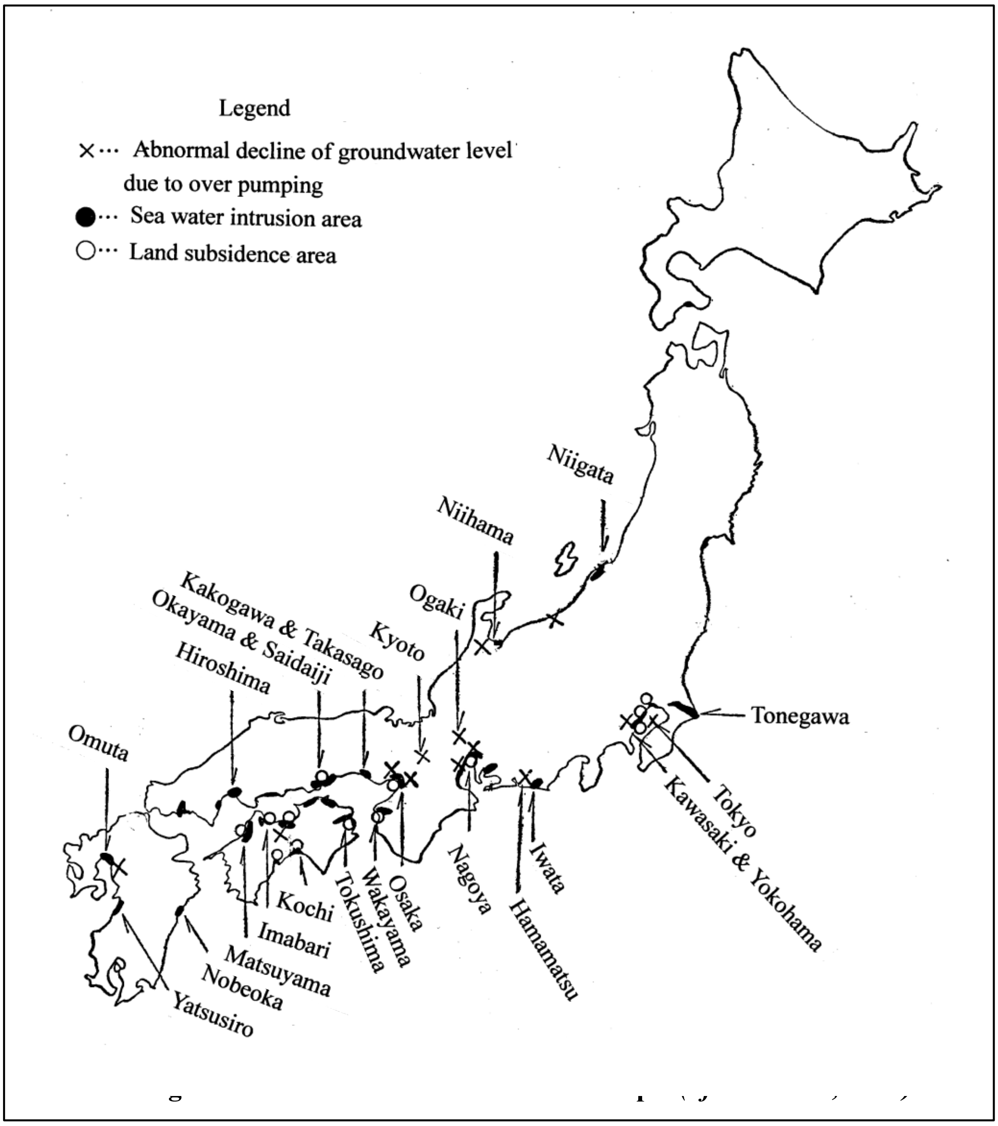

Fig. 6. Groundwater issues in 1960 in Japan (after Kurata, 1960)

Japan has two main laws for preventive action of the groundwater pollution. A large amount of groundwater was used for industry and agriculture in Japan from the 1950s to the 1970s, causing declines in hydraulic head and land subsidence. Japanese government made "Industrial Water Law" since 1956 to prevent land subsidence owing to groundwater pumping. The other law is "Water Pollution Control Law" to prevent intrusion of waste water on the groundwater made in 1971.

Local governments, moreover, has set on some regulations to prevent land subsidence and groundwater pollution. According to the acts, most factories in such a region have changed water supply from groundwater to surface water. In consequence, groundwater level has gradually recovered and land subsidence has stopped along seaside after late 1970's.

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III-3-(4)
Groundwater Monitoring data from bedrock aquifer in Korea

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Abstract

The groundwater quality data used in this study is based on the data from 221 national groundwater networks in 2008 (Kim, 2013). And, groundwater levels, temperatures and ECs were presented from the published national groundwater monitoring annual reports. Groundwater level, temperature, and EC data are closely related to the topography and various factors such as precipitation, seawater intrusion, and contamination. Based on groundwater monitoring data, systematic and scientific groundwater management, development and utilization will be possible, and researches have also been made on the relationship between geology, hydrogeological units and groundwater resources in Korea.

Keywords: groundwater, monitoring, level, temperature, EC, hydrogeological unit, Korea

1. Introduction

Geologically, Korea is comprised mainly of Precambrian gneiss and Jurassic granite in the middle area and Cretaceous sedimentary rocks in the southern part. Quaternary alluvial deposits with high permeability and high groundwater yield (up to 800 m^3/day) are mostly found along large rivers including the Han-gang, Nakdong-gang, Yeongsan/Seomjin-gang rivers. Therefore, the development of high production aquifers is limited to low plains in the west coastal areas where most of the rice paddies are distributed and the Jeju volcanic island where groundwater is the sole water resource. Because most of the country is covered by a thin (~5 m) unconsolidated sediment or soil, dominant aquifers are bedrock aquifers particularly in the hills and low relief mountainous areas with their lateral extension being limited (Lee and Kwon, 2016).

Korea government (Ministry of Land and Transport) has installed the National Groundwater Monitoring Network (NGMN) to observe the nation's overall groundwater levels and water qualities. As of 2017, there are 402 monitoring sites, containing 167 alluvial aquifer wells and 402 bedrock aquifer wells nationwide. The purpose of this study is to investigate the groundwater quality and the groundwater level distribution in bedrock aquifer from the NGWN. The data were obtained from the National Groundwater Information Center (www.gims.go.kr) and the national groundwater annual reports (2015-2017).

2. Hydrogeological units

The aquifers are divided into 8 hydrogeological units: metamorphic rock, limestone, clastic sedimentary rock, intrusive igneous rock, non-porous volcanic rock, semi-consolidated sedimentary rock, porous volcanic rock, and unconsolidated sediment. Alluvial aquifers are composed of unconsolidated sediments, and are widely distributed within large river basins such as the Han-gang and Nakdong-gang rivers (MCT and K-water, 2006). Generally, the water level in unconsolidated sediments is high and close to the ground surface, which results in the direct influence of pollution due to rapid penetration of polluted surface water and surface runoff. Metamorphic rocks and intrusive rocks account for about 60 % of the total. The relationship between hydrogeological units and groundwater quality, or between geology and groundwater quality, is under continuous investigations and researches.

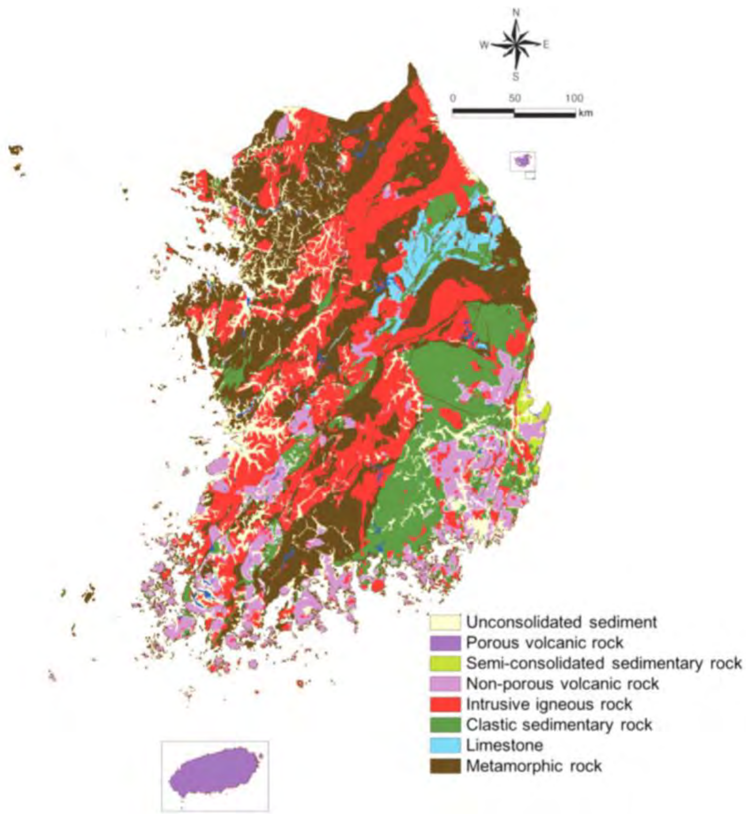

Fig. 1. Hydrogeological units in Korea

3. Korean groundwater database in GSi system

3.1 Groundwater monitoring locations

As mentioned before, the groundwater used in this study is based on the water quality data from 221 National Groundwater Networks in 2008 (Kim, 2013). The database includes the concentrations of major cations, anions in groundwater, and groundwater levels, temperature and electrical conductivities, including the location, depth and altitude of the stations.

The national groundwater monitoring networks in Korea have been operated with an automatic measuring and data transfer system. The groundwater level, temperature, and EC are automatically collected at a certain time interval, and stored in a central database server (www.gims.go.kr). In addition, the data is published as an annual report at the end of the year through the complete reviews. The data presented in the database are the groundwater data in bedrock aquifer extracted from the annual reports. The 2,014 data are the annual mean, maximum and minimum values for groundwater level at each station. 2015 and 2016 data additionally contain temperature and EC data. But, there are no oxygen and hydrogen isotope data and temperature profile data at each station.

The monitoring stations are distributed all over the country including Jeju Island. The monitoring networks are operated under major watershed regions, which are the Han-gang, Nakdong-gang, Geum-gang, Youngsan-gang/Seomjin-gang. The altitudes of the stations are minimum 3.5 m (EL.), maximum 986.5 m (EL.), and average 101.2 m (EL.). The well depths are minimum 17.0 m, maximum 490.0 m and average 75.6 m. The wells with more than 400 m located in Jeju Island, which are deep wells in the mountainous areas in order to observe the groundwater levels around seawater level.

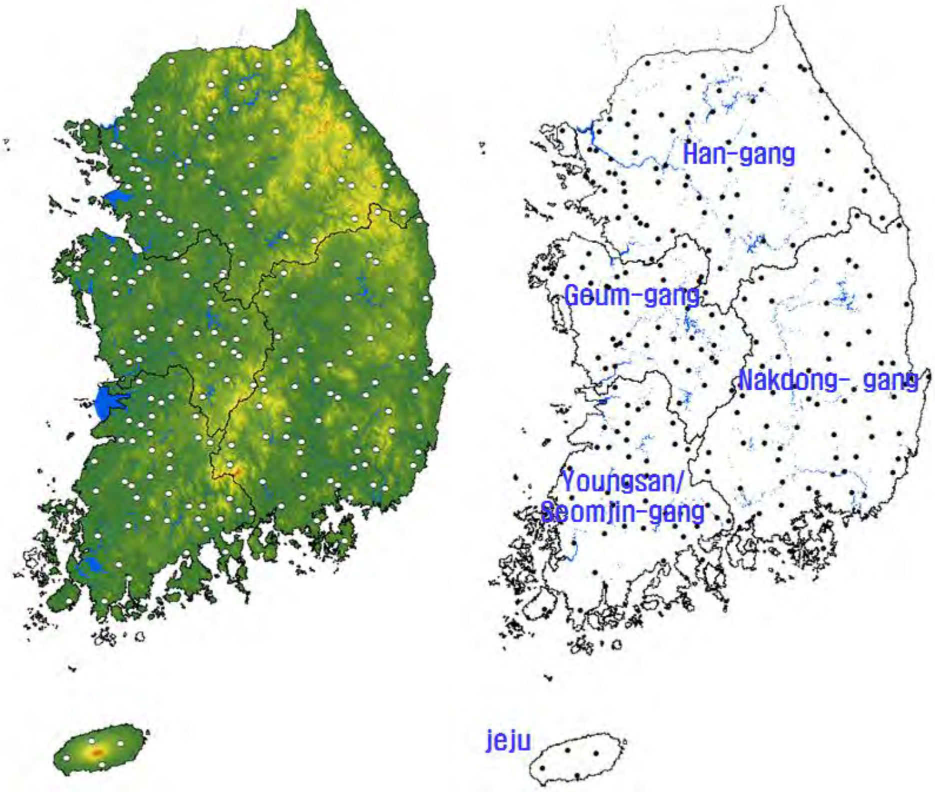

Fig. 2. The groundwater monitoring well location

3.2 Data structure and explanation

The Excel file has a total of 50 fields. Column A and B have serial numbers and well IDs in order, and column C and D indicate latitude and longitude. Column E shows the altitude, column F is for the well depth, and column G for electrical conductivity (EC) is empty in this field, because there are data from the column AM to the column AO, from the column AV to the column AX. From the column H to the column AC, the 22 columns show dissolved major components in groundwater at each well. No data are the isotope contents in the column I, column J, and NH_4 in the column Q, Li in the column V, NO_2 in the column W, PO_4 in the column X.

From the AD to the AF column, the groundwater levels in 2014 are shown as average, maximum and minimum values. The groundwater level, temperature, and EC from the AG to the AO column are shown as average, maximum, and minimum values, respectively. And, the groundwater level, temperature, and EC of the year 2016 are expressed as average, maximum, and minimum values from the AP to the AX column. The groundwater level fluctuates yearly and the maximum, minimum, and average values can be found from the groundwater level graph. The data are one-day based, which are averaged from the hourly data at each well.

	A	AD	AE	AF	AG	AH	AI
1	No.	2014_GW(EL.m)_ave	2014_GW(EL.m)_max	2014_GW(EL.m)_min	2015_GW(EL.m)_ave	2015_GW(EL.m)_max	2015_GW(EL.m)_min
2	1	58.34	59.04	58.12	58.38	59.34	58.13
3	2	109.68	109.99	109.44	109.54	109.84	109.36
4	3	135.85	137.22	135.64	135.86	137.42	135.63
5	4	51.12	51.83	50.39	50.48	51.19	49.8

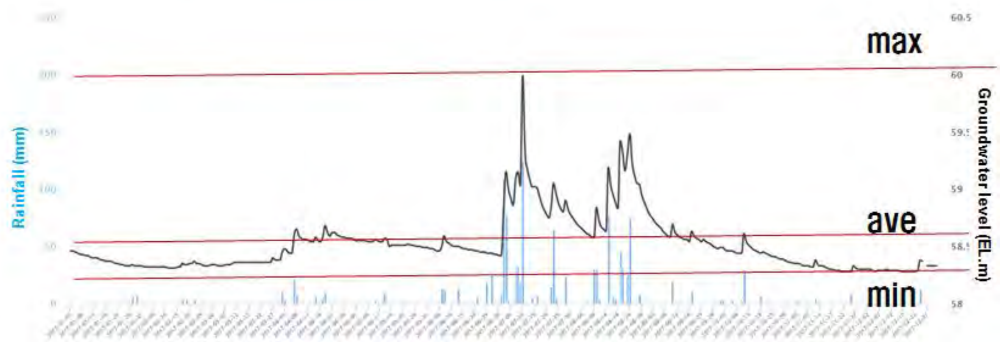

Fig. 3. Data descriptions

The annual groundwater level is -7.0 ~ 970.7 m in 2014 with an average of 91.0 m. In 2015, the annual groundwater level is -7.3 ~ 970.7 m with an average of 90.9 m, and -6.1 ~ 970.8 m with an average of 91.0 m in 2016. The spatial groundwater levels tend to follow the terrain, and the groundwater levels are high in the eastern and central parts of the Korean peninsula.

The annual groundwater temperature is 9.5 ~ 20.8 °C in 2015 with an average of 14.5 °C. In 2016, the annual groundwater temperature is 9.6 ~ 20.9 °C with an average of 14.6 °C. The average temperature of groundwater in Korea is about 14.5 °C, showing a high trend in the southeast and a low trend in the northeast. Similarly, there is some correlations with the terrain.

The annual groundwater EC is 32.0 ~ 30,176 µS/cm in 2015 with an average of 552.4 µS/cm. In 2016, the annual groundwater EC is 34.0 ~ 29,580 µS/cm with an average of 579.6 µS/cm. EC of groundwater is formed high around the eastern and western coasts. Higher ECs in the southeastern part of the country and in some areas may also indicate groundwater contamination.

In addition, Total Dissolved Solid (TDS) is correlated with EC, which is highly distributed in the eastern and southern coastal areas and in some inland areas. The correlation equation between TDS and EC is TDS = 0.708 EC+35.896 (R^2=0.76). Nitrate is one of the most frequently mentioned content among the groundwater quality problem in Korea, and it indicates groundwater pollution by human activities, mainly from agricultural activities. The drinking water quality standard for NO3-N in Korea is 10 mg/L, which is about 44 mg/L in terms of nitrate concentration.

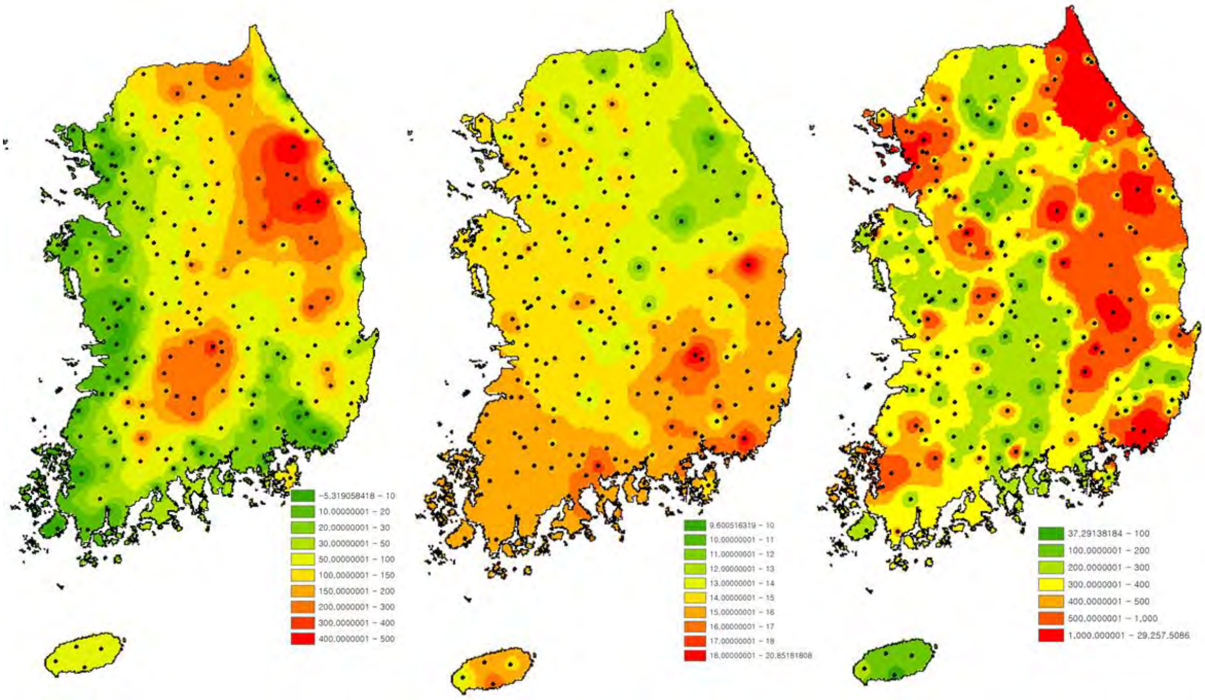

Fig. 4. Distribution of the average groundwater level (left), temperature (middle), and electrical conductivity (right) in 2016

4. Groundwater management in Korea

In 1996, the Groundwater Act was implemented, in which it was declared that groundwater is a public, not private asset, and the government should take an obligation to protect and conserve national groundwater resources. Complying with this law, the national groundwater monitoring network (NGMN), the groundwater quality monitoring network (GQMN), and the local groundwater monitoring network (LGMN) were established to examine any changes in groundwater quantity and quality across the country. In addition, the Korean government (Ministry of Environment) has invested a substantial research fund towards developing effective and efficient monitoring and remediation technologies for contaminated groundwater since 2008.

Groundwater in Korea is regulated by multiple subdivided laws, each law with its own distinct purpose. Because of this mission-based subdivision, one groundwater source is often managed by several laws and authorities. Complementary approaches between different authorities are expected in water management, but the subdivided laws indeed complicate comprehensive groundwater management. A comprehensive law that integrates all groundwater affairs has long been requested but to date, it has not been established (Lee and Kwon, 2016).

The primary law controlling groundwater affairs is the Groundwater Act, which was implemented in late 1993. This law embodies many duties and rights of the central and local governments and the public to secure groundwater resources. According to Article 5 of the Act, the Ministry of Land and Transport (MLT) conducts a basic investigation regarding the reserve characteristics and the available volume of groundwater throughout the country.

Complying with this article, the K-water, a governmental agency operated by the MLT, has conducted groundwater investigations from 1997 and evaluated 52 % of the total area of the nation as of 2012. Hydrogeological maps (groundwater atlas) have been produced at city and county scales. Article 6 obliges the MLT to establish a comprehensive groundwater management plan. The national plan designs general management strategies for groundwater preservation and quality conservation and characterizes the reserves and amount of exploitable groundwater as well as the conditions for groundwater utilization. This plan is renewed every 10 years, and was first established in 1996 in order to reflect the changes in hydrological and societal conditions. Local governments also establish their own groundwater management plans. With the increasing trends in groundwater use, various problems have been encountered including significant decline in the groundwater level, groundwater contamination by chlorinated solvents and petroleum hydrocarbons, and land subsidence. To address these problems, the Korean government implemented laws and regulations which oblige the government ministries to monitor groundwater quantity and quality.

When groundwater is used for drinking water, the Drinking Water Management Act applies under the authority of the Ministry of Environment (ME). The Act addresses the management of natural water used for drinking purpose, treated tap water, drinking spring water (bottled groundwater), drinking saline water, and drinking deep sea water. When groundwater is developed for commercial bottled water, a strict environmental impact assessment is required. This law also requires the private enterprises abstracting groundwater and selling bottled groundwater to regularly monitor the groundwater level and its quality, and to report the monitoring data to the environmental authority.

Groundwater use in agriculture is guided by the Rearrangement of Agricultural and Fishing Villages Act. This law obliges the Ministry of Agriculture, Food, and Rural Affairs (MAFRA) to establish management plans for sustainable agricultural groundwater. The Korea Rural Community Corporation, a governmental agency under the supervision of MAFRA, also operates the Seawater Intrusion Monitoring Network (SIMN) complying with the enforcement of the law to protect rice paddies in coastal areas from seawater intrusion. On the other hand, the groundwater and related facilities used in military operations are regulated by the Act on National Defense and Military Installations Projects. The jurisdiction authority is the Ministry of National Defense. The groundwater facilities (wells) prepared for national emergencies (war, disasters, etc.) are managed by the Ministry of Public Safety and Security following the Framework Act on Civil Defense.

The Hot Spring Act controls groundwater with temperature over 25 °C. The Act strictly regulates the development of hot spring water. However, drastic decline of groundwater level, water depletion, and water contamination are often reported mainly due to injudicious exploitation of deeper water in the current absence of regulation about tapping depths for the wells.

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III-3-(5)

Hydrogeology and Groundwater Development of Sebatik Island, Malaysia-Indonesia

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Abstract

Under the Scientific and Technical Co-operation Programme in The Field of Geology and Mineral Resources Between the Department of Mineral and Geoscience Malaysia and the Geological Agency of Indonesia, all available hydrogeological data of Sebatik Island was compiled and interpreted. The island with 450 km² in size; separated from mainland Borneo with an approximately 7 km in distance from Tawau, Malaysia and around 15 km from Nunukan Province, Indonesia; has a moderate fresh water aquifer that can be developed. Hydrogeological analysis data within the alluvium area from Malaysia and hard rock from Indonesia showed that currently about 700 m³/day of groundwater can be abstract in the island to fulfil 3800 people needs for water.

Keywords: Groundwater transboudary, Sebatik Island, MALINDO

1. Introduction

The Department of Minerals and Geoscience Malaysia (JMG) together with the Geological Agency of Indonesia (GAI) had carried out a joint research on the Hydrogeology of Sebatik Island in conjunction of the scientific and technical cooperation between the Government of Malaysia and the Government of Indonesia in the field of geology and mineral resources. These joint research were carried out from year 2010 to year 2015 and numerous numbers of joint fieldworks were conducted respectively. This joint report described the hydrogeology of Sebatik Island based on the published and collected field data by the respectively countries.

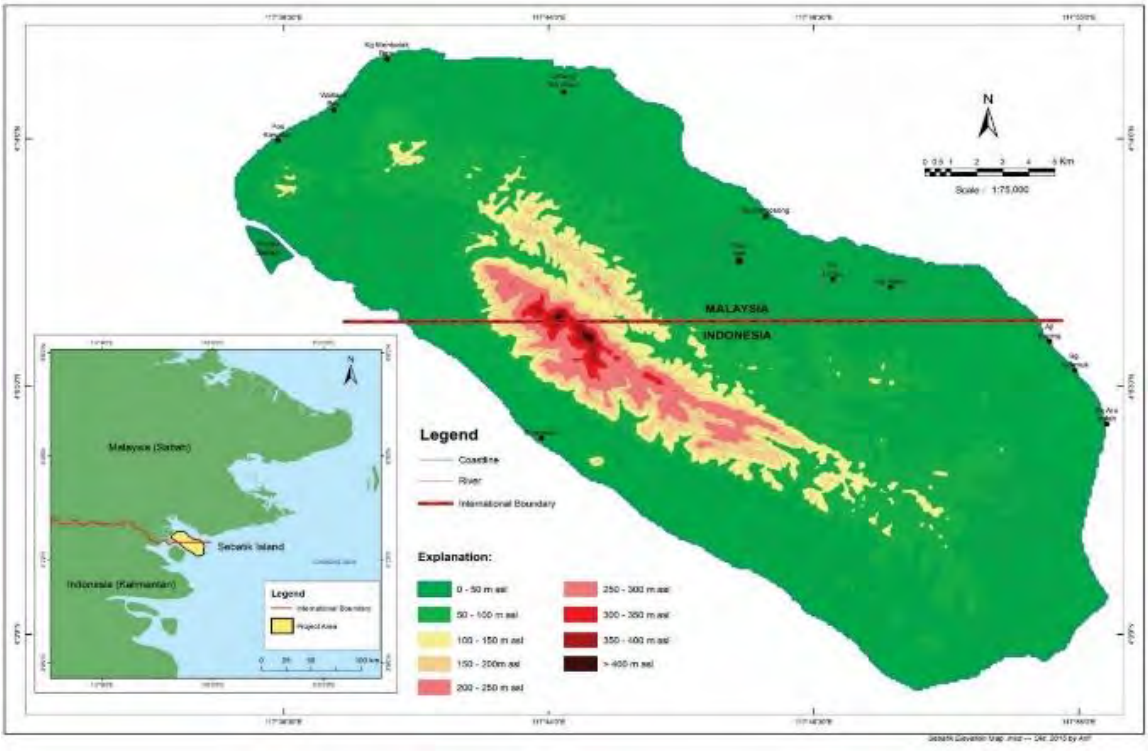

Fig. 1. Location of the study area

The study area lies in the eastern coast of Sabah and Kalimantan. It is approximately bounded by latitudes 4°03'N and 4°15'N and longitudes 117°38'E and 117°55'E (Fig. 1). Sebatik Island occupies the east part of Sabah and Kalimantan which is surrounded by the Celebes Sea. The total land area is approximately 450 km^2 with two main administrative countries, Malaysia in the north and Indonesia in the south.

The aimed of the study is to compile the hydrogeological information in order to enhance the knowledge for better understanding on the current hydrogeological condition of the Sebatik Island. Both countries will have better groundwater database information on the Sebatik Island and jointly established the Hydrogeological Map of Island which subsequently will provide better groundwater management and development.

2. Geology and Hydrogeology of Sebatik Island

Geology

In 2012-2013, a detailed study on lithological formation of Sebatik Island was jointly conducted within the Technical Working Group 1 (TWG1) and they concluded the lithological formation in Sebatik Island into four main units; (a) *Sandy Alternation*, (b) *Shaly Alternation*, (c) *Sandy Cross-bedded* and (d) *Alluvium* (Fig. 2 and Fig. 3). The environment of deposition of the lithological units in Sebatik Island was apparently deposited in shallow water, with brackish deltaic conditions.

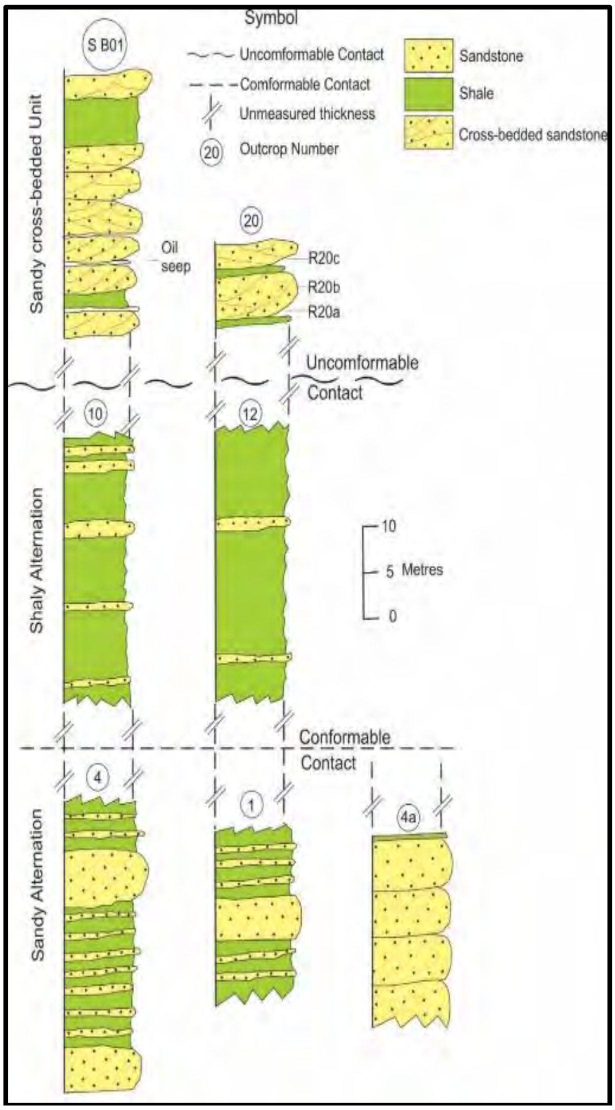

Fig. 2. Typical stratigraphic sequences of the Sebatik Island correlate by TWG1

(a) ***The Sandy Alternation Unit*** is characterised by mainly hard thick bed sandstone with thin bed of shale (Photo 1). It forms the core of the Sebatik Anticline; the sandstone sometimes more than 1 m thick with fine to medium grained shale in minor amount. The sandstone beds generally steeply dipping in range of 50^o-80^o. In places, thick beds of sandstone show graded bedding.

(b) ***The Shaly Alternation Unit*** is immediately overlying the Sandy Alternation Unit. It covers the areas of lowland and undulating ground. It is made up mainly of shale beds, but in places there are beds showing equivalent amount of shale/sandstone. The beds are quite gently dipping (approximately 30^o) towards the coastal region, away from the anticlinal core. In places, predominantly thick shaly sequence with very thin layer of sandstone were also observed in field (Photo 2).

(c) ***The Sandy Cross Bedded Unit*** is characterised by low angle cross-bedded sandstone interbedded with shale and claystone (Photo 3) which occupies the gentle or flat land. The occurrence of shallow marine fossils is common within this unit and most of the sandstone is friable. This unit is observed overlying the Shale Alternation unit unconformally.

(d) ***Alluvium unit*** is mostly formed by unconsolidated to semi-consolidated sedimentary unit comprising of silt, mud, sand and peat. The Alluvium unit occupies most of the beach, river bed and swamp area; the lower ground (coastal area and low valleys).

