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Geological Survey of Japan, AIST

National Center for Water Resources Planning and Investigation (NAWAPI)

Project Report of the
CCOP-GSJ/AIST-NAWAPI
Groundwater Phase III Meeting
16-18 March 2016, Hanoi, Vietnam

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

The CCOP-GSJ/AIST-NAWAPI Groundwater Project Phase III Meeting was held on 16-18 March 2016, in Hanoi, Vietnam. It was attended by nineteen participants from Cambodia, China, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand, Vietnam and the CCOP Technical Secretariat. In the meeting, participants confirmed progress of the project from February 2015 to March 2016, and discussed work plan for 2016 by three group discussions.

Each CCOP Member Country made a country presentation on the topic, "*Recent Groundwater Issues and Their Action Study*". Since the current groundwater problem varies from one CCOP member country to another because of various hydrogeological and geographical settings, each Member Country should share the information for efficient groundwater management in the CCOP regions.

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

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

Youhei UCHIDA

Chief Editor

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The Minutes of the CCOP-GSJ/AIST-NAWAPI Groundwater Project Phase III Meeting

16-18 March 2016, Hanoi, Vietnam

The CCOP-GSJ/AIST-NAWAPI Groundwater Project Phase III Meeting was held on 16-18 March 2016, in Hanoi, Vietnam. It was attended by nineteen participants from Cambodia, China, Indonesia, Japan, Republic of Korea, Lao PDR, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand, and Vietnam and the CCOP Technical Secretariat.

The Opening Ceremony started with the Welcome Remarks and Addresses delivered by Dr. Nguyen Thi Minh Ngoc, Regional Expert of the CCOP Technical Secretariat, and Dr. Youhei Uchida, Groundwater Project Leader, Geological Survey of Japan, AIST. The Opening Speech was made by Mr Nguyen Manh Cuong, Deputy Director-General of Vietnam's National Center for Water Resources Planning and Investigation (NAWAPI).

Dr. Youhei Uchida presented the progress of the Project from 10 February 2015 to 11 March 2016. During the period, the report of the CCOP-GSJ/AIST-DGR Groundwater Phase III Project Kick-Off Meeting held on 10-12 February 2015 in Bangkok, Thailand has been published, circulated to all the participants of the meeting, and uploaded to the CCOP website, http://www.ccop.or.th/download/GW5.pdf. The CCOP Geoinformation Sharing Infrastructure for East and Southeast Asia (GSi Project) portal is under development and is accessible by the project members from http://ccop-gsi.org. The compiled groundwater data of Japan, Thailand and Vietnam from the Project Phase II temporarily available from http://jcbwebgis.com/ccop_water/, will soon be made accessible from GSi Portal.

On the CCOP Groundwater Sub-Project: Development of Renewable Energy for Ground-Source Heat Pump System in CCOP Regions, two installations have been made during the period, (1) Installation of GSHP Horizontal Heat Exchanger at Chulalongkorn University, Saraburi campus, Thailand on June 2015 and (2) Installation of Ground Source Heat Pump System at Golden Jubilee National Geological Museum, Department of Mineral Resources, Thailand on March 2016.

Country reports on "Recent Groundwater Issues and Their Action Study" were presented by CCOP participants. Project report with the country papers will be published within 2016.

Group discussions were held on the actions taken according to the 2015 Workplan and the plan for 2016.

DB Group I - China, Indonesia, Japan, Korea (Group Leader) and Thailand will submit groundwater data in excel format provided, by the end of May 2016. The data will be as follows:

- China : Groundwater monitoring data based on the published year book
- Indonesia : Groundwater data of Java Island
- Japan : Groundwater data of the aquifers in Kanto plain, Yamagata plain
- Korea : Groundwater monitoring data based on the published year book (2013)

- Thailand : Groundwater data of the Upper Chaophraya (Sukothai, Phitsanulok, and Pichit Provinces)

For 2016 Workplan, China, Indonesia, Korea and Thailand will update these data, while Japan will provide Groundwater data in Ishikari plain, and Kumamoto Plain.

DB Group II – Indonesia (Group Leader), Malaysia, Philippines, Vietnam plans to compile groundwater data as follows:

- Malaysia: 2015 – excel groundwater database of Langat Basin, 2016 – update excel groundwater database of Langat Basin and hydrogeological and groundwater map of Langat Basin.
- Philippines: 2015 - groundwater excel data in excel format of Luzon Island; 2016 – update groundwater excel data in excel format of Luzon Island and GIS groundwater / hydrogeological maps will follow.
- Vietnam: 2015 – groundwater data excel format of Thanh Hoa, Ha Tinh, Quang Nam, and Quang Ngai provinces; 2016 – update groundwater data excel format of Thanh Hoa, Ha Tinh, Quang Nam, and Quang Ngai provinces and GIS data will be uploaded.

For the Public Policy Group – Cambodia, Lao PDR, Myanmar, PNG, Timor-Leste (absent), CCOP TS (Group Leader), the following actions were taken on 2015 Workplan.

- Attended GSJ GW Project meeting in February in Bangkok, GSHP sub-project meeting in June in Bangkok
- Attended the KIGAM-CCOP-UNESCO Meeting on "Trans-boundary Groundwater Resources in Mekong basin" 19-21 May 2015 Bangkok, Thailand with 26 participants from Mekong countries & publication
- Attended the GSi Project Kick-off meeting in September 2015 in Bangkok
- Attended KIGAM/ISGeo regular training course on "Landslide and slope stability assessment & Groundwater Theory and Practices" on November 9 ~ December 4, 2015
- Attended some Web-GIS training courses within framework of harmonized geology project
- Attended the CCOP- BGR Workshop on transboundary aquifer in January 2016 in Can Tho, Vietnam
- Attended the VIETADAPT Workshop on Water & Food security on March 12, 2016 in Siem Reap, Cambodia

In 2016, the group plans to continue availing the relevant training courses and workshops offered by CCOP and its member countries. The group requests more on-the-job training and participation of Web-GIS training courses. For enhancing policy of data sharing, the countries suggested official approach the governments for permission, and more assistance/support for survey & data collection.

Dr Kyoochul Ha of KIGAM recommended that members of this group participate KIGAM's ISGeo Regular Training Courses on Groundwater.

Dr Shrestha Gaurav from GSJ/AIST gave a lecture on "Temporal and Spatial Analysis of Water Quality of River Basin using GIS".

Dr Bui Du Duong of NAWAPI, presented on "Managing trans-boundary waters in Vietnam: Challenges and opportunities for cooperation". The Meeting considers the possibility of collecting groundwater data on transboundary aquifers, within this year or the next.

The Meeting agreed that CCOP issues letter to all the Permanent Representatives of CCOP Member Countries requesting nomination of groundwater data coordinators for the GSi Project, with the attachments of participants list of the CCOP-GSJ/AIST Groundwater Phase III Project.

This minutes is adopted as signed.

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

Groundwater Resources in Prey Veng and Svay Rieng Provinces

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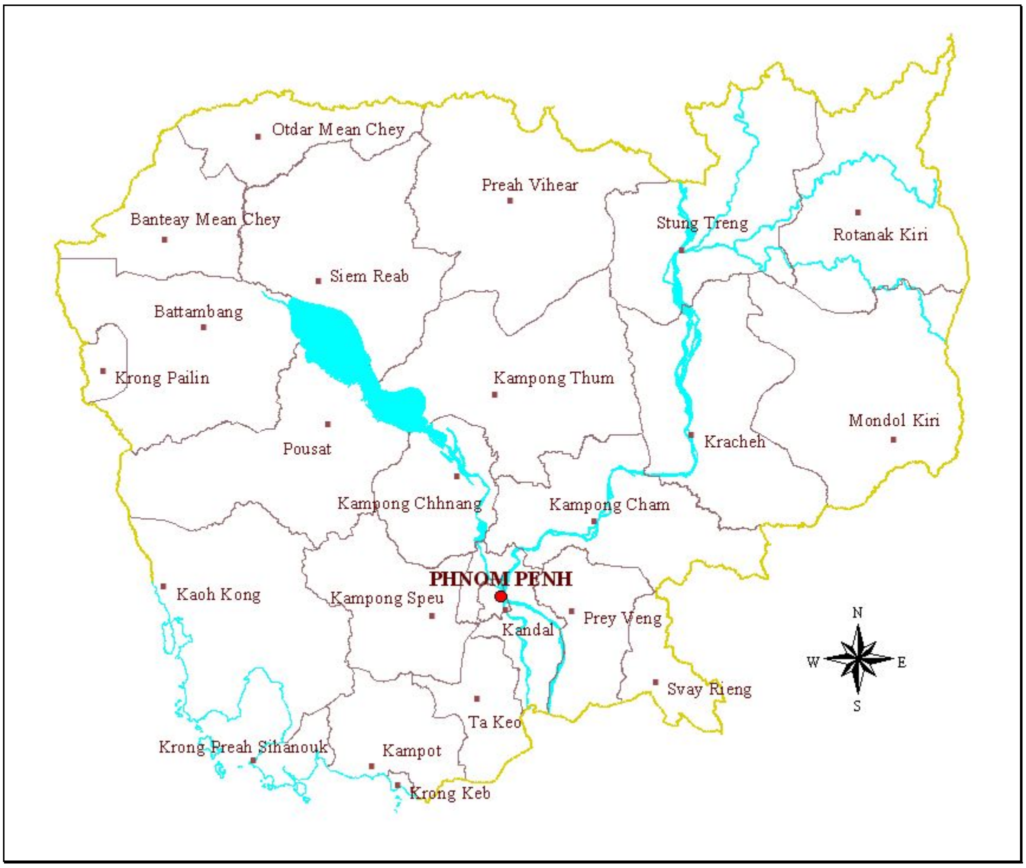
A - GEOGRAPHY

1 - Location

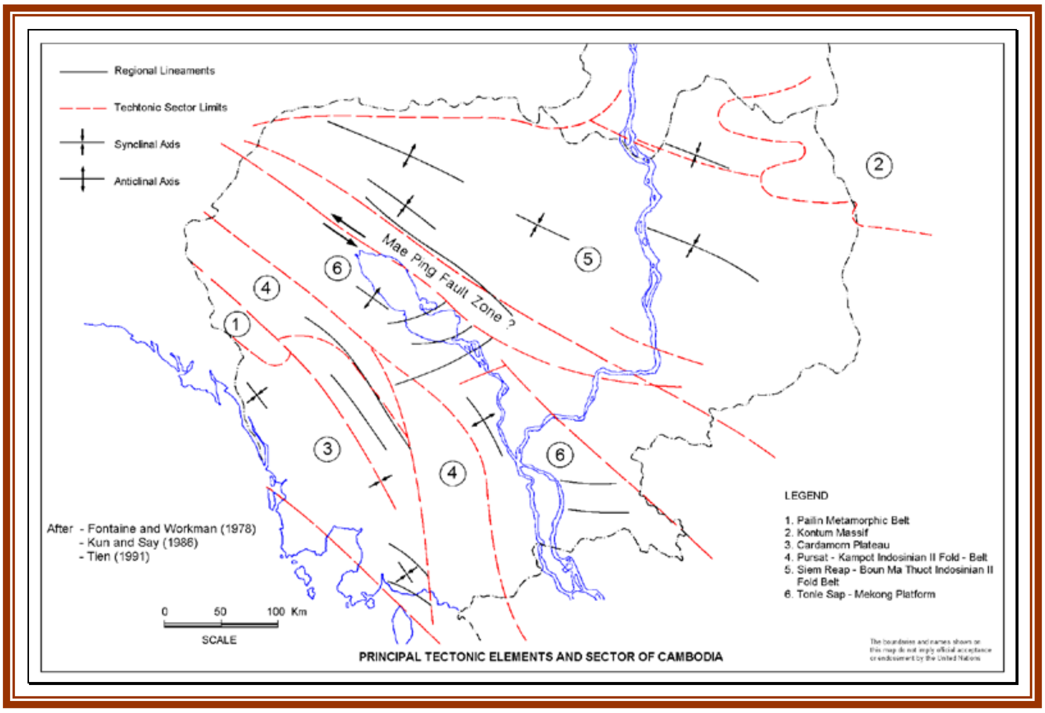
Cambodia is located on the peninsula of Indochina in Southeast Asia between latitudes $12^0 00$ and $15^0 00$ N and longitudes $102^0 00$ and $108^0 00$ E and cover an area of 181,035 sq.km. It divides 24 provinces and cities as show in fig. below and has a population of about 12 millions (National Statistic, 1998).

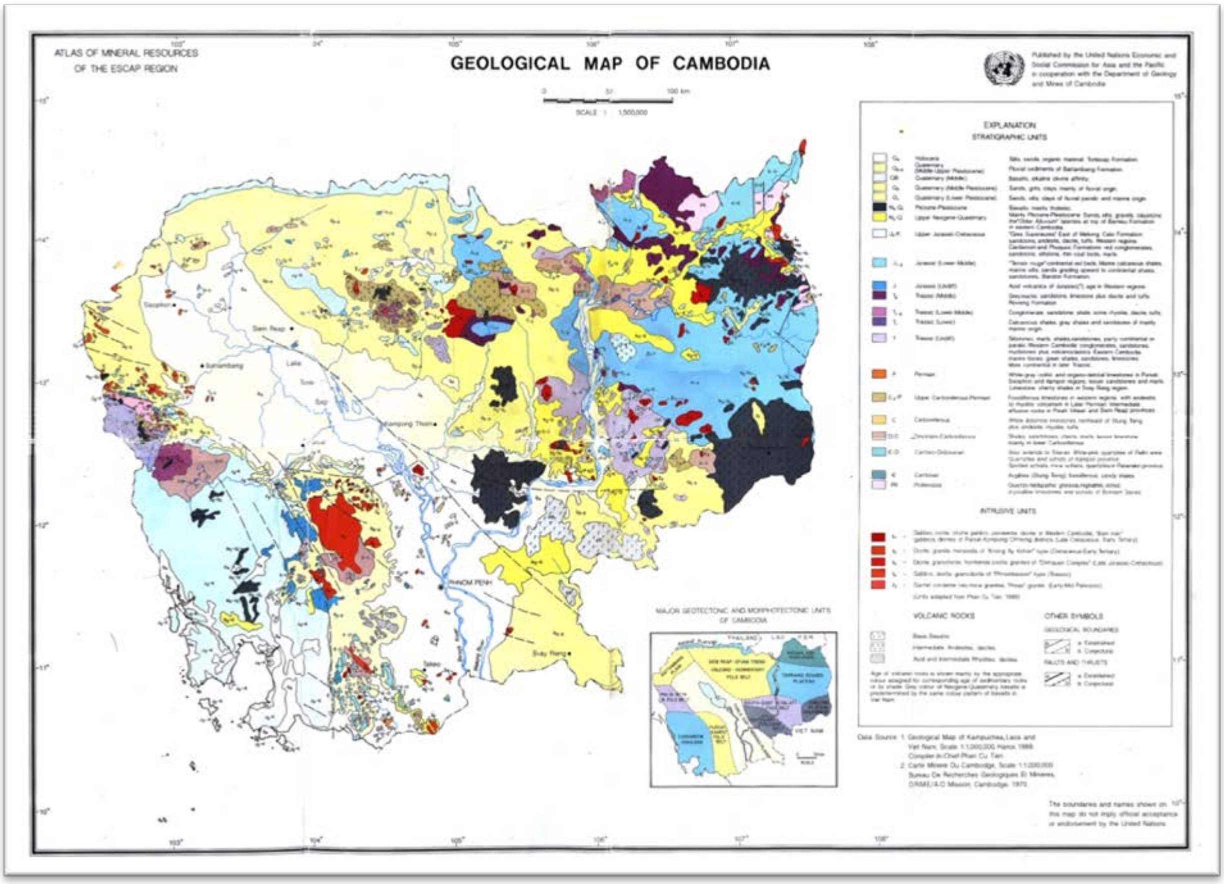
ADMINISTRATION MAP OF CAMBODIA



2 – Topography and Geology

The topographical feature of Cambodia derived into three occupies. There are the central plain, eastern plateaus and mountainous ranges at the western and northern part of the country.


Regional Lineaments
Techtonic Sector Limits
Synclinal Axis
Anticlinal Axis
Mae Ping Fault Zone ?
1
2
3
4
5
6
After - Fontaine and Workman (1978)
- Kun and Say (1986)
- Tien (1991)
0 50 100 Km
SCALE
LEGEND
1. Pailin Metamorphic Belt
2. Kontum Massif
3. Cardamom Plateau
4. Pursat - Kampot Indosinian II Fold - Belt
5. Siem Reap - Boun Ma Thuot Indosinian II Fold Belt
6. Tonle Sap - Mekong Platform
PRINCIPAL TECTONIC ELEMENTS AND SECTOR OF CAMBODIA


ATLAS OF MINERAL RESOURCES OF THE ESCAP REGION
GEOLOGICAL MAP OF CAMBODIA
EXPLANATION
STRATIGRAPHIC UNITS
INTRUSIVE UNITS
VOLCANIC ROCKS
OTHER SYMBOLS
PHNOM PENH

The central plain comprises about 75% of the land area. It is include the Mekong, Tonle Sap (include Tonle Sap Lake) and Bassac river delta and an elevation varies between 10 to 30 m amsl. The main feature is old and young alluvial deposits. The hilly plateau covers by weathered rock as terrain rouge (laterite), sand and basalt basement rocks. The mountainous ranges are the watershed boundaries at the northern and western parts of the country. There is mainly sandstone continental formation of the Cardamom mountainous rang at the northern part and Kravanh mountainous range at western and southwestern part of Cambodia. The highest elevation is Oral Mountain about 1810 m amsl of the Kravanh Mountainous range. The principal tectonic elements of Cambodia as show in fig. below. They are occupies a small central part from Indochina peninsula, eastern Thailand, Laos, the southern Malay peninsula, western Kalimantan and the intervention area of Gulf of Thailand. This crustal block known as Indosinia.

B - CLIMATE

The climate in Cambodia is tropical, dominated by seasonal wind of monsoons. It is semiannually experiences dry season (November-April) and wet season (May-November). The mean annual temperature varies from 26.9^{o}C to 27.8°C. The annual rainfall varies from 1000-1800 mm in lowland and more than 1800 mm in western mountainous and eastern plateau area. The humidity is around 76-80%.

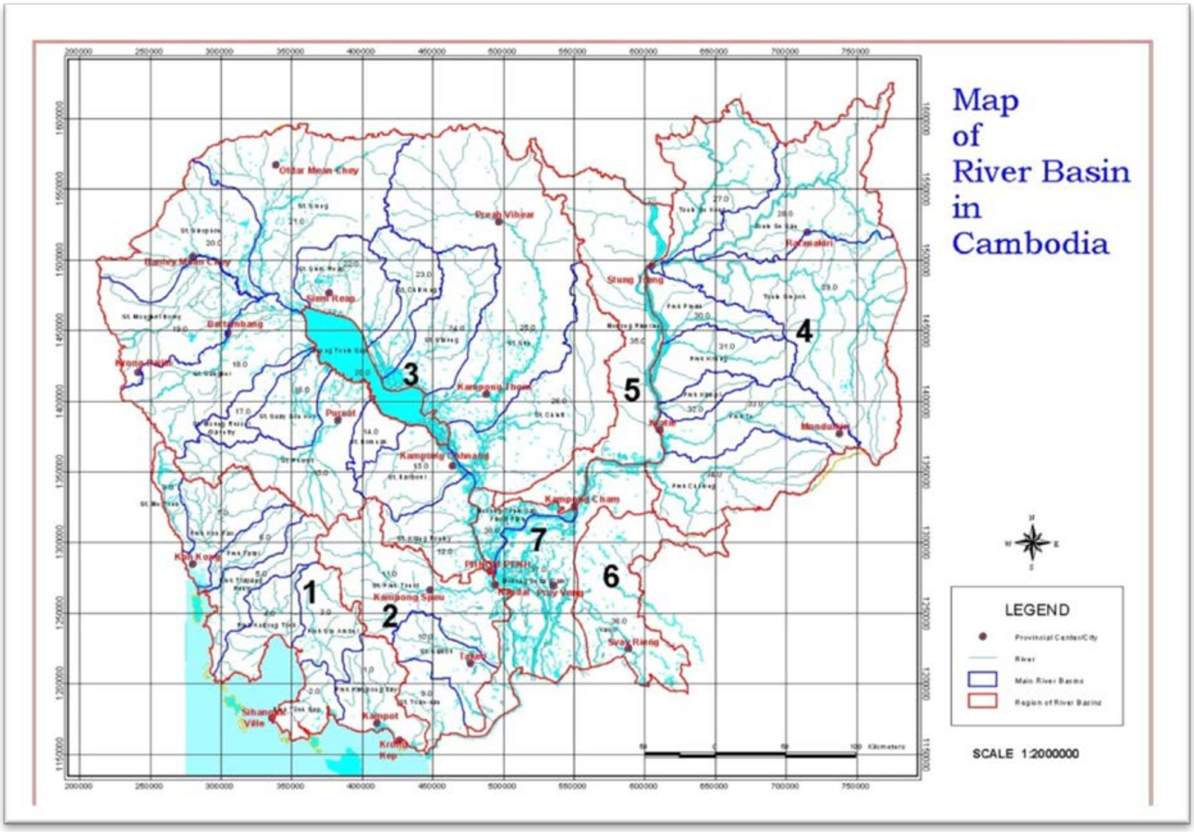
C - GROUNDWATER INVESTIGATION

1 - Introduction

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

During 1960-63, 1103 holes were drilled of which 795 of approximately 72 percent productive wells at rates were ranging from 1.1 to 2,967 l/min. The productive wells ranged in depth from 2 to 209.4 m and were 23.2 m deep on the average. Mr. Rasmussen studied the sub surface geology of Cambodia in considerable detail by examining drillings logs and constructing nine geologic cross sections. The principal aquifer tapped by drilled wells in Cambodia is the Old Alluvium. In many places, however, dug wells and a few shallow drilled wells obtain water from the Young Alluvium. Sandstone of the Jurassic - Cretaceous formation yields are moderate to small quantities of water to wells in a number of places. Also, numbers of wells tapping water -bearing basalt have a small to moderate yield.

The quality of water is recorded in only a few analyses. The dissolved-solids concentrations appear to be generally low so that the water is usable for most purposes without treatment. Some well waters are high in iron and would have to be filtered before use.



2 - Study Area

STRATEGIC STUDY OF GROUNDWATER RESOURCES IN PREY VENG AND SVAY RIENG

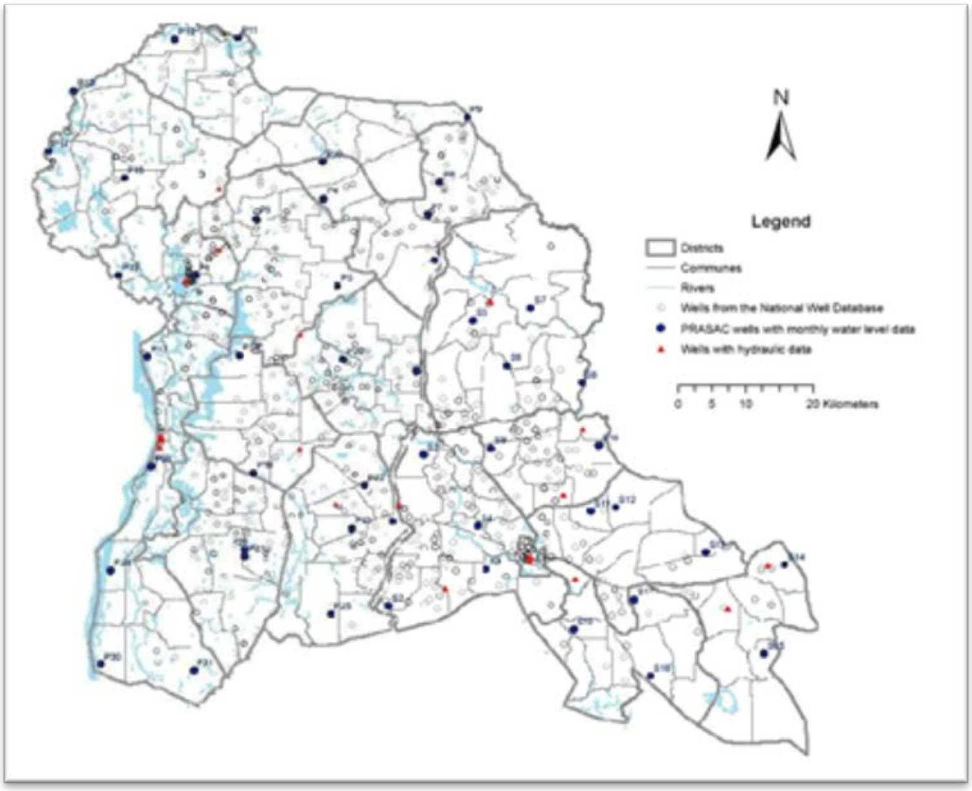
Overview

Prey Veng and Svay Rieng provinces have groundwater resources that can be accessed throw relatively inexpensive boreholes. Since the early 1990s, rapid growth in the use of groundwater for irrigation has led to increased yields and incomes for farmers but has also raised concerns about whether such withdrawals are sustainable. Monthly records of groundwater levers gathered from 49 wells from 1996 through 2008 indicate an average annual decline of 0.14 m/year. If the water levels drop more than 6 m below the ground surface, some 130,000 hand pumps used for domestic water supplies in the two provinces may become unusable.

The objective of this study was to estimate sustainable rates of groundwater withdrawal for irrigation in Prey Veng and Svay Rieng provinces. To achieve this, a three-dimensional numerical groundwater flow model was constructed using the MODFLOW software package and calibrated to ensure a close match with observed water levels.

The calibrated model was used to determine the sustainable groundwater withdrawal, which is defined as “the maximum amount of water that can be withdrawn from the aquifer when water levels across Prey Veng and Svay Rieng are drawn down to a specified depth” . In total, seven predictive scenarios were analyzed, each scenario corresponding to a different maximum water level depth. For the “6 m below groundwater surface” scenario, the sustainable groundwater withdrawal is estimated to be 2.3 million m^3/day, which is equivalent to 0.29 mm/day over the area of the two study provinces. Rough estimated of groundwater use for domestic and agricultural purposes in 2005 suggest that 53% of the sustainable withdrawal was being used at that time. Also, if the total sustainable withdrawal amount were devoted entirely to irrigating dry-season rice, the total area that could be irrigated would be about 45,000 ha.

Another objective of the study was to develop Cambodian technical capacity.



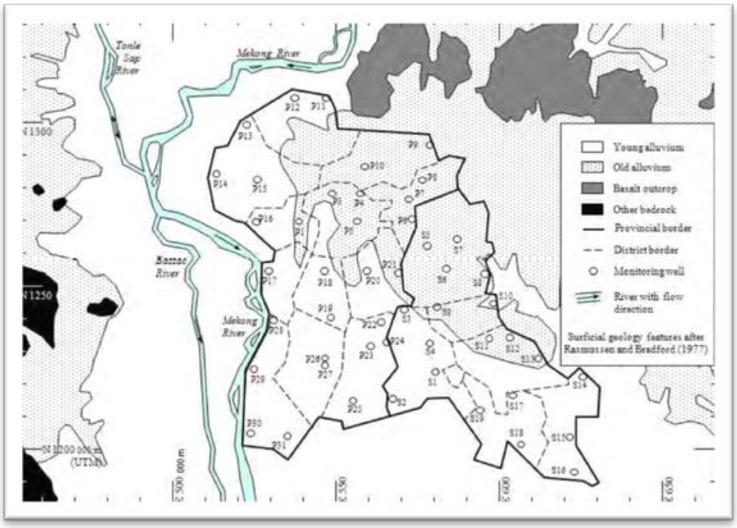
3 - Hydrogeology of the Study Area

This section provides an overview of the geology and groundwater dynamics in the Prey Veng and Svay Rieng study area. A basic understanding of local hydrogeology will help the reader to follow the descriptions and discussions in the report.

The geologic formations underlying the study area are made up of river sediments overlaying deep bedrock. Good aquifer materials tend to occur at lower elevations and poor aquifer materials occur closer to the surface. Although the boundary between the good and poor aquifer material is not sharply defined, two broad sedimentary layers can be defined:

- The lower layer, or old alluvium, consists mainly of coarse-grained sand and gravel that from a good aquifer. The layer is up to 200m thick.
- The upper layer, or young alluvium, covers much of the study area to a depth of 10 to 40m and consists mainly of fine-grained silts and clays.

The young alluvium acts as impermeable blanked overlaying the old alluvium aquifer across much of the study area. At higher elevation in the northeast portion of the study area, the young alluvium thins out to nothing and the coarser-grained old alluvium layer is exposed (see Figure 1).



