GW-7

Project Report of the

CCOP-GSJ-GA

Groundwater Phase III Meeting

21-23 March 2017, Bali, Indonesia

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

In cooperation with

GEOLOGICAL SURVEY OF JAPAN (GSJ), AIST

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Youhei Uchida (Chief Editor)

PREFACE

Groundwater is one of the limited natural resources of the world. Because of the lack a feeling of importance of groundwater, especially, in the late 20th century, groundwater has been significantly damaged by human activities, resulting in groundwater issues, such as land subsidence, seawater intrusion, and groundwater pollution by toxic substances, that have become remarkable problems in everywhere in the world. The countries in the East and Southeast Asia have been also faced the many groundwater problems which are needed international cooperation to be solved.

The CCOP-GSJ-GA Groundwater Project Phase III Meeting was held on 21-23 March 2017, in Bali, Indonesia. It was attended by 32 participants from Cambodia, China, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand, and Vietnam and the CCOP Technical Secretariat. In the meeting, participants confirmed progress of the project from February 2016 to March 2017, and discussed work plan for 2017 by three group discussions.

Each CCOP Member Country made a country presentation on the topic, ***"Hydrogeological map - Present status and future plan"***. Since the current groundwater problem varies from one CCOP member country to another because of various hydrogeological and geographical settings, each Member Country should share the information for efficient hydrogeological map in the CCOP regions.

This is the publication which was compiled each country report presented in the CCOP-GSJ-GA Groundwater Phase III Meeting. These reports have made clear the resent situation of hydrogeological mapping and groundwater issues in each Member Country and cooperation policy of Phase III project, and will conduct outcome of the GW Phase III Project. I believe we will be able to have some solutions about not only groundwater management but also energy problem in the CCOP member countries.

I am very grateful to the authors for their invaluable contributions and to the Organizations to which the authors belong for their permission to publish those important reports.

Youhei UCHIDA

Chief Editor

Contents

The Minutes of the CCOP-GSJ-GA Groundwater Project Phase III Meeting

21-23 March 2017, Bali, Indonesia

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The Opening Ceremony started with the Welcome Remarks and Addresses delivered by Dr. Adichat Surinkum, Director of the CCOP Technical Secretariat (CCOPTS), and Dr. Youhei Uchida, Groundwater Project Leader, Geological Survey of Japan (GSJ, AIST). The Opening Speech was made by Dr. Ego Shyarial, Permanent Representative of Indonesia to CCOP & Head of the Geological Agency of Indonesia (GA).

Dr. Youhei Uchida presented the progress of the Project from 16 February 2016 to 20 March 2017. During the period, the report of the CCOP-GSJ-NAWAPI Groundwater Phase III Project Meeting held on 16-18 March 2016, in Hanoi, Vietnam has been published, circulated to all the participants of the meeting, and uploaded to the CCOP website, http://ccop.asia/pdf/publication/GW-6.pdf. On the project's main objective of compiling groundwater data of CCOP Member Countries using Open Web GIS System, to date the groundwater data submitted by Japan, Korea, Malaysia and Philippines are already accessible at the GSi Groundwater Portal, https://ccop-gsi.org/gsi/ccop_water/index.php. Data from Thailand and Vietnam from previous GSJ-CCOP Groundwater projects are also available from this portal.

On the CCOP Groundwater Sub-Project: Development of Renewable Energy for Ground-Source Heat Pump System in CCOP Regions, one GSHP System was installed at Vietnam Institute of Geosciences and Mineral Resources (VIGMR), Hanoi in October 2016. Consequently, a workshop on Practical Analysis of GSHP Logging Data was organized at VIGMR headquarters on 20 February 2017 with 50 participants from Geological Survey of Japan, University of Fukushima, Akita University, Institute of Energy (MOIT), Vietnam Institute of Geosciences and Mineral Resources as well as scientists, managers from units within and outside of the Ministry of Natural Resources and Environment, Vietnam and a number of private companies interested in GSHP system.

Country reports on "Hydrogeological map - Present status and future plan" were presented by CCOP participants. Project report with the country papers will be published within 2017.

Dr. Gaurav Shrestha from GSJ updated the participants on the deliverables of the 3 groups, DB1 (Korea, China, Indonesia, Japan, Thailand), DB2 (Indonesia, Malaysia, Philippines, Vietnam) and Public Policy Group (CCOPTS, Cambodia, Lao PDR, Myanmar, Papua New Guinea, Timor-Leste [absent]).

Group discussions were held on the challenges faced in carrying out the 2015 and 2016 workplan, and on the workplan for 2017.

For DB1 and DB2, Indonesia and Thailand have just provided their data in accordance to the 2015 and 2016 Workplan, following the Project's Excel template during the meeting. China and Vietnam still have to provide the data planned to be submitted for 2015 and 2016 following the Excel template provided by the Project. They still need permission from their respective office and will communicate with CCOPTS on the requirements which may be needed to get this permission. The challenge identified in the delay of data submission was communication gap, since different persons attend in the project meetings. For countries like Indonesia and Philippines whose groundwater data are distributed in different government agencies and/or regional and local government offices, difficulty in obtaining data is rather high.

Below is the agreed 2017 Workplan.

DB Group I

- **China**: After getting permission from his office, will submit groundwater monitoring data based on the published year book (2016 workplan) following the Project's Excel template, and will update data in 2017.
- **Japan**: Expand to the Nobi plain around Nagoya City
- **Korea**: Already submitted 221 groundwater monitoring networks, and will supplement the missing data in 2017, such as temperature profile data
- **Thailand**: Expand to Khonkaen province

DB Group 2

- **Indonesia**: add data for one more big island, Sumatra Island
- **Malaysia**: add 10 or more wells data
- **Philippines**: update data for Luzon Island and add available data for Mindanao Island
- **Vietnam**: to submit GW data according to excel template provided on Thanh Hoa, Ha Tinh, Quang Nam, and Quang Ngai (2015), and update these data (2016), and for 2017 to complete 2015-2016 workplan and expand areas.

DB1 and DB2 agreed to submit data for 2017 Workplan by July 2017 to the CCOPTS.

For the ***Public Policy Group*** the 2016 workplan was completely carried out, and the following actions will be taken for year 2017.

1) Starts Sending the Groundwater DB in the excel format/template to CCOPTS by the end of May 2017.
2) Providing a list of organization for groundwater resources management in each member country to the CCOPTS and Project Leader in order to have a better coordination regarding this project
3) Attend the KIGAM-CCOP-UNESCO Meeting on "Groundwater-surface water interaction and comparative study of groundwater dependent ecosystem in the Mekong basin: application to Transboundary aquifer management", June – July 2017, Phnom Penh, Cambodia
4) Attend Asian Pacific Coastal Aquifer Management Meeting July 2017 in Danang, Vietnam
5) Attend Web-GIS training courses within framework of harmonized geology project in Lao PDR, August 2017
6) Attend the GSi Project Meeting in Lao PDR in 6-8 September 2017
7) Attend the Workshop organized by International Research on Karst, September 2017 in China (tentative)
8) Attend VACI (Vietnam Water Cooperation Initiative) Conference on October 2017 in Hanoi, Vietnam
9) Attend KIGAM/ISGeo regular training course on "Landslide and slope stability assessment & Groundwater Theory and Practices" on November ~ December, 2017
10) Formulate a bilateral program on groundwater monitoring system under CCOP work plan

DB1 and DB2 are welcome to participate to the activities planned by the Public Policy Group, except for action 1.

The participants agreed to produce a technical report on CCOP Groundwater Project Phase III by the end of the project in 2019 as proposed by Dr. Youhei Uchida. The technical report will include the following:

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

The next project meeting will be held in the first quarter of 2018 in Cambodia. Each member country should keep communication in their own organization on this project, importantly on carrying out the 2017 workplan.

Prof. Dr Shinji Tsukawaki of Kanazawa University made a presentation on “Water Resources and Water Management in Popular Tourist Areas - An Example of the Angkor World Heritage Site, Cambodia”.

This minutes is adopted as signed.

Cambodia	Myanmar
China	Malaysia
Indonesia	Papua New Guinea
Japan	Philippines
Republic of Korea	Thailand
Lao PDR	Vietnam

The Current Developments of Arsenic Contamination in Kendal Province, Cambodia

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1. Introduction

Cambodia's official name became the Kingdom of Cambodia in the 1990s. 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 percent 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 (Figure 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.

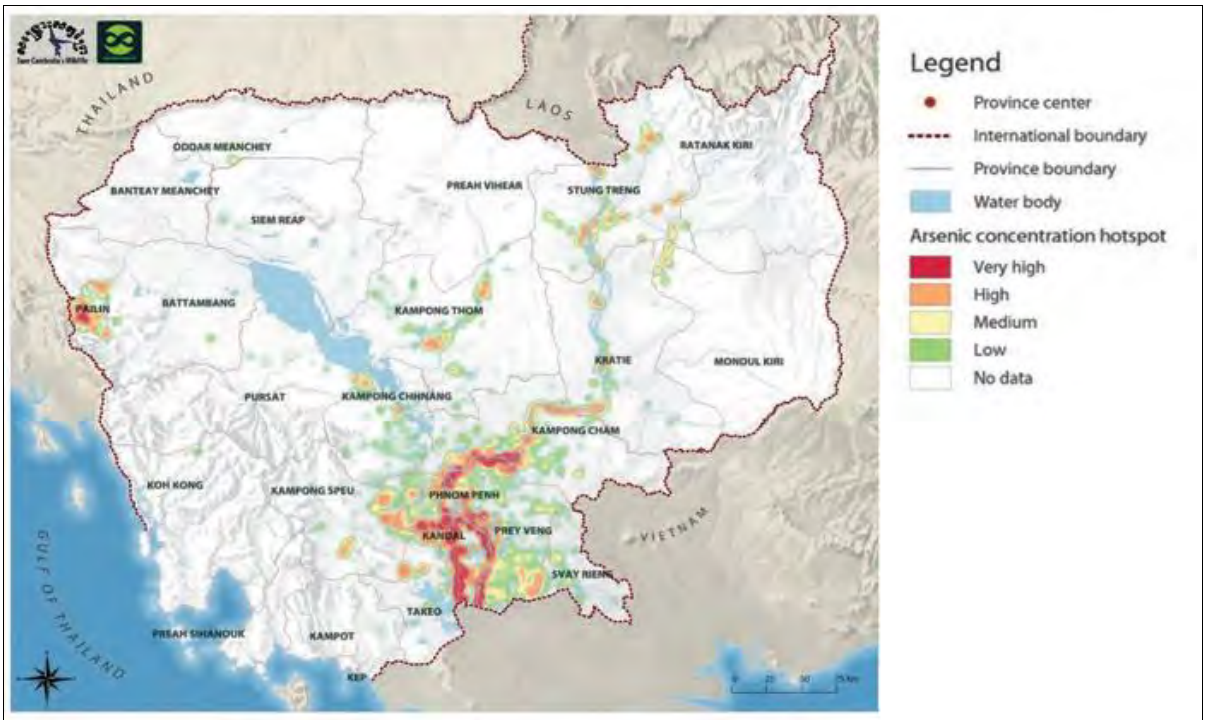

Fig. 2. Arsenic concentration hotspot map of Cambodia

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): $H3AsO4$, $H2AsO4-1$, $HAsO4-2$, $AsO4-3$

Arsenate-As (III): $H3AsO3$, $H2AsO3-$

4.2. Impacts of arsenic (As) on human health (Figure 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 (2L/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.

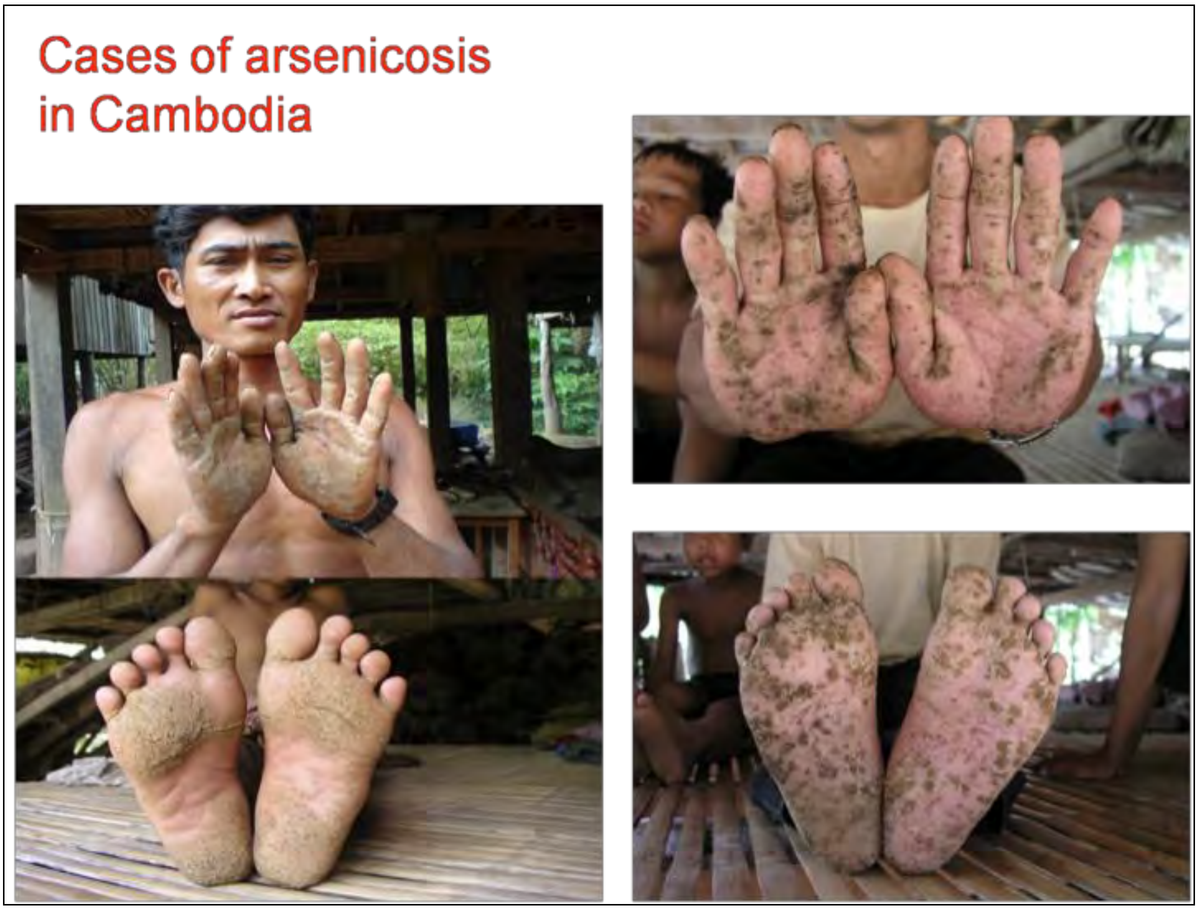

Fig.3. Impacts of **As** on human health

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 $884\times10^9 m^3/a$, 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 - 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.

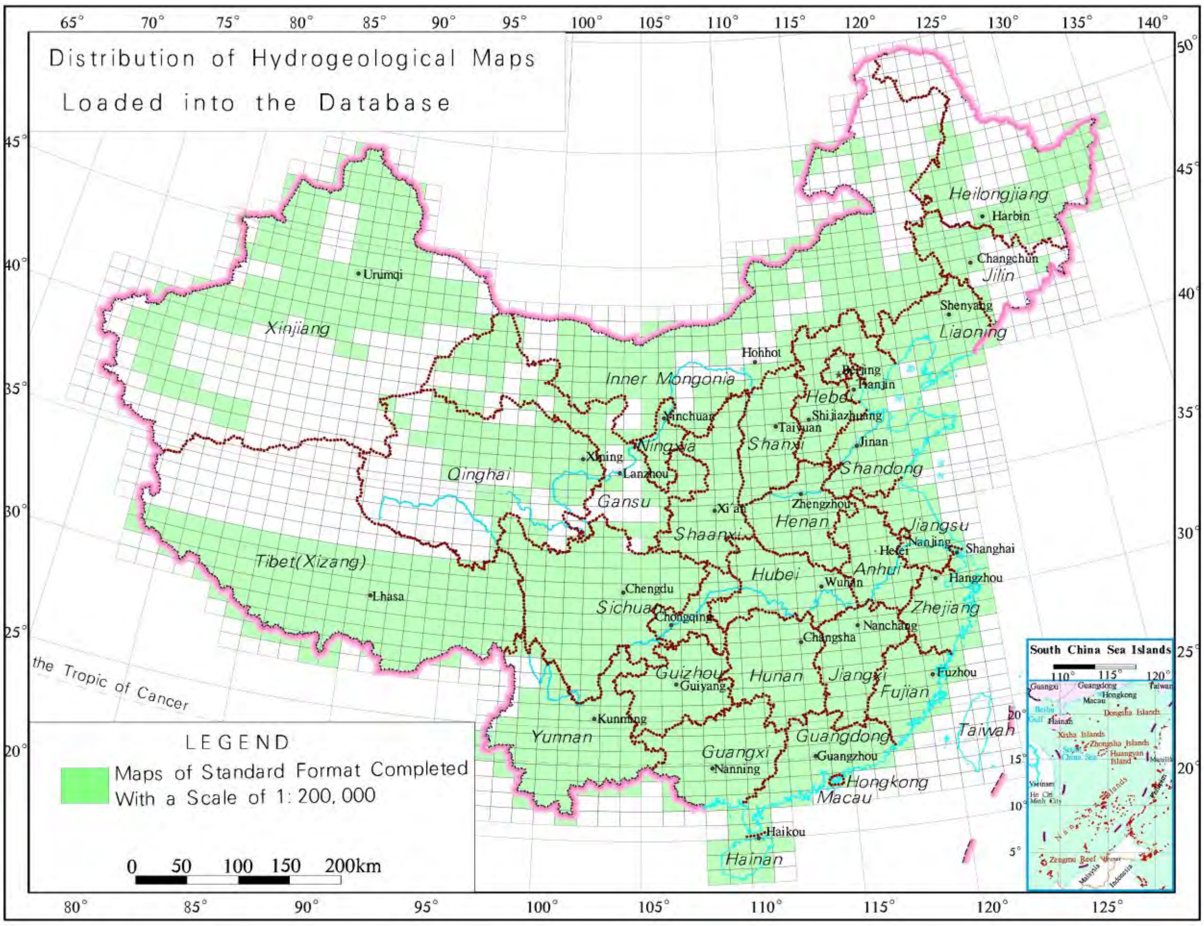

Fig. 1. National Hydrogeological Map Database (scale of 1:200,000)

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 1980's 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 since2016 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 servies" 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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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 year 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 year 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

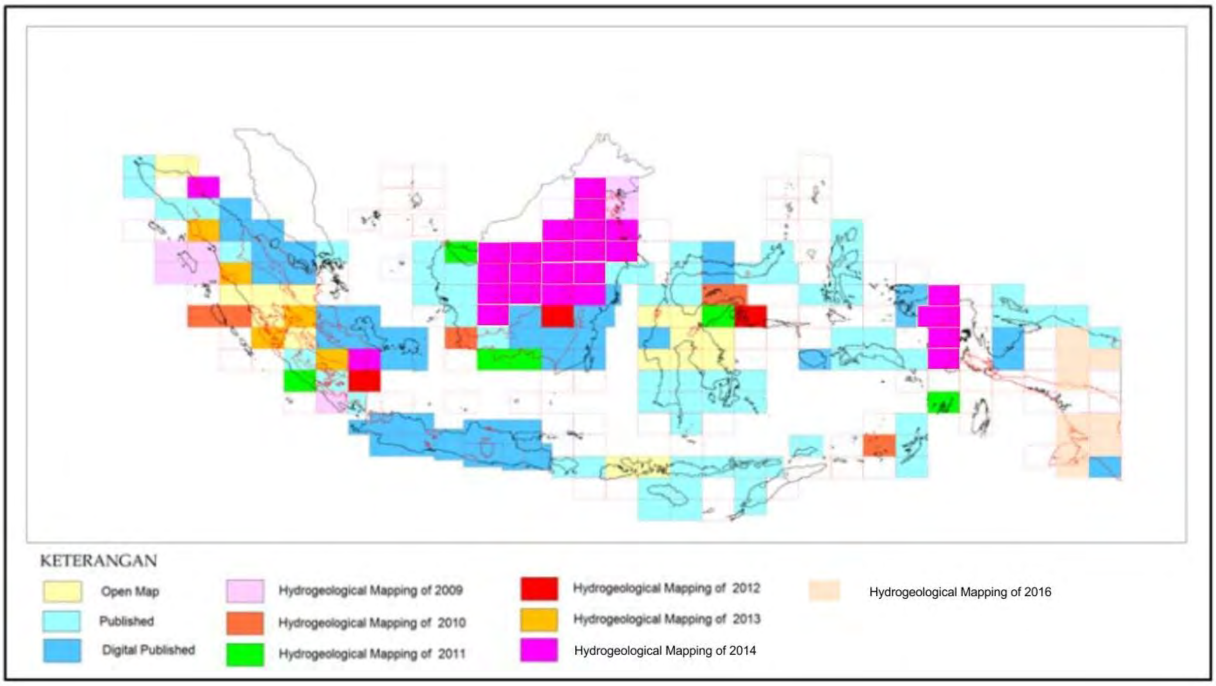

Fig. 1. The status of hydrogeological map scale of 1 : 250.000 in Indonesia until 2016 presented in a different color.