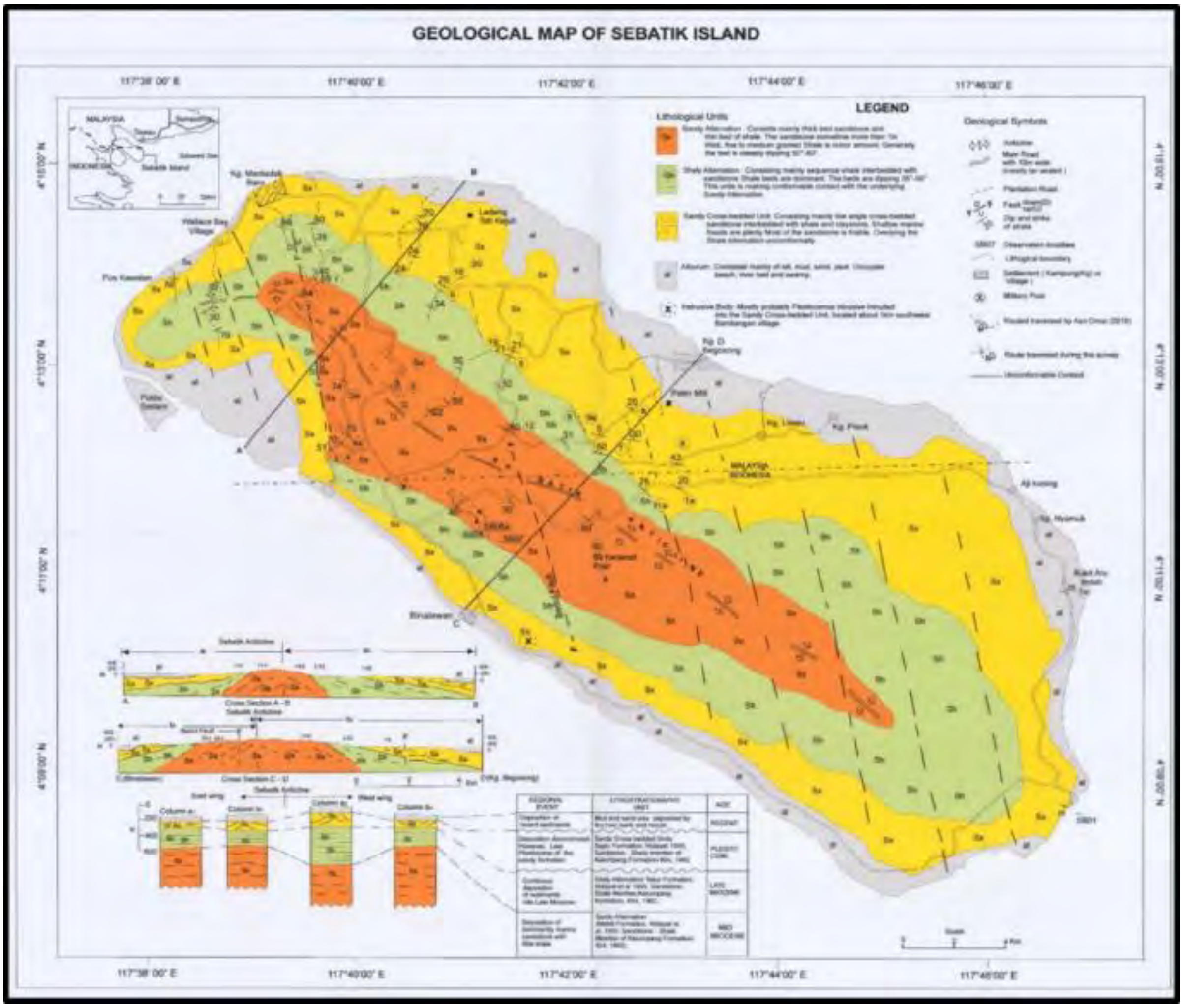

Fig. 3. Geological map of Sebatik Island (Source: TWG1)

Photo 1. Sandy Alternation Unit; consists mainly thick bed sandstone and thin bed of shale

Photo 2. Shaly Alternation Unit; consisting mainly shale sequence interbedded with thin bed of sandstone

Photo 3. Sandy Cross-bedded Unit; consisting mainly low angle cross-bedded sandstone interbedded with shale

Hydrogeology

Sebatik Island underlain by several rock types, which can be classified into two main hydro-lithology characteristic that is unconsolidated rock and consolidated rock. The unconsolidated rock generally composes of mixture of fine to coarse grain of clay-silt and sand. Most of the unconsolidated rock; high porosity and hydraulic conductivity, can be classified as aquifer. In some cases, consolidated rock also can be classified as aquifer if fractures and joints were found within the layer. As described in Table 1, igneous rock (andesite) is classified as aquifug which cannot store or allow groundwater seeping within the layer except fracture zone were found within it. The Sandy Alternation Unit and Shaly Alternation Unit (formerly known as Meliat Formation and Tabul Formation respectively) can be classified as aquitard or non-aquifer, where the porosity and hydraulic conductivity of the rock formations are assumable lower than the Sandy Cross-bedded Unit. Therefore, the Sandy Cross-bedded Unit (formerly known as Sajau Formation) is classified as the best aquifer in Sebatik Island.

Table 1. Relation of lithostratigraphic and hydrostratigraphic unit (Agus, 2011)

<table>
<tr><th>Period</th><th colspan="2">Epoch</th><th colspan="2">Lithostratigraphic Unit</th><th colspan="2">Hydrostratigraphic Unit</th></tr>
<tr><td rowspan="4">Quarterly</td><td colspan="2">Holocene</td><td colspan="2">Alluvium (Qa): mud, silt, sand, gravel, coral.</td><td colspan="2">Mud, silt, sand, gravel, coral (Aquifer)</td></tr>
<tr><td rowspan="3">Pleistocene</td><td>Late</td><td rowspan="4">Sandy Cross-Bedded Unit: consist mainly low angle cross-bedded sandstone interbedded with shale and claystone.</td><td rowspan="4">Plug and dyke andesite (Qpia)</td><td rowspan="4">Quartz sandstone, claystone, siltstone, coal, lignite and conglomerate (Aquifer)</td><td rowspan="4">Andesite (Aquifug)</td></tr>
<tr><td>Middle</td></tr>
<tr><td>Early</td></tr>
<tr><td rowspan="4">Tertiary</td><td colspan="2">Pliocene</td></tr>
<tr><td rowspan="3">Miocene</td><td>Late</td><td colspan="2">Shaly Alternation Unit: consist mainly sequence of shale interbedded with sandstone. Shale beds are dominant. Beds dipping 35°-50°.</td><td colspan="2" rowspan="2">Sandstone, claystone, mudstone, shale and coal (Aquitard)</td></tr>
<tr><td>Middle</td><td colspan="2">Sandy Alternation Unit: Consist mainly thick bed sandstone and thin bed of shale. Beds dipping steeply 50°-80°.</td></tr>
<tr><td>Early</td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

Based on the lithological unit and groundwater flow system, the aquifer in Sebatik Island can be divided into three systems (Agus, 2011) namely;

i) Intergranular Flow Aquifer System

Most of the alluvium area in Sebatik Island is best known as the intergranular flow aquifer system which consists of low hydraulic conductivity of fine materials and moderate permeability of medium coarse grained materials such as sand-gravel. The system consists of unconsolidated to semi consolidated materials. This aquifer system occupies the coastal area such as Kg. Aji Kuning, Kg. Sungai Nyamuk, Kg. Bergosong, Kg.Mentadak Baru and some area in the south-southwestern area.

ii) Fissures and Interstices Flow Aquifer System

This aquifer system is commonly found in Sandy Cross Bedded Unit (Photo 3) which consists of consolidated and semi-consolidated materials with low to moderate hydraulic conductivity. This aquifer system occupies most of the northeastern to southeastern part of Sebatik Island such as Kg. Mendatak Baru, Kg. Limau, Sg. Lemo, Sinjai and Kg. Bajo, as well as around the western part of Sebatik Island such as Kg. Bambangan, Kg. Binalawan and Kg. Setabu.

iii) Fissure or Fracture Flow Aquifer System

The fissure-fracture flow aquifer system is commonly found in the Sandy Alternation Unit and Shaly Alternation Unit which composed mainly consolidated materials. This aquifer system has a low to very low conductivity and occupies most of the central part of Sebatik Island elongated northwest-southeast.

3. Hydrological Data In Sebatik Island

Shallow Aquifer: Northern Sebatik Island (Malaysia)

In the year 2002, groundwater investigation was conducted by JMG around Kg. Bergosong, Kg. Sungai Lahi, Kg. Sungai Tamang and Kg. Sungai Tongkang as shown in Fig. 4 and the location of exploration wells at Wallace Bay and Kg. Sungai Tamang are shown in Fig. 5 and Fig. 6. Jetting and augering methods were used were in this investigation which subsequently involved the construction of exploration, testing, observation well and followed by pumping test.

In Kg. Sungai Tongkang, a test well with a depth of 12.5 m was constructed within the unconfined aquifer with a thickness of 11 metres which consists of fine-grained sand to coarse medium. At the Kg. Sungai Lahi three test wells also constructed with depth of 13 m. An unconfined aquifer was identified with thickness approximately 9 m which consists of fine to very fine grained sand mixed with fragments of wood decays and corals. Meanwhile, exploration at Kg. Sungai Tamang has led to the construction of a production well with a depth of 16 m.

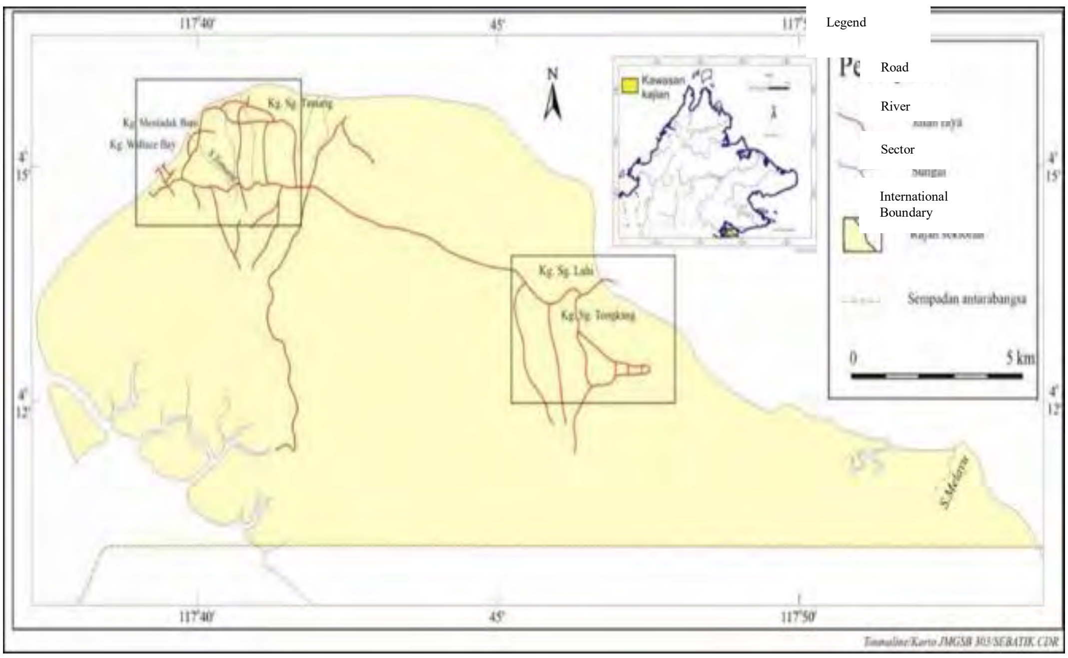

Fig. 4. Location map of groundwater exploration study area in Malaysia Sebatik Island (*Wan, 2001*)

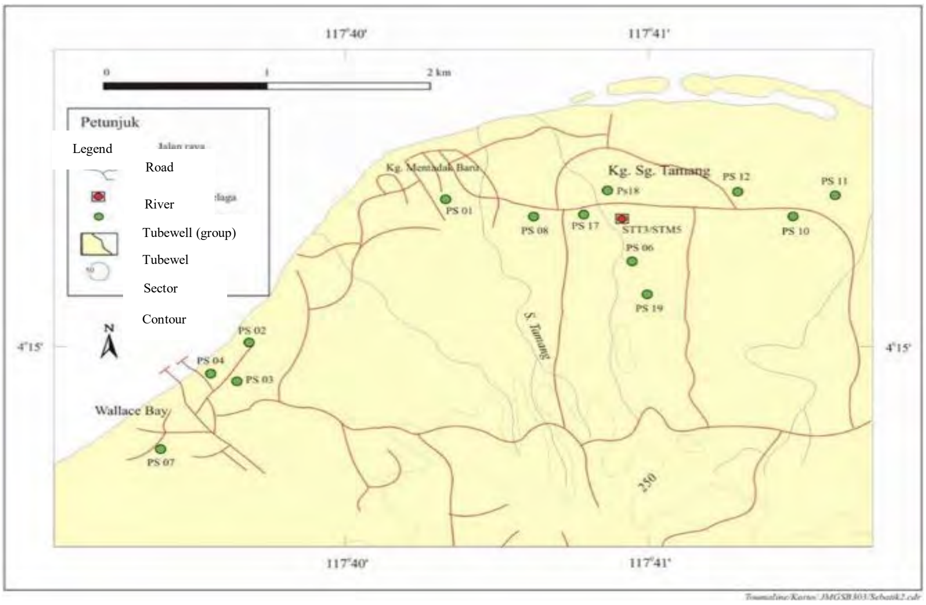

Fig. 5. Location map of exploration wells at Wallace Bay and Kg. Sg. Tamang *(Wani, 2001)*

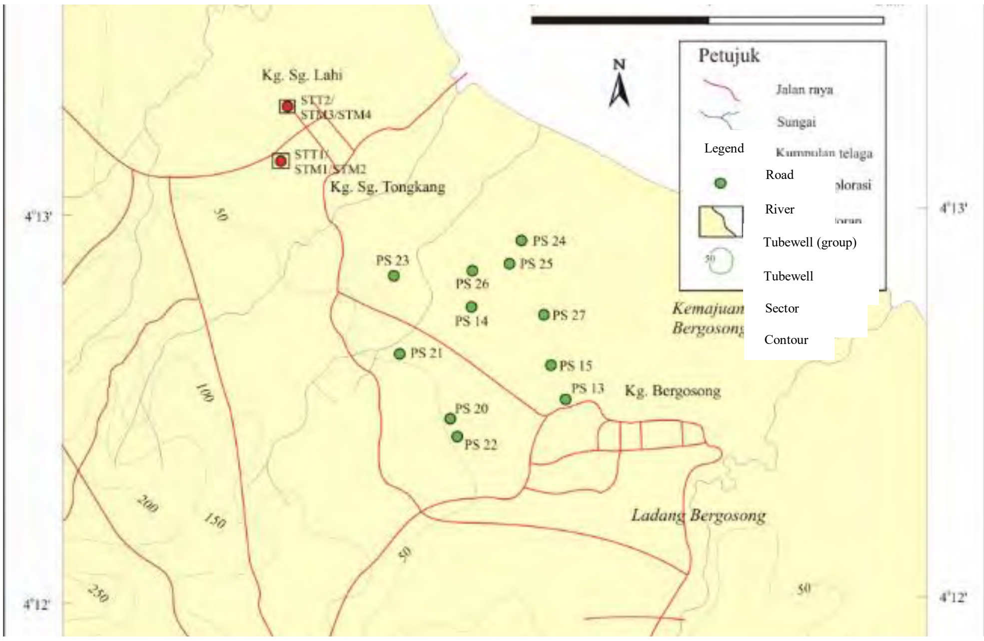

Fig. 6. Location map of exploration wells at Kg. Sg. Lahi and Kg. Sg. Tongkang (*Wan, 2001*).

Results of the groundwater exploration carried out in the Sebatik Island, Malaysia indicated that the aquifer at Kg. Sungai Tongkang, Kg. Sungai Lahi and Kg. Sungai Tamang have an area of 0.15 km^2, 0.1 km^2 and 0.3 km^2 respectively. Pumping test conducted at Kg. Sungai Tongkang and Kg. Sungai Lahi showed an estimated yield of 67.2 m^3/day and 38.4 m^3/day respectively. Meanwhile, pumping test conducted on tube well at Kg. Sungai Tamang has an estimated yield of 16.8 m^3/day. Detailed of the pumping test results are shown in Table 2.

Medium-Deep Aquifer: Southern Sebatik Island (Indonesia)

Geological Agency of Indonesia (GAI) has conducted a deep groundwater exploration around Kg. Aji Kuning, Kg. Sungai Pancang and Kg. Binalawan. Locations of the groundwater exploration study areas are shown in Fig. 7.

Table 2. Pumping test and hydraulic properties

Location	Exploration Well No.	Transmissivity, T (m^2/day)		Conductivity, K (m/day)	
		Constant Test	Recovery Test	Constant Test	Recovery Test
Sungai Tongkang	STM1	28.08	28.94	4.02	4.15
	STM2	51.98	52.70	7.43	7.54
Sungai Lahi	STM3	8.50	8.57	1.70	1.71
	STM4	70.70	70.13	14.17	17.02
Sungai Tamang	STM5	5.98	8.65	0.85	1.23

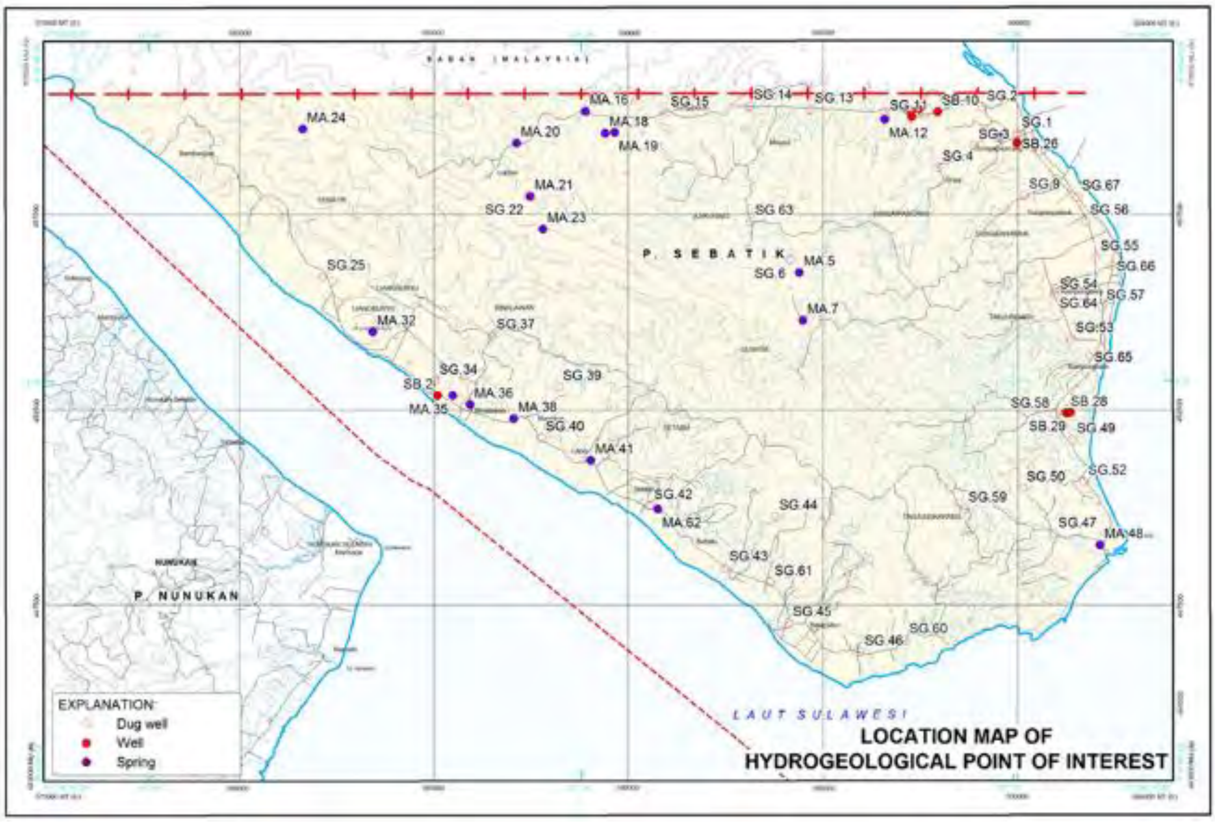

Fig. 7. Location map of hydrogeological point of interest (source: Geological Agency of Indonesia)

The medium-deep aquifer in island generally is a confined aquifer with more 100 metres depth. In Kg. Binalawan, a test well (SB.2) with a depth of 150 m was constructed by GAI within the confined aquifer which consists of fine sandstone-clayey sandstone and conglomerate with a thickness of 21 m which penetrate the Alluvium and Sandy Cross Bedded Unit (Fig. 8). The pumping test result showed low hydraulic conductivity; 3.90 x 10^{-6} cm/sec. Apart from that, PDAM constructed a well with a depth of 150m in Sg. Aji Kuning. This well (SB10) believed penetrate a multi-layers confined aquifer which consists of sand and clayey sand. The recorded groundwater level at this well is -28 m with approximately yield 2 liter/sec (7.2 m^3/hour).

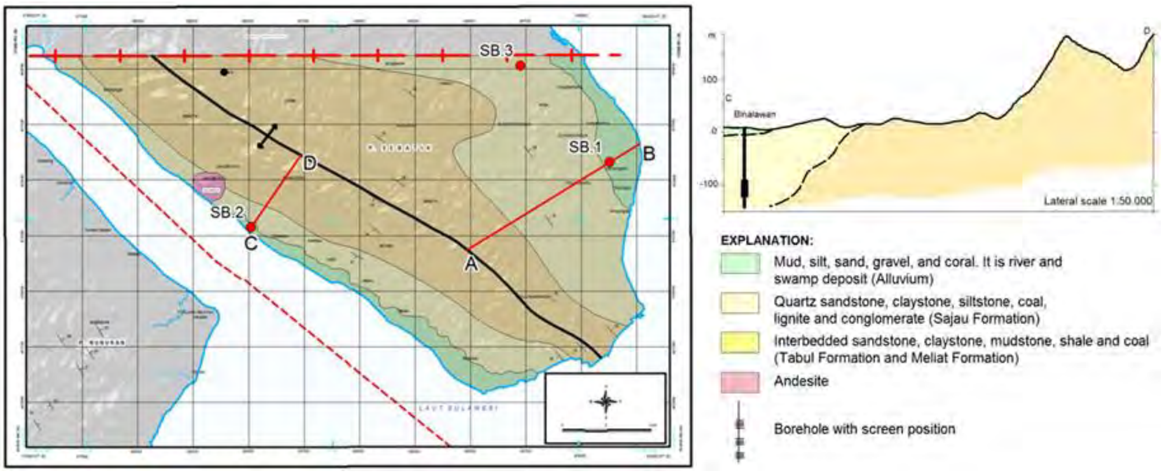

Fig. 8. Location deep well and cross section of the aquifer unit in Kg. Binalawan (Source: Geological Agency of Indonesia).

4. Groundwater Management

Based on the previous hydrogeological and fieldwork collected data, certain area of alluvium in Sebatik Island have potential for groundwater development. Fig. 9 showed that the total yield of water in the respectively area mentioned based on the pumping test which carried out on the wells constructed in that area.

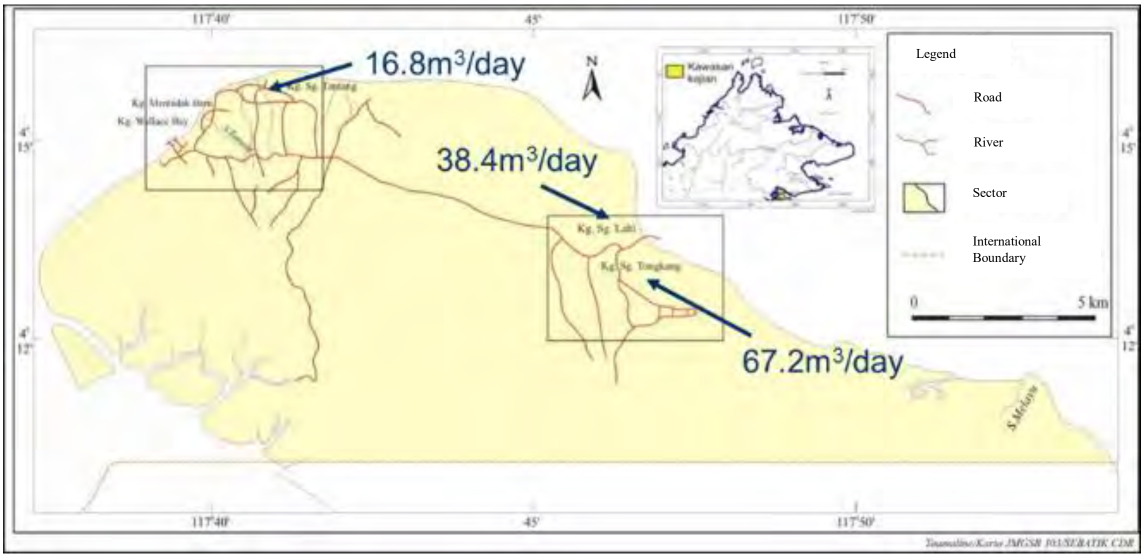

Fig. 9. Wells discharge in Kg. Sg. Tamang, Kg. Sg. Lahi and Kg. Sg. Tongkang.

Based on this study, the amount of groundwater on the respective area can be calculated and summarized as in Table 3. Kg. Sg. Lahi has the most amount with 1,417 m^3 and followed by Kg. Sg. Tongkang with 1,114.5 m^3 and Kg. Sg. Tamang with 255 m^3.

Hardrock aquifer can be further investigate with proper deep drilling on the geological structure prominent site such as fault, joint and fold. Initial data from GAI showed that the hardrock well can yield 7 m^3/h/well. Occurrence of sandstone layer in the island with good fractures and joint indicates high yield for hardrock tubewell to be constructed in the island.

Table 3. Groundwater calculated reserve in the respective area of Malaysia site

Location	Aquifer (area)	Conductivity, K (mean)	Qmax
Kg. Sg. Tongkang	0.15 km^2	7.43	1114.5 m^3
Kg. Sg. Lahi	0.10 km^2	14.17	1417.0 m^3
Kg. Sg. Tamang	0.3 km^2	0.85	255.0 m^3

In Malaysia, Geological Survey Act 1974 and State Water Enactments are the main legal laws related to the groundwater management. Legally, all development and management of water resource matters are under the State Government authority. However, JMG are the lead agency for groundwater development and management for most State in Malaysia. To date, there is no legal law was setup related to groundwater transboundary development and management within states or countries.

JMG developed a groundwater database (HydroDAT) to manage and monitor the groundwater quality based on field sampling which done annually. Certain state (*ie.* Kedah, Kelantan & Selangor) is in progress of setting up the real time monitoring system for groundwater.

Acknowledgement

The authors wish to express sincere thanks and appreciation to Geological Agency of Indonesia (GAI), namely Mr. Agus Taufiq NZ., Mr. Idham Effendi and Mr. Suhari for their tremendous cooperation to ensure the successful of this project.

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III-3-(6)
Hydrogeology of Pampanga, Philippines

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Abstract

This paper presents an overview of the geology, hydrogeology, and hydrochemistry of the Pampanga, Luzon Island, Philippines. Pampanga has a land area of 2,261 km^2 and bounded by five provinces, namely Nueva Ecija, Tarlac, Zambales, Bataan, and Bulacan. The rock units in the study area are the Bamban Formation and the Guadalupe Formation of Pleistocene age. These formations are composed of tuffaceous sandstone, lapilli tuff, conglomerate, sandstone, mudstone and pyroclastic breccias which are distributed at the eastern (Guadalupe) and western (Bamban) portions of Pampanga. These Pleistocene rock units are overlain by quaternary pyroclastics and tuffaceous sedimentary rocks from the eruption of Mt. Pinatubo. Majority of the areas of Pampanga are within the Central Luzon Basin with potential deep groundwater extraction considering the thick Quaternary alluvium and pyroclastics. The unconsolidated alluvium, especially the sand and gravel layers, is considered as a good aquifer and widely utilized for domestic an industrial water supply. About 78 % of Pampanga is expected to have a high productivity of groundwater; 322 km^2 of the recent alluvium is classified as an extensive and highly productive aquifer. About 13 % of the study area belongs to the quaternary pyroclastics with local groundwater productivity. 5 % (Pleistocene formations) of Pampanga is considered as a less extensive aquifer and 3% (Quaternary plug of Mt. Arayat) is categorized as rocks without any known significant groundwater productivity. Furthermore, 100 groundwater samples were collected and analyzed to evaluate the hydrochemical characteristics based on the Piper and Durov plots. Using the Piper plots, the dominant Na-HCO_3 (24 %) water type is observed in the low lying areas while Ca Mg-HCO_3 water-type were identified at the elevated recharge areas. The presence of these two facies suggests the possible ion exchange processes in the aquifer. The Durov diagram revealed that majority of the samples represent a Na dominant environment and downgradient waters through dissolution.

Keywords: groundwater, geology, hydrogeology, hydrochemistry, Pampanga, Luzon Island, Philippines

1. Introduction

Groundwater is considered as the major source of water supply for domestic and industrial purposes in many parts of the Philippines. This is due to the abundant and thick sedimentary aquifers which are considered as good groundwater sources. Unlike Metro Manila (the national capital region of the Philippines) that largely depends on the surface waters, the Province of Pampanga still utilized the groundwater as its main source of potable water. Groundwater development is intensive in Pampanga due to the rapid population increase and urban development. In order to evaluate the groundwater resource of Pampanga, the hydrogeology and the recent hydrochemical data were presented in this paper. Hydrogeological and geological data from previous works were incorporated with the newly acquired data for the preparation of the hydrogeology part of this paper. The hydrochemical information can serve as a baseline data for future studies regarding the effect of urbanization on the groundwater quality and can provide the scientific basis for sustainable management and protection plans.

The province of Pampanga is composed of 22 municipalities and located in the island of Luzon within the geographic coordinates of 14° 45’ 00” to 15° 15’ 00” North Latitude and 120° 20’ 00” to 121° 30’ 00” East Longitude. It has a land area of 2,261 km^2 and bounded by five provinces: Nueva Ecija to the northeast, Tarlac to the northwest, Zambales to the west, Bataan to the southwest, and Bulacan to the east (Fig. 1). Majority of the study area is covered by alluvial plain and forms part of the north-trending Central Luzon Basin/Valley. The valley is bounded to the west by the Zambales Mountain Range and to the east is the Southern Sierra Madre Range. The Mt. Pinatubo forms part of the Zambales Mountain Range where the highest elevation (~ 1,400 masl) of the study area is located. The 1991 Mt. Pinatubo eruption is considered as one of the largest eruptions in the world in the 20th century that deposited around 5-7 km^3 of pumiceous pyroclastic-flow deposits and about 0.2 km^3 of tephra-fall deposits (Pierson et al., 1992). The Central Luzon Valley drains south towards Manila Bay through the Pampanga River and the Pasac River. The high deposition of sediments in the southern swamp areas of the Pampanga Delta is due to the low velocity of surface water flow. The inland Candaba swamp is one of the prominent physiography in Pampanga. It is believed that the formation of the swamp is due to the very low stream gradient, low elevation and the shallowness of the water table in the area (Sandoval and Marmaril, 1970).