Important implications of these geologic conditions include the following:

- The upper, impermeable young alluvium layer prevents the annual flood waters from directly recharging the underlying aquifers.
- Instead, the aquifers are recharged from the following sources:
  - o Infiltration from the Mekong River in places where the river is deep enough to cut through the young alluvium into the underlying old alluvium,
  - Infiltration of rainwater runoff through the exposed old alluvium in the northeast portion of the study area and beyond.
- The water in the old alluvium aquifer, being recharged from higher elevation sources, is held under pressure by the overlaying blanket of the young alluvium. When boreholes are drilled through the young alluvium into the aquifer, the water level rises in the borehole to within a few meters of the ground surface.
- The dominant direction of groundwater flow in the study area from north,
- where the recharge area lay, to south.
- Close to the Mekong River, east-west flow also occurs:
  - o In the dry season, when the Mekong River water level is low, groundwater flows generally westward from the aquifer into the river;
  - o In the wet season, when the Mekong River water level is high, water flows generally eastward from the river into the aquifer.

The area modeled for this study includes the full extent of Prey Veng and Svay Rieng provinces and extends beyond to natural hydrologic boundaries. The modeled area is shown in Figure 2. Cross-sections showing the ground surface, top of old alluvium, and top of bedrock elevations in the modeled are shown in Figure 3 and Figure 4.

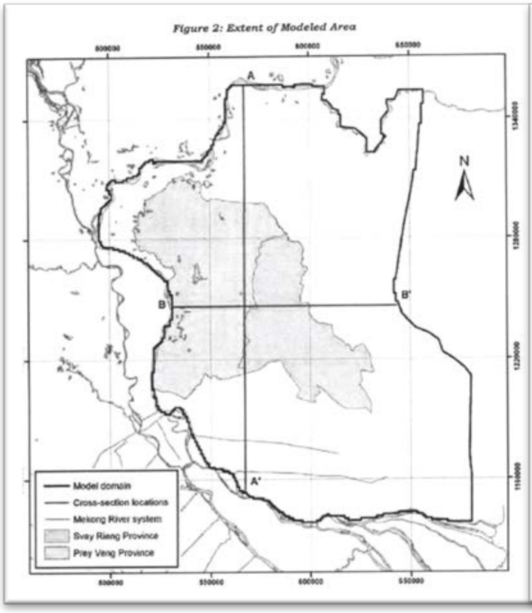


Figure 2: Extent of Modeled Area

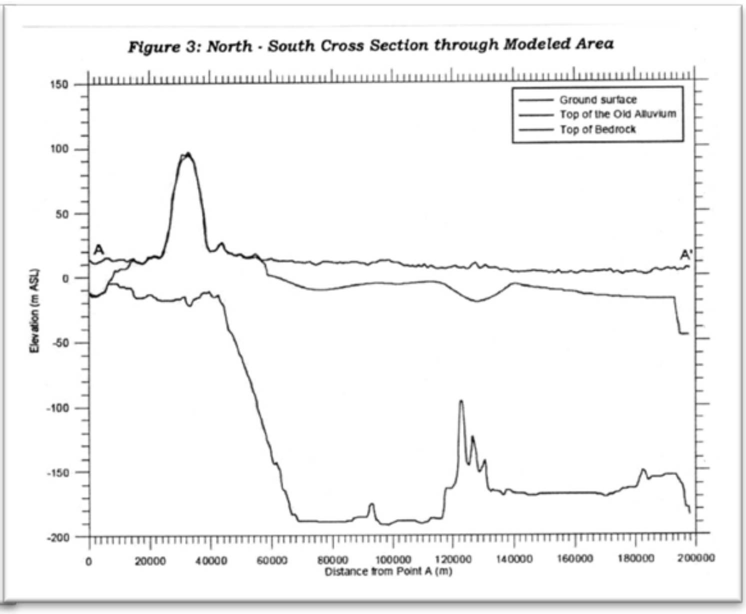


Figure 3: North - South Cross Section through Modeled Area

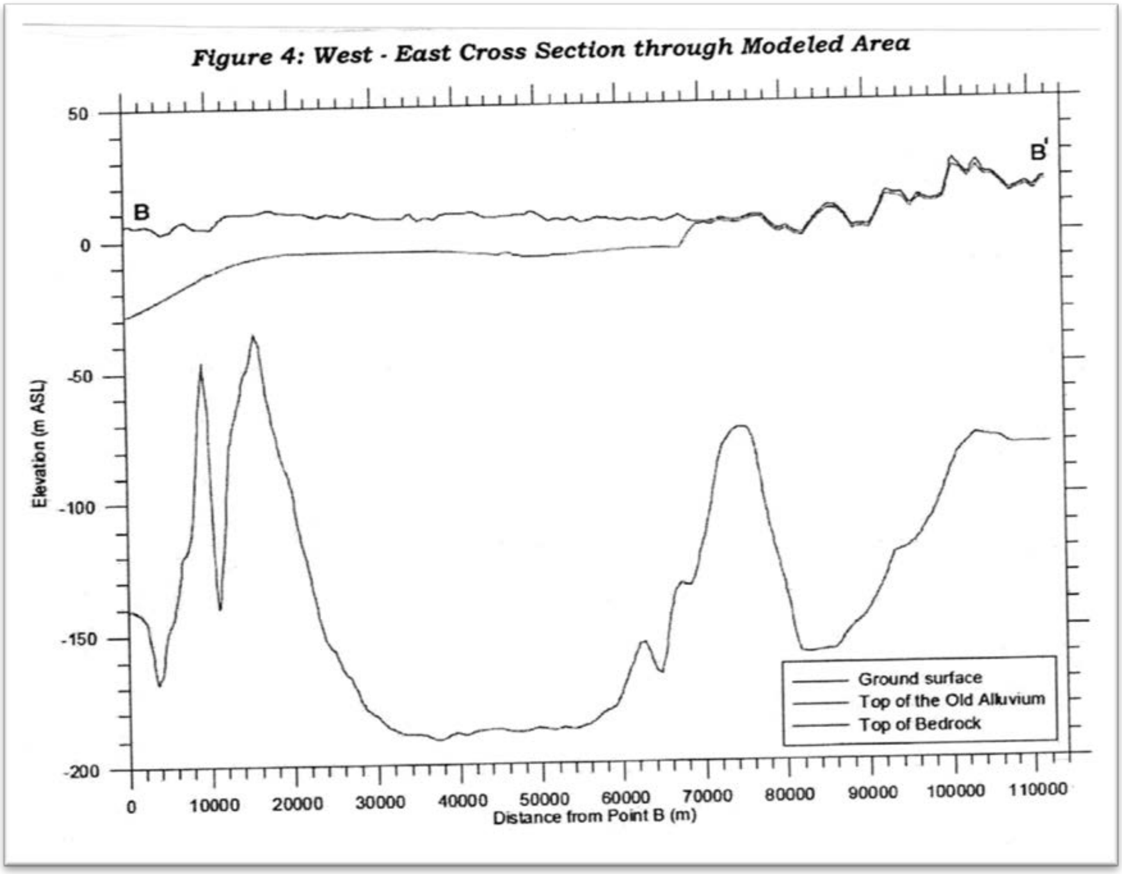


Figure 4: West - East Cross Section through Modeled Area

Reference

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Recent Groundwater Issues and Their Action Study in China

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Abstract

Fresh water in China covered an area of about 810×10^4 km^2, with annual natural fresh groundwater recharge of 8 840$\times10^8$m3， accounting for about 31% of water resources in China. Groundwater is the most significant water source for many cities and energy bases in Southern and Northern China, it is also the main supply for addressing severe drought in China. Most of groundwater in China buried deeply but unevenly, which results in difficulty on investigation and exploitation, and brings about engineering water shortage in karst area in Southern China and energy bases in Northern China. With the increasing human activities, groundwater is polluted seriously in some area of China; global climate change and over exploitation of groundwater by human beings make the water table descended, springs dried up, even the geohazard happened like karst sinkholes or surface subsidence.

Since 1999, China Geological Survey (CGS) has organized professional teams to investigate and evaluate groundwater resources and environment, with the following achievements being achieved: the hydrogeological survey in 1: 250 000 scale to 2.20$\times$ 10^6km^2 area covering 16 districts has been completed; the hydrogeological survey in 1:50 000 scale to 3.5×10^5 km^2 covering key areas including karst area of Southwest China, Erdos Basin, Qaidam Basin, and energy bases like Shanxi and Shananxi has also been completed; moreover, the regional investigation on groundwater pollution in 1:250 000 scale to 4.40$\times$ 10^6km^2 has been fulfilled with a spacial database for the studied area created. Based on investigation, the total quantity, expected exploitable quantity and current exploited quantity of groundwater in whole China and the catchments under investigation have been evaluated; meanwhile, the groundwater pollution evaluation in whole China and key areas as well as karst sinkhole risk assessment of areas under investigation have been conducted. In dry area with water shortage in Northwest China, karst area and red bed area in Southwest China, low-quality water area with high concentration of F and As in Northern China, more than 6 000 deep wells with 200 shallow wells both for survey and exploitation have been drilled. Besides, over 10 demonstration projects for underground rivers and large karst springs development have been constructed, which have helped to solve drinking water problems for more than 22 million people. Sustainable utilization of groundwater in North China Plain, karst process and carbon cycle, global climate change, as well as groundwater investigation and research have drawn much attention from home and abroad. At present, CGS is making its effort to conduct the national groundwater monitoring projects construction, and establish a national network for groundwater monitoring.

Keywords: groundwater, China

1 Introduction

The fresh groundwater distributes in an area of about $810\times10^4 km^2$, with the total groundwater quantity of China up to 9 235 $\times10^8$ m^3/y. The annual natural recharge for fresh groundwater is 8 840$\times10^8 m^3/y$, accounting for about 31% of water resources in China. The groundwater in China could be classified into three types including pore water, karst water and fissure water. The natural fresh pore water quantity is 2 500 $\times10^8 m^3/y$, with the exploitable quantity as 1 686$\times10^8 m^3/y$. The pore water mainly distributed in loose sediments of plain, valley-plain and valley-basin. The natural karst water quantity is about 2 080$\times10^8 m^3/y$, with the exploitable quantity of 870$\times10^8 m^3/y$. The karst water mainly occurred in karst caves and eroded fissures or fractures of carbonate rocks. The natural fresh fissure water quantity is about 4 260$\times10^8 m^3/y$, with the exploitable quantity of 971$\times10^8 m^3/y$. The fissure water mainly presented in fissures of bedrocks of hilly and mountainous area (Zhang zongfu, 2004).

At present, more than 400 cities out of 655 cities in China have the groundwater as drinking source, especially the northern cities. Currently,for cities in northern China,65% domestic water, 50% industrial water and 33% agricultural water relied on groundwater (Fan Hongxi, 2011);meanwhile, domestic water and industrial water of karst area in southern China was also mainly supplied by groundwater. Besides, groundwater could also be used as the major emergent source for fighting for drought; for example, the groundwater had been served as emergent source for serious drought in southwest China during 2009-2010, north China in 2011, and Yunnan Province in 2012. Due to over utilization of groundwater by human beings, a series of problems about resources and environment occurred, like over exploitation of groundwater, water level descent, springs dried up, water pollution, land subsidence, and karst sinkholes, which threatened the drinking water and ecological safety of local people.

China has paid great attention to the investigation, research, exploitation and protection of groundwater. China Geological Survey has set up Department of Hydrogeology and Environmental Geology to organize scientists and technicians to carry on groundwater and environment investigation and research all across China specially, with a professional team with more than 50 000 scientists and technicians from the Institute of Hydrogeology and Environmental Geology of Chinese Academy of Geological Sciences (CAGS), the Institute of Karst Geology of CAGS, China Institute for Geo-Environmental Monitoring, Center for Hydrogeology and Environmental Geology, China University of Geosciences, and provincial hydrogeological team and geo-environmental monitoring stations formed. Recently, the major fields for the related work include: hydrogeological and environmental geological investigation, dynamical monitoring of groundwater and its environment, the relationship between groundwater and global climate change and human activities, international trans-boundary aquifers research, and the exploitation, utilization and protection of groundwater, as well as the projects for addressing geohazards caused by groundwater. All the related investigation and research has not only provided important support to the development, utilization and protection of groundwater in China, but also promoted the research on groundwater and its environment internationally.

2 Current Groundwater Issues

2.1 Engineering Water Shortage

In some areas, despite of great amount of natural water resource, yet it is still very difficult to detect and exploit groundwater effectively due to its special geological conditions and geographic environment; besides, because of undeveloped facilities for water conservancy projects, the engineering water shortage has been brought about. Engineering water shortage is very common in every drainage area of China, especially in the karst mountainous area of Southwest China—the watershed of Yangtze River Drainage Area and Pearl River Drainage Area.

In Southwest China, sub-tropical monsoon climate made this area had great amount of precipitation but uneven annually. Karst fissures and conduits developed well underground, the rainfall converged transiently on the surface and dispersed and infiltrated or converged together to recharge groundwater. The rainfall discharged to deep-cut valley through rapid runoff, with dramatic dynamical change of karst water table and flux. Therefore, it is quite difficult for karst aquifers to adjust groundwater effectively, which made the extremely uneven spacial and temporal distribution of groundwater resources; meanwhile, due to rough landform of karst mountainous region in Southwest China and its complicated karst aquifers' structures, it is very difficult to explore and develop the karst water resource technically and it will cost more economically. This region is an entirely undeveloped-economic area, whose engineering water shortage had not yet been solved effectively. Taking Yunnan Province as an example, the overall reservoir capacity only accounts for 2% of multi-years' average runoff, with a lot of dangerous reservoir existed (Wang Yongde, 2014). Especially since 2009, the provinces or cities like Yunnan, Guizhou, Guangxi, Sichuan and Chongqing have suffered continuously serious drought during winter and spring, which highlighted the predominant problems like lack of water source projects in this region, serious engineering water shortage and lagging of water conservancy infrastructure facilitates (Li Wei, 2012).

Fig. 1. Water Storage Project for Epikarst Springs in Guohua Town, Pingguo County, Guangxi-Solution to the *Engineering Water Shortage*

2.2 Groundwater Pollution

Before this century, China has not yet carried out the investigation and evaluation of groundwater pollution all over China. Formerly, the investigation and research of groundwater mainly focused on the formation conditions and the resources amount, with less attention to water quality or pollution, or only investigated locally. There is no systematical investigation of groundwater quality or pollution, even no understanding of organic pollution in groundwater.

During 2005-2016, the Ministry of Land & Resources of China has carried out national groundwater pollution investigation and evaluation .The mainly studied water level is less shallow than 100 m but also with some deep area studied. The results showed that the overall groundwater quality is relatively good, but still not so good and polluted severely in some particular regions. According to the investigation and monitoring results, the overall over-standard percentage of groundwater contamination elements in China is 15%, of which, nitrogen and metallic pollution is more serious. Besides, the organic pollution has begun to become more severe. The groundwater pollution spread from shallow level to deep level, from a point to a region. Nitrogen contamination is the most serious pollution to groundwater, with the major nitrogen from overuse of fertilizer, dispersed breeding, landfill of rubbish and discharge of living sewage etc. Nitrogen contamination mainly distributed in agricultural areas of Northeast China, North China and Huaihe Plain, as well as in periphery of urban area and on both banks of sewage discharging channels. Besides, heavy metallic pollution could also be found in some places, like over-standard concentration of Pb, Cr, and Hg. Most over-standard contamination mainly distributed around urban area, factories or mines. Meanwhile, organic pollution could be detected from groundwater in some area, including Benzene serials of petrochemicals, organic chlorine solvent, and pesticide etc, distributing in eastern part of China with developed economy and inland cities with larger population. Comprehensively, widespread agricultural pollution is an important reason for resulting in widespread shallow groundwater pollution.

Key issues of ground water pollution prevention in China have three points: Firstly, there are many and large areas of ground water pollution. Secondly, lacking regional detailed data of ground water pollution. And thirdly, no good treatmental experiences and technology of the ground water pollution.

2.3 Groundwater Over exploitation to Water Table Descent

With the increasing rigid demand of groundwater resources for national economic construction, the groundwater was over exploited and caused continuous descent of water table. There are more than 300 areas where the groundwater is overexploited with the area up to 190 000 km^2 , 720 00 km^2 of which is under serious overexploitation. More than 100 regional cones of groundwater depression are formed all over China with the total area up to 150 000 km^2.Especially, over exploitation of groundwater is rather serious in Northern China, like the North Plain, six basins of Shanxi Province, Songnen Plain, and inland basin of Northwest China and so on.

Due to over exploitation of groundwater in North China Plain, the shallow groundwater of Hebei Province and Beijing descended 20-40m generally in the past 30 years. The deep groundwater of North China Plain has already formed a regional cone of groundwater depression crossing Hebei Province, Beijing, Tianjin, and Shandong Province. Up to 76 732 km^2 area was covered by below-sea-level groundwater, accounting for 55% of the whole area of North China Plain.

The groundwater in six great basins of Shanxi Province is over exploited to different degree. Until 2006, the over exploitation amount of groundwater in middle basins has reached to $3.75\times10^8 m^3$ annually for last 5 years. Due to water level descending, it has begun to become difficult to draw water from the groundwater source in Datong and Yuncheng; shallow groundwater of Changzhi Basin unwatered, which made local residents difficult to get drinking water. In the inclined plain of western Songnen Plain and the low plain in the middle, the phreatic water level descended 3-5m averagely comparing with that of 1960s, and may even descend 3-8m in some places; in the exploitation area of concentrated water supply source in the high plain of eastern Songnen Plain, the water table declined 5-25m. Since the groundwater has been over exploited for long term, the groundwater has changed from confined water to unconfined interlayer water, with the water level 10-18m lower than aquifer roof and the yield of single well declined 30-50%. In northwest area, the Shiyang River Drainage Basin has its water table declined most dramatically. In the middle of the drainage basin, water level descended 10-20m above the overflow zone of springs, and descended 1-5m below the overflow zone, which decreased the springs' flow rate even to dry up.

2.4 Land Subsidence and Karst Sinkhole Caused by Groundwater Exploitation

Groundwater over exploitation not only caused the water table descent, but also resulted in land subsidence and karst sinkholes. In early 1990s, the land subsidence area reached to about 48 700km2 crossing 16 provinces (districts, cities) including Shanghai, Tianjin, Beijing, Jiangsu, Zhejiang, and Hebei Provinces. Until 2003, the land subsidence area has reached to 93 855km2 with a serious land subsidence region comprised of Yangtze Delta, North China Plain and Fen River and Wei River fault basin formed (Yin Yueping, 2005).

Yangtze Delta is the most serious land subsidence area in China. Shanghai area in Yangtze Delta is the city suffered from the earliest and most influenced land subsidence which caused most severe damage. In 1920s, a great scale of urban constructions along with the increasing exploitation of groundwater around the urban area caused immediate land subsidence. So far, the surface subsidence over 200 mm in Shanghai downtown area, Suzhou, Wuxi, Changzhou, and Jiaxing has covered an area about 10 000 km2, accounting for 1/3 of the total area, and was expected to connected into a sheet. Although, the groundwater exploitation ban have been carried out recently, and the water table in most part is beginning to rebound, yet the subsidence rate is still keeping between 20mm and 40 mm per year, even reaching to 80-120mm a (Fig 2).

As the largest land subsidence area in China, the North China Plain has an area of more than 70 000 km^2 subsided, with Tianjin, Cangzhou and northeast rural area of Beijing as three centers. Land subsidence of Tianjin happened simultaneously with that of Shanghai since 1920s; however, its deepest land subsidence is over 3.1m, the deepest subsidence in China. The land subsidence of North China Plain connected with Hebei Plain westwards, which coincided with the big cone of groundwater depression formed by groundwater exploitation in North China Plain.

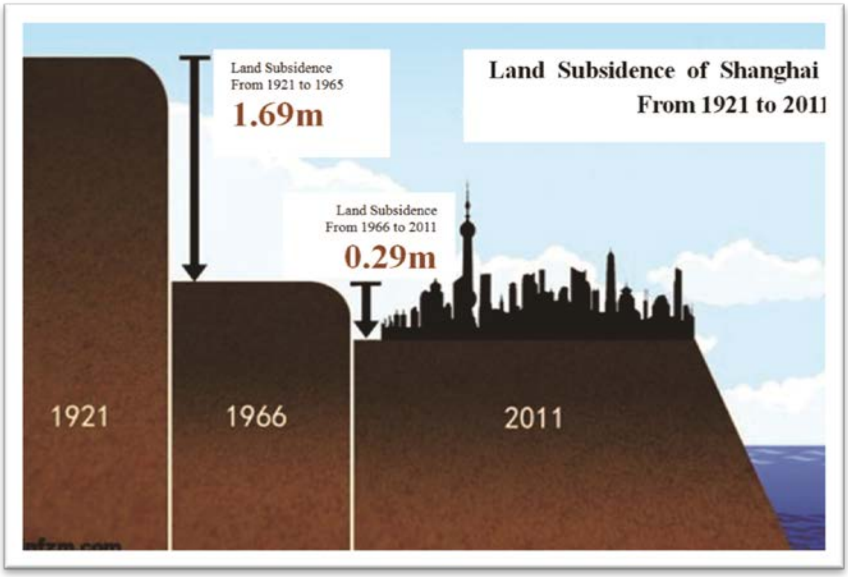

Fig.2. 1921-2011 Land Subsidence Model of Shanghai, China

Fen-Wei Graben developed along Wei River in Shaanxi and six basins in Shanxi and spread obliquely. It is an area with very strong tectonic movement, where the base structure rose and fell dramatically. Due to groundwater exploitation, not only land subsidence occurred, but also many ground fissures spread along tectonic lines. Xi'an area has land subsided continuously up to 2.6 m, with13 ground fissures in total length of 73 km occurred; Taiyuan has land subsidence reached 3 m with the total length of ground fissures as to 15 km.

Karst sinkhole is a very special geohazard in karst area, mainly distributing in South China, Middle China, Southwest China and East China. The high-risk area for karst sinkholes is about 600 000 km2, including more than 30 metropolis or medium cities like Guangzhou, Wuhan, Shenzhen as well as 328 counties and small cities. Karst sinkholes showed an increasing trend according to time, changing from dozens of times per year before 1980 to several hundreds of times per year currently (Fig.3). Spatially, karst sinkhole has presented urbanized and industrialized trend.

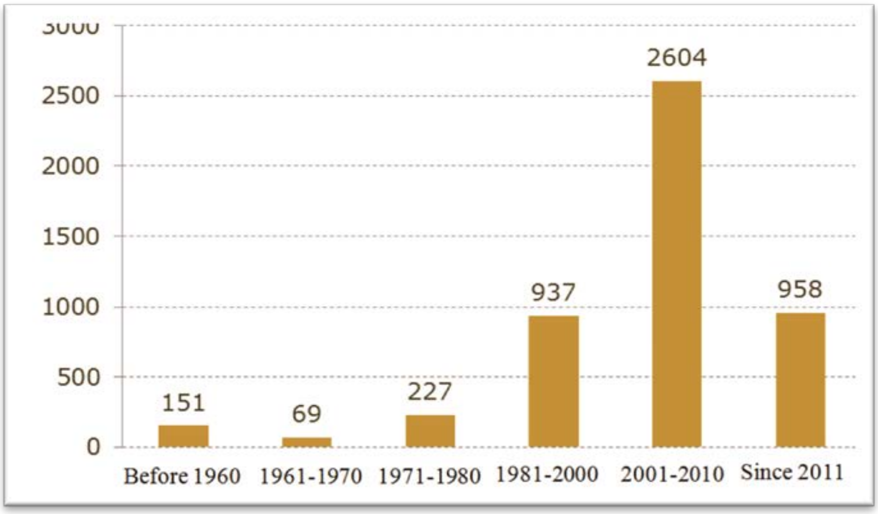

Fig.3. Change of the Frequency for Karst Sinkholes in China since 1960

81% karst sinkholes of China were caused by human engineering. Over exploitation of groundwater, mines unwatering and discharging, and underground engineering construction by human beings are major incentives for karst sinkholes. For example, 97 karst sinkhole sites and 161 times of karst sinkhole occurred in Tailai Basin in Shandong Province has been recorded. The karst sinkholes mainly concentrated in cone of karst groundwater depression and the area under its influence, which are caused by over exploitation of groundwater that resulted in over-10m descent of water table (Wang Yanling, 2015).

3. Investigation and Research Progress of the Ground Water

3.1 Hydrogeological Investigation

Since 1950s, a great amount of work on hydrogeological investigation and evaluation has been carried out by the sectors under Ministry of Land & Resources of China with a lot of materials and data about hydrogeology acquired. Based on the hydrogeological survey in 16 districts to 2.2 million km^2 in the scale of 1:250 000, CGS has organized a new round of evaluation on groundwater resources in China. According to the administrative districts of China, 32 provinces (region, city) with Hongkong Special Administrative Region and Macau Special Administrative Region, as well as 7 key areas like the Yellow River Drainage Basin and Yangtze Delta according to regional division were evaluated scientifically; meanwhile, a comprehensive evaluation on groundwater across China were implemented. *China Groundwater and Environment Atlas*was compiled and China Groundwater resources database was set up.

] In order to increase the accuracy of regional hydrogeological survey and groundwater exploitation, the hydrogeological survey (1:50 000) to 350 000 km^2 key areas, like karst area in Southwest China, Ordos Basin, Qaidam Basin, Shanxi and Shaanxi energy bases, has been finished by the end of 2015. The hydrogeological conditions and their changes were further clarified with groundwater systems divided. Groundwater resources were re-evaluated by new methods like numerical modeling, with the potential for groundwater exploitation and utilization analyzed. Besides, the main geo-environmental problems related to groundwater were detected, with the scheme of groundwater exploitation and utilization proposed. Moreover, a series of maps on groundwater and its environment in China and the surrounding areas were compiled, with the database for original data on groundwater resources and its environmental evaluation established which has helped to realize the digital management of geological survey data and results.

The general investigation of groundwater resources has shown that the natural recharge of fresh groundwater resources is 8 840×10^{8}m^3/y; the exploitable groundwater quantity is 3 530×10^{8}m^3/y, and the current exploited quantity of groundwater is 1 115×10^{8}m^3/y, which indicates a relative greater potential for groundwater exploitation and utilization (Wang Xiaojun, 2010).

Considering the new situation for national eco-civilization construction, CGS took the support and service to developing strategy of national key areas as a core, embraced around the significant and essential demands of key economic areas closely, and planned to carry on basic hydrological, engineering and environmental geological work in a medium scale to key areas including key economic areas, main groundwater exploitation areas, high-risk geohazards areas, critical civil engineering areas and concentrated mining area of mineral resources, evaluate resources and environmental carrying capacity comprehensively, establish a completed hydrogeology-engineering-environment information system and deepen the understanding of national and regional hydrogeological-engineering-environmental geological conditions and rules in the future.

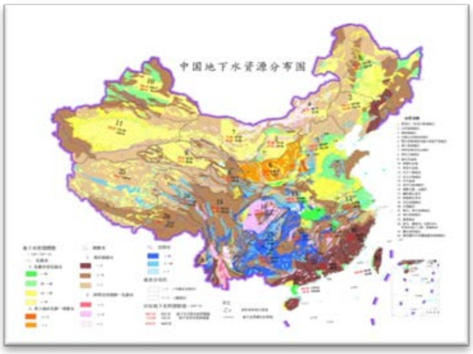

Fig.4. Groundwater Resources Distribution in China (left)
Fig.5. Groundwater Environment of China (right)

3.2 Groundwater Pollution Investigation, Evaluation and Control

The first round of national groundwater pollution investigation and evaluation work was started by CGS in 2005. It aimed to detect the situation of groundwater pollution, evaluate the pollution situation and its variety comprehensively, plan the regionalization for addressing groundwater pollution and protection, and set up a groundwater quality and pollution warning system. By 2015, regional groundwater pollution survey (1:250 000) has been implemented in 4 400 000 km^2, which covered 10 provinces (municipalities) including Beijing, Tianjin, Hebei, Henan, Shandong, Anhui, Shanghai, Jiangsu, Zhejiang and Guangdong, involving 420 million populations. The investigation and evaluation mainly focused on fresh water aquifers with more than 12 200 groundwater samples collected, each of which had 7 physical and chemical indexes analyzed in situ, 27 inorganic chemical indexes and 36 organic chemical indexes analyzed in the lab, as well as 51 organic indexes were selected to be analyzed according to different conditions of different study area. This round of survey and evaluation is a systematic and comprehensive work on regional groundwater quality and pollution in China with a great amount of original data obtained.

