Geological Survey of Japan, AIST

Project Report of the CCOP-GSJ-MME Groundwater Project Phase III Meeting

5-7 March 2018, Siem Reap, Cambodia

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

The CCOP-GSJ-MME Groundwater Project Phase III Meeting was held in Siem Reap, Cambodia from 5 to 7 March 2018. It was attended by 24 participants from Cambodia, China, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand, and the CCOP Technical Secretariat. Representatives from the Safe Water Supply Team Cambodia and UNESCO-Bangkok also presented there. In the meeting, participants confirmed the progress of the project from March 2017 to March 2018 and discussed on the work plan for 2018 in three groups.

Each CCOP Member Country made a country presentation on the topic of "***Explanation documents for the country's capital city or representative area in the CCOP GW DB***" (DB1& DB2 Groups) and ***"Public policy for Groundwater observation system"*** (Public Policy Group). Since the current problem varies from one country to another due to different hydrogeological and geographical settings, all Member Countries should share the information to create a useful hydrogeological map in the CCOP region.

This publication compiles all the country reports presented in the CCOP-GSJ-MME Groundwater Phase III Meeting and will constitute the major outcomes of the GW Phase III Project, which will complete in 2019.

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

Youhei UCHIDA
Chief Editor

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Groundwater Project Phase III Meeting
5-7 March 2018, Siem Reap, Cambodia

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The Opening Ceremony started with the Welcome Remarks delivered by **Dr. Youhei Uchida**, Groundwater Project Leader, Geological Survey of Japan (GSJ, AIST). The Opening Speech was made by **Dr Sitha Kong**, Director, Geological Department, General Department of Mineral Resources (GDMR), Ministry of Mines and Energy (MME).

Dr. Youhei Uchida presented the progress of the Project from 21 March 2017 to 4 March 2018. During the period, the report of the CCOP-GSJ-GAI Groundwater Phase III Project Meeting (GW-7) held on 21-23 March 2017 in Bali, Indonesia has been published, and uploaded to the CCOP website, http://ccop.asia/pdf/publication/GW-7.pdf. **Dr Gaurav Shrestha** from GSJ reported on the status of the project's main objective of compiling groundwater data of CCOP Member Countries using Open Web GIS System. According to the 2017 Project workplan, Indonesia, Japan, Korea, Malaysia, Philippines and Thailand have submitted their data accordingly, with some variation from the 2017 workplan for Philippines and Korea. The groundwater data submitted are accessible from the GSi Groundwater Portal, https://ccop-gsi.org/gsi/ccop_water/index.php. Recent data received from Indonesia, Malaysia and Philippines are still to be uploaded to the Portal. China and Vietnam have still to contribute data to the Project as agreed in the previous meetings.

Dr Youhei Uchida also reported on the CCOP Groundwater Sub-Project: Development of Renewable Energy for Ground-Source Heat Pump System in CCOP Regions. One Heat Exchanger was installed at the National Laboratory for Energy Conversion Technology (B2TKE), Agency for the Assessment and Application of Technology (BPPT), Indonesia in October 2017. Regarding the GSHP system installed at the Chulalungkorn University, Thailand, Thermal Response Test (TRT) was conducted to evaluate the apparent thermal conductivity on the ground. To do TRT, heat medium (water) is circulated in the well with fixed heat load and the temperature at inlet and outlet of the well is measured. It was found out that the ground at the Chulalungkorn University is a good thermal conductor.

Country reports on "Explanation documents for the country's capital city or representative area" (DB1& DB2) and Public policy for Groundwater observation system

(Public Policy Group) were presented by the participants. These papers will be published in the Project report, GW-8, within 2018.

Dr Uchida presented the required format for the full paper for this meeting report (GW-8), and requested all the participants to revise their paper accordingly if not following this format, and submit to the CCOP Technical Secretariat within August 2018.

For DB I & II

1. Introduction
2. Geology and Hydrogeology in study area
3. Hydrological data in study area
4. Groundwater Management in study area and/or country

For PP Group

1. Introduction
2. Geology and Hydrogeology in study area
3. Hydrological issues
4. Plan of Groundwater Observation System and Management reflects on the hydrological issues.

Group discussions were held on the challenges faced in data submission as well as on the project workplan for 2018.

For DB1 (China, Indonesia, Japan, Korea <Group Leader>, Thailand) & DB2 (Indonesia <Group Leader>, Malaysia, Philippines, Vietnam <absent>), discussion topics are 2018 work plan about adding or updating data, extending the target areas, and data reviewing and revising plan with each national compiler of the member country.

Korea. Considering newly published groundwater monitoring annual book, the database will be added and updated for the existed monitoring well locations. The data will be delivered to the GSi national compilers of Korea, **Dr. Saro Lee** and **Dr. Jong Gyu Han**, also from KIGAM.

Malaysia. Data in Kedah state will be added in 2018. Kedah state is located in the northern part of Malaysia. **Mr. Alvyn Clancey Mickey** will contact GSi national compiler of Malaysia, **Mr. Mohd Zulkiflee Bin Che Soh**.

Philippines. Database for 2 provinces, Bulacan and Nueva Vizcaya, will be added to the existing database, and **Mr. Mel Anthony A. Casulla** will contact the GSi national compiler of the Philippines, **Mrs. Carleen Joy Gatdula**.

Thailand. Additional database for Khon Kean province will be prepared, and **Ms. Phuengchat Chantawongso** will discuss the data with the Thai national compilers of GSi from DMR, **Mr.Sompob Wongsomsak** and **Mr. Preecha Saithong**.

Indonesia. Database for Borneo (Kalimantan) island will be added to the existing database, and **Mr. Budi Joko Purnomo** will contact with the Indonesian national compilers of GSi, **Mr. Dwi Nugroho Sunuhadi** and **Mr. Hadianto**.

China. Although the country report is good during the meeting, China doesn't submit groundwater database for GSi system. **Mr. Shuangbao Han** will talk to the Chinese participants in the project's annual meetings during 2015-2017. The participant for the groundwater phase III meeting in 2015 is **Dr. Liu Wenbo**. **Mr. Shuangbao Han** will ask the Chinese groundwater database management authority, CGS (China Geological Survey) to submit the database. It seems that the published data in annual book or scientific papers are possible to submit to CCOP.

Japan. Database for Sendai plain will be added to the existing database. GSi national data compilers of Japan are **Dr. Joel Bandibas** and **Dr. Shinji Takarada**.

All member countries agree that the full paper of country report presented at this meeting to be published in 2018 will be submitted by 31 August, 2018, and database updating completion will be done by 1 October, 2018.

Additionally, the members agreed that discussions are needed to better utilize the DB in this field, and the interest and cooperation of the CCOP countries. Improvement of the GSi system and further related project will also be needed in the future.

For the Public Policy Group (Cambodia, Lao PDR, Myanmar, PNG, Timor-Leste<absent>), the following actions will be carried out in 2018.

- Member Countries (MCs) will draft the Workplan for GW monitoring and GW management program and send to CCOPTS.
- MCs will organize a CCOP GW Team composed of hydrologist, geologist, GIS specialist, and local administration, as a national GW team.
- CCOPTS will communicate with Permanent Representative of MCs for more detailed cooperation procedure in the near future.
- MCs will provide contact persons on GW to CCOPTS both on management level and working level.
- MCs will provide the present situation on GW of their own countries with some recommendation for more assistance from CCOP.
- MCs will do their best in providing their available groundwater data according to the database template (excel file) by 1 October 2018.

There were three invited lectures, (1) The role of Water in the conservation of the Angkor World Heritage Site, Cambodia by **Dr Hang Peou** of the APSARA National Authority (2) Groundwater modeling of arsenic contamination in the Mekong Delta Cambodia by **Dr May Raksmey** and (3) Arsenic removal using Cambodia laterite by **Dr Pich Bunchoeun** of the Institute of Technology of Cambodia (ITC).

Prof. Dr Shinji Tsukawaki from Kanazawa University gave an overview of the hydrogeological excursion around the world heritage site, Angkor Wat, and Tonle Sap.

The next project meeting will be in Chiang Mai, Thailand in February 2019.

This minutes is adopted as signed.

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

Current Status of Hydrogeological Issues in Cambodia

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Abstract

Cambodia is a flooded country during the rainy season and is a locally drought country during the dry season. Groundwater is not well-known for Cambodian society yet. Topographically, Cambodia is bordered by mountain range/plateau and has a flood plain in the center. The country is divided by two equally seasons which are rainy season (May to October) and dry season (November to April). During the rainy season, precipitation is high with the average annual rainfall up to 1833 mm. In term of surface and groundwater interaction, Cambodia is categorized in four regions: Great lake region, Coastal zones, Upper Mekong region and lower Mekong region. Groundwater is store as pore water in the center and fissure-pore water in the other regions. There is a tendency to use groundwater and it is questioning on the possible negative issues such as arsenic content in the groundwater, groundwater drawdown due to the over-extraction of the groundwater in the emerging provinces such as Siem Reap and Kompong Som. Thus this paper will address some of those issues and the initiative to form a groundwater observation system in Cambodia starting from the pilot projects in Siem Reap and introducing to the administration of Kompong Som province.

Keywords: groundwater, hydrogeological map, Asia

1. Introduction

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

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

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

2. Geology and Hydrogeology in Cambodia

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

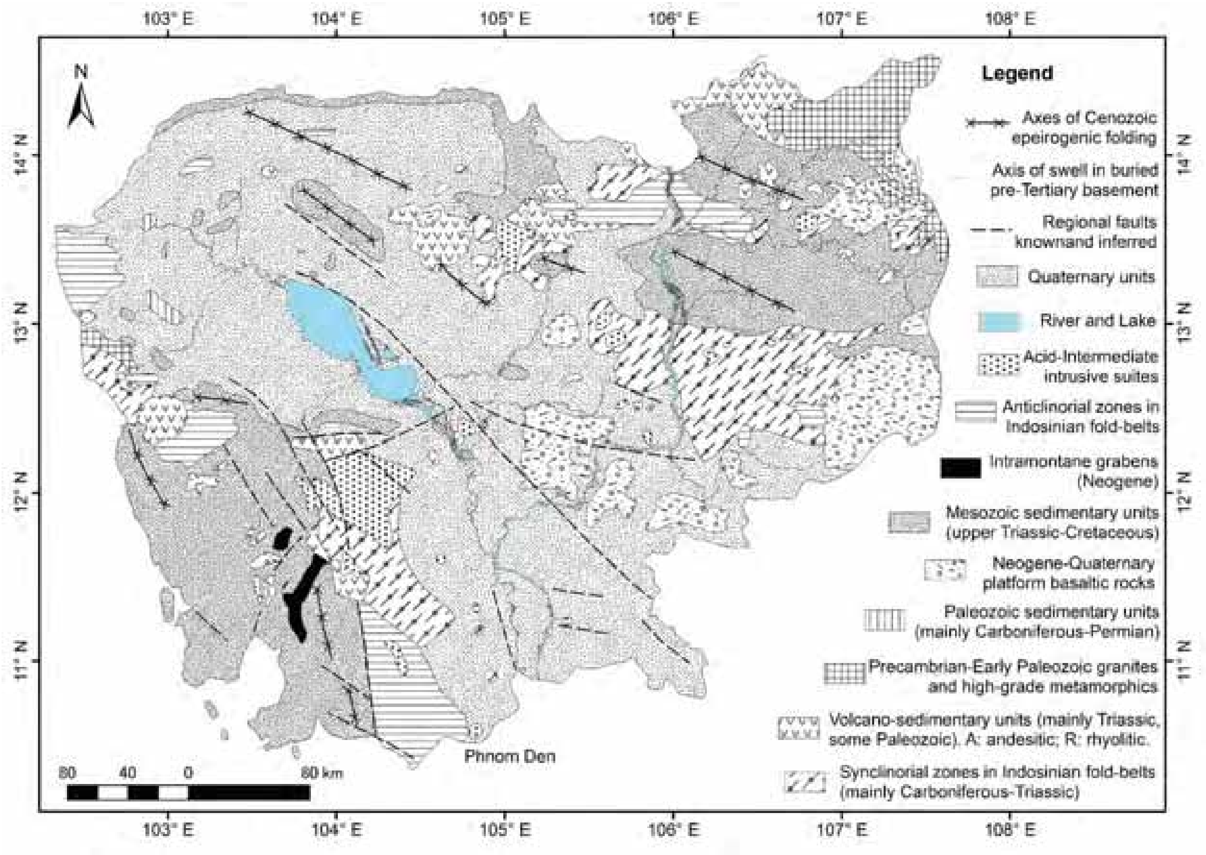


Fig. 1. Geological map of Cambodia (Fontaine and Workman, 1978)

As part of the tropical region, Cambodia obtains high annual rainfall up to 1833 mm with average up to 28^{o}C based on the average climatic data from 1901 to 2015 recorded by the World Bank Group's portal on Climate Change Knowledge (Figure 2). There is two main river system, i.e. Mekong River and Tonlé Sap (Great Lake) system. Mekong River is the main source of water in Cambodia flowing from Lancang River, China. Tonlé Sap River system connects with Mekong River in Phnom Penh discharging to Mekong River during dry season and recharging from Mekong River during rainy season.

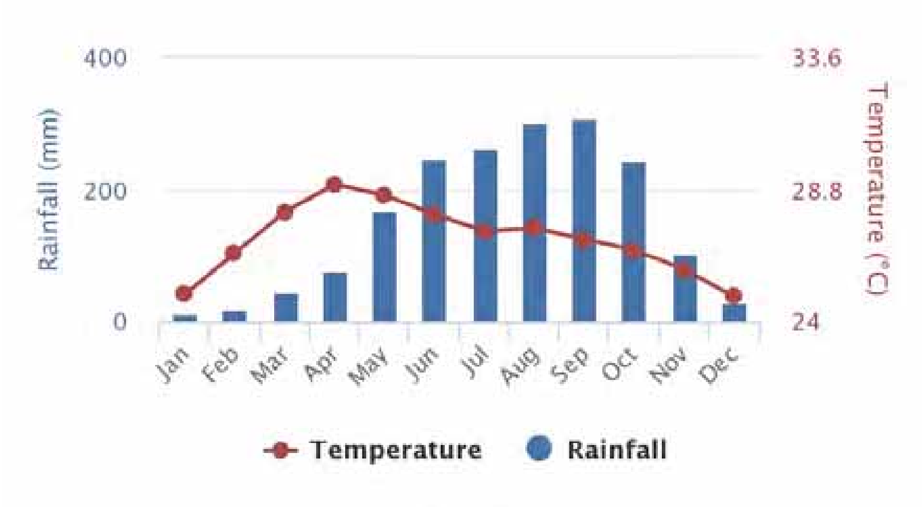
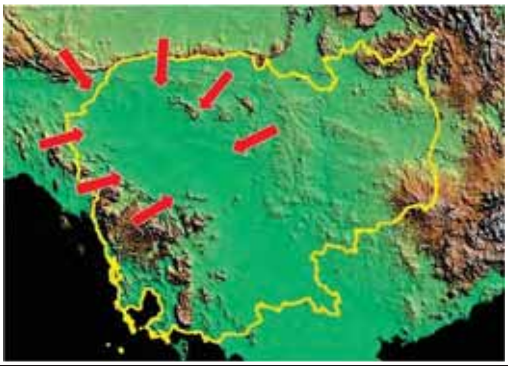
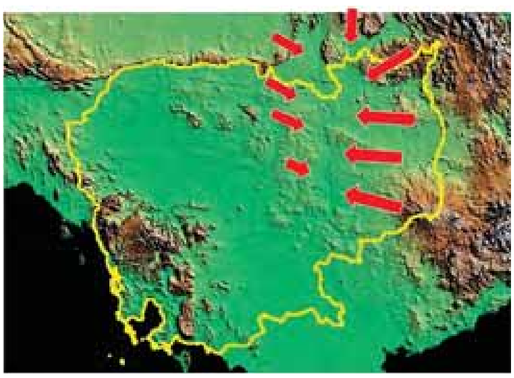
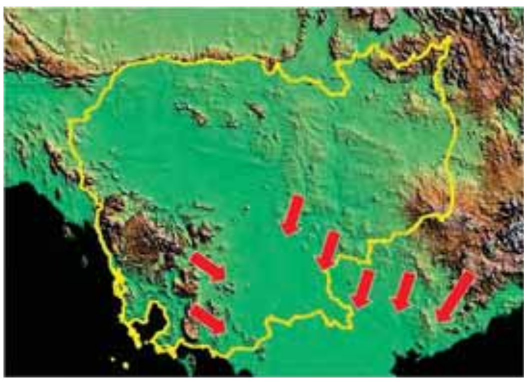


Fig. 2. Average annual rainfall (World Bank Group's database)

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

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

3. Hydrogeological Problems in Cambodia

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

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

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

4. Plan of Groundwater Observation System in Cambodia

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

5. Conclusion

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

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Explanation document – Utilization and Management of the Groundwater Resources in North China Plain, China

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Abstract

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

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

1. Introduction

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

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

Zhengzhou are located at the region border. Its population and cultivated area account for about one fifth of China. According to the National Statistical Yearbook data, the total population of the entire district was 125.99 million in 2004 (Wu Aimin, 2010), accounting for 9.2% of the national total. The GDP supported by groundwater was 1560.8 billion RMB in 2003, and it quickly increased to 3758.5 billion RMB in 2011 (Liu min, 2017).

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

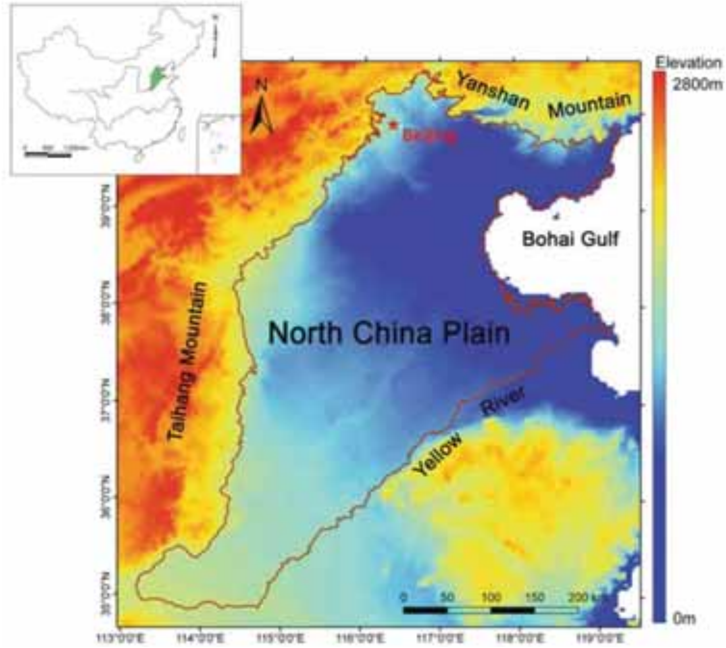

Fig. 1. Location of the North China Plain (Liu J., 2011)

2. Geology and Hydrogeology in North China Plain

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

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

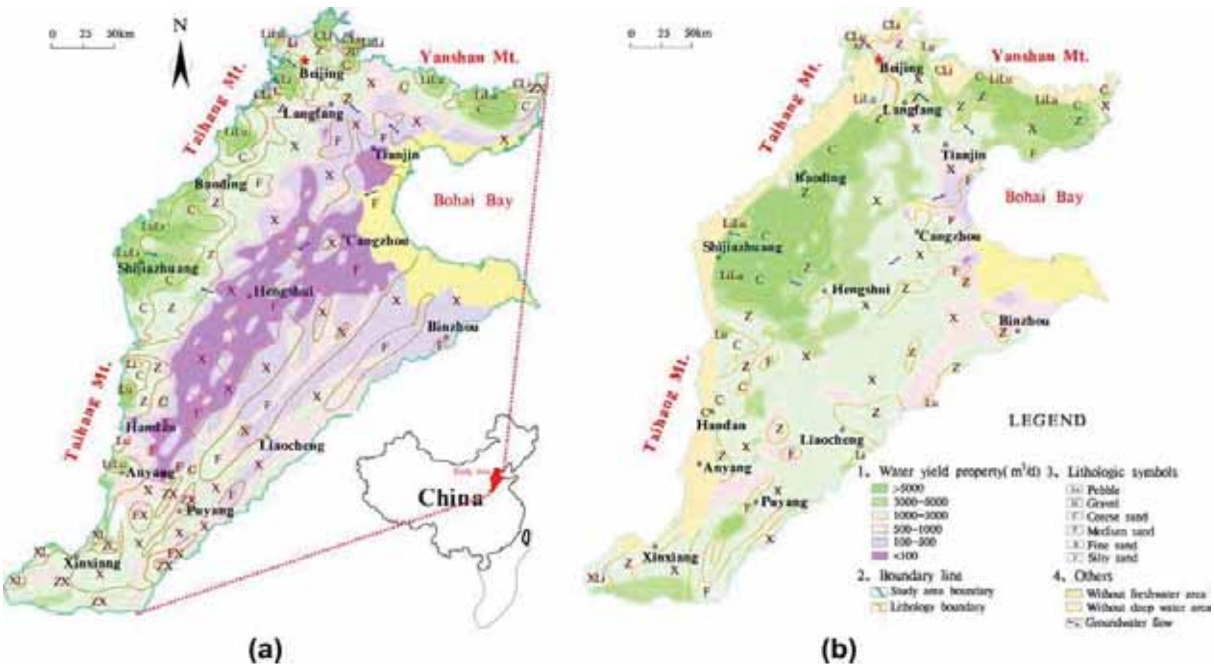

Fig.2. Hydrogeologica map of shallow aquifers (a) and deep aquifers (b)in the North China Plain (Xing Lina, 2013)

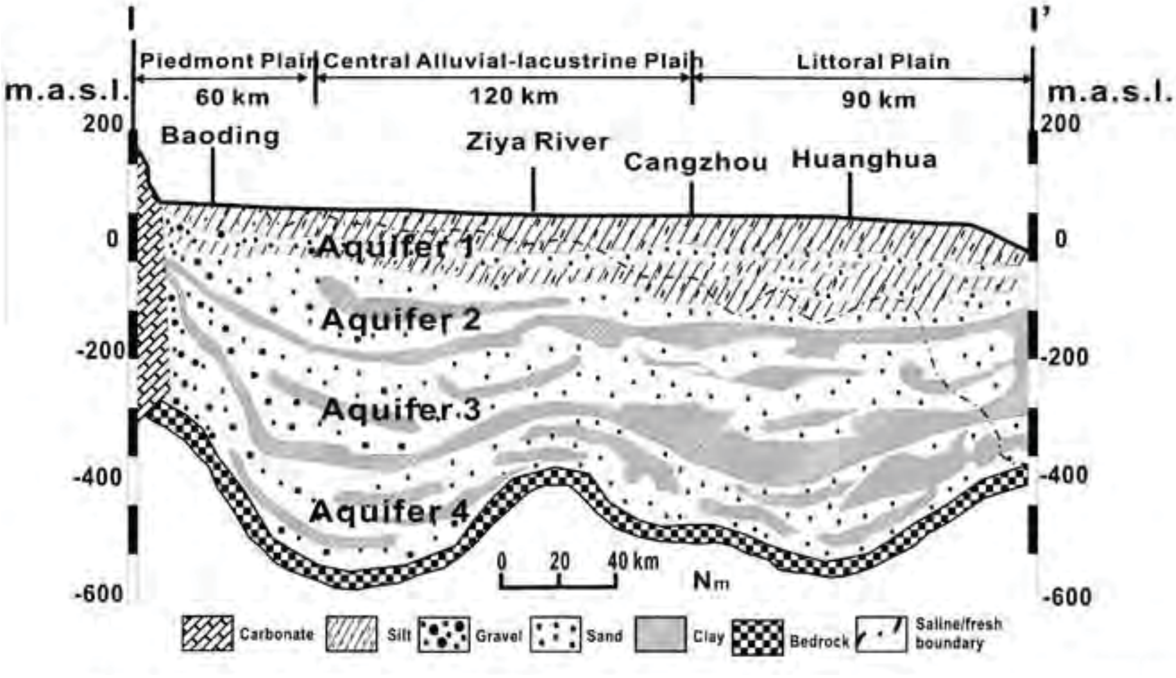

Fig. 3. Hydrogeological cross section from the piedmont Baoding to Cangzhou. The Quaternary aquifers are divided into four groups name as Aquifer 1-4. The boundary between shallow saline water and deep freshwater is marked as a dashed line. (Li Xiaoqian, 2012)

The groundwater recharge mainly includes precipitation infiltration, lateral inflow, irrigation infiltration and river infiltration, among which the precipitation infiltration is one of the main recharge of groundwater, and the irrigation, is the main driving force of vertical recharge. The recharge volume increases with the increase of irrigation (Lu X., 2011). Groundwater exploitation has become the main groundwater discharge in the North China Plain, including agricultural, domestic and industrial exploitation and a small amount of ecological water. Shallow exploitation is mainly concentrated in the piedmont zone, while deep mining mainly concentrated in the central plains of Hebei Province. The exploitation of groundwater in the North China Plain in 2002 and 2003 was $211.16\times10^8 m^3$, $199.22\times10^8 m^3$ respectively, among which, the exploitation shallow groundwater was $180.79\times10^8 m^3$ and $166.39\times10^8 m^3$, and the exploitation of deep groundwater was $30.37\times10^8 m^3$ and $32.83\times10^8 m^3$. Shao Jingli, used precipitation and rivers information of years, evaluated the annual average groundwater recharge rate based on water balance analysis, which is $256.68\times10^8 m^3/a$, and the annual average recharge modulus is $18.47\times10^4 m^3/(km^2\cdot a)$, the precipitation infiltration rate is $179.70\times10^8 m^3/a$, accounting for 70.00% of the total supply. Using the model, the total safe yield of groundwater in the North China Plain is calculated to be $213.49\times10^8 m^3/a$, among which, shallow aquifers safe yield is $191.65\times10^8 m^3/a$, and average exploitation modulus is $13.79\times10^4 m^3/(km^2\cdot a)$; Deep aquifers safe yield is $22.64\times10^8 m^3/a$, and average exploitation modulus is $1.93\times10^4 m^3/(km^2\cdot a)$ (Shao Jingli, 2009).