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).

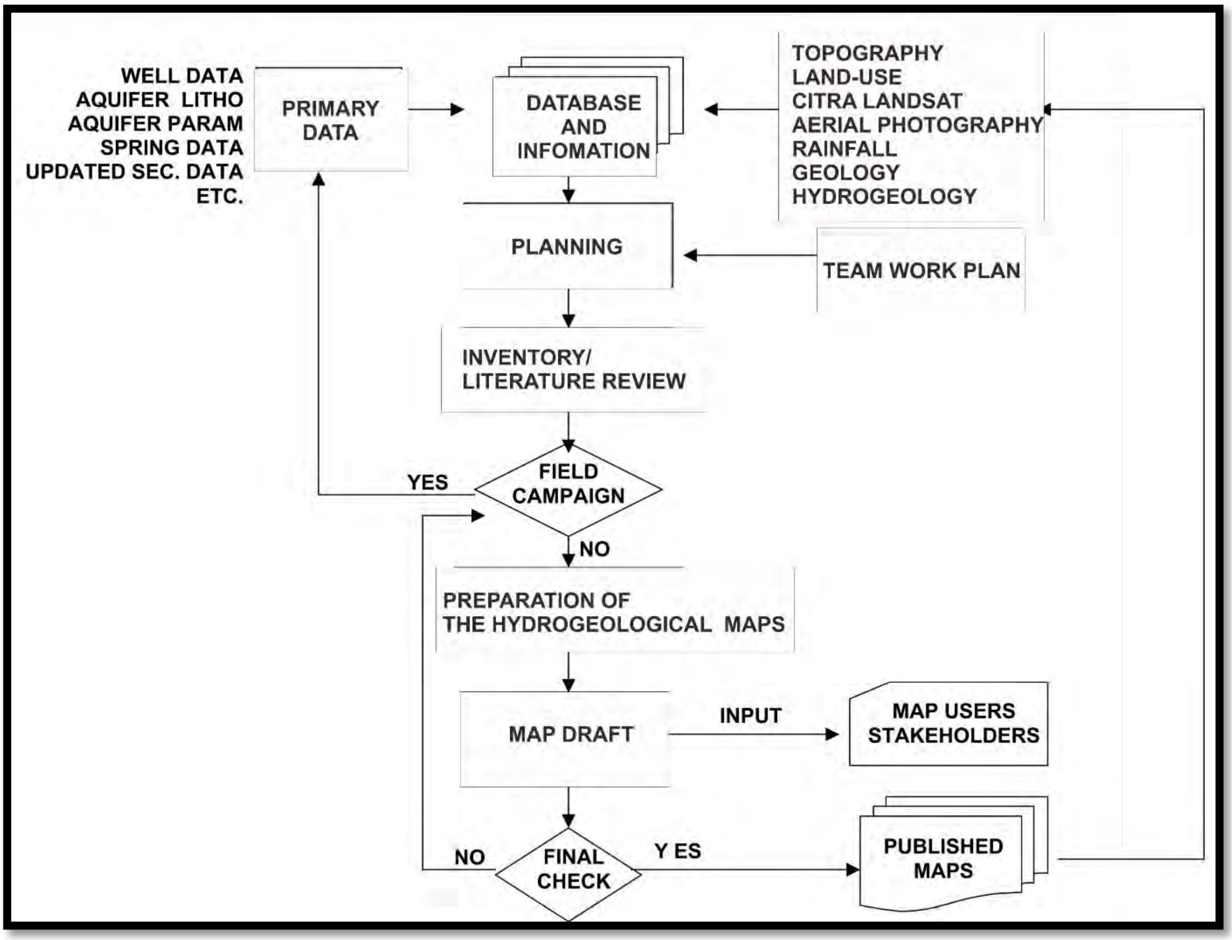

Fig. 2. The flowchart of hydrogeological mapping scale of 1 : 250.000 in Indonesia.

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.

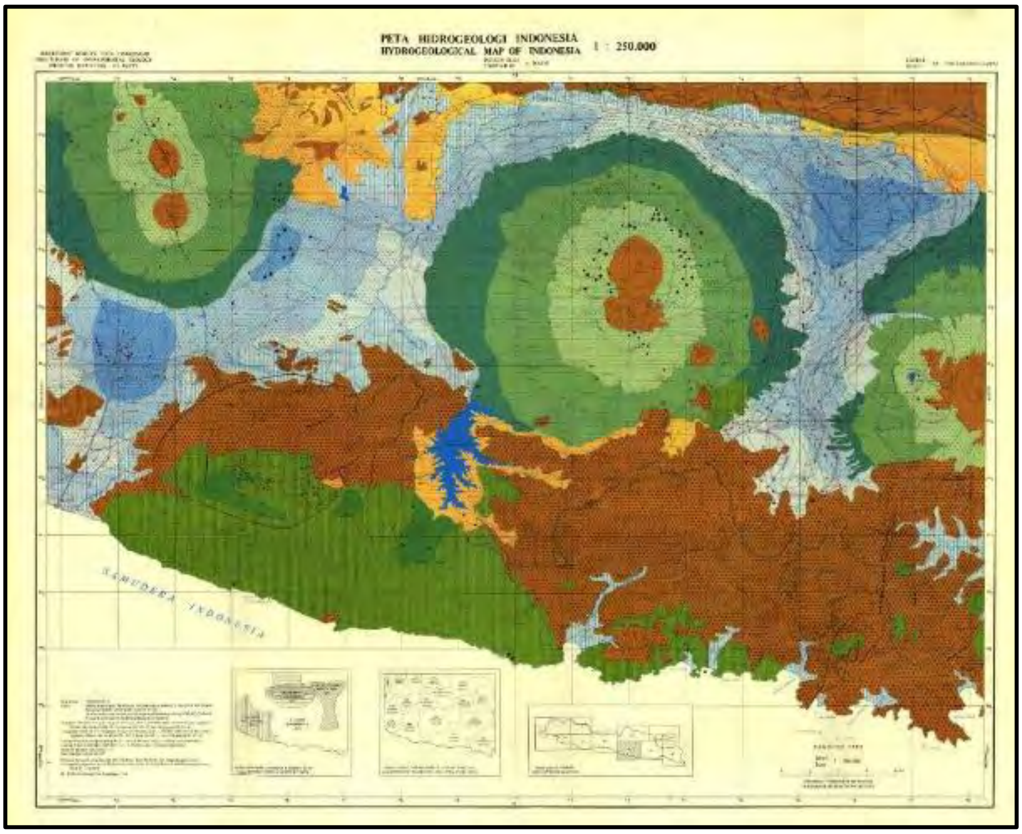

Fig. 4. Example of the hydrogeological map scale of 1: 250.000

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.

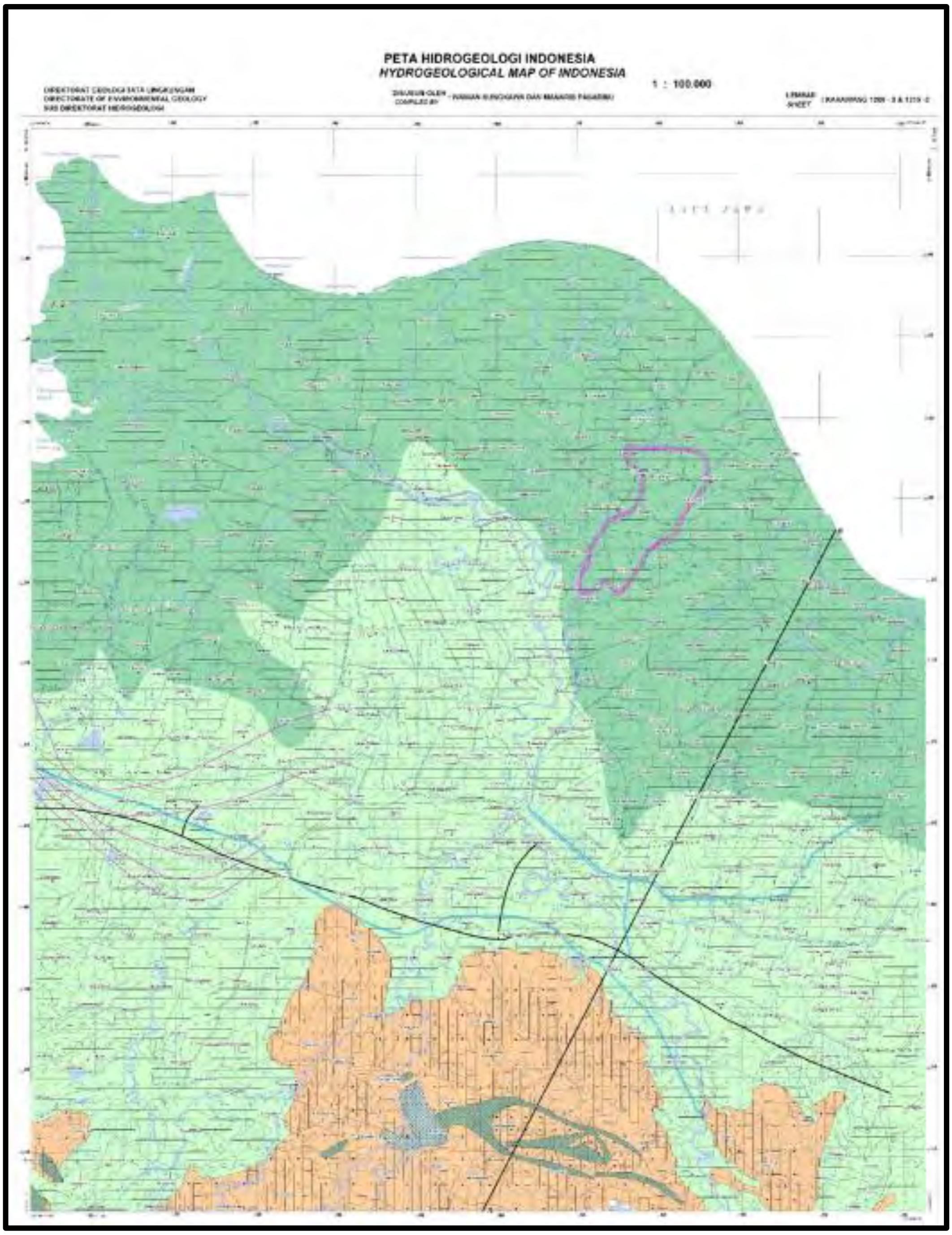

Fig. 5. An example of hydrogeological map scale of 1: 100.000 i.e., Karawang sheet.

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.

Penurunan muka air tanah / Kualitas air tanah	< 40%	40% - 60%	> 60% - 80%	> 80%	Amblesan tanah
TDS< 1000 mg/L DHL< 1000 μS/Cm	Aman				
TDS 1000–10.000 mg/L DHL>1000–1500 μS/Cm		Rawan			
TDS > 10.000–100.000 mg/L DHL1500–5000 μS/Cm			Kritis		
TDS>100.000 mg/L DHL>5000 μS/Cm Logam berat dan B3				Rusak	

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.

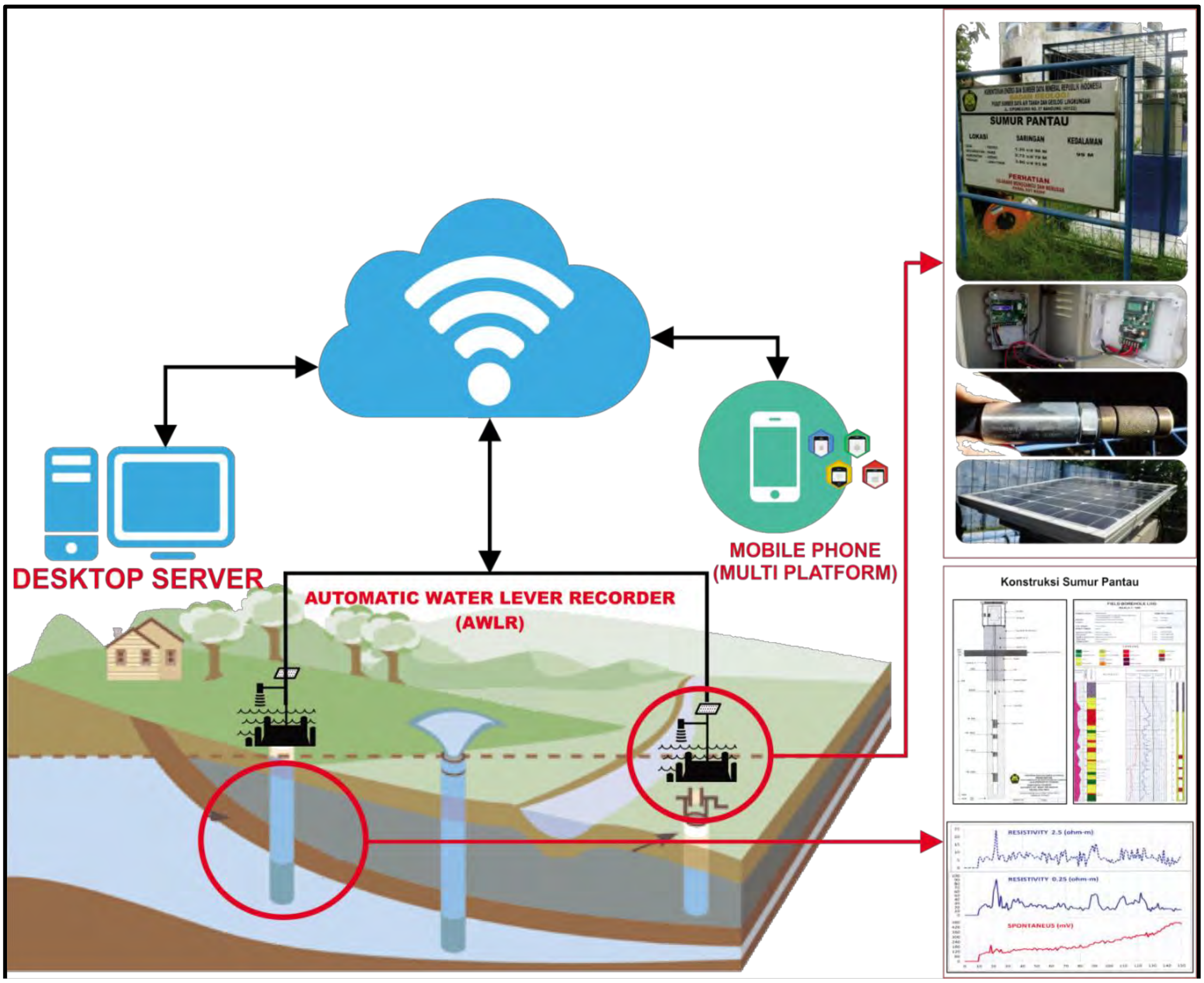

Fig. 9. Web base telemetric information system of the groundwater monitoring wells network.

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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Hydrogeological mapping in Indonesia - Groundwater Condition in Jakarta Groundwater Basin

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Abstract

Groudwater Conservation Office does this activity to find out groundwater condition in Jakarta groundwater basin from quality and quantity groundwater side. The method used in this activity is by measuring groundwater surface level and other physical parameter also chemical analysis from 164 observation wells. The result showed that the depth of groundwater surface level ranged from 0.7 – 44 m above the surface. There are conical pattern appear in unconfined and confined aquifeer from groundwater surface contour zoning analysis and that is an indication of excessive groundwater extraction. The other result from groundwater physical character and chemical analysis in unconfined aquifer showed about 83% groundwater samples not suitable from standard of ministry of health regulation *No. 492/MENKES/PER/IV/2010* about drinking water quality requirements. While at confined aquifer, about 80% groundwater samples are not suitable. Generally in nothern area Jakarta groudwater basin dominated by high value of TDS, EC, Na, Cl, and Fe and it is an indication of saltwater intrution. Saltwater intrution in north Jakarta Groundwater Basin also supported by the result of salty level analysis, Cl/HCO^3 ratio and groundwater facies with location that relatively close to the shoreline. While in southern area, groundwater characteristics are acid pH and high value of Fe, Mn, and Pb. This research is expected to be an important public information and can be used as a reference for researchers also governments to maintain and conserve sustainable groundwater.