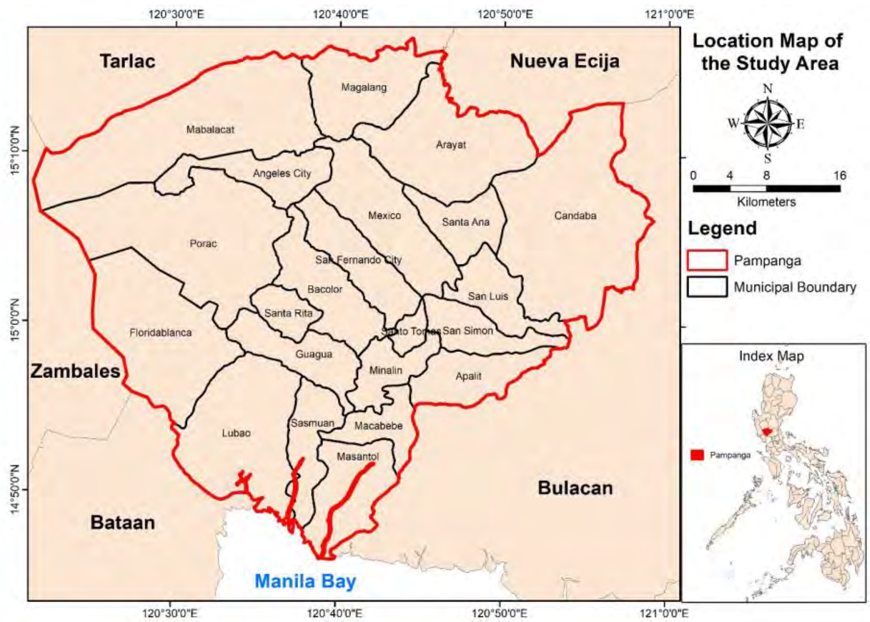

Fig. 1. Location Map of the study area

Pampanga River and Pasac River are the main watersheds in the study area (Fig. 2). Pampanga River Watershed has an area of about 7,697 km^2 which considered as the fourth largest River Basin in the Philippines. Water drains from the mountain range of Nueva Ecija to the tributaries traversing the southern Nueva Ecija, northwestern Bulacan, eastern Pampanga and exits to the Manila Bay. On the other hand, the smaller 1,126 km^2 Pasac River Basin drains its water are from the eastern side Mt. Pinatubo and southwestern side of Mt. Arayat. Some of the tributaries (e.g., Pasig-Potrero) within the Pasac River Watershed have been modified by the deposition of recent sediments caused by the 1991 Pinatubo eruption. Pampanga is located in an area categorized as Type I based on the Corona Classification of the Philippine Climate. The study area has two pronounced seasons (PAGASA, 2015). The period from November to April is considered as dry season while the remaining months are characterized by wet season.

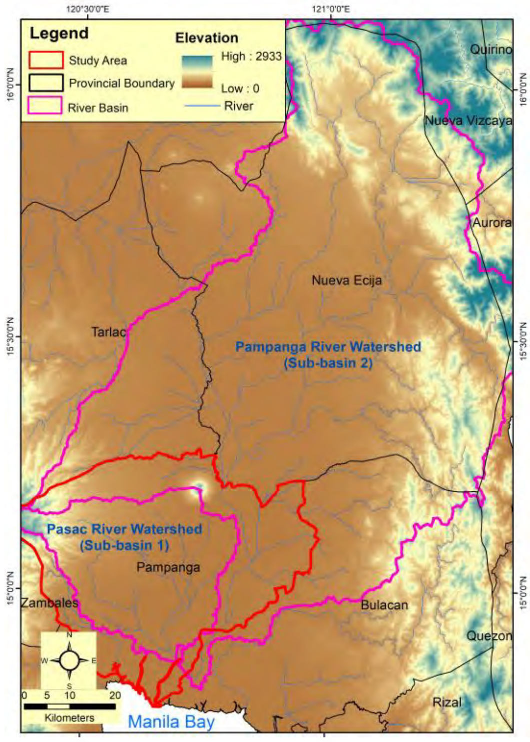

Fig. 2. Elevation map showing the two main watersheds that drains south to the Manila Bay. The index map shows the extent of the sub-basin 2.

2. Geology and Hydrogeology of Pampanga

The rock units in the study area are the Bamban Formation and the Guadalupe Formation with an age of Pleistocene. The following rock descriptions were adopted from the Geology of the Philippines (Mines and Geosciences Bureau, 2010). The Bamban Formation is exposed at the western side of Pampanga. It is composed of tuffaceous sandstone and lapilli tuff with basal conglomerate that may have been deposited under water (Corby et al., 1951). The conglomerate is massive, fairly consolidated and poorly sorted. The clasts were identified as sub-angular to sub-rounded pebbles, cobbles, and boulders of diorite, andesite, and basalt with minor amounts of scoria set in a tuffaceous sand and volcanic ash matrix. The sandstone is fine to coarse-grained, fairly sorted, soft, porous and tuffaceous. It consists mainly of angular to sub-rounded grains of feldspar, quartz and ferromagnesian minerals set in fine silt and volcanic ash matrix. The hard and brittle tuff is composed of well cemented, fine volcanic ash, dust, and lapilli with characteristic minor mafic minerals and small fragments of scoriaceous materials. On the other hand, the Guadalupe Formation is subdivided into the Alat Conglomerate Member and the Diliman Tuff Member distributed at the eastern side of Pampanga (Teves and Gonzales, 1950). The sequence of conglomerate, sandstone, and mudstone defines the Alat Conglomerate. The conglomerate is the dominant lithology characterized by poorly sorted and well-rounded pebbles and small boulders set in a coarse-grained, calcareous and sandy matrix. The Diliman tuff consists of fine-grained vitric tuffs and welded pyroclastic breccias. Fine to medium-grained tuffaceous sandstone are also present in some portions. The glassy tuffaceous matrix has specs of mafic minerals and bits of pumiceous and scoriaceous materials. The Bamban Formation is overlain by quaternary pyroclastics and tuffaceous sedimentary rocks from the eruption of Mt. Pinatubo. The central portion of the study area is dominantly covered by the Quaternary alluvium. Geological information indicates that the Pleistocene sedimentary rocks and the Quaternary alluvium can be considered as significant groundwater reservoir.

The generalized Hydrogeological Map of Pampanga was prepared based on the UNESCO/IAH Legend (1970) classification of the hydrogeological units. Since the groundwater movement through interstices in the soil and rocks is governed by the rock's permeability, the grouping generally depends on the type and age of geological formations. Based on the occurrence and movement of groundwater, there are two major hydrogeological groups are that were identified in the study area: (1) rocks in which flow is dominantly intergranular and (2) rocks with local or no groundwater. Each group is further subdivided into sub-hydrogeological units based on the extent and productivity of the formations and on the degree of cementation, consolidation, and fracturing of the rocks which indirectly controls their permeabilities.

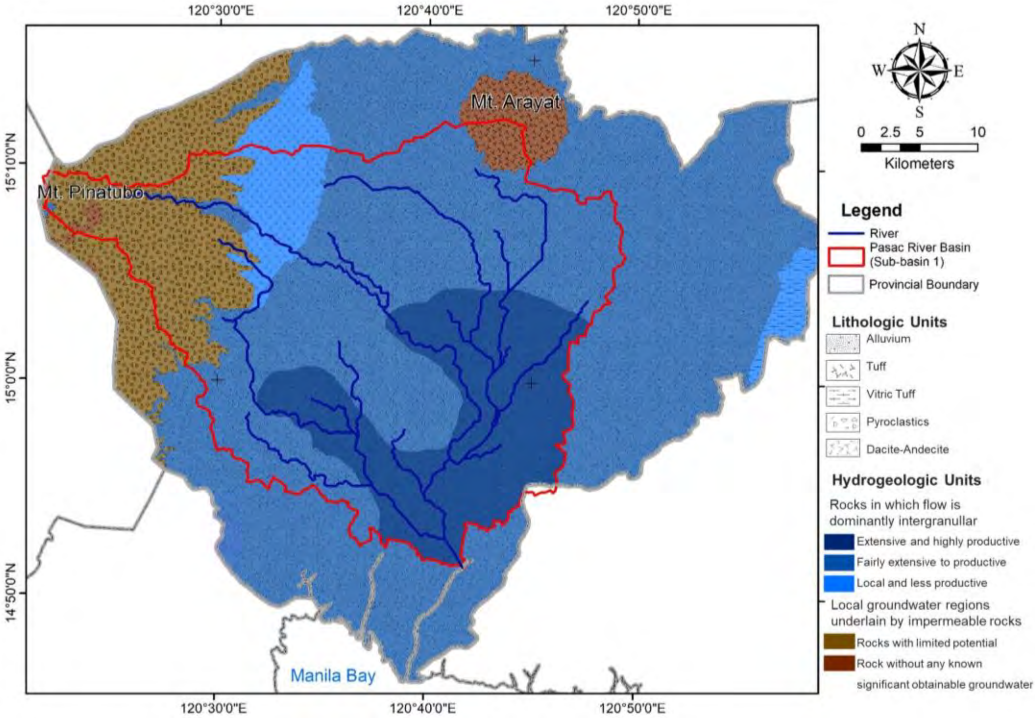

Fig. 3. Generalized hydrogeologic map of Pampanga

The rock units in which groundwater flow is dominantly intergranular generally consist of the unconsolidated alluvial deposits and the Pleistocene tuffaceous rocks of Guadalupe and Bamban Formation. Pampanga utilized most of the groundwater for domestic use from the unconfined aquifers of alluvial deposit. Some shallow clay aquitards produce artesian aquifers in the alluvium. After the alluvial deposits, the pyroclastic rocks of the Guadalupe and Bamban Formation offer the best sources of groundwater in the study area. However, cementation and compaction have slightly reduced the porosity and permeability of the rock units of Bamban and Guadalupe Formation. Nonetheless, these formations still produce sufficient groundwater and can be considered one of the more important groundwater reservoirs of the Province. The Guadalupe Formation contains sufficient clastic units which can be utilized extensively. Most of the aquifers within the Guadalupe Formation are confined by fine-grained sedimentary rocks. The Alat conglomerate is composed of poorly sorted, compact and moderately cemented clastic rocks with tuffaceous and other clayey materials. The Sandstone layer of Alat Formation can be considered as potential good aquifers in the area. There were some reports that the groundwater from the lower portion of Alat Formation is slightly brackish and water from the drilled wells flows freely over the land surface (Sandoval and Marmaril, 1970).

On the other hand, the western quaternary pyroclastics from Mt. Pinatubo and the dacitic-andesitic quaternary plug of Mt. Arayat are considered as local groundwater regions. This is due to the semi-permeable to impermeable layers where the potential groundwater flow is restricted to the residuum, leached mantle, and few interconnected fracture and fissure openings. However, the areas underlain by the quaternary pyroclastics were categorized as zones with limited potential due to some known water discharge points.

The groundwater wells have variable depth according to their usage. Majority of the wells for domestic use were constructed at the depth of around 20 to 30 m only and the commercial wells of water districts utilized the deep aquifers of around 100 to 200 m. The coefficient of transmissivity and storage of aquifers in the study area were determined from pumping tests of previous studies and recent well developments. The results of the aquifer tests are classified based on the underlying formations. The Bureau of Public Works has conducted extensive testing of aquifers in the lower depth (8 m to 152 m) of wells as part of well construction; these data were presented in the work of Sandoval and Marmaril (1970). The recent pumping test data of the newly constructed groundwater wells were integrated to the previous data to come up with updated sub-classified hydrogeologic units. Majority of the areas of Pampanga are within the Central Luzon Basin where the deep groundwater extraction is possible considering the thick quaternary alluvium and pyroclastics. The unconsolidated alluvium, especially the sand and gravel layers, is considered as a good aquifer and widely utilized for domestic and commercial water supply. About 78% of Pampanga is expected to have a high productivity of groundwater; 322 km^2 of the recent alluvium is classified as extensive and highly productive aquifer. About 13 % of the study area belongs to the quaternary pyroclastics with local groundwater productivity. 5 % (Pleistocene formations) of Pampanga is considered as a less extensive aquifer and 3 % (Quaternary plug of Mt. Arayat) is categorized as rocks without any known significant groundwater productivity.

3. Hydrogeological database of Pampanga

3.1 Groundwater Data

All available groundwater-related information of the individual inventoried well/spring in Pampanga were organized and systematically encoded in a Mines and Geosciences Bureau (MGB)-established database. The locations of the wells in terms of the coordinates (latitude and longitude) were taken using a Global Positioning System (GPS). Important information for each well/spring includes elevation, groundwater level (i.e., SWL, PWL), discharge (volume of water extractable/or flowing out per unit of time), water usage, owner, year constructed, etc. In-situ water quality tests are also being conducted parallel to the well inventory activity. The physical parameters that were measured on site include temperature, pH, Total Dissolved Solid (TDS), ORP, conductivity, turbidity, dissolved oxygen, and salinity. In situ sampling provides readily available values to initially assess the water quality in an area. Aside from the result of in-situ tests, the results of the laboratory analysis of collected groundwater samples were included in the water quality database. These water quality data were used to assess the potability of groundwater by comparing them with the Philippine Standard for Drinking Water. However, for simplicity, this section only presented the groundwater data in CCOP format and generally discussed the hydrochemistry of Pampanga. It must be noted that some of the water parameters were not being analyzed by the MGB (e.g., Br, NO_3, NH_4, F, Li, NO_2, PO_4, δD, $\delta^{18}O$).

Table 1. Groundwater data of Pampanga in CCOP format

Well name	Lat.	Lon.	Elevation	Depth	EC	pH	Cl	SO4	HCO3	Na	K	Mg	Ca	Water_Type
PAM-ADT-01	15.17039	120.6203	75	200	36.32353	7.25	10.46	16	252.18	21.81	5.88	13.89	3.18	Mg-HCO3
PAM-ADT-02	15.07686	120.6027	52	189	21.02941	7.16	10.71	3	160.48	14.11	2.72	8.76	1.55	Mg-HCO3
PAM-ADT-03	15.15114	120.5919	94	172.27	19.85294	6.92	12.75	20	100.04	12.11	3.56	8.13	1.55	Mg-HCO3
PAM-ADT-04	15.14672	120.566	126	178.4	26.02941	6.74	14.79	40	97.95	13.44	3.57	8.24	2	Mg-HCO3
PAM-ADT-05	15.1685	120.5108	244	181.8	23.67647	7.32	11.73	30	107.68	14.56	2.4	6.55	1.87	Na-HCO3
PAM-ADT-06	15.21256	120.5775	107	152	21.17647	7.23	10.2	9	132	12.93	2.53	5.26	2.2	Na-HCO3
PAM-ADT-08	15.18881	120.5885	106	64	28.38235	7.16	13.52	24	147.97	15.72	3.39	10.57	2.17	Mg-HCO3
PAM-ADT-09	14.87317	120.501	13	180	85.29412	7.19	155.56	2	226.48	24.9	3.67	38.07	13.51	Mg-Cl
PAM-ADT-10	14.87317	120.5193	14	131	126.3235	7.78	224.42	7	351.52	120.89	13.52	4.58	5.12	Na-Cl
PAM-ADT-11	14.91694	120.552	8	149	119.8529	7.25	255.02	12	197.99	83.35	21.15	67.08	5.3	Mg-Cl
PAM-ADT-12	14.94064	120.5377	14	142	44.70588	7.82	35.7	20	220.92	51.56	7.44	10.64	1.59	Na-HCO3
PAM-ADT-13	14.94519	120.5881	4	149	34.26471	7.72	10.2	11	229.25	29.58	9.25	13.74	1.28	Na-HCO3
PAM-ADT-14	14.97408	120.5662	16	184	37.05882	7.63	10.2	5	268.16	20.2	5.83	17.17	2.89	Mg-HCO3
PAM-JGG-01	15.04631	120.7863	9	152.4	27.11765	8.05	58.91	10	147.57	62.81	6.41	0.83	1.56	Na-HCO3
PAM-JGG-02	15.01553	120.8384	11	146.609	68.08824	7.75	152.35	8	126.82	122.3	6.89	15.41	25.65	Na-Cl
PAM-JGG-03	15.05783	120.8027	11	100.584	31.32353	7.85	10.16	3	149.3	75.59	4.27	1.26	1.78	Na-HCO3
PAM-JGG-04	15.03447	120.7914	10	146.304	29.36765	8.15	10.66	7	160.83	74.44	6.01	1.19	1.5	Na-HCO3
PAM-JGG-05	14.90942	120.7142	7	149	55.73529	8.20	97	3	153.91	115.45	8.78	5.26	17.63	Na-Cl
PAM-JGG-06	14.90556	120.6936	3	155	68.23529	7.89	91.79	4	240.16	97.72	7.3	5.5	21.14	Na-HCO3
PAM-JGG-07	14.89842	120.7179	8	150	55	8.08	49.58	1	281.12	103.48	10.2	3.39	11.81	Na-HCO3
PAM-JGG-08	14.92564	120.7218	8	197	31.91176	7.96	15.33	11	167.98	61.33	10.42	2.47	6.09	Na-HCO3
PAM-JGG-09	15.121	120.7763	10	129.54	41.17647	8.20	4.6	1	305.41	91.7	2.38	0.7	0.64	Na-HCO3
PAM-JGG-10	15.15528	120.771	12	152.4	91.91176	7.70	68.49	18	416.31	150.81	6.93	17.36	19.55	Na-HCO3
PAM-JGG-12	15.15233	120.7479	13	152.4	43.82353	7.62	7.67	9	261.95	60.82	4.86	13.38	17.44	Na-HCO3
PAM-JGG-13	15.16006	120.6869	32	6.096	47.35294	6.87	15.84	27	226.87	28.11	10.73	16.97	32.9	Ca-HCO3
PAM-JGG-14	15.18914	120.6621	43	152.4	30.14706	8.39	4.09	9	182.43	31.36	7.72	12.56	13.45	Na-HCO3
PAM-LOB-01	15.02489	120.8833	16	175	475	7.2	1824.58	95	69.03	956.93	25.08	74.58	418.71	Na-Cl
PAM-LOB-02	15.02308	120.8484	9	158	107.3529	7.4	286.21	19	226.37	218.52	12.92	33.49	29.06	Na-Cl
PAM-LOB-03	15.09558	120.8285	14	145	34.55882	8.1	29.13	13	256.87	104.57	5.01	0.82	1.97	Na-HCO3
PAM-LOB-04	15.09183	120.8098	6	155	26.54412	8.2	14.31	6	226.37	79.19	5.85	1.81	3.49	Na-HCO3
PAM-LOB-05	15.12703	120.816	11	48.8	71.47059	8.0	33.73	4	414.21	206.6	5.86	7.88	8.59	Na-HCO3
PAM-LOB-06	15.12125	120.8137	9	42.7	74.85294	7.9	132.88	3	419.03	210.1	8.06	9.42	23.57	Na-HCO3
PAM-LOB-07	15.10322	120.7704	11	152	25.35294	7.9	12.27	8	211.92	70.29	3.81	1.4	1.78	Na-HCO3
PAM-LOB-08	15.18897	120.6523	53	152	23.16176	7.4	10.22	17	181.42	27.45	7.75	14.37	18.8	Na-HCO3
PAM-LOB-09	15.19344	120.638	58	79.25	18.75	7.4	13.29	30	112.38	18.84	3.49	11.61	15.85	Mg-HCO3
PAM-LOB-10	15.23564	120.6623	39	150	19.38235	7.4	9.71	17	146.1	21.14	6.05	11.78	16.29	Mg-HCO3
PAM-LOB-18	14.89339	120.7116	7	150	50.58824	8.05	77.19	11	203.49	109.57	7	6.18	18.72	Na-HCO3
PAM-LOB-19	14.86236	120.6988	4	150	33.97059	8.00	20.31	7	185.62	75.12	7.28	3.56	10.74	Na-HCO3
PAM-LOB-20	14.8965	120.7104	5	200	39.26471	8.05	76.18	40	172.94	80.08	8.77	3.62	10.76	Na-HCO3
PAM-MBP-13	15.11669	120.7731	11	135	36.02941	7.4	21.98	54	197.47	100.87	13.45	1.35	4.89	Na-HCO3
PAM-MBP-15	14.96389	120.7572	6	154	46.02941	7.7	70.02	13	255.27	110.57	5.2	8.98	14.42	Na-HCO3
PAM-MBP-16	14.95333	120.7778	10	154	57.5	7.5	95.06	18	305.04	89.1	4.39	23.65	37.34	Na-HCO3
PAM-MBP-17	14.96444	120.8373	13	185	68.82353	7.3	176.32	23	200.68	176.13	7.43	7.16	13.42	Na-Cl
PAM-MBP-18	14.96556	120.7886	11	6	86.47059	6.9	99.66	48	523.38	107.1	1.93	60.01	77.81	Mg-HCO3
PAM-MBP-19	14.94639	120.7485	5	160	23.26471	7.4	20.44	20	138.07	64.91	5.98	0.81	1.62	Na-HCO3
PAM-MBP-20	14.94389	120.7508	6	185	21.29412	7.5	15.33	24	128.44	57.08	6.06	0.53	0.76	Na-HCO3
PAM-MBP-26	14.93083	120.6696	5	53	43.67647	7.50	19.42	3	390.13	416.12	2.74	1.47	0.83	Na-HCO3
PAM-MBP-27	14.98475	120.8447	9	23	81.02941	7.50	92	25	537.83	261.22	6.66	8.02	8.37	Na-HCO3
PAM-MBP-28	15.02778	120.6778	6	245	28.02941	7.50	21.98	37	154.12	81.95	9.43	0.63	2.59	Na-HCO3
PAM-MBP-29	15.06733	120.655	29	239	20.76471	7.70	75.64	15	141.28	50.99	7.63	4.41	4	Na-HCO3
PAM-MBP-30	14.86222	120.6986	4	230	19.16176	7.40	28.11	21	125.23	38.32	5.89	7.27	7.75	Na-HCO3
PAM-MBP-32	15.04139	120.6581	18	244	22.27941	7.50	14.82	12	165.36	54.22	11.62	3.12	5.99	Na-HCO3
PAM-MBP-33	15.03306	120.6882	11	180	24.51471	7.60	16.87	29	150.91	77.32	13.39	0.43	0.99	Na-HCO3
PAM-VAL-01	15.06401	120.5472	77	88.39	100.8824	6.70	19.89	325	68.72	28.2	8.92	80.94	45.99	Mg-SO4
PAM-VAL-03	15.09894	120.5242	141	106.68	114.2647	6.84	50.49	312.5	90.23	56.08	9.48	95.34	26.5	Mg-SO4
PAM-VAL-05	15.02385	120.5574	40	109.73	24.11765	7.30	9.18	22	106.89	11.4	4.43	15.77	7.98	Mg-HCO3
PAM-VAL-25	15.01409	120.6069	20	12	17.64706	7.49	4.08	6	152.73	16.27	8.94	11.56	15.17	Mg-HCO3
PAM-VAL-27	15.00991	120.5937	21	12	47.20588	6.77	45.9	32	303.63	52.93	13.56	32.22	39.21	Mg-HCO3
PAM-VAL-34	15.01195	120.7137	6	149.35	28.82353	7.96	14.28	40	164.46	45.25	11.9	1.43	3.92	Na-HCO3
PAM-VAL-36	14.99781	120.7023	7	96.01	26.17647	8.09	3.06	22	187.97	37.23	9.78	3.62	10.17	Na-HCO3

3.2 Hydrochemistry of Pampanga

An overview of the hydrochemistry of Pampanga was also presented in this section in the form of graphical diagrams (i.e., Piper, Durov diagrams) to investigate the hydrochemical facies and processes involved. The Pasac River Basin, with an area of 1,127 km^2 is the focus of the general hydrochemical analysis. It is located in the central portion of the Pampanga (Fig. 4). Tributaries from the northwestern Mt. Pinatubo and northeastern Mt. Arayat joins at the central portion and drains south to the Pampanga/Manila Bay.

The effect of chemical processes, lithology and groundwater flow can be reflected by the hydrochemical facies. Piper and Durov diagrams were used to determine the hydrochemical facies of groundwater in Pampanga Province (Fig. 4). Piper diagram is a multipart plot where the milliequivalents percentage concentrations of major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (HCO_3^-, SO_4^{2-}, and Cl^-) are plotted in two triangular fields; these plots are being projected further into the central diamond field (Piper, 1944). On the other hand, Durov diagram is a merged plot consisting of 2 ternary diagrams where the milliequivalents percentages of the cations are plotted against the anions. The combination of these two plots forms a binary plot of total cation vs. total anion concentrations in a rectangular area (Durov, 1948). The Piper diagram categorized the water type or the hydrochemical facies based on the plots on the subdivided diamond field. On the other hand, the Durov diagram defines the hydrochemical processes along the water type of the samples. This was done by projecting and plotting the intersection of lines from the points in 2 ternary diagrams. 100 groundwater samples were collected within the Province of Pampanga and subjected to chemical analysis by the MGB.

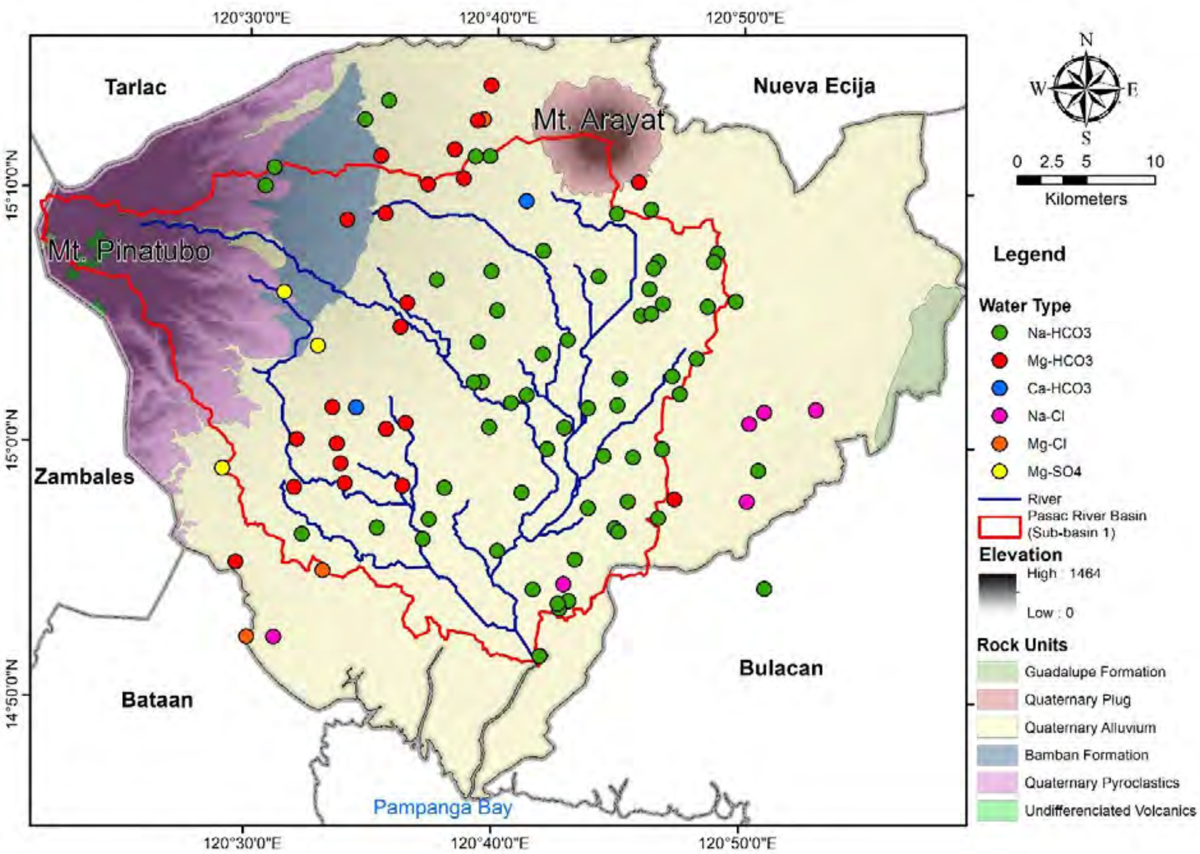

Fig. 4. Distribution map of the hydrochemical facies in Pampanga

After analyzing the groundwater samples and plotting the result on Piper's diagram (Piper, 1944), it can be observed that most of the major cations are represented by Na+ and Mg^{2+}, and the anions are dominated by HCO_3^- and Cl^-. The majority of the plots at the bottom portion of the diamond indicates the dominance of alkali over the alkaline earth and weak acidic anions over strong acidic anions. Specifically, 64% of the samples belong to the Na-HCO_3 water-type, 24% to the Ca Mg-HCO_3, 6 % to the Na-Cl, 3 % to the Mg-SO_4 and 3 % to the Mg-Cl (Fig. 5).

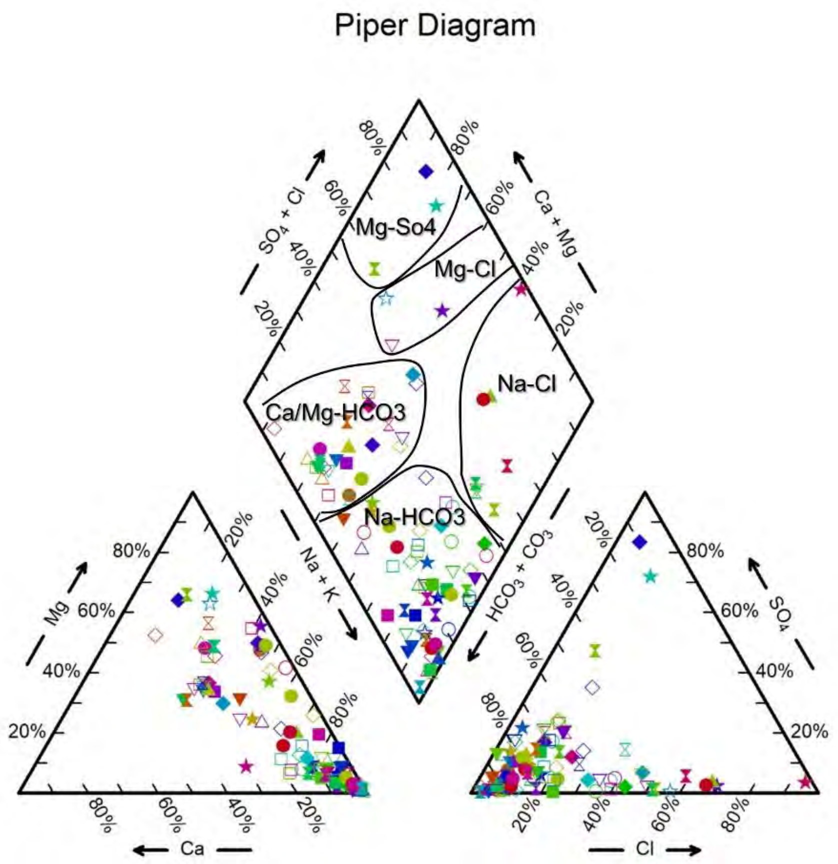

Fig. 5. Piper Diagram showing the hydrochemical facies of groundwater samples in Pampanga

The Calcium-Magnesium Bicarbonate (Ca, Mg-HCO_3) water type dominated the western side of the Pasac River Basin (Fig. 4). The Ca, Mg-HCO_3 water along the foot of the Mt. Pinatubo can be attributed to the young/fresh recharge groundwater. The lithologic characteristic of Bamban Formation is one of the major factors that contribute to the high Mg concentrations in the area. Bamban Formation consists of tuffaceous sandstone and lapilli tuff with the basal conglomerate. The sandstone is composed of ferromagnesian minerals and the tuff is described to have mafic minerals and fragments of scoriaceous materials (MGB, 2010). As the groundwater moves to the lower elevation, the water type becomes Na-HCO_3. The formation of the dominant Sodium Bicarbonate water type in the low-lying areas can be acquired by cation exchange when the water passes to the quaternary alluvium with clay layers. Furthermore, the Na-HCO_3 may be formed when the recharged groundwater from the elevated areas occupies the NaCl - rich low-lying areas that were previously submerged in seawater. During Pleistocene time, a general uplift of land and regression of the sea may cause the deposition of sediments with high NaCl content (e.g., Sandoval & Marmaril, 1970). The Ca and Mg in Calcium-Magnesium Bicarbonate water type exchanges with the Na when the groundwater passes the rock units with brine remnants.

The sodium-chloride water type in the study area can be attributed to saltwater intrusion in the coastal zones or can be due to the brine fossil water in the inner municipalities (i.e, Candaba, San Luis). Furthermore, the Mg-Cl type of water in the southwestern side (Lubao) of the study area can also be due to the dominant ferromagnesian minerals near the Mt. Pinatubo. Lastly, the abnormal Mg-SO_4 water type in the elevated areas of Mt. Pinatubo can be attributed to the lahar and/or the oxidation of reduced sulfur in the shallow aquifer with lower pH (e.g., Kirk Nordstrom et al., 2009). The groundwater samples were also plotted on the Durov diagram (e.g., Durov, 1948; Lloyd & Heathcote, 1985) to determine the dominant hydrochemical processes. Based on the Durov diagram (Fig. 6), the majority of the samples plot in the field 9 indicating a Na dominant environment and downgradient waters through dissolution. The plots of samples within field 5 and 6 is attributed to simple dissolution and mixing. The groundwater samples in field 7 and 8 can be related to reverse ion exchange of Na-Cl waters. Furthermore, rapid groundwater flow can be interpreted based on the consistent HCO_3 dominant water type from the recharge zones to low-lying discharge areas.