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

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

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

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

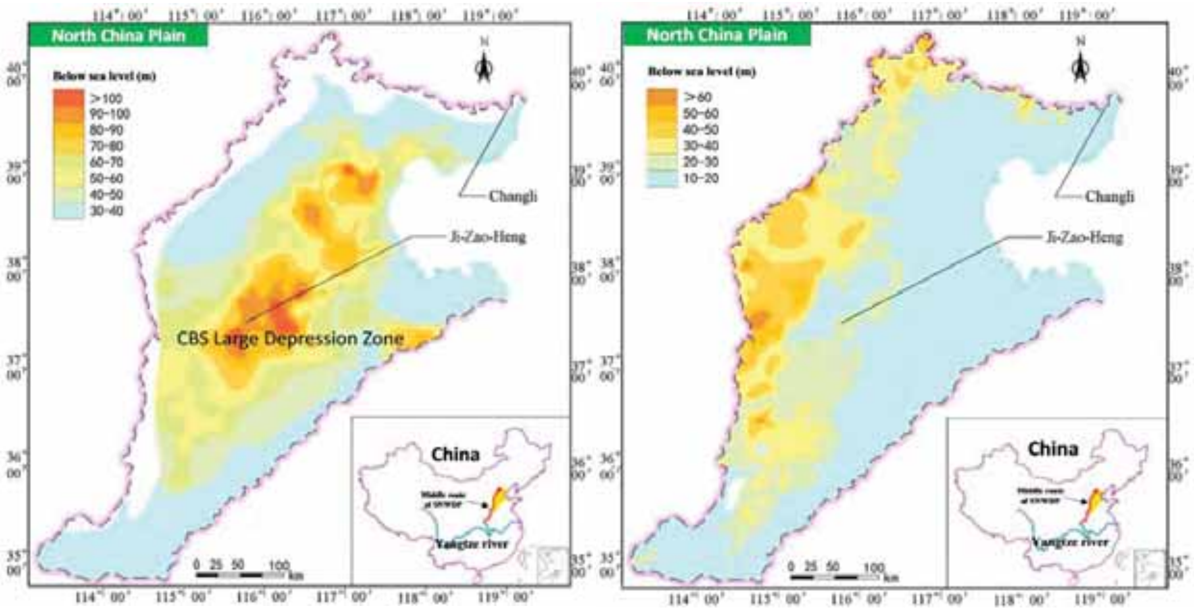

Fig.4. Depth of deep groundwater (left figure) and shallow groundwater in the North China Plain in China (Colored area shows the Cirum-Bohai-Sea (CBS) large depression zone. Data were collected in 2014. Shang Yizi, 2016)

3. Hydrological database in North China Plain

3.1 Groundwater monitoring and database

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

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

Sum	Newly designed monitoring point		Upgraded monitoring point	
	MWR	MLR	MWR	MLR
5845	2536	1590	927	792

In 2015, a new *"National Groundwater Monitoring Project"* of China is implemented by the Ministry of Land and Resources (MLR) and the Ministry of Water Resources (MWR). The China Geological Survey (CGS) is responsible for part of the construction of MLR. The main objective of this project is to construct a comprehensive monitoring network covering the 16 dominant plains/basins in China. Total 20401 monitoring wells are schemed, among which 10103 wells are implemented by CGS. The Huang-Huai-Hai Plain where North China Plain is located is one of 16 Plains/basins, there are 5,845 Monitoring points that constituted of 4126 newly designed and 1719 should be upgraded from the available old wells (Table 1, *www.cigem.cgs.gov.cn*). By now, the most of the monitoring sites have been completed. The focal monitoring areas include the groundwater pollution areas, the areas with environmental geological problems caused by human activities, the groundwater sources, urban areas, railway and subsidence areas.

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

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

3.2 Geological cloud and database

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

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

The project "*Investigation and Assessment of Sustainable Utilization of Groundwater Resources in the North China Plain*" is sponsored by the China Geological Survey between 2003 and 2005. The project had established "*NCP Geodatabase*" containing data of hydrogeological drilling, groundwater level, groundwater exploitation, and groundwater chemical information. In addition, the three dimensional numerical groundwater model of NCP was established by Feflow and GMS software. The groundwater evolution trend with different conditions, the South-to-North Water Diversion Project especially, have predicted by the model. In addition, the regional investigation on groundwater pollution by CGS in 1:250

000 scale had been fulfilled with a spatial database, the hydrogeological survey in 1:50000 scale by CGS has also been implemented. These data and information would be retrieved in the *Geological Cloud*, and obtained through application and authorization.

4. Groundwater Management in North China Plain

4.1 Laws and Regulations

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

4.2 Organization

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

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

4.3 Comprehensive Management for Groundwater Over-exploitation

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

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

4.4 The South-to-North Water Diversion Project

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

5. Conclusions

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

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

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

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

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

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Explanation Documents-Jakarta Groundwater Basin, Indonesia

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Abstract

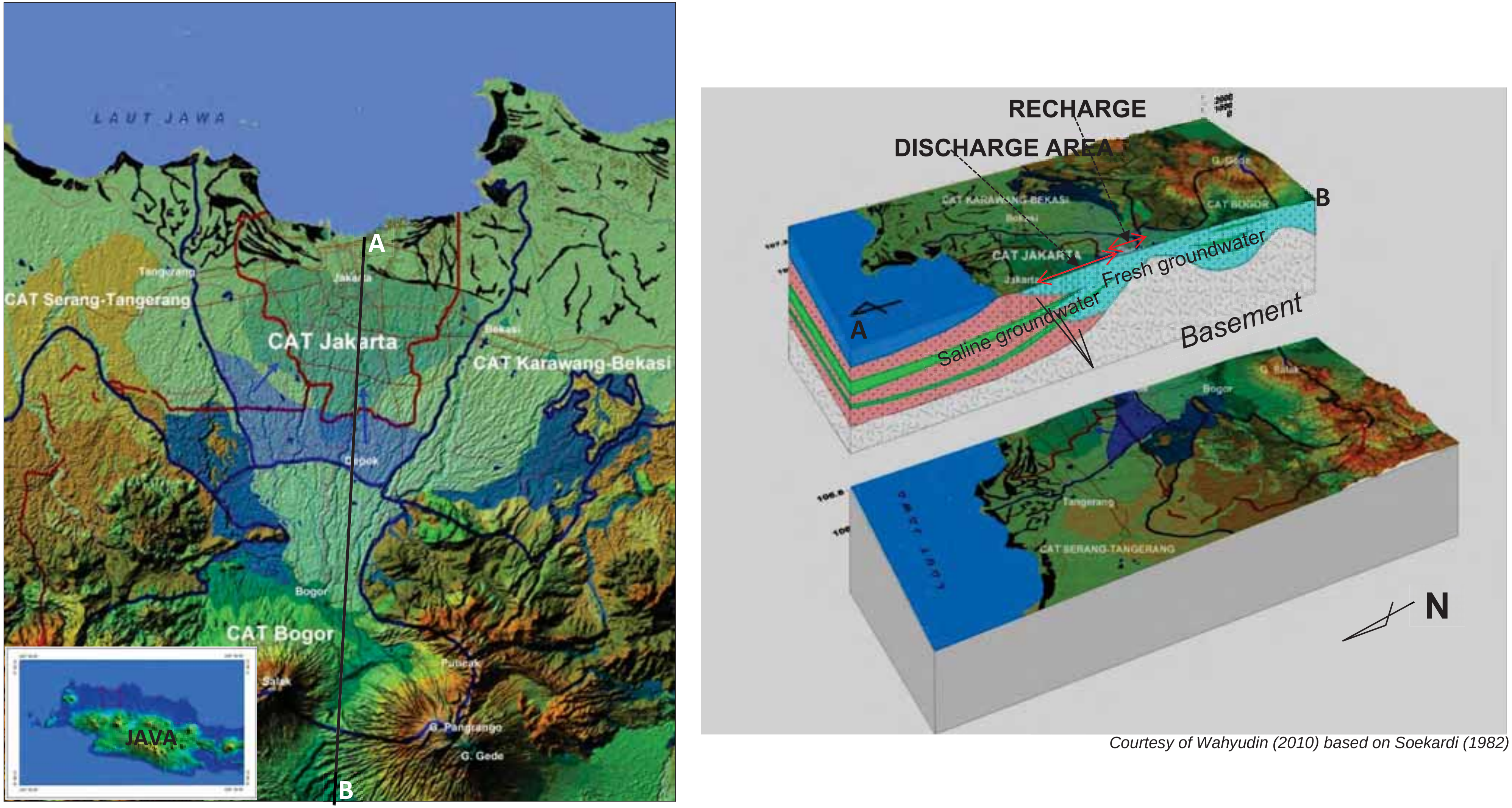
This paper describes geology, hydrogeology, groundwater condition, and groundwater management in Jakarta groundwater basin. The basin is an inter-provincial basin consisting of marine and non-marine deposits. Boundary types of the basin are Java Sea in the north, influent stream in the east and west, and basement undulation in the south. Insufficient municipal water network causing over abstraction of groundwater some areas, which is followed by seawater intrusion and land subsidence. Water level record indicated a drastic drop during early 1980's. Since then, water level has been dropping slowly up to present. Salty water from confined aquifer reached far away to the land and severe land subsidence is going in north Jakarta, especially in Muara Angke, by up to 12 cm. annually. Management of the basin is shared between central and provincial government, in which the former publishes conservation map and issues technical recommendation for production wells, whereas provincial government issues wells registration. In order to better monitor groundwater condition, a master plan of monitoring wells network is on going and will be followed by installation of additional monitoring wells systematically. Government is also conducting an action to fight against illegal wells.

Keywords: groundwater, Jakarta, basin, management

1. Introduction

Jakarta as the capital city of Indonesia has been for a long time becoming a hot spot of its groundwater and related problems. With a population of c.a. 10,17 million in 2015 (BPS, 2016), Jakarta is considered as a megacities, equal with other big cities in Asia, e.g., Delhi, Bangkok, Manila, Tianjin (Onodera et al., 2008). In this kind of city, without sufficient municipal water network coverage, groundwater normally will be the main source of water supply. Over abstraction of has been identified triggering land subsidence and, in coastal cities, also seawater intrusion (Abidin et al., 2010; Huang et al., 2012; Murdohardono and Sudarsono, 1998; Onodera et al., 2008; Phien-wej et al., 2006; Suripin, 2005; Zhu et al., 2015). Recently, groundwater degradation in Jakarta becoming a hot issue, due to big flooding evens occured at some strategic areas, e.g., Monas, Bundaran Hotel Indonesia, and recently Kemang. The floods have been associated with land subsidence due to over abstraction of groundwater. Data from Jakarta provincial administration reported that in 2011 water demand in Jakarta reached 846 billion m^3, and only 35.2 % covered by municipal water network, hence the rest, 64.8 %, obtained from groundwater. From the number of 64.8 %, only 9.3 % were registered, hence troublesome for such a management effort. Recent flooding events in some strategic areas in Jakarta, has been associated with groundwater abstraction.

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



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

Fig. 1. Boundaries configuration of the Jakarta groundwater basin

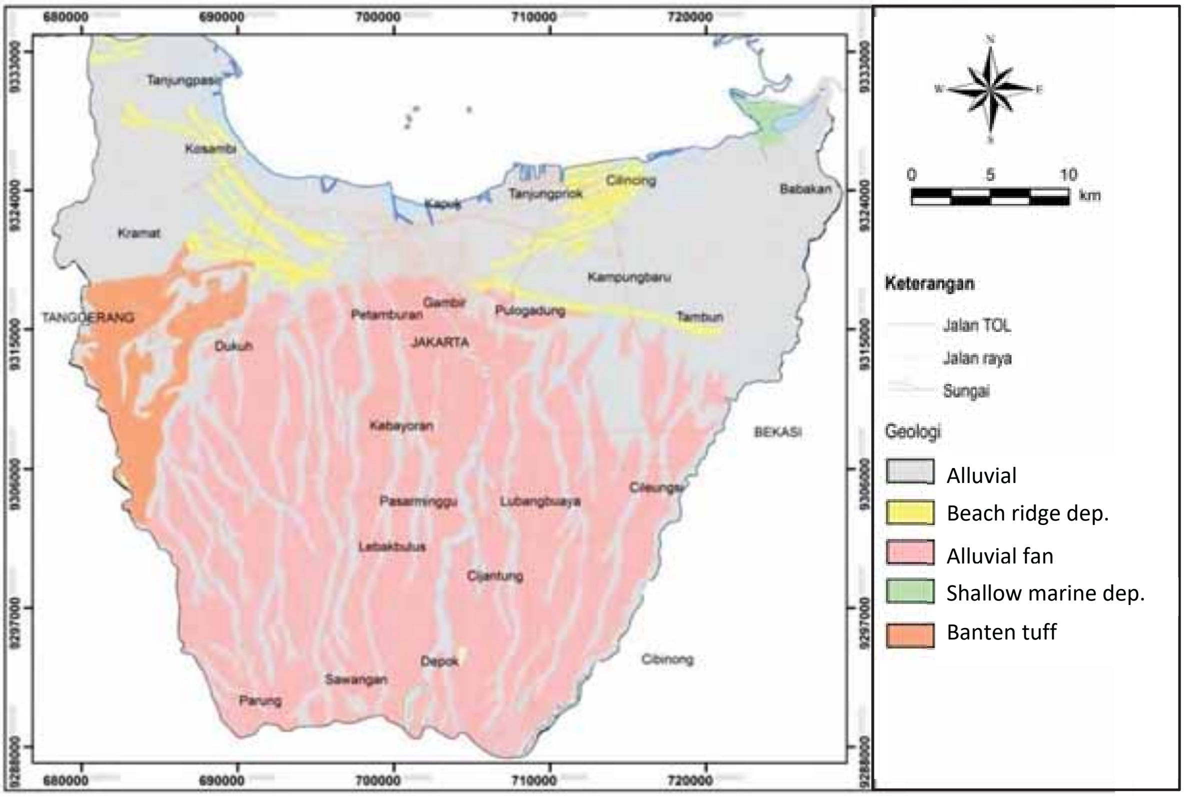


Fig. 2. Geological map of the Jakarta Groundwater basin (Turkandi, et.al., 1992)

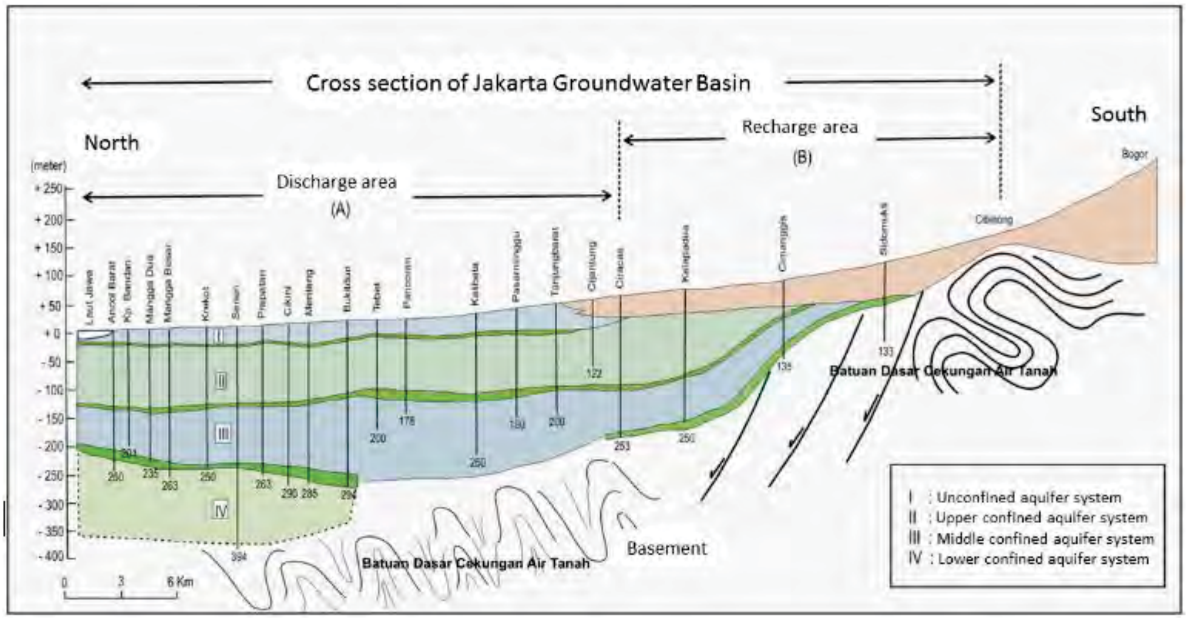


Fig. 3. The aquifer configuration of Jakarta basin modified from Soekardi (1982)

2. Geology and Hydrogeology in Jakarta, Indonesia

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

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

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

3. Hydrological database in Jakarta

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

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

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

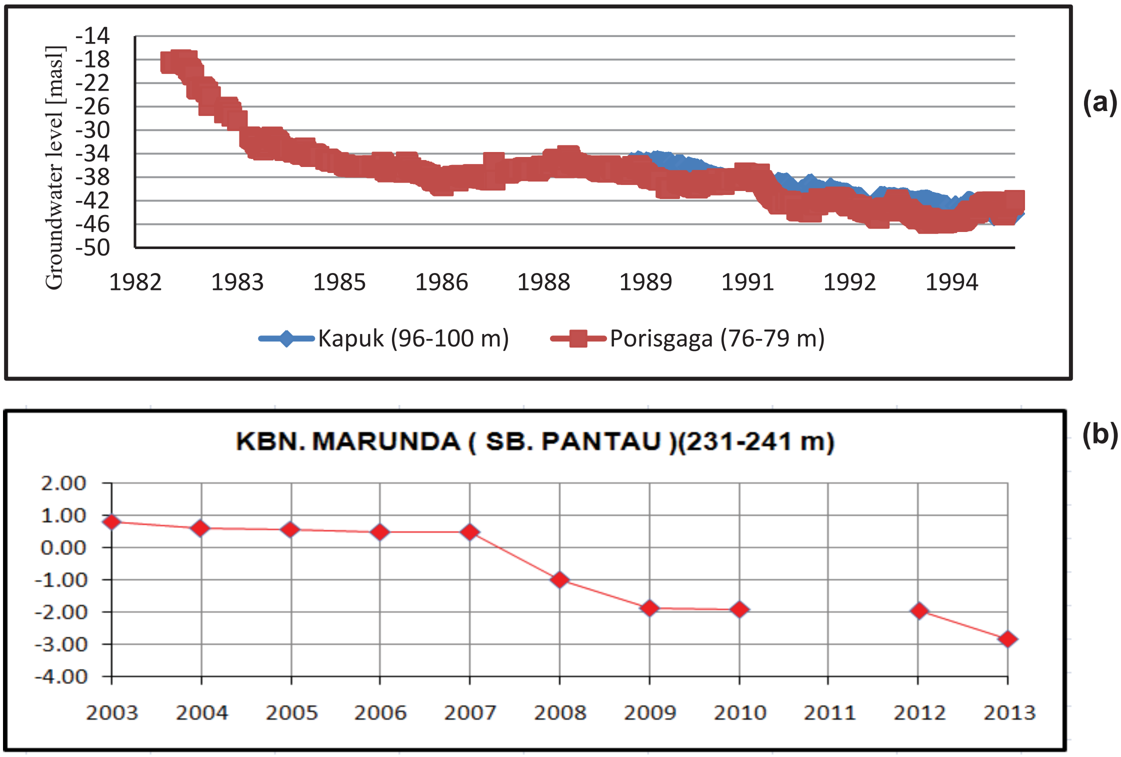


Fig. 4. a) Groundwater level of upper confined aquifer recorded from monitoring wells of Kapuk and Porisga. During 1980's water level dropped rapidly; b) Groundwater level of middle confined aquifer recorded from monitoring wells of KBN Marunda.

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

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

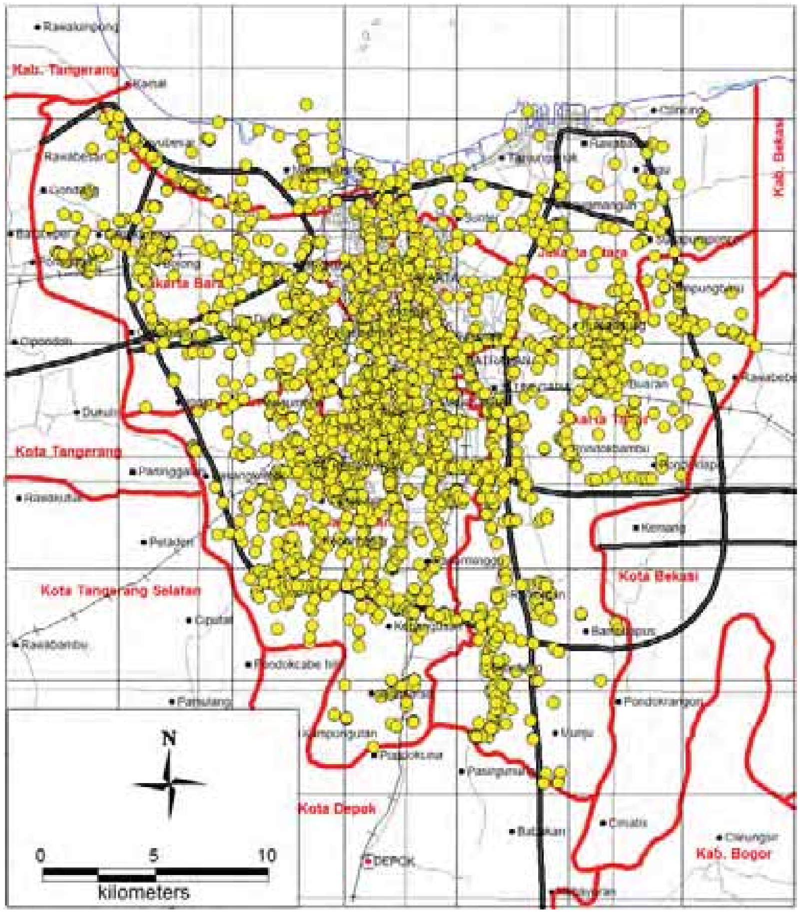


Fig. 5. Distribution of deep production wells in Jakarta

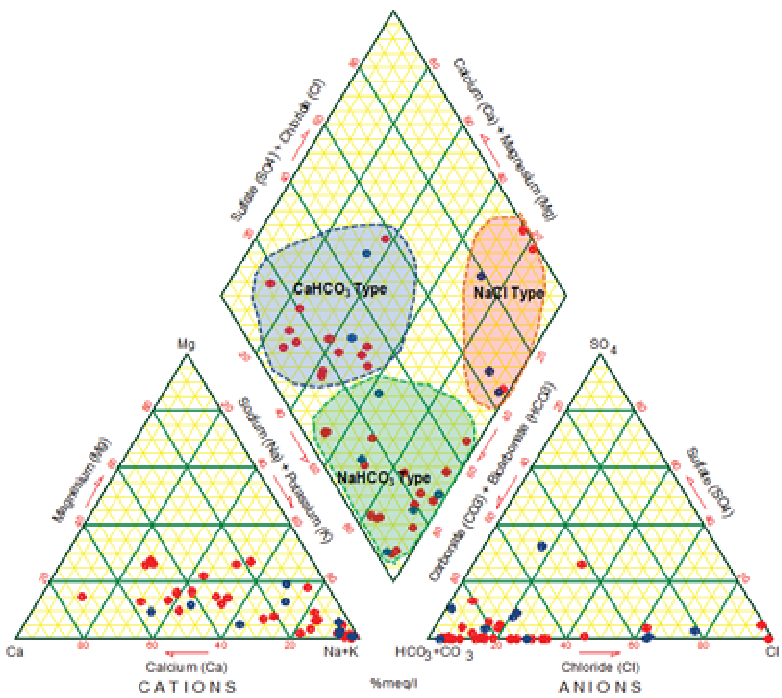


Fig. 6. Groundwater facies of the confined aquifer (Setiawan et al., 2014)

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

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

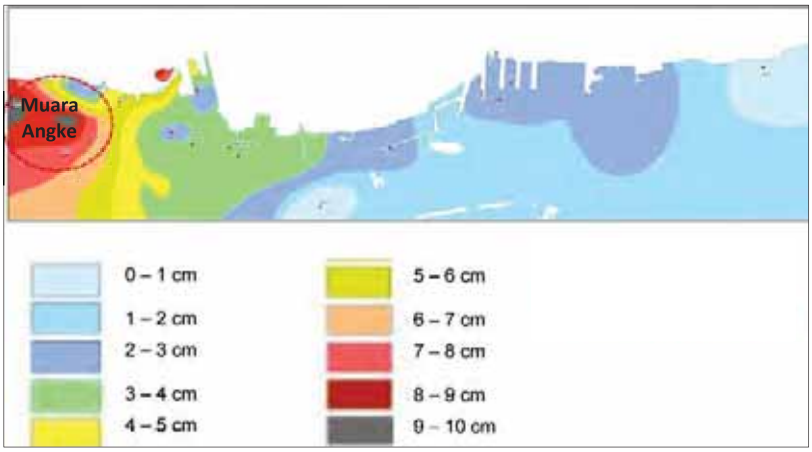


Fig. 7. The level of land subsidence in northern Jakarta

4. Groundwater Management in Jakarta

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

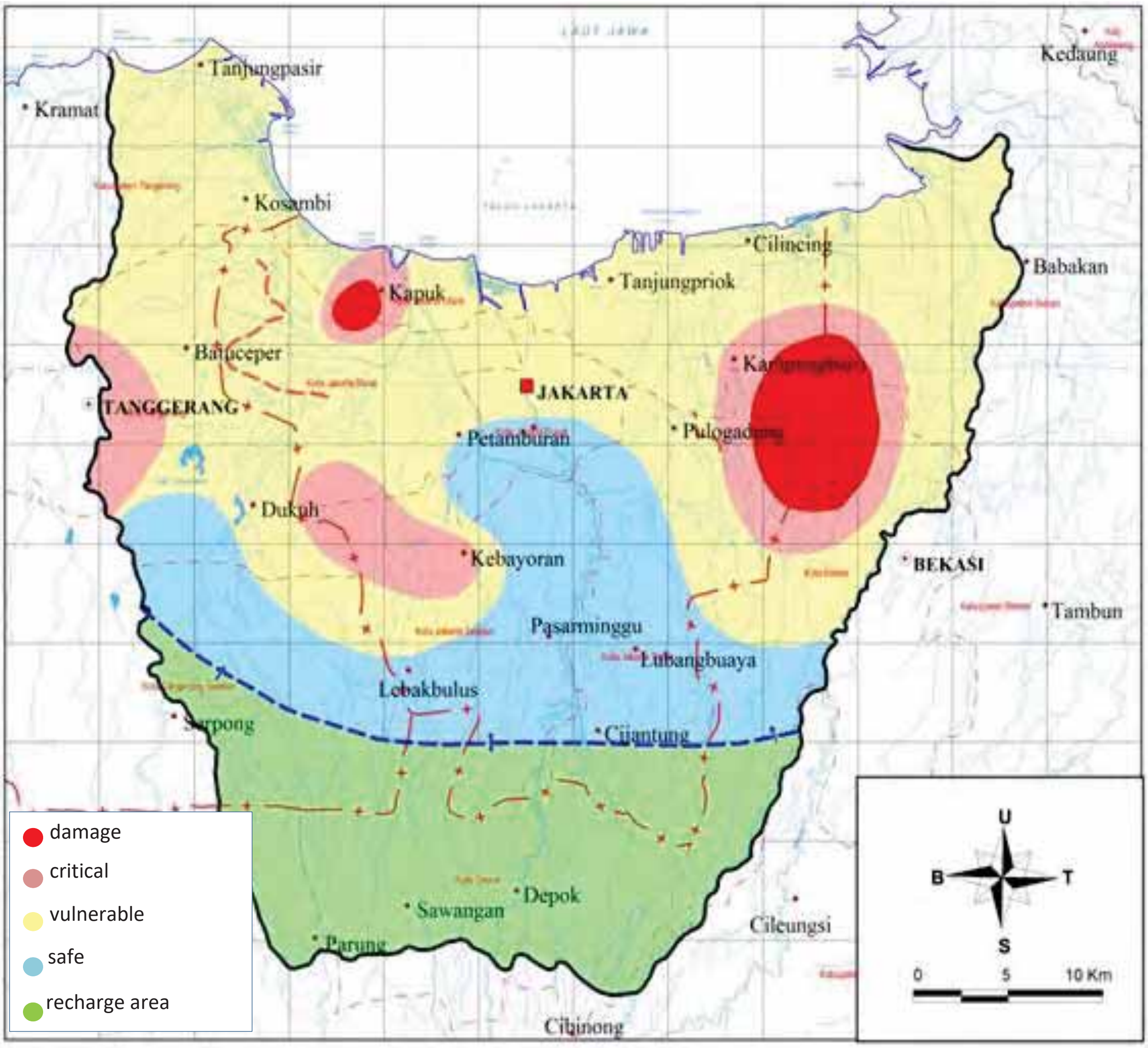


Fig. 8. Groundwater conservation map in Jakarta published in 2013

5. Conclusions

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

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

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Explanation document -Kanto Plain, Japan-

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Abstract

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

Keywords: Kanto Plain, groundwater, hydrogeological map, Japan

1. Introduction

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

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

2. Geology and Hydrogeology in Kanto Plain, Japan

The Kanto Plain is the largest plain in Japan (about 15,000 km2, Fig. 1), and it is surrounded by the Tanzawa Mountains, the Kanto Mountains, the Ashio Mountains and the Yamizo Mountains. The topography of the plain is classified into three types, lowlands along the river, uplands and hills which are located in border of the plain. The Kanto plain consists of the sedimentary layers which is more than 3000 m in thickness (Suzuki, 1996). The sedimentary layers are classified into three groups: Shimousa group, Kazusa group and Miura group. The Shimousa group and upper part of the Kazusa group are the most useful aquifer in the plain. It is difficult to delineate the boundary between the Shimousa group and the Kazusa group, using their geological feature (Suzuki, 1996).