Keywords: Groundwater, Jakarta, Hydrogeochemical

1. Introduction

Research area is in Jakarta Groundwater Basin which includes 3 provinces that is DKI Jakarta, Banten and West Java. Based on Turkandi (1992) regional geology of research area is composed of 6 formation units: alluvium (Qa) with lithology characters shale, silt, sand, gravel. Shallow marine sediment (Qnd) with lithology characters sand, silt, shale and thin layers contains of shells and foraminifera. Dike Beach sediment (Qbr) with lithology characters fine-coarse sand well sorted with mollucs shell in few place. Alluvial fan (Qav) with lithology characters fine tuff layer, sandy tuff - conglomerate tuff intercalation. Quarternary volcanic rocks are with lithology characters breccia, lahar, pumice tuff. Banten tuff (Qtvb) is with lithology tuff, pumice tuff, and tuffaceous sand. Also Serpong formation (Tpss) with lithology characters conglomerate intercalation, sandstone, siltston, shale, pumice conglomerate and pumice tuff. While from Poespowardoyo (1986) hydrogeological condition in research area included in the group of aquifer with the flow through the grains space. This aquifer generally consists of productive aquifers and distribution area, medium productive aquifer and distribution area, and local medium productive aquifer.

2. Research Method

The method used in this research is observation in dug and pump well with less than 40 metres depth to analyze groundwater quality in unconfined aquifer and obsevation in monitor well and production well to analyze groundwater quality in confined aquifer. The activities in the field are pH, EC (electrical conductivity), TDS (total dissolve solid), and groundwater temperature measurment using pH meter and EC meter tool and groundwater sampling to chemical content analysis (Fe, Mn, Ca, Mg, Na, Cl, Pb) in laboratorium,other step is measuring groundwater surface level with water level indicator tool to observe groundwater flow pattern. Thematic maps made with Surfer and Map Info software.

3. Hasil Survey Research Result

Groundwater conservation office monitoring the groundwater condition in Jakarta Groundwater Basin from 164 wells consist of 96 wells for unconfined aquifer (dug well and pump well) and 68 wells for confined aquifer (monitor well and production well). The result in unconfined aquifer is just 16 locations that suitable to standart or about 83% groundwater samples in unconfined aquifer not suitable from standart of ministry of health regulation *No. 492/MENKES/PER/IV/2010* about drinking water quality requirements (table 1), whereas groundwater in uncofined aquifer still become a priority for middle to lower society class to fulfill they need in drinking water and daily activities. While in confined aquifer is just 13 location that suitable to standart or about 80% from all confined aquifer samples not suitable from standart of ministry of health regulation (Figure 2).

Table 1. Maximum standart element content in groundwater for drinking water that recommended by Ministry of Health

Parameter	**Standar Value**	**Parameter**	**Standar Value**	**Parameter**	**Standar Value**
Smell	Odorless	Mn^{2+}	0,4	SO_4^-	250
Flavor	Tasteless	K^+	-	NO_2	3
DHL (µS/cm)	-	Li^+	-	NO_3^-	50
pH	6,5 – 8,5	Na^+	200	TDS	500
$CaCO_3$ (Mg/L)	500	NH_4^+	1,5	Zn	3
Ca^{2+}	-	CO_3^-	-	Cu	2
Mg^{2+}	-	HCO_3^-	-	Pb	0,01
Fe^{3+}	0,3	Cl^-	250		

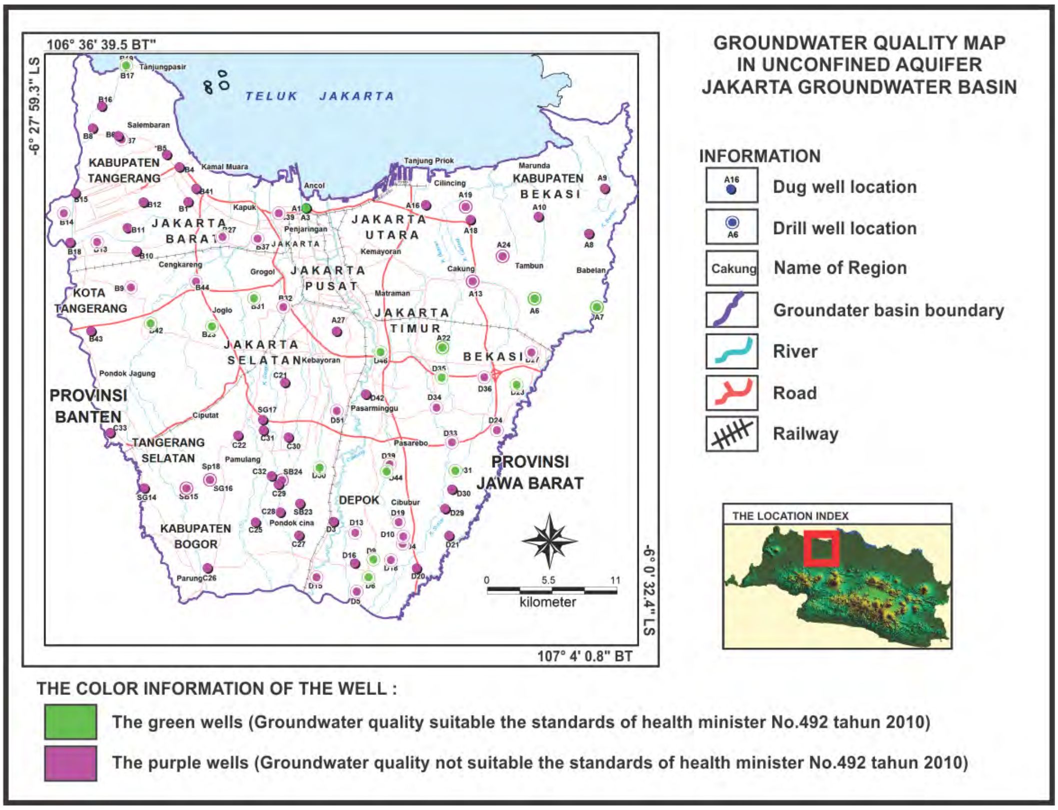

Fig. 1. General condition groundwater quality for unconfined aquifer in research area

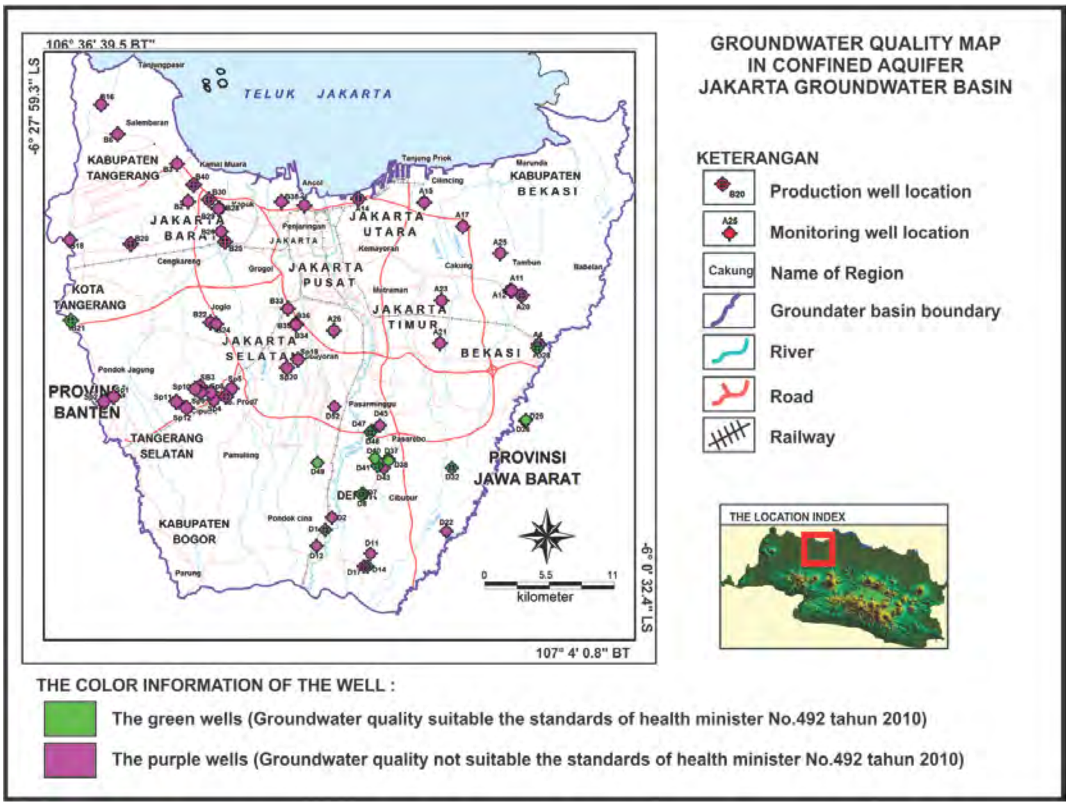

Fig. 2. General condition groundwater quality for confined aquifer in research area

Generally in nothern area Jakarta groudwater basin dominated by high value of TDS, EC, Fe, Na, and Cl that exceed the quality standart of Ministry of Health. While in southern area, groundwater characteristics are dominated by acid pH and high value of Fe, Mn, and Pb that exceed the quality standart of Ministry of Health. It is likely to be influenced by rock lithology in the South or CAT Jakarta is dominated by volcanic rocks (Figure 3).

No	Parameter	Standards of Health Minister	The highest levels in the northern region
1	TDS	500 mg/L	21.628 mg/L
2	Na	200 mg/L	14.599 mg/L
3	Cl	250 mg/L	6240 mg/L
4	Fe	0,3 mg/L	18,38 mg/L

No	Parameter	Standards of Health Minister	The highest levels in the Sothern region
1	pH	6,5 – 8,5	4,34 (pH asam)
2	Mn	0,4 mg/L	2,5 mg/L
3	Fe	0,3 mg/L	13,73 mg/L
4	Pb	0,01 mg/L	0,09 mg/L

Fig. 3. Highest element domination in research area

Based on groundwater flow pattern result, generally groundwater flow in both unconfined and confined aquifer is flowing from south to north (figure 4). But in the middle and north Jakarta Groundwater basin there is a conical pattern which indicates excessive groundwater extraction that causing groundwater surface level drastically declining. Recorded in 2015 groundwater surface level ranged at 0,6 metres until 44 metres from surface and the deepest is in Bintaro-South Tangerang area. If we look the directions of that groundwater flow, it is very possible some areas with a good groundwater quality can be polluted by poor groundwater quality.

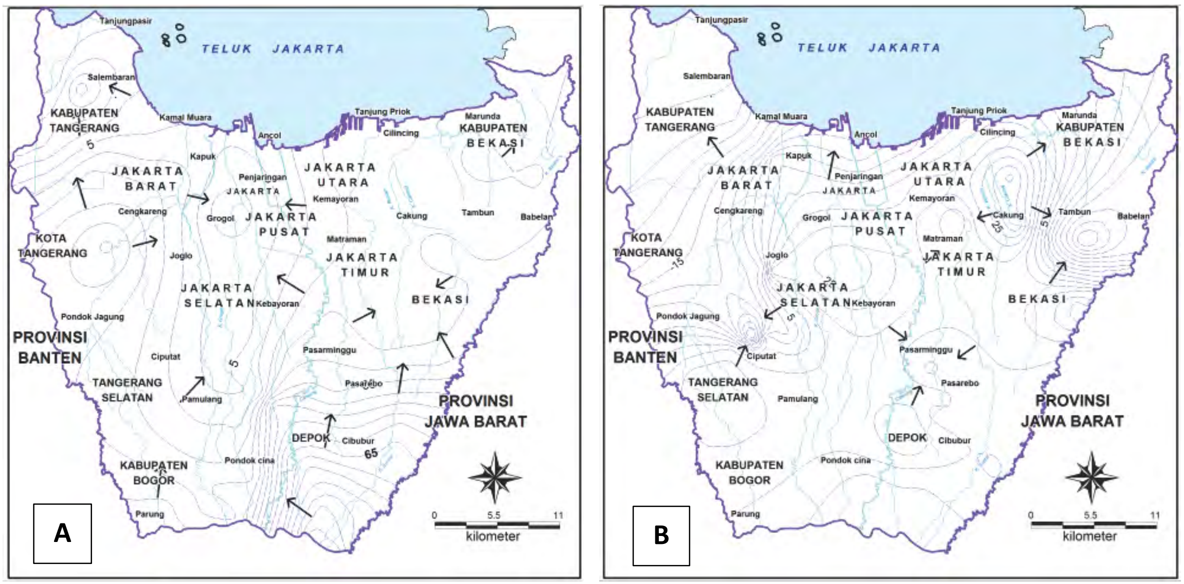

Fig. 4. Groundwater flow pattern map in unconfined aquifer (A) and confined aquifer (B)

4. Groundwater Salinity Level Zoning Analysis

This analysis was conducted to determine the level of groundwater salinity in the study area, both located in unconfined aquifer system and confined aquifer system. Refers to groundwater classification set by PAHIAA (Ad Hoc Groundwater Intrusion Comitee) in Jakarta 1986 that categorize water character basen on TDS, EC, and Chloride (Cl) value in water, it can be categorized by groundwater salinity level ini research area with freshwater, fresh-brackish, brackish, silty, and connate. Here is the classification of groundwater salinity levels by PAHIAA presented in Table 2.

Table 2. Groundwater salinity level classification (PAHIAA, 1986)

No	Water Character	TDS (mg/L)	EC (μS/cm)	Cl^- content (mg/L)
1	Fresh	<1.500	<1.500	<500
2	Fresh – Brackish	1.000-3.000	1.500-5.000	200-2.000
3	Brackish	3.000-10.000	5.000-15.000	2.000-5.000
4	Saline	10.000-35.000	15.000-50.000	5.000-19.000
5	Connate	>35.000	>50.000	>19.000

From analysis result on each observation well in North-West Jakarta Groundwater Basin, generally in uncofined aquifer divided in to 3 category salinity level that is fresh water (green color in map), fresh-brackish (yellow color in map) and brackish (orange color in map). Fresh water still dominating about 80% in west Jakarta Groundwater Basin, but in shoreline appears fresh-brackish groundwater category (Teluk Naga-Tangerang District, Penjaringan – North Jakarta and Pesir Polgar – West Jakarta). Beside that there is also brackish water at Kamal – North Jakarta (Figure 5).

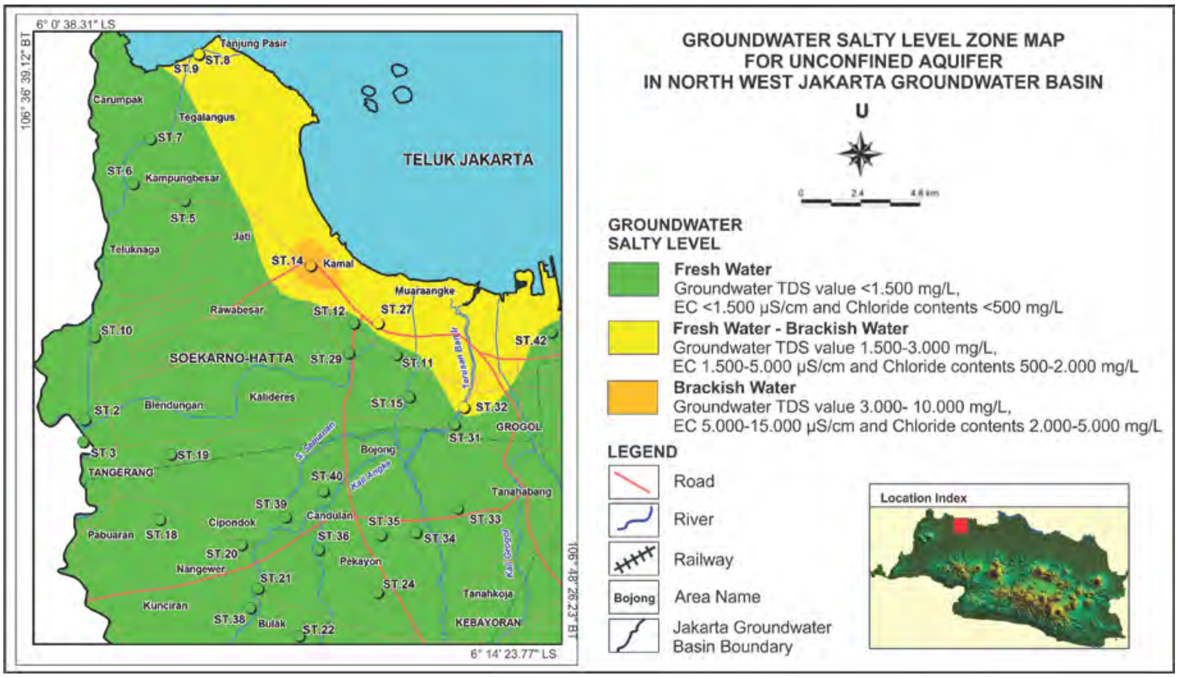

Fig. 5. Groundwater salinity level zoning in unconfined water North-West Jakarta Groundwater Basin

While in cofined aquifer divided in to 4 category salinity level that is fresh water (green color in map), fresh-brackish (yellow color in map) and brackish (orange color in map) and silty (red color in map). Fresh water dominate about 75% in northwest Jakarta Groundwater Basin, but in northern shoreline appear fresh-brackish groundwater category (Kamal – North Jakarta and Pluit – North Jakarta). Other analysis result there is brackish water in Senayan – West Jakarta and Salty category in Kosambi – Tangerang City with TDS value 26.544 mg/L, EC value 39.816 µS/cm and Chloride content 16.431,9 mg/L, it become indication of saltwater intrusion because well location near from shoreline (it is about 5 km near). General condition groundwater salinity level in confined aquifer shows in figure 6.

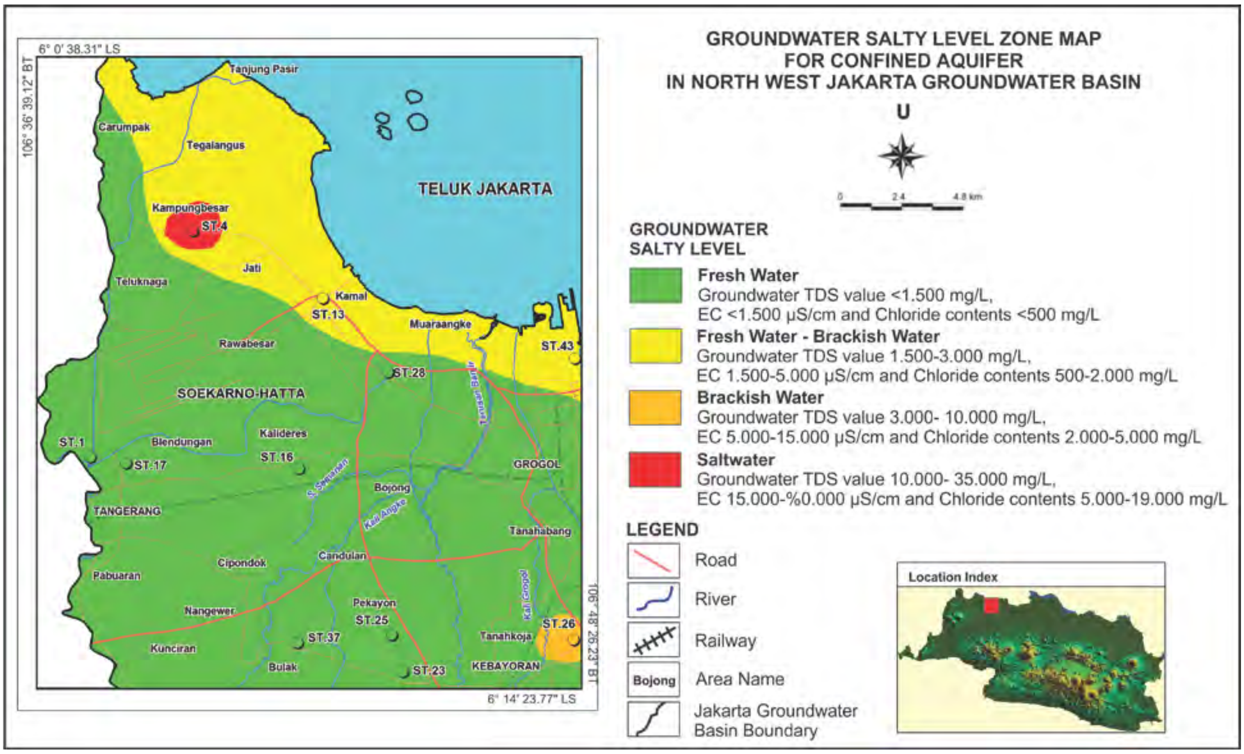

Fig. 6. Groundwater salinity level zoning in confined water North-West Jakarta Groundwater Basin

5. Groundwater Facies Analysis

Groundwater facies is an identification groundwater type based on difference and water genesis that related to groundwater system and body where the groundwater takes a place (Back, 1961, 1966; Morgan and Winner, 1962; Seaber, 1962 dalam Freeze and Cheery, 1979). The way of doing this analysis is by plotting chemical elements on Piper Diagram to determine groundwater facies in research area either unconfined aquifer or confined aquifer so it can be linked to presence of Na-Cl facies (sodium chloride) which is one indication of the saltwater influence. Figure below is the groudwater chemical type on each well that represent unconfined and confined aquifer condition in research area (Figure 7).