In 2011, China government published the *Action Plan for Prevention and Treatment of Water Pollution (2011-2020)* with the target, measures and specific projects put forward. By the end of 2015, it required to grasp the general groundwater pollution situation, to fully start the experimental sites for groundwater pollution rehabilitation, to renovate the soil affecting the groundwater environmental safety gradually, to control the pollution sources initially, to establish groundwater environment supervision system comprehensively, to improve water quality of centralized drinking groundwater source in cities and towns, and to contain the groundwater quality worsen trend initially. By then end of 2020, it has also claimed to supervise typical groundwater pollution sources comprehensively, to control the soil affecting groundwater environmental safety effectively, to implement the groundwater rehabilitation scientifically, to guarantee the water quality safety in important drinking groundwater sources principally, to enhance the capacity of supervision to groundwater environmental safety comprehensively, to improve the groundwater quality in key areas obviously, to prevent and control the groundwater pollution risk effectively and to establish a prevention and controlling system for groundwater.

At present, the national groundwater pollution survey in 1:250 000 is completed. Furthermore, the 1:50 000 investigation in key area will be carried on. Meanwhile, some experimental sites for groundwater rehabilitation in large-scale and medium-scale cities were launched.

3.3 Groundwater Protection and Geohazards Prevention

Geohazards including water table descent, springs dried up, land subsidence and karst sinkholes are mainly caused by groundwater overexploitation, which could only be solved directly and effectively by strict control of groundwater exploitation. In 2004, China started the groundwater protection action project, and conducted pilot groundwater protection in fragile ecological areas, karst areas in Southwest China, main mining area and geothermal exploitation area in Northern China, water receiving areas on east and middle routes of South-to-North Water Diversion Project. By taking the groundwater over exploitation area as a key controlling site, a groundwater over exploitation prevention plan was compiled. In this plan, the targets for controlling the groundwater overexploitation and recovering the ecosystem were determined, the measures and scheme including allocation of groundwater source for exploitation, groundwater artificial recharge and reinjection, sealing wells, metering and monitoring to groundwater etc were defined; meanwhile, the groundwater recharge and management of water-receiving areas in South-to-North Water Diversion Project and land subsidence regions has been boosted actively. In recent years, local regulations and laws corresponding to control groundwater overexploitation have been made by different regions in China.

But the key for reducing groundwater exploitation is to find out a replaced water source. People lived on water, industry and agriculture also rely on water, whereas, the water usage is contradicted to water environment protection, especially in more serious North China. In North China, groundwater over exploitation is mainly caused by irrigation. Without solution of water used for agricultural irrigation in North China Plain, it could only be impossible mission to solve the problems like surface subsidence. In order to find a proper replaced water source, many areas in China are conducting trans-drainage basin water diversion, such as water diversion between provinces or regions. Currently, a significant strategic project- South-to-North Water Diversion Project implemented by China is a large-scale water diversion project aimed to remit the water resources shortage in North China.

Except for restricting the exploitation, some areas in China were reinjected to increase the recharge, which could be very effective to remit the water table descent and land subsidence. Since 1966, Shanghai government started the groundwater reinjection project. According to real monitoring data for surface subsidence of last year, the target for controlling subsidence of the next year was made. From 1966 to 2003, the total reinjection amount reached to 600 million m^3. As to the exploitation of 2003 in Shanghai, it reached to almost 100 million m^3 and was reduced to 13.31 million m^3 in 2011 but with the rejection amount to 18.61 million m^3, which realized more reinjection than exploitation for the first time. At the same time, the subsidence of Shanghai decreased from 8.4mm in 2005 to 6mm in 2011. Groundwater reinjection not only recovered the water table, but also controlled the surface subsidence effectively; meanwhile, groundwater reinjection could also increase the groundwater resources to enhance utilization rate of resources.

Since 2005, geohazards investigation including land subsidence in 1:50 000 scale covering 100 000 km^2 crossing Yangtze River Delta, North China Plain, Fen-Wei Grabenetc was implemented. Since 2010, karst sinkholes investigation in 1:50 000 scale covering 20 000 km^2 crossing Pearl River Delta, Wuhan area, middle of Hunan Province and middle of Guangxi Region has been implemented. For the geohazards investigation to these two aspects, groundwater was a necessary element for geo-environment, the investigation of the number of wells and exploitation amount, as well as the selection of representative wells for sampling and investigation on groundwater dynamic changes were conducted.

A monitoring network for land subsidence covering the whole country with national GPS and IN-SAR satellite was set up initially, which could be used to realize joint monitoring in different districts. In key areas, the monitoring network could be used for real-time monitoring and in-time forewarning; in the serious area, the network could be used to monitor land subsidence comprehensively. A comprehensive monitoring network with GPS, IN-SAR, leveling, bedrock index and layering index will be set up.

3.4 Groundwater Sustainable Utilization in North China Plain

The investigation indicates that the groundwater safety yield in North China Plain is $223.60\times10^8 m^3/a$, of which, the shallow groundwater (less than 100m) safety yield is $202.94\times10^8 m^3/a$, and that of deep groundwater is $20.66\times10^8 m^3/a$. The spatial distribution of groundwater resources is extremely uneven, with the shallow groundwater concentrates in sub-mountain region of Taihang Mountain. The resources amount in unit area could exceed $30\times10^4 m^3/km^2\cdot a$, but it decreased in the central and east areas. As a consequent, it is less than $10\times10^4 m^3/km^2\cdot a$in coastal regions. The exploitable deep groundwater resources amount is generally less, of which, the region with the exploitable resources amount of unit area more than $4\times10^4 m^3/km^2\cdot a$ distributed in the central and west parts of North China Plain, while that of coastal areas less than $1\times10^4 m^3/km^2\cdot a$ except Tianjin.

Evaluation on sustainable utilization potential indicates that the shallow groundwater in North China Plain is a little sufficient with the sufficient amount of $27.33\times10^8 m^3/a$ and the exploitable potential module as $1.96\times10^4 m^3/km^2\cdot a$. Generally, the exploitation and recharge are relatively balanced, but the exploitation potential is normal with uneven spatial distribution. In cone of groundwater depression along the sub-mountain of Yanshan and Taihang Mountain, the shallow groundwater is over exploited or seriously over exploited with the over exploitation amount reached to $27.83\times10^8 m^3/a$, and the area suffered from overexploitation accounting for 23.89% of the total area, showing no potential anymore. In the ancient river channels along sub-mountain of the Yellow River or in the central and east plain, shallow groundwater still has some potential for exploitation with the surplus of exploitation of $54.95\times10^8 m^3/a$, accounting for 52.99% of the total area. Especially in the central and east plain, the exploitation potential of brackish water and saline water is relatively greater. The exploitation and utilization rate could be enhanced if the conditions were allowable, which could increase the sustainable utilization potential of shallow groundwater. Deep groundwater is generally over exploited with the exploitable potential module as $-0.73\times10^4 m^3/km^2\cdot a$, and the overexploitation amount up to $8.79\times10^8 m^3/a$. Overexploitation and serious overexploitation areas account for 61.9% of the total area without any exploitable potential anymore. The groundwater sustainable utilization investigation results in North China Plain shows that it is very necessary to control the groundwater exploitation, especially the deep groundwater exploitation. According to national economic development plan, the groundwater resources should be allocated scientifically, with the groundwater exploitation and utilization rate being reduced reasonably and the wells distribution for exploitation being adjusted year by year.

3.5 Global Climate Change and Groundwater Research

In 2007, Spain Government signed an agreement with United Nations (UN), providing 5 hundred million US dollars to UN for establishing the Spain millennium development fund. In this fund, 12 million dollars will be used to carry out the project of framework for climate change cooperation between China and the United Nations (CCPF).The participants of this project are comprised of 12 government institutions from

China and 9 institutions from United Nations. CCPF has 15 projects in China, one of them is about global climate change and groundwater research. There are three main objectives in this project, including strengthening the construction of monitoring capacity for climate change to groundwater impact, monitoring and simulation of water table and water quality change to serve for the groundwater management and exploitation control, and establishing national platform for information, technology and experience exchange. According to the research, water table is mainly controlled by precipitation and human activities in recent 30-40 years. Human activities are impacted by precipitation with good synchronicity between. Evaporation and temperature have barely direct impacts to water table, but comparatively greater impact to water consumption, which means they have comparatively greater indirect impacts to water table. In shallowly-buried area of groundwater and the neighboring area near river way, the influence weight coefficient of precipitation to water table is of 25%-30%, while that indeep-buried area of groundwater is only about 10% (confidence coefficient is 0.05) (Gao Zhanyi, 2008). It has also found that human activities played a role of amplifier to influence on climate change and groundwater. The influence weight coefficient of climate change to groundwater is between 10% and 30%, but it is amplified by 2 to 3 times due to human activities. The decrease of precipitation with endless human activities may increase the extraction of groundwater, which have a significant indirect impact to groundwater, equaling to a function of amplifier.

China also carried out the IGCP379 project of *Karstification and Carbon Cycle* (1995-1999).In this project, the preliminary CO_2 carbon sink amount caused by karst process in China and other countries in the world was calculated. Since 2010, CGS has organized professional teams to carryout comprehensive geological investigation on carbon-water-calcium cycle in karst area. Many dynamic monitoring stations were established including 29 stations in China and other stations in Thailand, Slovenia and USA and so on. These monitoring stations were used to monitor the process and flux between karstification and carbon cycle under different environmental conditions. The monitoring data were used to analyze the contribution and pathway of karst carbon cycle to recycle the global atmospheric CO_2 with the measures to increase karst carbon sink proposed. It does not only provide supports to international academic exchange and training on groundwater and environmental change in karst area, but also help the International Research Center on Karst (IRCK) under UNESCO to play its important role.

The contribution of karst groundwater to the recycle of global atmospheric CO_2 is mainly manifested in three aspects: the first one is to bring the inorganic carbon sink with high concentration of HCO_3^- to the ocean through water-rock interaction; the second one is to promote the accumulation of regional vegetation and organic carbon in soil; the third one is to facilitate the fixation and transform of inorganic carbon by aquatic vegetation in karst water (Jiang Zhongcheng, 2012).In August of 2011, the absorption process of HCO_3^- by aquatic vegetation was monitored in outlet of Guancun Underground River, Guangxi. From the outlet to Leiya Village which is 1.35 km away from the outlet, the reduction of HCO_3^- in the stream is negatively related to stable carbon isotope, which indicated the influence of aquatic vegetation (Fig. 6). According to the research data, the daily fixed DIC value of aquatic vegetation in Guancun Underground River is calculated as 94.9 kg, namely 1152 mmol/d.m. This result is higher than DIC settlement value of 130 mmol/d.m of surface river which is recharged by large karst spring in Florida, USA (Zhang Cheng, 2011). It indicated that the amount of carbon sink produced by photosynthesis of aquatic vegetation in surface river of subtropical karst area in Southern China is higher than that in Florida, USA

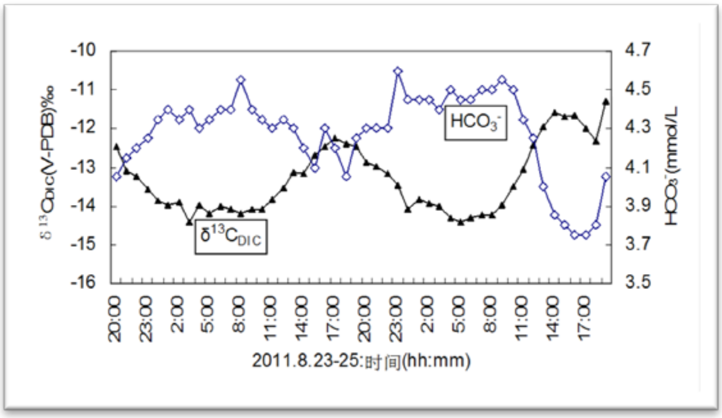

Fig.6. Temporal change of HCO_3^- and $\delta^{13}C_{DIC}$ of Karst Water in Leiya Village of Guanchun Underground River

3.6 Demonstration of Groundwater Exploitation and Utilization

At present, the patterns for groundwater exploitation and utilization in China are as follows (Xu Hengli, 2001): vertical well drilling that is usually used for collecting water through tubular wells or large-opening wells, it is widely used in China and also the most common pattern to use groundwater currently; horizontal interception system, which is widely used in kariz projects in Hami, Turpan, and Shanshan in Xinjiang of China, it is used by intercepting the shallow groundwater in the upper of alluvial-proluvial fans; horizontally and vertically combined system that combined all kinds of wells, ponds and reservoirs to exploit and utilize groundwater; spring diversion system, which is mainly used in water supply and medicine treatment by collecting and regulating spring water according to the exposed conditions. It also can be used for agricultural irrigation when the spring discharge is sufficient, such as oasis in Gobi desert and loess plateau area in Northwest China, and karst mountainous area in Southern China.

Since 1999, combined with hydrogeological survey, more than 6 000 deep wells with 200 shallow wells both for survey and exploitation have been drilled in dry area with water shortage in Northwest China, karst area and red bed area in Southwest China, low-quality water area with high concentration of F and As in Northern China. Besides, over 10 demonstration projects for underground rivers and large karst springs development have been constructed, which have helped to solve drinking water problems for more than 22 million people. With complicated topography of karst mountainous area in Southwest China, the groundwater exposed to surface mainly through large karst springs and underground rivers. According to the distribution, exposed conditions and water supply demands of karst water, the groundwater exploitation and utilization patterns mentioned above are widely used in karst area of Southwest China, for instance, vertical well drilling in karst valley area, horizontal interception for gathering water inside karst cave, diversion of water from surface-subsurface connected reservoir and karst springs for supply in karst peak cluster-valley area, and so on. Therefore, the exploitation and utilization of karst groundwater should adapt to local conditions, and the karst water should be reasonably used through comprehensive ways including damming, storing, diverting and pumping. Many demonstration projects have been implemented successfully so far, such as epikarst spring diversion project in peak-cluster mountainous area in Guangxi of China, damming large karst springs in Pijiazhai, Yunnan (Fig.7), intercepting underground river channel to form a surface-subsurface connected reservoir in Luota, Hunan and Fuliulang, Guangxi (Jiang Zhongcheng et al., 2006; Wang Yu, et al., 2006; Mo Risheng, et al., 2006).

Fig. 7. Restricting Flow Rate and Adjusting the Pressure by Damming Large Karst Springs in Pijiazhai, Luxi Basin

3.7 Groundwater Monitoring Projects

Since 1950s, China began to carry out the groundwater monitoring, which is mainly in implemented by the Ministry of Water Resources (MWR), Ministry of Land & Resources (MLR) and Ministry of Environment Protection (MEP). They have different focuses, for instance, MWR focused on groundwater quantity, MLR focused on water level change may be caused by geo-environmental problems like land subsidence, collapse, and groundwater pollution, while MEP focused on groundwater pollution. MWR and MLR have begun the groundwater monitoring earlier, with a preliminary national scale of groundwater monitoring network formed. By the end of 2012, over 48 300 long-term groundwater dynamic monitoring stations have been established and operated (Jing Liuxin, 2013).

In 2015, China launched a national groundwater monitoring project, which meant to establish a national groundwater monitoring center and 31 provincial monitoring centers by MLR and MWR. MLR planned to set up (reconstruct) 10 103 monitoring stations (Fig. 8) within 3 years in North China, East China, West China, Central South China, Southeast China, and Southwest China; meanwhile, MWR planned to establish (reconstruct) 10 298 groundwater monitoring stations. This project will greatly enhance the groundwater monitoring level of China, it will also be very significant to support the implementation of the most strict management regulation of water resources, to promote the sustainable utilization of water resources, to facilitate ecological civilization construction, and to ensure the sustainable development of economic society.

Fig. 8. Groundwater Flow Rate Monitoring through Multilevel Rectangular Weir in Subtropical Monsoon Climate Area---Zhaidi Underground River, Guangxi

4 Conclusions

(1) The annual natural recharge for fresh groundwater is 8 840 $\times 10^8 m^3$/y, accounting for about 31% of water resources in China. The groundwater in China could be classified into three types including pore water, karst water and fissure water. China is abundant in groundwater resources, with the exploitable quantity as 1 686 $\times 10^8 m^3$/y, which is the significant water sources for karst area in Southern China and many cities and energy bases in Northern China, it is also the main supply for addressing severe drought in China. Most of groundwater in China buried deeply but unevenly, which results in difficulty on investigation and exploitation, and brings about engineering water shortage in karst area in Southern China and energy bases in Northern China. Therefore, China Government strengthened the 1:50 000 scale hydrogeological survey in key areas with higher accuracy, and constructed different types of demonstration projects for groundwater development and utilization, which have helped to solve drinking water problems for more than 22 million people.

(2) Groundwater overexploitation problems are serious in some areas like North China Plain, with the area suffering from overexploitation up to 190,000 km^2. It not only resulted in water table descent with over 100 regional cone of groundwater depressions formed, but also brought about geohazards like springs dried up, land subsidence in cities and plains, karst sinkholes and ground fissures in Northern China. Therefore, China Government launched *Groundwater Protection Action Project* to carry out pilot groundwater protection and South-to-North Water Diversion Project including artificial recharge, groundwater exploitation, water sources allocation, groundwater reinjection, sealing and filling wells with notable effects on preventing and treating geohazards caused by groundwater achieved.

(3) The groundwater quality of China is generally good, however, in some regions, the agricultural non-point source pollution, heavy metallic pollution in mines and organic pollution in some cities are worsening, which has become the key issues for drinking water safety. China Government strengthened the support to investigation and prevention of groundwater pollution, and established a groundwater monitoring network, which makes investigation, monitoring and prevention of groundwater pollution become new hot issues for groundwater research.

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Recent Groundwater Issues in Indonesia

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Abstract

Groundwater has become one of sources of raw water for drinking water for domestic, municipal and industries in Indonesia. Since the last three decades, in the era of developing of the country, populous cities serving as centers of development for services, education, tourism and other sectors are growing in the whole of Indonesia. The need for water, therefore, is increasing correspondingly to the population and economic growth. Unfortunately, to meet the demand for water, there is still a need to rely on groundwater resources.

Related to the lack of water supply infrastructure from surface water, it causes to exploitation groundwater resources for water demand. It is estimated about 80 % of the total clean water supply for rural and urban areas rely on groundwater, whereas industry relies nearly 90 % of its water need on groundwater resources. Consequently, degradation, both quantity and quality of those resources is already an evidence. Therefore, proper integrated water management in concept of groundwater management is essential to ensure its availability both its quality and quantity and hence, its sustainability can be utilized for the benefit of the people of Indonesia.

Keywords: population and economic growth, the lack of water supply infrastructure, exploitation groundwater, integrated water management

1. Introduction

Water is essential for life; without water all life on earth will be extinct. At current and future, water as a natural resource (includes groundwater) is a very important factor for the development. There would be no development without guarantee of water availability. The role of water to support the development becomes more and more strategic and it becomes a reliable resource of income to the government and people. Therefore God's gift should be managed properly in order to maintain groundwater sustainability for the benefit of mankind.

In Indonesia, the groundwater resources, primarily shallow groundwater, have been developed for centuries. The deep groundwater has become one of sources of raw water for drinking water for several big towns and the Government needed to manage the groundwater and put into effect a series of water regulations.

The occurrence and properties of groundwater, its origin, movement and chemical, constituents, are controlled by the geological frame work; that is, the lithology, structure and porosity of rocks and sediment through which the groundwater moves. Based on the geological setting, in general the occurrence of groundwater in Indonesia can be distinguished into four regions; groundwater in unconsolidated and semi-consolidated rocks, groundwater in Quaternary volcanic products, groundwater in carbonate rocks, and groundwater in consolidated rocks (Figure 1).

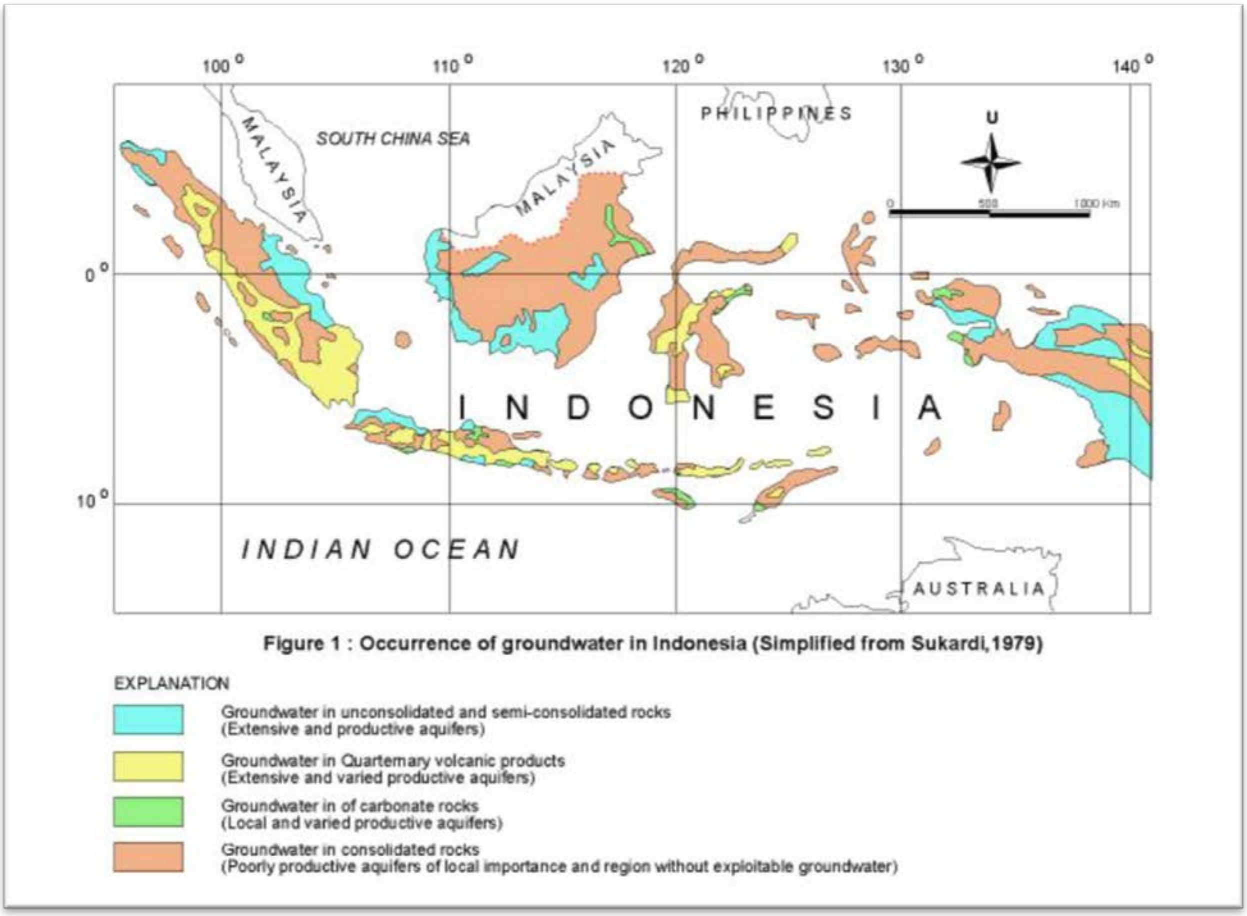

Fig. 1. Occurrence of groundwater in Indonesia (simplified from Sukardi, 1979)

Groundwater in Unconsolidated and Semi-Consolidated Rocks

In Indonesia, the Quaternary sedimentary rocks comprising unconsolidated and semi-consolidated rocks are generally permeable enough to yield large quantities of water to wells. The unconsolidated rocks displayed by fluvial deposits are composed of gravel, sand, silt or clay.

The types of occurrence of these aquifers may be broadly grouped as coastal plain, intermountain basin, and river valley, whereas the mode of saturated flow within these aquifers is intergranular.

Fluvial materials occur in nearly all regions and the aquifer of fluvial origin are important sources of water supply, such as in eastern Sumatera, northern Java, coastal plain of Kalimantan, and southern Papua. The delineation of aquifer zones in these deposits using borehole data is difficult task, because the variability of sediment sources and flow.

The fluvial deposits that located in the intermountain basins e.g. Bandung, Madiun, Kediri, and Bondowoso basins consist of sand and gravel and these basins are major source of groundwater supply for these areas.

Groundwater in Quaternary Volcanic Products

The Indonesia archipelago contains one of the most extensive volcanic regions in the world with 129 active volcanoes, approximately 333,400 km2 in area or 12.5 % of the whole Indonesia territory. The material of Quaternary volcanic products is composed by lava, gravel, volcanic sands, and fine materials of volcanic origin. Groundwater flows in Quaternary volcanic products, either through granular interstices or through fissures. As in the fluvial deposits, groundwater in Quaternary volcanic products which cover extensive regions along Sumatera, Java, Sulawesi, Bali, Lombok, and Sumbawa are high potential groundwater resources in Indonesia.

Groundwater in Carbonate Rocks

Carbonate rocks, in the form of limestone and dolomite are widely spread in Indonesia, although they occupy only a few percent of the entire territorial area of Indonesia and they are exposed in Sumatera, Java, Bali, Lombok, and Sulawesi until Papua.

The carbonate rocks generally are good groundwater bearing formations in Indonesia. The occurrence of groundwater in limestone is governed by the presence of secondary porosity. The groundwater is, therefore, unevenly distributed, and its potential depends mainly on the intensity of solution channeling. The intensive development of groundwater in the carbonate rocks has been done in Southern Mountain Area of Yogyakarta.

Groundwater in Consolidated Rocks

Since rocks generally have low permeability, the occurrence of groundwater in consolidated rocks in Indonesia has little significance. Groundwater especially fills fissures, cracks and bedding planes. However, the occurrence of groundwater is limited because the fissures system is closed and is not interconnected. The occurrence of groundwater of this type is spread over areas in North and South Sumatra, West and Central Kalimantan, South Sulawesi, East Timor, and Papua.

2. Recent Groundwater Issues in Indonesia

Based on the results of the distribution calculation of surface water by the Ministry of Public Works (Fig. 2), the raw water potential that available is 3,906,500 million m^3 per year, which it can be utilized only 691.300 million m^3 per year or about 18 percent.

The potential of water resources of the 18 percent which can be utilized is only 175,100 million m^3 per year or about 25% that has been utilized. The amount of water that has been utilized about 19.5% is used for domestic consumption and urban while the remaining 80.5% is used for irrigation.

The water resources are operated by water supply company which mostly comes from surface water tends to decline in quality which will result in high operating cost and have difficulties in the development of services.

Based on BPS – Statistics Indonesia (Fig. 3), the main source of water for public is dominated from the groundwater. The groundwater usage in Sumatera, Java, and Bali reached 60% of the total water resources. The groundwater use is expected to increase as the high rate of population growth.

Accordance to the national water resources policy that groundwater is the last alternative source after the water surface, but in fact the groundwater is currently become a major of water source for public and industrial use.