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

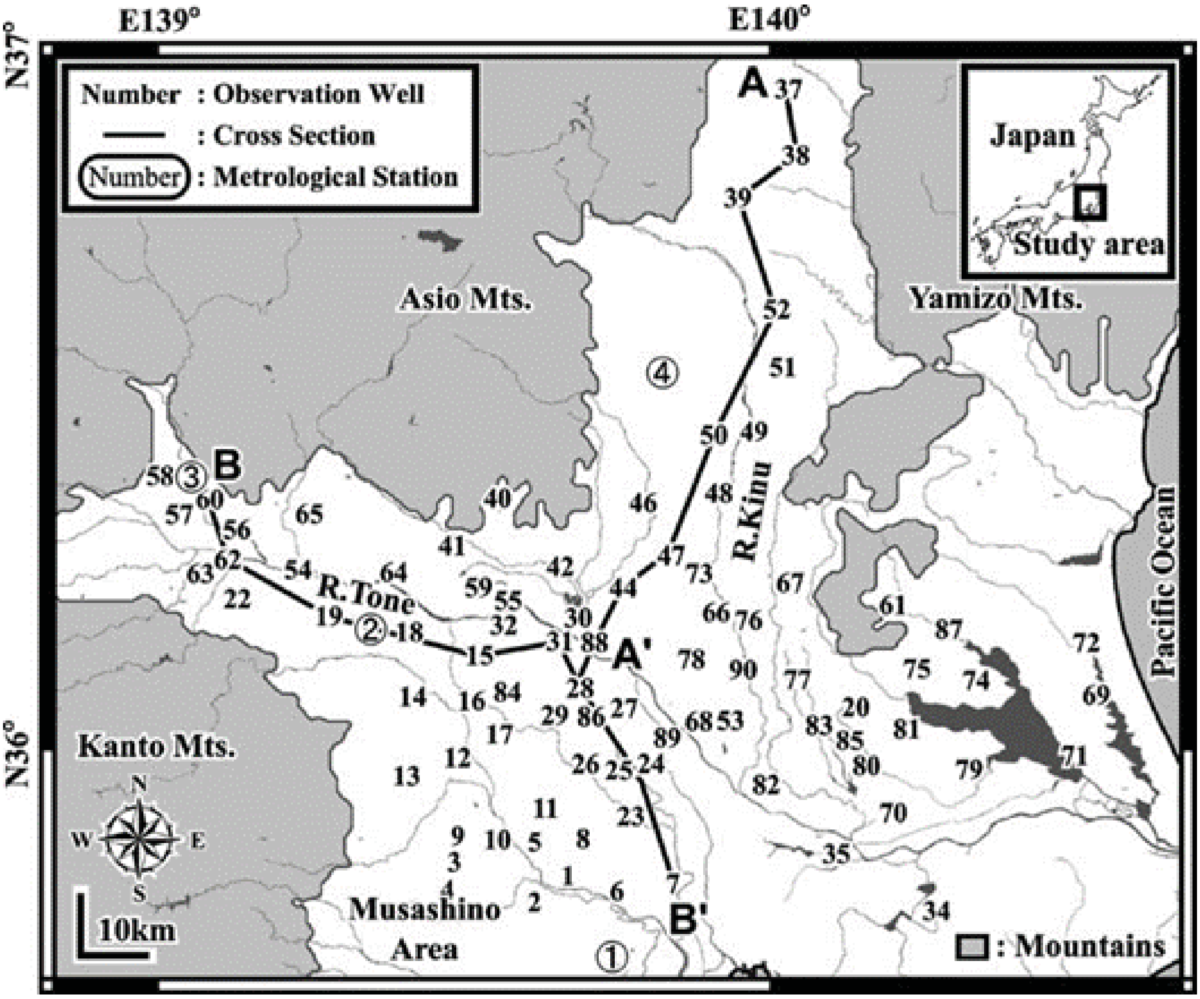

Fig. 1. Location Map of the study area and distribution of observation wells.

3. Hydrological database in Kanto Plain

3.1. Groundwater flow system and their subsurface thermal regime

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

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

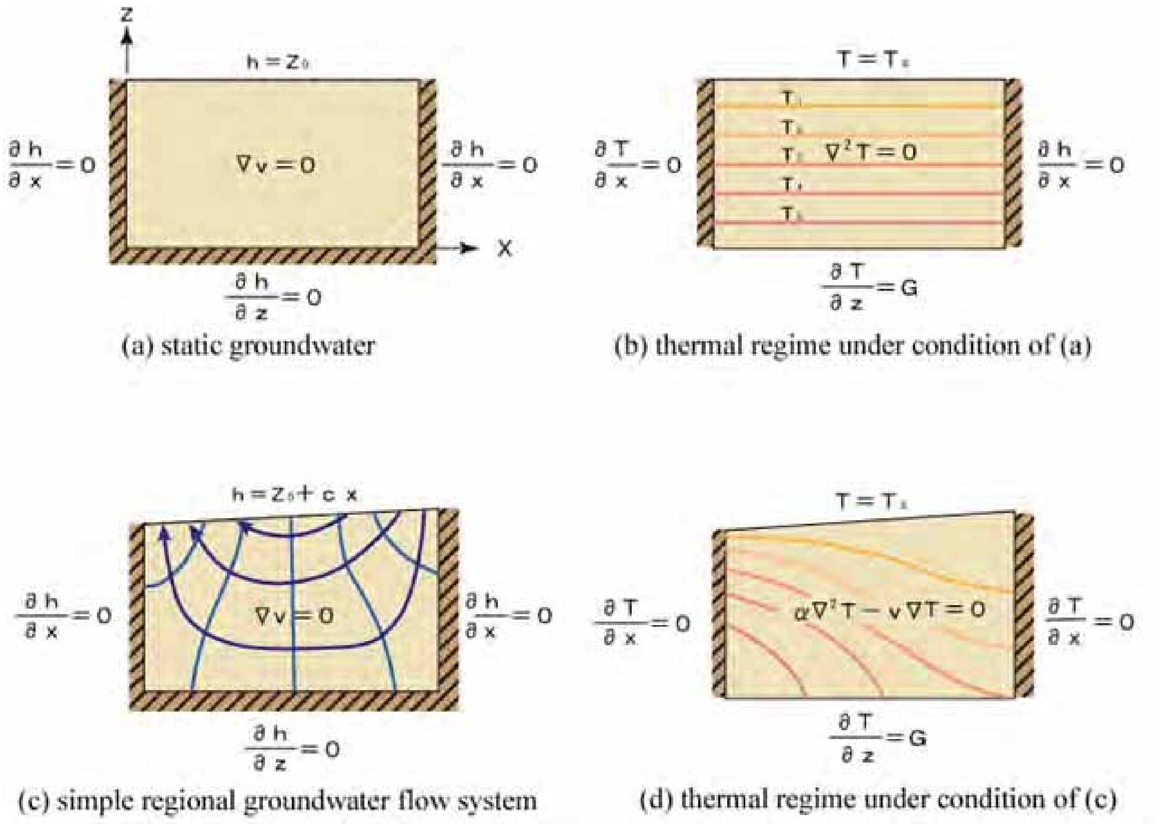

Fig. 2. Subsurface thermal regime affected by a groundwater flow system. (modified Domenico and Palciauskas, 1973)

(a) static groundwater, (b) thermal regime under condition of (a),

(c) simple regional groundwater flow system, (d) thermal regime under condition of (c)

3.2. Measurement methods

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

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

3.3 Observation Results

Fig. 3a and b show vertical 2-D distribution of hydraulic heads along the Kinu river (A–A') and the Tone river (B–B'), respectively. Hydraulic heads are high in the surroundings of the plain such as hills or highlands, and low in the lowlands which are located along the river. Hydraulic heads gradually decrease from highlands to lowlands. Especially, in the lowlands which are located in central part of the plain, hydraulic heads are anomalously low. There were a lot of artesian wells in the central part of the plain before 1970 (Kino, 1970). At present, there are very few artesian wells in this area, because of effects of pumping (Tochigi Prefecture, Japan, 1999; Saitama Prefecture, Japan, 1999). These distributions show the existence of groundwater flow system. Groundwater gets recharged in hills and highlands and discharged at lowlands.

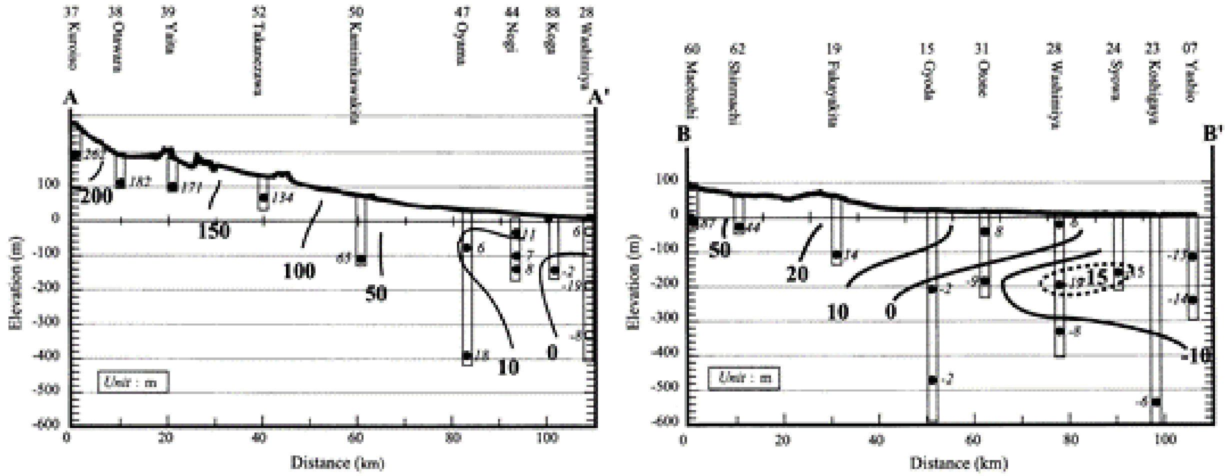

Fig. 3. Vertical distribution of hydraulic heads in cross section along (a) A–A', (b) B–B' in Fig. 1. Italic number shows the hydraulic head at the screen.

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

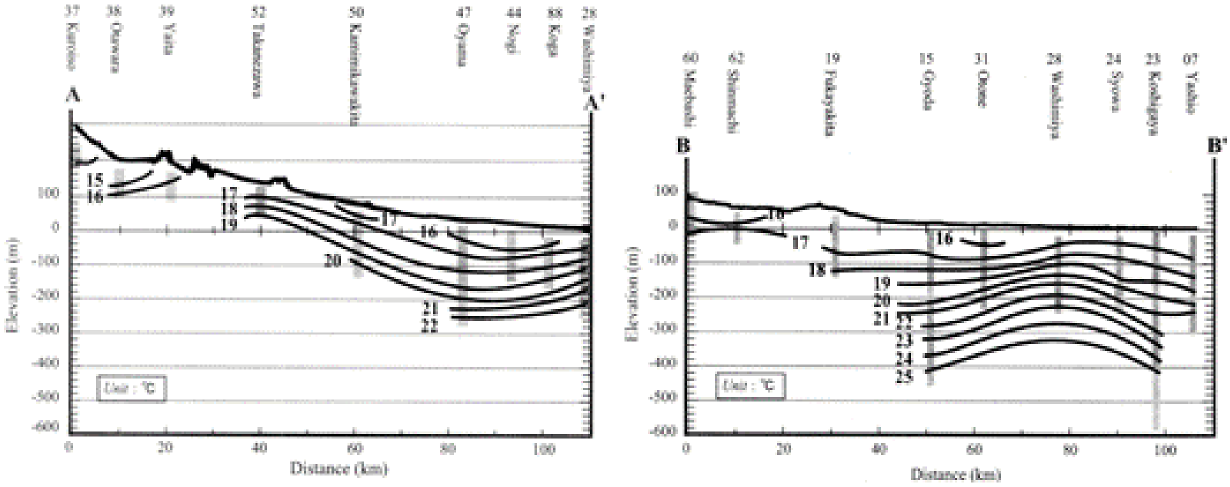

Fig. 4. Isotherms of subsurface temperature in the same cross section in (a) Fig. 3a, (b) Fig. 3b.

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

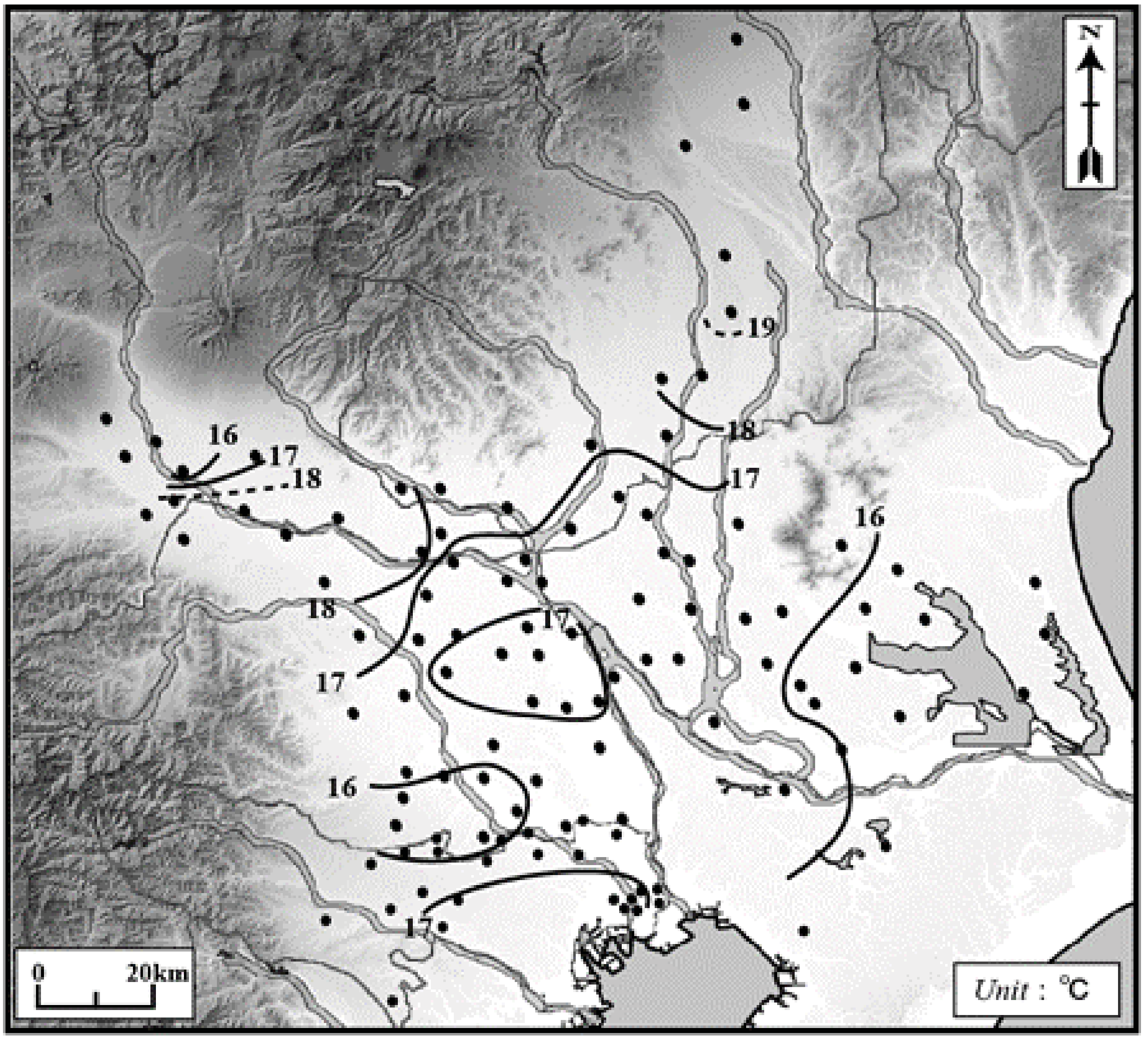

Fig. 5. Isotherms of subsurface temperature at 50 m below sea level.

4. Discussion

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

5. Groundwater Management in Japan

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

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

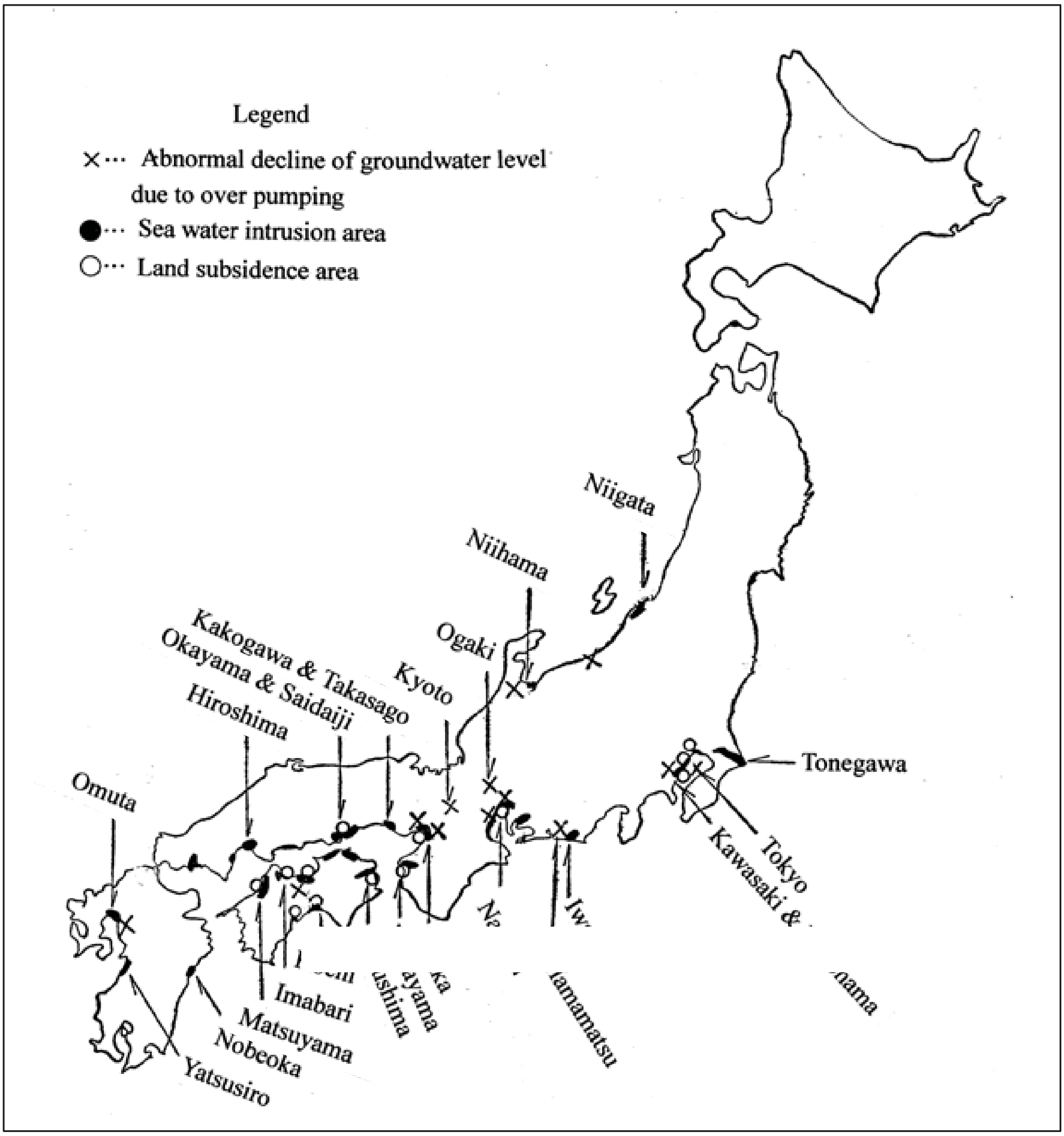

Fig. 7 Groundwater issues in 1960's in Japan*(after Kurata, 1960)*

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

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

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Explanation document – Groundwater Monitoring data from bedrock aquifer in Korea

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Abstract

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

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

1. Introduction

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

2. Geology and Hydrogeology in study area

In Korea, the hydrogeological units are divided into 8 units based on geological features. They are metamorphic rocks, intrusive rocks, unconsolidated sediments (landfill included), limestones, porous volcanic rocks, non-porous volcanic rocks, clastic sedimentary rocks, Semi-consolidated clastic sedimentary rocks. Metamorphic rocks and intrusive rocks account for about 60% of the total. The relationship between hydrogeological units and groundwater quality, or between geology and groundwater quality, is under constant investigation and research.

3. Hydrological data in study area

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

The national groundwater monitoring networks in Korea have been operated with an automatic remote recording system. The groundwater level, temperature, and EC are automatically collected at a certain time interval, and stored in a central database server (www.gims.go.kr). In addition, the data is published as an annual report at the end of the year through the complete reviews. Therefore, the data presented in the database are the groundwater data in bedrock aquifer extracted from the annual reports. The 2014 data are the annual mean, maximum and minimum values for groundwater level at each station. 2015 and 2016 data additionally contain temperature and EC data. However, there is no oxygen and hydrogen isotope data and temperature profile data at each station.

4. Groundwater Management in Korea

4.1 Groundwater monitoring wells

The monitoring stations are distributed all over the country including Jeju Island (Fig. 1). The monitoring networks are operated under major watershed regions, which are the Han-gang, Nakdong-gang, Geum-gang, Youngsan-gang/Seomjin-gang. The altitudes of the stations are minimum 3.5 m(EL.), maximum 986.5 m(EL.), and average 101.2 m(EL.). The well depths are minimum 17.0 m, maximum 490.0 m and average 75.6 m. The wells with more than 400 m or more are located in Jeju Island, which are deep wells in the mountainous areas in order to observe the groundwater levels around seawater level.

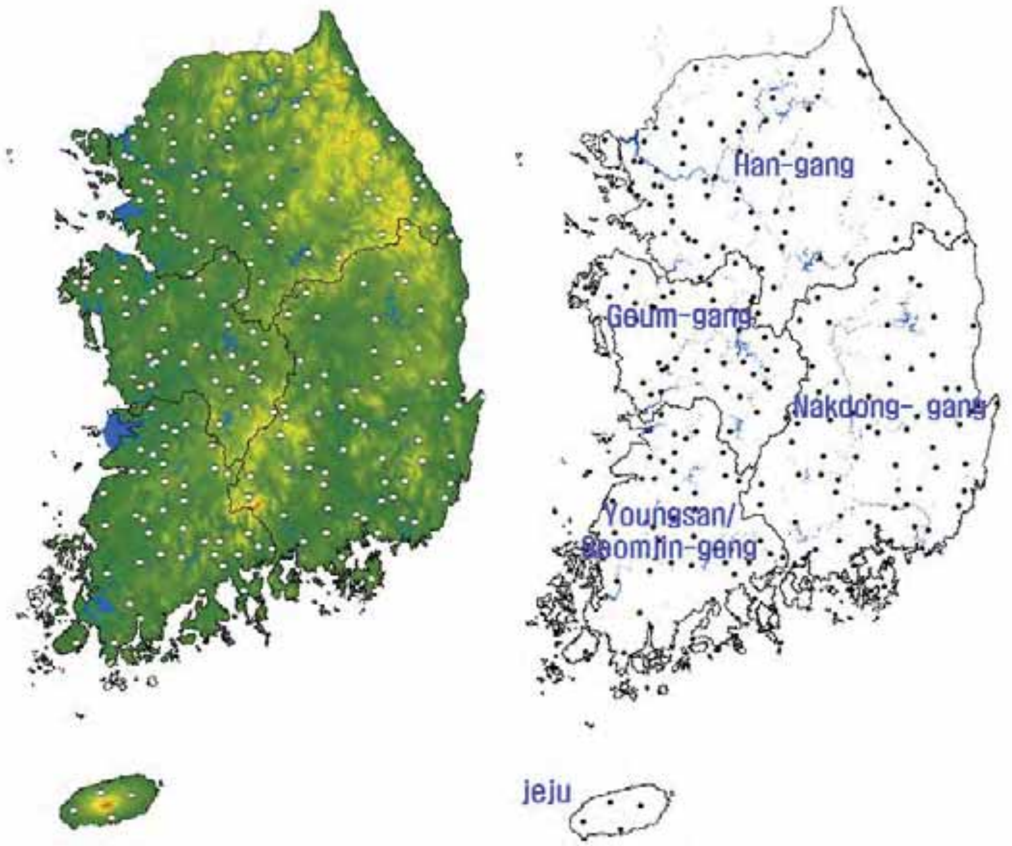

Fig. 1. The groundwater monitoring well locations

4.2 Data structure and explanation

The Excel file (Fig. 2) has a total of 50 fields. Column A and B have serial numbers and well IDs in order, and column C and D indicate latitude and longitude. Column E shows the altitude, column F shows the well depth, and column F for electrical conductivity (EC) is empty in this field, because there are data from the AM to the AO column, from the AV to the AX column. From the H to the AC column, the 22 columns show dissolved major components in groundwater at each well. Items without data are the isotope column I, column J, and NH4, Li, NO2, PO4 data columns.