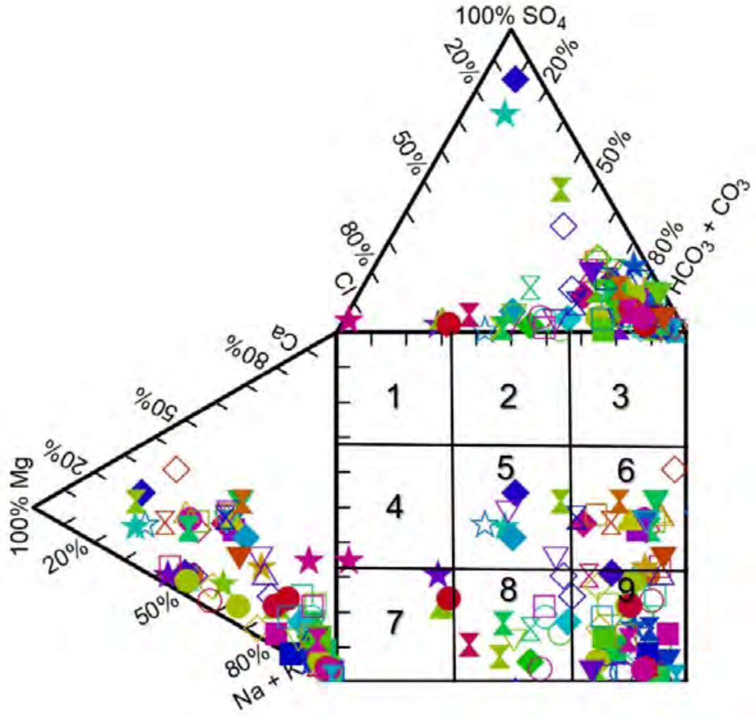

Fig. 6. Durov plot showing the sub-classifications of groundwater samples based on hydrochemical processes (e.g., Lloyd & Heathcote, 1985). Majority of the samples plotted inside field 9.

4. Groundwater Management in Pampanga

It is widely recognized that groundwater is highly utilized in Pampanga for domestic and industrial purposes. Water for domestic uses is often derived from shallow wells around 5 to 15 m from the land surface. Water districts and other factories use groundwater to larger extents. The commercial wells are usually at the depth of 100 to 200 m especially in areas underlain by thick pyroclastic and Pleistocene sedimentary rocks. Large withdrawals of groundwater produced a high rate of groundwater level decline in the province. The decline varies in different places depending on the usage of water and the type and depth of aquifers being tapped. It was noted that groundwater converges towards depressions caused by heavy pumping in the municipality of Mexico and Santa Ana. Saltwater contamination of the shallow aquifer in coastal municipalities is highly attributed to the entrance of saline water from seawater encroachment during high tide. Due to the lowering of pressure in confined aquifers, seawater seeps into the deeper aquifers. Brackish fossil waters that have not been completely flushed out by the meteoric water contributes to the high salinity of groundwater in some inland municipalities (e,g., Candaba). The management of the groundwater of the Philippines is being implemented in close coordination with the National Water Resources Board (NWRB). The policy formulation, and resource and economic regulation are the functions given to the NWRB. Furthermore, the NWRB coordinates and regulates, thru the water districts, all water-related activities in Pampanga.

5. Summary

The discussion of the geology, hydrogeology, and hydrochemistry of Pampanga presented an example of the groundwater status in the Philippines. The explanation document about the hydrogeology of Pampanga, as the representative area, can be summarized as follows:

1) Pampanga is chiefly underlain by Quaternary alluvium and young Pleistocene sedimentary rocks which have good groundwater storage capability.
2) The hydrogeology of Pampanga is mainly defined by rocks in which groundwater flow is dominantly intergranular. 78% is expected to have the high productivity of groundwater.
3) The Na-HCO_3 and Ca Mg-HCO_3 water types dominate the low-lying and elevated areas, respectively. Majority of the samples represent downgradient waters through dissolution.

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III-3-(7)
The 1:50,000 Groundwater Map and Hydrogeological Map of Khon Kaen, Thailand

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Abstract

Department of Groundwater Resources (DGR), Ministry of Natural Resources and Environment has a plan to produce groundwater map of Thailand at a scale of 1:50,000. Since 2012, we have created 380 groundwater map sheets of Northeastern Thailand at a scale of 1:50,000. Although all map sheets have been produced following the standards of International Association of Hydrogeologists (IAH), the status of data imported into maps are different. For example, variability of topography and spatial distribution of hydrogeological characteristics lead the ways to identify hydrogeological units are adapted. Also, advance technologies to explore groundwater are implemented so the quality of groundwater data is better. Moreover, groundwater well status (e.g. groundwater level and groundwater quality) varies to climate change, land use change, population growth, and attitude of people toward conservation. The 1:50,000 Groundwater map in Northeastern Thailand shows that groundwater quality and quantity significantly change over time. It can be observed from overlaying hydrogeological database over time.

The results of producing Groundwater map and Hydrogeological map at a scale of 1:50,000 in Northeastern Thailand point outs that hydrogeological data are discontinuous. In addition, from data processing to create groundwater map, we found that groundwater quantity and quality are time - dependent. Imported data into maps as groundwater data, geologic data, and hydrologic data collected before 2012 created 1:100,000 provincial groundwater maps which have quite low groundwater quantity and rare groundwater in Northeastern areas of Thailand. However, imported data collected since 2012 creates 1:50,000 groundwater maps which have moderate groundwater quantity. These results indicated that reliability of map is also dependent on imported data.

To manage groundwater, we also search for potential groundwater source areas. Therefore, we need to build confidence in using groundwater map as a tool to support information for decision - making on optimal groundwater planning and development.

Keywords: groundwater map, hydrogeological map, HYDRO - Geological Information System (HYGIS)

1. Introduction

DGR is a government agency of Thailand which is responsible for optimal groundwater management and development. We have conducted "The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1:50,000" since 2012. Also, we have carried on a subsequent project which is “The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1:50,000 Area 2: The mid - northeastern Thailand” in Khon Kaen province since 2015. The main objective is to prepare and comply maps scaled of 1:50,000 utilized as a source of information for groundwater assessment and management, and to improve the groundwater database systems by designing HYdro - Geological Information System (HYGIS) in Khon Kaen.

2. Geology and Hydrogeology in Khon Kaen, Thailand

Khon Kaen is a part of northeastern provinces of Thailand. It is located at 16.4419° N latitude and 102.8360° E longitude. Khon Kaen comprises an area of 10,886 Sq.km and consists of 26 districts, 199 sub - districts and 2,331 villages. The population has 1.80 million. Neighboring provinces are Nong Bua Lamphu, Udon Thani, Kalasin, Maha Sarakham, Buriram, Nakhon Ratchasima, Chaiyaphum, Phetchabun, and Loei.

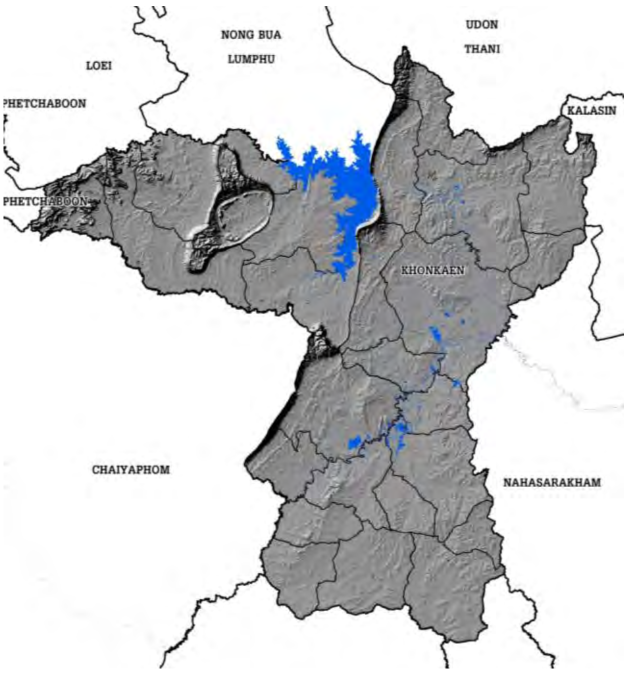

Fig. 1. Topography of Khon Kean province

Topography of Khon Kaen consists plain, lower flat plain, and higher flat plain. The western part of Khon Kaen is high mountain close to Phu Kradung and Phetchabun range. The Eastern and Southeastern parts is hilly undulate, high and low tilts downward to east and south. The height is about 100-200 above Mean Sea Level.

Geology in Khon Kaen province is mostly covered with various types of sedimentary rocks from Khorat Group and some alluvial deposits. Rock sequences of the Khorat Group comprised 7 formations from older to younger rocks follow as: Huai Hin Lat Formation, Nam Phong Formation, Phu Kradung Formation, Phra Wihan Formation, Sao Khua Formation, Phu Phan Formation, and Khok Kruat Formation; Reddish-brown to light-grey sandstones, conglomeratic sandstones, siltstones, claystones and conglomeartes are the main lithologies of these rocks.

The Structure Geology in Khon Kaen area is represented by folding structure, which is part of Loei-Petchabun Fold Belt exposed continuously from the western part of Khon Kaen Province to northwestern part of Chaiyaphum Province and to southern part of Petchabun

Province. Geology was categorized as unconsolidated and consolidated rock units with age ranging from Cretaceous to Quaternary.

Hydrogeological units of Khon Kaen consists of unconsolidated aquifers and consolidated aquifers as follows:

1) Unconsolidated aquifers

Unconsolidated aquifer is normally found in plain areas. It is composed of sediment, gravel, sand, and clay. An average aquifer thickness is generally around 10 - 30 m, and groundwater yield is in the rank of 2 - 20 cubic meters per hour. Groundwater quality is blackish and salty. However, in area of old waterways, an aquifer thickness is about 20 - 40 m, and groundwater quality is good.

2) Consolidated aquifers

Consolidated aquifer is characterized by the Upper Korat aquifer (Kuk), Middle Korat aquifer (Kmk), and Lower Korat aquifer (Klk).

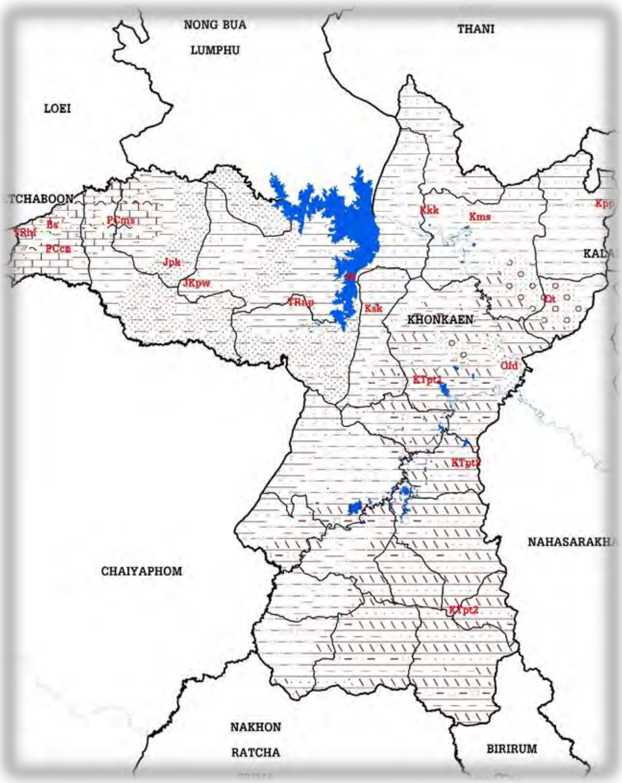

Fig. 2. Hydrogeological unit in Khon Kaen province

The hydrogeological units in Khon Kaen can be categories about 16 units. From hydrogeological field inventory, new hydrogeological unites are classified. We classifies Phu Thok aquifers to be three subunits as Phu Thok Nawa aquifers, Phu Thok Kham Tha Kla aquifers, and Phu Thok Noi aquifers.

In this study, Hydrogeological unit can be classified three main groups, which are 1) Unconsolidated rocks aquifer 2) Consolidated rocks aquifer and 3) Igneous rocks aquifer.

Table 1. Hydrogeological unit of Khon Kaen province.

No.	Legend	Hydrogeological Unit	Descript	Aquifer Type
1	Qfd	Alluvial deposits / Floodplain aquifer	gravel, sand, well sorted, well rounded, interbedded with thin bedded or lenses of sandy clay or lateritic soil, composed of gravel and sand of river bed or river channel, groundwater accumulated in voids of sediments, shallow groundwater.	Unconsolidated aquifers
2	Qt	Terrace Deposits aquifer	sand and clay, gravelly, formed as multi-aquifers, interbedded with clay, gravel and sand mostly well rounded, poorly sorted.	
3	KTpt3	Phu Thok Noi aquifer	sandstone, massive, fine-gained , calcareous cement, intercalated with conglomerate and shale, mostly dark red and reddish brown in some area : groundwater accumulated in fractures, bedding planes and weathered zones	Consolidated aquifers
4	KTpt2	Kham Ta Kla aquifer	sandstone, fine-grained, silstone, silty mudstone, brick red, calcareous, calcite nodules and thin calcite layers commonly found: groundwater accumulated in fractures, bedding planes and weathered zones.	
5	KTpt1	Na wa aquifer	mudstone, reddish brown, intercalated with thin anhydrite lalyers, calcareous and mostly saturated with salty water; groundwater accumlated in fractures, bedding planes and weathered zones.	
6	Kms	Maha Sarakham aquifer	mudstone, yellow grey, brounish grey, gypsum bed commonly found at lower part, salty water encounterd where rock salt underlain.	
7	Kkk	Khok Kruat aquifer	sandstone, siltstone, interbedded with shale, shale with granules, reddish brown to reddish purple, thin beds of gypsum or anhydrite commonly found, groundwater accumulated in weatherd and fractured zones.	
8	Kpp	Phu Phan aquifer	shale, sandstone and comglomerate, yellowish grey, coarse-grained sandstone,with clay matrix, groundwater accumulated in weathered, fractured zones and bedding planes.	
9	Ksk	Sau Khua aquifer	shale and sandstone, reddish brown, with lime nodules, groundwater accumulated in weathered, fractured zones and bedding planes.	
10	JKpw	Phra Wihan aquifer	sandstone, grey, white, dense, fine-to coarese-grained, consisted mainly of quartz, interbedded with reddish brown shale, groundwater accumulated in fractured zones and bedding planes.	
11	Jpk	Phu Kradung aquifer	sandstone, conglomerate, with ovule shaped gravel, overlain with thick layer of shale interbedded with sandstone, purplish brown, purblish grey, groundwater accumulated in weathered, fractured zones and bedding planes.	
12	TRnp	Nam Phong aquifer	sandstone, shale and conglomerate, intercalated with lenses of limestone and chert, lime and chert nodules commonly presented in conglomeratic sandstone, groundwater accumulated in weatherd, fractured zones and bedding planes.	
13	TRnl	Huai Hidlad aquifer	conglomerate, sandstone, agglomerate and tufffaceous sandstone, overlain with thick layer of shale, partially derived from lacustrine sediments, coal seams and natural fuel commonly presented, groundwater accumulated in weathered, fractured zones and bedding planeds.	
14	PCcn	Carbonate aquifer	limestone of Saraburi Group, limestone light ot dark grey, mainly massive, bedded limestone found from place to place, fossiliferous, chert bed or chert lenses commonly found, recrystallized limestone found in some localities, groundwater accumulated in weathered zone or marl and underground cavities.	
15	PCms	Metasediment aquifer	carboniferous low-grade metamorphic rocks of Kaeng Krachan Group, sandstone, shale, chert and quartzite, foloding commonly presented, groundwater accumulated in weathered, fractured zones and bedding planes.	
16	Bs	Basalt aquifer	basalt, greenish black to greyish black, groundwater accumulated in weathered, fractured zones and interface zones.	Igneous rock aquifer

3. Hydrological database in Khon Kaen, Thailand

"The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1:50,000 Area 2: The mid - northeastern Thailand" has been implemented in Khon Kaen. Hydrogeological map

and groundwater map at a scale of 1:50,000 have been created by improving groundwater map, hydrogeological map and HYGIS.
The scope of works is up-to-date the data to collect, study and analyses of secondary data pertaining to the development of hydrogeological and groundwater mapping including the setting up of preliminary data inventory which study and review of spatial distribution of existing data were crucial to determine factors affecting the subsequent plan for the fieldwork and investigation.

All data was outstandingly the fieldwork. The fieldwork was purposed to verify all the data collected earlier to ensure validity at the actual field level from systematic field inventory and to systematically plan exploration drilling and development of groundwater wells.

Addition investigations were identified and conducted including groundwater well status investigation, by using visual inspection of groundwater well status and quantitative use of groundwater well data.

The development of hydrogeological database includes 3 objectives as follow

1) To provide a ready information for the purpose of analysis, interpretation and reporting
2) To be a database for mapping the hydrogeology and groundwater detailed map scale of 1:50,000
3) To be used as part of the provisioning hydrogeology data system

HYGIS consists nine layers of data as follows: 1) Fundamental geographic layers, 2) Geologic layers, 3) Hydrogeological unit layers, 4) Groundwater well location layers, 5) Groundwater level layers, 6) Groundwater availability layers, 7) Groundwater quality layers, 8) Groundwater utilization layers and 9) Hydrogeological cross- section layers.

All these data sets were arranged into 9 main layers under the HYGIS data configuration prior to the spatial analysis or the determination of relationship of all data map into map format. For map making process, the overlay method of various layers of data was applied on the geographic information system (GIS) mapping techniques. Due to the limited numbers of sample which will be used for data processing and analysis. The groundwater map and hydrogeological map on scale 1:50,000 are presented in below figures.

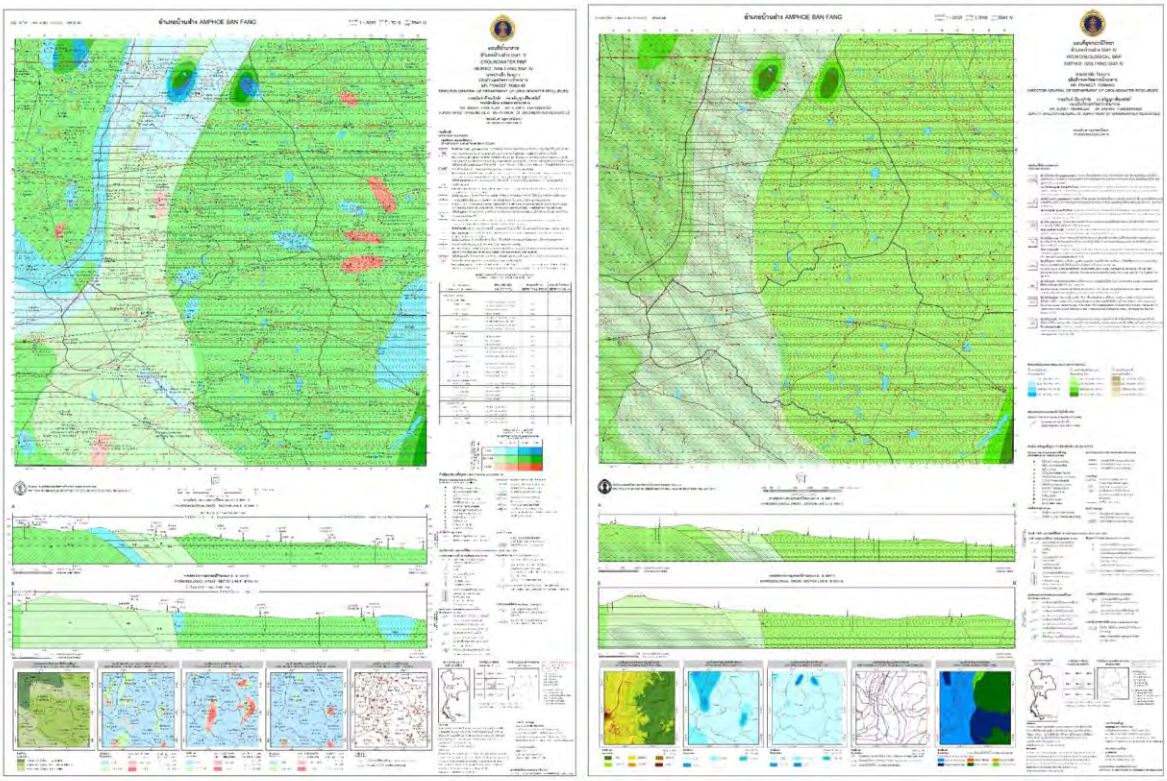

Fig.3. Groundwater Map and Hygrogeological map on scale 1:50,000 on Sheet 5541IV.

Groundwater mapping and hydrogeological mapping aim to present different data layers which are complex enough for providing necessary information to meet map's objectives. Groundwater map presents data layers which users can understand easily. It consists 3 layers as groundwater quantity, groundwater quality, and depth to aquifer. Hydrogeological map, however, comprises 6 layers as groundwater quantity, groundwater quality, depth to aquifer and aquifer thickness, amount of groundwater use, hydrogeological units, and groundwater level and flow direction as shown in Table 1.

Table 2. Complex level of hydrogeological map and groundwater map following IAH standards.

Complex level following IAH standards		Complex level of data in hydrogeological map	Complex level of data in groundwater map
Complex level of data →	A	1st layer, groundwater quantity	1st layer, groundwater quantity
	B	2nd layer, groundwater quality	2nd layer, groundwater quality
	C	3rd layer, depth to aquifer and aquifer thickness	3rd layer, depth to aquifer
	D	4th layer, amount of groundwater use	
	E	5th layer, hydrogeological units	
		6th layer, groundwater level and flow direction	

Groundwater level and flow systems in various hydrogeological units were partly from processing and interpretation of all available data. It can be concluded that the groundwater flow direction was obviously from higher groundwater level to the lower, physically from edges of the catchment area and central operating area to the lower elevation areas along Tributaries of these main rivers.

Groundwater quantitative potential of groundwater resources is theoretically determined by a complication and reconciliation of analytical pumpage data and exploration and development data of each well. The groundwater quantitative can be represented by the ranges between less than 2 cubic meters per hour, more than 2 and 10 cubic meters per hour (>2-10 cu.m./hr.), more than 10 and 20 cubic meters per hour (>10-20 cu.m./hr.) and more than 20 cubic meters per hour (>20 cu.m./hr.). The higher yield (>10 cu.m./hr.) areas are found in in small scattered areas throughout the operating area, particularly in Mueang and Ban Had district of Khon Kaen.

Groundwater quality in unconsolidated aquifer is blackish and salty. Some areas in Khon Kaen are accumulated by salt layers which salt can be eroded by rain, flows, and accumulates in plain areas. Therefore, groundwater quality is blackish or salty. Groundwater in consolidated aquifer is similar to in unconsolidated aquifer.

Groundwater quality in Khon Kaen can be represented by Total Dissolved Solids (TDS), and is characterized as the following:
1) TDS is less than 500 milligram per liter (mg/l), groundwater quality is excellent.
2) TDS is between 500 and 1,500 milligram per liter (mg/l), groundwater quality is moderate.
3) TDS is more than 1,500 milligram per liter (mg/l), groundwater quality is poor.

This area can be found the higher total dissolved solids in these area were found in aquifers underlain by the lower Phu Thok Formation (KTpt1)

4. Groundwater Management in Khon Kaen, Thailand

DGR has an important role in supplying groundwater as a secondary source of water for consumption and domestic use, and managing groundwater resources in Thailand. We have different bureaus and divisions to work under the DGR's policies in order to manage all aspects of groundwater resources, and to achieve DGR's targets. DGR has the central office in Bangkok and 12 regional offices in different provinces as Lampang, Suphanburi, Saraburi, Khon Kaen, Nakhon Ratchasima, Trang, Kamphaeng Phet, Ratchaburi, Rayong, Udon Thani, Ubon Ratchathani, and Songkhla in order to drive groundwater projects and manage groundwater throughout Thailand.

Groundwater management of Department of groundwater resources, DGR use Groundwater Act (1977) and amendments has contained provisions for: Controlling the exploration and drilling for groundwater; Use of groundwater; Protection and conservation of groundwater resources; Groundwater operating licenses requirement for state agencies or organizations that use groundwater in critical areas; Identification of restricted and groundwater-pumping zones, Groundwater-charging rates, Penalties and fees for groundwater activities, Advancement of knowledge for well drillers.

Nowadays, a rapid population increase and fast economic development have significantly affected the demand of groundwater. DGR have established various groundwater projects such as supplying groundwater for consumption, domestic use and agriculture, supplying drinking water for schools, and carried on different research and studies on groundwater resources.

In the part of the management of groundwater resources. DGR can be use the outputs of these maps is therefore the groundwater volume or transmissibility which can be developed and brought up for consumption .Since 2008, DGR has carried out the Groundwater map at a scale of 1:50,000 are designed for non-technical users and shows groundwater resources information up to the village level. It can be used for effective groundwater well site selection and drilling according to groundwater potential (quality and quantity) information. In addition, hydrogeological map at a scale of 1:50,000 are a helpful primary data sources for technical users since it does not show only groundwater resources information but also aquifer hydraulic properties and characteristics.

Currently DGR is providing the project of the training the local administrators that the main objective of this project is to provide the knowledge and understanding on the groundwater map to the local administrators who are responsible for developing groundwater resources for public consumption in areas of responsibilities.

Fig. 4. The training courses for the local administrators on using groundwater map

In addition, the Project of Groundwater Development against Chronic Drought was carried out with the aim to provide groundwater with suitable quality for people in the water scarcity areas.

Besides, DGR can be established the Project on Information Technology Development Project for Surveillance and Monitoring of Groundwater Operation which to collect and store water level data to monitor water level decline as well as changes in water quality from routine work and put into geographic information system and to design and develop an automatic real-time surveillance and monitoring of groundwater operation system network with the data from observation wells. The management of groundwater database for the decision makers can utilize this database properly once the nation encounters groundwater crisis. Moreover, monitoring of groundwater operation system able to support the groundwater situation forecasting system for groundwater resource management.

5. Conclusions

By conducting the projects of groundwater mapping on scale 1:50,000 in Northeastern Thailand, we find that data imported into maps and HYGIS need to be improved in order to increase map reliability. The more reliable map, the better information supporting groundwater planning and development. Therefore, DGR will continuously improve groundwater map so that it can be confidently utilized to support decision - making for optimal groundwater planning and development.

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III-3-(8)
Groundwater database of Red River Delta, Vietnam

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Abstract

The research aims to accommodate the safeguard the health of the people, able to serves agricultural and industrial production. The research aimed to elucidate the Groundwater in the Red River Delta exists in 3 main aquifers: including Holocene aquifer (qh), Pleistocene aquifer (qp), Neogene aquifer (n) (mainly for the two main aquifers of Holocene and Pleistocene) the depthof distribution, the thickness, water conductivity, groundwater dynamics and the relationship between them also with recharged water sources. Furthermore, showing the Groundwater monitoring network about level as well as quality by including manual and semi-automatic, the groundwater level in the Red River Delta towards decreasing, really complex, averaging 0.7 m/y, the concentration of Arsenic in large groundwater, saltwater intrusion, from that problems can be discovered early to find solutions.

Keywords: Red River Delta, Groundwater, Hydrogeology, Monitoring

I. Introduction

Vietnam has abundant groundwater resources but is unevenly distributed not only by territory but also over time. The exploitation of groundwater is strong in urban, rural areas as well. Calculation of groundwater resources in Vietnam in general, the Red River Delta and the Southern Delta, in particularly, that is how to exploit and sustainable use, prohibit or unprohibited the exploitation of groundwater in Hanoi and Ho Chi Minh City able to serve citizen at sand dunes, prohibition or exploitation of groundwater for ore extraction in coastal strips of the North, South Central Coast... There are many legal issues already decided but applying to reality see various problems. The conflict between environmental protection, water resources protection, exploitation and using of water sources for different purposes; the conflicts between them is complicated.

The Red River Delta is located in the northern part of Vietnam (Fig. 1). This delta with its flood plain covers an area of 21,063 km^2 and inhabited by a fast growing population, which in 2010 numbered 19.8 million inhabitants (General Statistic Office 2011). In the rural areas, the socio-economic activities are based on intensive agricultural production of mainly rice and vegetables, with an irrigation system based on surface water. In the urban areas, e.g. Hanoi and Haiphong, the growing population and increasing industrial activities result in an increasing use of potable water, which in the Red River flood plain comes from groundwater abstraction. Even though the Red River flood plain cannot be characterized as a region of water scarcity, water quality problems can locally lead to critical situations. The main groundwater quality problems are elevated concentrations of arsenic, manganese, ammonium and iron and the occurrence of salty groundwater.

2. Hydrogeology in the Red River Delta, Vietnam

2.2.1. The aquifer

The Red River Delta is composed of unconsolidated sediments of quaternary, directly covering the hard foundations of the Cenozoic formations to Proterozoi. The hydrogeological section is divided based on the geological section (Fig. 2). The development of the delta is associated with the process of sediment accumulation but due to the influence of the progressive seas, the sea recedes, the quaternary sediments are mainly riverbeds and mudflats where there are alternate lakes, swamps, and the sea. Geological tectonic activities cause the bottom of the delta to be divided into sections, low-lying areas overlapping pillows, lifting blocks... dragging the thickness, the unconsolidated sediment composition changes, there is quite a strong place within paralysis and mutation.

According to various researches have been published, based on lithological composition - general and hydrogeological characteristics such as permeability, hydrodynamic characteristics... The hydrological quality by RRB has 21 aquifers. However, this research is limited with only two porous aquifers in the quaternary distributed widely in the research area. Neogen formations are researched relatively fully are being exploited the most, only the above-mentioned aquifers are described in detail.

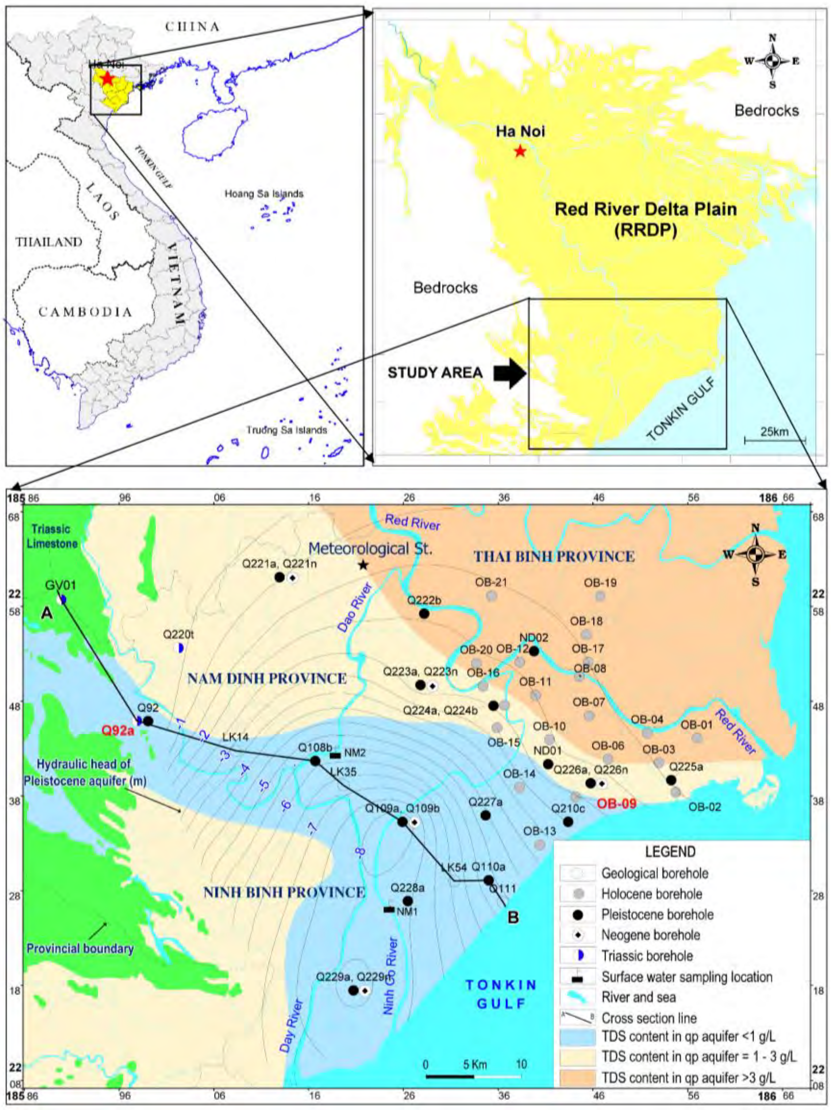

Figure 1. Red River Delta plain and Nam Dinh provice location

2.2.1.1. Holocene aquifer (qh)

This is the first aquifer from the ground and widely distributed from the center to the East Sea, Hanoi and surroundings have appeared a narrow band along the Red River and narrow valleys in the valley between the mountains and other small rivers.