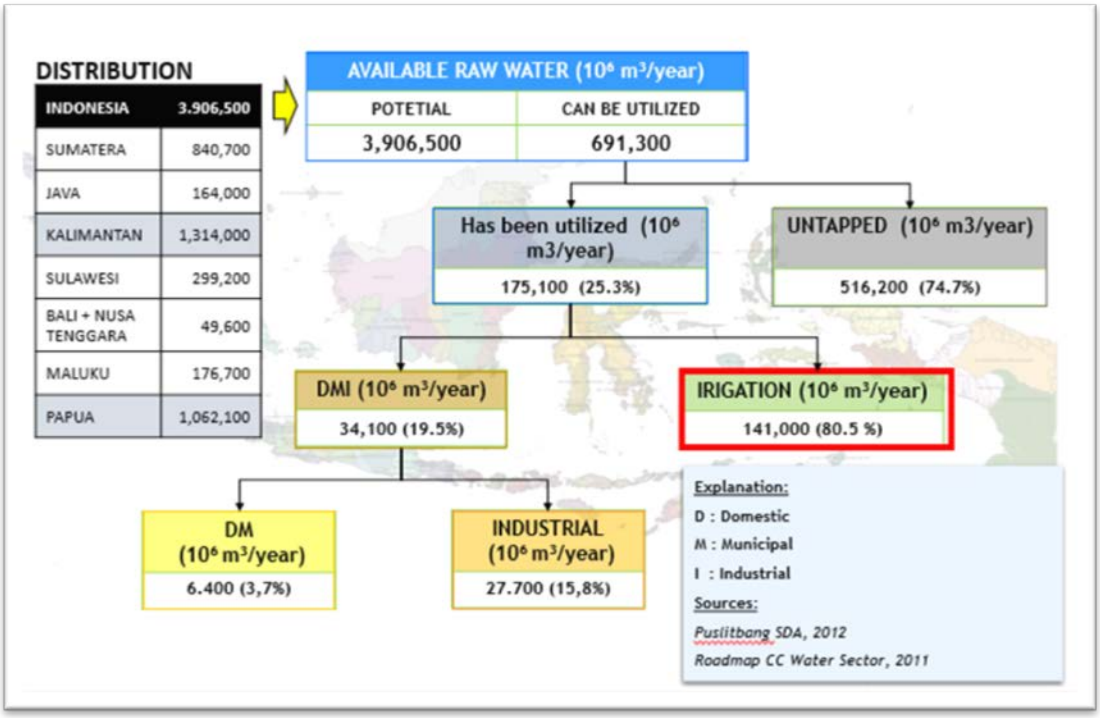

Fig. 2. Distribution of Raw Water

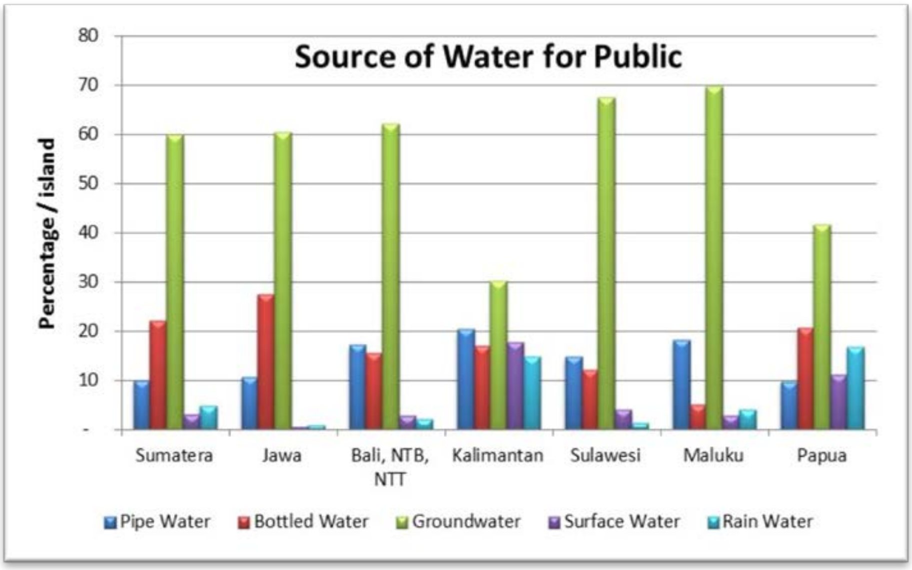

Fig. 3. Percentage of the water source for public

In Java island generally occurs the concentration of industrial and residential in the plains area which is generally an area of unconsolidated sediment, has caused some groundwater environmental problems such as high groundwater level decline, land subsidence, and salt water intrusion.

The groundwater use in Java Island almost 40% of the groundwater potential (Table 1), leading to the industrial and residential areas became the groundwater critical areas.

Table 1. Groundwater use in Indonesia

No	Island	Population (2010)	% of Groundwater Use to Total Water Resources	Groundwater Use (10^6 m^3/thn)	Groundwater Potential (10^6 m^3/thn)	Specific Yield (20%) (10^6 m^3/thn)	% of Groundwater Discharge
1	Sumatera	50,630,931	60	1,107	123,528	24,706	4.48
2	Jawa	136,610,590	60	3,010	38,851	7,770	38.73
3	Bali, NTB, NTT	13,074,796	62	297	11,694	2,339	12.68
4	Kalimanta n	13,787,831	30	152	67,963	13,593	1.11
5	Sulawesi	17,371,782	68	429	19,694	3,939	10.88
6	Maluku	2,571,593	70	65	11,943	2,389	2.74
7	Papua	3,593,803	42	55	222,524	44,505	0.12

3. Action Study for the Groundwater Issues

Due to the groundwater condition that decreased in quality and quantity, the groundwater conservation efforts are needed by monitoring, observations and research as input for making of national water resources management policy.

Some action studies that have been done to support the implementation of groundwater conservation such as groundwater exploration, research, development and management of monitoring wells, groundwater database and modeling

The groundwater exploration activities that carried out for compiled the geometry of aquifer system is the identification of aquifer system using a simple geophysical method (geo electric method, 1D and 2D) and combine with the well drilling data.

The groundwater research that has been done such as the identification of recharge areas with environmental isotope methods in the area of Bandung and Semarang, has identified the groundwater recharge areas as part of the preparation of groundwater conservation zones delineation.

In 2015, the Geological Agency has built 13 monitoring wells with the depth of about 120 m in several locations in Java for support the determination of conservation zone.

4. Conclusions

For support the groundwater conservation is necessary to integrated water resources management thus the use of water resources from ground water can be reduced, especially in big cities, so that the groundwater conditions can be maintained in the future.

The management of groundwater database is an important effort in the analysis of the research that could support in determining of water resources management policy and spatial planning.

The science and technology of groundwater resources management are constantly being developed by other countries is a challenge for Indonesia continues to develop. Research, application of science and technology and development of human resource improvement is necessary, in order to Indonesia more capable and independent in the management of groundwater resources.

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Recent Groundwater Issues and Their Action Study in Japan

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Abstract

Groundwater Research Group, GSJ/AIST, publish Hydro-Environmental Map to understand and record groundwater situation in large plains and basins in Japan. After the Great East Japan Earthquake, hydrogeological research were carried out in the east coast of Tohoku to make clear the impact of the earthquake to the groundwater environment by tsunami and an accident of Fukushima Daiichi Nuclear Plant.

Keywords: groundwater survey, hydro-geological map, Great East Japan Earthquake, groundwater risk

1. Hydro-Environmental Map in Japan

The Groundwater Research Group of the GSJ/AIST is implementing five researches 1) construction of hydro-environment map, 2) basic study for groundwater hydrology, 3) study of coastal deep groundwater, 4) technical transfer for South-east Asian countries and 5) study of ground source heat pump system.

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

Photo 1. Observation well for monitoring land subsidence in Japan

Fig.1 Area of hydrological maps in Japan

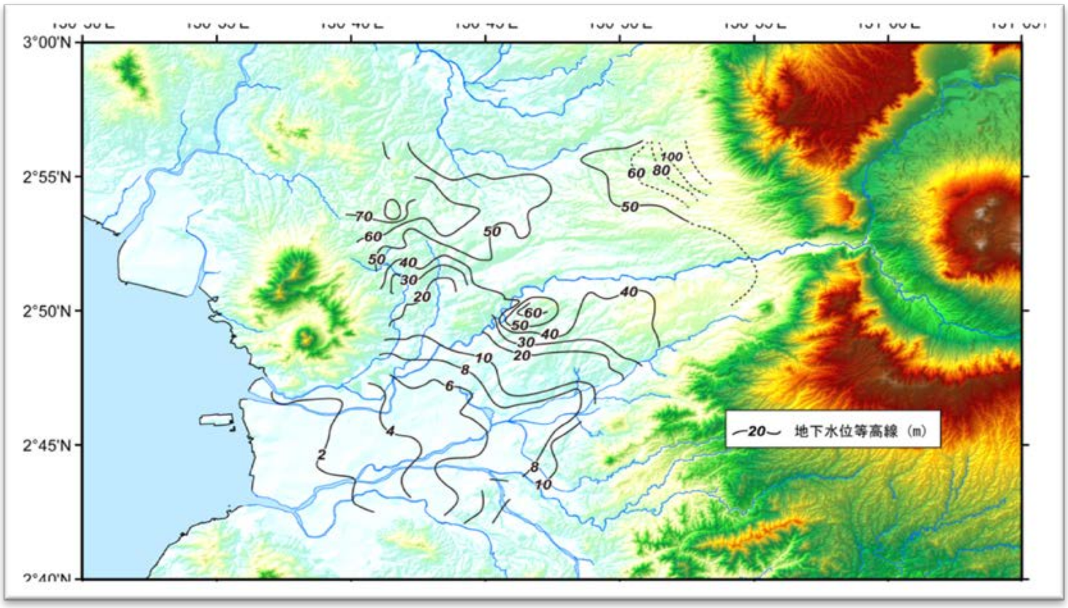

Fig. 2 Example of Hydro-Environmental Map, Equipotential line of Groundwater at Kumamoto Plain, Kyushu Island, Japan.

GSJ publish the hydrological map named "Hydro-Environmental Map" of the country. The map gives digital information in various kinds of hydrogeological understanding. Water quality including isotope analysis, temperature, flow condition, and water level have prepared in the information. The information of deposited layers about Quaternary and Tertiary of the whole Japanese Island had been analyzed and the total volume of water was estimated. We released "Kumamoto Plain, Kyushu" and "Ishikari Plain, Hokkaido" in the end of FY 2014, and also intended "Mt. Fuji area" in 2015.

2. Research on Groundwater Contamination Risk by Great East Japan Earthquake

Hydrogeological research were carried out in the east coast of Tohoku to make clear the impact of the Great East Japan Earthquake at 11th March 2011, to the groundwater environment by tsunami and an accident of Fukushima Daiichi Nuclear Plant.

The research project was constructed from groundwater study and geophysical sounding study. Groundwater research are operated in step by step, the first, overview work was operated in whole area by using rivers, springs and existing wells. The next, four points were selected to make a detail work with a drilling holes. And finally, evaluation of groundwater pollution risk were analyzed by groundwater flow simulations.

Groundwater flow simulation was conducted to contribute the reconstruction from the disaster by the 2011 off the Pacific coast of Tohoku Earthquake. Wide and detailed 3D hydro-geological models were built for the saturated and constant simulation of whole Fukushima Prefecture and around the Fukushima Daiichi Nuclear Power Plant. The dataset of geologic basement depth in the whole Japan (Koshigai et al., submitting), which is one of the AIST's DB of geology and groundwater in the whole Japan, was used to set the depths of layers for the model. The constant recharge was given from the dataset of submarine groundwater discharge in the Japan Islands.

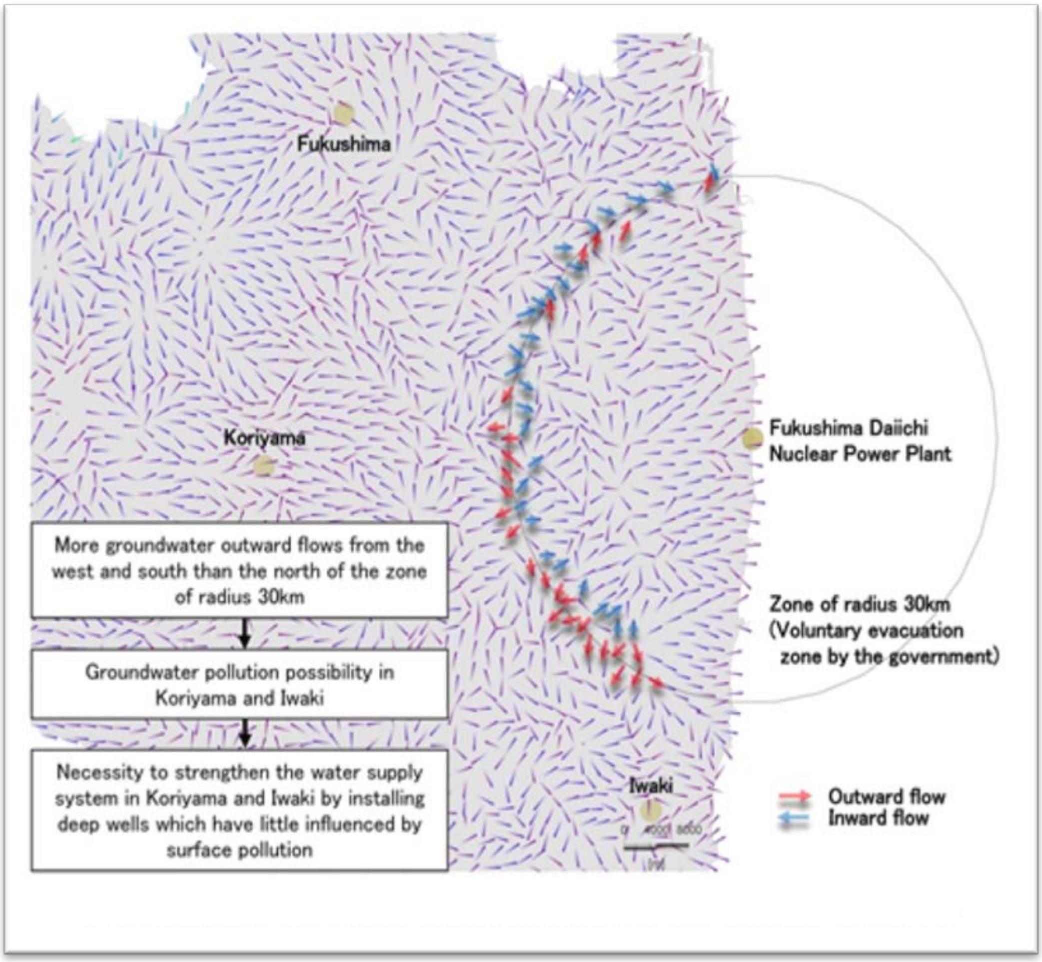

Fig.3 Groundwater flow directions around the radius 30 km of Fukushima Daiichi Nuclear Power Plant

(Ito and Marui, 2010). The simulated groundwater flow directions are shown in Fig.3. More outward groundwater flows are represented from the west and south than the north around the zone of radius 30 km of Fukushima Daiichi Nuclear Power Plant. It indicates some risk to make influence to daily water of city area in Koriyama and Iwaki when reaching the polluted water. In these cities, deep wells may strengthen the water supply system to avoid pollution risk, because deep groundwater has little influenced from surface pollution.

3. Latest Countermeasures on Fukushima Daiichi Nuclear Power Station

After five years from the accident, contaminated groundwater discharge to the marine was just closed by the Sea-side wall in October 2015. Groundwater around the buildings has pumped and cleaned to release to marine. And TEPCO (Tokyo Electric Power Company) will be started the running of Frozen wall to dry-up the buildings, that is, reactor and turbine buildings. First step of countermeasures about the groundwater will be finished, and we will move to the next stage if it works well.

3.1. Hydrogeology at Fukushima Daiichi Nuclear Power Station

Fig.4 shows aerial photograph of Fukushima Daiichi NPS. The premise of Fukushima Daiichi NPS is on the shore terrace at an altitude of 35m above sea level (hereinafter called “35m plate”), whose surroundings were eroded by rivers shown in purple. The green lines show water parting. The yellow lines show the position of the geological profile shown in Fig. 4.

Fig. 4 Aerial photograph of Fukushima Daiichi NPS. (Source: TEPCO website)

A plate at an altitude of 10m above sea level (10m plate) was made by scraping this shore terrace, and the buildings for Reactors Daiichi to 6 and the turbine buildings were constructed on it. At the port section there is a port (4m plate) made by reclamation. The surroundings of the shore terrace were eroded downward by rivers, and paddy fields exist on the alluvial lowland. These rivers originate in Abukuma Mountains, which is considered to supply water to the paddy field area. The average precipitation during past 30 years is 1560 mm/year, about 600 mm of which is estimated to evaporate and about 20% is estimated to directly flow out of the area. Therefore, the groundwater is considered to be recharged by 600 to 700mm of precipitation.

Fig. 5 shows geological profile of the premise of Fukushima Daiichi NPS at the position shown in Fig. 4 (red line). It is composed of terrace sediments that cover Neogene period Tomioka formation with nonconformity. The groundwater level is within the terrace sediments (5 to 6m below the ground surface). Alluvium is out of the premise. A plate at an altitude of 10m was made by scraping part of a table-shape shore terrace whose altitude was 35m above sea level originally, and then buildings were constructed on it. It is estimated that the original water level was within the terrace sediments (shown in red in the figure).

The most important water-bearing layers to take countermeasures hereafter are middle-grained sandstone beds. The bases of buildings for Reactors No. 3 and 4 reach the alternate strata, and radiation contamination has been detected at part of the alternate strata. The groundwater between the two layers is considered to be recharged by precipitation. The groundwater of lower two water-bearing layers is supplied by advection from Alluvium.

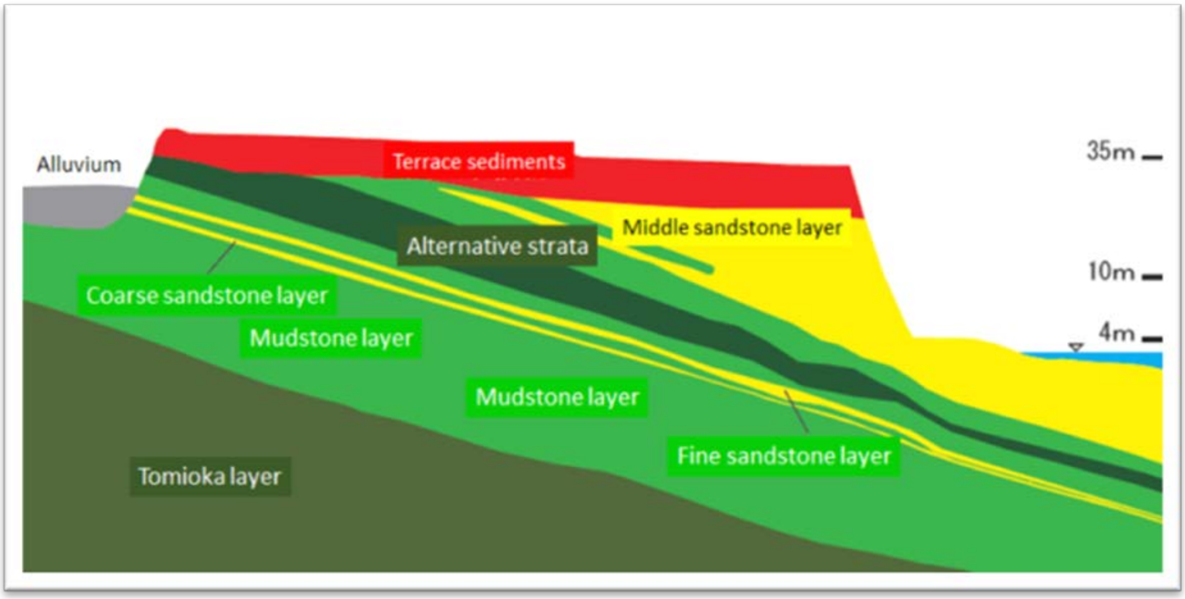

Fig. 5 Geological profile of the premise of Fukushima Daiichi NPS

3.2. Schedule for decommissioning

For decommissioning, debris which melted down has to be retrieved finally. Countermeasures for contaminated groundwater are discussed below considering what should be done and the steps to be adopted for retrieval. The overall decommissioning plan is as follows:

1) Drying-up: Remove contaminated water from the buildings of Reactors Daiichi to 4 (reactor buildings and turbine buildings), and apply waterproof treatment, etc., internally. Then, repair the reactor buildings to recover a structure where cooling water can be circulated for cooling melt-down debris. Dry-up, including engineering work necessary for cooling, is scheduled to be completed by around 2020.

2) Retrieval of debris: Develop robot technologies, etc., and retrieve debris accumulated in the reactor with safety secured. There are many challenges and technologies to be developed hereafter for this purpose, such as development of technologies to grasp the condition and position of debris, equipment to break down hardened debris and to retrieve it, and storage methods after retrieval.

3) Demolishing the building and equipment over than 15 years Based on the current conditions, it is scheduled that dry-up is finished within 10 years after the accident, circulative cooling is performed for about 15 years after then, and debris is retrieved during the next 15 years or more. Because there are many technologies to be developed and many challenges found at present (contaminated groundwater problems, etc.), it is inevitable that completion of decommissioning will become in the latter half of this century.

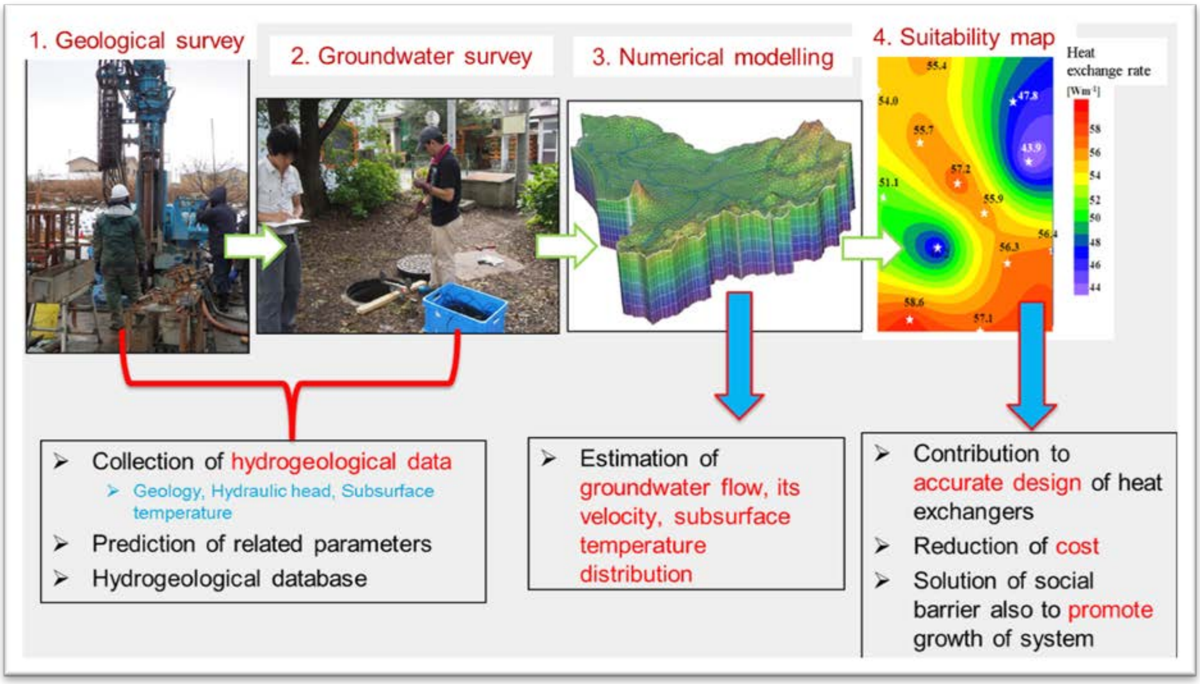

Fig. 6 Procedure for preparing a suitability map of GSHP system

4. Hydrogeological Study for Ground Source Heat Pump System

The objective of suitability mapping for Ground Source Heat Pump (GSHP) system is to evaluate appropriate areas for installing GSHP system. The term suitability for GSHP system is mainly related to heat exchange with surface, which depends on geology, groundwater flow system and subsurface temperature distribution. Hence, suitability assessment should be done based on hydrogeological and thermal information.

Fig. 6 shows the procedure for preparing a suitability map. At first, we perform geological survey, then groundwater survey in the target area. Based on field observation data, we conduct numerical analysis of groundwater flow and heat transport in regional scale. From the results of numerical analysis, suitability map is prepared with groundwater velocity, hydraulic head, and subsurface temperature distribution.

Red colored areas of the suitability map in Fig. 6 show higher potential which means these areas are suitable for system installation than blue colored areas.

5. Conclusions

Three topics of recent groundwater issues and their action study in the Groundwater Research Group, GSJ/AIST were introduced in this paper. We published Hydro-Environmental Map “Kumamoto Plain, Kyushu” and “Ishikari Plain, Hokkaido” in the end of FY 2014, and also intended “Mt. Fuji area” in 2015. Hydrogeological research were carried out in the east coast of Tohoku to make clear the impact of the Great East Japan Earthquake at 11th March 2011, to the groundwater environment by tsunami and an accident of Fukushima Daiichi Nuclear Plant. Moreover, we are conducting research on suitability mapping for GSHP system based on hydrogeological study.

Large basin scale assessment of groundwater resources according to climate change

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Abstract

The study aims to develop a numerical model simulating impacts of climate change on recharge and the groundwater flow system in a large watershed scale. VELAS model, a GIS based hydrological model coupled with MODFLOW, was developed and applied to one of the large basin, Nakdong River basin. The model simulates interception, runoff, evapotranspiration, soil water variation, and recharge on a daily basis. Climate change scenario and land-use change prediction model were also put into the model to enhance the reality of environment change in the future. Precipitation, evapotranspiration and surface runoff were calculated by 2050 under the RCP8.5 scenario, and then groundwater recharges were finally evaluated yearly from present to 2050. The simulated groundwater recharge variations are more than 200% during the simulation period. In reference to the simulated results, groundwater management may be established and implemented on each watershed.

Keywords: climate change, groundwater, VELAS, land-use change

1. Introduction

The climate change is expected to modify the hydrological cycle and affect freshwater resources. Groundwater is a critical source of fresh drinking water for almost half of the world's population and it also supplies irrigated agriculture. Groundwater is also important in sustaining streams, lakes, wetlands, and associated ecosystems. But despite this, knowledge about the impact of climate change on groundwater quantity and quality is limited (Treidel et al., 2011). Climate change can have an impact on water resources systems resulting in changes in both, the hydrologic cycle and water availability (IPCC 2007). The magnitude of local climate change depends on the rate of change of weather conditions, precipitation and temperature. Direct impacts of climate change on natural processes (groundwater recharge, discharge, storage, saltwater intrusion, biogeochemical reactions, chemical fate and transport) may be exacerbated by human activities (indirect impacts). Groundwater response to global changes is a complex function that depends on climate change and variability, topography, aquifer characteristics, vegetation dynamics, and human activities.

The purpose of this research is to develop a numerical model simulating impacts of climate change on recharge and the groundwater flow system in a large watershed scale. Research objective is mainly focused on analyzing climate change data from the Korea Meteorological Administration, developing a land-use change prediction model based on existing land-use maps which are provided by the Water Management Information System, and estimating water balance in the basin with a GIS-based water balance model according to climate change.

2. Method

2.1. Study area

The Nakdong River basin has the length of 521.5 km, the second largest drainage area of 23,817 km^2 occupying 24.1% of South Korea. The Ministry of Construction and Transportation (2001; MOCT) of Korea has reported that the country may suffer from a water shortage of 382×10^6 m^3 per year by 2011 in the three major basins (Han River basin, Geum River basin, and Nakdong River basin). Among total water shortages predicted by MOCT, the greatest, as much as 171×10^6 m^3 per year, will occur in the Nakdong River basin. Within the last 10 years, most of the cities in the Nakdong River basin have experienced at least two incidents of water supply restrictions due to drought (Korea Water Resources Corporation 2006). This particular basin is also affected by the monsoon climate: 58% of the annual flow occurs from July to September during the flood season while only 42% of the annual flow occurs during the 9-month dry season from October to June. Effective water resource management is as important in ensuring adequate supply of water as it is in preventing flooding. The Nakdong River basin in Korea has been historically vulnerable to drought and flood. Climate change effects could make that vulnerability even more extreme.

2.2. VELAS model

VELAS model is a GIS based hydrological model coupled with MODFLOW, which is **VE**getation-**LA**nd cover-**S**oil water dynamics model (VELAS) was developed by Developed by Department of Geosciences, University of Missouri in USA, Kongju National University and KIGAM in Korea. VELAS calculates interception, runoff, evapotranspiration, soil water variation, and recharge under various conditions of vegetation, land cover, and soil in a fully-distributed manner. A daily response of soil water balance depending on the vegetation-land cover dynamics is a key feature of the VELAS model.

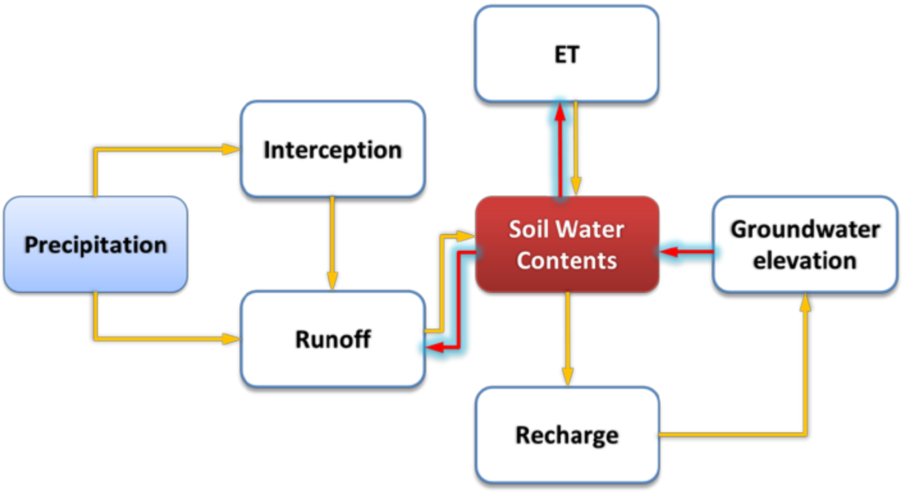


Fig. 1. VELAS model framework.