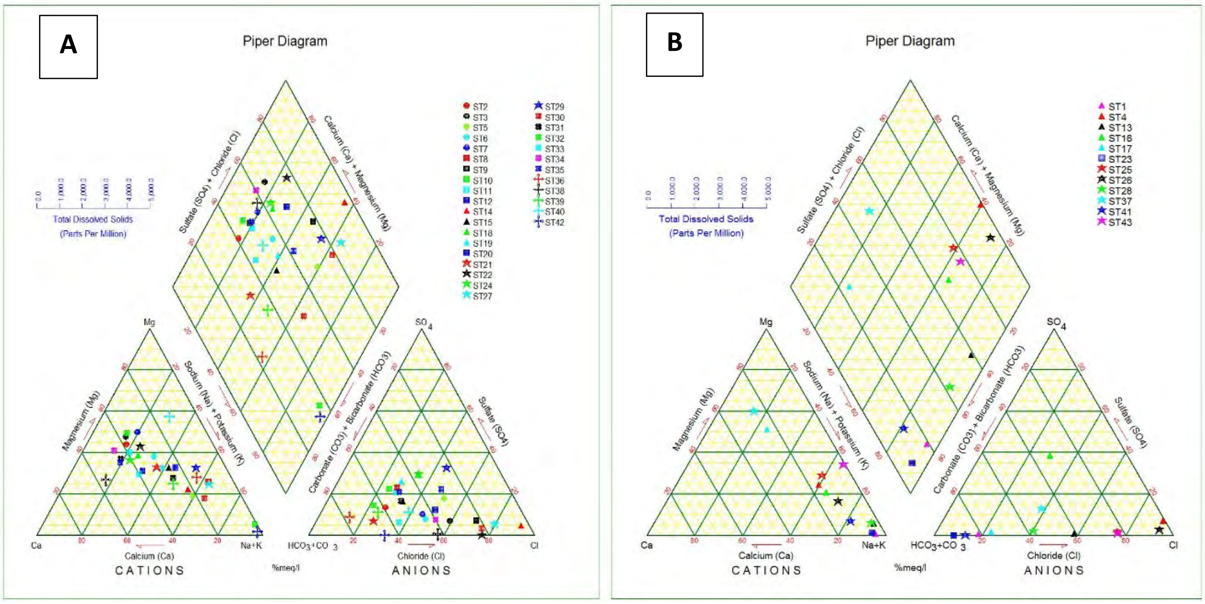

Fig. 7. Piper Diagram Analysis in unconfined aquifer (A) and confined aquifer (B)

Based on Piper diagram analysis, groundwater facies in unconfined aquifer in research area divided in to 6 facies: Na-HCO_3 facies (Sodium Bicarbonate), Ca-HCO_3 facies (Calcium Bicarbonate), Mg-HCO_3 facies (Magnesium Bicarbonate), Ca-Cl facies (Calcium Chloride), Mg-Cl facies (Magnesium Chloride), and Na-Cl facies (Sodium Chloride). While in confined aquifer, it is divided in to 4 groundwater facies: Na-HCO_3 facies (Sodium Bicarbonate), Mg-HCO_3 facies (Magnesium Bicarbonate), Na-SO_4 facies (sodium sulfate) and Na-Cl facies (Sodium Chloride). The existence of Na-Cl facies is an indication of the influence from saltwater to groundwater in research area, especially for observation wells that near the shoreline.

6. Ratio Cl/HCO_3 Analysis

Revelle (1941) explains that the ratio analysis Chloride / Bicarbonate (Cl/HCO_3) was conducted to determine how much influence the contamination of brine (saltwater) to groundwater. To analize the ratio we should dividing chloride ion with bicarbonate ion in mg/L from groundwater chemical analysis in laboratorium. Chloride is the dominant ion contained in saltwater and normally its extince only in very small amounts in groundwater. While the bicarbonate ion is usually abundant in groundwater and less contained in saltwater. This is Revelle's classification for saltwater influence to groundwater:

- ✓ Fresh water is groundwater with chloride-bicarbonate comparison value 0-0.5.
- ✓ Less saltwater contamination is groundwater with chloride-bicarbonate comparison value 0.5-1.3
- ✓ Medium saltwater contamination is groundwater with chloride-bicarbonate comparison value 1.3-2.8
- ✓ High saltwater contamination is groundwater with chloride-bicarbonate comparison value 2.8-6.6

- ✓ Very high saltwater contamination is groundwater with chloride-bicarbonate comparison value 6.6-15.5
- ✓ Brine is groundwater with chloride-bicarbonate comparison value 15.5-200.

Cl/HCO_3 ratio analysis result in unconfined aquifer research area divided into 4 categories: freshwater, less saltwater contamination, medium saltwater contamination and very high saltwater contamination. Generally dominated by freshwater, some location less contaminated by saltwater. Another result obtained medium contaminated location is in Kapuk Kamal Raya Street, Penjaringan – North Jakarta. While well location that contaminated with high saltwater is in Kamal, Penjaringan – North Jakarta with 2 km distance from nearest shoreline. In general overview of the zoning saltwater contamination influence can be seen in Figure 8 below.

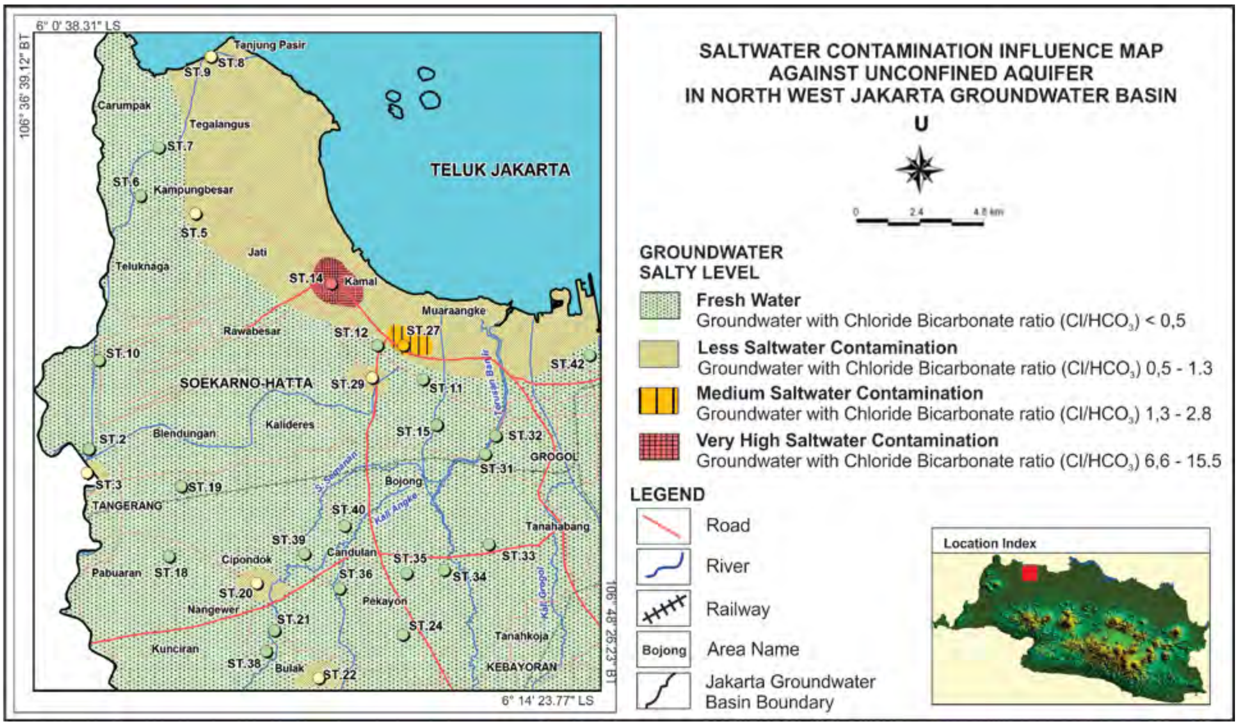

Fig. 8. Saltwater contamination influence in unconfined aquifer research area

In confined aquifer few locations (Kosambi area-Tangerang district) have contaminated by saltwater with Cl/HCO_3 ratio reach 36.684 because well location relatively near shoreline. Here is a general overview of zoning influence of salt water to groundwater confined aquifer in the research area (Figure 9).

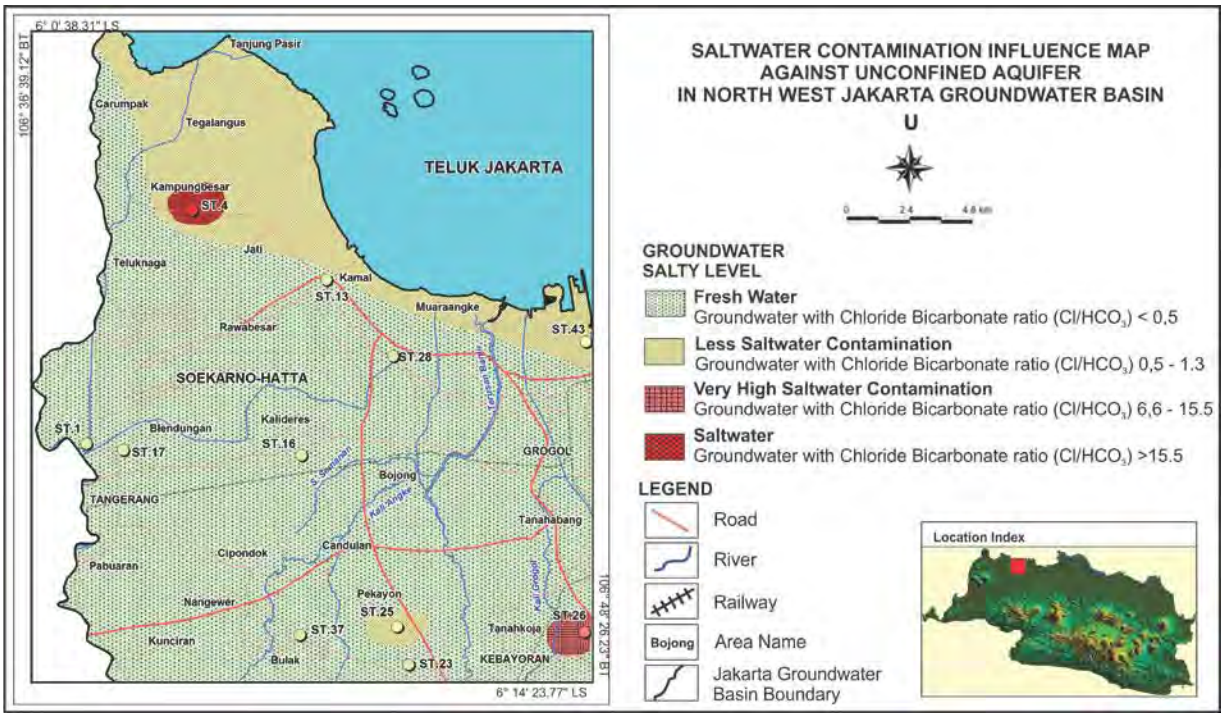

Fig. 9. Saltwater contamination influence in confined aquifer research area

7. Future Plan

In fulfilling the tasks Groundwater Conservation Office to monitor groundwater conditions and mitigation of the impact of groundwater extraction in Jakarta Groundwater Basin, as well as the development of groundwater conservation technology, there are some plans program that we will do such as:

- Build new monitoring wells in areas that haven't been represented so it will be more details in monitoring groundwater condition.
- Artificial recharge technology development such as injection well, an infiltration pool and infiltration trench.
- Monitoring well technology development with Automatic Water Level Recorder (AWLR) system connected to Geographic Information System (GIS) Groundwater Conservation Office so can be obtained real time modeling of groundwater surface level and can be used by public directly.
- Monitoring and verifying the production wells in commercial building to keep control and monitor groundwater extraction which directlu resulted in the up and down groundwater surface level.

8. Conclusion

Groundwater quality condition in Jakarta Groundwater Basin is generally not suitable from the standard of ministry of health regulation *No. 492/MENKES/PER/IV/2010* about drinking water quality requirements. Based on the observation in unconfined aquifer, there are 17% locations that are suitable to standard, 83% groundwater samples in unconfined aquifer not suitable from standart recommended. While in confined aquifer is just 20% from total sample that suitable to standart of ministry of health regulation. Generally in northern area not suitable from standart because high value ofTDS levels, Na, Cl and Fe that exceeds the maximum standard. While in the southern area in general has an acidic pH, Mn, Fe and Pb beyond the standard so that the groundwater becomes unfit for consumption. Based on groundwater flow pattern result, generally groundwater flowing from south to north, but in some locations there are a conical pattern which indicates excessive groundwater extraction Recorded in 2015, the deepest groundwater surface level at 44 metres from surface in Bintaro-South Tangerang area. From the analysis of salinity level and Cl/HCO_3 ratio to identificate saltwater influence to groundwater in research area found that in unconfined aquifer there is an indication of saltwater intrusion around Kamal, Penjaringan – North Jakarta area with 2 km distance from the nearest shoreline while in confined water there is an indication of saltwater intrusion in kosambi – Tangerang district with 5 km distance from the nearest shoreline. It is supported by groundwater facies analysis in Piper diagram that shows Na-Cl facies (Sodium Bicarbonate) in area indicated of saltwater influene. In order to preserve groundwater in Jakarta Groundwater Basin it is necessary to conserve groundwater efforts and more detail monitoring. Some things can we do like build an artificial recharge such as recharge well, infiltration pool and infiltration trench. And also supported by monitoring and verifying production well so it can be control the extraction of groundwater which is directly resulted in the up and down groundwater surface level.

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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).

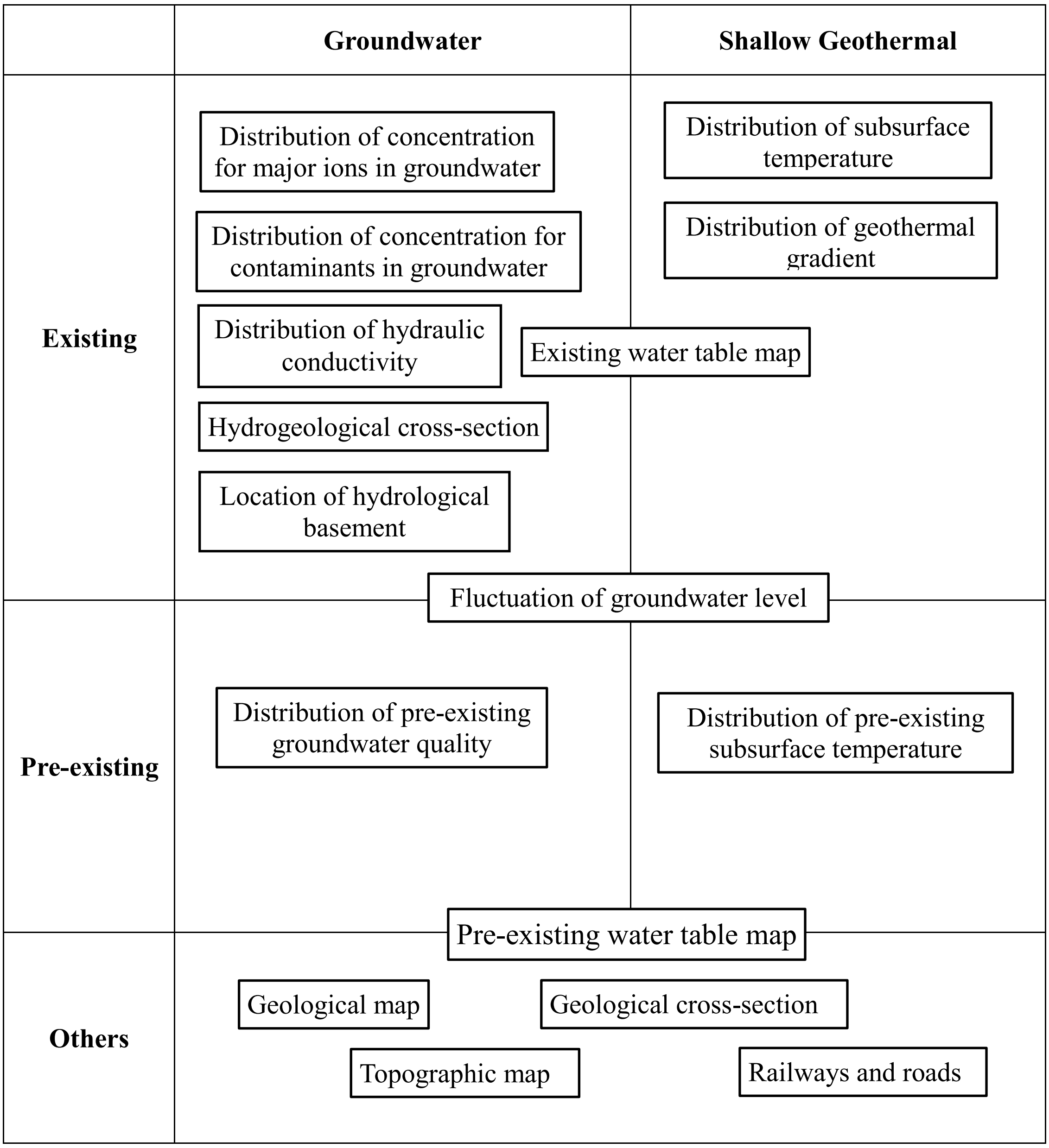
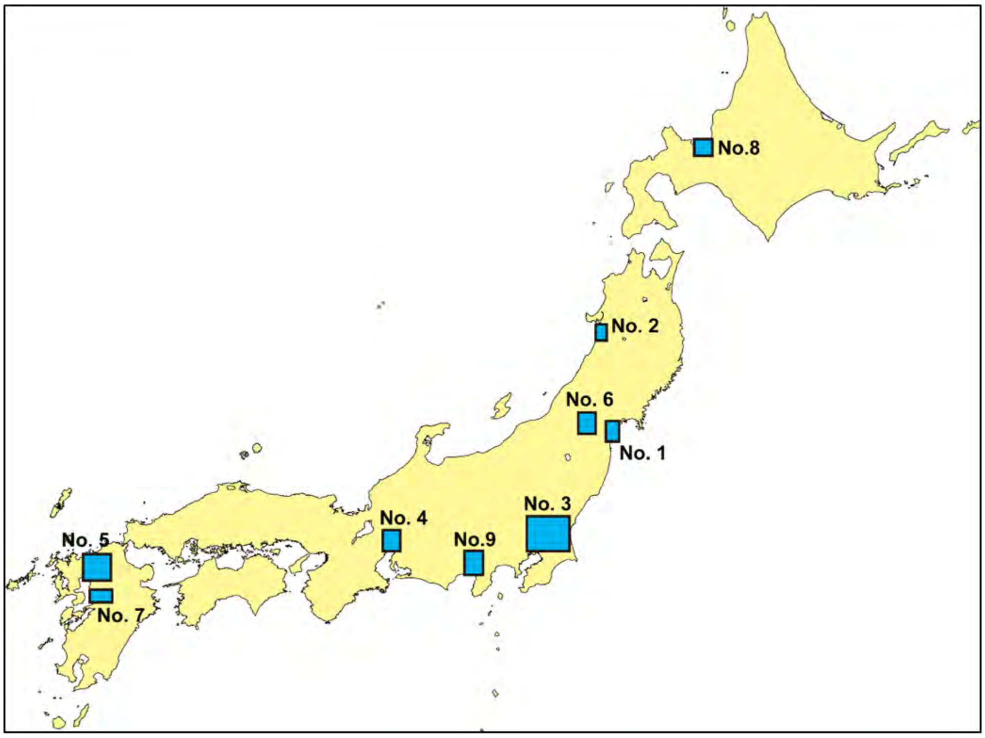