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

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

Fig. 2. Data descriptions

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

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

The annual groundwater EC is 32.0 ~ 30,176 µ0,cm in 2015 with an average of 552.4 µ52 cm.

In 2016, the annual groundwater EC is 34.0 ~ 29,580 µ9,cm (Fig. 3) with an average of 579.6 µ79 cm. EC of groundwater is formed high around the eastern and western coasts. Higher ECs in the southeastern part of the country and in some areas may also indicate groundwater contamination.

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

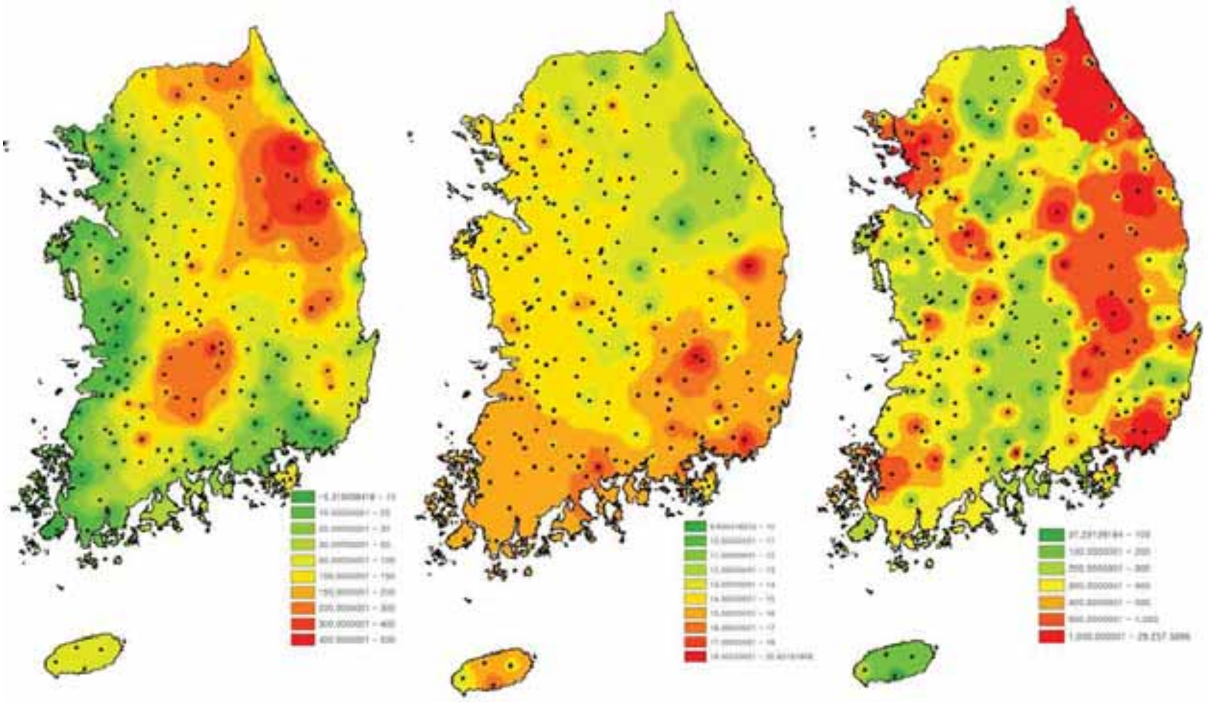

Fig. 3. Distribution of the average groundwater level (left), temperature (middle) and electrical conductivity (right) in 2016

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Groundwater Management in Lao PDR

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Abstract

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

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

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

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

1. Introduction

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

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

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

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

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

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

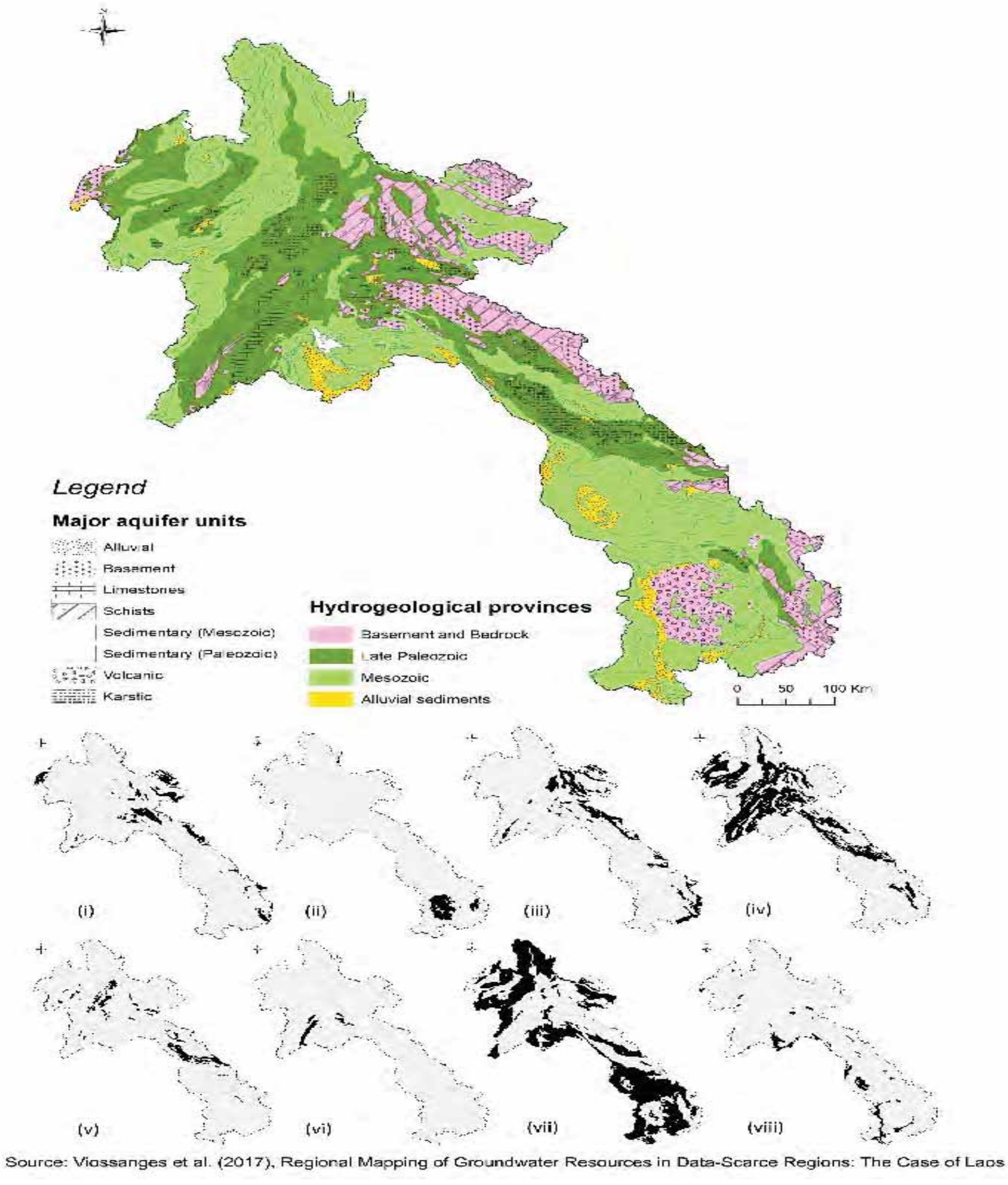

Fig. 1. Synthetic map of the four MRC hydrogeological groups (greyscale filling) and the eight identified aquifer units (textures). Sub-maps present the spatial repartition of the 8 aquifer units as (i) Basement aquifers, (ii) Volcanic aquifers, (iii) Schists, (iv) Paleozoic sedimentary, (v) Karsts,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

2. Geology and Hydrogeology in Lao PDR

In Term of aquifer there are eight aquifer units have been described and evaluated: (i) Basement aquifers (ii) Volcanic aquifers (iii) Schists (iv) Paleozoic sedimentary (v) Karsts (vi) Limestones (vii) Mesozoic sedimentary (viii) Alluvial sediments (Fig. 1). Aquifer map is shown in Fig. 2.

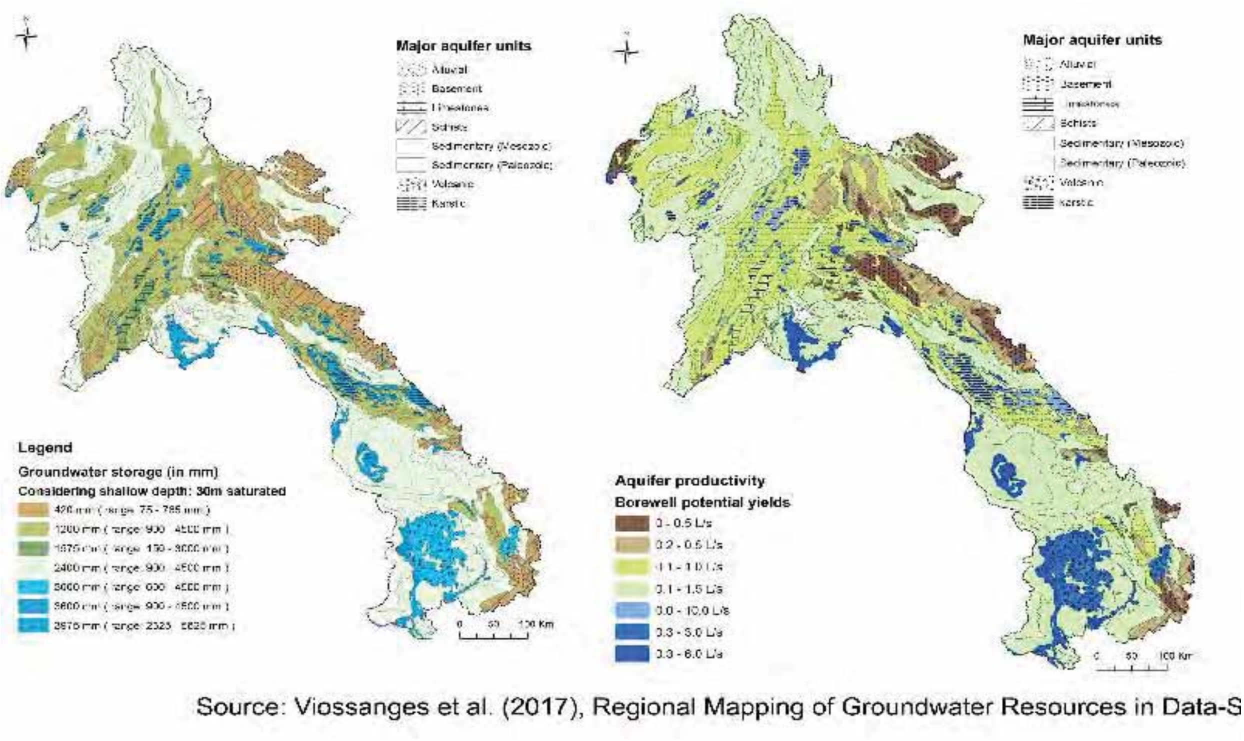

Fig. 2. Map of shallow groundwater storage in Laos, considering a 30 m saturated thickness and map of shallow aquifer productivity in Laos

<u>Areas of Significant Groundwater Importance</u>

- *Alluvial aquifers* extend over limited areas and limited thickness; however, with both high storage and important yields, it represents the most productive aquifer type in Laos. Groundwater is already largely used in some of Laos Alluvial plain for domestic uses, and marginal cash crop irrigation.
- *The Mesozoic sandstones* are considered of great importance in Laos. This is due to their intrinsic storage properties, their important thickness, up to several hundred meters, regional groundwater flow system support, and their ubiquitous occurrence in the lowlands. These sandstone aquifers represent the main source of water for hundreds of villages across the country. In most cases, yields constrain its use to domestic purposes only.

<u>Areas of Probable Groundwater Development Potential</u>

- The large *Karsts systems* found in Laos possibly possess both a high storage and high yield. However, the lack of knowledge on these formations has been highlighted.
- The *Volcanic aquifers* found in southern Laos could also host a significant potential for groundwater development. They are in some place already developed (JICA) and exploited for domestic uses in several villages. They also support local small-scale water bottling companies. With high storage and yield indicators, coupled with high rainfall and

recharge from the plateau during the rainy season, these volcanic aquifers could represent a hydrogeological region of high importance. However, in several places, the thickness of the basalt is limited to a few tens of meters, underlain mostly by sandstones.

Areas of Limited Groundwater Development Potential

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

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

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

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

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

The baseline found that Atsaphone households were more likely to use dug wells as a secondary supply. Poorer Atsaphone households are seven times more likely to use a dug well as their main supply. In Phine, two thirds of poor households use surface water as their main supply. In Phine, secondary supplies were also more likely to be streams or ponds.
Currently, issues related to groundwater show a number of droughts, such as in the 242 Border Protection Corridor of Ban Ang Gai, Sisattanak District, Vientiane capital, there is a problem of water depletion and drainage of up to 200 m deep to underground water. The problem of water quality is same as in Seno, Sepon and Xecham Phon Districts and saline soils find saline problems in the city of Seno and limestone that affect the use of the people in the area.

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

3. Hydrological Problem in Laos

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

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

One of the best samples for River basin management in Laos is Nam Ngum river basin (NNRB) this basin located in the central part of the Lao PDR and covers an area of 16,800 km2. There are four provinces Xieng Khuang, Luang Prabang, Vientiane, Boulikhamxay and the Vientiane municipality within the basin. It is one of the major tributaries of the Mekong River contributing 14% of the mainstream flow at the Mekong.

The Nam Ngum Basin comprises two major rivers the Nam Ngum and its major tributary the Nam Lik. The headwaters of the Nam Ngum are at an elevation of 2800 m in the northeast of the basin and the river travels southwards for 420 km to its outlet with the Mekong, approximately 100 km downstream of the capital, Vientiane. Downstream of the Nam Lik confluence, the Nam Ngum River has a gentle slope of between1/10000 to 1/25000 as it meanders its course. The Vientiane plain extends from each bank and covers an area of about 2000 km2 at elevations of 160 to180 m. The plain is formed mostly of alluvium soil suitable for the cultivation of rice and other short duration crops. The river is constricted by a narrow cross-section at the Tha Ngon Bridge (20km north of Vientiane) which, during the wet season, influences flooding on the upstream floodplain

3.1. Climatic Setting

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

Rainfall

The mean annual rainfall of the basin is 2000 mm and ranges from 1450 to 3500 mm across the basin (Figure 2). The rainfall distribution in the region is significantly influenced by the central mountain range. The largest rainfalls are near Vang Vieng and the lowest near Phonsavan in the north east (WRCC, 2007).

Evaporation

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

Flow

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

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

3.2 Water Use

Irrigation Use

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

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

Domestic and Industrial Use

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

Hydropower

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

3.3. For Scenarios and Water Allocation

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

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

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

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

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

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

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

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

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

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

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

5. Conclusions

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

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

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

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Hydrogeology and Groundwater Development of Sebatik Island, Malaysia-Indonesia

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Abstract

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

Keywords: Groundwater transboudary, Sebatik Island, MALINDO

1. Introduction

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

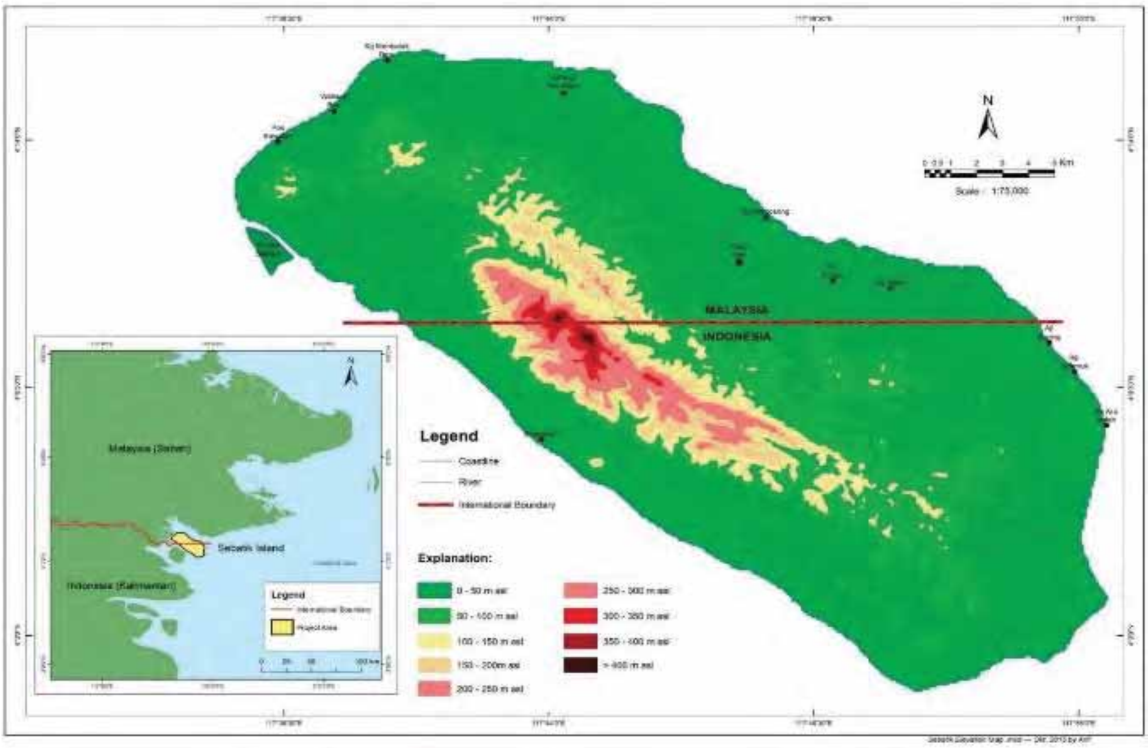

Fig. 1. Location of the study area

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

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

2. Geology and Hydrogeology of Sebatik Island

Geology

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

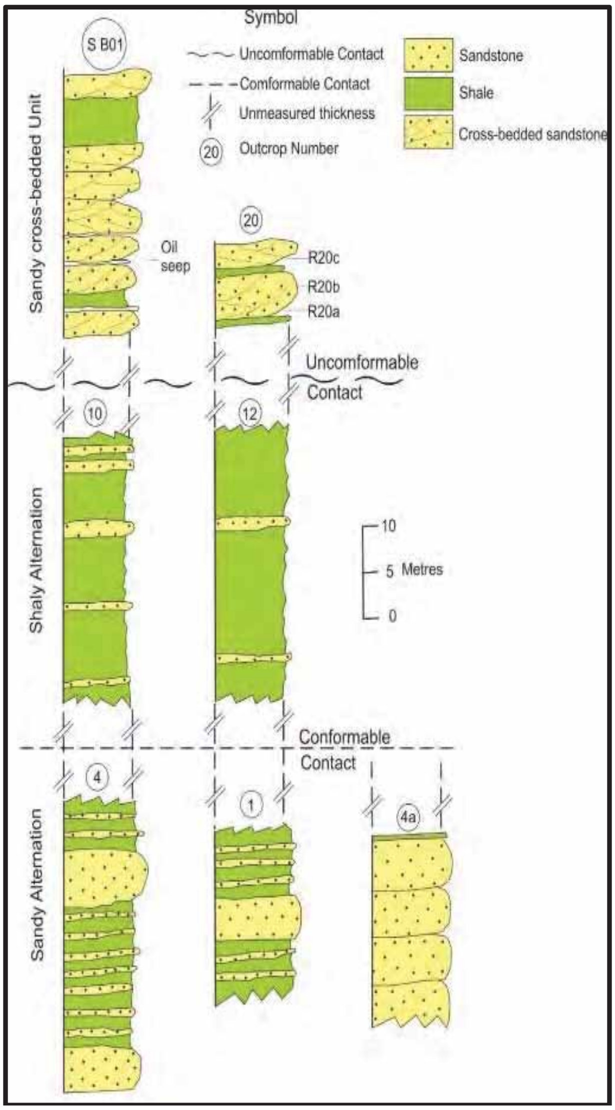

Fig. 2. Typical stratigraphic sequences of the Sebatik Island correlate by TWG1

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

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

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

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

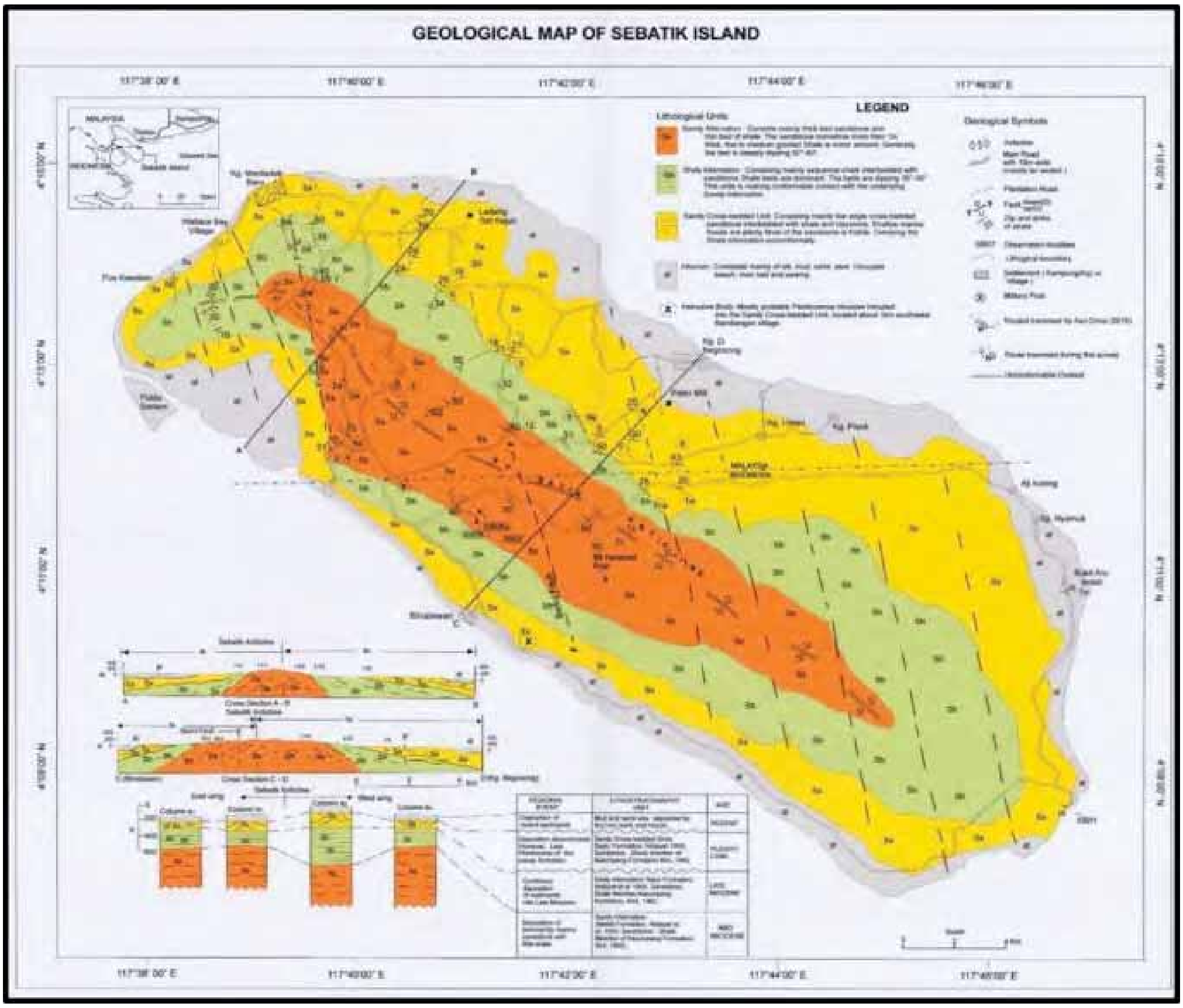

Fig. 3. Geological map of Sebatik Island (Source: TWG1)

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

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

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

Hydrogeology

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

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

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

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

i) Intergranular Flow Aquifer System

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

ii) Fissures and Interstices Flow Aquifer System

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

iii) Fissure or Fracture Flow Aquifer System

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

3. Hydrological Data In Sebatik Island

Shallow Aquifer: Northern Sebatik Island (Malaysia)