2.3. Land Change Modeler (LCM)

The Land Change Modeler for ArcGIS software extension is an innovative land planning and decision support tool. With an automated, user-friendly workflow, Land Change Modeler for ArcGIS simplifies the complexities of change analysis, resource management and habitat assessment. Land Change Modeler for ArcGIS provides a start-to-finish solution for land change analysis needs. Model land cover transition potentials that express the likelihood that land will transition in the future using one of three methodologies—a multi-layer perceptron neural network with full reporting on the explanatory power of driver variables, logistic regression, and SimWeight, a modified machine-learning procedure. Incorporate into the prediction model dynamic or static environmental variable maps that might drive or explain change (https://clarklabs.org/land-change-modeler-for-arcgis/).

2.4. Climate change scenario

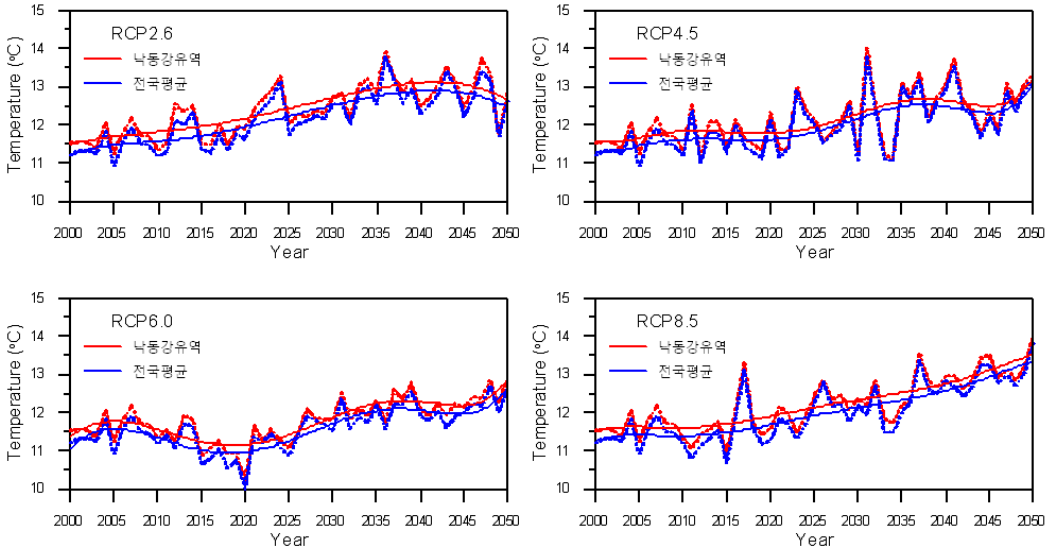
The most updated global climate projections were released by the IPCC in 2013. These apply new versions of well-established climate models that simulate changes in the Earth's climate. New climate models project similar climate changes for the same amount of greenhouse gas emissions. The pathways are used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively) (source: Wikipedia). Korea Meteorological Agency published the prediction of future climate change in Korea based on the four RCP scenarios, and we can apply the results to the VELAS model for the assessment of groundwater resources according to climate change in a large watershed.

3. Results and discussions

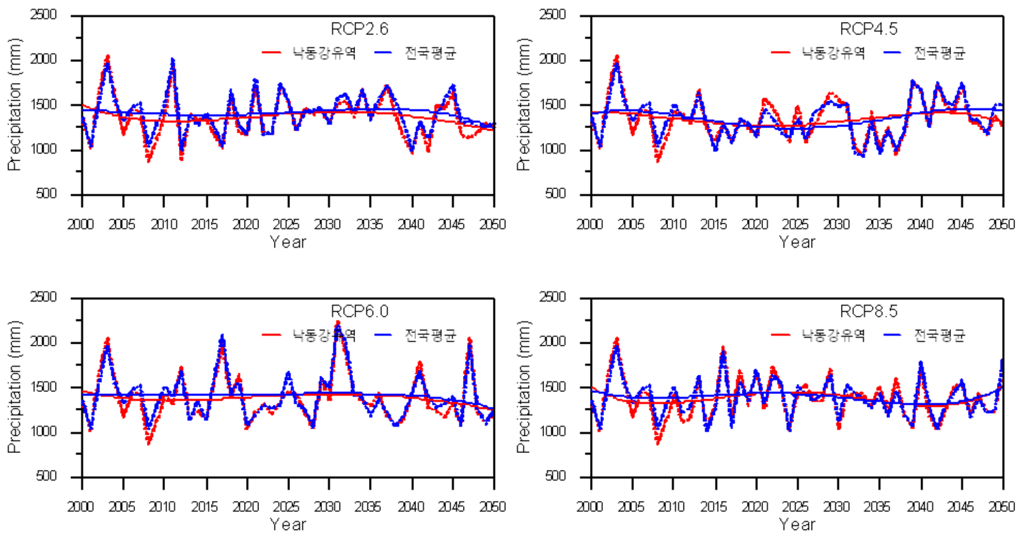
3.1. Prediction of climate change in Korea

The Korea Meteorological Administration published the "Korean Peninsula Climate Change Outlook Report" in December 2012. It applies representative concentration pathways (RCP), a new climate change scenario adopted by the IPCC (Intergovernmental Panel on Climate Change) in 2011. According to the report, future climate change on the Korean Peninsula will involve the warming trend from the past 30 years continuing steadily until 2100. If greenhouse gases are emitted at current levels (RCP 8.5 scenario), a temperature rise of 0.63°C/10 years is forecast until 2100, which is 1.6 times faster than the past 30 years. If greenhouse gas reduction policies are substantially fulfilled (RCP 4.5 scenario), the temperature is expected to rise at a rate of 0.33°C/10 years, which is somewhat lower than the trend on the Korean Peninsula from the past 30 years.

Air temperature in Korea will increase as a whole with yearly variations in the future, and the magnitude and increasing trend are much clearer in RCP 8.6 than in RCP 2.6. Air temperatures of the Nakdong River basin are a little bit higher than the average of the whole country. The precipitations do not show clear in the long term, but the yearly variations are expected in the future. Similar to air temperature, the precipitations of the Nakdong River basin are a little bit higher that the average of the whole country.



(a) Air temperature



(b) Precipitation

Fig. 3. Predictions of air temperature and precipitation prediction in Korea according to each RCP scenario. Red line and blue line represent Nakdong River basin and country average, respectively.

3.2. Prediction of climate change and land-use change

Various types of GIS data were collected and analyzed in order to apply the VELAS model in the Nakdong River basin. Those data are topography(DEM), forest type, land-use, soil map and so on. Land-use data (1975-2005) were obtained from Water Resources Management Information System (WAMIS) under Ministry of Land and Transportation and land-use changes were predicted based on the data using LCM. Besides, groundwater data, stream networks, and meteorological data were collected to be used for the application of the VELAS model.

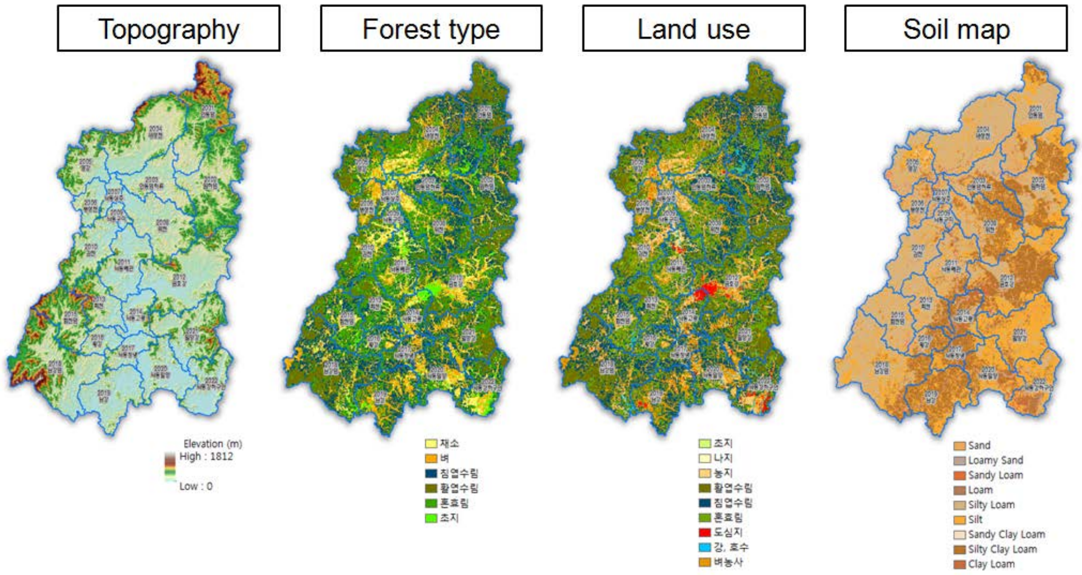


Fig. 4. Data collection in the Nakdong River basin

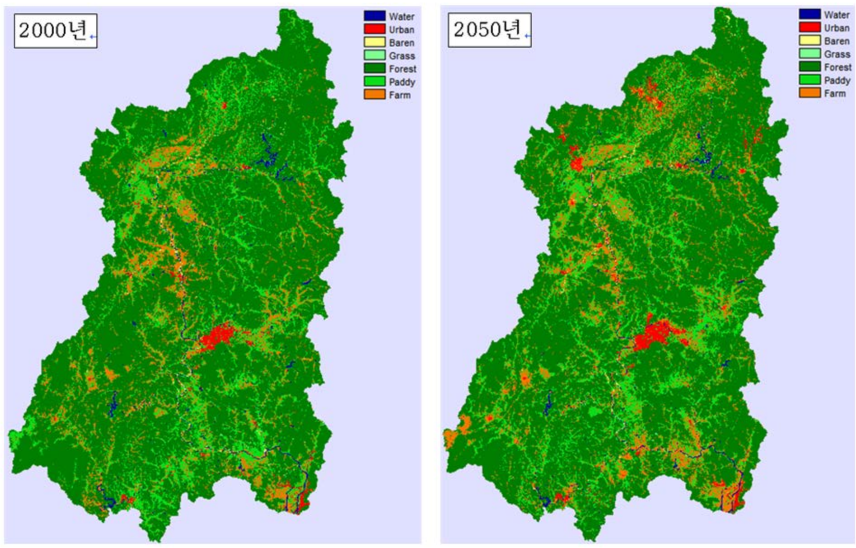
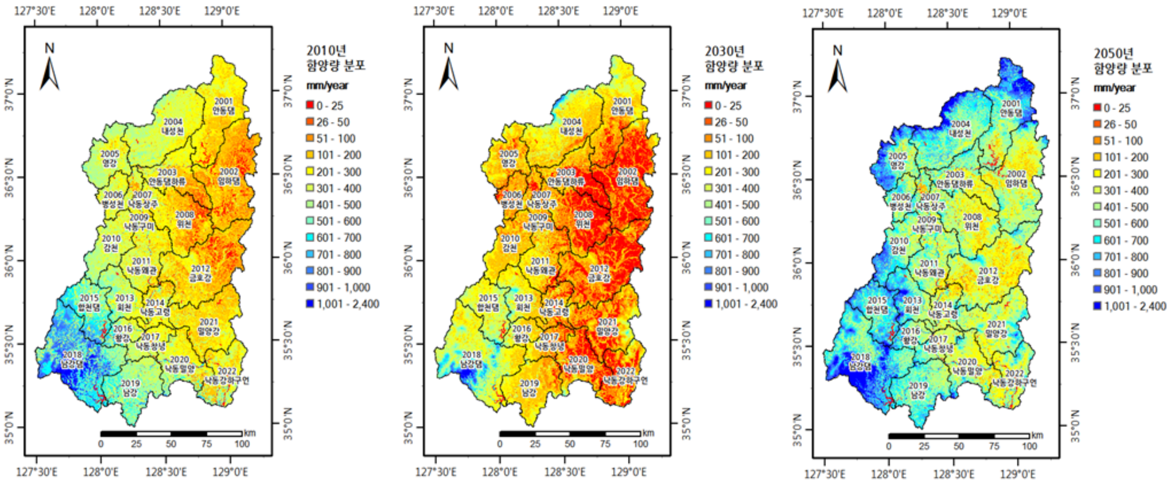


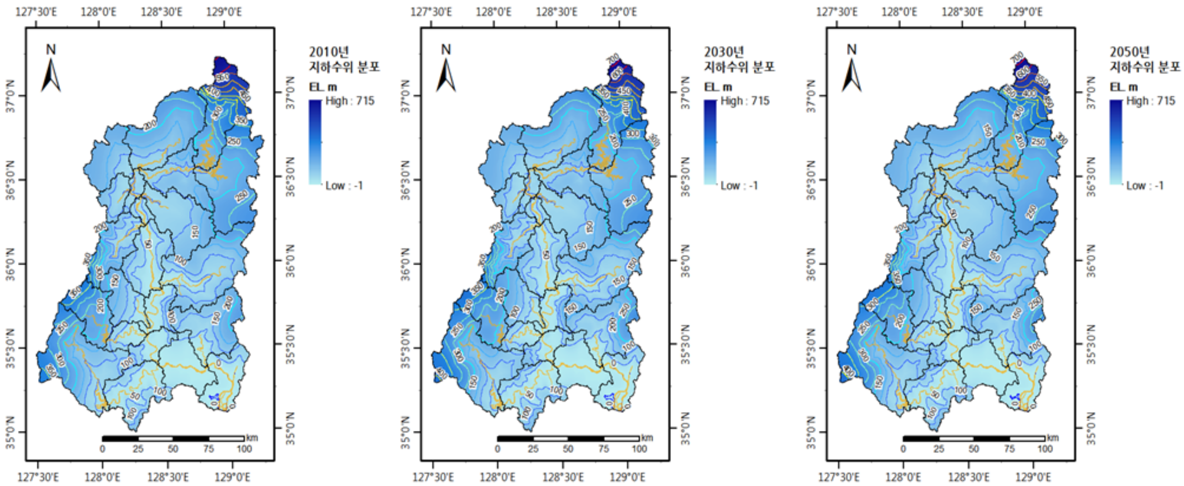
Fig. 5. Prediction of land-use change

3.3. Water budget and groundwater recharge according to climate change

VELAS model simulates each element of hydrologic cycle using land-use and climate change scenarios by 2050 under the RCP8.5 scenario. Precipitation, evapotranspiration and surface runoff were calculated, and then groundwater recharges were finally evaluated yearly from present to 2050. Groundwater recharge is generally an alternative amount for the sustainable groundwater development or yield. On the basis of the groundwater recharge, groundwater management may be established and implemented on each watershed. The groundwater recharge is very sensitive to precipitation relative to other factors such as surface runoff evapotranspiration. The simulated groundwater recharge variations are more than 200% during the simulation period.



(a) Groundwater recharge



(b) Groundwater levels

Fig. 6. Prediction of groundwater recharge

4. Summary and conclusion

The VELAS model was developed to advance performance of spatial and temporal simulation of hydrologic feedbacks to the vegetation growth, land transition, soil water variation, and climate change in a large watershed scale. GIS database of the Nakdong River basin was established to simulate the groundwater resource variation with the VELAS model. RCP scenarios of climate change and land-use change with LCM model were used to simulate the VELAS model and groundwater flow modeling. The groundwater resources efficiently were assessed by a fully distributed hydrologic model, VELAS, and groundwater recharge will be variable according to climate change, and this means the variations of the sustainable groundwater resource.

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CCOP- GSJ/AIST-DGR Groundwater Project Phase III
Meeting on 16- 18 March 2016, Hanoi, Vietnam
Member Country Report

Somphone KHONGSAB

Department of Water Resources under the
Ministry of Natural Resources and Environment
Lao People's Democratic Republic (Lao PDR)

1. Introduction

Laos is situated within the Indochinese Peninsula in Southeast Asia and home to around 6.5 M people. Most of the population earns their livelihoods as subsistence farmers, predominantly from the production of rice. One third of the population lives below the international poverty level of US$ 1.25 per day, particularly those in upland villages that are remote from the major economic corridors. Rapid economic growth has been achieved in recent years, with support from a large number of donors, which has contributed positively to the poverty alleviation and improvement in general health and wellbeing as indicated by declines in child infant mortality and prevalence of communicable diseases.

Located within the tropics the rainfall of Laos is high and ranges from 1,300 to 3,700 mm per annum, but is largely concentrated within the four month long wet season. The country is also mountainous, with about 50 percent of the native forest still retained and cover and only 9 percent of the land under agriculture. It is these and other resources that provide the engine for socio-economic development and a means to lift many out of entrenched poverty and malnutrition, as Laos strives to rise above LDC status by the year 2020 (Government of Lao PDR, 2004). The water resources sector has a vitally important role in the government's vision of becoming the so-called 'Battery of South East Asia' to feed local demand for electricity and that of neighboring countries such as Thailand and Vietnam.

Developing water resources effectively to achieve short-term socio-economic development targets, whilst at the same time meeting longer term sustainability goals is a major challenge. An overall water policy has yet to be formulated, although incremental efforts are being made at the national level (e.g. GHD, 2010) and also at the wider Mekong level (MRC, 2012).

The following map created by the Department of Statistics and the Center For Development and Environment in MoNRE, can be used to assess the current water supply situation. Data was derived from the 2010 census.

Source	Area	% Total
Piped water	267,539	1.3%
Borehole	2,808,284	13.2%
Dug well	3,775,056	17.8%
Surface water	7,893,477	37.2%
Mountain spring	6,322,772	29.8%
Rainwater	1,271	0.0%
Other sources	151,439	0.7%

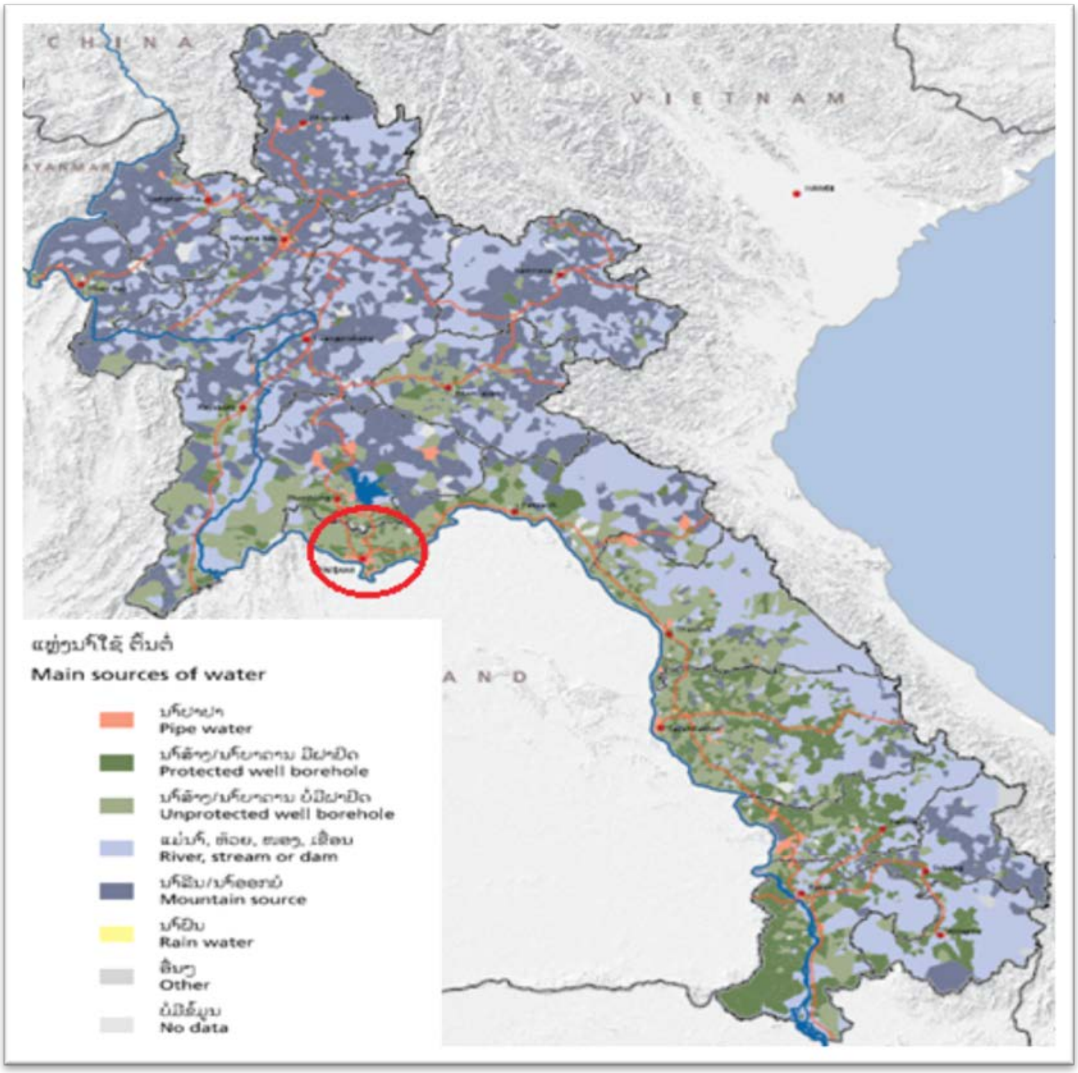


Figure 1; main source of water usage in Lao
Sources: Department of Water Supply, 2010

2. Objective of study area

The main objective of the works will be applicated groundwater modeling in Vientiane plain. The specific objectives are as follows;

2-1. To develop the conceptual groundwater flow model which is presented the natural groundwater flow in Vientiane plain which can be further converted to mathematical model.
2-2. To build the capacity of Lao team particularly NREI team on groundwater modeling application and.
2-3. To establish the database for groundwater modeling.

2-4. The Scop of study area
This research of works will focuse on the review and interpretation of available data particularly hydrogeological and hydrological data, preparation of conceptual model, Field data collection, selection and construction of mathematical model, model calibration and validation, model prediction and uncertainty analysis and Model documentation.

3. Methodology

① General information of the study area

Vientiane plain ground water model application having 4500 Square kilometer area in Vientiane province, Bolikhamxai province and Vientiane Capital, it is situate in central part of Laos. Total river length of Nam ngum river basin is 180 kilometer. It starts at Hinheup district lower Vientiane province to Pak-Ngum in Vientiane Capital are two main province which are include in the basin of Nam Ngum river basin. The Nam ngum river basin is one of the major tributaries of the Mekong river contributing 14.39% of the mainstream flos at the Mekong river confluence(DWR;2008)

② Location

The study area are covers approximatly of 4500 square kilomater in two provinc and one capital located in central part of Laos. In Vientiane province, Boikhamxai province and Vientiane Capital the figure show as below;

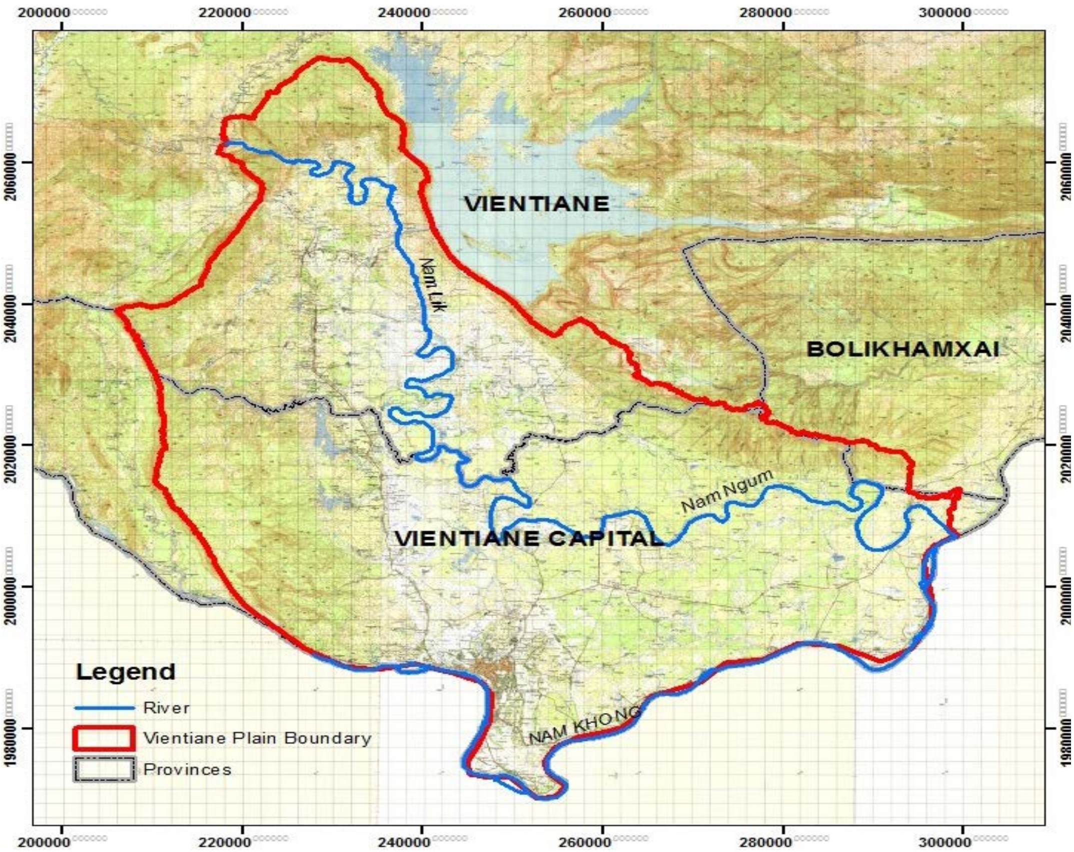


Figure 2; study area

③ Weather and Hydro station

In the case of a figure shown the weather and hydro distributiob station in the study area, 7 weather stations were selected within Hinheupdistrict (lower), Pakkayoung, Napeng, Paktrouay, Thangon, Naxaon and Vientiane Km4 and water level of 9 stations along the NamNgum and Nam Kong river basin as of Ban Pak Ngum, Phon Phisai, Ban Nabong, Veunkham, Ban Mang Dam site, Vietiane, Nongkhai and Hinheup station. All of these data will import to Arc GIS to identify groundwater conceptual model.