The depth of the layer from 2 - 8 m in Hai Duong and Hung Yen areas where soil and rock contain water on the ground, in another hand, there are also places distributed at 19 - 20 m. The part from Nam Dinh-Thai Binh to the East Sea is often larger, sometimes up to 40 - 45 m. The depth of the bottom of the layer is 20 - 30 m, in Nam Dinh-Thai Binh 40 - 50 m, particularly to 54 m. The thickness is about 10 - 20 m, able up to 30 - 40 m, especially on the edge of the area with only 1.5 - 3 m. The average thickness of the whole area is 13.6 m. The petrographic composition is all kinds of sand, the bottom layer has gravel and little pebbles. Flow of experimental boreholes 0.6 l/s to 5 - 10 l/s; flow rate varies from 0.1 to 20.87 l/sm. The specific yield coefficient tends to increase from the edge of the valley to the river, from 0.015 - 0.05 in remote areas to 0.09 - 0.17, an average of 0.1 in the coastal zones.

2.2.1.2. Pleistocene aquifer (qp)

This is the most researched and most detailed main aquifer being exploited to serve the economy of the people in Hanoi, Vinh Phuc, Son Tay, Ha Dong, Bac Ninh, etc. It is widely distributed and covered deep except for a few exposing areas with a narrow area in Phuc Yen and Soc Son. From Hanoi to the East Sea of the qp stratum is located in the qh floor and between them there is a layer to prevent weak water infiltration, the thickness of this weak permeable layer changes in a very wide range from 0.6 to 55 m. In the Northwestern part of the plain, because the qh layer only exists as a narrow band along the Red River, most of the qp area is covered by a weak permeable layer. In addition, the intrusion activities have completely cut off the separation layer, making the two aquifers lying directly together forming a single hydrodynamic system. The qp aquifer is composed of two layers: the upper layer is fine-grained sediment, and the lower layer is gravel, coarse-grained sand.

The upper layer (qp2) is mainly composed of fine-medium sand and gravel whose thickness varies from 1 m to 55.7 m. The discharge ranges from 0.57 to 10.82 l/s; the rate of flow from 0.037 to 5.35 l/s. The coefficient of water release is from 0.04 to 0.24.

The lower layer (qp1) is mainly composed of gravel and medium-grained sand, large water resources. The thickness of the product layer varies in a wide range from 4 to 60.5 m, an average of 25 - 30 m according to the rule of increasing from the edge to the center and from the top to the sea. However, due to the influence of neotectonic activities and the process of invasion of the river, the original rock foundation was raised and lowered unevenly, forming deep and alternating lift edges making the layer surface tend to sink deeper towards the sea. If in Son Tay, Dan Phuong (Hanoi) is the depth of the pebble, gravel, gravel, sand layer is usually only 15 - 20 m, then to Van Dien (Hanoi) is 30 - 40 m; to Cam Giang-An Thi-Khoai Chau-Hung Yen is 50 - 60 m. And in Nam Dinh-Thai Binh increased to 70 - 80 m, some places up to 100 m. The volume of boreholes exploiting near the river reaches 50 - 80 l/s, the projects far from the river are 20 - 30 l/s. The coefficient of release of elastic water reaches from one percent to several thousandths.

These two aquifers form a unified hydraulic system with a common water surface. The qp aquifer is a pressure aquifer. The hydraulic head changes in a very wide range, following the increasing rule from the top to the sea. In Vinh Tuong, Lap Thach, Dong Anh, Son Tay, Dan Phuong, and Hoai Duc, the value of the qp aquifer averages 10 - 20 m, in some places less than 5 m. In Van Dien, Gia Lam and Tu Son, the average pressure is 20 - 30 m, sometimes up to 40 m. In Cam Giang - My Van, An Thi - Khoai Chau, Hung Yen, Phu Ly - Phu Xuyen - Thuong Tin has average of 30 - 40 m, some places up to 50 m. In Nam Dinh, Thai Binh increased markedly by 50 - 60 m on average, sometimes up to 85 m.

Pleistocene aquifer is formed mainly by infiltration from the rain on the surface of the aquifer above the ground. The intensity of infiltration has been determined in some areas as follows: Vinh Tuong and Lap Thach 458 mm/year; Son Tay 192 mm/year, Dong Anh and Da Phuc 158.8 mm/year, Bac Ninh 82 mm/year, Dong Trieu and Pha Lai 69 mm/year. Pleistocene aquifer also receives continuous supply from river water. As mentioned above, the RRD has a quite dense river network, most notably Red River, Day River, Cau River, Da Bach, Thai Binh, Luc Nam, Hoang Long, Ninh Co Rivers, etc. Role the rivers supply to groundwater varies widely, even for the same river. Red River from Viet Tri to Hung Yen between surface water and groundwater has a direct hydraulic relationship, the amount of river water supplied to the aquifer with the permeability module is 37,000 m^3/day/km of coastline. While the section from Hung Yen to the sea, the relationship between them is indirect, so the supply from the river for the aquifer is limited. Day River section in Yen So - Ha Dong and Phu Ly between surface water and groundwater are directly related to the quantity supplied 710 m^3/day/km of coastline. For Cau River, Hoang Long, Da Bach, Duong, Nhue River and Thai Binh Rivers, etc., there is no relationship between river water and groundwater, and the quantity of infiltration is often very small. For example, the quantity absorbed of Nhue River water is only 80 m^3/day/km of coastline. Another important factor in the formation of groundwater reserves, especially for porous aquifers, is the vertical penetration of water from the aquifer to the other aquifer. Due to the impact of groundwater extraction, the difference in water level between the two layers increases and the infiltration amount also increases, which is 10 times larger (6.91 l/s km^2) than in natural conditions. Pleistocene aquifer drains mainly to the sea, rivers, lakes, ditches, swamps, evaporates and penetrates

2.2.1.3. Neogene aquifer (n)

Neogen aquifer is distributed mainly between two Chay-Lo rivers rifts from Tam Dao to the East Sea. To the extent of Thanh Oai and Cam Binh districts, the aquifer is extended to Hai Duong-Hai Phong fault in the North and Red River fault in the South. Most of the distribution area of aquifers is submerged under Quaternary sediments. The part near to Viet Tri, the aquiferis usually distributed 5 ÷ 10 m above the ground, but on the sea, the distribution depth increases to 100 ÷ 130 m is larger. The depth of lying in the aquifer according to statistical data of 137 boreholes showed that the depth of 30 m accounted for 8.8%; depth (30 - 40) m: 14.6 %; (40 - 50) m: 8.8 %; (50 - 60): 5.8 %; (60 - 100) m: 48.9 %, deeper than 100 m: 13.1 %. Petrographic composition varies from the place in depth with different permeability and water content. In Vinh Tuong, Lap Thach, Quat Luu-Xuan Hoa, Son Tay-Dan Phuong and along the edge of the plain, mainly rolling, conglomerate, gritstone, sandstone interbedded with siltstone, claystone, coal clay lenses poor water.

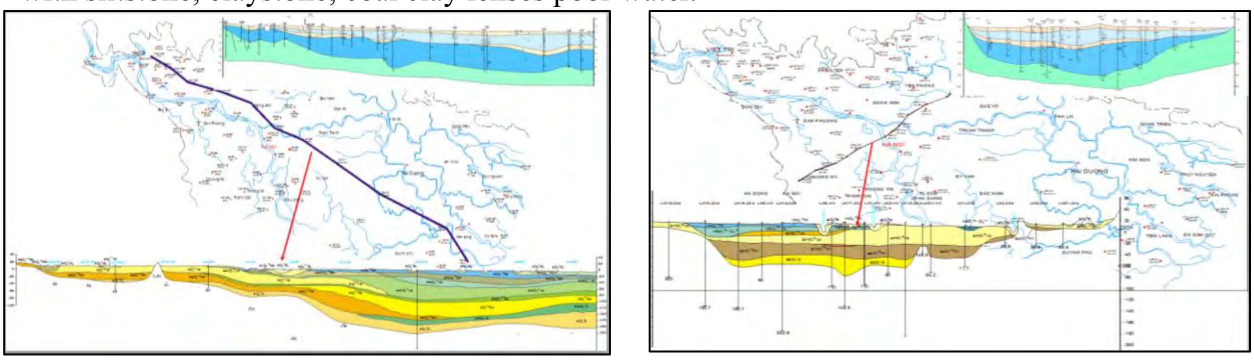

Figure 2. Geological and hydrogeological sections of the Red River Delta

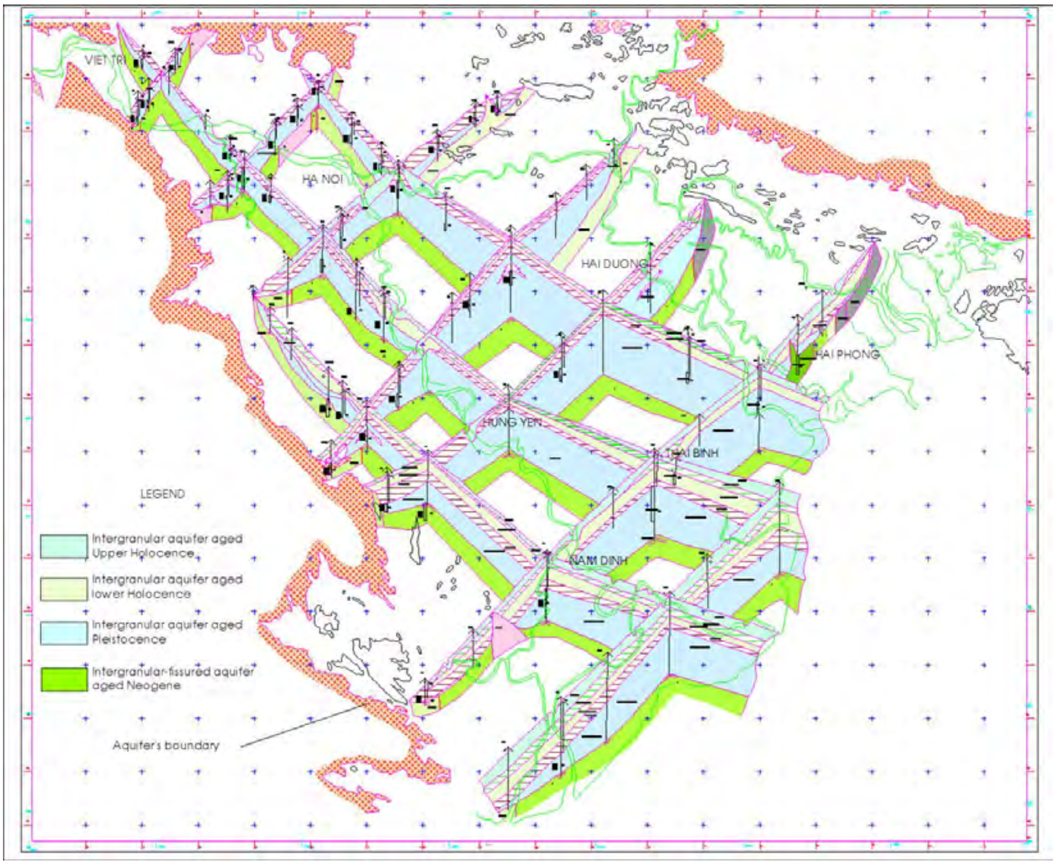

Figure 3. Geological structure of Red River Delta

2.2.2. Groundwater dynamics

As previously mentioned, the quaternary sediments in the Northern Delta are divided into two main aquifers. In the top-down order, the Holocene aquifer is located above and the Pleistocene layer is below. Based on the results of monitoring groundwater resources in 2013 and May 2014, the picture of groundwater resources development can be summarized as follows.

The national monitoring and groundwater control network in the Northern Delta was established in 1990 and basically completed in 1995 on an area of 17,000 km^2. Currently, there are 77 stations with 140 monitoring works (each station has from 1 to 3 works); 06 routes with 49 monitoring works to study hydraulic relations between surface water and groundwater (Red River, Thai Binh River, and the East Sea); 03 balance stations; 10 stations for surface water monitoring. The aquifer in quaternary sediments has 133 structures and the aquifer before quaternary has 7 missions. The monitoring works are distributed in the area of 12 provinces including Vinh Phuc, Ha Tay - Hanoi, Bac Ninh, Hung Yen, Ha Nam, Ninh Binh, Nam Dinh, Hai Phong, Thai Binh, Hai Duong and reach 80 km^2 density/monitoring works. In the Northern Delta region, Hanoi City has invested in building a network to monitor the dynamics of groundwater including 67 stations with 117 projects. In which, Holocene aquifer has 47 works; Pleistocene aquifer has 62 projects; Neogen aquifer has 3 works and surface water has 5 works. Currently, monthly and quarterly information from the Center for Warning and Forecast of Natural Resources directly under the National Assembly and National Water Resources Center updated on the website of the Ministry of Natural Resources and Environment (MONRE) about the dynamics of groundwater within a report.

Table 1. Distribution of groundwater of Red River Delta

Aquifer	Year	Area (km²)		
		TDS<1 g/l	1≤TDS≤3 g/l	TDS>3 g/l
Holocen (*qh*)	2005	3,307	2,589	5,565
	2013	3,915	2,524	5,022
Pleistocen (*qp*)	2005	7,743	3,534	1,226
	2013	7,555	3,347	1,601

3. Groundwater monitoring network and their hydrological data in the Red River Delta

3.1. Water level monitoring

The groundwater monitoring network in the Red River Delta has 198 monitoring points, including 82 manual observation points and 116 semi-automatic monitoring points.

Manual monitoring mode

- For hydrodynamic measurement points: the rainy season measures the regime 10 times/month, the dry season measures the regime 5 times/month.

- For meteorological regime measurement points: the rainy season measures the regime of 10 days/month, the dry season measures 5 days/month. The dry season is calculated from November to April, the rainy season from May to October.

- In the tidal influence, the zone has measured 12 times a day at odd hours. The water temperature only measured once at 13 o'clock.

Semi-automatic monitoring mode

Self-recorded devices are prioritized to be installed in the monitoring areas affected by mining activities, tidal influences with the following monitoring frequencies:

- For self-recording heads installed in areas affected by mining operations, the frequency of measurement is 12 times/day.

- For self-recorded heads installed in tidal affected areas, the frequency of measurement is 24 times/day.

Semi-recorded devices are checked periodically twice a month on the 6th, 24th of the month, 2 times to collect data on the 15th and 30th of every month.

3.2. Water quality monitoring

Water sampling is carried out twice a year, in the dry and rainy seasons. The requirement for periodic sampling is the time when the water level reaches the biggest and smallest extremes of the year.

The criteria for uniform analysis of the entire groundwater observation network include: Comprehensive samples: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, CO_3^{2-}, CO_2, NH_4^{+}, Al^{3+}, NO_3^{-}, NO_2^{-}, desiccant, pH, hardness, physical properties; Iron samples: Fe^{2+}, Fe^{3+}. Contaminated samples: NH_4^{+}, NO_3^{-}, NO_2^{-}, PO_4^{3-}, COD, Eh.

Particularly for microelements, the analysis criteria in each region are specified on the basis of geochemical characteristics of each region, analysis of arsenic (As), mercury (Hg), selenium (Se), chromium (Cr), cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn), manganese

(Mn).

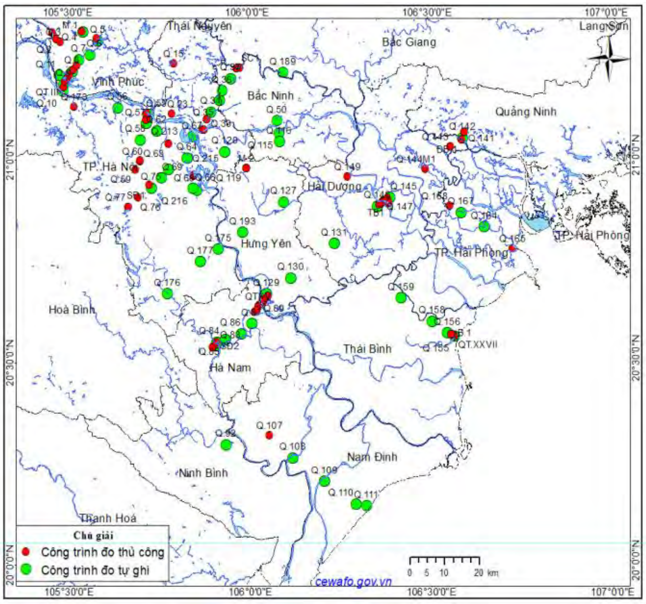

Figure 4. Monitoring network in Red River Delta

4. Groundwater issues and groundwater management

4.1. **Decline in groundwater levels**

Groundwater level in the Red River Delta tends to decrease, averaging 0.7 m/y. Water level forecast shows a continuous downward trend.

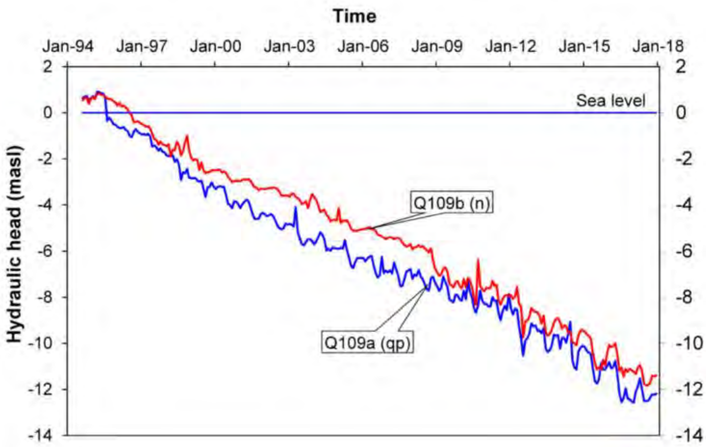

Figure 5. The hydraulic heads of the groundwater have been consecutively monitored in boreholes Q109a and Q109b since 1994 indicating the inter-aquifer leakage between the two aquifers due to the over rate of freshwater mining from the Pleistocene aquifer

4.2. **Groundwater contamination**

The distribution of groundwater as concentrations is illustrated (Fig. 6). Maps depicting the spatial distribution of an additional 32 chemical parameters are provided in the hydro chemical atlas. Arsenic concentrations were found to vary greatly throughout the delta (< 0.1 -

810 µgL-1) and 27% of the wells exceeded the WHO guideline value of 10 µgL-1. Our results imply that some three million people are currently using groundwater burdened with As concentrations > 10 µgL-1 and one million people use groundwater containing > 50 µgL-1, with both rural and urban populations being affected by toxic levels of As. The highest concentrations are present in a 20 km wide band along the NW-SE boundary of the delta plain, to the SW of the modern Red River course, and coinciding with the location of the palaeo-Red River channel (9,000 y B.P.). The spatial distribution of As in this region matches a pattern of elevated, and dissolved organic carbon (DOC) concentrations, along with negative redox potentials (Eh) and low sulfate (SO_4) concentrations indicating anoxic groundwater. These conditions are the trigger for reductive dissolution of iron phases and subsequent release of surface-bound as.

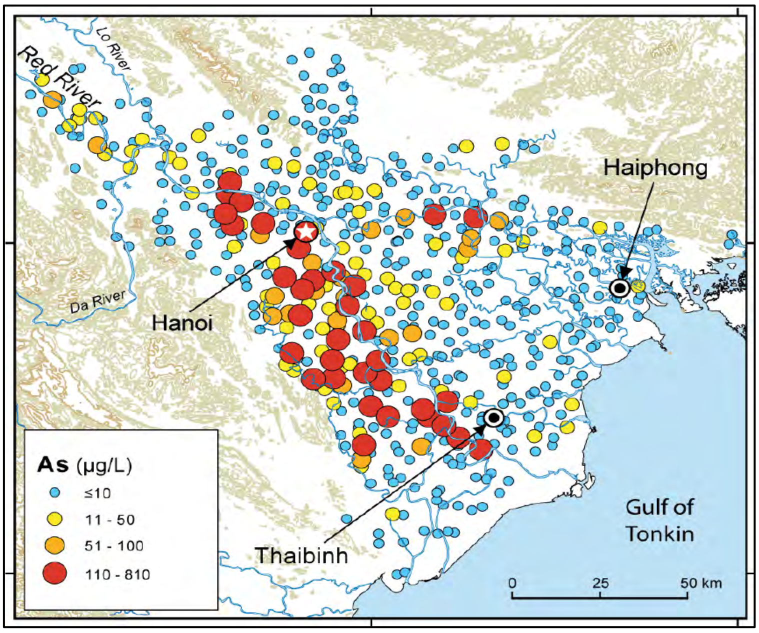

Figure 6. Arsenic in the Red River Delta

4.3. Saltwater intrusion

Deep aquifer (Pleistocene aquifer)

The results of the analysis of salinity of the water in 2018 at most monitoring works are smaller than 1,500 mg/l (fresh water), some places exceed the allowed limit:

Salinity from 1,500 – 3,000 mg/l (brackish water) distributed in monitoring works in the provinces of Hung Yen, Hai Duong, Thai Binh, Ha Nam, Quang Ninh (Holocene aquifer); Hai Duong (Pleistocene aquifer).

Salinity > 3,000 mg/l (saline water) distributed in monitoring works of provinces and cities: Hai Duong (qh); Hai Duong (qp).

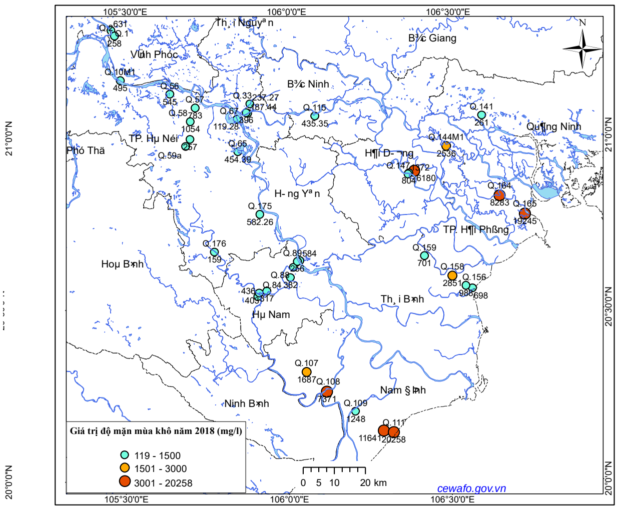

Figure 7. *Salinity distribution in dry season in the qh aquifer*

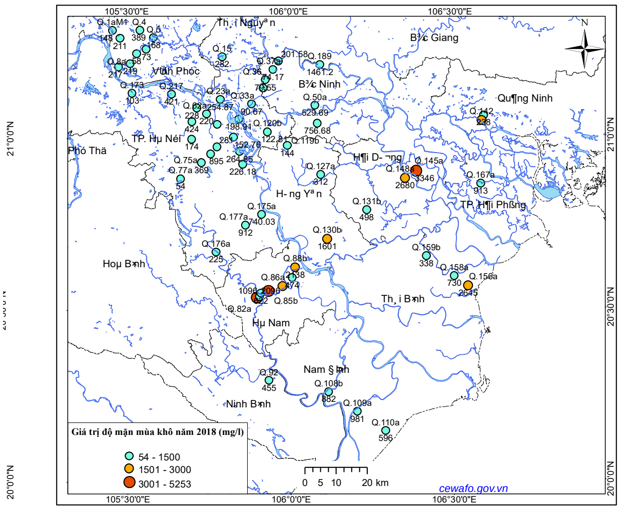

Figure 8. *Distribution of salinity in dry season in qp aquifer*

4.4. Groundwater management in the Red River Delta

In order to strengthen more effective measures for management and protection of groundwater resources, MONRE has now developed and submitted to the Government for promulgation a Decree regulating the restriction of groundwater exploitation, in which, proposed specific and comprehensive regulations on delineation, approval, announcement and implementation of measures to limit exploitation of groundwater.

Currently, groundwater resources are exploited to supply for many different purposes, including mainly urban water supply, rural domestic water supply, water supply for production... Groundwater in Red River Delta is being degraded in both quantity and quality: groundwater levels are deeply and continuously lowered over time, especially in some big cities focusing on exploiting groundwater. The issue of large-scale centralized water exploitation in addition to leading to lower water levels is also the cause of saline intrusion and water pollution.

Recently, in order to manage water resources in general and groundwater in particular, the MONRE has advised and submitted to the Government for promulgation and promulgated according to its competence many legal documents, such as: Decree, detailing the implementation of a number of articles of the Law on Water Resources, including specific provisions on granting permits for exploration and licensing of groundwater to manage the exploitation and usage for groundwater exploration and exploitation projects with a volume of 10 m^3/day; prescribing the order and procedures for delineating, announcing and registering for groundwater exploitation projects of less than 10 m^3/day in the areas subject to registration exploitation of groundwater; The Circular regulates the determination and announcement of the area of sanitation protection for areas where drinking water is available (including the establishment of sanitation protection zones for groundwater exploitation projects); Circular on supervision of exploitation and usage (including monitoring and supervision of exploitation and use of groundwater); Circular on treatment and filling of unused wells; Circular regulating groundwater protection in drilling, excavation, exploration and exploitation of groundwater.

Getting more effective measures for management and protection of groundwater sources, the MONRE has now developed and submitted to the Government for promulgation a Decree regulating the restriction of exploitation of groundwater., in which, proposed specific and comprehensive regulations on delineation, approval, announcement and implementation of measures to limit exploitation of groundwater. At the same time, the MONRE has also focused on directing relevant localities and agencies to focus on the following main tasks: (i) Focus resources (human and financial) to accelerate the planning of water resources planning (including contents of groundwater planning) in localities; (ii) Accelerate the completion of Government Projects related to approved groundwater protection,

Conclusions

Groundwater in the Red River Delta exists in 3 main aquifers, the depth of distribution and the thickness of the aquifer decrease in the direction of NW-SE (towards the sea). The groundwater monitoring network is arranged evenly according to the area of the entire delta (mainly for the two main aquifers of Holocene and Pleistocene). The monitoring mode is established and works for the characteristics of the hydrodynamic regime of each region. Monitoring equipment including manual and semi-automatic. The groundwater level continuously decreases by an average of 0.7 m/y (for Pleistocene aquifer), according to the results of the analysis of groundwater samples, showing that the concentration of Arsenic in large groundwater is distributed in the south and southwest of the plain. Saltwater intrusion occurs in all aquifers. In measurement, the Holocene aquifer has a larger area than the Pleistocene aquifer.

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III-4-(1)
Current Status of Hydrogeological Issues in Cambodia

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Abstract

Cambodia is a flooded country during the rainy season and is a locally drought country during the dry season. Groundwater is not well-known for Cambodian society yet. Topographically, Cambodia is bordered by mountain range/plateau and has a flood plain in the center. The country is divided by two equally seasons which are rainy season (May to October) and dry season (November to April). During the rainy season, precipitation is high with the average annual rainfall up to 1,833 mm. In term of surface and groundwater interaction, Cambodia is categorized in four regions: Great lake region, Coastal zones, Upper Mekong region and lower Mekong region. Groundwater is store as pore water in the center and fissure-pore water in the other regions. There is a tendency to use groundwater and it is questioning on the possible negative issues such as arsenic content in the groundwater, groundwater drawdown due to the over-extraction of the groundwater in the emerging provinces such as Siem Reap and Kompong Som. Thus this paper will address some of those issues and the initiative to form a groundwater observation system in Cambodia starting from the pilot projects in Siem Reap and introducing to the administration of Kompong Som province.

Keywords: groundwater, hydrogeological map, Asia

1. Introduction

Cambodia situates in the southernmost Southeast Asian Mainland influenced by the Monsoon climate of tropical region, i.e. it is equally rainy and dry throughout the year. During May-October period, it is time for groundwater recharge and it is vice-versus from November to April. Water is very essential to the human life on Earth but there is different degree of interaction between the hydrosphere and human societies.

Hydrogeology is not well-known for Cambodian society yet. Surface water becomes the common use in the city where groundwater has been recently used in the remote areas. However, nowadays there is tendency to use groundwater instead of surface in order to replace the costly urban water supply.

This paper will reflect the current influence of groundwater to Cambodian society and will share some possible action plan to deal with groundwater issues in Cambodia.

2. Geology and Hydrogeology in Cambodia

Cambodia is part of Indochina craton which was influenced by subsequent micro-continent break down and collision (Metcalfe, 2009). As a result, Cambodia shows high relief along the border with shallow rocky bed and has flood plain in the central part thick sediment cover (Fontaine and Workman, 1978) (Fig. 1).This topographical and geological conditions control the interaction between surface water and groundwater.

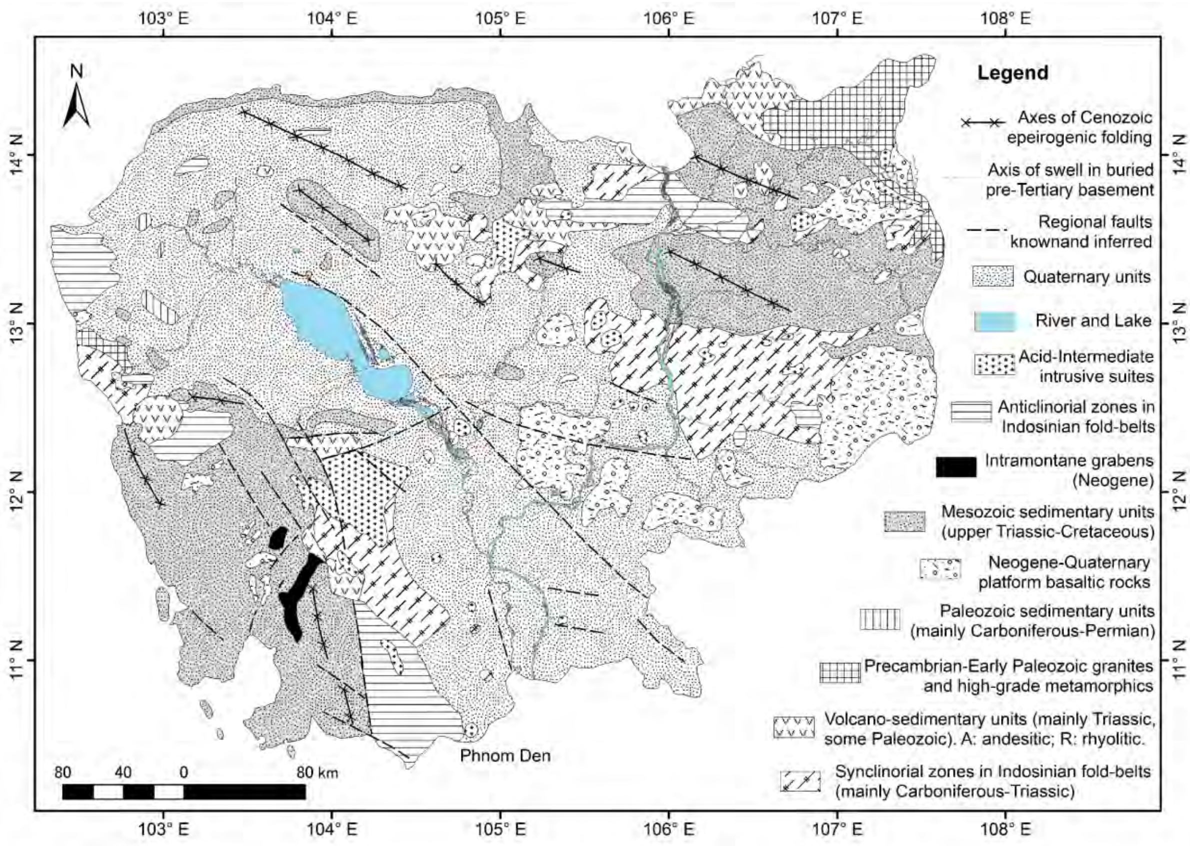


Fig. 1. Geological map of Cambodia (Fontaine and Workman, 1978)

As part of the tropical region, Cambodia obtains high annual rainfall up to 1,833 mm with average up to 28 °C based on the average climatic data from 1901 to 2015 recorded by the World Bank Group's portal on Climate Change Knowledge (Figure 2). There is two main river system, i.e. Mekong River and Tonlé Sap (Great Lake) system. Mekong River is the main source of water in Cambodia flowing from Lancang River, China. Tonlé Sap River system connects with Mekong River in Phnom Penh discharging to Mekong River during dry season and recharging from Mekong River during rainy season.