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

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

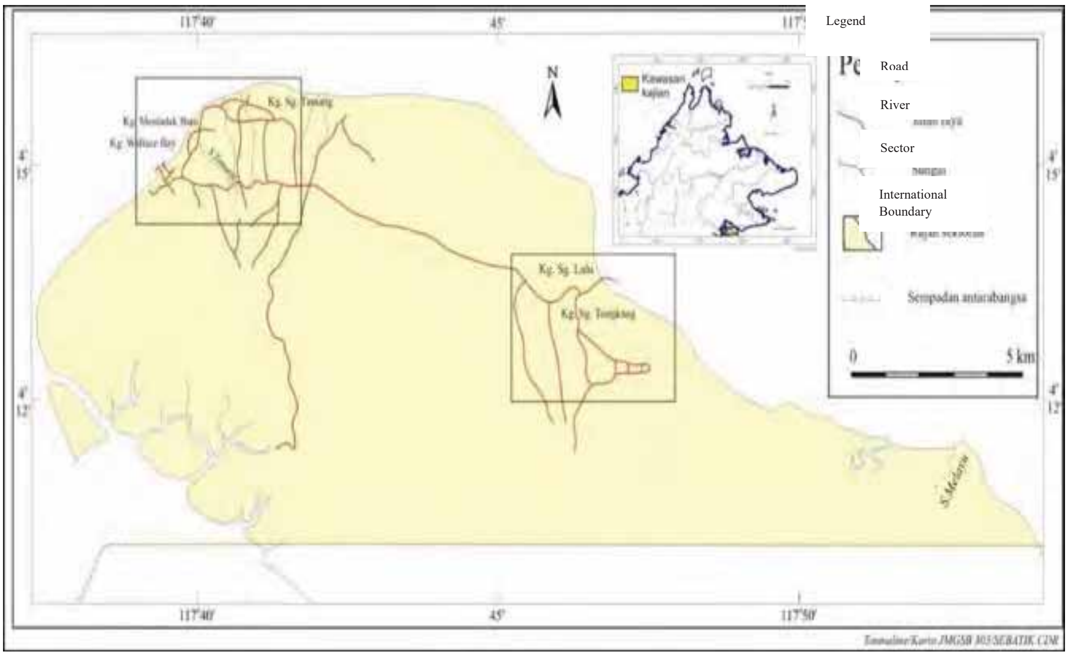

Fig. 4. Location map of groundwater exploration study area in Malaysia Sebatik Island (*Wan, 2001*)

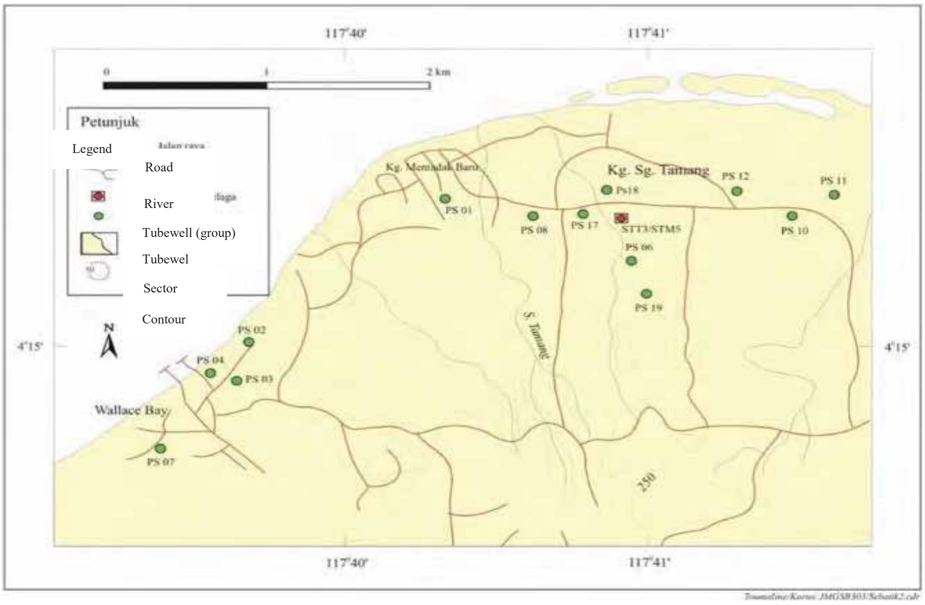

Fig. 5. Location map of exploration wells at Wallace Bay and Kg. Sg. Tamang *(Wani, 2001)*

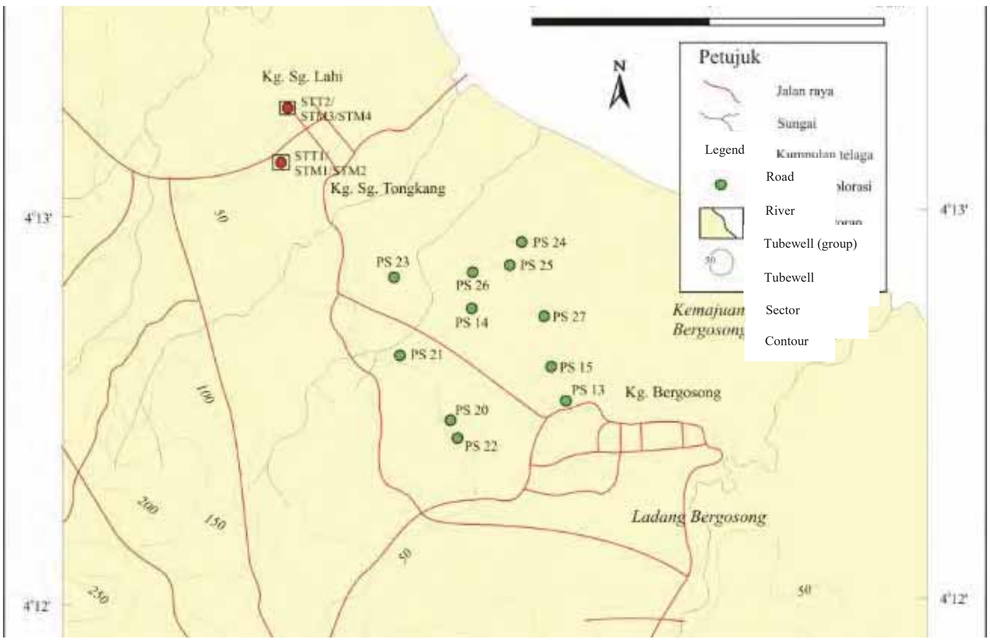

Fig. 6. Location map of exploration wells at Kg. Sg. Lahi and Kg. Sg. Tongkang (*Wan, 2001*).

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

Medium-Deep Aquifer: Southern Sebatik Island (Indonesia)

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

Table 2. Pumping test and hydraulic properties

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

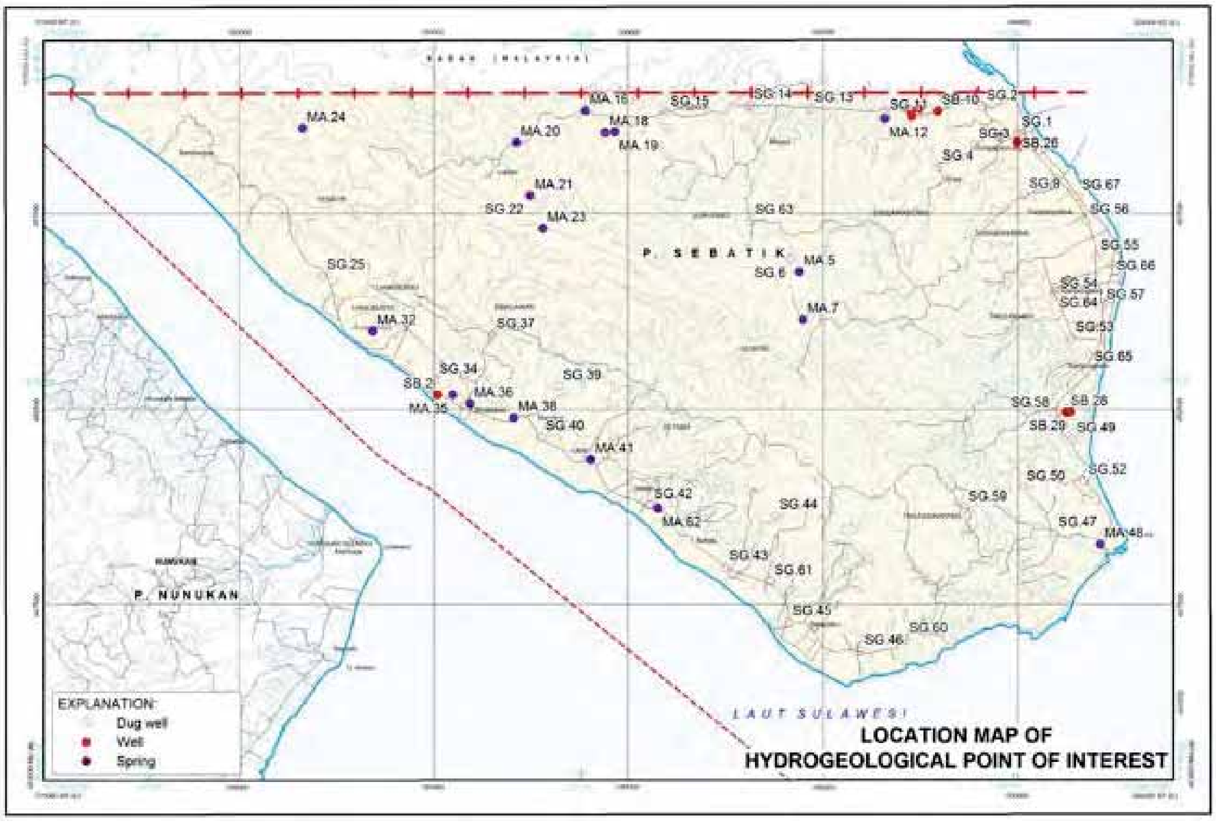

Fig. 7. Location map of hydrogeological point of interest (source: Geological Agency of Indonesia)

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

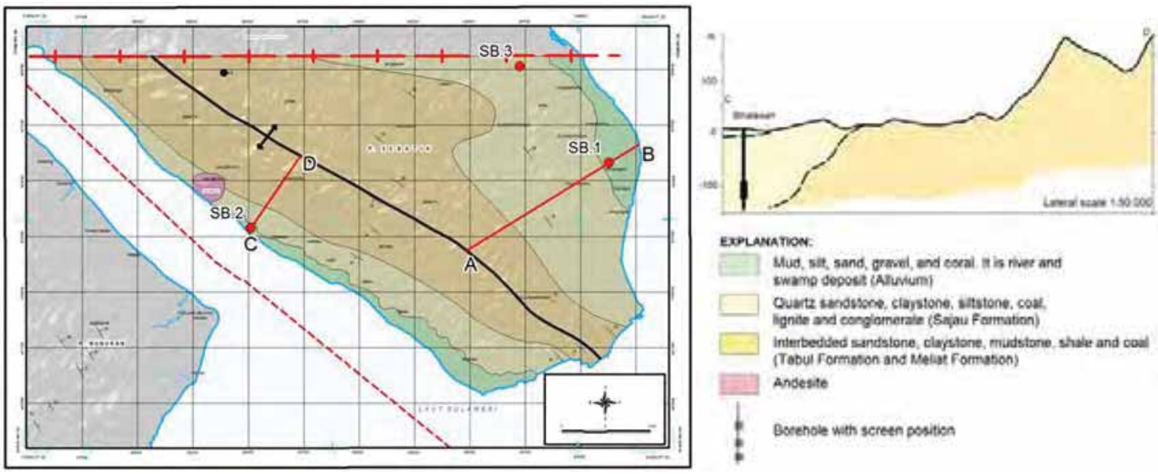

Fig. 8. Location deep well and cross section of the aquifer unit in Kg. Binalawan (Source: Geological Agency of Indonesia).

4. Groundwater Management

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

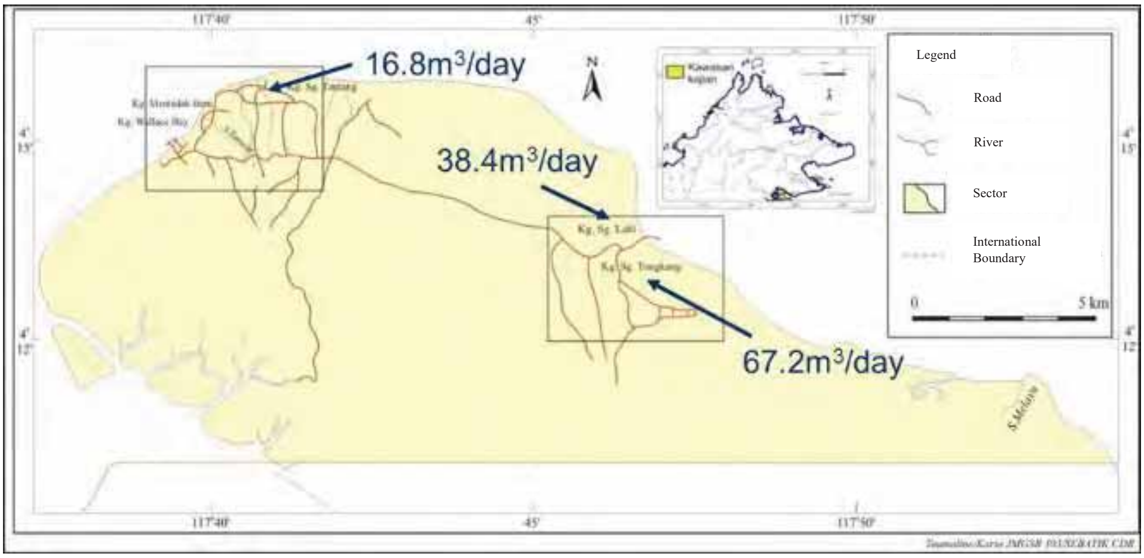

Fig. 9. Wells discharge in Kg. Sg. Tamang, Kg. Sg. Lahi and Kg. Sg. Tongkang.

Based on this study, the amount of groundwater on the respective area can be calculated and summarized as in Table 3. Kg. Sg. Lahi has the most amount with 1417 cubic meter and followed by Kg. Sg. Tongkang with 1114.5 cubic meter and Kg. Sg. Tamang with 255 cubic meter.

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

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

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

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

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

Acknowledgement

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

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Preliminary Study of Groundwater Occurrence in Nay Pyi Taw, Myanmar

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Abstract

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

Keywords: groundwater, sustainability, Nay Pyi Taw

1. Introduction

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

Fig. 1. Location Map

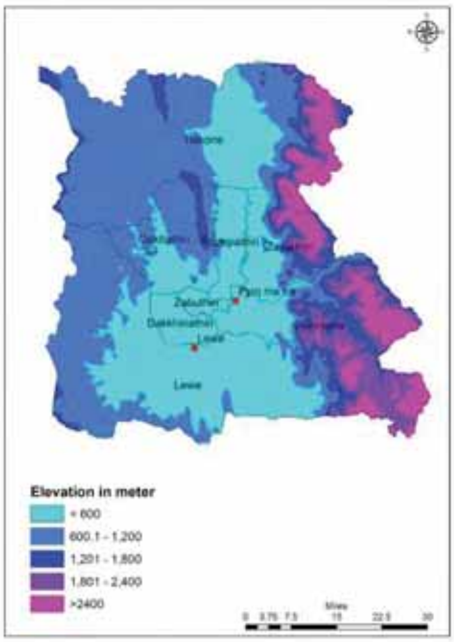

Fig. 2. Topographic Map

2. Geology and Hydrogeology in Nay Pyi TawArea

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

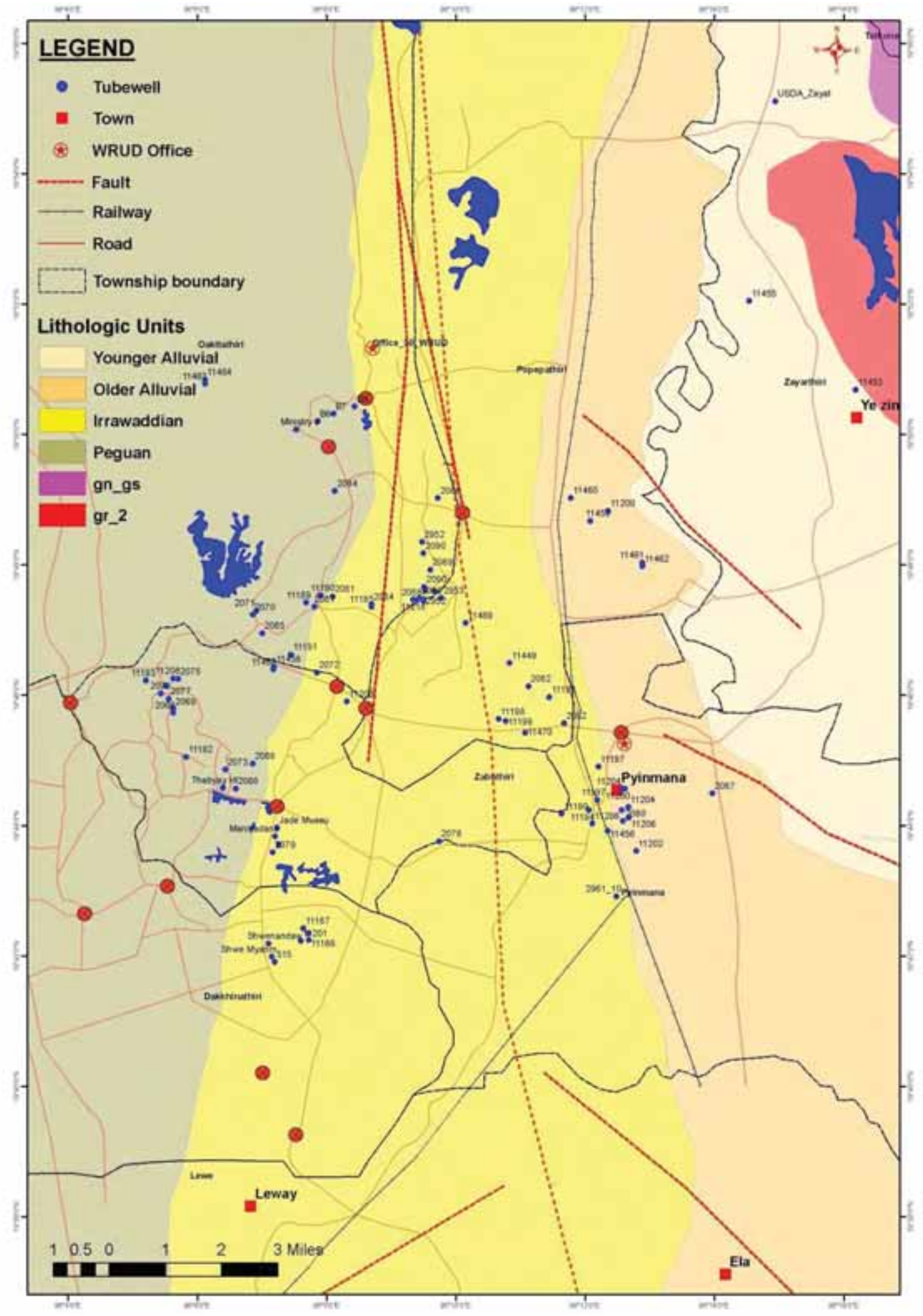

Fig. 3. Geological Map

2.1 Lateral and vertical variation of aquifer

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

Township	Depth to aquifer (ft), below ground level
Outtarathiri	200 - 560
Popathiri	275 – 600
Zeyarthiri	~ 300
Zabuthiri	250 - 550
Dakhinathiri	450 - 900
Pyinmana	300 - 650
Lewe	~ 400

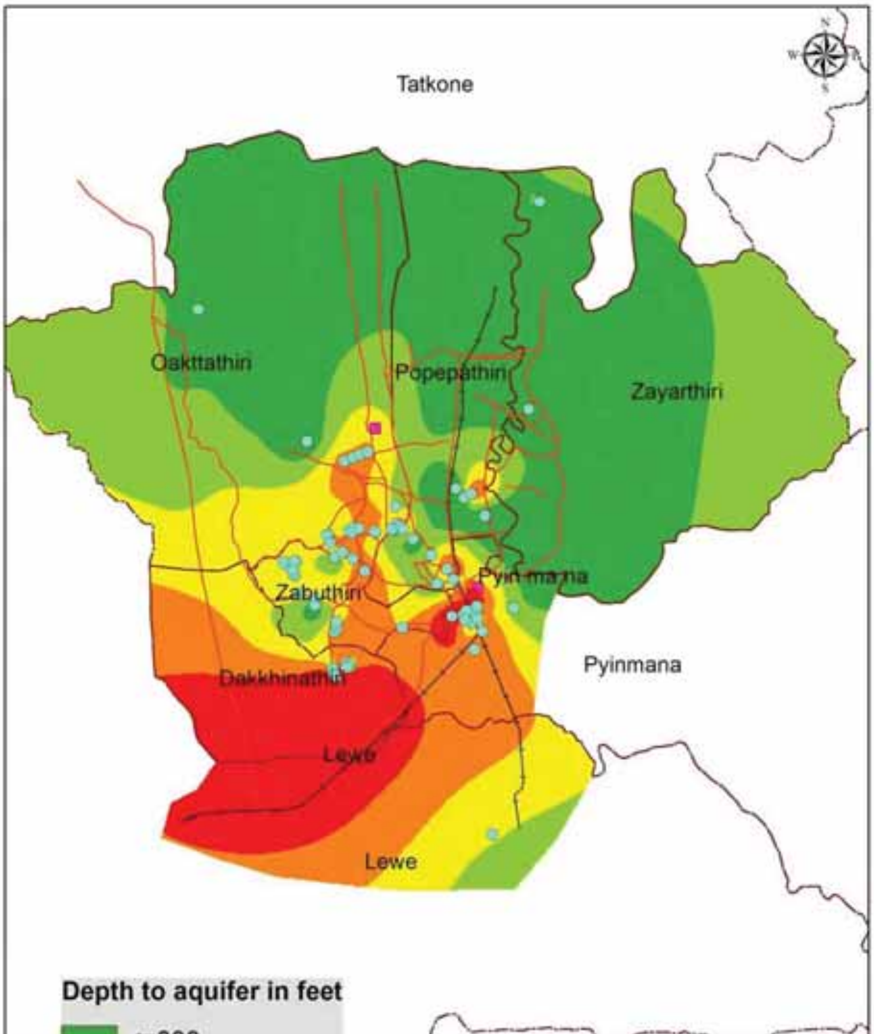

Fig. 4. Depth to Aquifer Map

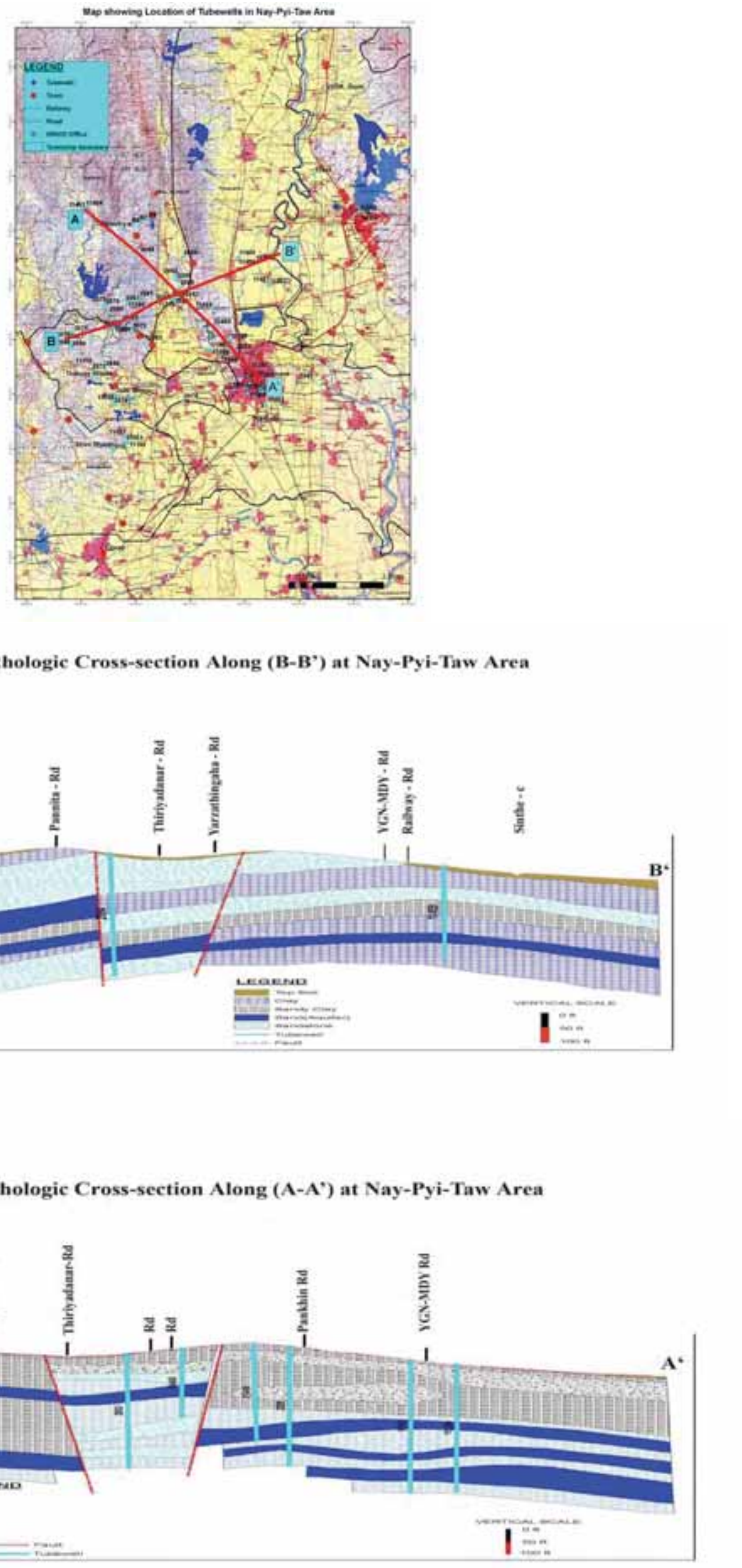

Fig. 5. Lithologic Cross-Sections

2.2 Depth to Groundwater Table

The minimum depth to water table (Fig. 6) is about 20 feet below natural ground level and the maximum depth to water table observed that about 150 feet below ground level.