Fig. 1. Main editing items of water environment map



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

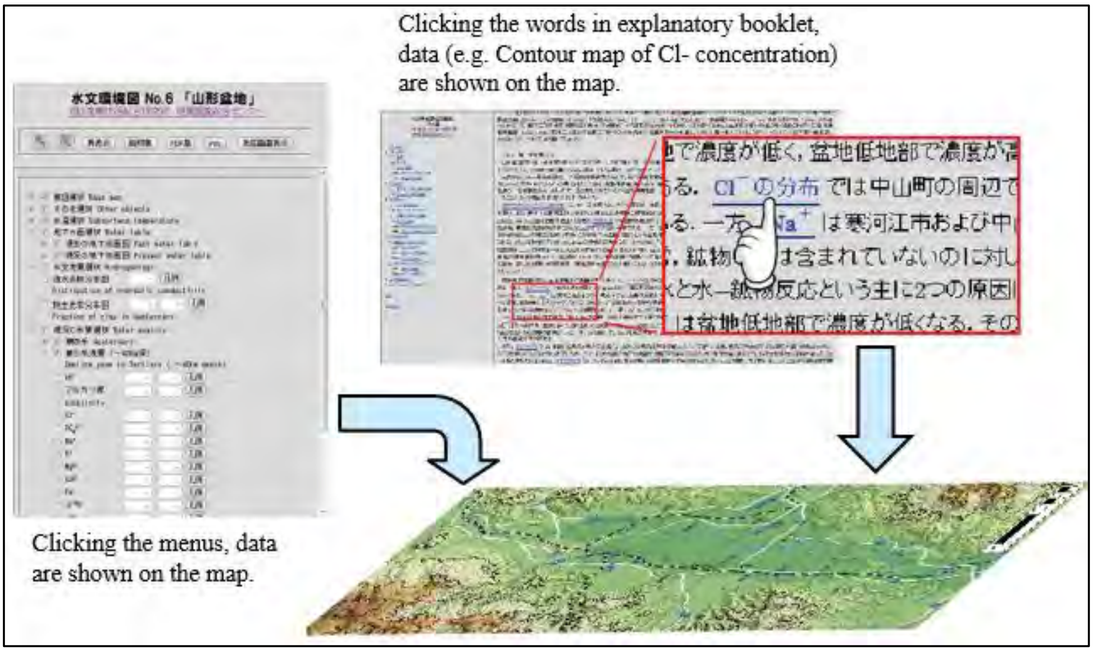


Fig.3. Explanatory booklet and map in the water environment map in Japan

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.

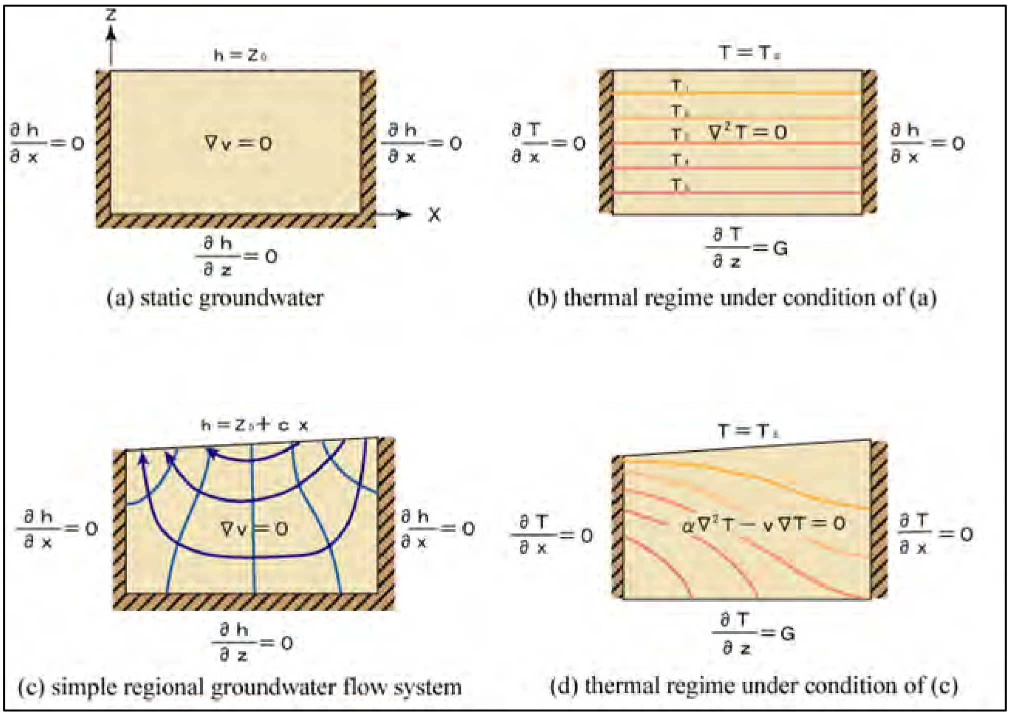


Fig. 4. Groundwater flow system and subsurface temperature distribution (modified from Domenico and Palciauskas, 1973)

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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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.

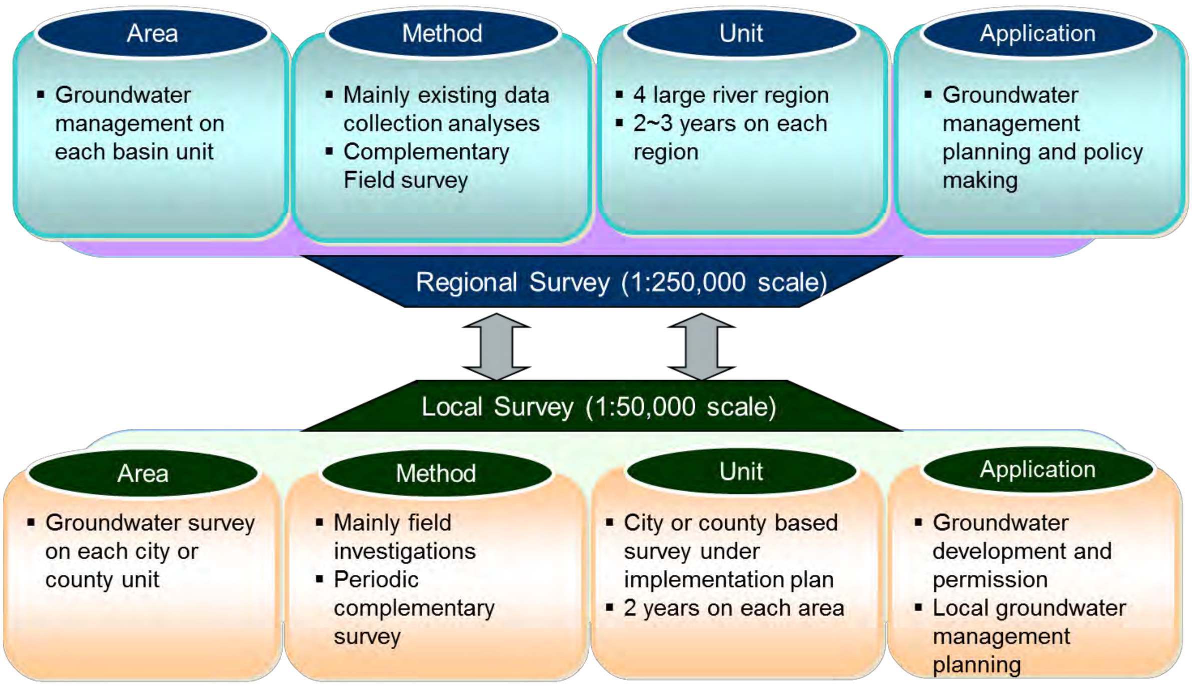

Fig. 1. Basic groundwater surveys in Korea

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.

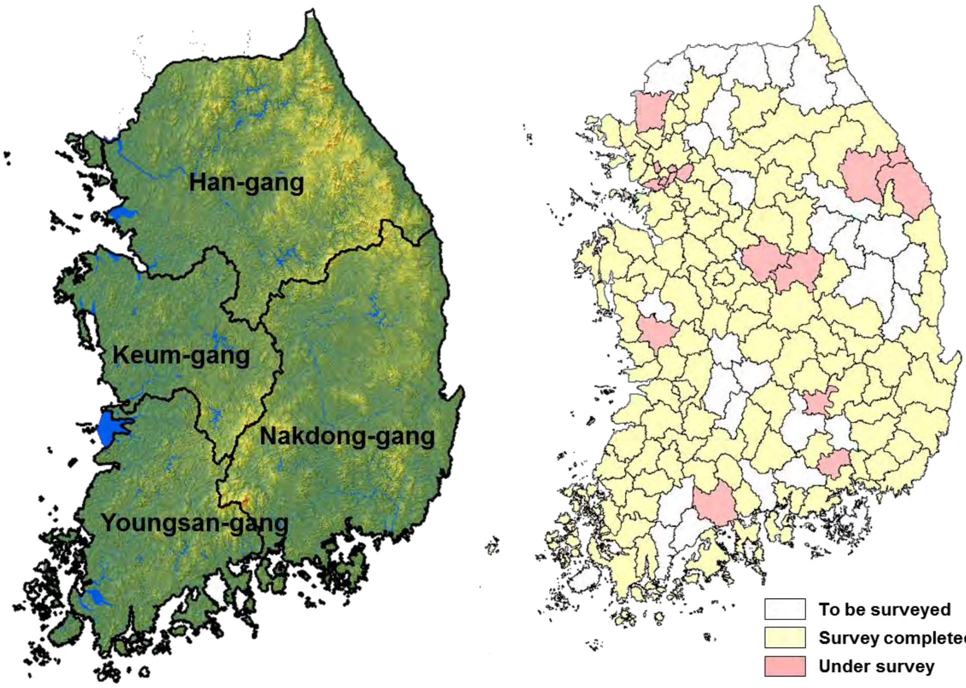

Fig. 2. The status of the regional (left) and local (right) groundwater surveys in Korea

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.

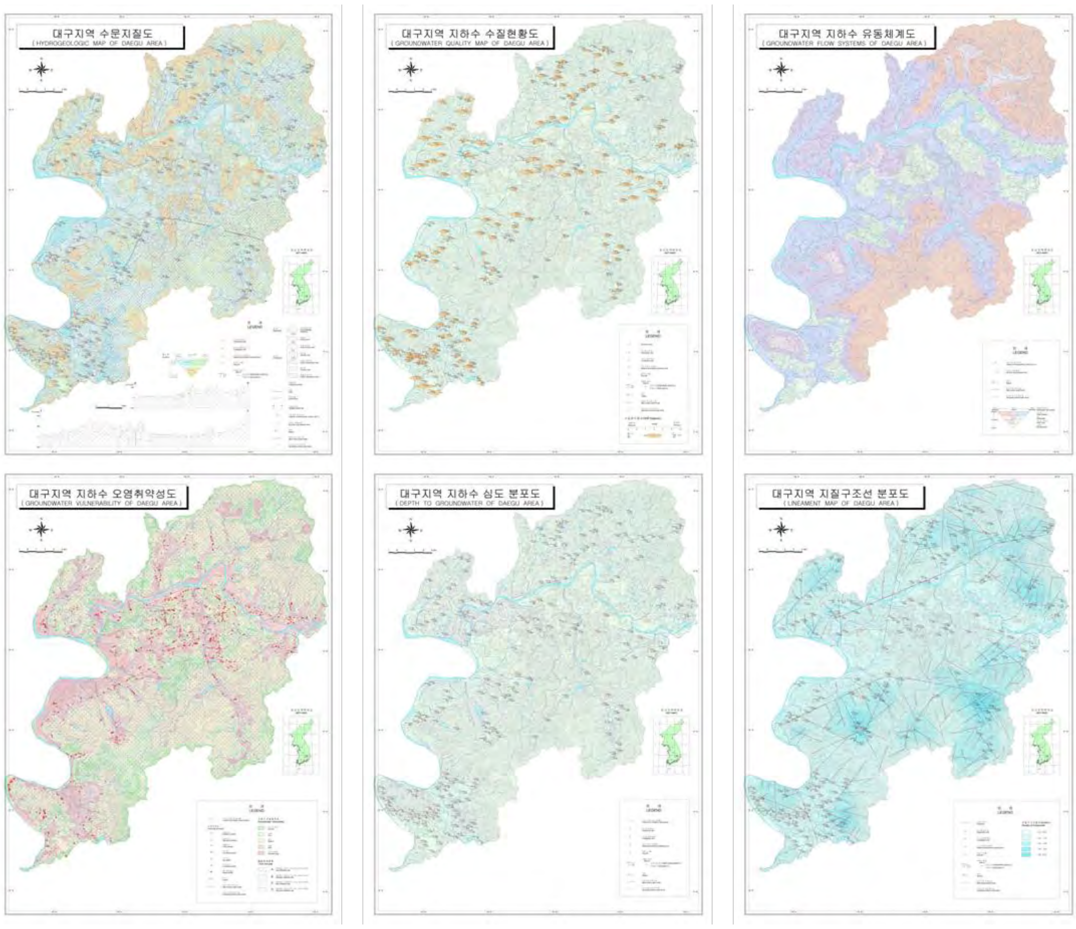

Fig. 3. The product maps of the basic groundwater survey in Korea

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).

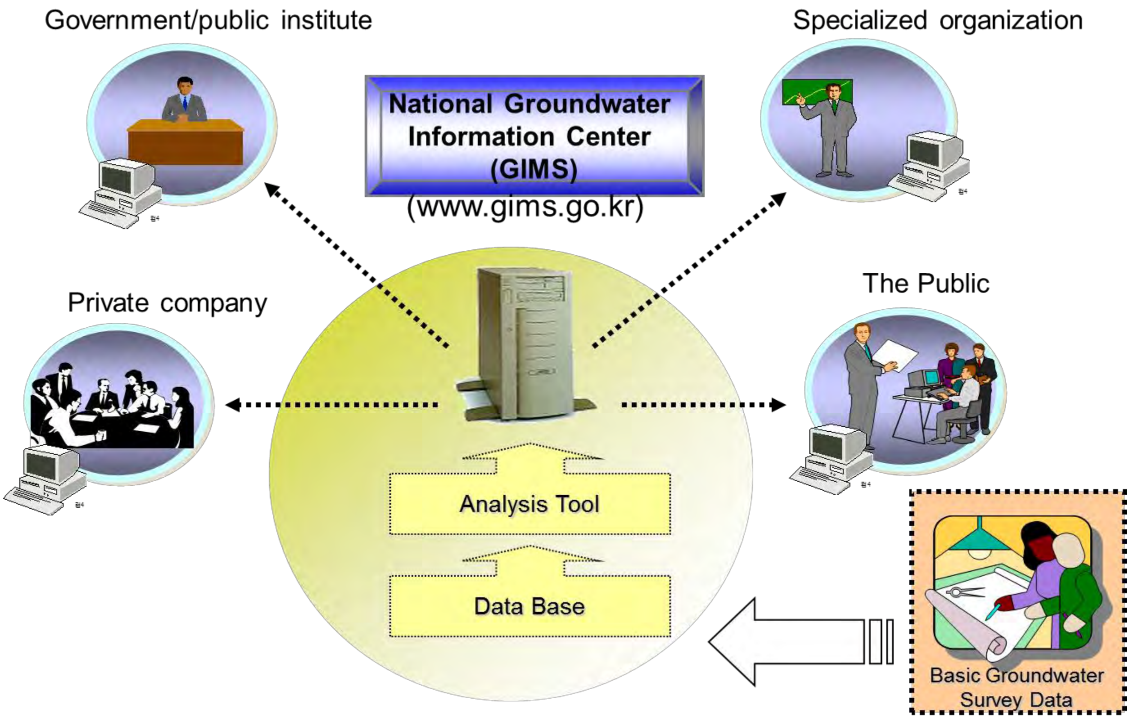

Fig. 4. The data management and service

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www.encyclopedia.com

www.gims.go.kr

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 PDR has average 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).*