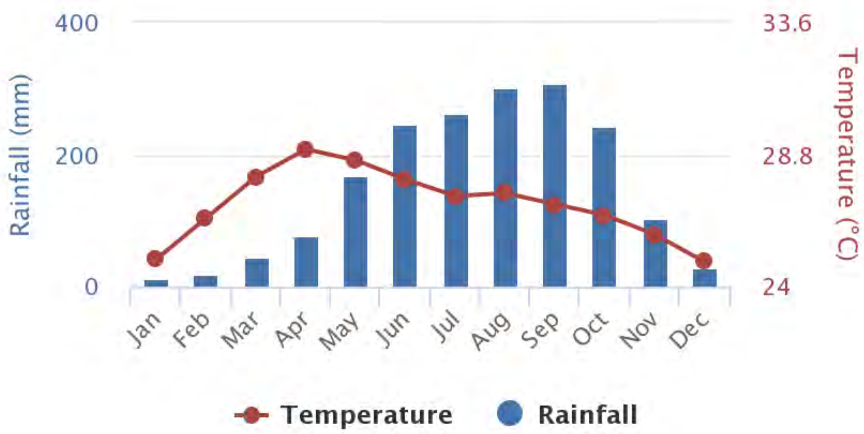
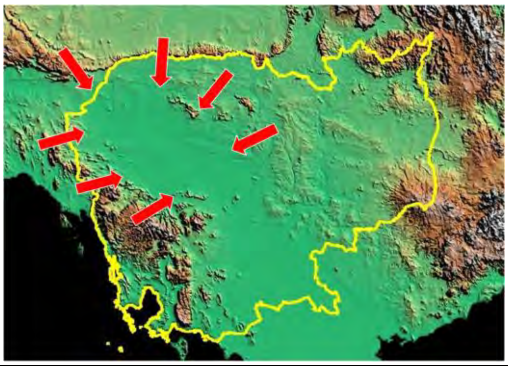
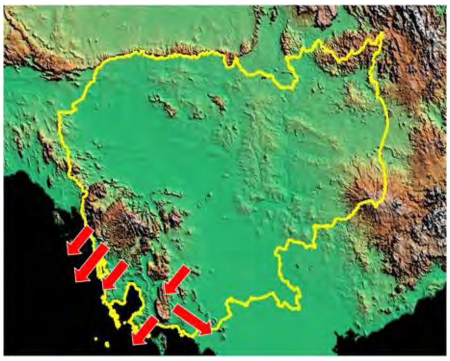
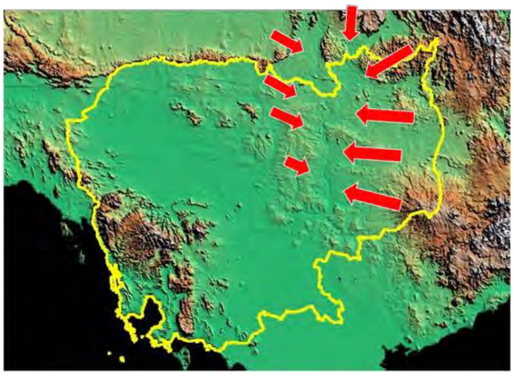
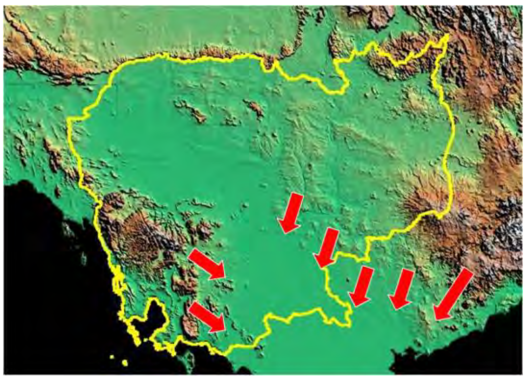


Fig. 2. Average annual rainfall (World Bank Group's database)

The surface and groundwater interaction in Cambodia is divided into four regions:

A. Great Lake region: this region is predominantly covered by Triassic sedimentary rocks and Quaternary sediment. Run-off from Krovanh Mountain range in the West and Dangrek Mountain range (Korat Plateau in Thailand) and Phnom Koulen in the North flows and infiltrate to recharge to the Great Lake and respected groundwater reservoir. The groundwater discharges are observed from the fissure-pore water in the Triassic-Jurassic bedrock (Predominant sandstone) as spring water occurring in Pursat, Koh Kong and Phnom Koulen in addition to the localized groundwater discharge from pore water to the river/stream.	B.Coastal zones: this region is predominantly covered by sedimentary rocks. Run-off from Phnom Aoral in Kompong Speu as part of Krovanh Mountain rage in the localized North and from Bokor mountain range in the localized East flows to tributaries and Karst system in Kampot region. The groundwater discharges are observed from the Triassic bedrock as spring water in Kirirom (Kompong Speu), Kbal Chhay (Kompong Som), Pich Nil and Bokor (Kampot) and from Permian Karst in Kompong Trach (Kampot).
	
C. Upper Mekong region: the run-off is collected by two rivers: Mekong from Lao PDR and Se San River from Annam Highland Viet Nam. This region is covered by igneous rocks from different sequences. Thus there is limited groundwater-surface interaction except the local waterfall system observed in Ratanakiri and Mundulkiri associated with Quaternary basalt.	D. Lower Mekong region: this area is covered by predominant loose sediment of the Mekong delta. The recharge is controlled by the Mekong river input. The groundwater is stored in the thick loose sediment up to more than 100m in Kean Svay.
	

3. Hydrogeological Problems in Cambodia

With the emerging economy, Cambodian society starts to think about groundwater resources. Cambodia is a flooded country however, there is also deficit of surface water in the dry season. Thus there is a tendency to use groundwater in the remote areas where there is shortage of surface water. Yet there is no specific institution who deals regularly with groundwater issues in Cambodia.

Arsenic and iron content in the shallow groundwater is one of the groundwater issues observed in the lower Mekong region and some places of Kompong province and Siem Reap province. The source of the Arsenic and Iron is still ambiguous.

Another issue is the groundwater drawdown. It is observed from some emerging provinces such as Siem Reap and Kompong Som. In Siem Reap, due to the high demand of water supply for hotels and restaurants it may cause the groundwater drawdown especially during the dry season which surely affect the foundation of the Angkor Wat temple. The world heritage is built on the shallow foundation sit on aquifer. Fortunately there is a special groundwater monitoring program conducted by APSARA (Authority for the protection of the site and the Management of the Region of Angkor) in the Siem Reap town and Angkor Wat site. In Kompong Som, there are recently fast growing of hotels, restaurants and Casinos. This coastal province is limited in water supply. The only water source locates at Kbal Chhay. The increase of groundwater extraction may cause the salt water intrusion along this coast and its vicinity.

4. Plan of Groundwater Observation System in Cambodia

In Cambodia, there is no national groundwater observation system yet except the area of APSARA for the purpose of world heritage conservation program. The system of APSARA is working because it has the influence in the construction permit application. However, groundwater observation system need to be initiated using this model. Department of Geology, Ministry of Mines and Energy will start the pilot project with APSARA to build a provincial groundwater observation system. This initiative will be introduced to other emerging provinces as well before it can reach the National level.

5. Conclusion

In Cambodia, there is time break and limited access to water. Groundwater is key to water supply in Cambodia especially during the dry season. Thus, national groundwater monitoring system has to be formed in order to control the sustainability of the hydrogeological condition. The pilot project could be done starting from Siem Reap province and then Kompong Som province. However, budget for the drilling may slow down the progress.

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III-4-(2)
Groundwater Management in Lao PDR

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Abstract

This country report purpose to present the situation of ground water management in Lao PDR. Laos is landlocked country and located in south-East Asia with approximately 7 million of population. There are two seasons as dry and rainfall season. Agriculture is main activity for economic development. People need water resources for agricultural and needed the water supply options. One of these options is groundwater.

Since the early 1990s the Japan International Cooperation Agency (JICA) has been support groundwater at the village, providing water access to the villagers by constructing various community wells throughout the village community objective for hygiene aspect. Groundwater is also used for domestic purposes also use groundwater for supplementary irrigation in the wet season and exclusively in the dry season. In the rural area each household has at least one well; some have three or four wells, depending on the scale of the agricultural activities.

This report shoes the information on the situation of ground water management in Laos. In tern of aquifer study groundwater is emerging as a large and generally untapped resource. However, there is very little monitoring of groundwater quality in the country. Moreover, the report expressed the situation of data information of ground water in Xebanghieng Basin. Hydrological Problem also expressed thought sample of Nam Ngum River Basin some data regards to climate setting, rainfall, evaporation, flow, water usage are express in this paper. The next step for Groundwater observation system setting is plans to set up in Savannakhet Province of Lao PDR.

Keywords: groundwater management, Geology, Hydrogeology, hydrogeological and Groundwater observation.

1. Introduction

Lao PDR located in a central position in the Southeast Asian Region. There is approximate total population of 7 million and total area of 236,800 km^2. There are 17 provinces with 148 districts. Around 90 percent of the country is within the Mekong basin, accounting tapproximately 35 percent of the total area of Mekong river basin.

In the past, there was little interest in groundwater resources due to Lao PDR plenty of surface water resources. Groundwater is an important source for rural people, particularly in the area far from surface water (no perennial rivers).

Use of groundwater can increase food security in regions such as Savannakhet, by increasing the number of crops per year. Around 80 % of the rural population use groundwater for household purposes an at least 25 town water supply schemes & some factories currently use groundwater.

There is no formal mechanisms for data collection, compilation and storage and has no protocols or government entities tasked with groundwater management projects, nor for strategic planning.

There is no regulatory framework for groundwater usage and monitoring yet. Information on groundwater resources (quantity, quality) is very limited. Monitoring and evaluation activities for groundwater are not carried out to any significant degree. However, there are recently a small number of projects and activities that focus on groundwater for specific reasons that provide isolated pieces of insight.

In conclusion, Groundwater information is limited in the country. Groundwater is an important source of drinking water and use water for rural people and less in city, particularly in plateaus located far from surface water such as the South and the West of Champasack province, Xe Bang Hieng and Xe Don Plateaus. In addition, monitoring and evaluation activities on quantity and quality of groundwater have not yet carried out systematically and regularly *(draft of National Water Strategy 2020 and 5 years action plan 2011-2015, MoNRE, 2011)*

2. Geology and Hydrogeology in Lao PDR

In Term of aquifer there are eight aquifer units have been described and evaluated: (i) Basement aquifers (ii) Volcanic aquifers (iii) Schists (iv) Paleozoic sedimentary (v) Karsts (vi) Limestones (vii) Mesozoic sedimentary (viii) Alluvial sediments. Aquifer map is below.

Areas of Significant Groundwater Importance

- **Alluvial aquifers** extend over limited areas and limited thickness, however, with both high storage and important yields, it represents the most productive aquifer type in Laos. Groundwater is already largely used in some of Laos Alluvial plain for domestic uses, and marginal cash crop irrigation.

- **The Mesozoic sandstones** are considered of great importance in Laos. This is due to their intrinsic storage properties, their important thickness, up to several hundred meters, regional groundwater flow system support, and their ubiquitous occurrence in the lowlands. These sandstone aquifers represent the main source of water for hundreds of villages across the country. In most cases, yields constrain its use to domestic purposes only.

Areas of Probable Groundwater Development Potential

- The large **Karsts systems** found in Laos possibly possess both a high storage and high yield. However, the lack of knowledge on these formations have been highlighted.

- The **Volcanic aquifers** found in southern Laos could also host a significant potential for groundwater development. They are in some place already developed (JICA) and exploited for domestic uses in several villages. They also support local small-scale water bottling companies. With high storage and yield indicators, coupled with high rainfall and recharge from the plateau during the rainy season, these Volcanic aquifers could represent a hydrogeological region of high importance. However, in several places, the thickness of the basalt is limited to a few tens of meters, underlain mostly by sandstones.

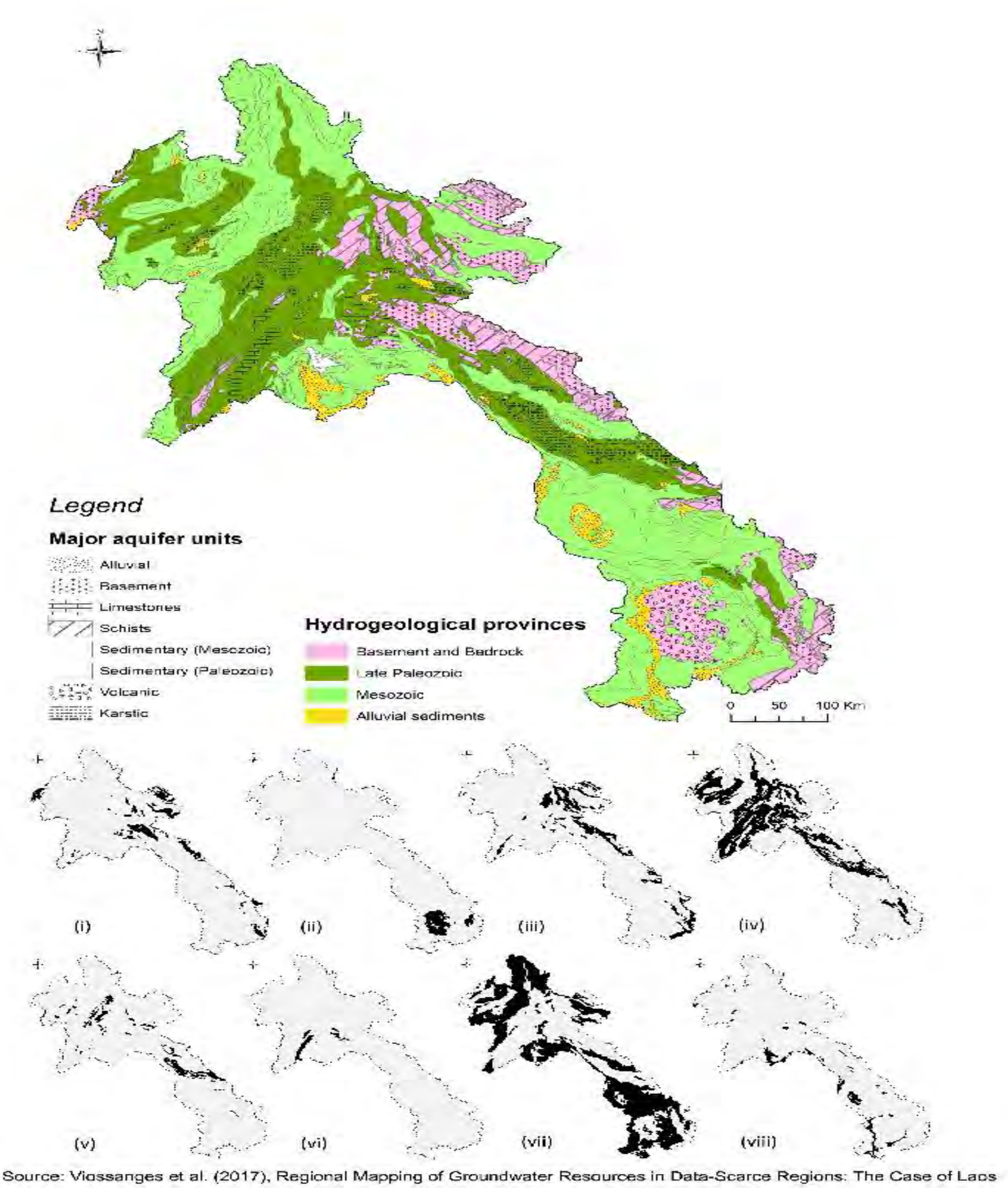

Figure 1. Synthetic map of the four MRC hydrogeological groups (greyscale filling) and the eight identified aquifer units (textures). Sub-maps present the spatial repartition of the 8 aquifer units as (i) Basement aquifers, (ii) Volcanic aquifers, (iii) Schists, (iv) Paleozoic sedimentary, (v) Karsts, (vi) Limestones, (vii) Mesozoic sedimentary, (viii) Alluvial sediments.

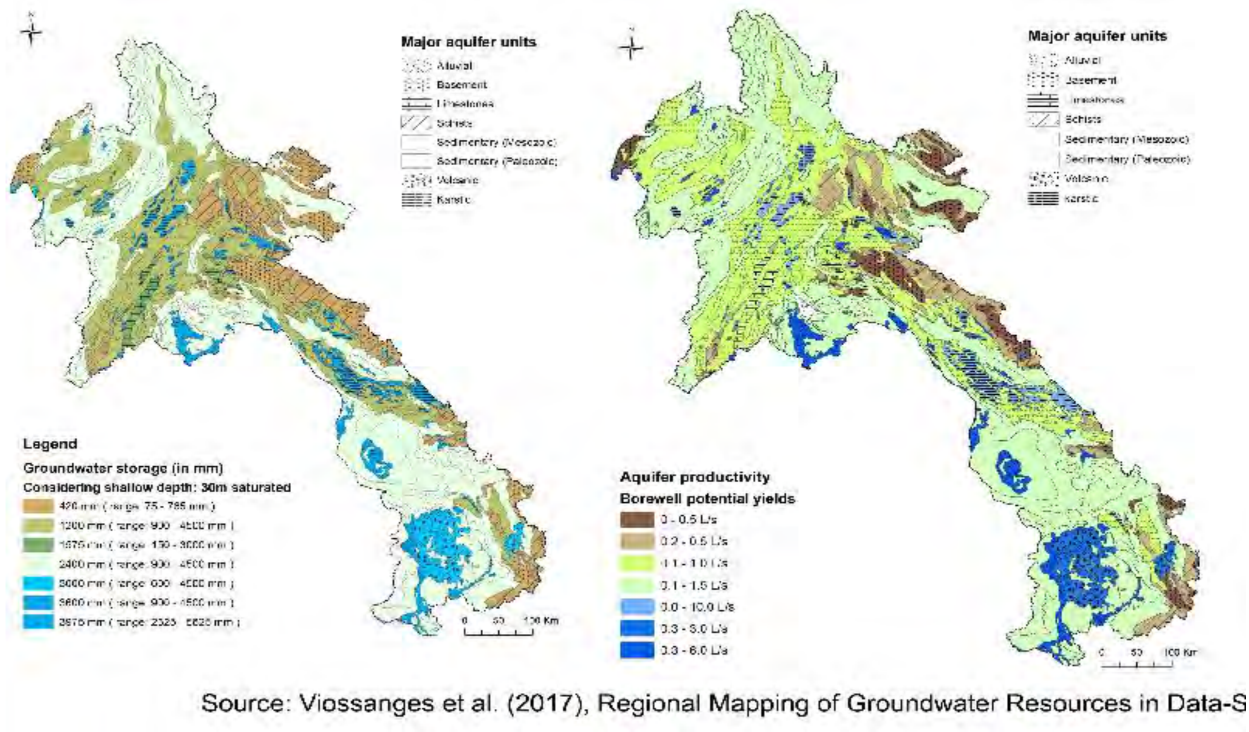

Figure 2. Map of shallow groundwater storage in Laos, considering a 30 m saturated thickness and Map of shallow aquifer productivity in Laos.

Areas of Limited Groundwater Development Potential

- **The Paleozoic sedimentary** aquifers support larger storage, and expected yields are unknown in Laos, however, their location in mostly upland areas with low population density and very limited arable land, overall limited regional groundwater flow, and likely low yields (based on Mekong scale studies [11–13]), are strong constraints to their use as a viable resource.
- **The Basement rock and Schist** aquifers possess low storage and low yield properties, and are thus considered as poor aquifers, although local condition (weathering, fractures) can provide small supply.

Groundwater is emerging as a large and generally untapped resource. However, there is very little monitoring of groundwater quality in the country, even though it is the main source of rural water supply. A study made by the Interim Mekong Committee (1986) observed that the country is divided into two geological areas: the Annamian Strata occupying most of northern and eastern part and the Indosinian sediments mainly along the Mekong.

According to the Geology and mineral map of Laos by DGM (1:1,000,000) main part of XBH are Mesozoic (cover Cretaceous (Mz2) and Jurassic (Mz1)). Mz2 : mostly red continental sand stone and clay with lagoon mud rock. The Mz1 mainly continental red clayey. The main part of the XBH is the Indosinian group while the North east part are Annamian aquifer.

Ground water resources can be available throughout the basin and it is the important sources of water for drinking and water supply as well as industry where the sources of surface water not available. However, having it for the sustainable sources is yet unclear as there is no available study the basin yet.

The baseline study report from SNV shows that most households use a borehole for water supply in both Atsaphone (73 %) and Phine (64 %) Districts. The second most used supply in Atsaphone is dug wells whilst in Phine it is natural surface water sources. A surprisingly low number of households use rainwater as a water supply. In both districts, wealthier households are twice as likely to rely only on boreholes as their main supply, inferring that most are private supplies. In both districts, wealthier households are twice as likely to rely only on boreholes (under the WHO/UNICEF Joint Monitoring Programme classification ground water is assumed to be safer than surface water) as their main supply.

The baseline found that Atsaphone households were more likely to use dug wells as a secondary supply. Poorer Atsaphone households are seven times more likely to use a dug well as their main supply. In Phine, two thirds of poor households use surface water as their main supply. In Phine, secondary supplies were also more likely to be streams or ponds.

Currently, issues related to groundwater show a number of droughts, such as in the 242 Border Protection Corridor of Ban Ang Gai, Sisattanak District, Vientiane capital, there is a problem of water depletion and drainage of up to 200 m deep to underground water. The problem of water quality is same as in Seno, Sepon and Xecham Phon Districts and saline soils find saline problems in the city of Seno and limestone that affect the use of the people in the area.

Based on current climate change conditions, groundwater quality is changing in quantity and quality. Underground water management is inadequate to ensure that clear groundwater management and groundwater use are in the way that is needed by anyone, particularly in areas underground underground drilling, which are not in the way that affect the use and systems of groundwater. In the past, there has been a lack of official data collection mechanisms, no agencies or organizations that are responsible for explicit and formal groundwater management, lack of monitoring and monitoring of the use of underground water; Information on groundwater (both quantitative and qualitative) is very limited, monitoring and evaluation activities can not be implemented as far as possible.

3. Hydrological Problem in Laos

The Mekong river is the main river and 90 % of the country is located in the Mekong river basin. It forms the border with Thailand over a very large distance and almost every part is navigable. In the south, near Pakse, it enters the country with an estimated 280 km^3/year at the confluence with the Chi/Mun river coming from Thailand. About 25 % of the Mekong river basin is located in the Lao People's Democratic Republic, which contributes 35 % of the Mekong's total flow. There are about 39 main tributaries in the Mekong river basin and the main ones that have their largest catchment area in the Lao People's Democratic Republic are from north to south: Ou, Suang and Khan in the northern region; Ngum and Nhiep in the northern-central region; San, Theun-Kading and Bangfay in the central region, Banghiang in the Savannakhet plain in the central-southern region; Done in the southern region; and Kong in the southeastern region. Rivers that are not part of the Mekong river basin, such as the Tale, Ma, Mat and Xa rivers, drain from the Lao People's Democratic Republic towards Viet Nam, and the Luang and Mô rivers join in Viet Nam before reaching the sea. Significant part of the water resources of the country (143.13 km^3/year) comes from neighbouring countries: 73.63 km^3/year enters from China (after first becoming the border between Myanmar and Lao People's Democratic Republic and then over a short distance the border between Thailand and Lao People's Democratic Republic before entering the country), 17.6 km^3/year from Myanmar (contribution of Myanmar to the Mekong in the border reach), and 51.9 km^3/year from Thailand (contribution of Thailand to Mekong in the border reach). The outflow from Lao People's Democratic Republic to other countries (333.55 km^3/year) consists mainly of the Mekong River to Cambodia with 324.45 km^3/year and small rivers, the Ca and Ma rivers, with 9.1 km^3/year to Viet Nam.

The internal renewable surface water resources have been estimated as the difference between the outflow and the inflow to the country, which is 190.42 km^3/year, while groundwater resources are an estimated 38 km^3/year, all forming the base flow of the rivers, thus being considered the overlap between surface water and groundwater resources. The total renewable water resources are therefore an estimated 333.55 km^3/year, which is equal to the total flow out of the country.

One of the best sample for River basin management in Laos is Nam Ngum river basin (NNRB) this basin located in the central part of the Lao PDR and covers an area of 16,800 km^2. There are four provinces Xieng Khuang, Luang Prabang, Vientiane, Boulikhamxay and the Vientiane municipality within the basin. It is one of the major tributaries of the Mekong river contributing 14% of the mainstream flow at the Mekong.

The Nam Ngum Basin comprises two major rivers the Nam Ngum and its major tributary the Nam Lik. The headwaters of the Nam Ngum are at an elevation of 2,800 m in the northeast of the basin and the river travels southwards for 420 km to its outlet with the Mekong, approximately 100 km downstream of the capital, Vientiane. Downstream of the Nam Lik confluence, the Nam Ngum river has a gentle slope of between1/10,000 to 1/25,000 as it meanders it's course. The Vientiane plain extends from each bank and covers an area of about 2,000 km^2 at elevations of 160 to180 m. The plain is formed mostly of alluvium soil suitable for the cultivation of rice and other short duration crops. The river is constricted by a narrow cross-section at the Tha Ngon bridge (20 km north of Vientiane) which, during the wet season, influences flooding on the upstream floodplain

- **Climatic Setting**

The climate of the Nam Ngum Basin is largely tropical with a distinct wet season from June to October and a mostly dry season for the rest of the year. The hottest months are March and April, when average temperatures range from 30°C to 38°C, depending on location and altitude. Coolest temperatures occur between November and February at higher elevations, where they average 15°C.

- **Rainfall**

The mean annual rainfall of the basin is 2,000 mm and ranges from 1,450 to 3,500 mm across the basin (Figure 2). The rainfall distribution in the region is significantly influenced by the central mountain range. The largest rainfalls are near Vang Vieng and the lowest near Phonsavan in the north east (WRCC, 2007).

- **Evaporation**

Although the rainfall varies considerably across the catchment the evaporation is reasonably constant with an average annual evaporation across the basin of 1400 mm. Evaporation is highest in April to May and lowest in December January. Figure 3 shows the range of rainfall and evaporation for selected stations in the basin.

- **Flow**

Flow and water level data are available for the Nam Ngum River at Ban Na Luang upstream of Nam Ngum 1, downstream of Nam Ngum 1, below the Nam Lik confluence at Ban Pakkangoung. Data is also available for the Nam Lik below the Nam Song confluence at Ban Hin Heup.

The average annual discharge of the Nam Ngum River to the Mekong River is 21,000 mm. The flows are very seasonal with the lowest flows from March to April and the largest flows from August to September

3.1 Water Use

- **Irrigation Use**

The predominant crop in the basin is rice followed by a number of other crops that include maize, starchy root crops, vegetables, peanut, soybean, mung bean, tobacco, cotton and sugarcane. Vegetables comprise more than 80 % of the ‘other crops’ category in Vientiane Municipality reflecting close access to the major population centre and market. Vegetables comprise approximately 50 % of the ‘other crops’ category for Vientiane Province and Xiang Khouang Province whilst maize and starchy crops (sweet potatoes and cassava) are also significant. Based on this data, the area of irrigated agriculture in the dry season on the Vientiane Plains is of the order of 64,000 ha although this would include small areas in Vientiane Province that are not on the Plains and some of Vientiane Municipality that is not in the NNRB.

The area of wet season rice is slowly increasing and is by far the largest area of crop in all jurisdictions. Whilst dry season rice increased significantly (by about 300 %) in the 7 years to 2001, it has since levelled off in Vientiane Municipality and may be falling slightly but has reduced significantly in Vientiane Province. The area of non rice crops has increased greatly over the last decade. Most of this growth has been as a result of the large increase in vegetable production in all jurisdictions. However, in the last year of data (2004), the area of vegetables in Vientiane Province reduced significantly, in 2005 the area of vegetable production in Vientiane Municipality (Agricultural Statistics 1976 - 2005, MAF) also fell (by 30 %).

- **Domestic and Industrial Use**

The NNRB had a population of approximately 500,000 people in 2005 with most of these people located on the Vientiane plain with another but smaller cluster on the Plain of Jars in Xiang Khouang Province. Water usage for domestic and industrial purposes is correspondingly highest in lower Nam Ngum, reflecting not only the higher population, but also greater access to water supply and higher level of irrigation water use and industrialization

- **Hydropower**

The Nam Ngum river basin has significant hydropower potential with high rainfall and large differences in elevation. The only major hydropower currently generated in the basin, however, is from the Nam Ngum 1 reservoir with an average annual power production of 900 GWh/year. There are two hydropower stations located outside of the basin that transfer water into the basin. The Nam Leuk storage, commissioned in 2000, transfers water into the basin upstream of Nam Ngum 1. The Nam Mang 3 storage, commissioned in 2004, transfers water to the Nam Ngum river downstream of Nam Ngum 1.

3.2 For Scenarios and Water Allocation

The NNRB is modelled by the SWAT catchment model and the river system is modelled by IQQM V7.42.1 (MRC, 2004). The model commences with headwater inflows from the Upper Nam Ngum, Nam Lik and Nam Song rivers. The model ends at the confluence with the Mekong River. The last calibration gauge is Ban Pakkanough.

The SWAT model represents the NNRB with 15 sub-catchment models that represent the inflows from these sub-catchments. This model has been refined and re-calibrated since the original seven sub-catchment models developed by MRC as part of WUP (MRC, 2004).

The baseline IQQM model of the NNRB, supplied by MRC, represents the system with 78 links and 79 nodes arranged into 9 river sections. This model has been refined and recalibrated in conjunction with the SWAT recalibration and consequently differs from the original WUP model. The model has been divided into 15 sub-catchments with revised estimates of irrigated area and domestic and industrial demands. These have been adjusted based on more recent information.

Each of the scenarios for this study has a different IQQM configuration to simulate each of the future development scenarios. To ensure consistency between these models the original MRC model was modified to create the H4 high development scenario, as this scenario encompasses all of the development. The other scenarios were subsequently created by removing nodes until finally the ‘natural’ scenario was built.

4. Plan of Groundwater Observation System in Savannakhet Province, Lao PDR

Savannakhet province representing the geographical condition of the southern part of middle region of Lao PDR. The total population 1,037,553 person, Total area is 23,225.13 km^2, 15 districts, there are 13 districts in the Xebanghieng basin area namely: 1. Phin, 2. Xepon, 3. Nong, 4. Thapangthong, 5. Xonbouly, 6. Vilabouly, 7. Atsaphone, 8. Champhone, 9. Phalanxay, 10. Songkhone, 11. Atsaphangthong, 12. Outhoumphone, and 13. Xayphouthong, there is 886 villages with 114,306 household, total population is 697,725 persons.

The northeast monsoon creates dry season conditions, including low temperatures, low rainfall and low humidity from mid-October to mid-April. The south-west monsoon causes heavy rainfall, higher temperatures and high humidity from mid-April to mid-October. Similar to the other parts of Laos, Approximately 90% of the total rainfall occurs in the wet season, with the highest rainfall occurring during June and August. Northeast winds are most common from Mid-October to April (the dry season) and west-southwest winds are more common from May to October (the wet season). The meteorological data compiled from overall meteorological monitoring stations in the region revealing their mean values from the period of 1997 – 2012.

Due to characterized two different mountainous and plain geographic conditions of the basin; the plain area the middle and lower part of XBH basin are outcropped by the Khorat group formations while the mountainous area of Xepon and Vilabouly district is outcropped by the Khorat group formations and overlain by Maha Sarakham formation of the middle Cretaceous. The Khorat group formations outcropping Xe Bang Heing basin consisted of Khok Kruat formation of early Cretaceous known as Champon formation on top cover main part of Savanakhet province, Phra Wihan formation known as Salavan formation of early Cretaceous in the middle and Phu Kradung formation known as Lamo formation of early Cretaceous and late Jurassic period at the bottom (SEATEC International, 2003).

According to the Geology and mineral map of Laos by DGM (1:1,000,000) main part of XBH are Mesozoic (cover Cretaceous (Mz2) and Jurassic (Mz1)). Mz2 : mostly red continental sand stone and clay with lagoon mud rock. The Mz1 mainly continental red clayey. The main part of the Xe Bang Heing (XBH) is the Indosinian group while the North east part are Annamian aquifer.