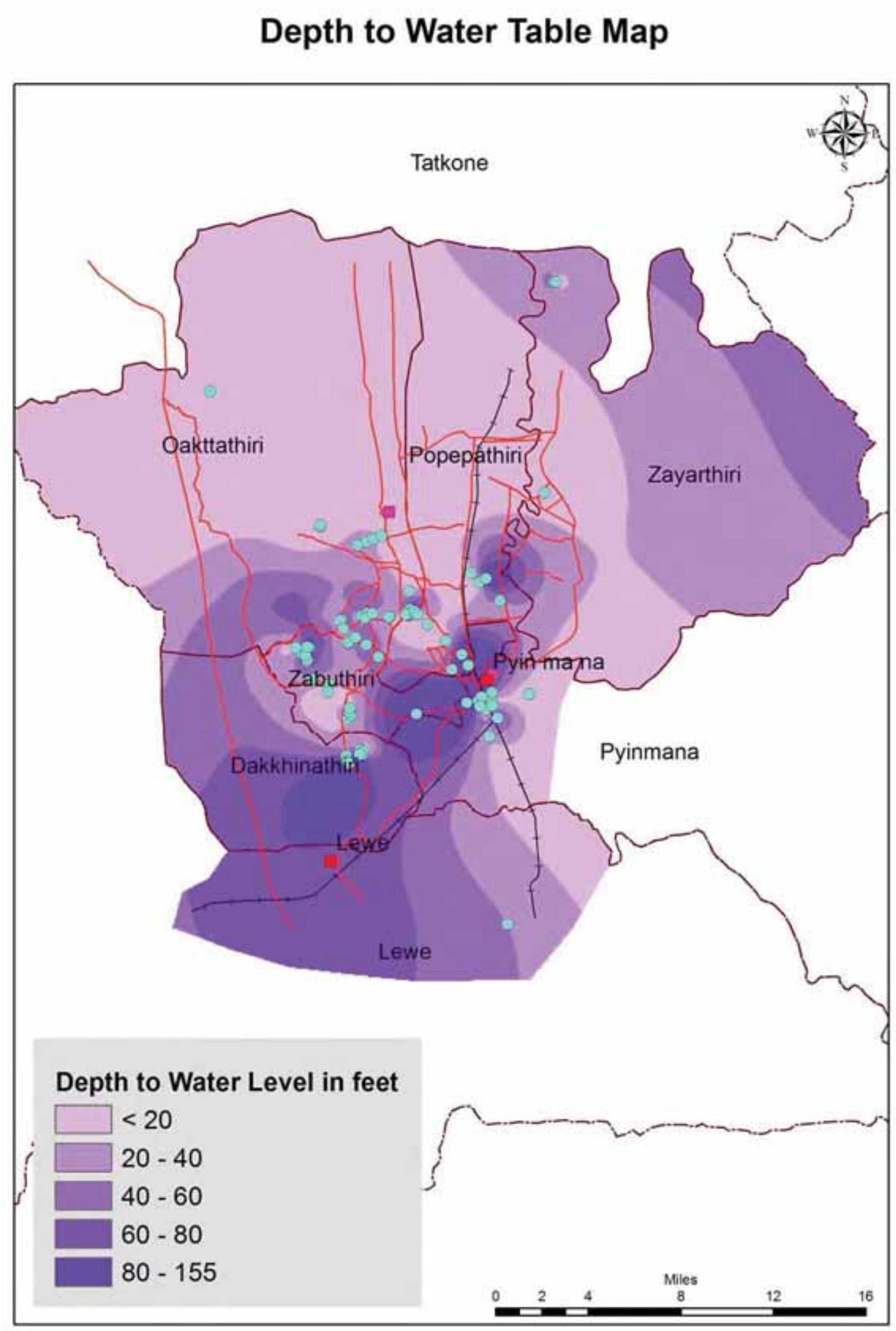

Fig. 6. Depth to water table

2.3 Tubewell Yield

The minimum tube well yield (Fig. 7) for 4 inch diameter is about 2000 gallon per hour (gph) and maximum found about that 5000 gph in study area.

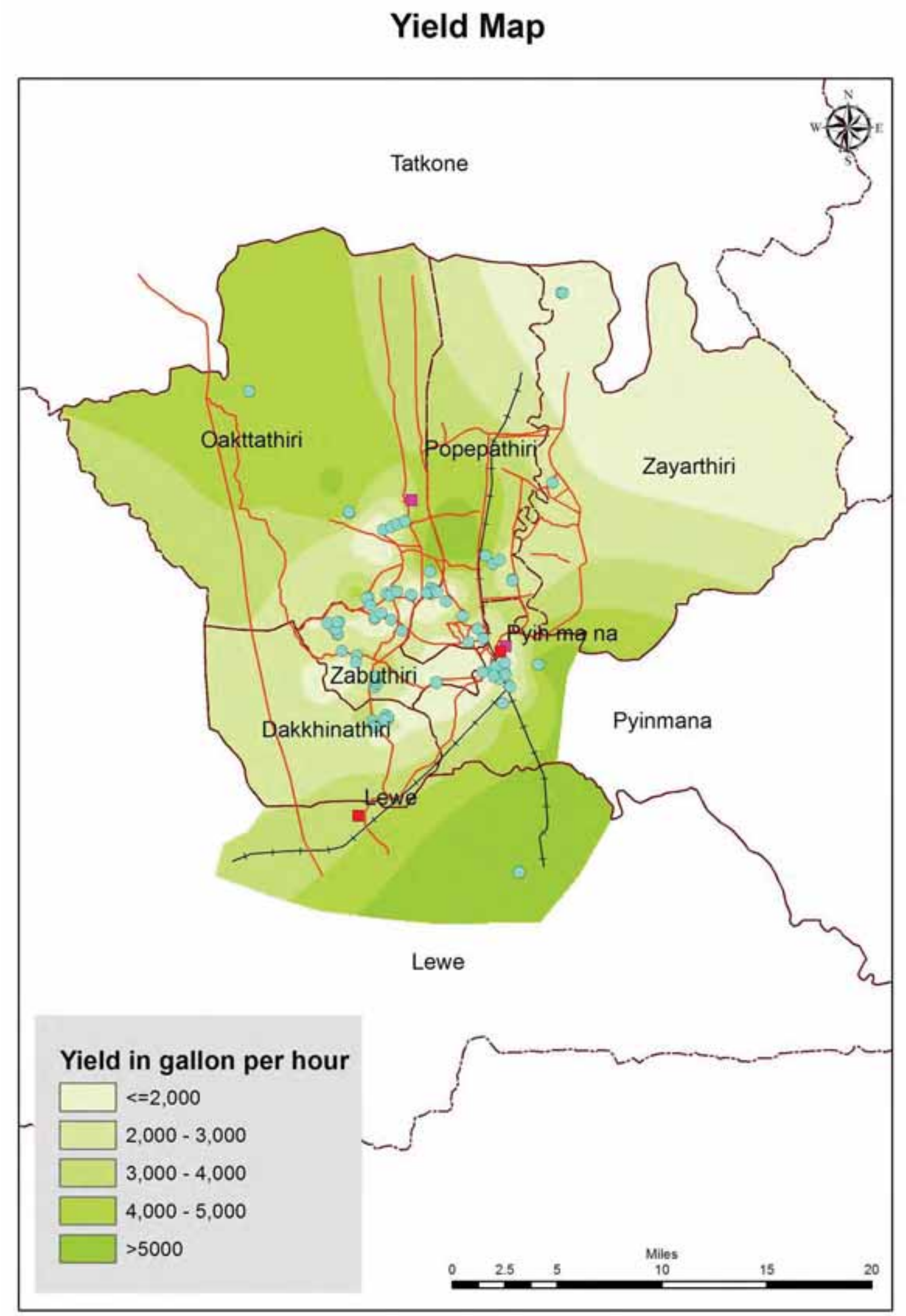

Fig. 7. Tubewell Yield

2.4 Groundwater Quality

Groundwater quality estimation was based on the water quality result of 22 selected samples (Fig. 8). The chemical quality testing was carried out by WRUD's laboratory. The Electrical Conductivity (EC), pH, and Total Dissolved Solid (TDS) were mentioned in this paper.

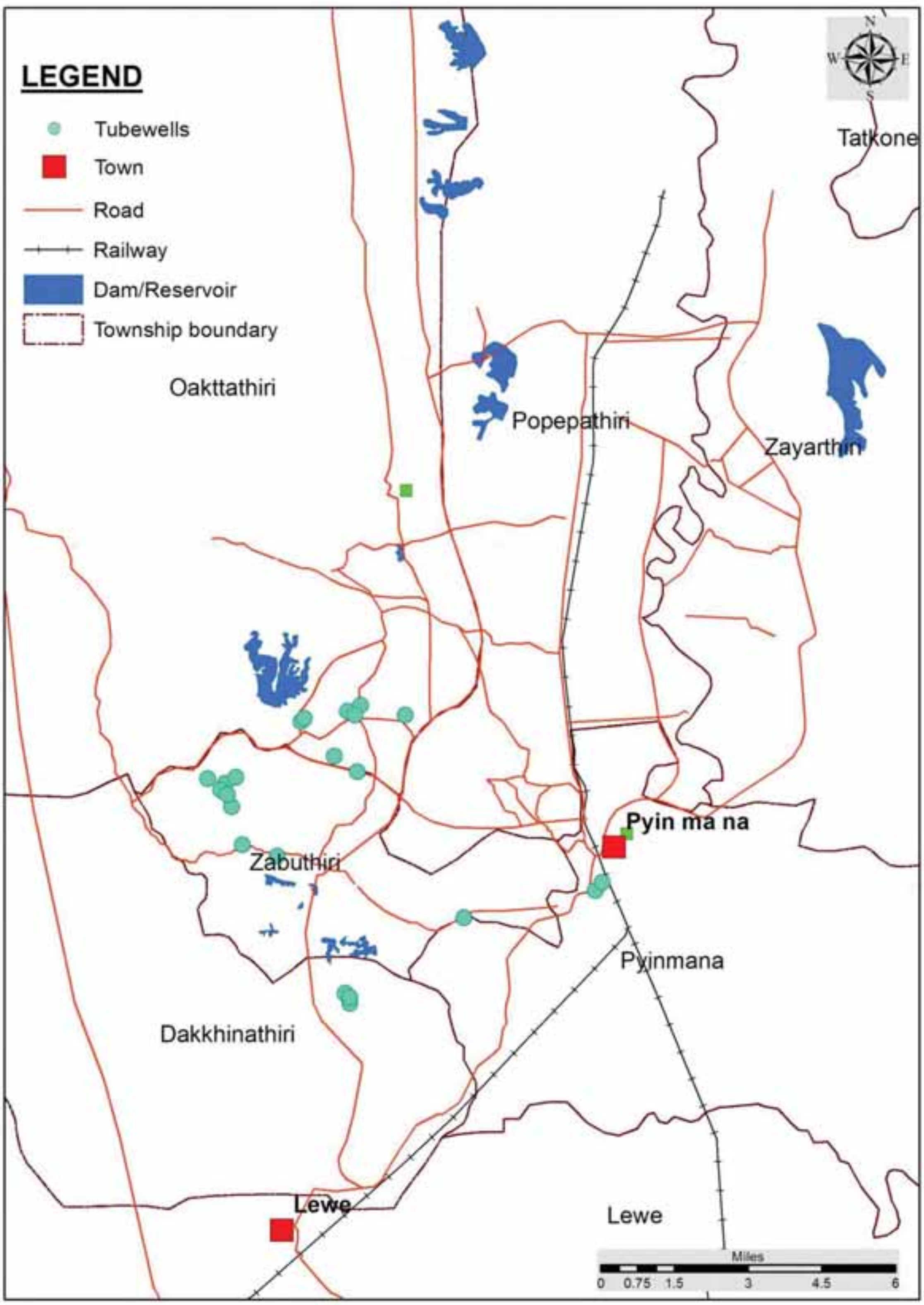

Fig. 8. Location of water samples

2.4.1 pH

According to the chemical analysis result of 22 samples, the minimum and maximum pH (Fig. 9) value of groundwater in Nay Pyi Taw is found that 6.6 to 8 respectively.

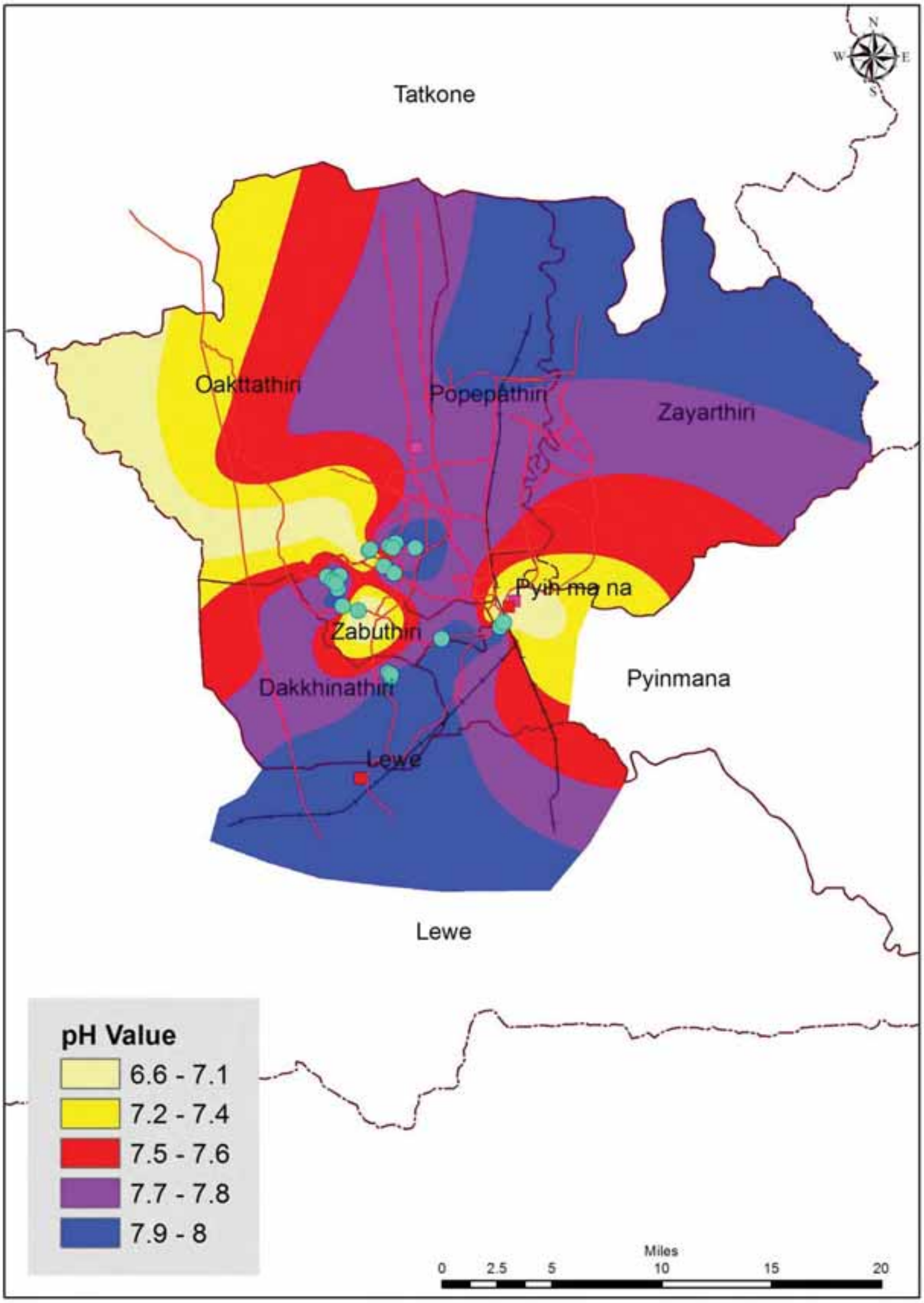

Fig. 9. pH

2.4.2 Electrical conductivity (EC)

The minimum EC value of the groundwater in Nay Pyi Taw area (Fig 10) is found that (208) µmho/cm and maximum value is (900) µmho/cm.

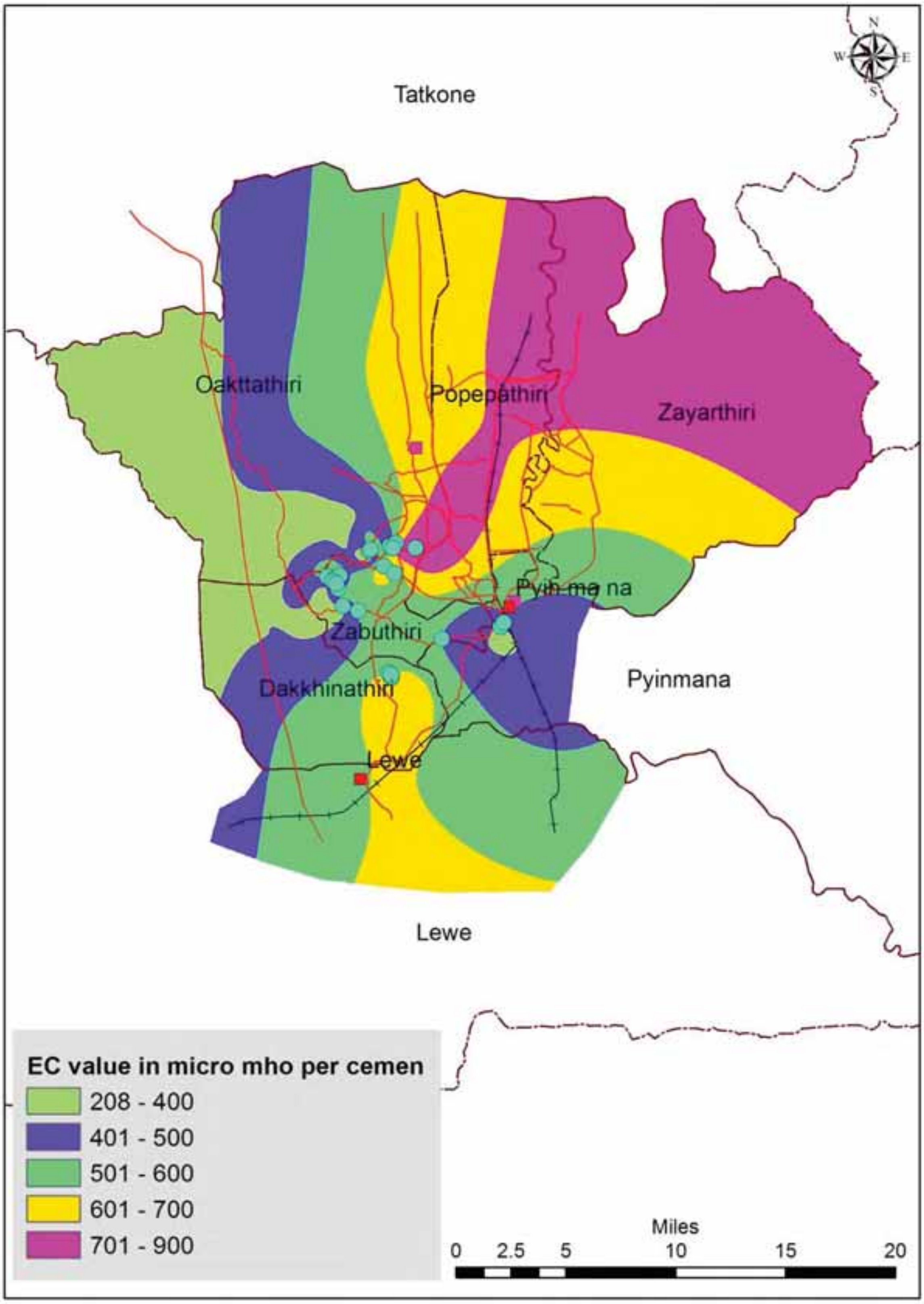

Fig. 10. Electrical Conductivity

2.4.3 Total Dissolved Solid (TDS)

The concentration of total dissolved solid (TDS) (Fig. 11) is ranging from 136 mg/l to 530 mg/l in groundwater of Nay Pyi Taw area.

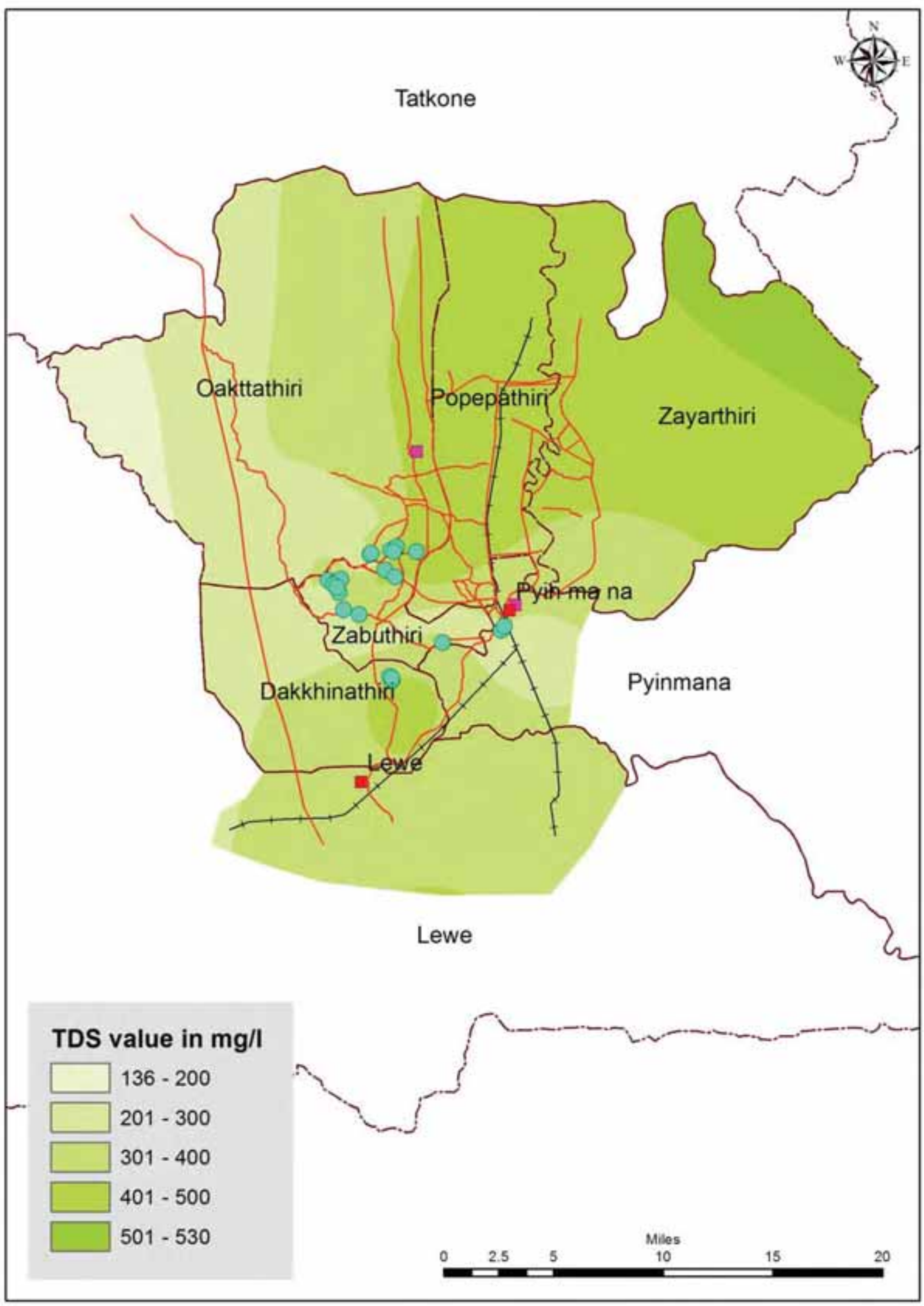

Fig. 11. Total Dissolved Solid

3. Hydrogeological issues

Geologically, the Union Territory area (Nay Pyi Taw area) is covered by Recent Alluvial Sediments of sand, silt, clay, loosely cemented sand rocks of Irrawaddy Formation and the sandstone and shale sedimentary layers of Upper Pegu Group. The groundwater yield of 4 inches diameter is ranging from 2000 gph to 5000 gph was found in the area. The static water level of aquifer in the area is ranging from 20 feet to 150 feet below ground level. The groundwater potential is limited, based on the recharge condition and comprehensive study on evaluation of aquifer parameters and estimation of groundwater potential is urgently needed for future groundwater development programs and sustainability of groundwater resources in Nay Pyi Taw area.

The main hydrogeological issue in the study area is the less experience in groundwater monitoring works and legal enforcement for the drilling and usage of groundwater. In Myanmar, there is no groundwater law established until now, but the government is trying to establish groundwater law in progress. And also groundwater quality and quantity are also important issues. Generally, the concentration of iron (Fe) and Calcium (Ca) in the groundwater in Nay Pyi Taw are higher than the maximum permissible limit of WHO drinking water quality guideline value. The lateral continuation of the aquifer found discontinuous because of the geological structure control and different depositional environment of the sedimentation basin. The geological structural control and lateral and vertical sedimentary facies changes resulted to high variation of drilling depth to meet the water bearing layers in place by place.