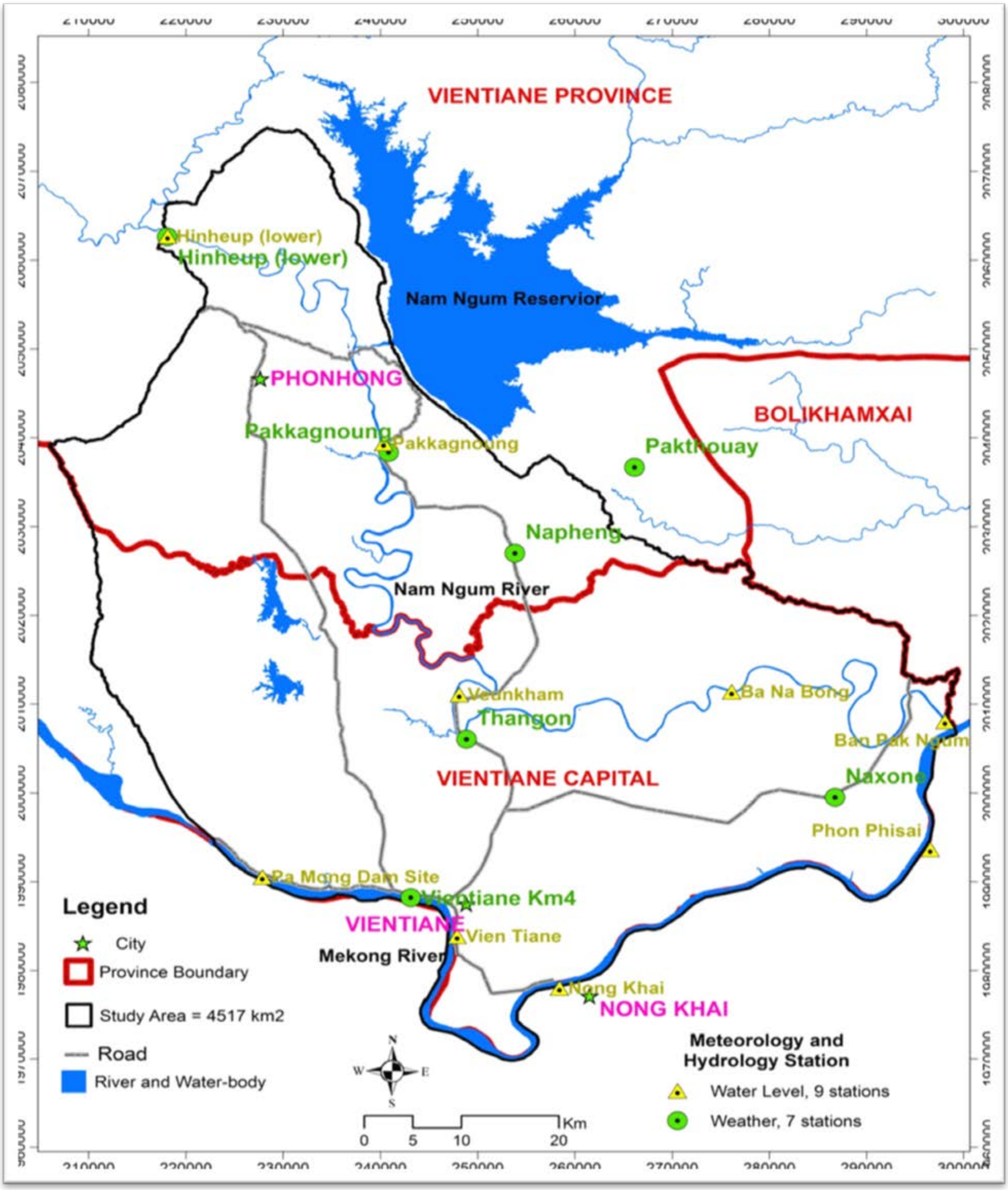
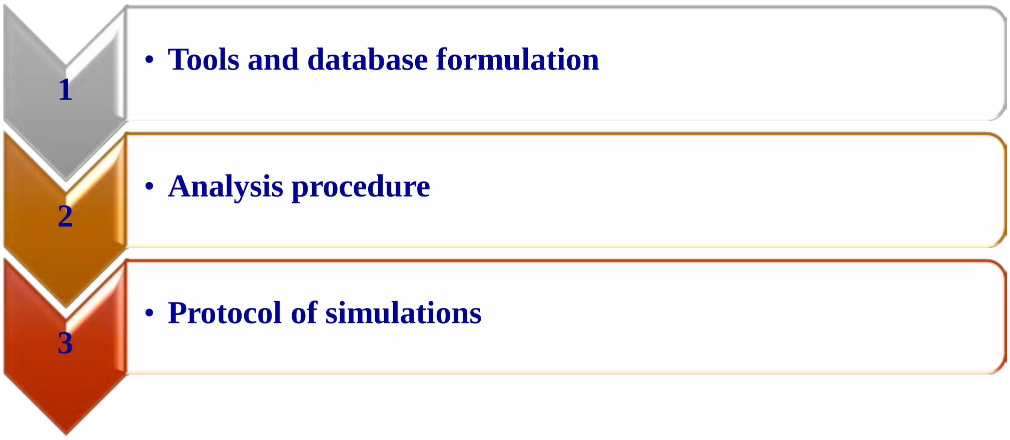


Figure3: meteorology and Hydrology station along Nam ngum and Nam Kong river basin

④ Research Design and Methodology

The research methodology will be suing Visual MODFLOW version 4.2 was used to establish the numericalmodle in ordertothe simulate the groundwater flow of Vientiane plain. MODFLOW is rather popular andcan be applied to simulate grounwater flow in 3 dimention.



4. Landuse

Landuse maps were adapted from the maps that cover the study area prepared by the Mekong River Committee (MRC,2002) and verified by field investigations. Landuse relateds directly and indirect to the groundwater occurrence e.g. water demand of plats, plant's growth period and root depths. Landuse can be categorized into 20 groups, which are agriculture plantation, closed evergreen forest, evergreen wood and shrubland, field crop, forest plantation,grassland and other landuse as below figure show.

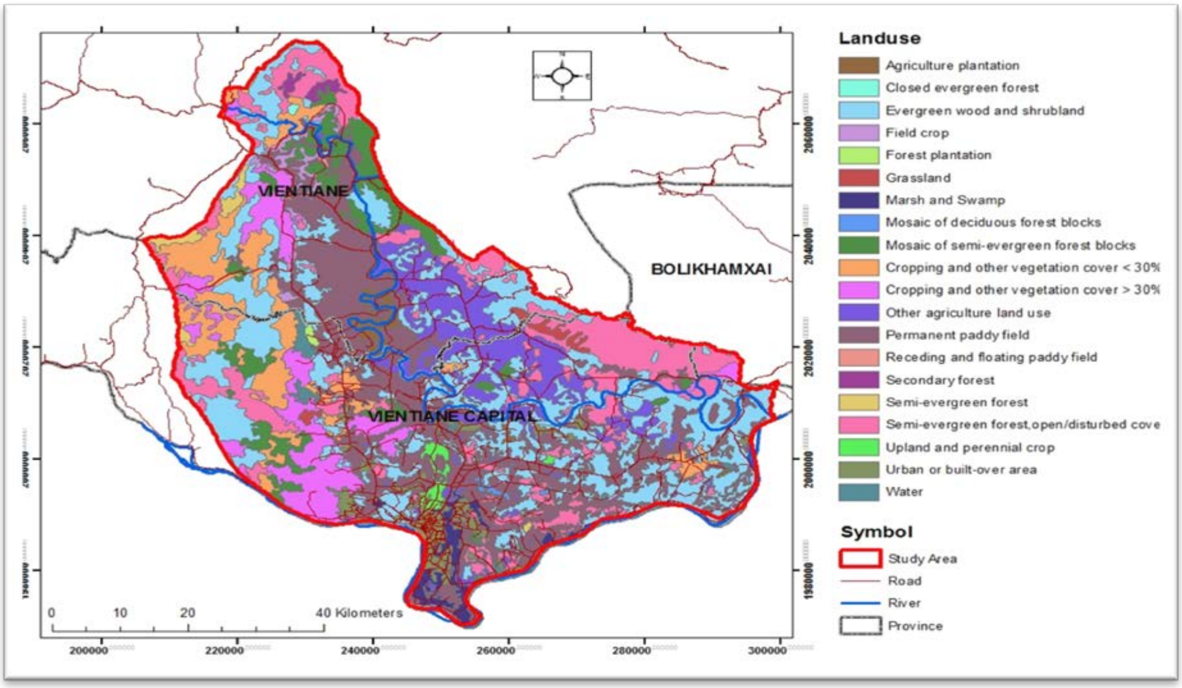
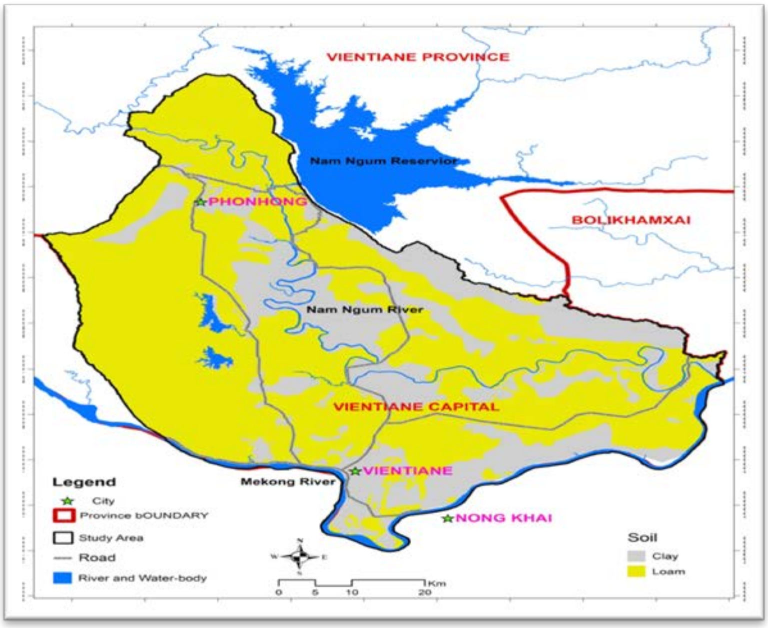


Figure 4: Landuse map

① Soil Group

Physical properties of soil from soil map of a scale of 1:10,000 of Vientiane plain (Mekong River Committee, 1998) were characterised based on their hydraulic conductivity values (verticaal K). the soil groups can be classified into two soil groups: highest soil loam covered by the area of 3,156 and 70 percentages, respectively. Slower hydraulic conductivity value of clay soil groups mainly covers in the area in Vientiane plain groundwater of 30 percentages and about 1,361 Square kilometer. As table show below.



Soil	Area Km2	Percentage
Clay	1,361	30%
Loam	3,156	70%
Sum	4,517	100%

Figure 5: Soil group map
Source: MRC,1998

② Geology

The study area is underlain by different rock unit which can be classified following stratigrapic sequence(Department of Mineral Resources, 2007) in ascending ordr as follow ands as shown in figure 6.

1. Vientiane formation (N2Qlvc): gravel, sand, clay, kaolin including in the second layer formd yellow laterite.
2. Tha ngon formation(K2tn): fine-grained na-salt bearing anhydrite and interbedded with gypsum foliation. Potassium-magnesium salt layer overlain claystone and limestone. Layer of rhyolite and tuff, gray claystone and composed of fossils like gnetaecaepollenites, classopollis sp. Exesipollenites.
3. Chamopa formation(K2cp): quartzite-sandstone, siltstone interbedded with sandstons having meduim thicknes. The upper layer is whitearkoss-sandstone.
4. Phouphanang formation(J-Kpn): sandstonewith micas interbedded with laminated sandstone. The upper layer contritutes of white sandstone interbbedded with conglomerates.
5. Nam sait formation (T3ns): the upper part is composed of brown to white sandstone, interbedded with clay stone having some micas. Shale and sandstone have lenticular gymsum and occasional blak coal seams. The lower part is fine-grained sandstone and white clay stone. The lowest part constitutes of coneglomerates.

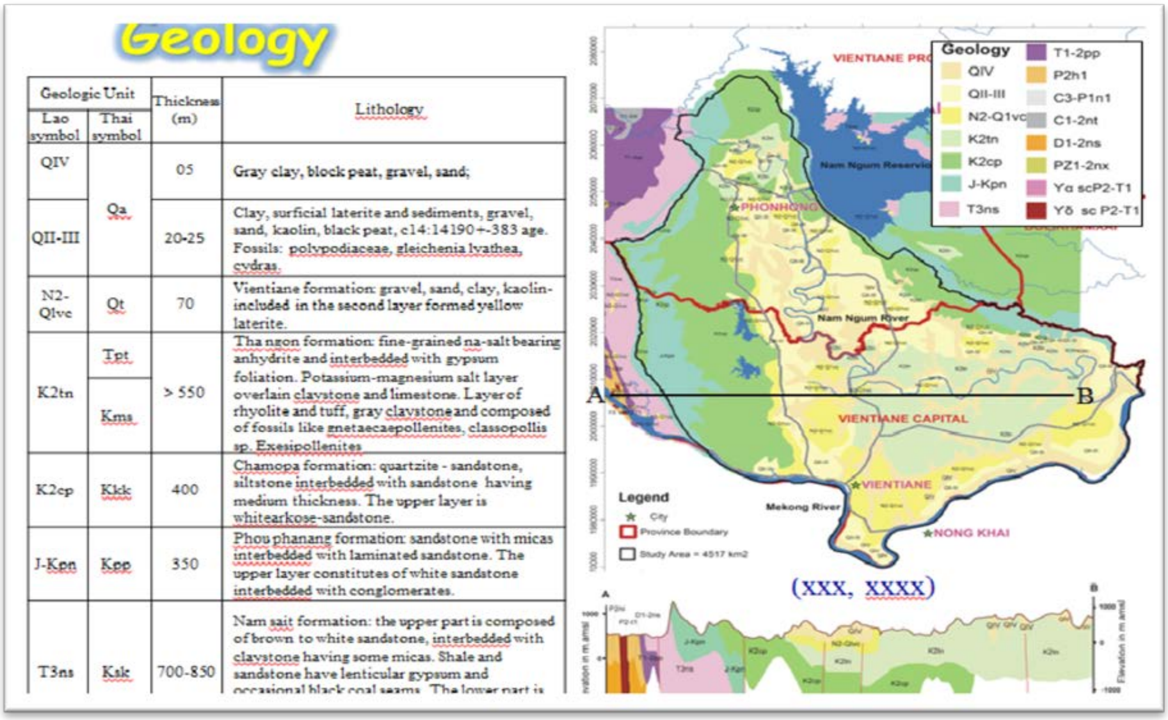
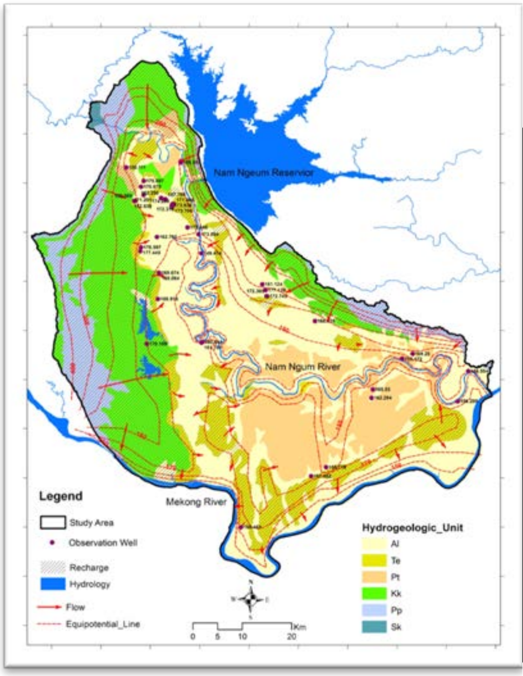


Figure 6: geologic unit Lao and Thailand symbol

③ Hydrologic Map



Geologic Unit		Generalized
Lao	Thai	Hydrogeologic Units
QIV,QII-III	Qa	Al (alluvium deposit)
N2-Qlvc	Qt	Te (terrace deposit)
K2tn	Tpt	Pt (Phutok)
	Kms	Ms (Mahasarakham)
K2cp	Kkk	Kk
J-Kpn	Kpp	Pp (Phupan)

Figure 7: Hydrologic map

In this case to identify the geologic unit of rock group in the study area. Generation, of alluvium deposit and terrace deposits, sand, clay along the major river bank and floodplains of the Namkong and Nam ngum river,located in the central and southern of the basin.

Hydrogeologic Units	Description	K (m/s)		S	
		Kh	Kv	Ss (1/m)	Sy
QIV,QII-III	Alluvium deposits, sand, clay along the major river banks and floodpalins of the Kong and Namgum Rivers, located in the central and southern of the basin	1.1×10^{-7} to 1.1×10^{-5}	1.1×10^{-9} to 1.1×10^{-6}	1.8×10^{-3} to 5.0×10^{-5}	0.005-0.16
N2-Qlvc	Gravel, sand, clay, and laterite of Vientiane Formation, one of major aquifer in the central region, 20 to 30 meters thick.	1.0×10^{-5} to 5.0×10^{-2}	1.0×10^{-7} to 5.0×10^{-3}	5.0×10^{-4} to 3.0×10^{-5}	0.001-0.20
Upper K2tn or UK2tn	Shale, dark brown color, massive layers, treated as aquifer and aquitard locally	3.7×10^{-7} to2.8×10^{-5}	3.7×10^{-9} to 2.8×10^{-6}	4.3×10^{-3} to 1.0×10^{-6}	0.20-0.36
Lower K2tn or LK2tn	Rock salts and Potash deposits interbedded with one to three layers of claystones, the unit can be treated as aquiclude and aquitard. Saturated water within this units is brackish to highly saline water. The unit is underlain by sanstone and siltstone of reddish brown color (Kk)	9.40×10^{-8} to 1.20×10^{-7}	9.40×10^{-10} to 1.20×10^{-8}	5.0×10^{-4} to 1.0×10^{-6}	0.0002 to 0.001
K2cp	Sandstone , siltstone interbedded with laminated sandstone, light brown color, massive beds, found in the western region, equivalent of Chamopag Fm (Lao)	7.49×10^{-8} to 5.76×10^{-5}	7.49×10^{-10} to 5.76×10^{-6}	1.0×10^{-3} to 1.0×10^{-6}	0.001 to 0.001
J-Kpn	Sandstone and conglomeratic sand stone, siltstone, friable, erosional beds of the unit can be found and forming dip slope in the western region. This is one of relatively high yield of groundwater.	8.0×10^{-7} to 8.8×10^{-5}	1.0×10^{-9} to 1.9×10^{-4}	5.0×10^{-4} to 1.0×10^{-6}	1.0×10^{-3} to 5.0×10^{-5}

Source: Spitz and Moreno, 1996 and Srisuk et al,1999

④ Block diagram of hydrologic unit and GW flow

Base on the block diagram on hydrogeologic unit on groundwater flow display generated was chosen Arc GIS and graphic technique to anayse groundwater flow. On this pictur show that were summery all of the information from above.

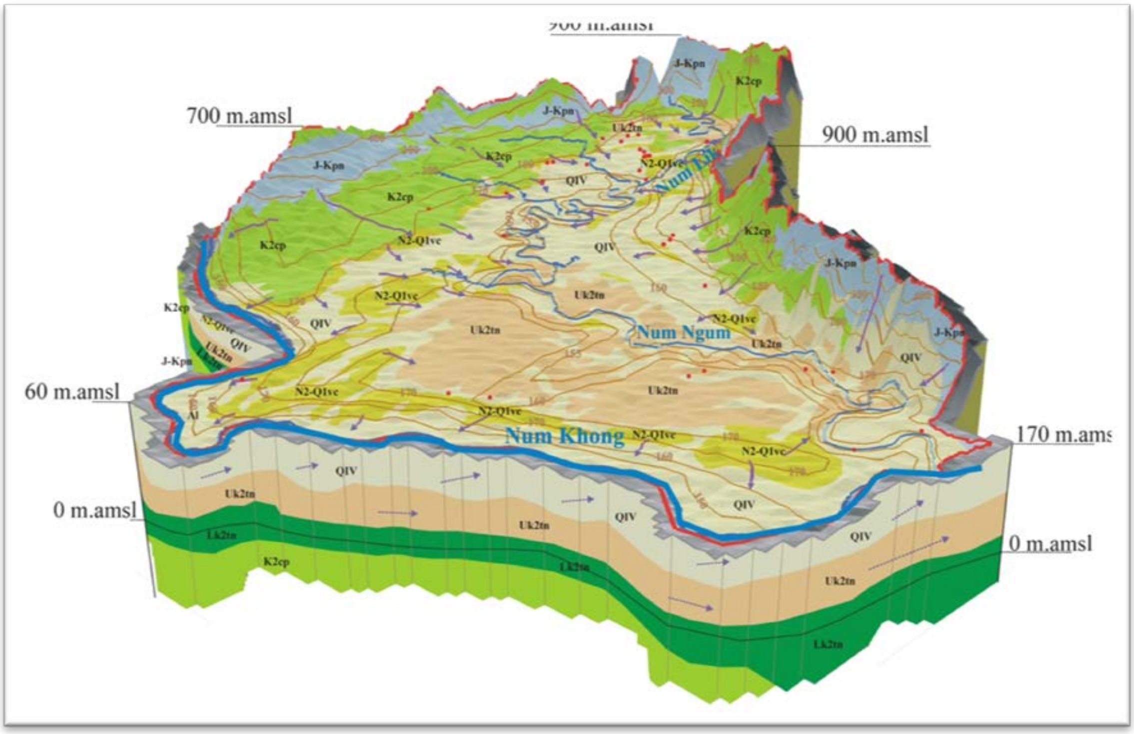
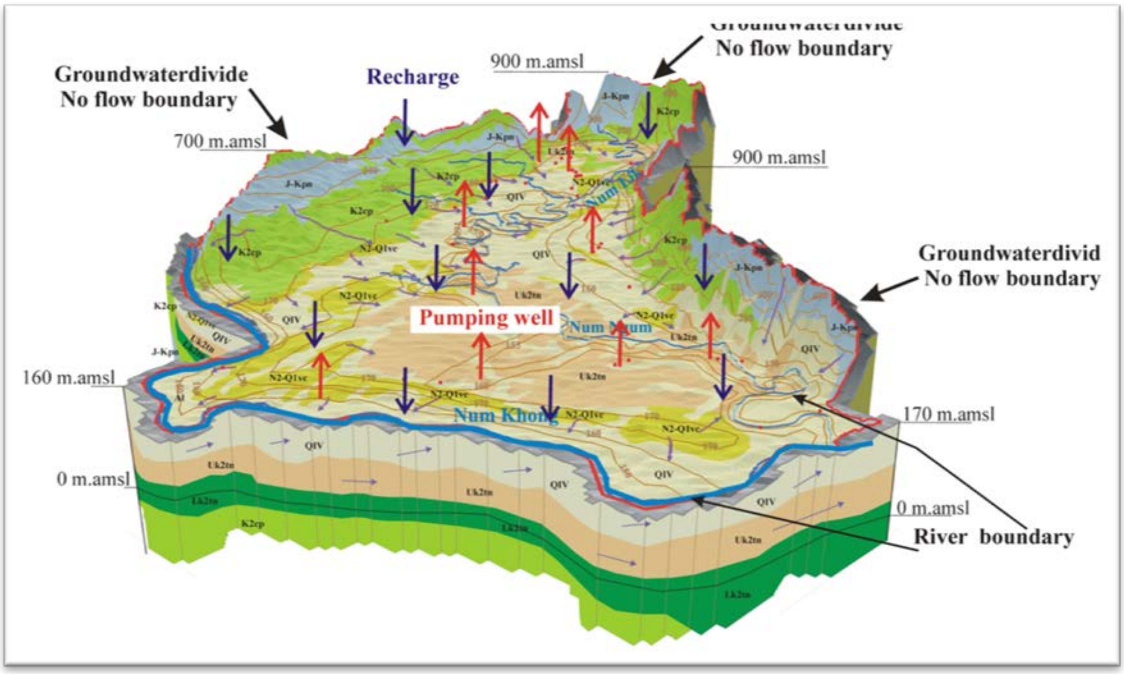


Figure 8: The block diagram on hydrogeologic unit on groundwater flow

5. Conceptual model

The groundwater divide of this study area shows on this map generated using digital elevation model in ArcGIS and graphic design represented on groundwater conceptual model occurre in Vientiane plain. The map shows that the groundwater divide ranged from 900 m.amsl to 160 m.amsl in this atudy area, groundwater divide no flow boundary is highest level among the another boundary because of the location of this is near the mountaine which is in drownstream and along the Mekong river and also with Nam ngum river. Eventhough, recharge and pumping well are lowland area than other part of this study area and most of people use pumping well from groundwater for usage.



6. Conclusions

Establishment of sets of database of the Vientiane Plain on GIS System in the form of derivative maps and tables e.g. climate, hydrology, geology, hydrogeology (hydrogeologic map and cross sections), well records, well location, groundwater usage etc.

Development of conceptual frame work and conceptual groundwater flow model of Vientiane Plain with proper boundary conditions.

Several personnel in NRIE teams are conducting the project and learning to perform the detailed groundwater modeling.

Initiate results of the modeling indicates the data gap of the study area such as monitoring water level data (more locations and depth of the monitoring wells), water quality, TDS, Chloride and heavy metals etc.

The model need to continues calibrate and will be used to develop a guideline or a management plan for groundwater in this area.

7. Recommendations

Investigation of alternative large and better quantity and quality of groundwater resources such as in sandstone and conglomeratic sandstone of the Phou Phanang Formation (Phu Phan FM in Thailand) at the deep groundwater resources; below the rock salt layers, K2tn or Kms Fm) which will be important as resource persons for Lao PDR in performing the future activities on groundwater resources assessment and development in other areas and other related problems, such as climate change impacts on groundwater resources, transboundary aquifer issues between next door countries.

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Recent Groundwater Issues and Their Action Study in Malaysia

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Abstract

Increasing trends to exploit groundwater from many sectors, apart from depending on only one source of water, groundwater has become an important source of water to meet the increasing requirement due to the population growth, urbanization, agricultural expansion, industrial growth and environmental requirements for the whole country. It is expected that the greater emphasis need to be given to the groundwater development and management as an alternative water resource in Malaysia.

The usage of groundwater in the whole country is still very low, however there are several issues that need to be addressed such as groundwater availability, groundwater supply, groundwater quality, emergencies supply, climate change and other water related hazards. The need rise abruptly especially in affected area where source of clean reliable surface water is scarce.

Systematic hydrogeological mapping, monitoring, assessment and management of groundwater in Malaysia are very important to the sustainable resources of groundwater for current and future valuable sources.

In the 11th Malaysian Plan (2016-2020), the implementation of groundwater development projects include the groundwater basin study, assessment of potential of groundwater resources at certain areas as well as to provide clean water for the people in water stress area facing shortage of water supply, water quality monitoring and preserve and prevent reduction of groundwater resources to ensure that future groundwater issues are not overlooked or misunderstood.

Keywords: groundwater, Asia

1. Introduction

Malaysia is a tropical country with an abundant amount of surface water received an average of 3000 mm rainfall annually, where rainfall continuously recharge the groundwater. Most of the states are using surface water to meet their various water demands. Groundwater is widely undervalued, inefficiently extracted and inadequately protected.

Unlike surface water, the usage of groundwater in Malaysia is still very low and has not been exploited in any major way except in the State Of Kelantan. The other states, which have developed their water supply systems from groundwater are Selangor, Terengganu and Pahang. In Sabah and Sarawak, it is the main source of water supply in several coastal and remote villages. Groundwater as a valuable resources is beginning to receive a lot of attention and beginning to focus on its use as a source of potable water.

To date, groundwater consumption in Malaysia is estimated about only 3% or 446 million litre/day (0.156 billion m^3/year) of total water use 13,216 million litre/day (12.687 billion m^3/day). 60% is use for domestic purposes, 35% for industrial supply while the other 5% is for agriculture. Japan International Cooperation Agency estimated the optimum yield of groundwater in Malaysia is 16,438 million litre/day (5 billion m^3/year), (JICA,1982).

Increasing trends to exploit groundwater from many sectors, apart from depending on only one source of water, groundwater has become an important source of water to meet the increasing requirement due to the population growth, urbanization, agricultural expansion, industrial growth and environmental requirements for the whole country. Minerals and Geoscience Department of Malaysia (MGDM) is the leading agency in groundwater research and development in the country. The department provides consultancy and technical services to the local authority, government agencies and the private sector related to the groundwater. Limitation on the availability and capacity of the surface water, groundwater is thus considered the only logical alternative to meet the supply.

2. Recent Groundwater Issues in Malaysia

Yunus and Hatta (2009) presented that although groundwater development and management has been in for quite some times, there are still bugging issues that Malaysia has to face till now as:

i. Misconception About Groundwater
ii. Assessment Methodology
iii. Water Budget and Recharge Estimation
iv. Technology of Groundwater Development
v. Demand from Agricultural Sector
vi. Groundwater Quality, Protection and Management
vii. Groundwater Databank
viii. Sustainability of Groundwater Resources
ix. Surface Water-groundwater Interaction
x. Groundwater Explorations, Development And Management
xi. Groundwater Pollution Control
xii. Existing Legislation

Recently, issues related to the groundwater facing by national water sector are groundwater availability, groundwater supply, groundwater quality, floods, droughts and other related hazards such as haze impact.

The actual potential of groundwater is often not appropriately evaluated and currently unknown as it has not been explored extensively. According to Hatta, this country needs to explore the potential of groundwater with basinal approach, the actual reserve and safe yield of the basin. Study of water balance is a prerequisite to study the region/ basin thoroughly. Sustainable groundwater usage is bound to natural recharge rate.

Due to the global weather changes, the increasing demand and severe pollution of the surface water, groundwater become an important source for water supply. Climate change brings about a lot of uncertainty and it may affect the Malaysia's hydrology, water resources systems and water supply, country experienced the extreme heavy rainfall and longer drought season recently.

Drought is a recurring climatic condition affecting many areas and surface water resources. Experiencing the dry spells in Malaysia especially to those in Melaka and Selangor in 1998, whose water supply are sourced from the upper Langat River catchment and a water crisis in 2014 affected Selangor and Negeri Sembilan, and again in 2015, it gives a favour reason of utilising groundwater resources to augment surface water supplies during these periods.

Other indirect issues of groundwater related to the drought is a drop of the water level in a peat area rather than the urbanization and development in peat area and surrounding. The cooperation with Environmental Department of Malaysia and other related agencies, Peat Fire Management Programme was launched in 2010, the aim was to utilise groundwater resources for wild fire management on peat areas to minimize the haze impact. The programme was a success when has been a showcase to the neighbouring country; the Ministry of Development of Brunei Darussalam visited in 2013 and a delegacy from Kalimantan, Indonesia in 2015 also made a working visit to flammable peatlands in Miri, Sarawak as the programme able to prevent and reduce the fires in peatlands during the dry season.