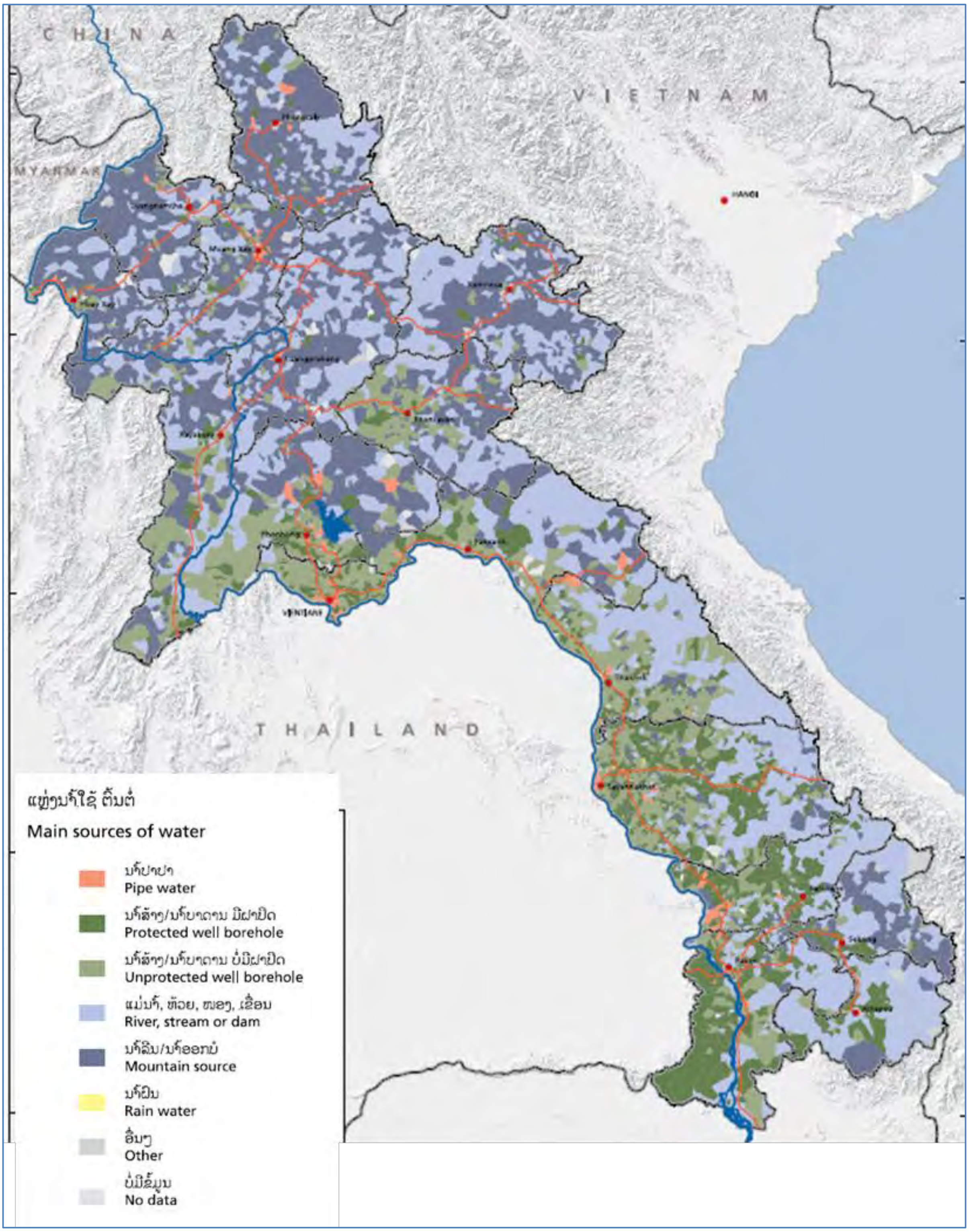
The existed using of 100 liters per capita per day, we can estimate that around 90 million cubic meters per year using groundwater in the country *(Stakeholder Assessment Working Paper by GHD supported by ADB, Nov 2013).*

3. Pilot activities

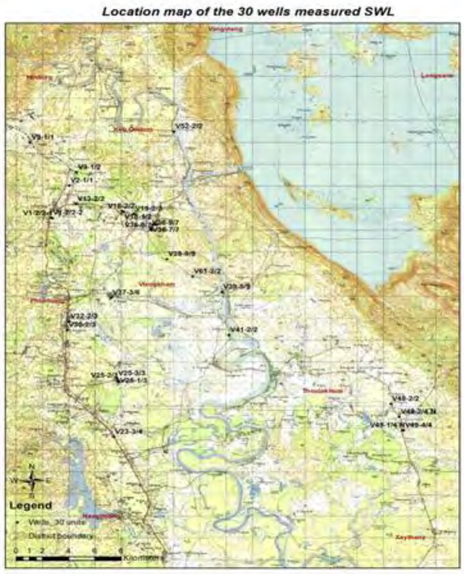
3-1 Background and location

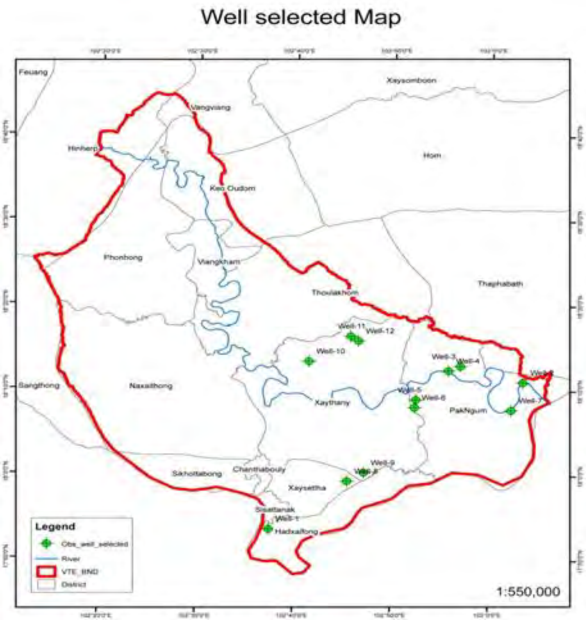
The Vientiane Plains have higher numbers, indicating greater priority, which is influenced by population pressure and generally favorable hydrogeological conditions (Stakeholder Assessment Working Paper by GHD supported by ADB, Nov 2013).

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).





3-2 Social and Economic

The area of In 4 districts is 2,432 km2, 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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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 11^{th} 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 25m in the south to more than 150m in Tumpat area.

Generally, the Kelantan and Terengganu alluvium aquifers can yield per well exceeding 100m^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 32m^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 67-117m^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 30m^3/hour. In phyllite/schists, yields are comparatively high ranging from 20.0 - 40.0m^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 22m^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 -12.0m^3/hr. In the district of Kota Tinggi (Johor), the fractured aquifer gives a yield of 10m^3/hr whereas, in the district of Alor Gajah (Melaka) it gives a yield of 4m^3/hr only.

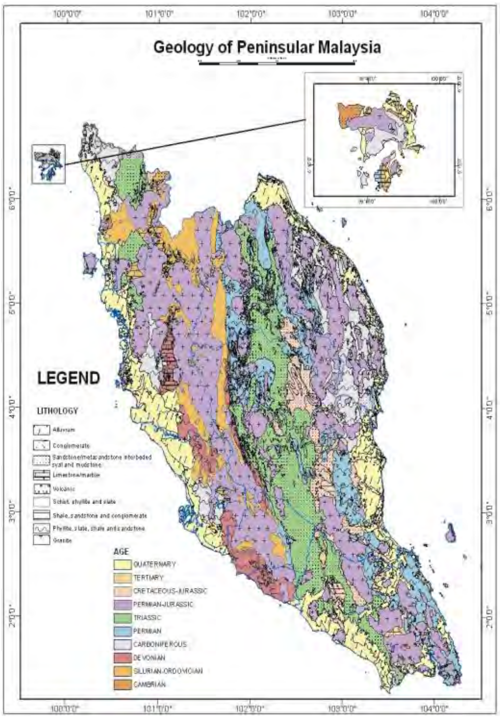

Fig. 1. Geological map of Peninsular Malaysia

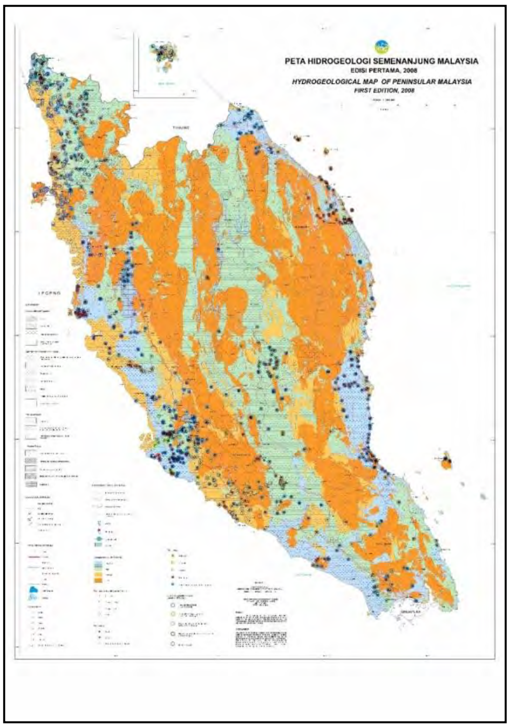

Fig. 2. Hydrogeological map of Peninsular Malaysia

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.

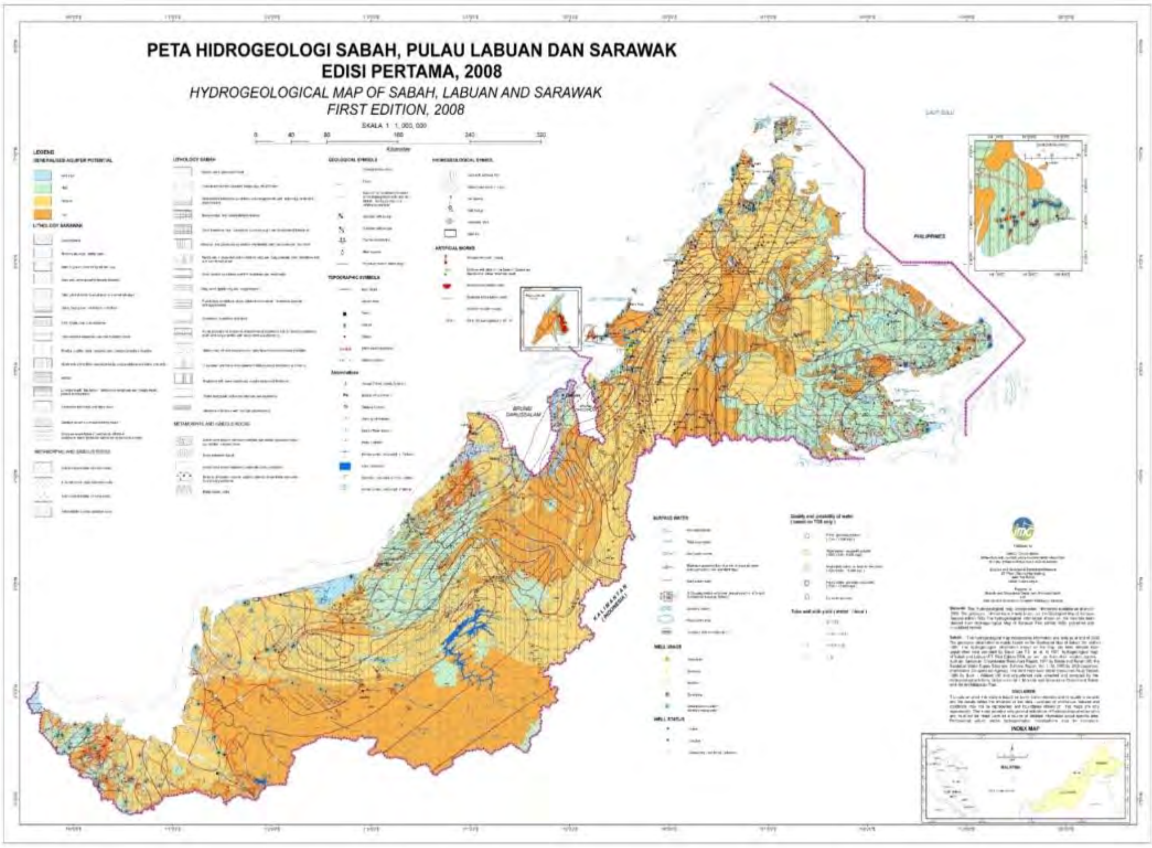

Fig. 3. Hydrogeological map of Sabah and Sarawak

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 11th 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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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 676557 square kilometers. 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 2030 mm to 3050 mm in the deltaic area, 2030 mm to 3810 mm in the north, about 1500 to 2000 mm in eastern hilly region, rising to 5080 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.

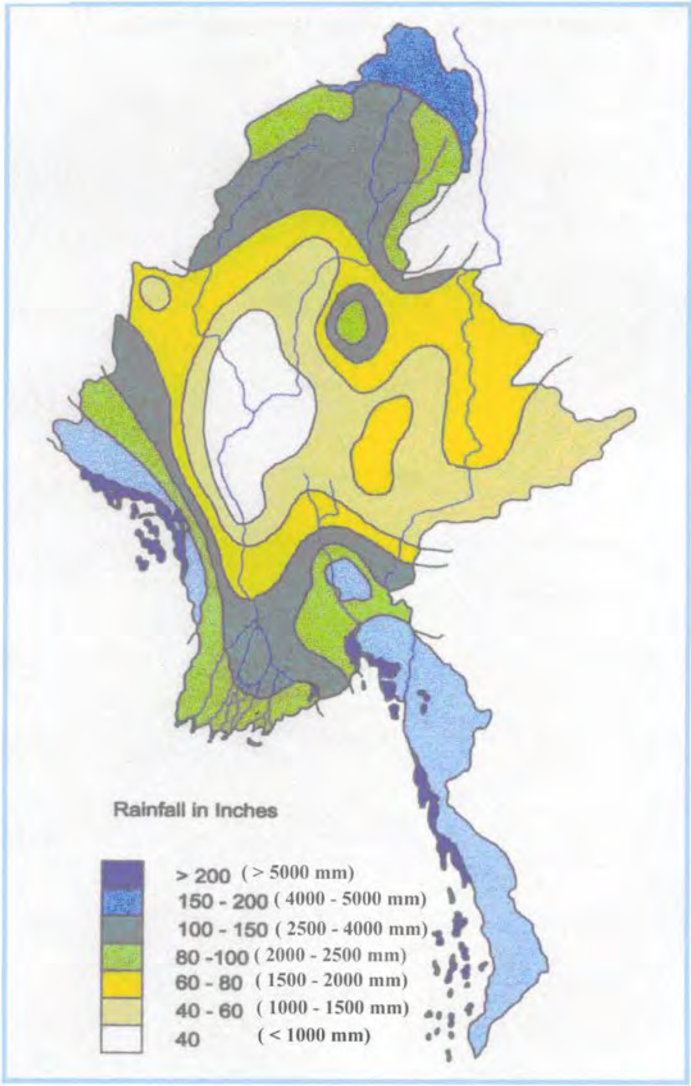

Fig.2. Annual Rainfall Map of Myanmar

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 1082km^3 and 495km^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(km³)	Estimated groundwater Potential (km³)
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.