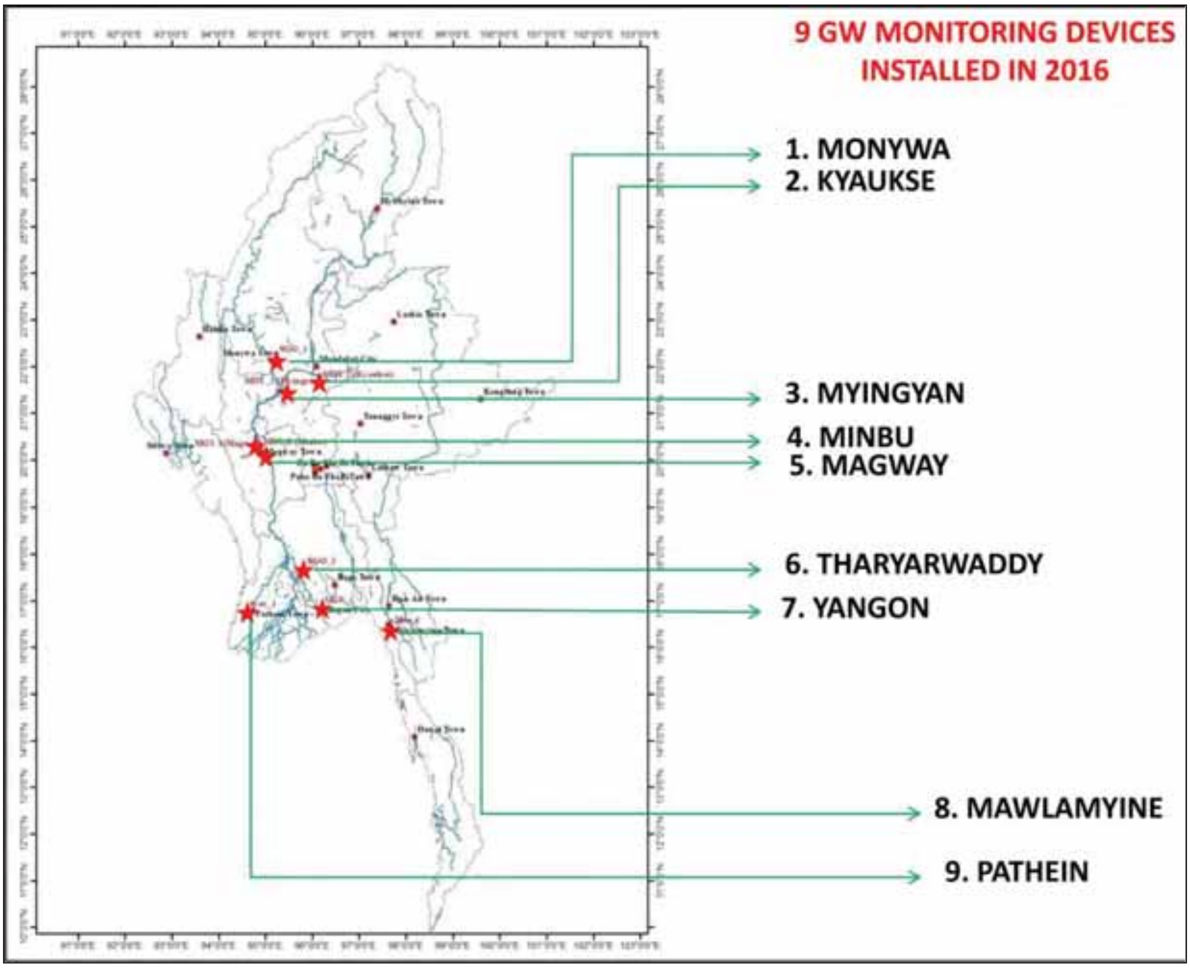

Fig. 12. Location of Groundwater Monitoring Stations in 2016

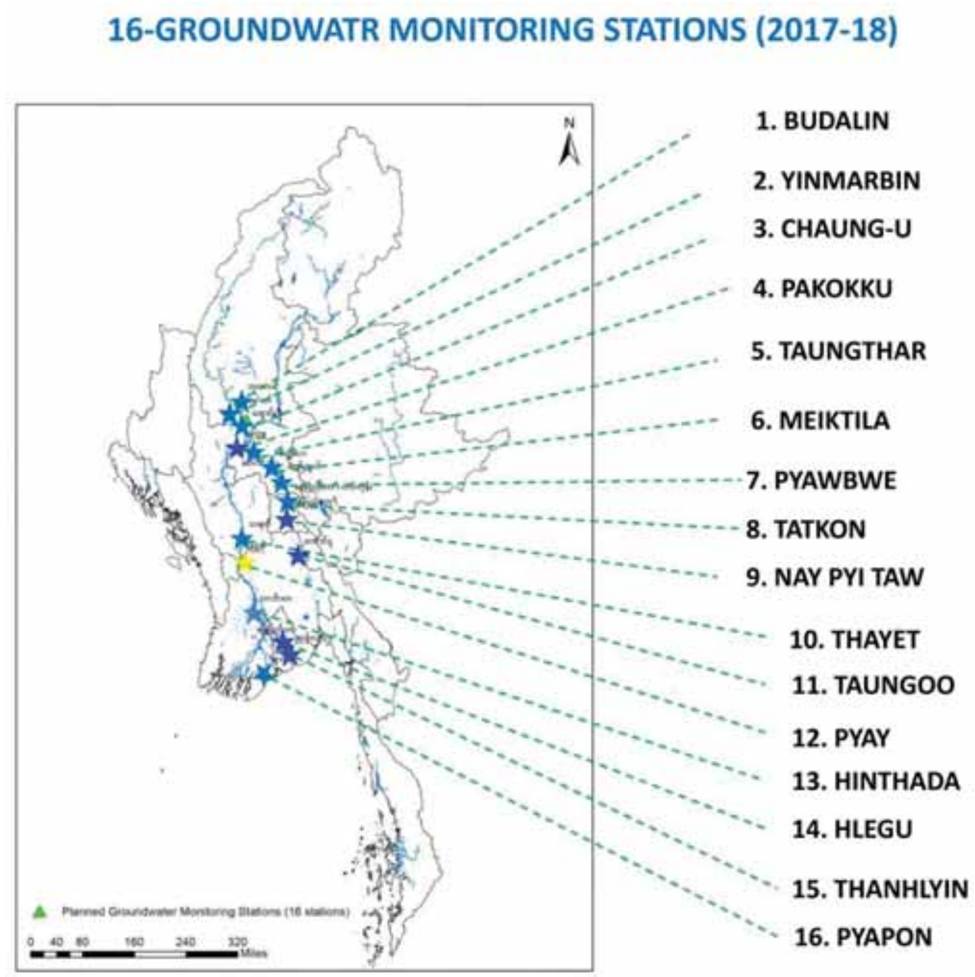

Fig. 13. Location of Groundwater Monitoring Stations in 2018

4. Plan of groundwater observation system and management reflection the hydrogeological issues

The total of 25 groundwater monitoring wells were drilled and installed the groundwater monitoring devices across the country (Fig. 12 and Fig. 13) by Irrigation and Water Utilization Management Department under the Ministry of Agriculture, Livestock and Irrigation (MOALI). The monitoring sensors were recorded groundwater level fluctuation, Electrical Conductivity (EC) and groundwater temperature. The purpose to know the aquifer parameter, the pumping test was performed 3 times within the study area. The extension of groundwater monitoring networks and detail hydrogeological mapping works are plan to development of the groundwater management in the study area.

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Public policy for Groundwater observation system in Port Moresby, Papua New Guinea

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Abstract

The geology of the Port Moresby area ranges from the Paleocene to Holocene age, the youngest deposits being that of the alluvial plains. Most outcrops within the area are of the Port Moresby Beds, with rare outcrops of the igneous formations of gabbro and tuff, while most of the low lying valley floors are covered in alluvium/ colluvium.

Two known aquifers exist within the area; the topmost part of the tuff is closely fractured and highly weathered, resulting in good permeability characteristics for groundwater, while the alluvial aquifer mainly to the north of Port Moresby consist of good sand and gravel layers which are favorable for groundwater storage.

Port Moresby lacks a groundwater observation system; however, groundwater data of historical boreholes along with recent boreholes have been collected to rebuild the groundwater database. This initiative of the database may aid in future plans for a proper groundwater observation system.

Keywords: groundwater, tuff, alluvial, Port Moresby.

1. Introduction

Port Moresby, the capital city of Papua New Guinea (PNG), is situated at 9^0S and 147^0E next to the equator. It lies within the Southern Region of PNG within the Central Province boundary.

The geology of the Port Moresby area comprises mostly of sedimentary formations and two units of igneous rocks, namely tuff and gabbro, with surficial geology of Quaternary alluvial deposits. The main rock units which are tapped into for groundwater are the tuff and gabbro units, and the alluvial deposits, of which, the alluvial aquifers are more productive.

Port Moresby has a considerable number of bores within the area, however there is no proper groundwater monitoring system in place.

2. Geology and Hydrogeology in Port Moresby, PNG

2.1 Geology in Port Moresby

The simplified geology of Port Moresby (Fig. 1) consists mainly of the sedimentary formations of the Port Moresby Beds, with tuff and gabbro outcropping in places. The Port Moresby Beds are the most evident rocks that outcrop within the area and comprise of three lithological units, the Paga Beds, the Nebire limestone and the Baruni limestone (Table 1).

The Paga Beds comprise mostly of calcareous and siliceous mudstone, chert and shale, with minor sandstone and limestone. This rock unit is closely fractured and jointed with calcite veins been common. The beds are well defined and occur in units of 0.1 – 0.3m thick.

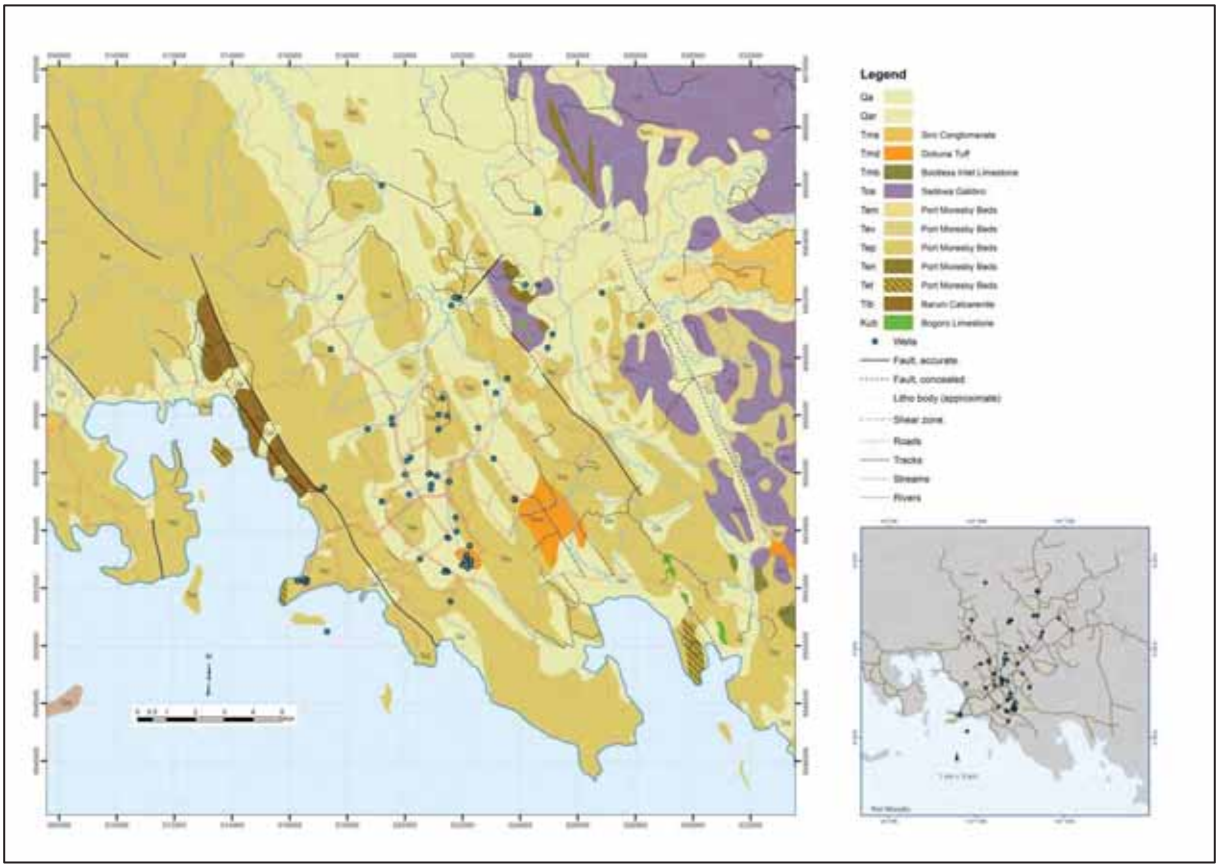

Fig. 1. Simplified geological map of the Port Moresby area

Table 1. Stratigraphic units of Port Moresby extracted and modified from Harris and Jacobson, 1972.

Stratigraphic Unit	Age	Engineering Geology Map Units
Alluvium and colluvium	Holocene	Mangrove swamp deposits Freshwater swamp deposits Coral reef deposits Beach sand Valley floor deposits Footslope deposits Hillslope deposits Terrace gravel
Dokuna Tuff	Early Miocene	Dokuna Tuff
Sadowa Gabbro	Oligocene	Sadowa Gabbro
Port Moresby Beds	Paleocene-middle Eocene	Paga Beds Nebire Limestone Baruni Limestone

The Nebire limestone is a grey to green, massive, strongly indurated, brittle and hard fine grained limestone which crops out in a series of northwest trending hills from Mt. Lawes through Mt. Eriama to Bootless Inlet. Less competent reddish brown and purple limestone occurs as bands and lenses in places. The competent Nebire limestone is quarried and crushed for concrete and sealing aggregate (Fig. 2).

Interbeds of limestone and siltstone occur in a northwest trending belt from Kila Kila in the south to Baruni in the north. This rock unit is massive to well-bedded which contains interbeds of conglomerate, chert, calcareous sandstone and siltstone. White fine-grained limestone is conformably overlain by pink coarse-grained limestone within the Baruni area which are characteristic of close fractures and joints.

The gabbro unit occurring within the area is locally known as the Sadowa Gabbro which intrudes the Port Moresby Beds. The gabbro is dark blue-grey in colour but occasional lighter leucocratic versions occur also. Outcrops may be seen near Mt. Lawes and Mt. Eriama (Fig. 3) north-east and east of Port Moresby respectively. In its fresh state, the gabbro is hard and strong but usually contains sheared and altered soft weak zones. Generally, outcrops of gabbro are highly weathered and disintegrate to sandy, silty gravel.

At the contact between the Sadowa Gabbro and Nebire Limestone, a narrow zone of calc-silicate hornfels occurs. This unit is fine grained, light grey to white, with white, brown or grey spots, which contains interbeds of very fine-grained, grey meta-limestone. The outcrops of this rock unit are typically massive, fresh, hard and competent. This competent rock is quarried and crushed for concrete and sealing aggregate at the Nebire Quarry (Fig. 2).

Fig. 2. The Nebire Quarry limestone and calc-silicate hornfelsed siltstone

There are two main valleys that exist in the area which are the Boroko-Taurama Valley and the Moitaka Morata Valley (Fig. 3). The valleys are underlain by the Dokuna Tuff and to some extent, the Sadowa Gabbro. These igneous units rarely outcrop as they are overlain by surficial deposits of unconsolidated alluvium and colluvium (Egara, 1988). To the north of Port Moresby, floodplain deposits occur adjacent the Laloki River consisting mostly of finer fluviatile sediments with some well-rounded gravel and cobbles.

The Dokuna Tuff varies in degree of weathering, hardness and strength, and the lithological characteristics. An outcrop at a quarry site south of Jacksons Airport showed that the tuff is closely jointed and poorly bedded with intersecting thin veins of calcite and zeolite. The tuff grades up into an overlying more weathered tuff, which is then overlain by completely weathered tuff which consists of brown sandy clay with weathered rock fragments.

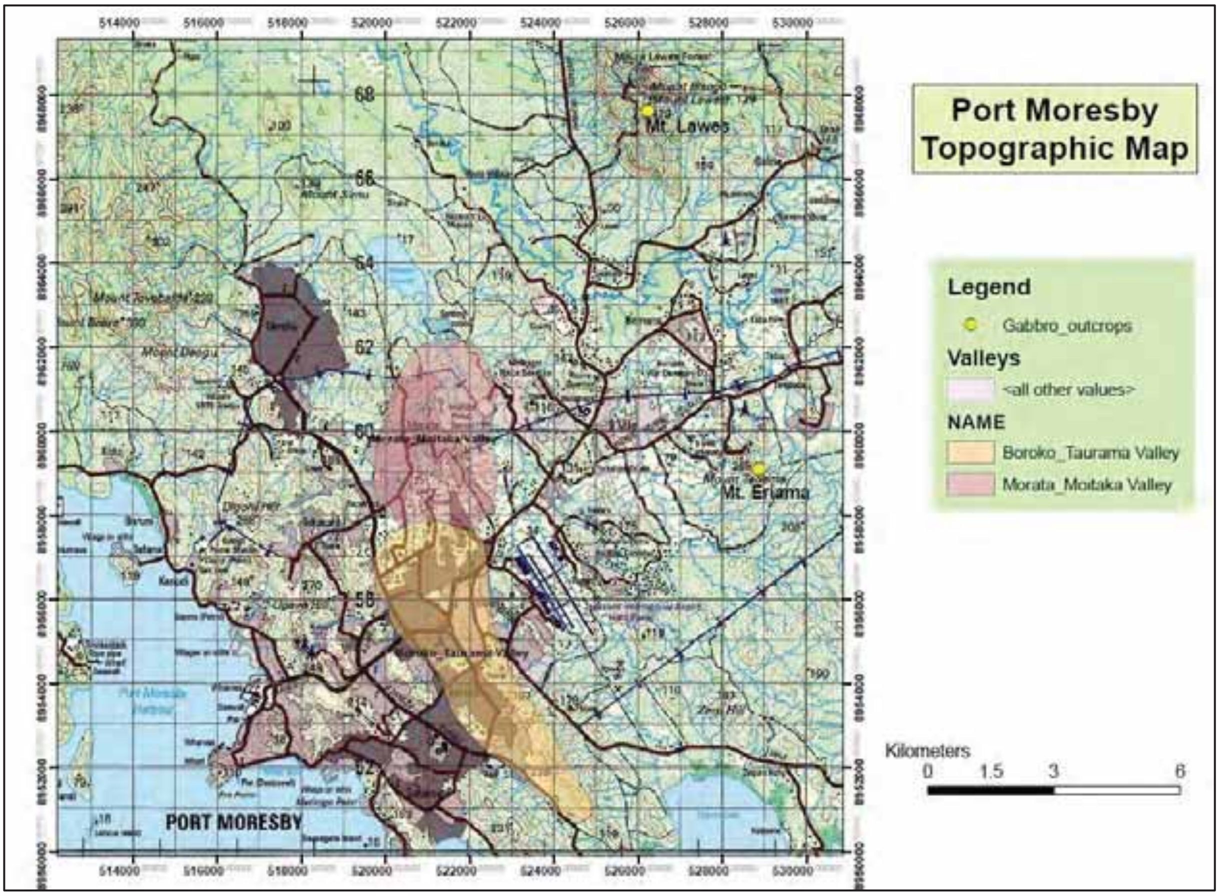

Fig. 3. Topographic map of Port Moresby outlining the main valleys within Port Moresby and locations of gabbro outcrops.

2.2 Hydrogeology in Port Moresby

From the rock units within Port Moresby, the Dokuna tuff and the alluvial deposits provide good aquifers. The Sadowa gabbro shows potential for groundwater (Fig. 4), however more tests need to be done on boreholes tapping into this formation as historical data indicates that boreholes within this unit dried up.

The Dokuna tuff is a known aquifer within the Boroko-Taurama Valley. The tuff is usually friable with a weathered brown or green colour. Its permeability depends largely on the intensity of fractures rather than primary depositional characteristics. The groundwater level within the tuff often rises above the initial standing water level (SWL) which indicates a semi-confined to confied aquifer due to the overlying alluvium/ colluvium mixtures of clay (Egara, 1988). In the past, few boreholes have tapped into the overlying alluvium; however the bores dried up rapidly.

The Laloki floodplain to the north-east of Port Moresby provides a good alluvial aquifer. The typical layers encountered in bores tapping into this unit consist mainly of silt, clay and sandy clay overlying river sand and gravel (Pounder, 1973). These unconsolidated layers of alluvium give a very high potential for recharge of groundwater. The most successful groundwater boreholes and wells in Port Moresby have been constructed in the Laloki floodplain or alluvial valley floors.

Fig. 4. Sadowa gabbro occurring beneath alluvial sandy clay layer in a dried up stream channel east of Port Moresby, Buswara 9mile

3. Hydrological Problem in Port Moresby

Within the two known aquifers within Port Moresby, historical data indicated hard water within the Laloki Valley and high content of salts in a localized portion of the Dokuna Tuff. Groundwater quality of former bores tapping into the Dokuna Tuff aquifer within the Boroko-Taurama Valley showed that water was potable and also suitable for gardening and irrigation purposes; however, one bore within this unit near the Boroko Hotel was reported to have high salt content (Thompson, 1955). This high concentration of salt may be localized around the Boroko Hotel area, but it is also possible that salinity of groundwater varies with depth.

According to work done by Pounder (1973), 11 bores were sampled within the Laloki and Sogeri Plateau area, 2 of which showed water hardness of less than 121 parts per million (ppm), three samples showed hardness within the range of 121 – 180ppm, while the remaining 6 samples showed hardness greater than 180ppm. According to the US Geological Survey scale of hardness, the groundwater within the Laloki alluvial aquifer is hard to very hard. If this water is to be used for domestic purposes, softening would be necessary; apart from this, groundwater within the Laloki area may be made potable subject to bacteriological examination.

4. Plan of Groundwater Observation System in Port Moresby, PNG

Proper groundwater observation for the Port Moresby area is lacking. Currently, no groundwater observation system is in place; however, groundwater data both from previous and recent boreholes and wells have been collected. Data collection is ongoing at present in an attempt to rebuild the groundwater database. The reconstruction of the groundwater database may be used as a platform to propose a groundwater observation system in the future.

5. Conclusions

Good groundwater potential is found within the Dokuna Tuff and the Laloki alluvial deposits. These aquifers can be further investigated to fully understand the groundwater behavior. Currently, no proper observation system is in place to monitor aquifer performance and groundwater quality data, however, the reconstruction of the groundwater database may be a first step to proposing a groundwater observation system in the future which will contribute to the overall groundwater monitoring for Papua New Guinea.

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Hydrogeology of Pampanga, Philippines: an Explanation Document

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Abstract

This paper presents an overview of the geology, hydrogeology, and hydrochemistry of the Pampanga, Luzon Island, Philippines. Pampanga has a land area of 2,261 km^2 and bounded by five provinces, namely Nueva Ecija, Tarlac, Zambales, Bataan, and Bulacan. The rock units in the study area are the Bamban Formation and the Guadalupe Formation of Pleistocene age. These formations are composed of tuffaceous sandstone, lapilli tuff, conglomerate, sandstone, mudstone and pyroclastic breccias which are distributed at the eastern (Guadalupe) and western (Bamban) portions of Pampanga. These Pleistocene rock units are overlain by quaternary pyroclastics and tuffaceous sedimentary rocks from the eruption of Mt. Pinatubo. Majority of the areas of Pampanga are within the Central Luzon Basin with potential deep groundwater extraction considering the thick Quaternary alluvium and pyroclastics. The unconsolidated alluvium, especially the sand and gravel layers, is considered as a good aquifer and widely utilized for domestic an industrial water supply. About 78% of Pampanga is expected to have a high productivity of groundwater; 322 km^2 of the recent alluvium is classified as an extensive and highly productive aquifer. About 13% of the study area belongs to the quaternary pyroclastics with local groundwater productivity. 5% (Pleistocene formations) of Pampanga is considered as a less extensive aquifer and 3% (Quaternary plug of Mt. Arayat) is categorized as rocks without any known significant groundwater productivity. Furthermore, 100 groundwater samples were collected and analyzed to evaluate the hydrochemical characteristics based on the Piper and Durov plots. Using the Piper plots, the dominant Na-HCO3 (24%) water type is observed in the low lying areas while Ca Mg-HCO3 water-type were identified at the elevated recharge areas. The presence of these two facies suggests the possible ion exchange processes in the aquifer. The Durov diagram revealed that majority of the samples represent a Na dominant environment and downgradient waters through dissolution.

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

1. Introduction

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

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

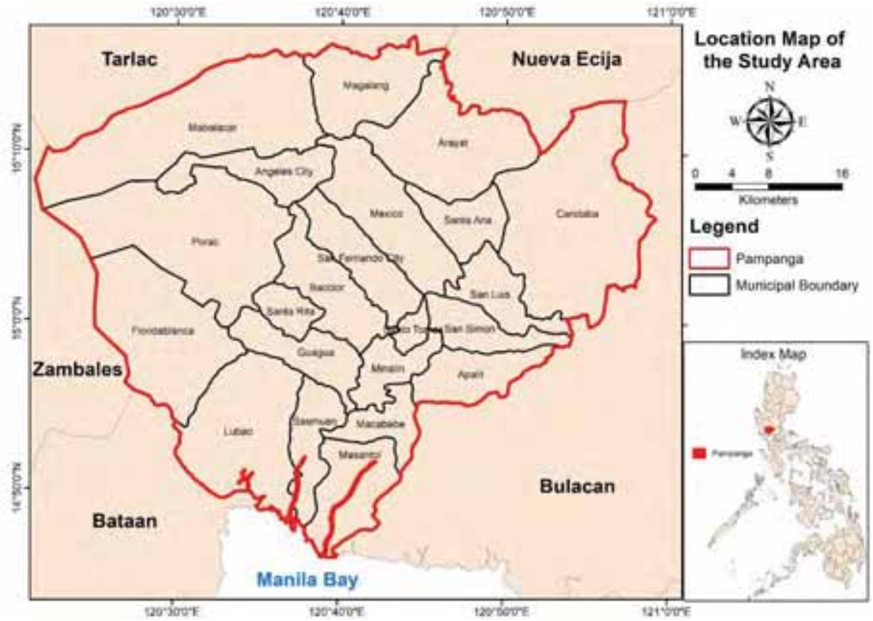

Fig. 1. Location Map of the study area

Pampanga River and Pasac River are the main watersheds in the study area (Fig. 2). Pampanga River Watershed has an area of about 7,697 sq km which considered as the fourth largest River Basin in the Philippines. Water drains from the mountain range of Nueva Ecija to the tributaries traversing the southern Nueva Ecija, northwestern Bulacan, eastern Pampanga and exits to the Manila Bay. On the other hand, the smaller 1126 sq km Pasac River Basin drains its water are from the eastern side Mt. Pinatubo and southwestern side of Mt. Arayat. Some of the tributaries (e.g., Pasig-Potrero) within the Pasac River Watershed have been modified by the deposition of recent sediments caused by the 1991 Pinatubo eruption. Pampanga is located in an area categorized as Type I based on the Corona Classification of the Philippine Climate. The study area has two pronounced seasons (PAGASA, 2015). The period from November to April is considered as dry season while the remaining months are characterized by wet season.

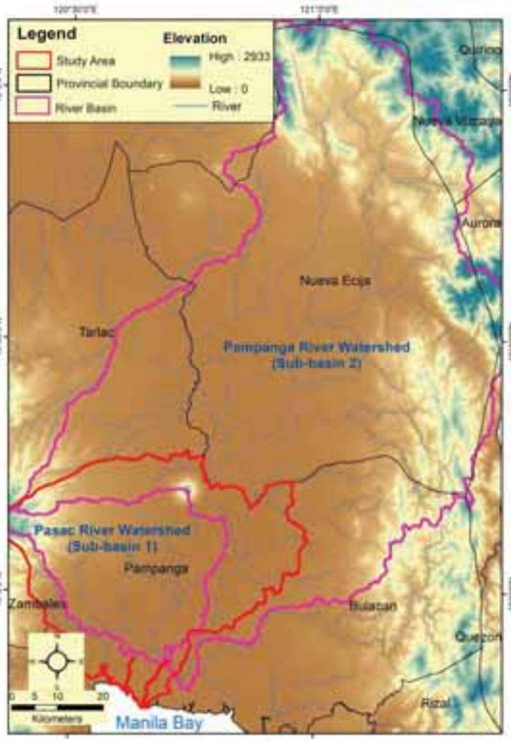

Fig. 2. Elevation map showing the two main watersheds that drains south to the Manila Bay. The index map shows the extent of the sub-basin 2.