The worst floods in 30 years have affected several states, especially the northern and eastern regions in December 2014. Water cuts due to worsening floods affected more than two hundred thousand people. Acute potable water shortage in Kelantan and some parts in northern area also in Johore, Negeri Sembilan and Sabah is forcing the government to turn to groundwater to supply water to evacuees. Many users in these states are rapidly searching for alternatives from the usual surface water supply. Groundwater is the answer as it is able to ensure sufficient supply where there is deteriorating quality of surface water and available in remote areas where water supply is hard to reach.

After a 6.0 magnitude earthquake hit the State of Sabah in March 2015, clean water supply from Kedamaian River, Liwagu River and Mesilou River for the people in Ranau and Kota Belud district has been affected. Mud, wood and debris flow have flooded its main rivers, the higher total dissolved solids, turbidity (>2000 NTU), lower dissolved oxygen, pH changes causing the district water treatment plant to cease operation. The treatment plants could not produce to their design production. In order to tackle those water crises, groundwater was used as an emergency water supply source.

The agricultural sector in Malaysia has been revived by the government to be another important sector to boost the country economy. Thus, these also give a stress in the water needs in this industry. By implementing extensive study of the resource, some of problems in the agricultural sector can be reduce. Recently MGDM has develop some tube wells for Sabah, particularly around Kota Belud and Tuaran. This programme aims to provide alternative water supplies for agricultural consumption and also a public water supply after the effects of an earthquake event which caused much of the area around Kota Belud and Ranau had a water shortage.

In Langat River Basin, one of the most potential groundwater basins in Malaysia, through the development of a numerical simulation. The demand for water in these basin has increased so tremendously that groundwater has been utilized in conjunction with surface water. The rapid development in the capital city Kuala Lumpur and the surrounding states e.g., the Selangor State contributes to the shortage of water. The quantity of surface water is not enough to supply water to the consumers, and the quality of surface water in the Langat River is slightly polluted (DOE 2006). Consequently, groundwater is considered to be a potential alternative water resource, and some industries have altered their surface water utilization to groundwater (JICA and MGDM 2002).

Due to the abundance of surface water, some parts of Malaysia have not yet disturbed this resource. Groundwater pollution were not identified as key issues in Malaysia since it had not been widely used, even there are misconceptions from the community who think groundwater are polluted and unreliable. Problems related to the quality and suitability for human consumption is manageable. However, groundwater is still under a considerable potential of contamination especially in areas with intense activities.

In general, groundwater quality in Malaysia is acceptable except for Iron (Fe) and Manganese (Mn) content that mostly is high due to the natural process. Iron (Fe) and Manganese (Mn) content in groundwater usually found exceeding the limits recommended by the World Health Organization (WHO) and Ministry of Health Malaysia especially in alluvial aquifer.

As in Kelantan, groundwater in the shallow aquifer is subjected to contamination with nitrate, ammonia, fertilisers, insecticides and microbial contamination. Due to rapid urbanisation and industrial as well as agricultural developments, there is an increasing threat of contamination to the groundwater.

Since the 1980s most of the coastal villages have been exploiting groundwater resource by digging shallow wells as a main source of water supply. Too much demand on potable groundwater can create induced recharge from ocean waters, resulting in saline intrusion into groundwater supplies. This can also happen in times of severe drought. Most of the salinity intrusion occurs naturally, salt water shoreline may also contribute to the drop of the water quality and not due to over usage of groundwater.

Tourism also are one of the economic driver in Malaysia. Blessed with beautiful islands, magnificient beaches, island, clear waters and extensive reef and coral formation, Malaysia as an outstanding tourist destination. Groundwater issues raised when groundwater as an important source of water due to insufficient or absent of surface water for daily domestic usage and tourist activities. Natural and human give stress to the groundwater in tropical islands to meet the demands. MGDM and a number of groundwater studies have been conducted and need to review extensively to give a clear picture and direction of groundwater in tropical islands in Malaysia.

Transboundary aquifers add another issue to the management of groundwater resources in Malaysia. Transboundary aquifers exist between Malaysia and Thailand, Indonesia and Brunei. The aquifers between Malaysia and Thailand predominantly occur in the Peninsular Malaysia area, between East Malaysia with Brunei and Kalimantan (Indonesia). Due to fairly limited transboundary hydrogeological studies in Malaysia to date, we only can speculate on the extent of transboundary aquifers in that areas. Under the MOU of Scientific and Technical Cooperation in the Field of Geology And Mineral Resources Indonesia-Malaysia, groundwater studied has been carried out in Sebatik Island as the both country shared the same island.

The important contributions of groundwater to the well-being of Malaysians and Malaysian ecological systems notwithstanding, groundwater issues have received an attention from the federal government and state governments in either an environmental or human-health context. It starts to trigger concerns of the various parties on how to conserving and managing groundwater resource efficiently and sustainably.

3. Action study for the groundwater issues

The government of Malaysia are committed towards the sustainable development of water resources. It is a concern that if Malaysia would face the negative consequences if they are fail to manage groundwater resource efficiently. The negative impacts would be towards the water ecosystem, the environment and indirect impacts to human health itself. Yunus and Hatta emphasized that Malaysian groundwater quality and quantity should be monitored systematically for good distribution and reliability. With groundwater set to be exploited in bigger scale in Malaysia to meet the increasing demands for various uses, this important resource must be managed wisely and effectively.

Increasing demands of groundwater in Langat Basin, The Study On The Sustainable Groundwater Resources And Environmental Management For The Langat Basin studied by JICA in 2002 are revised by MGDM to cope and attain a sustainable groundwater resources use and maintain a groundwater quality in this basin.

In North Kelantan River Basin, as the prolong extraction of groundwater from the alluvium, the groundwater modelling was calibrated and validated for the period 1989 -2012 to highlight the issues and increase the understanding of groundwater system and also to assist in long-term management in the basin.

Routine groundwater monitoring with regards to quality and groundwater levels was carried out twice a year for about 386 monitoring wells throughout Malaysia involving routine measurements of groundwater levels, groundwater quality and monitor possible land subsidence. The monitoring work was focused in areas where the groundwater resource is relatively important as a source of public water supply, such as in the northern state of Kelantan where 70 wells were monitored. Apart from the groundwater monitoring, the likelihood of ground subsidence in critical areas was also closely monitored such as in the Langat Basin in Selangor, 34 wells has been developed for the long term monitoring to identify regionals variations and changes of groundwater environment in this basin.

Systematic mapping, monitoring and assessment of groundwater are important for the whole country, MGDM has started the systematic mapping of alluvial aquifers in 1991 as a recurrent project and still continued. Hydrogeological study had been carried out to manage the groundwater resources in peatlands area such as in Selangor, Johore, Kelantan, Pahang, Sarawak and Sabah under the Peat Management Programme. In the 11th Malaysia Plan (2016-2020), to evaluate the potential and groundwater reserve, five major basins namely Selangor River Basin in Selangor, Pahang River Basin Pahang in Pahang, Kuala Muda River Basin in Kedah, Miri River Basin in Sarawak and Kedamaian-Tempasuk River Basin in Sabah will be study. Technical and scientific cooperation with Indonesia continued for another phase in transboundary aquifer studies in Pulau Sebatik.

The implementation of a groundwater management framework as well as the groundwater database information known as HYDROdat has been started since early 1980s in order to manage the groundwater information and the data keep updated. The HYDROdat combines data such as a hydrological data, geochemical (sampling and chemistry), and geological data including the data from Groundwater Monitoring Programme, are collected from a wide variety of sources from other government departments, industry and private. All available data in Malaysia are compiled to be able to analyse groundwater resources meaningfully. Currently, the HYDROdat application is the country repository of groundwater information managed by Minerals and Geoscience Department of Malaysia.

4. Conclusions

Groundwater plays an important role in supplying the domestic, industrial and agricultural water needs of the country. Unmanaged groundwater utilization may results in severe environmental problems such as land subsidence, saltwater intrusion, aquifer pollution, and surface water contamination. The increased demand for, and use of, groundwater resources requires proper assessment, planning, development and sustainable management.

From the current issues and status, systematic hydrogeological mapping, monitoring, assessment and management of groundwater in Malaysia are very important to the sustainable resources of groundwater for current and future valuable sources. The most important aspects of groundwater management in Malaysia is the identification of recharge area for the aquifer. In such, protection of the recharge area, aquifer and water quality is vital.

Global climate changes, current and future needs, emergencies supply, this suggests that groundwater studies in Malaysia are still in their infancy and clearly needed and has a long way to go. Comprehensive groundwater data are need to be collected, analyzed and reported as comprehensive as surface water and other water-related data as being publicly reported.

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RECENT GROUNDWATER ISSUES IN MYANMAR

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Abstract

Myanmar is geographically located between 9˙ 32' and 28˙ 31' North Latitude and 92˙ 10' and 101˙ 10' East Longitude. It is one of the South-East Asian nations with a total land area of (676557) square kilometers. The geological units of Myanmar range in age from Precambrian to Recent and morphologic and tectonic features of the Stratigraphic Units follow a general North-South trend. They are more or less related to the stratigraphy and tectonic setting of neighboring countries of India, China, Thailand, Malaysia and Indonesia. The territory of Myanmar is traditionally divided into five parallel North-South trending Morpho-tectonic belts from east to west. They are the Eastern High Lands & Upper Irrawaddy Province, the Central Low Lands, the Western Ranges or Western Fold Belts and the Arakan Coastal Belt, where each belt has its own outstanding stratigraphic succession, geological structures and metallogenic characteristics.

Myanmar has three distinct seasons. The cold season starts from November to end of January; dry season starts from February to April followed by the wet season. Myanmar receives its annual rain mainly from south-west monsoon from mid of May to mid of October. Ninety per cent of the annual rainfall in different regions of Myanmar is monsoonal. The rainfall intensity, pattern and rainy duration are varied depending on the locality and elevation of the region. Rainfall receives 2030 mm to 3050 mm in the deltaic area, 2030 mm to 3810 mm in the north, about 1500 to 2000 mm in eastern hilly region, rising to 5080 mm in the coastal regions of Rakhine and Taninthayi and only 760 mm in the central dry zone. And incidentally such localities experience temperature of 40 C during summer, and dropping to 10 C to 16 C in some hilly regions. Water loss by evaporation is high and ranging from 1500 mm to 2000 mm. Due to the climatic variation; scarcity of water during dry season becomes a main issue over most of the area of the country.

Among the water resources rich countries, Myanmar could still be classified as low water stress country. There are four major river systems, namely, the Ayeyarwaddy, the Thanlwin, the Chindwin and the Sittoung. There are some river systems in Rakhine State and Thanintharyi Division. These river systems contribute for the surface water resources of the country. Due to favorable climatic condition and physiographic features, there are eight river basins those cover about 90% of the country’s territory. Total surface and groundwater potential of Myanmar are approximately 828 km^3 and 495km^3 per year respectively .On the basis of stratigraphy, there are eleven different types of aquifers in Myanmar. Depending on their lithology and depositional environment, groundwater from those aquifers varies in quality and quantity. Of these, groundwater from alluvial and Irrawaddian aquifers is more potable for both irrigation and domestic uses. Groundwater extracted from Peguan, Eocene and Plateau limestone aquifers for domestic use in water sacred areas, even though these are not totally suitable for drinking purposes. The water use in Myanmar is appreciably increased especially in agriculture .Other Water use such as domestic and industrial sectors are very small compared with agriculture water use. The 89 present of the water use was for agriculture, about 8 percent was for domestic consumption and 3 percent was for industrial purpose.

As others countries, Myanmar is also affected by the change of abnormal condition such as climate change. Cyclone Nargis, the worst natural disaster in the history of Myanmar, struck Ayeyarwaddy Delta and Yangon region in 2008.Cyclone Mala (2006), Cyclone Nargis (2008) and Cyclone Giri (2010) are the alarming signal of climate change in Myanmar. Storm surge will contaminate the coastal aquifers and land. The seawater intrusion is a common problem in the coastal zones, especially in the delta. The groundwater recharges are being decreased by the climate change and also getting decreasing of groundwater table around country. It was affected the tube well in some area of central dry zone where were not available the groundwater during 2015. Another issue is increasing of urban population in delta areas. The awareness of knowledge among public is still needed by the Integrated Water Resources Management (IWRM).

The water resources related departments are preparing to start the monitoring and research to characteristics of aquifer in Myanmar. It is purposed to carry out the monitoring station for tube well, especially in coastal area. And it is being tried to raise the awareness distribution among people for knowledge in water.

1. Introduction

1.1 Land area and Boundary

Myanmar is geographically located between 9˙ 32' and 28˙ 31' North Latitude and 92˙ 10' and 101˙ 10' East Longitude. It is one of the South-East Asian nations with a total land area of (676557) square kilometers. Myanmar is bordered in the west by Bangladesh, in the northwest by India, in the north and north east by China, in the east by Lao' Peoples' Democratic Republic and in the south east by Thailand, covering the total length of the country's border is 4000 km. The Union includes seven states and seven regions. It is characterized by mountain ranges in the north, east and west and a long coastal strip in the south and west. The location map of Myanmar is shown in figure-1.

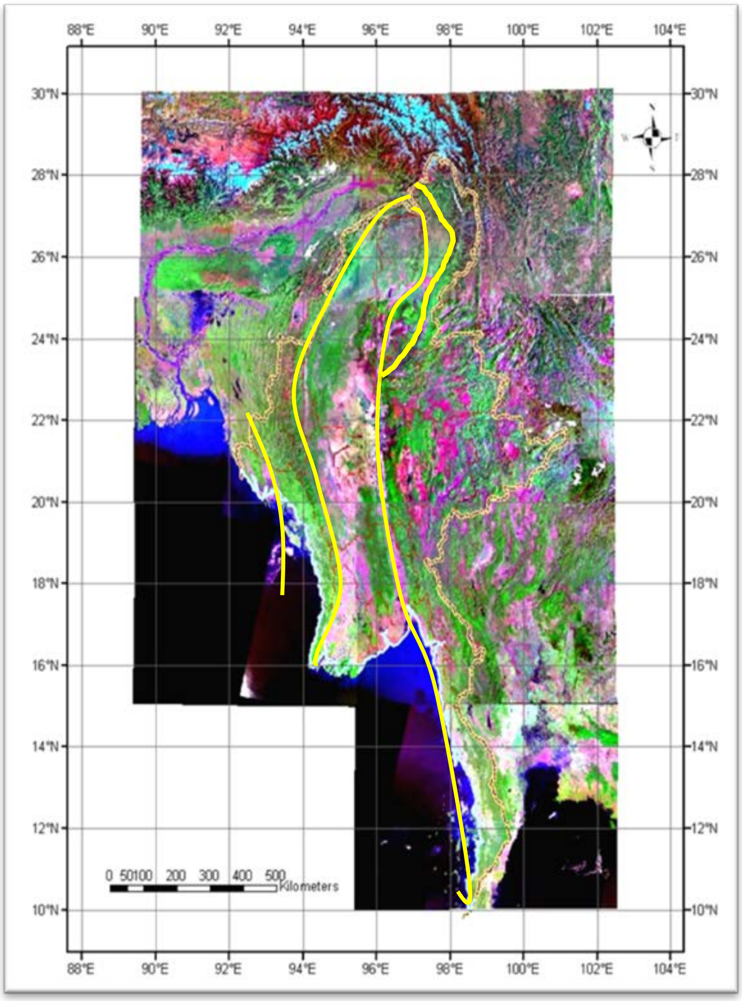

Figure.1. Location Map of Myanmar

1.2 Population

The population of Myanmar is estimated about 51.486 million in 2014 and rural population is about 70 % of the total. According to 2014 census, the growing rate is about 0.89% and the average population density of the country is 76 persons per square kilometer. There are one hundred and thirty five tribes in Myanmar.

1.3 Climate and Rainfall

Myanmar has three distinct seasons. The cold season starts from November to end of January; dry season starts from February to April followed by the wet season. Myanmar receives its annual rain mainly from south-west monsoon from mid of May to mid of October. The 90% of annual rainfall in different regions of Myanmar is monsoonal. The rainfall intensity, pattern and rainy duration are varied depending on the locality and elevation of the region. Rainfall receives 2030 mm to 3050 mm in the deltaic area, 2030 mm to 3810 mm in the north, about 1500 to 2000 mm in eastern hilly region, rising to 5080 mm in the coastal regions of Rakhine and Taninthayi and only 760 mm in central dry zone. And incidentally such localities experience temperature of 40 C during summer, and dropping to 10 C to 16 C in some hilly regions. Water loss by evaporation is high and ranging from 1500 mm to 2000 mm. Due to the climatic variation; scarcity of water during dry season becomes a main issue over most of the area of the country. The annual rainfall isohyets map is shown in Figure-2.

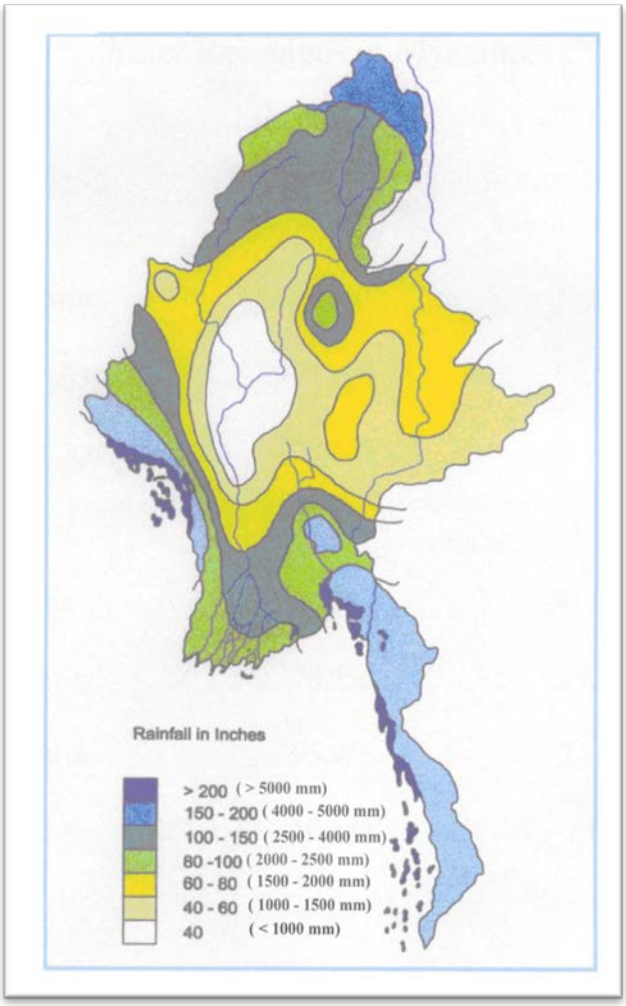

Figure.2. Annual Rainfall Map of Myanmar

1.4 Physiography and Drainage

The physiography of Myanmar closely reflects its geology. Then the country can be divided into four physiographic units. Major drainage lines in Myanmar are from north to south. The deeply dissected Shan Plateau rises to an average elevation of about 914m (3,000 ft) above sea level. Much of the surface of this plateau is of a steeply rolling, hilly nature. Several of the shorter streams in this plateau flow sluggishly through broad valleys, but the largest river, the Thanlwin, is deeply entrenched. The major part of the Central Belt is composed of ancient valleys that have been covered by deep, alluvial deposits through which the Ayeyarwaddy, its tributary the Chindwin, and the Sittoung rivers flow. The relief of the northern portion of the Central Belt where the ridges of the Himalayan Mountains curve southward and become the mountain system of Myanmar eastern frontier .These mountains are very high and rugged, the Hkakabo Razi ,the highest peak in the nation rises about 6,096m(20,000 ft).The Western Mountain Belt is composed of ranges that originates in the northern mountains and continues southward to the extreme southern corner of the country. The Rakhine Coastal Strip is a narrow, predominantly alluvial belt lying between the Rakhine Mountains and the Bay of Bengal. In its northern portion, there is a broad area of level land formed by flood plains of several short streams that come down from the mountains.

1.5 Geological Setting

The geological age of Myanmar Stratigraphy ranges from Precambrian to Recent and morphologic and tectonic features of the Stratigraphic Units follow a general North-South trend. They are more or less related to the stratigraphy and tectonic setting of neighboring countries of India, China, Thailand, Malaysia and Indonesia. The territory of Myanmar is traditionally divided into five parallel North-South trending Morpho-tectonic belts from east to west. They are the Eastern High Lands & Upper Irrawaddy Province, the Central Low Lands, the Western Ranges or Western Fold Belts and the Arakan Coastal Belt, where each belt has its own outstanding stratigraphic succession, geological structures and metallogenic characteristics.

2. Water Resources Potential & Recent Groundwater Issues in Myanmar

2.1 Water Resources Potential

Among the water resources rich countries, Myanmar could still be classified as low water stress country. There are four major river systems, namely, the Ayeyarwaddy, the Thanlwin, the Chindwin and the Sittoung. Besides, there are some river systems in Rakhine State and Thanintharyi Region. These river systems contribute for the surface water resources of the country. Due to favorable climatic condition and physiographic features, there are eight river basins those cover about 90% of the country's territory. Total surface and groundwater potential of Myanmar are approximately 828 km^3 and 495km^3 per year respectively. Details are mentioned in Table 1.

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

Region / river basin	Surface water (mcm /Yr)	Groundwater (mcm /Yr)
Regoin 1. Chindwin	104720	57578
Regoin 2. Upper Ayeyawady	171969	92599
Regoin 3. Lower Ayeyawady	229873	153249
Regoin 4. Sittoung	52746	28402
Regoin 5. Rakhine	83547	41774
Regoin 6. Tanintharyi	78556	39278
Regoin 7.Thanlwin	95955	74779
Regoin 8.Mekong	10580	7054
Total	**827946**	**494713**

2.2 Groundwater Resources in Myanmar

Based on the stratigraphy, there are eleven different types of aquifers in Myanmar. Depending on their lithology and depositional environment, groundwater from those aquifers varies in quality and quantity. Of these, groundwater from alluvial and Irrawaddian aquifers is more potable for both irrigation and domestic uses. Groundwater extracted from Peguan, Eocene and Plateau limestone aquifers for domestic use in water sacred areas, even though these are not totally suitable for drinking purposes. The groundwater resources of Myanmar could be summarized as below.

Figure.3. Aquifers in Myanmar

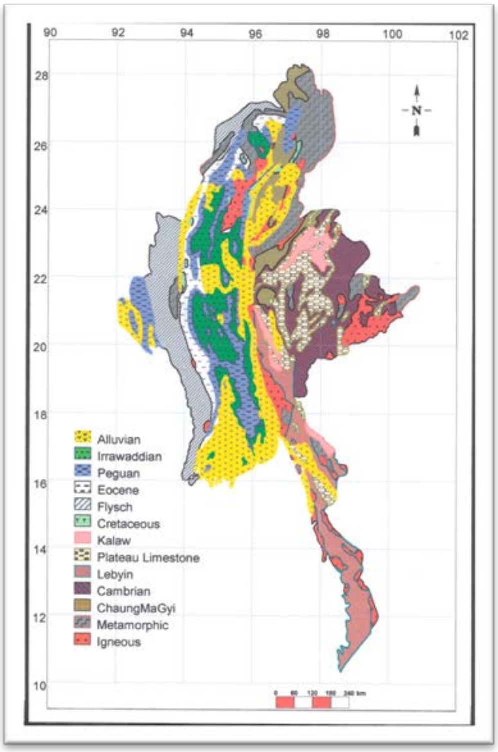

Table-2 Description of Aquifers in Myanmar

Sr.	Name of Aquifer	Major rock units	Area of occurrences	Remark
t	Chaung magyi Aquifer	Low grade metamorphic rocks	Eastern Highland	To be study in detail
2.	Cambrian – Silurian Aquifer	Molohein , Pindaya & Mibayataung Group	Eastern Highland	To be study in detail
3.	Lebyin-Mergui Aquifer	Greywacke, quartzite, argillite, slate, mudstone, gravel, etc;	Western boundary of Eastern Highland and Taninthari Ranges	To be study in detail
4.	Plateau Limestone Aquifer	Limestone & dolomite	Eastern Highland, Western boundary of Eastern Highland and Taninthari ranges	GW is being extracted in some places
5.	Kalaw-Pinlaung-Lashio Aquifer	Loi-an Group & Kalaw Red Beds	Eastern Highland	To be study in detail
6.	Cretaceous Aquifer	Flysch units and limestone units	Northern Kachin, Western Ranges	To be study in detail
7.	Flysch Aquifer	Inter-bedded units of sand, siltstones, shale and mudstone	Western Ranges	Probable GW source area
8.	Eocene Aquifer	Sandstones, siltstones and shale	Periphery of Central Lowland	Probable GW source area

Sr.	Name of Aquifer	Major rock units	Area of occurrences	Remark
9.	Pegu Group Aquifer	Sandstone, siltstones and shale	Central Lowland and Rakhine Coastal Plain	Mostly saline & brackish water, some fresh water in recharged areas
10.	Irrawaddian Aquifer	Mainly sands, sandstones with gravels, grits, siltstones and mudstones	Central Lowland and Rakhine Coastal Plain	Thick aquifer fresh GW with iron contents
11.	Alluvial Aquifer	Sands, gravels and mud	River basins and its tributaries, base of mountains and ranges	Fresh GW, seasonal water table changes

2.3 Groundwater Usage

The water use in Myanmar is appreciably increased, especially in agriculture .Other Water use such as domestic and industrial sectors are very small compared with agriculture water use. Surface and groundwater use are mentioned separately as follows.

Table-3 Water Use in Myanmar

Sr.	Use	Surface Water	Ground Water	Total
1.	Domestic	1.15 (3%)	2.55 (68%)	3.70 (8%)
2.	Industrial	1.17 (3%)	0.33 (9%)	1.50 (3%)
3.	Irrigation	41.97 (94%)	0.85 (23%)	42.82 (89%)
	Total	**44.29**	**3.73**	**48.02**

(Unit in million acre feet)

2.4 Recent Groundwater Issues

2.4.1 Seawater Intrusion

Seawater intrusion is a common problem in the coastal zones, especially in the delta areas of Myanmar. There are seven others outlets and deep water along the river side. The slat intrusion starts from October to April, during cold and dry seasons and, it propagates toward upstream. The distance of salt intrusion to upstream is different due to the discharge of outlets. So the aquifers in Ayeyarwaddy Delta are endangered by the seawater intrusion.

2.4.2 Impacts of Climate Change

Myanmar is also affected by the change of abnormal condition such as climate change. **The Cyclone Mala** (2006), **Cyclone Nargis** (2008), and **Cyclone Giri** (2010) are alarming signal of climate change in Myanmar. The Cyclone Nargis, the worst natural disaster in the history of Myanmar, struck Ayeyarwaddy Delta and Yangon Region in the year 2008. Currently, the groundwater tables are being decreased around country, especially in central dry zone by rainfall pattern of climate change.

2.4.3 Increasing of Urban People & Needs of Awareness Distribution

The urban population is growing around country and groundwater demand is being needed year by year. The awareness distribution will be needed among public for the knowledge in water.

3. IWRM & Program for Groundwater Issues in Myanmar

An IWRM plan should be formulated to guide the coordination of development activities in Myanmar. The National Water Resources Committee was formed in 2013 to facilitate IWRM and implementation of River Basin Management. The committee adopted National Water Policy of Myanmar in February, 2014.

Fig.4. Cover view of Myanmar National Water Policy

The Water Resources Utilization Department under the Ministry of Agriculture and Irrigation is one of the key player in groundwater resources management and development in Myanmar. The WRUD has primary responsibility to develop and manage groundwater for irrigation and domestic use in Myanmar, and is actively involved in groundwater assessment and utilization throughout the country. The drillings for water scare regions and hilly regions for both agriculture and domestic usages and geophysical investigation in the field and water quality testing in laboratory for water samples of drilled tube wells.

Fig.5. Annual Review of Individual Technical Activities

The extension of mangrove forest in marine deposit area in low land area is being carried out to prevent storm surge protection and conserving of marine ecosystem. Strengthening of polders and embankments in delta area were done by Irrigation Department. The water resources related departments are preparing to start the monitoring and research to characteristics of aquifer in

Myanmar. It is purposed to carry out the monitoring station for tube well, especially in coastal area for saltwater intrusion and central dry zone for groundwater table decreasing. It is being tried to raise the awareness distribution among people for knowledge in water.

4. Conclusions

The proposed future activities will be carried out such as Country level, basin wise estimation for groundwater potential, Volume estimation for country level groundwater extraction, Water quality monitoring in heavy groundwater extracted areas, Preparation of Hydrogeological Maps for the whole country, Searching the new groundwater prospect areas, Preparation of hazard maps, Establishment of Groundwater Database Management System using Geospatial Technology by the cooperation of International Organization. Myanmar would like to request to CCOP for capacity building program in Groundwater and Geosciences, and we have great expectation for the improvement of cooperation and coordination with CCOP Member Countries in future activities.