Ground water resources can be available throughout the basin and it is the important sources of water for drinking and water supply as well as industry where the sources of surface water not available. However, having it for the sustainable sources is yet unclear as there is no available study the basin yet.

Next step Ground Water Management Division plan to set up ground water Observation well in 8 districts of this province. The activity will implement by the end of 2019.

5. Conclusions

Ground water resources can be available throughout the basin and it is the important sources of water for drinking and water supply as well as industry where the sources of surface water not available. However, having it for the sustainable sources is yet unclear as there is no available study the basin yet.

The baseline study report from SNV shows that most households use a borehole for water supply in both Atsaphone (73 %) and Phine (64 %) Districts. The second most used supply in Atsaphone is dug wells whilst in Phine it is natural surface water sources. A surprisingly low number of households use rainwater as a water supply. In both districts, wealthier households are twice as likely to rely only on boreholes as their main supply, inferring that most are private supplies. In both districts, wealthier households are twice as likely to rely only on boreholes (under the WHO/UNICEF Joint Monitoring Programme classification ground water is assumed to be safer than surface water) as their main supply.

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In summary, groundwater is important source for social-economic development of savannakhet province as well as the sources of water for drinking. So, sustainable usage of groundwater is an important objective. Groundwater management plan is method for ground water management beside that data and information gathering also water user and developer register is need for groundwater management is this pilot project area.

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III-4-(3)

Preliminary Study of Groundwater Occurrence in Nay Pyi Taw, Myanmar

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Abstract

Irrigation and Water Utilization Management Department (IWUMD) is implementing the groundwater management works and water well drilling all over the country. The department is also implementing water well drilling works for both Irrigation and domestic purpose in Nay Pyi Taw area. In this connection the judicious use of ground water is the key requirement for the sustainability of groundwater resources. The lithologic cross-sections are depicted by using tuberwell data those drilled by IWUMD. The results of data analysis include depth to aquifer map, depth to water table map, tubewell yield map and water quality map generated in GIS platform. The information including in this preliminary groundwater study will support to future groundwater development activities.

Keywords: groundwater, sustainability, Nay Pyi Taw

1. Introduction

The Nay Pyi Taw, Union Territory area is located in the central part of Myanmar (Fig. 1). It comprised of 8 townships namely Tatkon, Leway, Pyinmana, Outtarathiri, Popathiri, Zeyarthiri, Zabuthiri and Dakhinathiri townships. The study area will not cover all townships of Union Territory. The Outtarathiri, Popathiri, Zeyarthiri, Zabuthiri, western part of Pyinmana Township and northern part of Lewe township area. This hydrogeological study is aim to support information for future groundwater development project in the Union Territory Area. The main objective of the study is to assess the groundwater condition in the area.

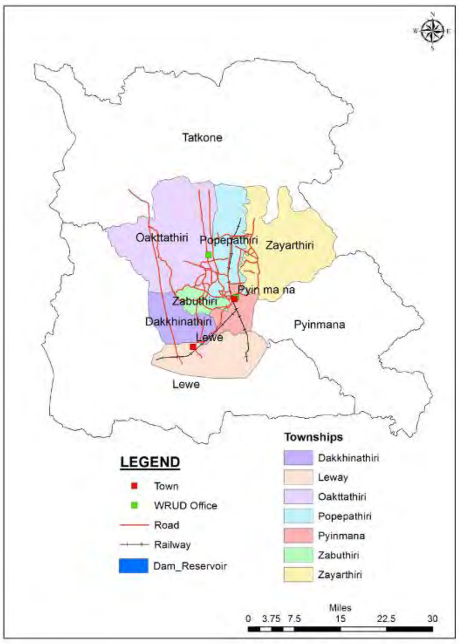


Fig. 1. Location Map

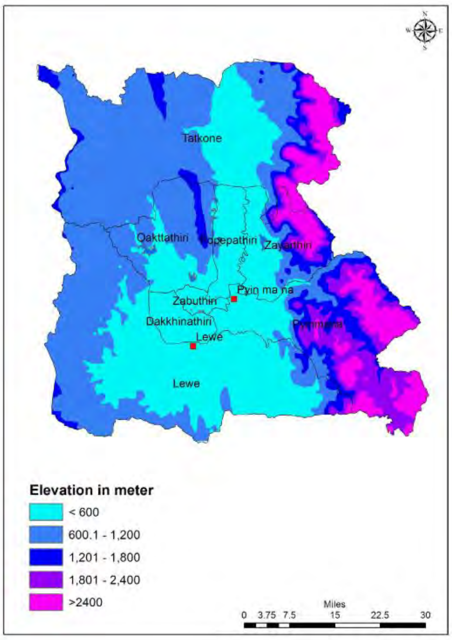


Fig. 2. Topographic Map

2. Geology and Hydrogeology in Nay Pyi Taw Area

The granitic intrusion occur as the basement of eastern part of the area and Paleozoic sedimentary unit of Lebyin Group and Mesozoic thick sedimentary formations of Pegu Group and Tertiary Pliocene aged Irrawaddy Formation are overlying the igneous intrusions (Fig. 2 and Fig. 3). The major well known strike slip fault, Sagaing Fault is passing through N-S trending in the central part of the area.

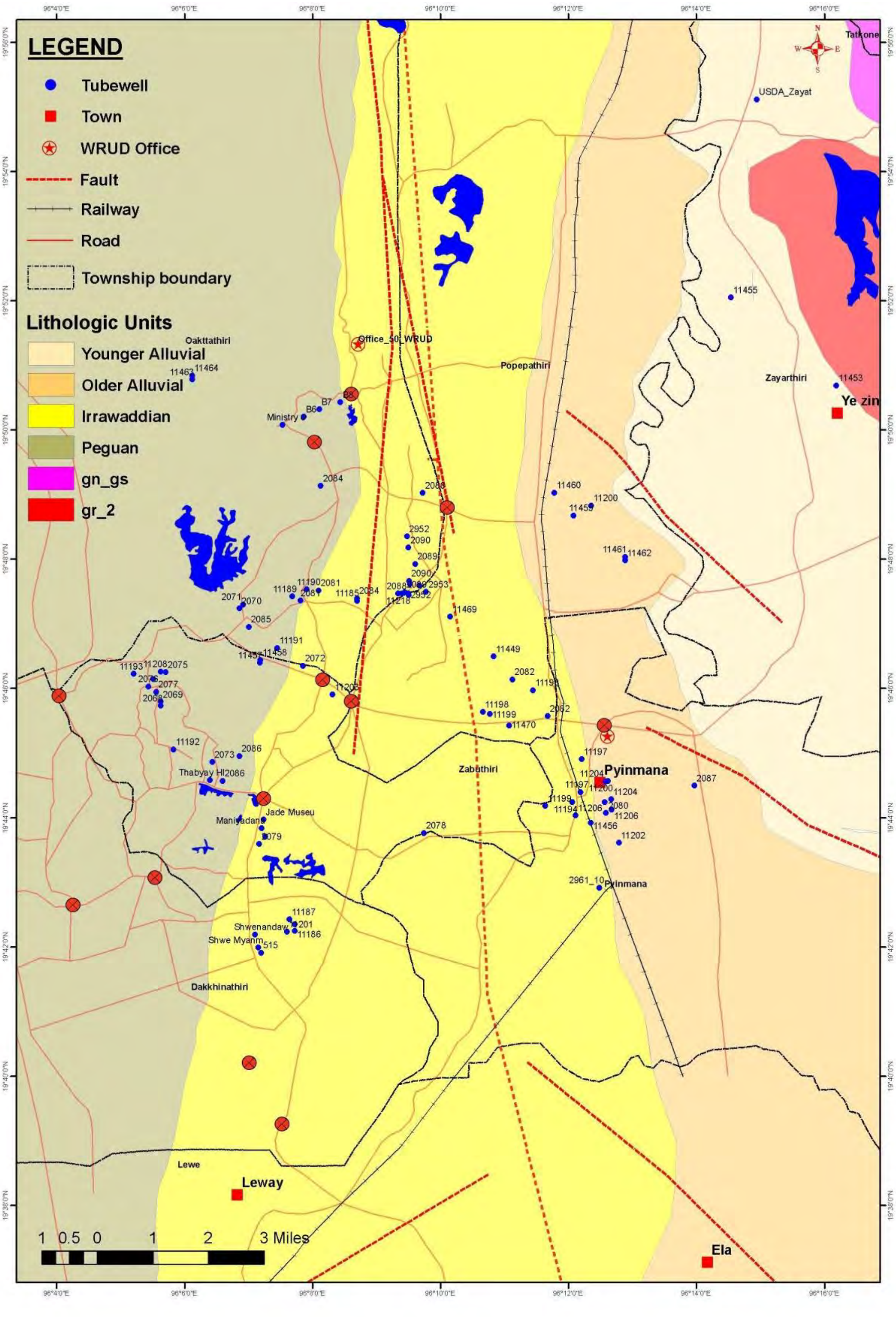


Fig. 3. Geological Map

2.1 Lateral and vertical variation of aquifer

The interpretation of the spatial variation of the aquifer in the study area is based on the lithologic cross-section (Fig. 5) drawn by using drilled tubewells of IWUMD. According to the data the depth to aquifer (estimated drilling depth) found as follow (Fig. 4).

Township	Depth to aquifer (ft), below ground level
Outtarathiri	200 - 560
Popathiri	275 – 600
Zeyarthiri	~ 300
Zabuthiri	250 - 550
Dakhinathiri	450 - 900
Pyinmana	300 - 650
Lewe	~ 400

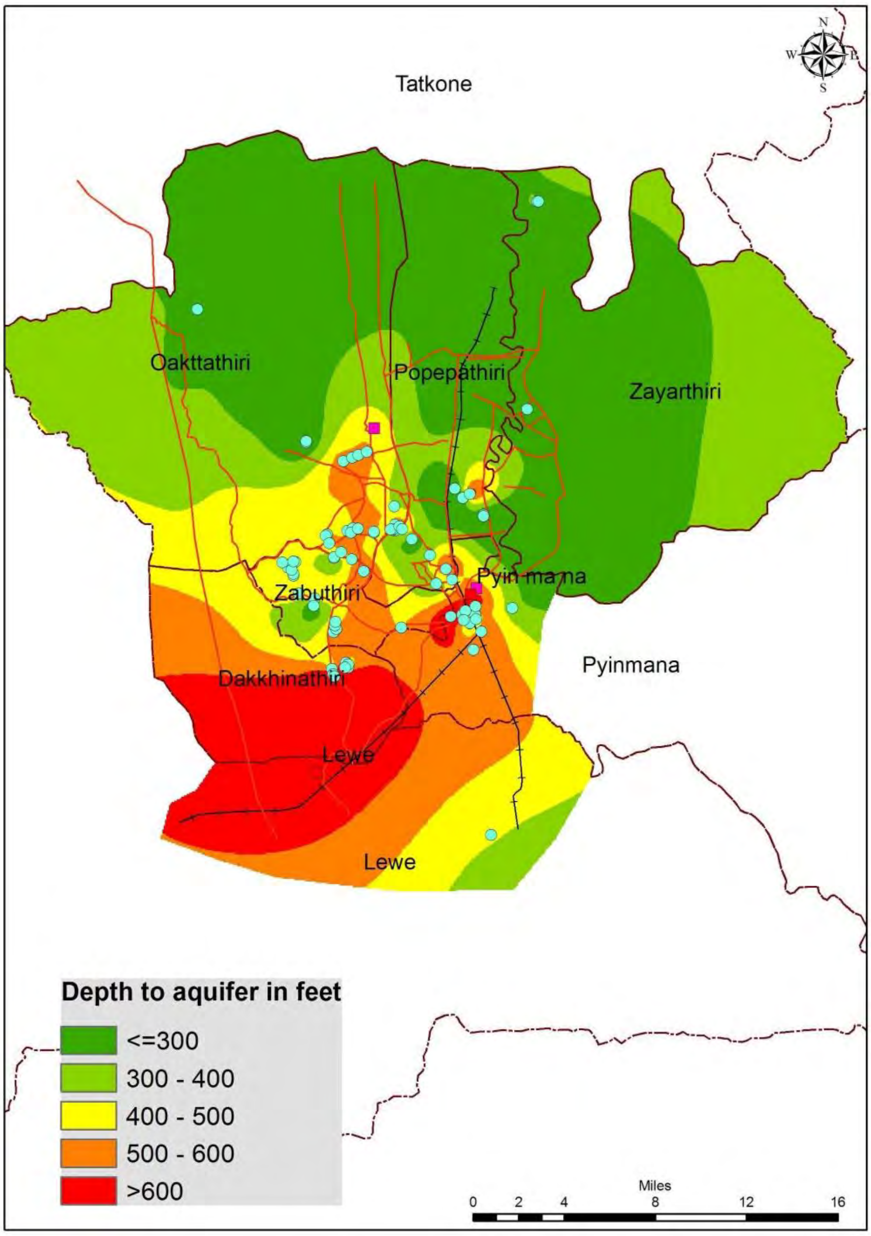
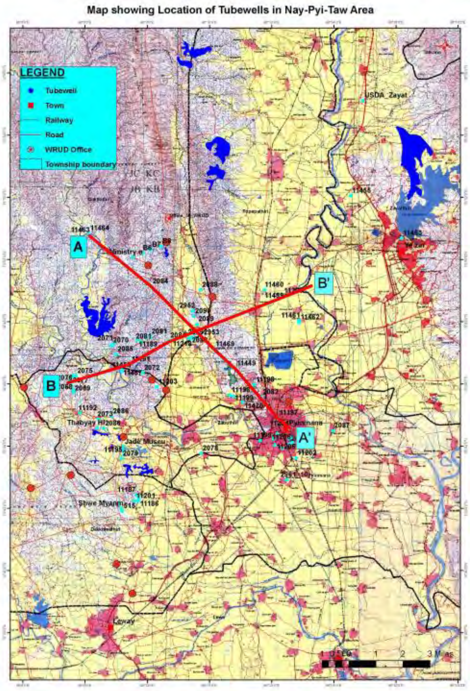
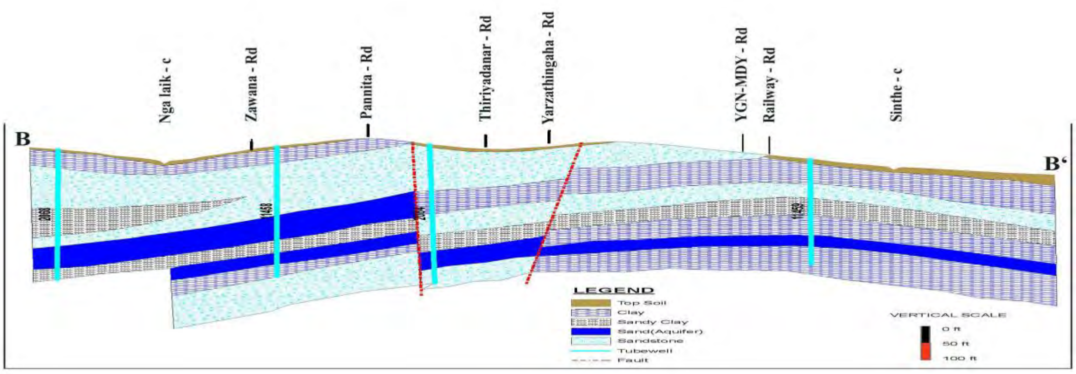


Fig. 4. Depth to Aquifer Map



Generalize Lithologic Cross-section Along (B-B') at Nay-Pyi-Taw Area



Generalize Lithologic Cross-section Along (A-A') at Nay-Pyi-Taw Area

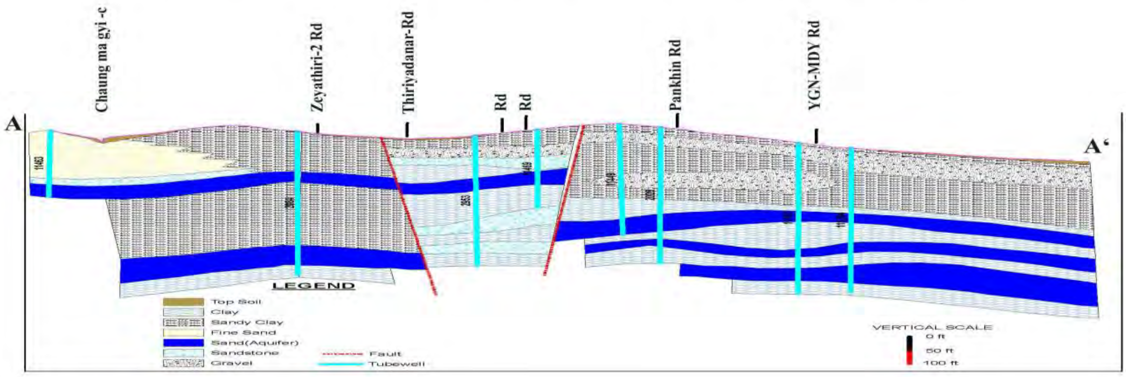


Fig. 5. Lithologic Cross-Sections

2.2 Depth to Groundwater Table

The minimum depth to water table (Fig. 6) is about 20 feet below natural ground level and the maximum depth to water table observed that about 150 feet below ground level.

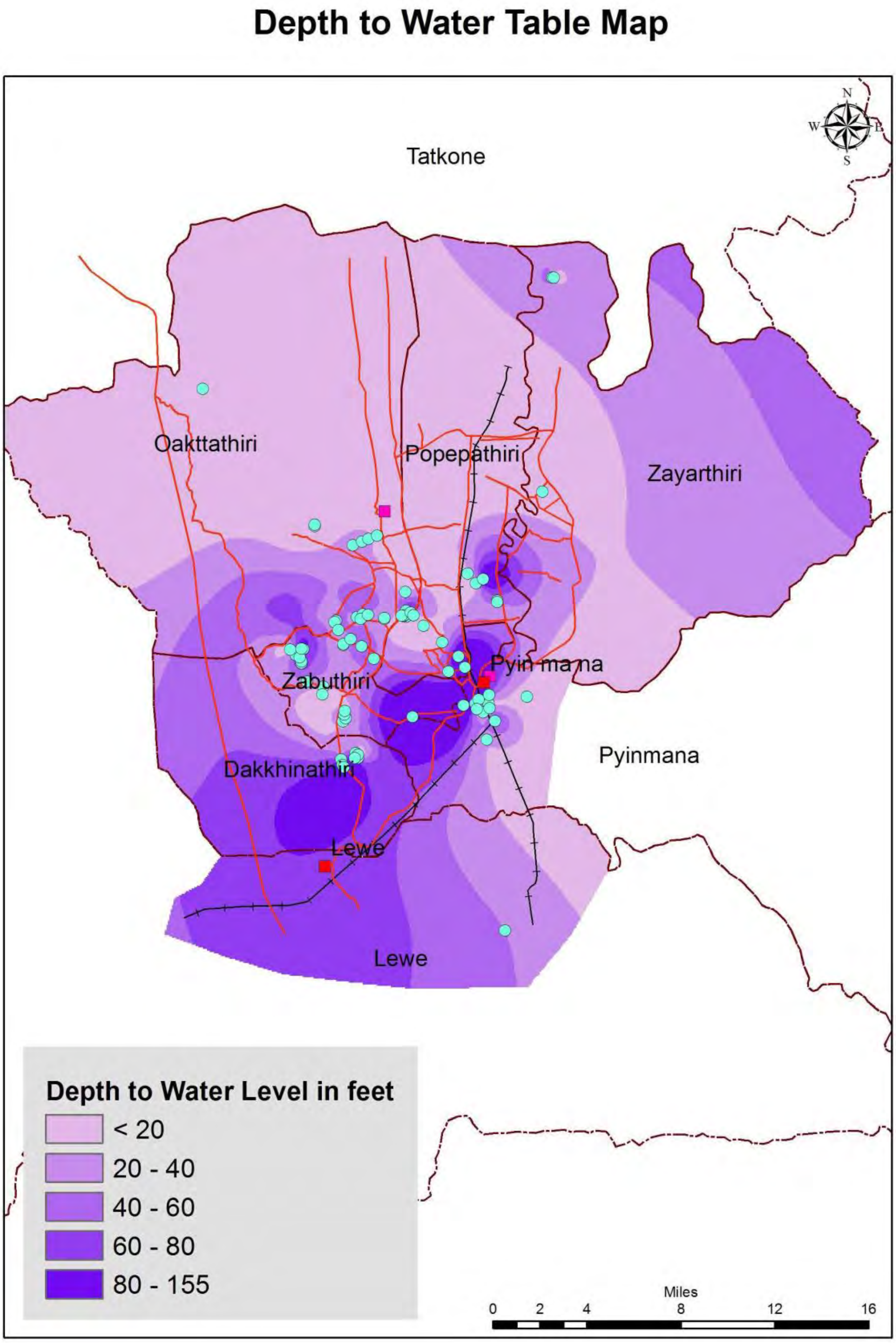


Fig. 6. Depth to water table

2.3 Tubewell Yield

The minimum tube well yield (Fig. 7) for 4 inch diameter is about 2000 gallon per hour (gph) and maximum found about that 5,000 gph in study area.

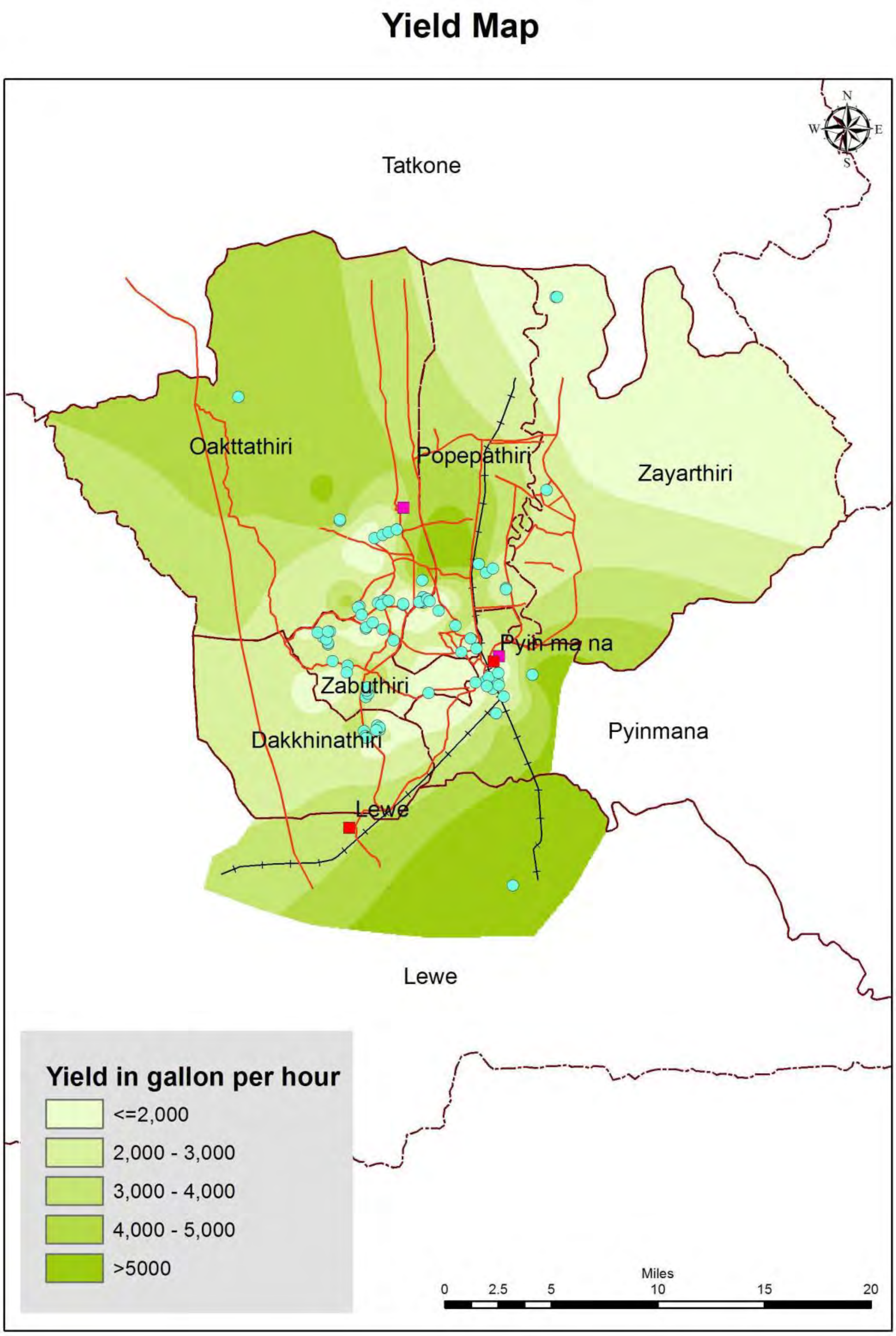


Fig. 7. Tubewell Yield

2.4 Groundwater Quality

Groundwater quality estimation was based on the water quality result of 22 selected samples (Fig. 8). The chemical quality testing was carried out by WRUD's laboratory. The Electrical Conductivity (EC), pH, and Total Dissolved Solid (TDS) were mentioned in this paper.

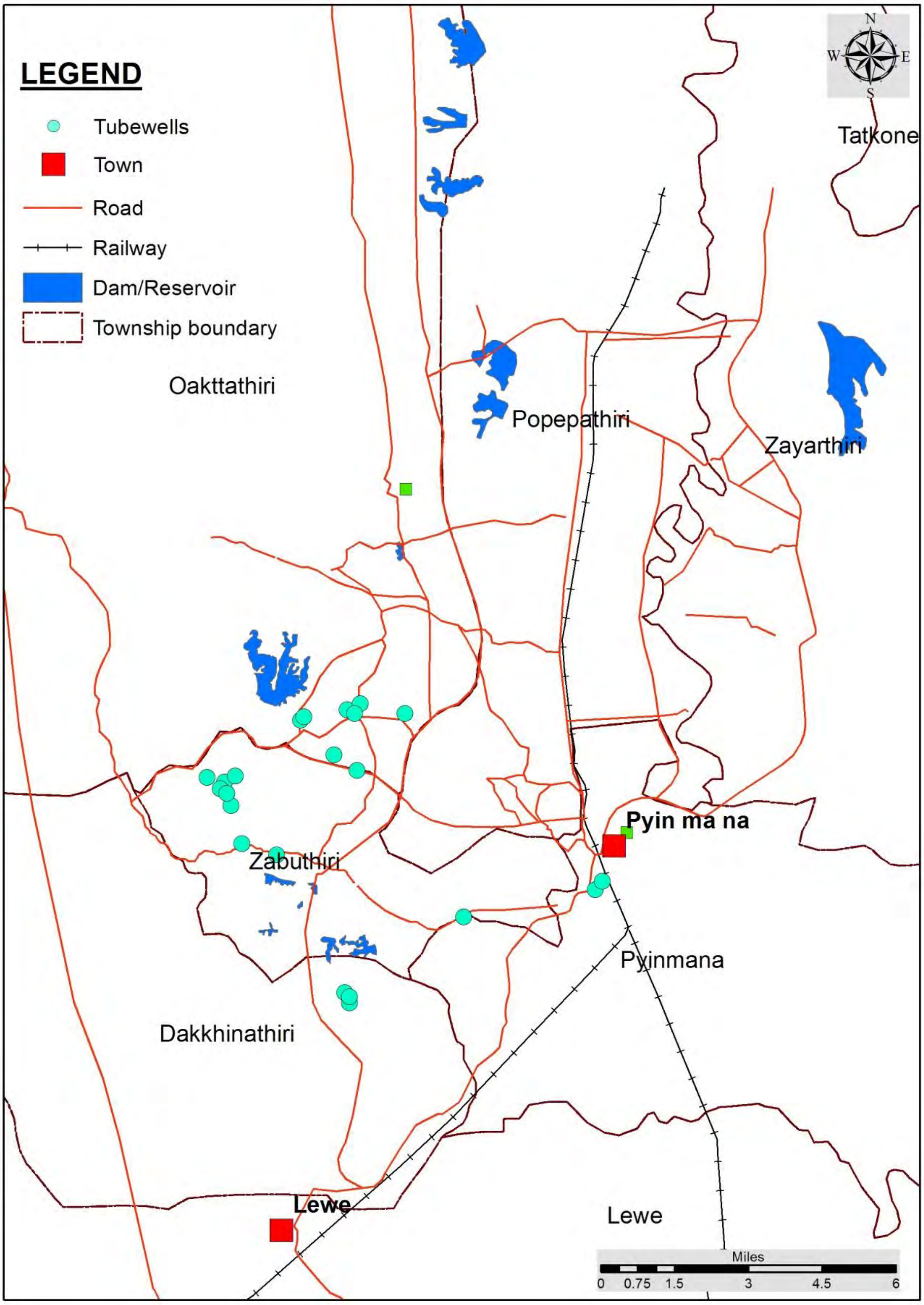


Fig. 8. Location of water samples

2.4.1 pH

According to the chemical analysis result of 22 samples, the minimum and maximum pH (Fig. 9) value of groundwater in Nay Pyi Taw is found that 6.6 to 8.0 respectively.

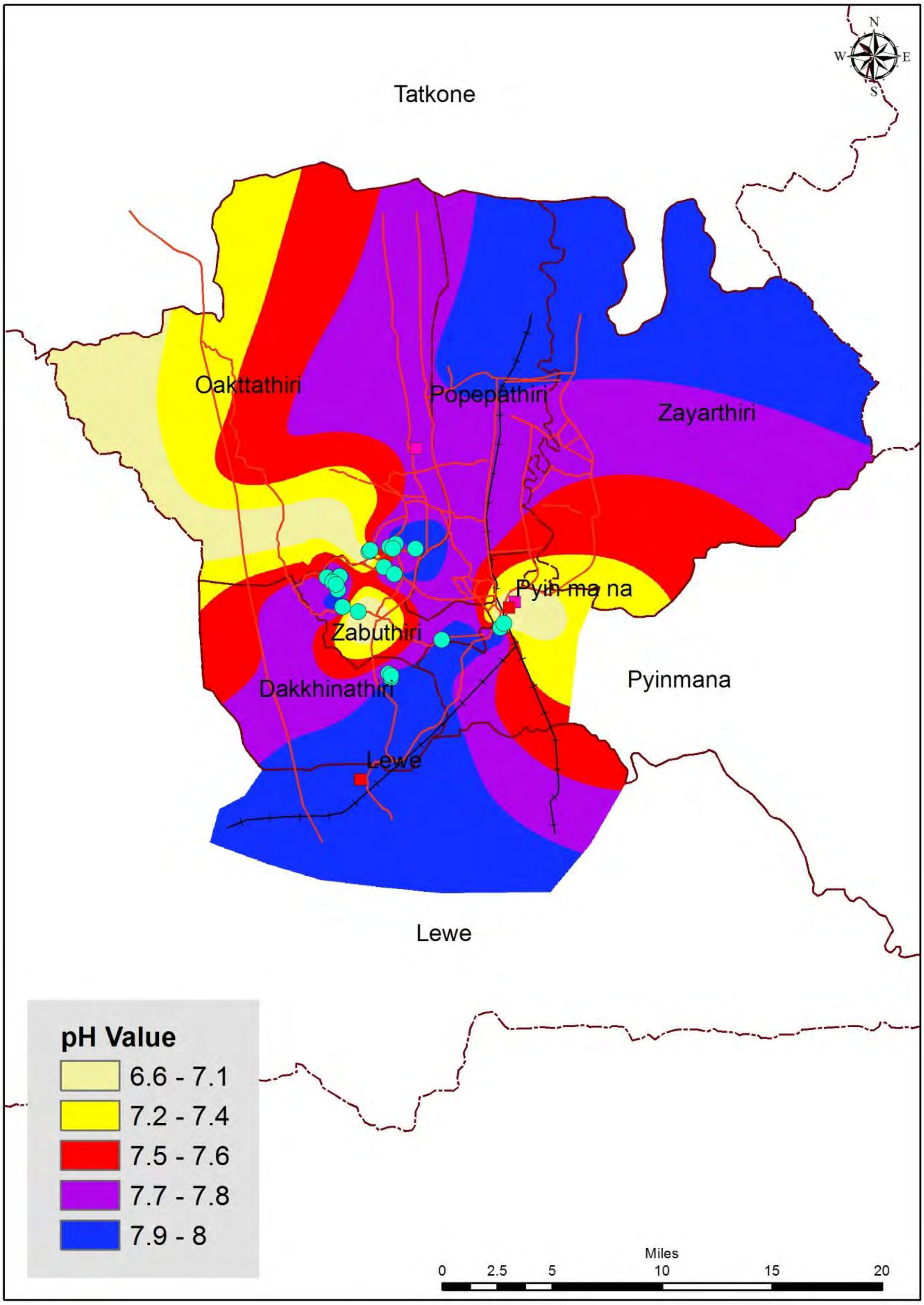


Fig. 9. pH

2.4.2 Electrical conductivity (EC)

The minimum EC value of the groundwater in Nay Pyi Taw area (Fig. 10) is found that 208 µmho/cm and maximum value is 900 µmho/cm.