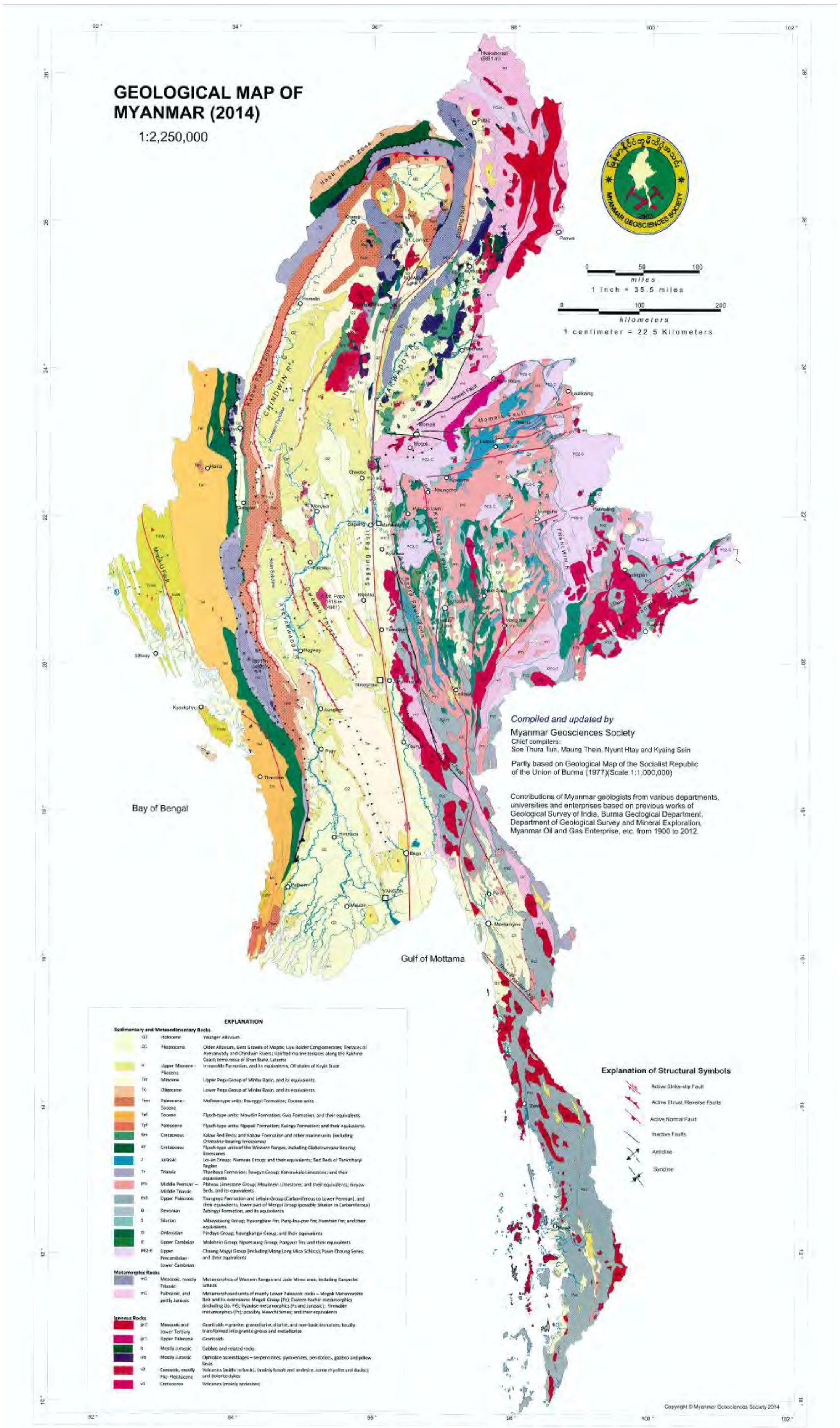

Fig. 4. Geological Map of Myanmar

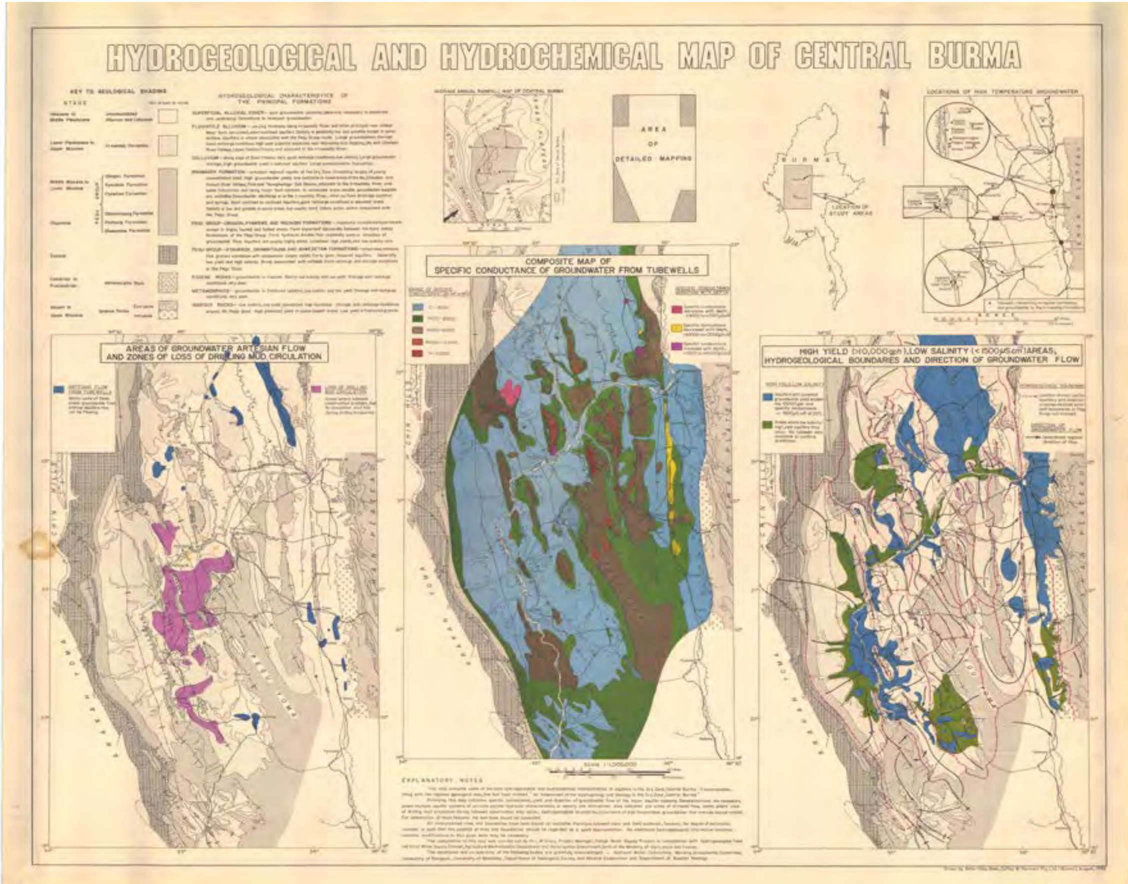

Fig. 5. Hydrogeoloigcal and Hydrochemical Map of Central Burma

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

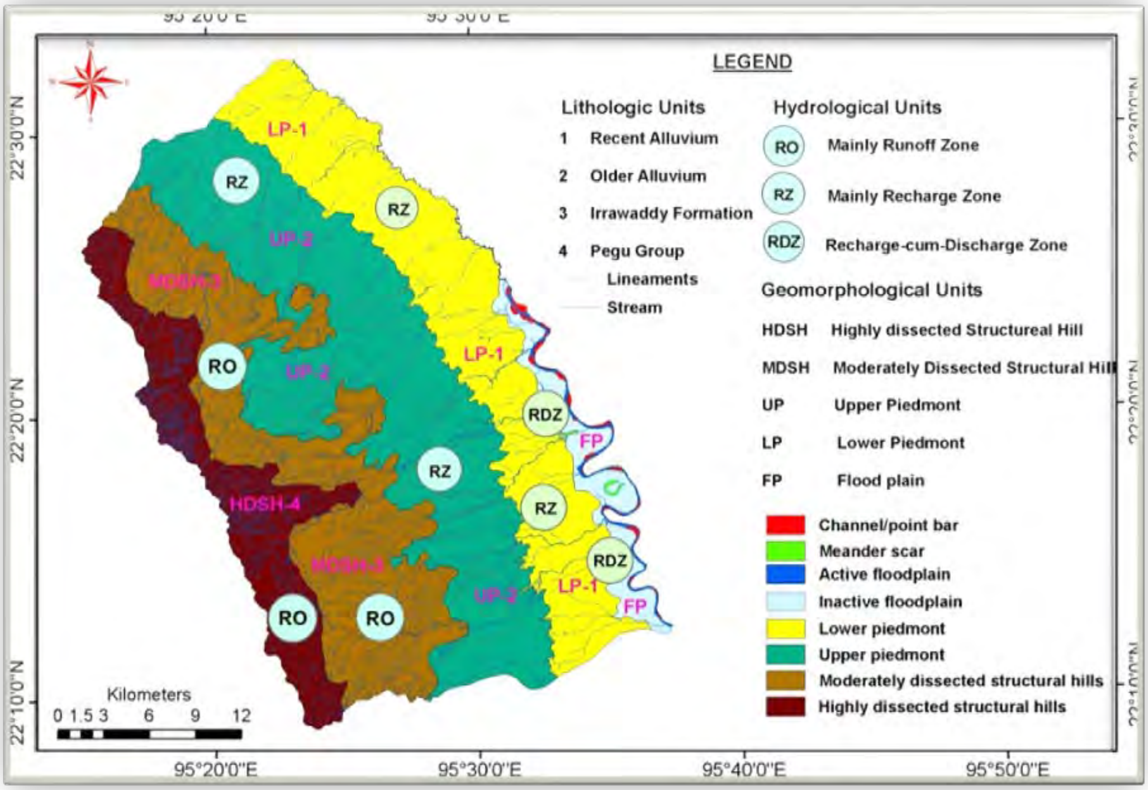

Fig. 10. GIS Mappping

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

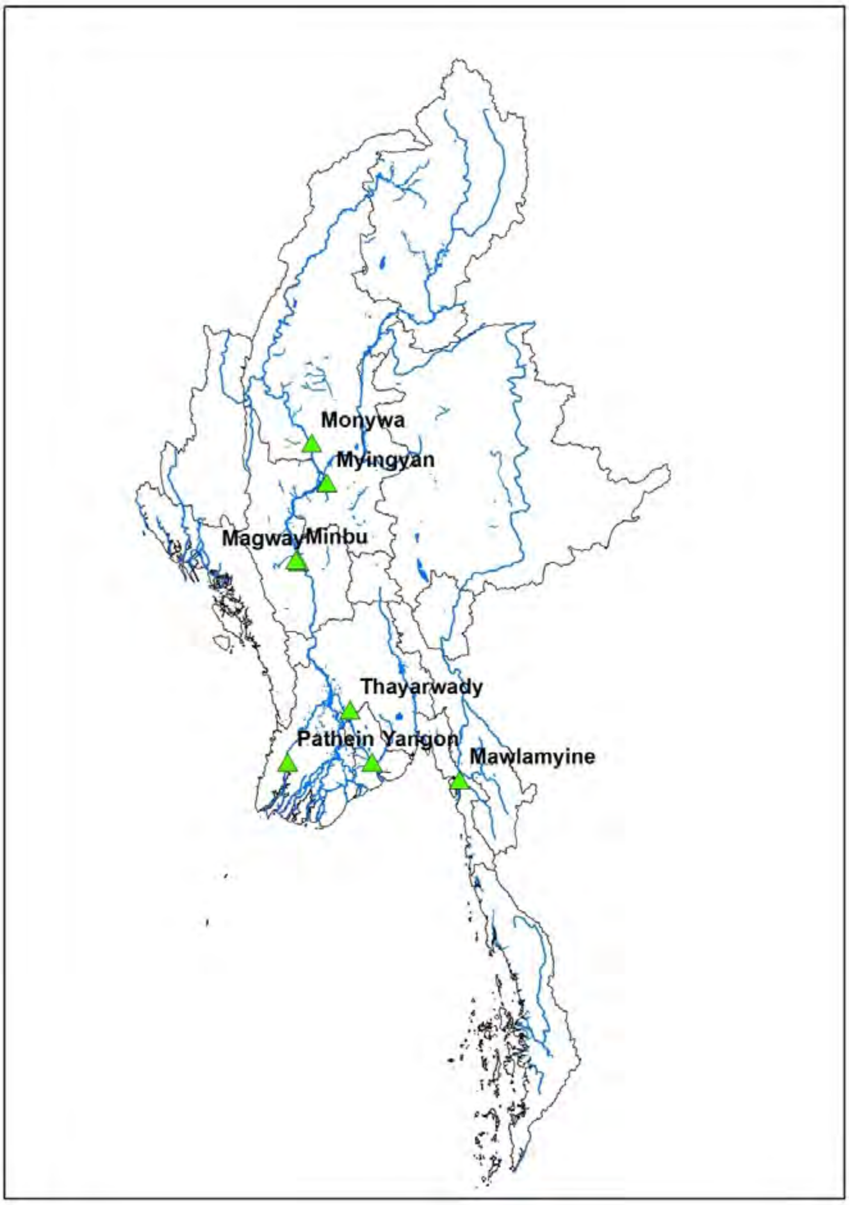

Fig. 11. Location map of groundwater monitoring stations in Myanmar (in progress)

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.

Data Sources:

Drury, L.W., An Assessment of the Hydrogeology and Geology in the Dry zone, Central Burma. Australian Development Assistance Bureau and Ministry of Agriculture and Forests, Union of Myanmar.

Unpublished Departmental Reports and Maps from Irrigation and Water Utilization Management Department, Ministry of Agriculture, Livestock and Irrigation, Myanmar.

Geological Map of Myanmar 2014, compiled by Myanmar Geosciences Society.

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 156^0E. The capital city, Port Moresby is situated at 9^0S and 147^0E. 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.

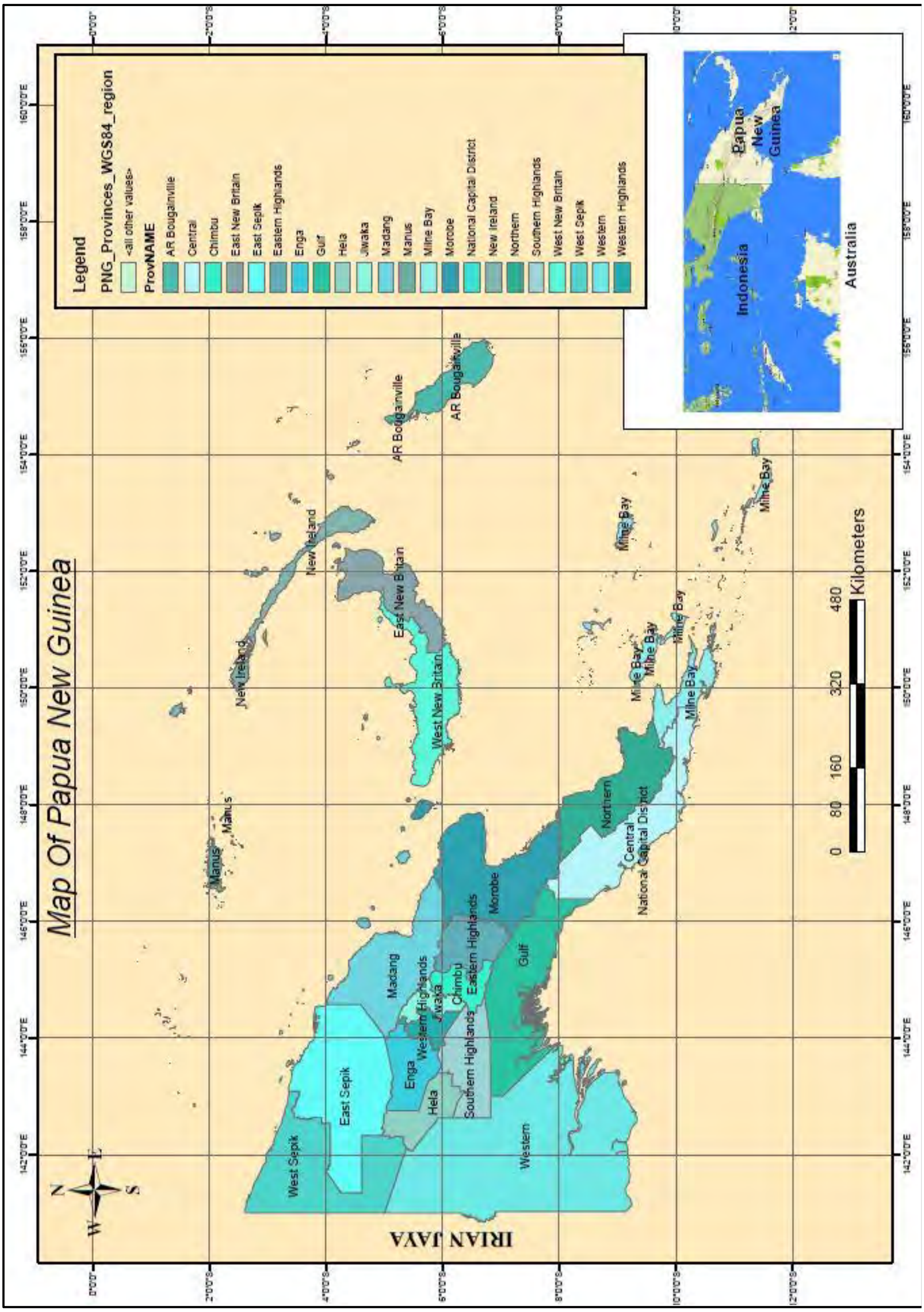

Fig. 1, Location map of Papua New Guinea (Fabila, 2017)

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

General Info / Lithology / Drilling Infor / Pump Test Data / Lab Test Data

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 (~5000m) and thin out further away, with an approximate thickness of 1000m 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.

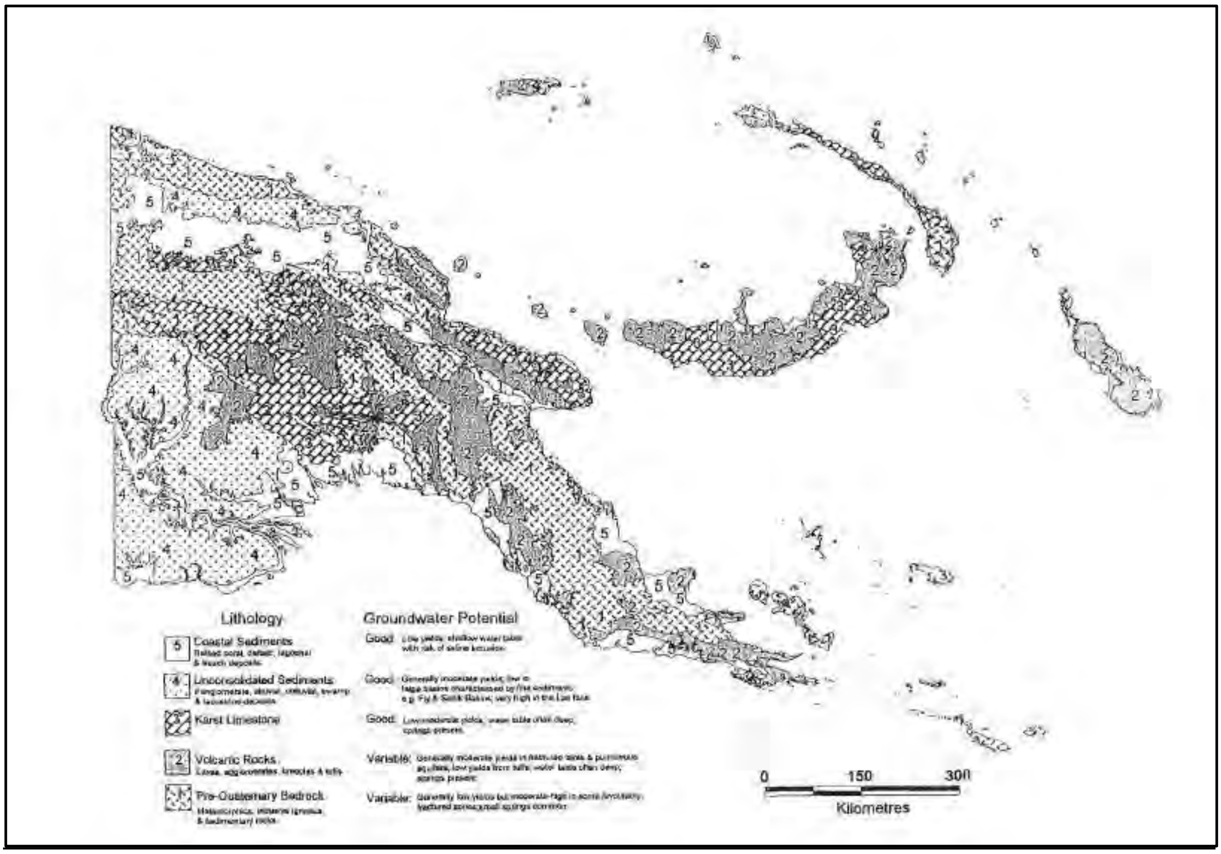

Figure 2 Previous groundwater potential map of Papua New Guinea (Egara, 1999).

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.

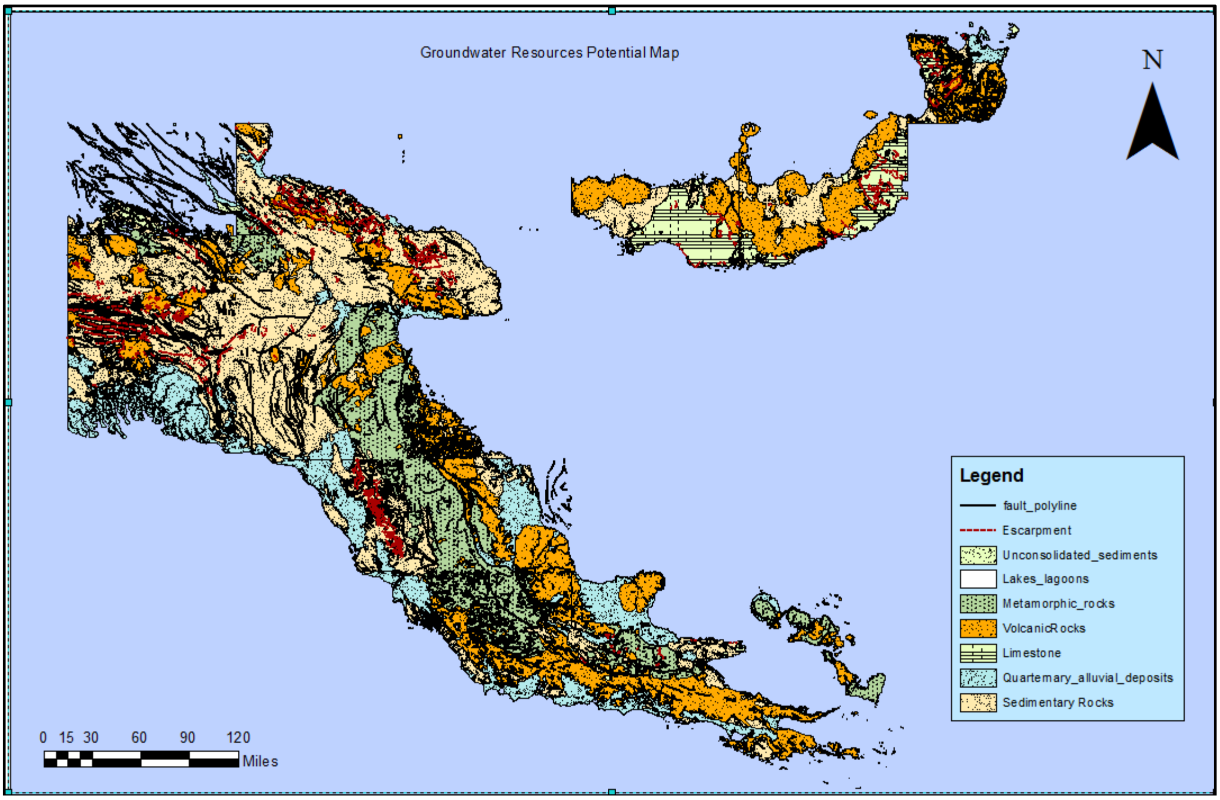

Fig. 3. Present groundwater potential map of Papua New Guinea (Kuman, 2017)

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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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.