2. Geology and Hydrogeology of Pampanga

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

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

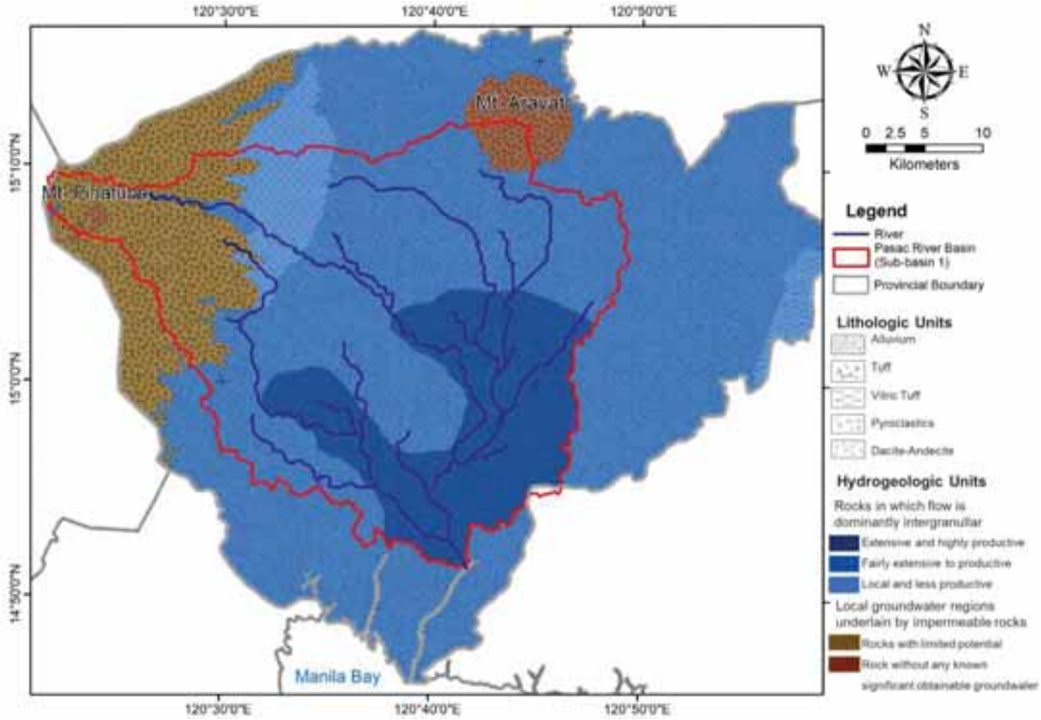

Fig. 3. Generalized hydrogeologic map of Pampanga

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

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

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

3. Hydrogeological database of Pampanga

3.1 Groundwater Data

All available groundwater-related information of the individual inventoried well/spring in Pampanga were organized and systematically encoded in a Mines and Geosciences Bureau (MGB)-established database. The locations of the wells in terms of the coordinates (latitude and longitude) were taken using a Global Positioning System (GPS). Important information for each well/spring includes elevation, groundwater level (i.e., SWL, PWL), discharge (volume of water extractable/or flowing out per unit of time), water usage, owner, year constructed, etc. In-situ water quality tests are also being conducted parallel to the well inventory activity. The physical parameters that were measured on site include temperature, pH, Total Dissolved Solid (TDS), ORP, conductivity, turbidity, dissolved oxygen, and salinity. In situ sampling provides readily available values to initially assess the water quality in an area. Aside from the result of in-situ tests, the results of the laboratory analysis of collected groundwater samples were included in the water quality database. These water quality data were used to assess the potability of groundwater by comparing them with the Philippine Standard for Drinking Water. However, for simplicity, this section only presented the groundwater data in CCOP format and generally discussed the hydrochemistry of Pampanga. It must be noted that some of the water parameters were not being analyzed by the MGB (e.g., Br, NO3, NH4, F, Li, NO2, PO4, δD, δ18O).

Table 1. Groundwater data of Pampanga in CCOP format

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

3.2 Hydrochemistry of Pampanga

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

The effect of chemical processes, lithology and groundwater flow can be reflected by the hydrochemical facies. Piper and Durov diagrams were used to determine the hydrochemical facies of groundwater in Pampanga Province (Fig. 4). Piper diagram is a multipart plot where the milliequivalents percentage concentrations of major cations (Ca2+, Mg2+, Na+ and K+) and anions (HCO3-, SO4 2-, and Cl-) are plotted in two triangular fields; these plots are being projected further into the central diamond field (Piper, 1944). On the other hand, Durov diagram is a merged plot consisting of 2 ternary diagrams where the milliequivalents percentages of the cations are plotted against the anions. The combination of these two plots forms a binary plot of total cation vs. total anion concentrations in a rectangular area (Durov, 1948). The Piper diagram categorized the water type or the hydrochemical facies based on the plots on the subdivided diamond field. On the other hand, the Durov diagram defines the hydrochemical processes along the water type of the samples. This was done by projecting and plotting the intersection of lines from the points in 2 ternary diagrams. 100 groundwater samples were collected within the Province of Pampanga and subjected to chemical analysis by the MGB.

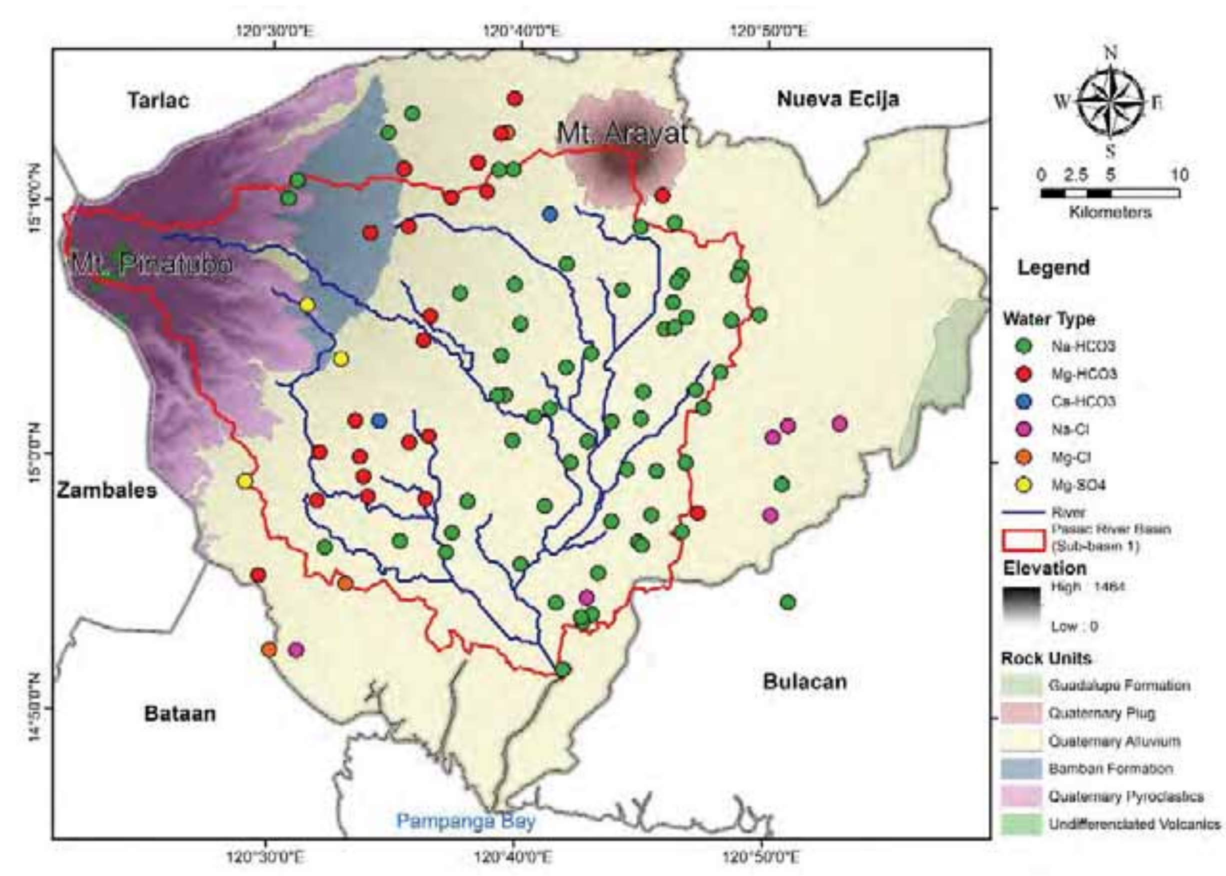

Fig. 4. Distribution map of the hydrochemical facies in Pampanga

After analyzing the groundwater samples and plotting the result on Piper's diagram (Piper, 1944), it can be observed that most of the major cations are represented by Na+ and Mg2+, and the anions are dominated by HCO3- and Cl-. The majority of the plots at the bottom portion of the diamond indicates the dominance of alkali over the alkaline earth and weak acidic anions over strong acidic anions. Specifically, 64% of the samples belong to the Na-HCO3 water-type, 24% to the Ca Mg-HCO3, 6% to the Na-Cl, 3% to the Mg-SO4 and 3% to the Mg-Cl (Fig. 5).

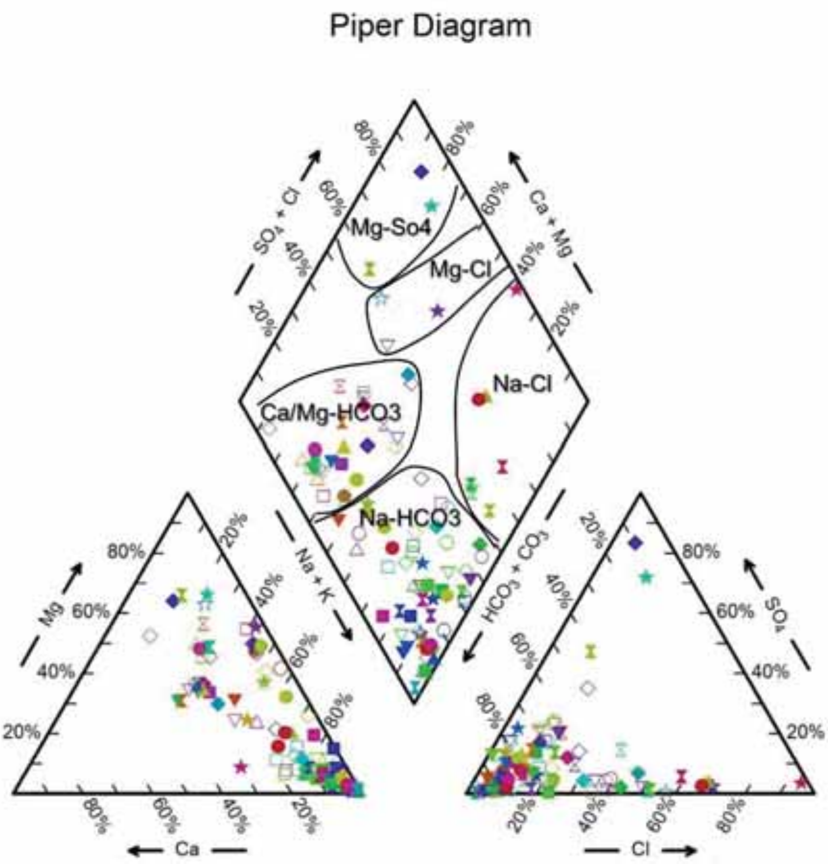

Fig. 5. Piper Diagram showing the hydrochemical facies of groundwater samples in Pampanga

The Calcium-Magnesium Bicarbonate (Ca, Mg-HCO3) water type dominated the western side of the Pasac River Basin (Fig. 4). The Ca, Mg-HCO3 water along the foot of the Mt. Pinatubo can be attributed to the young/fresh recharge groundwater. The lithologic characteristic of Bamban Formation is one of the major factors that contribute to the high Mg concentrations in the area. Bamban Formation consists of tuffaceous sandstone and lapilli tuff with the basal conglomerate. The sandstone is composed of ferromagnesian minerals and the tuff is described to have mafic minerals and fragments of scoriaceous materials (MGB, 2010). As the groundwater moves to the lower elevation, the water type becomes Na-HCO3. The formation of the dominant Sodium Bicarbonate water type in the low-lying areas can be acquired by cation exchange when the water passes to the quaternary alluvium with clay layers. Furthermore, the Na-HCO3 may be formed when the recharged groundwater from the elevated areas occupies the NaCl - rich low-lying areas that were previously submerged in seawater. During Pleistocene time, a general uplift of land and regression of the sea may cause the deposition of sediments with high NaCl content (e.g., Sandoval & Marmaril, 1970). The Ca and Mg in Calcium-Magnesium Bicarbonate water type exchanges with the Na when the groundwater passes the rock units with brine remnants.

The sodium-chloride water type in the study area can be attributed to saltwater intrusion in the coastal zones or can be due to the brine fossil water in the inner municipalities (i.e, Candaba, San Luis). Furthermore, the Mg-Cl type of water in the southwestern side (Lubao) of the study area can also be due to the dominant ferromagnesian minerals near the Mt. Pinatubo. Lastly, the abnormal Mg-SO4 water type in the elevated areas of Mt. Pinatubo can be attributed to the lahar and/or the oxidation of reduced sulfur in the shallow aquifer with lower pH (e.g., Kirk Nordstrom et al., 2009). The groundwater samples were also plotted on the Durov diagram (e.g., Durov, 1948; Lloyd & Heathcote, 1985) to determine the dominant hydrochemical processes. Based on the Durov diagram (Fig. 6), the majority of the samples plot in the field 9 indicating a Na dominant environment and downgradient waters through dissolution. The plots of samples within field 5 and 6 is attributed to simple dissolution and mixing. The groundwater samples in field 7 and 8 can be related to reverse ion exchange of Na-Cl waters. Furthermore, rapid groundwater flow can be interpreted based on the consistent HCO3 dominant water type from the recharge zones to low-lying discharge areas.

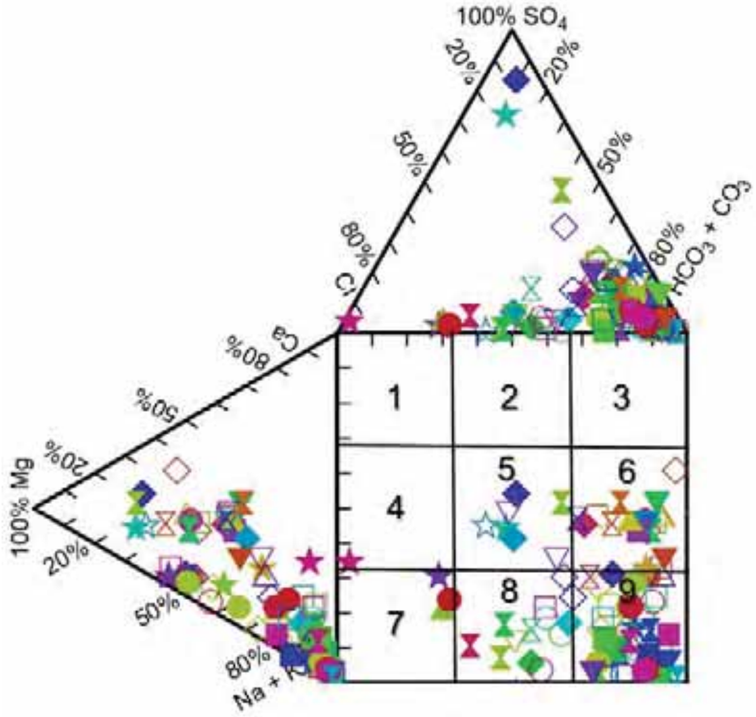

Fig. 6. Durov plot showing the sub-classifications of groundwater samples based on hydrochemical processes (e.g., Lloyd & Heathcote, 1985). Majority of the samples plotted inside field 9.

4. Groundwater Management in Pampanga

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

5. Summary

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

1) Pampanga is chiefly underlain by Quaternary alluvium and young Pleistocene sedimentary rocks which have good groundwater storage capability.
2) The hydrogeology of Pampanga is mainly defined by rocks in which groundwater flow is dominantly intergranular. 78% is expected to have the high productivity of groundwater.
3) The Na-HCO3 and Ca Mg-HCO3 water types dominate the low-lying and elevated areas, respectively. Majority of the samples represent downgradient waters through dissolution.

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The 1: 50,000 Hydrogeological Map of Khon Kaen, Thailand

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Abstract

Department of Groundwater Resources (DGR), Ministry of Natural Resources and Environment has a plan to produce groundwater map of Thailand at a scale of 1: 50,000. We have carried out "The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1: 50,000" since 2012. The 1: 50,000 hydrogeological and groundwater maps have been created by improving groundwater map, hydrogeological map and HYdro-Geological Information System (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. Also, It 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, and the Lower Khorat Plateau for 87 map sheets between 2015 and 2017. The total of 380 map sheets or 48 percent of the target was completed in 2017.

The future plan is to complete 1:50,000 hydrogeological and groundwater maps for the remaining 420 map sheets or 52 percent of the target so that the maps cover all the country's areas. The project will be implemented in Northern Thailand, the Lower Chao Phraya groundwater basin or the Central of Thailand, Eastern Thailand, Western Thailand and Southern Thailand.

Keywords: groundwater, hydrogeological map, Thailand

1. Introduction

DGR is a Thai government agency which is responsible for optimal groundwater management and development. To manage groundwater, we search for potential groundwater source areas. Also, we need to build confidence in using groundwater map as a tool to support information for decision - making on optimal groundwater planning and development. Therefore, DGR has carried out "The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1: 50,000" since 2012. In addition, we have implemented a subsequent project which is "The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1: 50,000 Area 2: The mid - northeastern Thailand" in Khon Kaen province since 2015. The main objectives are to prepare and comply maps scaled of 1: 50,000 which will be utilized as a source of information for groundwater assessment and management, and to improve the groundwater database systems by designing New-HYGIS in Khon Kaen.

2. Geology and Hydrogeology in Khon Kaen

Khon Kaen is a part of northeastern provinces of Thailand. It is located at 16.4419° N latitude and 102.8360° E longitude. Khon Kaen comprises an area of 10,886 Sq.km and consists 26 districts, 199 sub-districts and 2331 villages. The population has 1.80 million. Neighboring provinces are Nong Bua Lamphu, Udon Thani, Kalasin, Maha Sarakham, Buriram, Nakhon Ratchasima, Chaiyaphum, Phetchabun, and Loei. Khon Kaen Province: West area is high mountain close to Phu Kradung and Pherchabun range. East and Southeast is hilly undulate, high and low tilts downward to east and south. The height is about 100-200 MSL.

Khon Kaen is mostly covered with various types of sedimentary rocks from Khorat Group and some alluvial deposits (sand, silt and clay). Rock sequences of the Khorat Group comprises 7 formations from older to younger rocks as follow:

1) Huai Hin Lat Formation
2) Nam Phong Formation
3) Phu Kradung Formation
4) Phra Wihan Formation
5) Sao Khua Formation
6) Phu Phan Formation
7) Khok Kruat Formation; Reddish-brown to light-grey sandstones, conglomeratic sandstones, siltstones, claystones and conglomeartes are the main lithologies of these rocks

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

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

1) Phra Wihan Aquifers, Pw
2) Sao Khua Aquifers, Sk
3) Phuphan Aquifers, Pp
4) Floodplain Deposits Aquifers, Qfd
5) Khok Kruat Aquifers, Kk
6) Namphong Aquifers, Np
7) Phu Kradung Aquifers, Pk
8) Triassic Metasedments Aquifers, TRms
9) Huai Hin Lat Aquifers, Hi
10) Khok Kruat Aquifers, Kk
11) Silurian-Devonian Metamorphic Aquifers, SDmm
12) Maha Sarakham Aquifers, Ms
13) Permian Carbonate Aquifers, Pc
14) Nam Duk Aquifers, Nd
15) Phu Kradung Aquifers, Pk

3. Hydrological database in Khon Kaen

"The Project of Detailed Groundwater and Hydrogeological Mapping at a Scale of 1: 50,000 Area 2: The mid - northeastern Thailand" has been implemented in Khon Kaen. The 1: 50,000 Hydrogeological and groundwater maps have been created by improving groundwater map, hydrogeological map and HYGIS.

HYGIS consists 9 data sets as follows:

1) Fundamental geographic
2) Structural Geology
3) Hydrogeological unit
4) Groundwater well location
5) Groundwater level
6) Groundwater availability
7) Groundwater quality
8) Groundwater utilization
9) Hydrogeological cross- section

All these 9 data sets were arranged into 9 main layers under the HYGIS data configuration prior to the spatial analysis or the determination of relationship of all data map into map format. For map making process, the overlay method of various layers of data was applied on the geographic information system (GIS) mapping techniques.

The main objective of 1: 50,000 detailed hydrogeological mapping is for groundwater resources management at the local community levels. With details of all layers of groundwater and hydrogeological data, groundwater experts and executives of the DGR can use these maps as the main guide for the best managing groundwater resources in Khon Kaen. The 1:50,000 Hydrogeological map of Khon Kaen consists about 24 map sheets, for example, Hydrogeological Map sheet 5541II (Fig. 1).

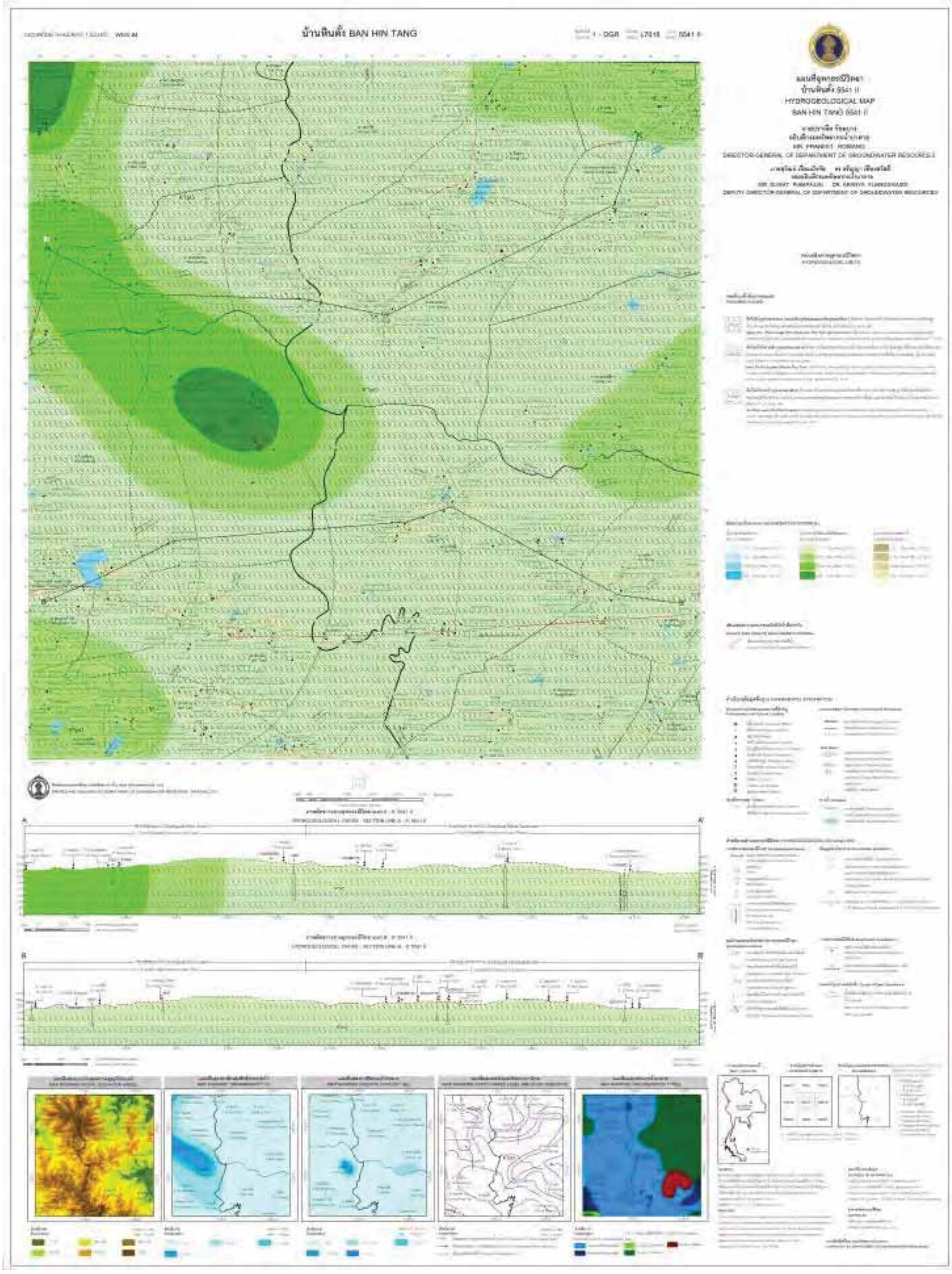

Fig. 1. The 1: 50,000 Hydrogeological Map Sheet 5541II.

The hydrogeological database of GIS layers is shown on the main map as the structural geology, along with their aquifer hydraulic properties and characteristics. The hydrogeological units are shown on main map and divided into 3 main groups which are intergranular flow aquifers, fissures flow aquifers, and localized aquifer. In addition, this map has layer of maximum available yield, layer of aquifer's thicknesses and layer of aquifer's depth.

4. Groundwater Management in Khon Kaen

DGR has an important role in supplying groundwater as a secondary source of water for consumption and domestic use, and managing groundwater resources in Thailand. We have different bureaus and sections to work under the DGR's policies in order to manage groundwater resources in every aspects and achieve DGR's targets. DGR has the central office in Bangkok and 12 regional offices in order to drive groundwater projects and manage groundwater throughout Thailand. We have established various groundwater projects such as supplying groundwater for consumption, domestic use and agriculture, supplying drinking water for schools, and carried out different research and studies on groundwater resources. Thus, the detailed hydrogeological and groundwater map at a scale of 1:50,000 is a helpful tool for groundwater development, to bring the knowledge and to support the effective groundwater management in the local areas.

5. Conclusions

The Hydrogeological maps are designed for the use of hydrogeologists, groundwater researches, students, pubic and non-public organizations. The detailed Hydrogeological maps at a scale 1:50,000 have been produced following the standard of International Associate of Hydrogeologists (IAH). The Hydrogeological Map of Khon Kean consists about 24 sheets and hydrogeological database.

After conducting the projects of 1: 50,000 groundwater and hydrogeological mapping in Northeastern Thailand, we found that input data and HYGIS need to be improved in order to increase map reliability. Therefore, DGR will continuously improve our maps so that they can be confidently utilized to support decision for optimal groundwater planning and development.

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