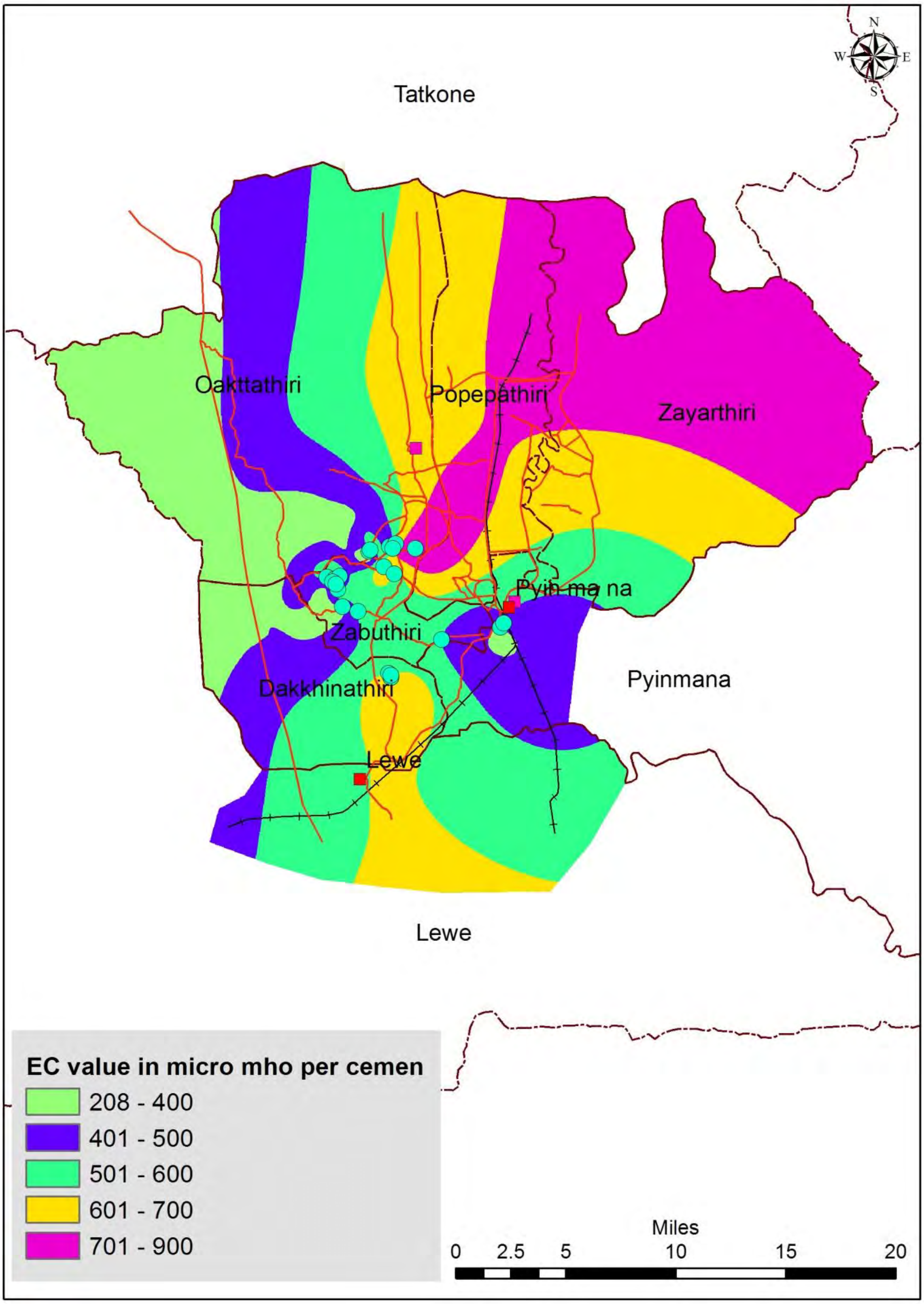


Fig. 10. Electrical Conductivity

2.4.3 Total Dissolved Solid (TDS)

The concentration of total dissolved solid (TDS) (Fig. 11) is ranging from 136 mg/l to 530 mg/l in groundwater of Nay Pyi Taw area.

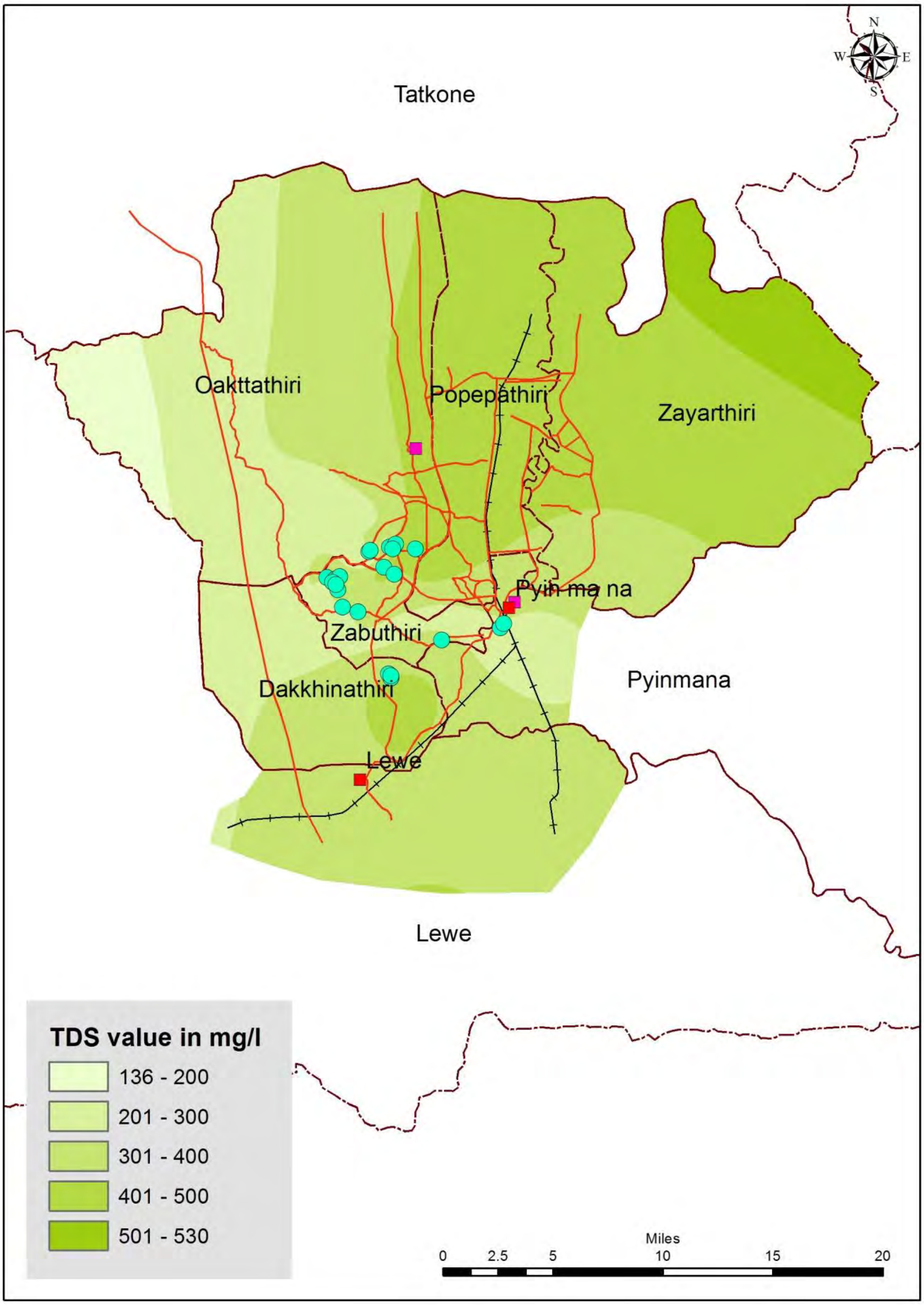


Fig. 11. Total Dissolved Solid

3. Hydrogeological issues

Geologically, the Union Territory area (Nay Pyi Taw area) is covered by Recent Alluvial Sediments of sand, silt, clay, loosely cemented sand rocks of Irrawaddy Formation and the sandstone and shale sedimentary layers of Upper Pegu Group. The groundwater yield of 4 inches diameter is ranging from 2,000 gph to 5,000 gph was found in the area. The static water level of aquifer in the area is ranging from 20 feet to 150 feet below ground level. The groundwater potential is limited, based on the recharge condition and comprehensive study on evaluation of aquifer parameters and estimation of groundwater potential is urgently needed for future groundwater development programs and sustainability of groundwater resources in Nay Pyi Taw area.

The main hydrogeological issue in the study area is the less experience in groundwater monitoring works and legal enforcement for the drilling and usage of groundwater. In Myanmar, there is no groundwater law established until now, but the government is trying to establish groundwater law in progress. And also groundwater quality and quantity are also important issues. Generally, the concentration of iron (Fe) and Calcium (Ca) in the groundwater in Nay Pyi Taw are higher than the maximum permissible limit of WHO drinking water quality guideline value. The lateral continuation of the aquifer found discontinuous because of the geological structure control and different depositional environment of the sedimentation basin. The geological structural control and lateral and vertical sedimentary facies changes resulted to high variation of drilling depth to meet the water bearing layers in place by place.

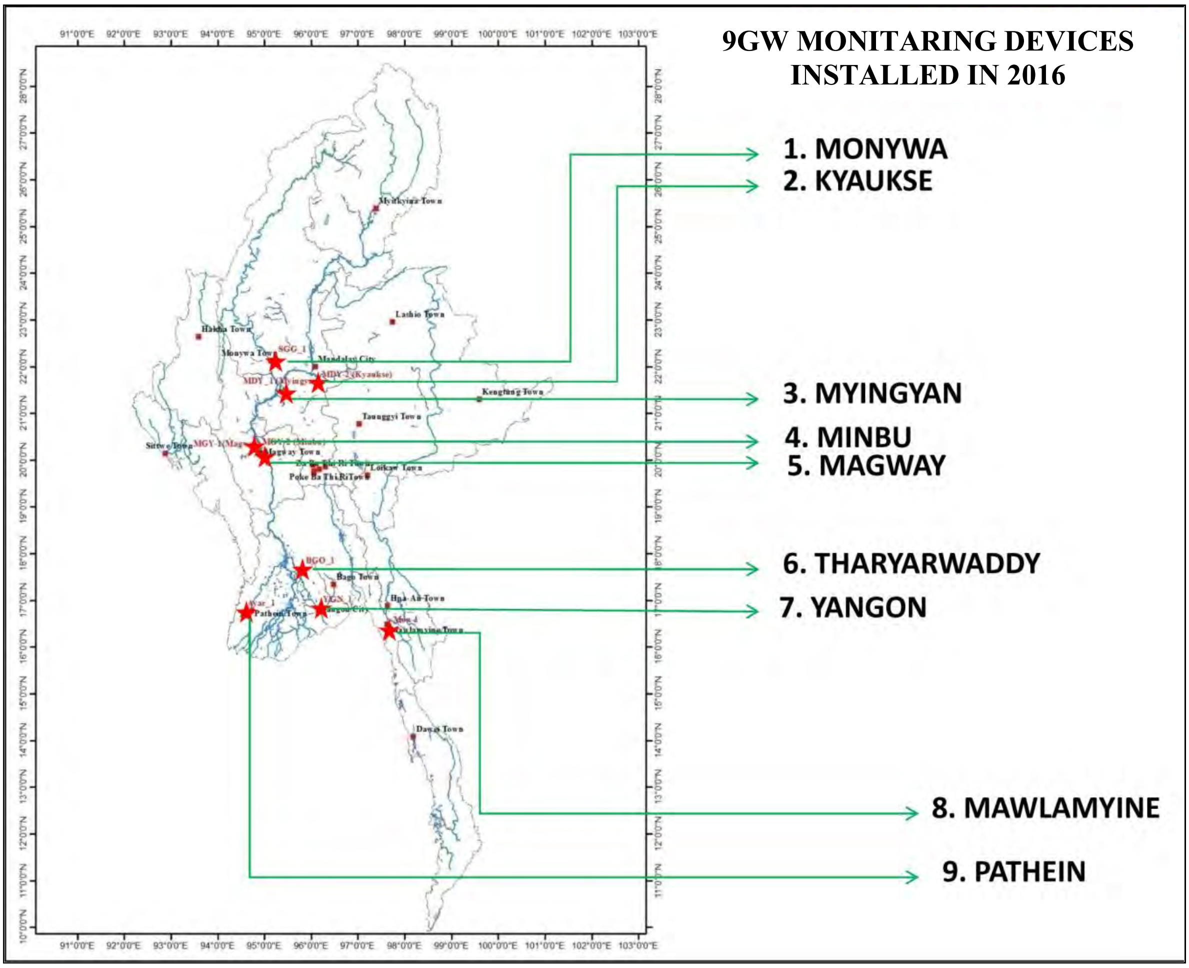


Fig. 12. Location of Groundwater Monitoring Stations in 2016

16-GROUNDWATER MONITARING STATION(2017-18)

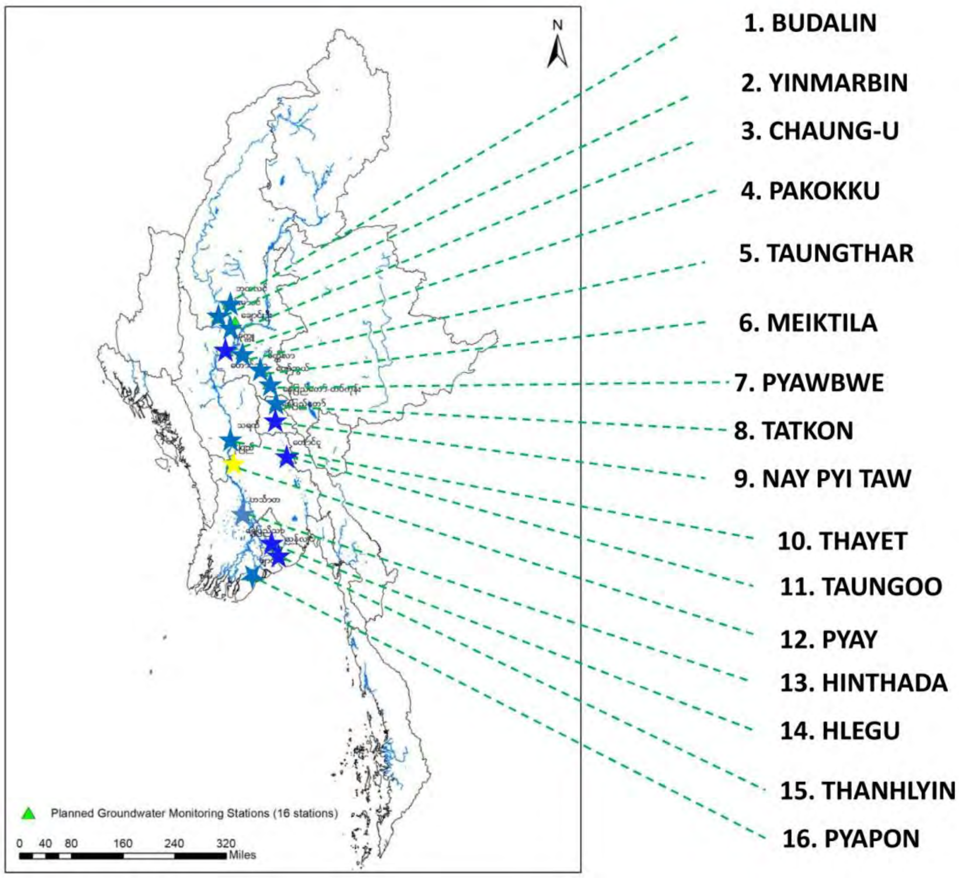


Fig. 13. Location of Groundwater Monitoring Stations in 2018

4. Plan of groundwater observation system and management reflection the hydrogeological issues

The total of 25 groundwater monitoring wells were drilled and installed the groundwater monitoring devices across the country (Fig. 12 and Fig. 13) by Irrigation and Water Utilization Management Department under the Ministry of Agriculture, Livestock and Irrigation (MOALI). The monitoring sensors were recorded groundwater level fluctuation, Electrical Conductivity (EC) and groundwater temperature. The purpose to know the aquifer parameter, the pumping test was performed 3 times within the study area. The extension of groundwater monitoring networks and detail hydrogeological mapping works are plan to development of the groundwater management in the study area.

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Public policy for Groundwater observation system in Port Moresby, Papua New Guinea

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Abstract

The geology of the Port Moresby area ranges from the Paleocene to Holocene age, the youngest deposits being that of the alluvial plains. Most outcrops within the area are of the Port Moresby Beds, with rare outcrops of the igneous formations of gabbro and tuff, while most of the low lying valley floors are covered in alluvium/ colluvium.

Two known aquifers exist within the area; the topmost part of the tuff is closely fractured and highly weathered, resulting in good permeability characteristics for groundwater, while the alluvial aquifer mainly to the north of Port Moresby consist of good sand and gravel layers which are favorable for groundwater storage.

Port Moresby lacks a groundwater observation system; however, groundwater data of historical boreholes along with recent boreholes have been collected to rebuild the groundwater database. This initiative of the database may aid in future plans for a proper groundwater observation system.

Keywords: groundwater, tuff, alluvial, Port Moresby.

1. Introduction

Port Moresby, the capital city of Papua New Guinea (PNG), is situated at 9^0S and 147^0E next to the equator. It lies within the Southern Region of PNG within the Central Province boundary.

The geology of the Port Moresby area comprises mostly of sedimentary formations and two units of igneous rocks, namely tuff and gabbro, with surficial geology of Quaternary alluvial deposits. The main rock units which are tapped into for groundwater are the tuff and gabbro units, and the alluvial deposits, of which, the alluvial aquifers are more productive.

Port Moresby has a considerable number of bores within the area, however there is no proper groundwater monitoring system in place.

2. Geology and Hydrogeology in Port Moresby, PNG

2.1 Geology in Port Moresby

The simplified geology of Port Moresby (Fig. 1) consists mainly of the sedimentary formations of the Port Moresby Beds, with tuff and gabbro outcropping in places. The Port Moresby Beds are the most evident rocks that outcrop within the area and comprise of three lithological units, the Paga Beds, the Nebire limestone and the Baruni limestone (Table 1).

The Paga Beds comprise mostly of calcareous and siliceous mudstone, chert and shale, with minor sandstone and limestone. This rock unit is closely fractured and jointed with calcite veins been common. The beds are well defined and occur in units of 0.1 – 0.3 m thick.

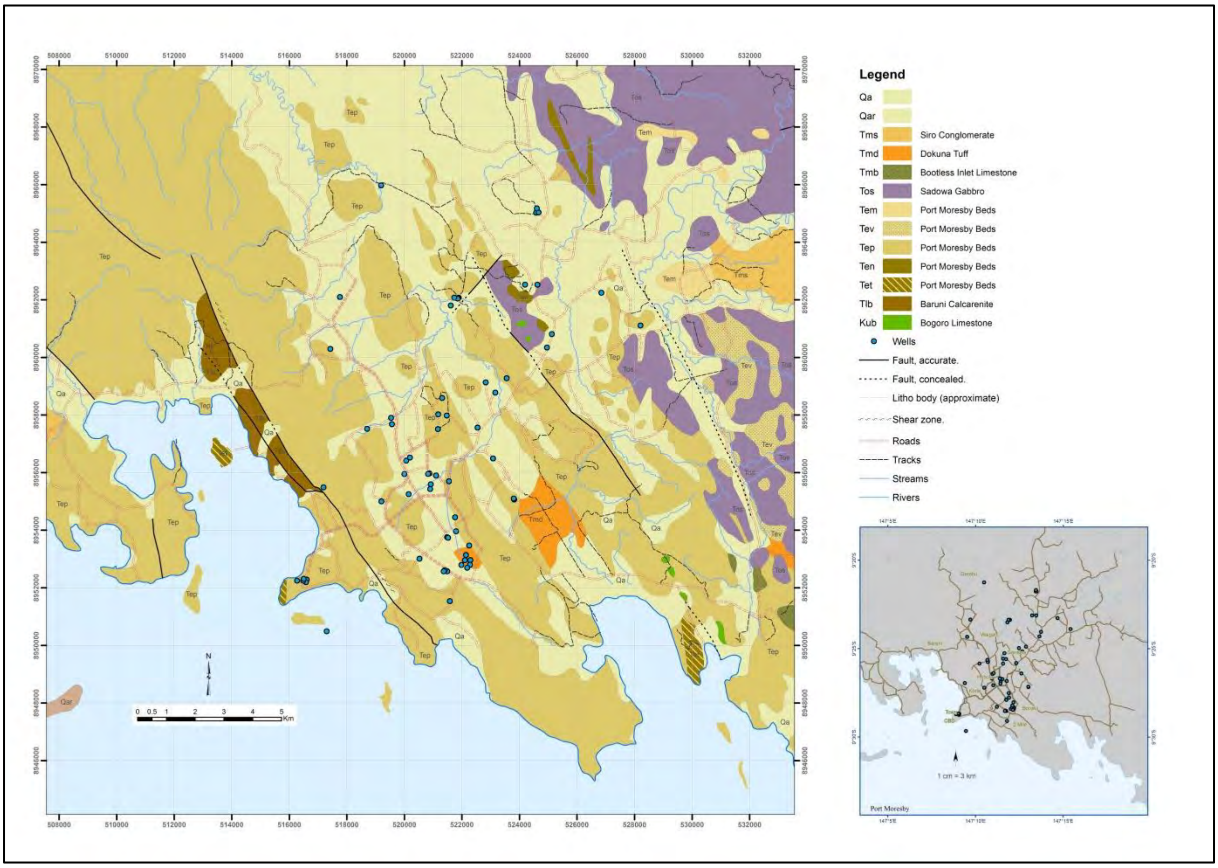

Fig. 1. Simplified geological map of the Port Moresby area

Table 1. Stratigraphic units of Port Moresby extracted and modified from Harris and Jacobson, 1972.

Stratigraphic Unit	Age	Engineering Geology Map Units
Alluvium and colluvium	Holocene	Mangrove swamp deposits Freshwater swamp deposits Coral reef deposits Beach sand Valley floor deposits Footslope deposits Hillslope deposits Terrace gravel
Dokuna Tuff	Early Miocene	Dokuna Tuff
Sadowa Gabbro	Oligocene	Sadowa Gabbro
Port Moresby Beds	Paleocene-middle Eocene	Paga Beds Nebire Limestone Baruni Limestone

The Nebire limestone is a grey to green, massive, strongly indurated, brittle and hard fine grained limestone which crops out in a series of northwest trending hills from Mt. Lawes through Mt. Eriama to Bootless Inlet. Less competent reddish brown and purple limestone occurs as bands and lenses in places. The competent Nebire limestone is quarried and crushed for concrete and sealing aggregate (Fig. 2).

Interbeds of limestone and siltstone occur in a northwest trending belt from Kila Kila in the south to Baruni in the north. This rock unit is massive to well-bedded which contains interbeds of conglomerate, chert, calcareous sandstone and siltstone. White fine-grained limestone is conformably overlain by pink coarse-grained limestone within the Baruni area which are characteristic of close fractures and joints.

The gabbro unit occurring within the area is locally known as the Sadowa Gabbro which intrudes the Port Moresby Beds. The gabbro is dark blue-grey in colour but occasional lighter leucocratic versions occur also. Outcrops may be seen near Mt. Lawes and Mt. Eriama (Fig. 3) north-east and east of Port Moresby respectively. In its fresh state, the gabbro is hard and strong but usually contains sheared and altered soft weak zones. Generally, outcrops of gabbro are highly weathered and disintegrate to sandy, silty gravel.

At the contact between the Sadowa Gabbro and Nebire Limestone, a narrow zone of calc-silicate hornfels occurs. This unit is fine grained, light grey to white, with white, brown or grey spots, which contains interbeds of very fine-grained, grey meta-limestone. The outcrops of this rock unit are typically massive, fresh, hard and competent. This competent rock is quarried and crushed for concrete and sealing aggregate at the Nebire Quarry (Fig. 2).

Fig. 2. The Nebire Quarry limestone and calc-silicate hornfelsed siltstone

There are two main valleys that exist in the area which are the Boroko-Taurama Valley and the Moitaka Morata Valley (Fig. 3). The valleys are underlain by the Dokuna Tuff and to some extent, the Sadowa Gabbro. These igneous units rarely outcrop as they are overlain by surficial deposits of unconsolidated alluvium and colluvium (Egara, 1988). To the north of Port Moresby, floodplain deposits occur adjacent the Laloki River consisting mostly of finer fluviatile sediments with some well-rounded gravel and cobbles.

The Dokuna Tuff varies in degree of weathering, hardness and strength, and the lithological characteristics. An outcrop at a quarry site south of Jacksons Airport showed that the tuff is closely jointed and poorly bedded with intersecting thin veins of calcite and zeolite. The tuff grades up into an overlying more weathered tuff, which is then overlain by completely weathered tuff which consists of brown sandy clay with weathered rock fragments.

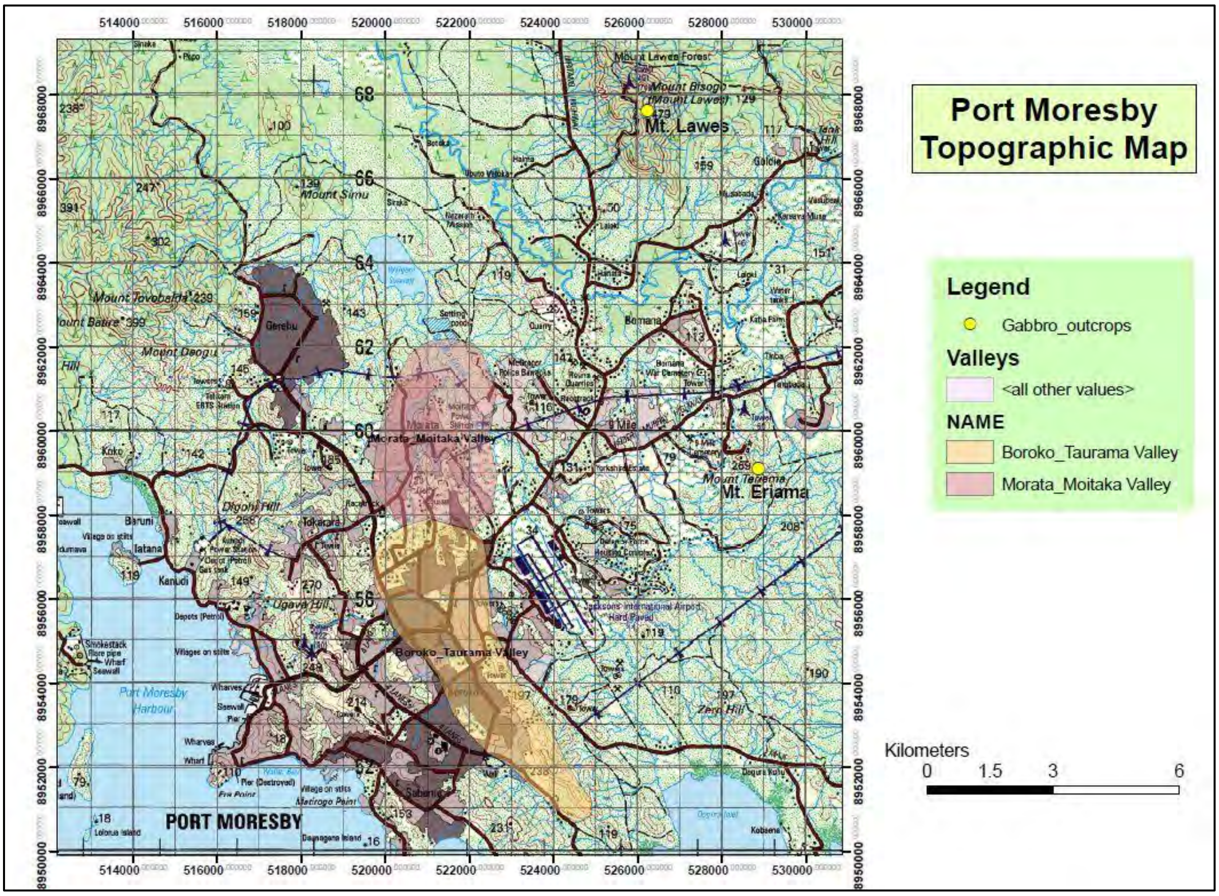

Fig. 3. Topographic map of Port Moresby outlining the main valleys within Port Moresby and locations of gabbro outcrops.

2.2 Hydrogeology in Port Moresby

From the rock units within Port Moresby, the Dokuna tuff and the alluvial deposits provide good aquifers. The Sadowa gabbro shows potential for groundwater (Fig. 4), however more tests need to be done on boreholes tapping into this formation as historical data indicates that boreholes within this unit dried up.

The Dokuna tuff is a known aquifer within the Boroko-Taurama Valley. The tuff is usually friable with a weathered brown or green colour. Its permeability depends largely on the intensity of fractures rather than primary depositional characteristics. The groundwater level within the tuff often rises above the initial standing water level (SWL) which indicates a semi-confined to confied aquifer due to the overlying alluvium/ colluvium mixtures of clay (Egara, 1988). In the past, few boreholes have tapped into the overlying alluvium; however the bores dried up rapidly.

The Laloki floodplain to the north-east of Port Moresby provides a good alluvial aquifer. The typical layers encountered in bores tapping into this unit consist mainly of silt, clay and sandy clay overlying river sand and gravel (Pounder, 1973). These unconsolidated layers of alluvium give a very high potential for recharge of groundwater. The most successful groundwater boreholes and wells in Port Moresby have been constructed in the Laloki floodplain or alluvial valley floors.

Fig. 4. Sadowa gabbro occurring beneath alluvial sandy clay layer in a dried up stream channel east of Port Moresby, Buswara 9 mile.

3. Hydrological Problem in Port Moresby

Within the two known aquifers within Port Moresby, historical data indicated hard water within the Laloki Valley and high content of salts in a localized portion of the Dokuna Tuff. Groundwater quality of former bores tapping into the Dokuna Tuff aquifer within the Boroko-Taurama Valley showed that water was potable and also suitable for gardening and irrigation purposes; however, one bore within this unit near the Boroko Hotel was reported to have high salt content (Thompson, 1955). This high concentration of salt may be localized around the Boroko Hotel area, but it is also possible that salinity of groundwater varies with depth.

According to work done by Pounder (1973), 11 bores were sampled within the Laloki and Sogeri Plateau area, 2 of which showed water hardness of less than 121 parts per million (ppm), three samples showed hardness within the range of 121 – 180 ppm, while the remaining 6 samples showed hardness greater than 180 ppm. According to the US Geological Survey scale of hardness, the groundwater within the Laloki alluvial aquifer is hard to very hard. If this water is to be used for domestic purposes, softening would be necessary; apart from this, groundwater within the Laloki area may be made potable subject to bacteriological examination.

4. Plan of Groundwater Observation System in Port Moresby, PNG

Proper groundwater observation for the Port Moresby area is lacking. Currently, no groundwater observation system is in place; however, groundwater data both from previous and recent boreholes and wells have been collected. Data collection is ongoing at present in an attempt to rebuild the groundwater database. The reconstruction of the groundwater database may be used as a platform to propose a groundwater observation system in the future.

5. Conclusions

Good groundwater potential is found within the Dokuna Tuff and the Laloki alluvial deposits. These aquifers can be further investigated to fully understand the groundwater behavior. Currently, no proper observation system is in place to monitor aquifer performance and groundwater quality data, however, the reconstruction of the groundwater database may be a first step to proposing a groundwater observation system in the future which will contribute to the overall groundwater monitoring for Papua New Guinea.

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