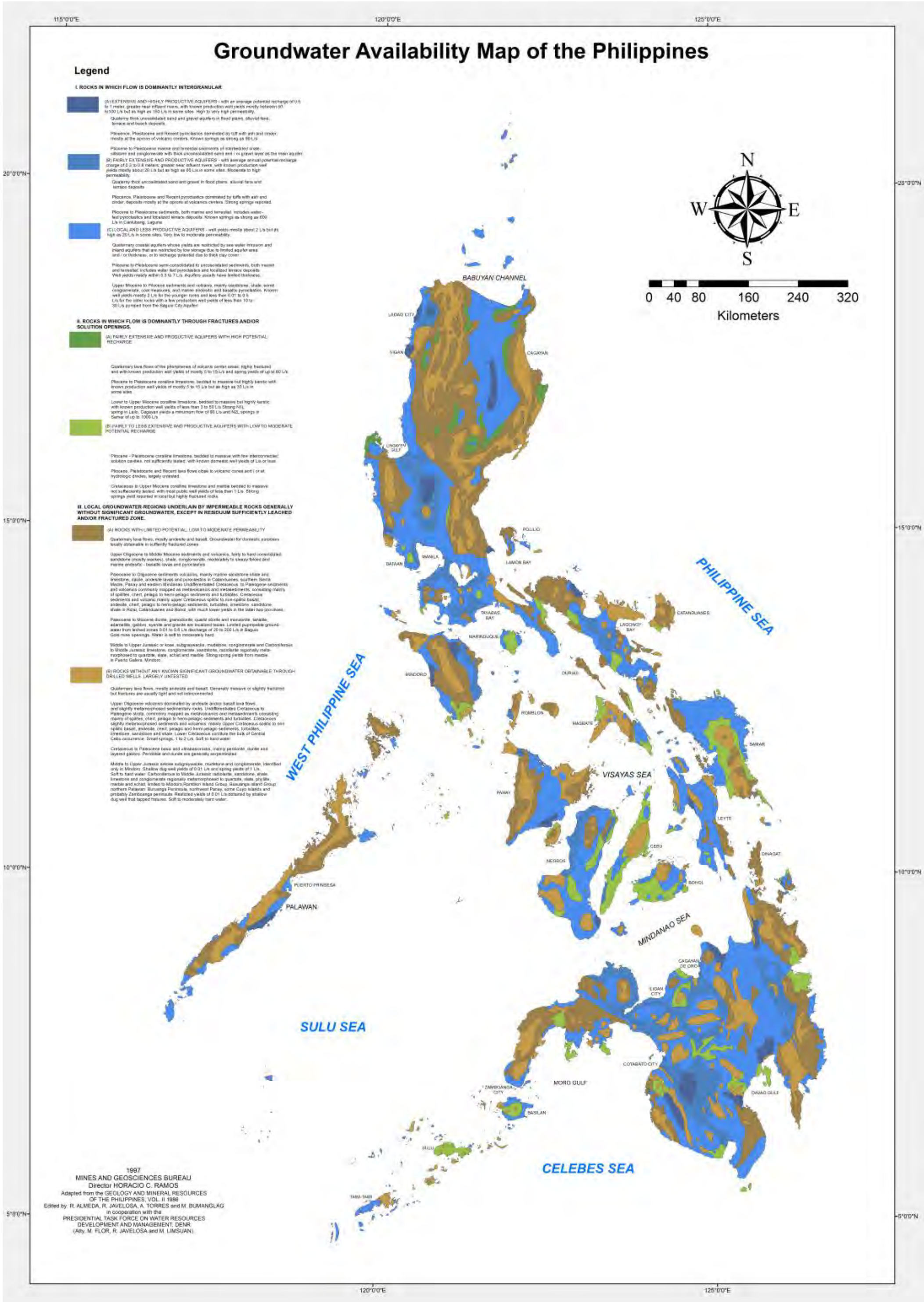

Fig. 1. Groundwater availability map of the Philippines.

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.

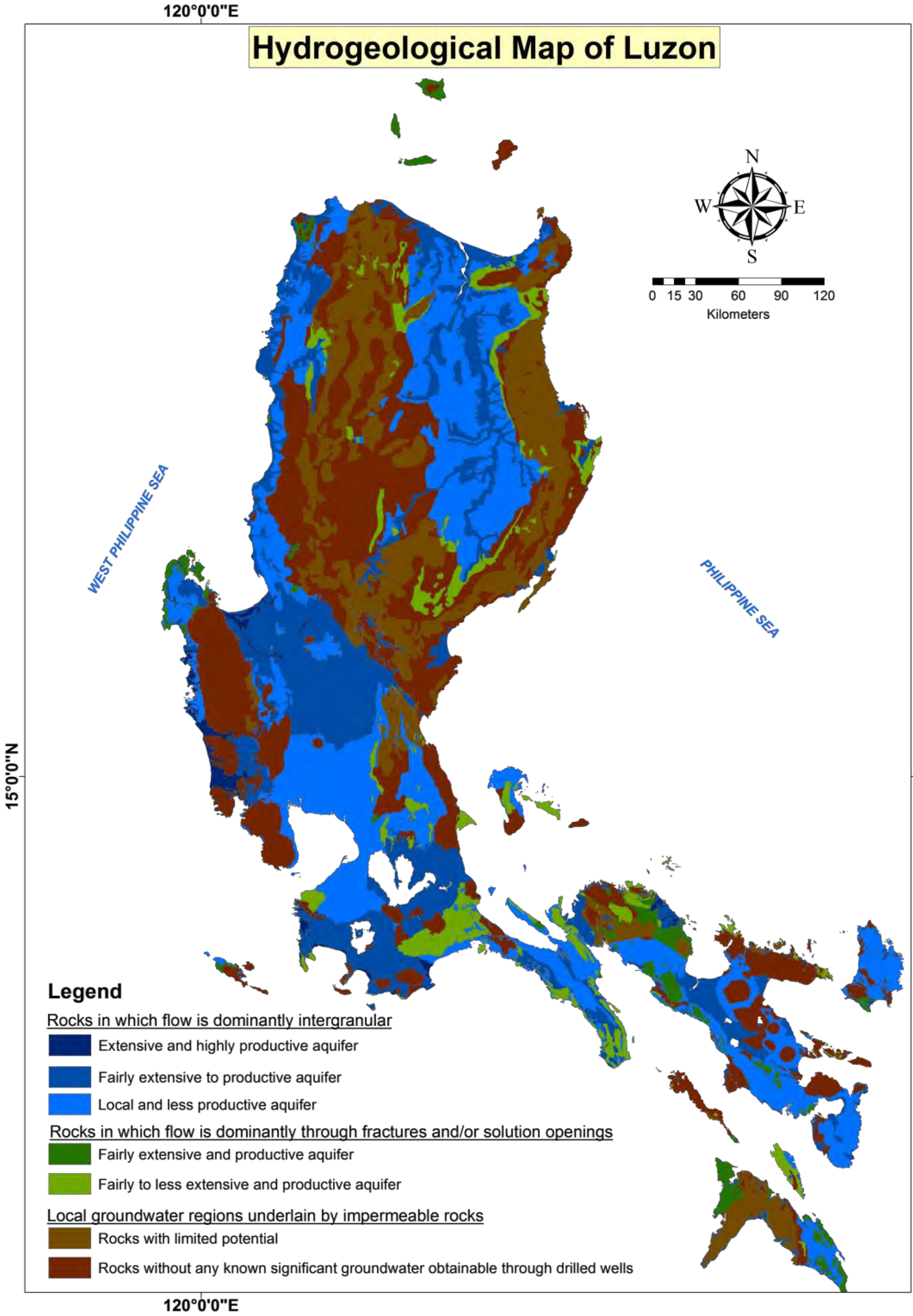

Fig 2. Hydrogeological Map of Luzon and its adjacent islands.

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.

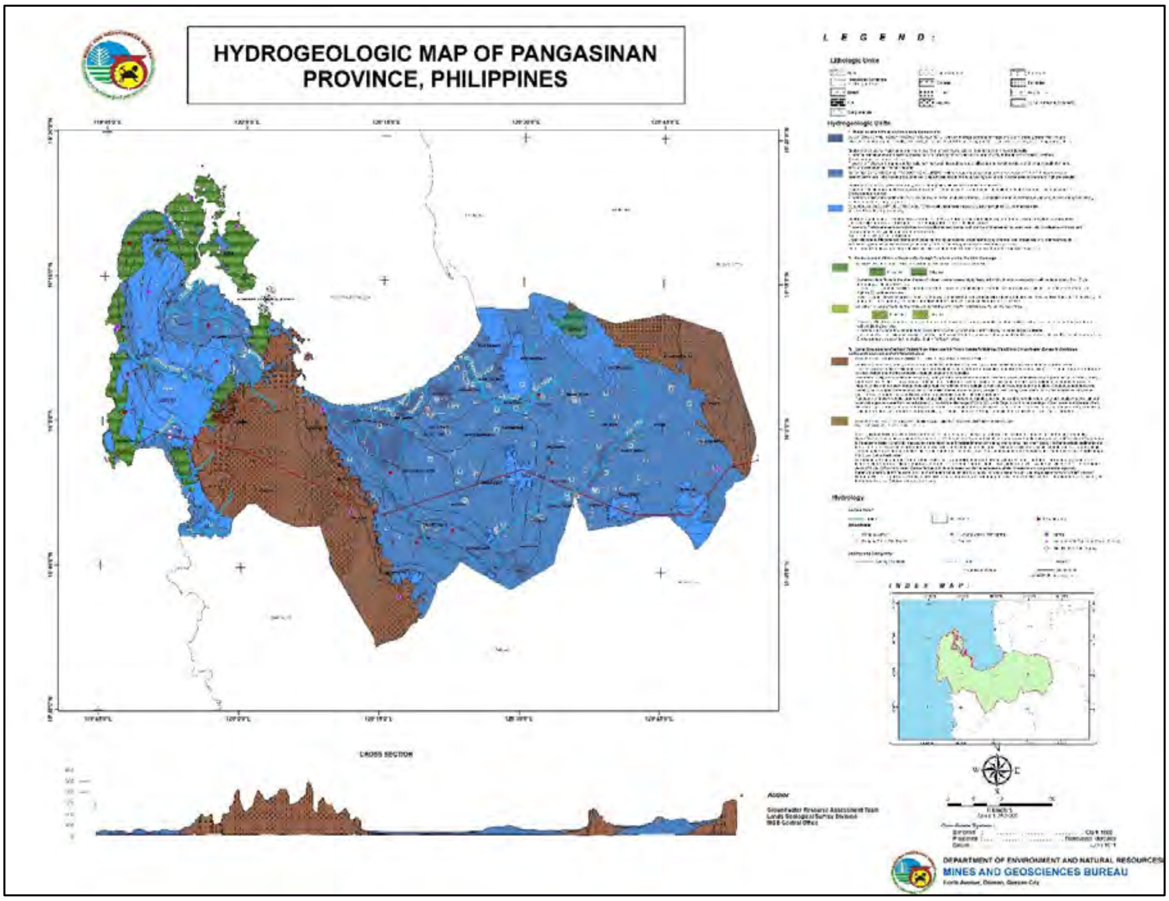

Fig 3. Sample layout of the Hydrogeological Map of Pangasinan Province.

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 δ18O) 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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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 100,000 :1 in period between 1989 and .2001However, 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 50,000 :1" 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 50,000 :1 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 100 :1,000. 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 50 :1, 000covering 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.

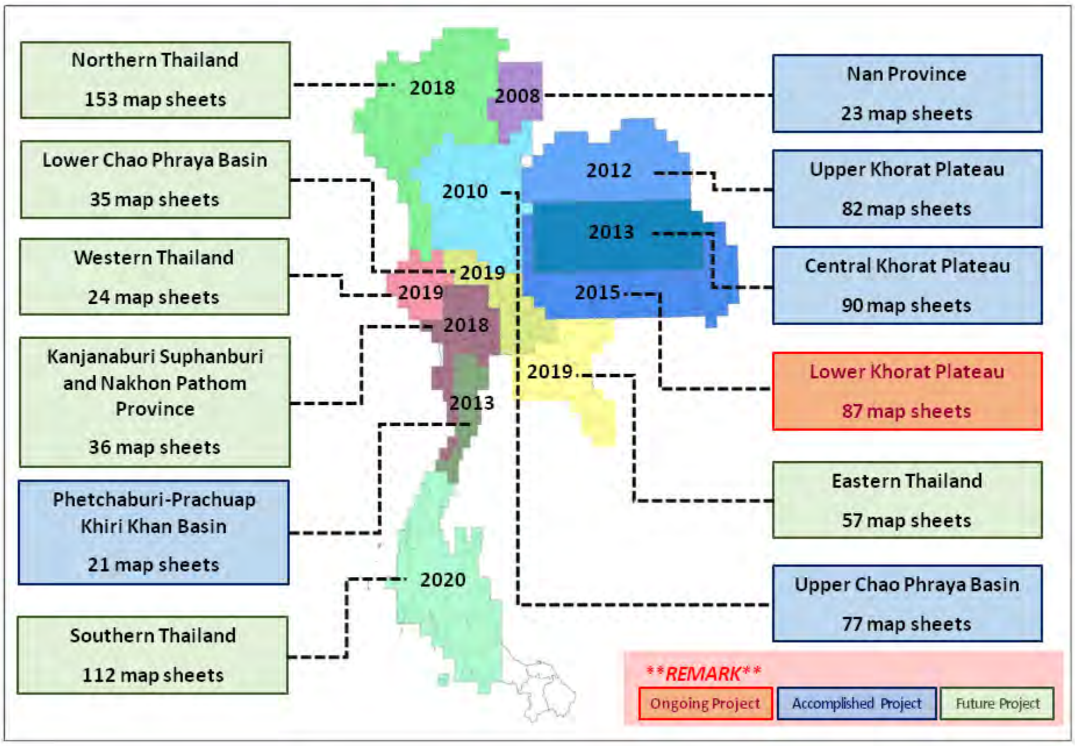

Fig. 1. The Project of Detailed Groundwater and Hydrogeological Mapping at a scale of 1:50,000 in Thailand.

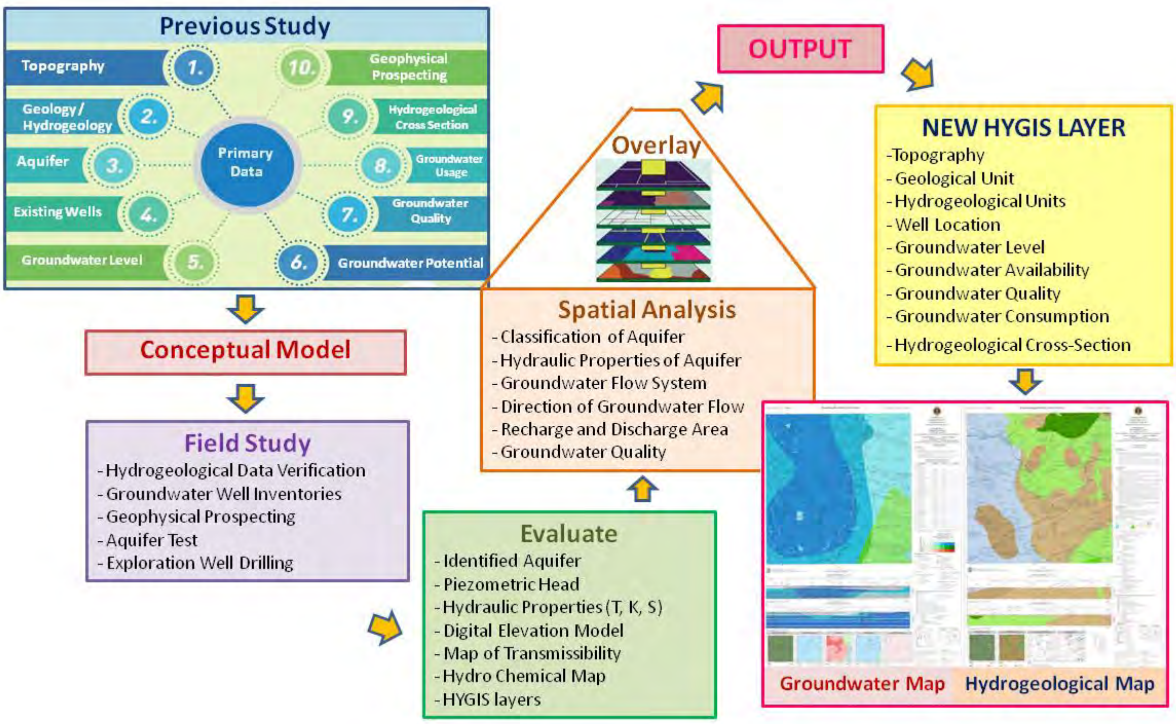

Fig.2. The groundwater and hydrogeological mapping framework

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.

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 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 square kilometers, 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 km2 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 km2, in which preliminary investigation and assessment of groundwater resources with an area of 8,090 km2.

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 1500m 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 km2, groundwater sources was detected and evaluated with total exploitation reserve of B 104,428 m3/day and level C1 1,186,991 m3/day and C2 11,366,465 m3/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 km2 in 20 provinces/towns. This exploitation characterized the aquifers properties; preliminary exploration with reserves of level A is 922.787 m3 /day, B 1.043.892 m3/day, C1 1.359.301 m3/day and C2 4,136,707 m3/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/ 80km2, the southern Delta is about 1 well/280km2 and the Central Highlands is 1 well/260km2.

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 m3/day, actually in Ha Noi, hundreds of wells have been drilled in the 300mm diameter range; wells or clusters of well of 1000-10,000 m3/day. These well clusters also drilled hundreds of boreholes; individual wells are less than 1000m3/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 km2) 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 km2, 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 m3/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 km2, 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 km2, 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 m3/day, level B is 160,631 m3/day, level C1 is 458,619 m3/day and level C2 is 8.059,213 m3/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 (1:500.00 - 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 km2 of the continental shelf and exclusive economic zone and more than 3,200km 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 -60 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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