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Hydrogeological and Geophysical Investigation subsequent to the 2013 M_w 7.2 Bohol Earthquake: Issues and Impacts to Groundwater in Western Bohol, Philippines

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Abstract

On October 15, 2013, the North Bohol Fault (NBF) generated a magnitude 7.2 earthquake that resulted to damaging impacts on the western portion of Bohol Province. Hydrogeological and geophysical studies have been conducted to recognize the subsurface effects of the earthquake on groundwater. Results have been compared with the pre-earthquake hydrogeological data from the Mines and Geosciences Bureau (MGB), National Water Resources Board (NWRB), Local Water Utilities Administration (LWUA), water districts, and city and municipal waterworks systems. It has been found that among the lithologies in western Bohol, karstic and coralline aquifer of Maribojoc Limestone in elevated areas adjacent to the NBF experienced water-level decline. Some springs issuing at shallow depths in relatively flat elevated areas (i.e., Catigbian, San Isidro) either ceased flowing or show marked decline in discharge. Most of these springs provide significant irrigation and domestic water supply in these areas. The permanent offset of groundwater levels is due to resultant cracks and openings which diverted flow in deeper and/or unconnected solution channel way systems. Portions of the island which are underlain by clastic units (e.g., sandstone, conglomerate) of Carmen Formation did not show any significant change in groundwater levels. The impacts of the 2013 earthquake on aquifers were also investigated by conducting electrical resistivity (ER) surveys to delineate and establish the current level of groundwater table and to determine the estimated thickness, depth and horizontal extent of identified aquifers.

Keywords: 2013 M_w 7.2 Bohol Earthquake, Groundwater, Hydrogeology, Geophysics, Electrical Resistivity

1. Introduction

Over the past years, several hydrogeological studies in different countries have examined earthquakes and their impacts on groundwater conditions (e.g., O'Brien, 1993; Fleeger et al., 1999; Chia et al., 2001; Bhagavan et al., 2002; Jain, 2003). In the Philippines, groundwater fluctuation was reported in the western Bohol as an aftermath of the 2013 M_w 7.2 Bohol Earthquake. The Philippine Institute of Volcanology and Seismology (PHIVOLCS) reported that its epicenter is near the boundary of Sagbayan and Catigbian municipalities in Bohol Province. Several areas were also affected by ground shaking, liquefaction and mass wasting. The earthquake was considered as one of the most destructive earthquakes in recent years in central Philippines. It affected around 600,000 families and claimed more than 200 lives (Perez et al., 2014). The government and private sectors took immediate action to study and rehabilitate the impacts (e.g., collapsed sinkholes, damaged properties and infrastructures) of severe ground shaking. However, groundwater changes following the earthquake must also be understood. This study, therefore, focused on the hydrogeological and geophysical investigation in order to constrain the factors that influence the attendant groundwater problems in western Bohol Island.

Bohol Island is situated in the south-central Visayas and forms part of the Philippine Mobile Belt (PMB). It is one of the components of the structurally, tectonically, and lithologically heterogeneous central Philippines separated from Mindanao by the northeast southwest-trending Bohol Sea (e.g., Faustino et al., 2003). The tectonic setting of Bohol Island makes it one of the seismically active zones in the Philippines, where local faults and trenches are recognized as earthquake generators. In fact, prior to the 2013 Bohol Earthquake, a magnitude 6.0 event devastated the southeastern portion of the island on February 08, 1990. The East Bohol Fault (EBF) is considered as the earthquake generator for the 1990 event but there are still incongruities among the gathered and observed data (i.e., epicenter, ground rupture, intensity distribution and tsunami runup height distribution) (Besana et al., 2011).

Four stratigraphic units underlie western Bohol: the oldest Eocene Ubay Volcanics, the middle Miocene Carmen Formation, the late Miocene Sierra Bullones Limestone, and the youngest Pliocene Maribojoc Formation (MGB, 1987) (Figure 1). Ubay Volcanics, presently known as Ubay Formation, is distributed in the northeastern portion of the study area. The formation consists of andesite, basalt, dacite, agglomerate and intrusive rocks including gabbro and diabase (UNDP, 1987). It is overlain by shale, sandstone, conglomerate and limestone of Carmen Formation (Cruz, 1956). Sierra Bullones Limestone, in the southern portion, overlies the Carmen Formation and composed of massive to rubbly limestone (Corby et al., 1951). Capping all the older formations in the western Bohol is the marly and coralline Maribojoc Limestone. It is widely distributed in the central portion of the study area, including the whole island of Panglao (Arco, 1962).

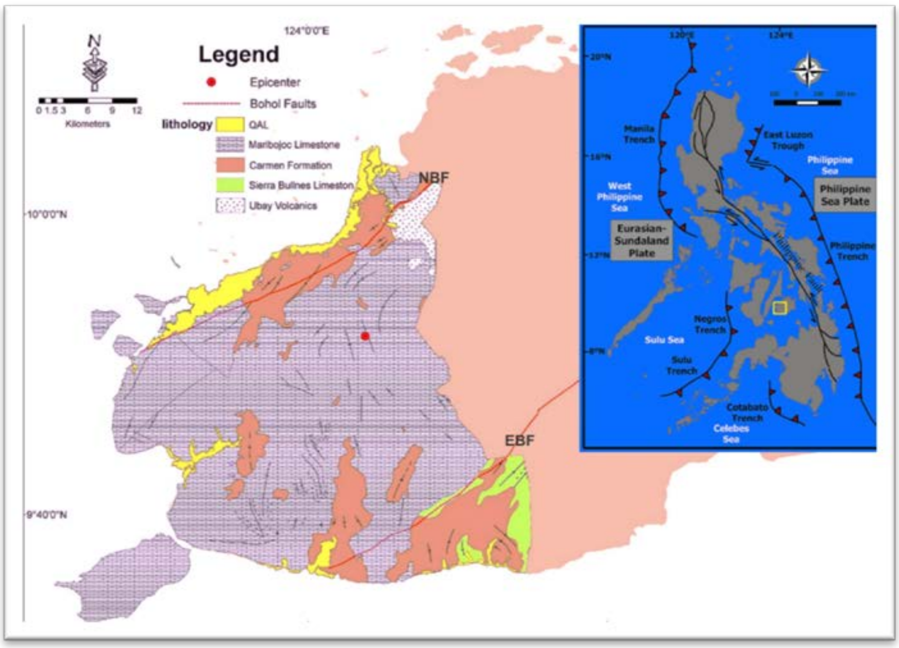

Fig 1. Generalized geologic map of the western Bohol and simplified tectonic map of the Philippines presenting the location of the study area (yellow square) (adapted from MGB, 1987)

2. Groundwater Issues in Western Bohol, Philippines

Following the 2013 Bohol Earthquake, the Mines and Geosciences Bureau (MGB,

2014) reported that the levels of groundwater in the Bohol Island were distorted based on the initial accounts of local water districts. The available suitable aquifers for local communities must be reestablished since the groundwater level in the western portion of Bohol Island was altered by the earthquake. In this regard, the Mines and Geosciences Bureau (MGB) conducted further investigation, particularly the hydrogeological and geophysical surveys, to recognize the subsurface impacts of the earthquake on groundwater levels.

3. Action Study for the Groundwater Issues

Hydrogeological Investigation

Well/spring inventory and in-situ water quality testing are the two major components of the hydrogeological investigation. The well/spring inventory was done to determine the well type, depth, water level, usage, discharge measurements and rock type in the study area (Fig. 2). On the other hand, the water quality testing was employed in order to know the physical parameters (i.e., pH, conductivity, temperature, salinity, TDS, turbidity) of the sampled water and determine if its quality is also affected. During the hydrogeological investigation, interviews with locals were also conducted to gather information regarding the water table fluctuations before and after the earthquake.

The hydrogeological investigation, in connection to the 2013 Mw 7.2 Bohol Earthquake, presented major significant points on why and how the initial groundwater configuration became distorted. It was noted that some springs issuing at shallow depths, in municipalities (i.e., Catigbian, San Isidro) with relatively flat elevated topography, either ceased flowing or show marked decline in discharge (Fig. 3). The black oval in figure 3 presented the elevated areas where wells and springs were affected by the groundwater level fluctuations. In connection to lithologies, the karstic and coralline aquifer of Maribojoc Limestone experienced significant water-level decline compared to other rock types in western Bohol. It was also observed that elevated areas adjacent to the NBF, regardless of its lithology, were affected by groundwater level changes (Fig. 3). Lastly and interestingly, the portions of the island which are underlain by clastic units (e.g., sandstone, conglomerate) of Carmen Formation did not show any significant change in groundwater levels except in highly elevated areas. With this field manifestations, the team established that the permanent offset of groundwater levels is primarily due to the resultant cracks and openings which diverted flow in deeper and/or unconnected solution channel way systems.

Fig. 2. Well inventory (left) and VES survey (right) that were conducted in the western Bohol.

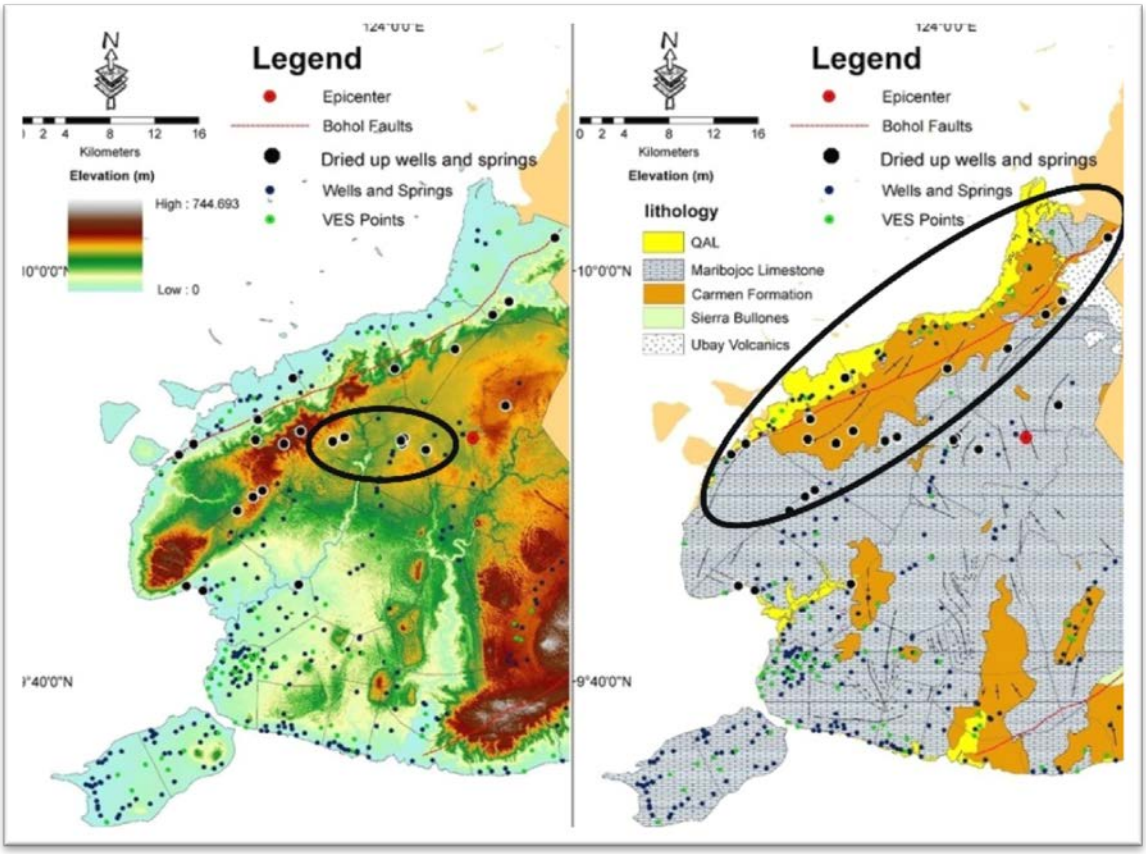

Fig. 3. Elevation (left) and geologic map (right) of the western Bohol presenting the factors (i.e., fault proximity, elevation and lithology) that influenced the groundwater level changes after the 2013 Bohol Earthquake.

Geophysical Investigation

The vertical electrical sounding (VES) method of the geophysical survey was preferred since the vertical variations of the conductivity of target strata (e.g., aquifers) are imperative. The VES investigates physical characteristics of the subsurface earth layers, thus, borehole and well logging can be minimized in delineating the post-earthquake groundwater level. The location of each VES point was strategically established in areas where groundwater fluctuations/ alteration were reported. Additional VES points in areas unaffected by earthquake were also conducted to produce more refined resistivity sections. In order to investigate a maximum depth of 145 meters, VES points were designed to have an AB length of 724 meters. The identification and calibration of the resistivity value for a certain lithology was carried out in areas where the lithology was positively identified and/or borehole lithologic data are available. Table 1 presents the deduced resistivity values for the study area.

Table 1. Deduced resistivity values in Western Bohol.

Deduced Lithologic Unit	Resistivity Value (ohm-m)	Layer Characteristics
Top soil	5 - 249	Highly variable due to different composition
Clay	5 -10	Impervious
Fine- to medium-grained clastics materials	15 -40	Moderately good aquifer
Medium- to coarse-grained clastics materials	40 -92	Good aquifer
Rock saturated with brackish to salt water	0.1 - 3	Salty, poor aquifer
Limestone	130 -450	Impervious to semi permiable

The apparent resistivity was computed by multiplying the resistivity values measured from the field and their corresponding geometric factor. Interpretations of the resulting apparent resistivity values were done using geophysical software such as Winsev and 1XID. For each VES point, the software plotted the apparent resistivity values versus the AB/2 on a logarithmic scale graph to produce the sounding curves. The resistivity curves were interpreted using the traditional curve matching technique. Using iterations, the software automatically fitted the generated sounding curve to the master curves of Orellana and Mooney (1966) to estimate the subsurface layers, resistivity values, thicknesses, and depths. The approximate models were interpreted, validated, and confirmed based on the geological knowledge of the study area, the calibrated resistivity values for the lithologic units, and the available well logs from the LWUA. By correlating the resistivity sounding data of VES points, the geo-electric cross sections were generated using Winsev to visualize the subsurface lithologic and aquifer layers.

The preliminary results of the geophysical investigation, particularly the ER survey can be summarized by the profile A-A' and B-B'. The profile A-A' is located in the southwestern portion of the study area, within Tagbilaran City, far from the rupture zone of the NBF (Fig. 3). There is no reported groundwater decline as result the 2013 Bohol Earthquake in the area. On the other hand, the profile B-B' is within the vicinity of Calape, relatively close to the NBF (Fig. 4). This section also runs along the affected well; the result of VES survey adjacent to the affected well gave an estimate depth and thickness of the distorted aquifer.

The profile A-A' presented the result of the resistivity sounding in Tagbilaran City. The profile is composed of VES-22, VES-1, VES-2, VES-3 and a strata log from LWUA (Fig. 3). From top to bottom, the area is underlain by white rock/soil, limestone, adobe with limestone, and sand/sandstone based on the well log. The strata log was connected to the ER data and presented a good correlation with the resistivity values. The limestone lithology is represented by the resistivity values of 287, 199, 136 and 260 ohm-m in VES-22, VES-1, VES-2, and VES-3, respectively. Below the thick limestone layer is the clastic layers of the Carmen Formation. In VES-22, two distinct geo-electric layers were encountered: the 83 ohm-m layer and the 41 ohm-m strata. The characterization/designation of aquifer as to good and moderately good aquifer is based on the associated resistivity values of the layers. The moderately good aquifer layer is characterized by fine- to medium-grained clastic materials while the good aquifer is defined by medium- to coarse-grained clastic materials.

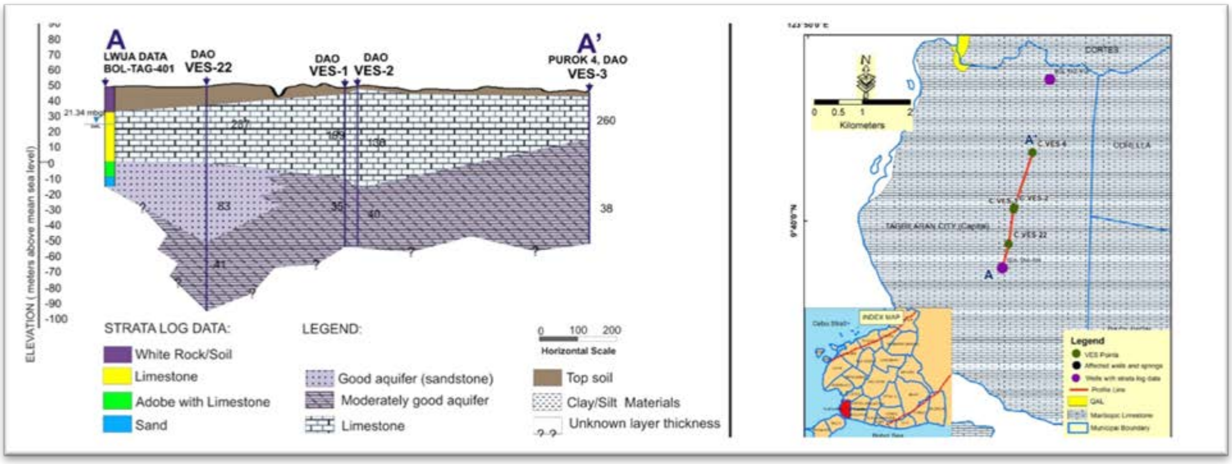

Fig 4. Resistivity profile A-A'(left) in Tagbilaran City (right) presenting the calibration with LWUA Data.

The Profile B-B' was prepared to show the results of the resistivity sounding in the municipality of Calape. This profile is composed of four interconnected resistivity soundings and a shallow strata log from LWUA, namely: VES-34, VES-35, A_VES-9, A_VES-10 and BOL-TAG-417. The section generally trends on a NE-SE direction and seated adjacent to the NBF (Fig. 4). Based on the geologic map, the area is underlain by clastic layers of QAL and Carmen Formation. This was confirmed by the strata log from LWUA that also gave the calibration for the resistivity layers in the vicinity.

Four mappable resistivity layers, including the topsoil horizon, were identified in this profile. The water-bearing layer is considered as good aquifer from the identified calibrated resistivity values of 92, 63, 53 and 30 ohm-m in VES-34, VES-34, A_VES-9 and A_VES-10, respectively. Generally, the aquifer is thick, continuous and capped by a thin clay/silt layer. The calibrated values of clay layer in the area range from 5 to 6 ohm-m. Saltwater has been identified at the depth of 130,121 and 139 in VES-35, A_VES-9 and A_VES-10, respectively. Moreover, this profile also runs along an affected well (violet circle) between VES-34 and the BOL-TAG-417 well. With this section, the depth of the distorted water table can be approximated to 15 to 20m. This technique is currently being applied to other affected wells/springs but unfortunately, majority of them are located in relatively steep, elevated, isolated areas unsuitable for the electrical resistivity survey. However, the result of this electrical resistivity survey still presents an avenue on rapidly estimating the current depth and thickness of the aquifer without conducting expensive drilling programs.

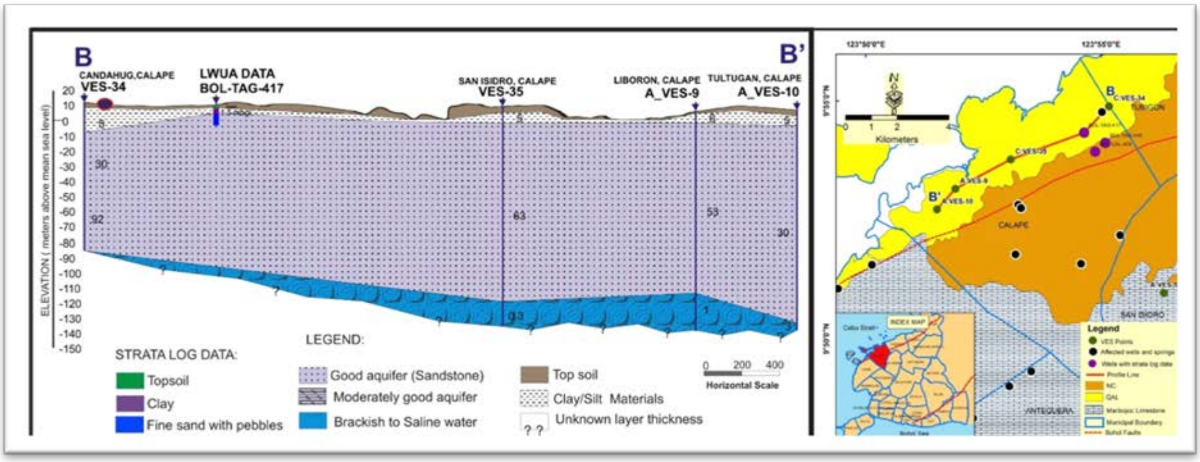

Fig 5. Resistivity profile B-B’(left) in the municipality of Calape (right) presenting the estimated depth of groundwater table of the affected well (violet circle).

4. Conclusions

The permanent offset of groundwater level is evident proximal to the fault line due to the ground rupture that produced brittle deformation (i.e., fracturing) and enhanced the interconnection with solution channels and secondary permeability of rocks. Furthermore, the flow of groundwater in the aquifer in elevated areas, where conduit systems are disturbed, was diverted toward deeper fractures and solution channels. It is also important to note that compared to the detrital limestone, the highly karstic and coralline unit of Maribojoc Limestone experienced significant water-level decline due to its porous (i.e., developed solution cavities) and non-compact texture. This study also established that ER survey (i.e., VES) is substantial in estimating and delineating the present depths and thickness of the distorted aquifer.

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Recent Groundwater Issues and Their Action Study in Papua New Guinea

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Abstract

Each year, the Geological Survey Division under the Mineral Resources Authority Papua New Guinea (PNG) carries out field work at the request of the Government to acquire quality geoscientific data. The hydrogeology team carries out a lot of projects to provide information on the groundwater state/ availability of an area, and to give recommendations on water supply options for that particular area. The work scope usually includes a review of previous investigations on the area of interest, a groundwater site investigation, and a geophysical investigation, usually done using resistivity surveys. The geophysical methods are used to give a more clear picture of the water bearing strata, at what depth it exists, and the thickness of that layer.

Most of the investigations carried out found that the water bearing strata consisted mostly of unconsolidated sediments, colluviums and alluviums. For island areas, coralline limestone was the host for the aquifer. Recommendations made mostly suggested that a test bore be constructed, but where this was inapplicable, a shallow well be constructed and tested. Also within the past year, PNG has experienced the dry spell, due the El Nino, of which water rationing has been carried out since then till present, in order to manage the very little water left in the Sirinumu Dam.

Although groundwater may be available in many parts of PNG, more technical expertise is needed in order to properly explore these groundwater resources. Funding is also another area that needs attention, and some areas may lack proper groundwater supply, due to insufficient funds.

Keywords: Groundwater, PNG, well (s).

1. Introduction

The hydrogeology team under the Mineral Resources Authority in PNG, for the past two years, worked on five main projects: 1. Groundwater Potential of Walium and Usino, Usino Bundi District, Madang Province, 2. Assessment of Groundwater Potential for Grace Memorial Secondary School, Wau, Morobe Province, 3. Kivori Groundwater Feasibility Study, 4. Emirau Water Supply Project, New Ireland Province, 5. Hydrogeology Database. The first three projects included site investigations and recommendations, while the fourth project is still waiting phase two of the site investigations (geophysical methods) to take place. The Groundwater/ Hydrogeology Database is a new initiative which is still to be built. Within the past year to present, PNG has also experienced a very dry period due to the El Nino, of which certain measures have been taken to withstand such conditions.

2. Recent Groundwater Issues in Papua New Guinea

2.1 Groundwater Potential of Walium and Usino, Usino Bundi District, Madang Province.

Since the Walium Station will be developed as the District Headquarters for Usino Bundi District, as part of the development plan, groundwater assessment was carried out to establish the suitability of groundwater as a source for the Walium and Usino Stations' water supply systems. Potential aquifers in the area at Walium and Usino comprise alluvial sediments (Fig 1), and potential fractured rock aquifer at depth. The unconsolidated alluvial fan/ fluvial deposits are the dominant potential aquifer present on the project sites and are laterally widespread. Resistivity profiles also suggested that alluvial deposits have good potential for storage of large volumes of groundwater. Moreover, outcrop exposures of the alluvial deposits showed relatively good permeability characteristics.

Although surface water is abundant and can be sourced from a nearby river, extended dry periods (i.e. El Nino) are likely to dry it up. Also, flooding may occur in the wet season, leading to damage of intake and other structures. Factors such as costly treatment and purification required after flooding are also a disadvantage. Hence, groundwater is the best option for a continuous supply without interruption.

Figure 1 – Top: Inter-bedded unconsolidated sedimentary deposits. Right: Unconsolidated boulder gravel deposits along the Ere River bank beside Walium Station.

Uncontrolled discharge and dumping of household waste, pit latrines and industrial wastes can pose serious threat to groundwater contamination in the unconsolidated alluvium formation. Therefore proper waste disposal and management is required to prevent pollution and contamination of the groundwater resources.

2.2 Assessment of Groundwater Potential for Grace Memorial Secondary School, Wau, Morobe Province

This study was the initiative of the Mineral Resources Authority (MRA) management to assist Morobe Mining Joint Venture (MMJV) to provide clean water supply to people within and around project-impacted areas. Methods used in this study included a geophysical survey using VES profiling method, and a review of the evidence for groundwater availability within the school boundary and the areas adjacent to the main entrance of the school.

The current water supply system for the Wau Township is old and dysfunctional. Furthermore, vandalism of water pipes and increasing number of water consumers (population growth) in the Wau area had contributed immensely to the inadequate supply of water to the school and eventual demise of the water supply system. Due to this, students and staff use nearby creeks and shallow water wells outside the school premises, which has posed considerable health and security concerns, especially for female students and staff. There is a swampy area just opposite the school's main entrance where staff and students have constructed shallow hand dug wells and trenches to collect water for the student mess, bath and laundry.

A shallow well, if constructed within the swampy area to about 7m depth, would adequately supply large quantities of water to the school. Exposures from the newly built excavated pits for toilets show an approximate thickness of 4m of moderately consolidated hill slope colluvium deposits composed mainly of angular fragments of the Kaindi Metamorphic rocks in a matrix of yellowish brown clay. Though these deposits are saturated, it is not regarded as an aquifer. The main aim of the resistivity survey (VES) was to determine the depth and thickness of a possible aquifer (water-bearing layer), and hence, identify suitable locations for test drills within the school area.

Figure 2 – Top: Moderately consolidated hill-slope deposit in exposed excavated pit toilet. Right: Trench dug by a staff member, in the swampy area opposite the school for water supply.

The resistivity survey gave some indication of fresh water saturated zone, however, inconclusive. Therefore, exploratory drilling can also be attempted. The test boreholes will help assess the potential for developing groundwater as a source of water. However, if the borehole is not practical, a shallow well should be considered.

2.3 Kivori Groundwater Feasibility Study

As part of the Pacific Adaptation to Climate Change Project (PACC) in which Papua New Guinea (PNG) is a participant, it received funding to establish and implement projects for "long term adaptation measures to increase resilience of a number of key development sectors in the Pacific Island Countries, which focuses on long-term planned adaptation strategies, policies and implementation strategies". Water resources management, Food production and Food security, and Coastal zone management are the key focal areas in this project, of which PNG's focal area is on "Food Production and Food Security". Hence, PACC selected Kivori villages (Kivori Poi and Kivori Kui) near Bereina Government Station, approximately 120km west of Port Moresby to trial the project.

Figure 3 – Food crop grown in Kivori Kui Food Security Farm (project site) after a recent rainfall.

On request, the Geological Survey Division, namely the Hydrogeology team and the Geophysics team of MRA conducted a groundwater feasibility study to assess the groundwater potential of the areas in and around Kivori villages, including Meauri further to the west. The villages in the Kivori area did not have any proper water supply system in place at the time of visit. An existing solar operated water supply system constructed in the early 1990's was vandalized, and hence abandoned, due to ingress of fine silt and sand. Majority of the population obtain water from shallow hand dug wells.

Figure 4 – Vandalized solar operated water supply system.

The potential aquifers in the project site included coastal alluvial and colluviums deposited along the alluvial fan, and potential fractured rock aquifer at depth, within the Apanaipi Formation. It was recommended that a shallow well should be constructed and tested, due to the inaccessible location.

2.4 Emirau Water Supply Project, New Ireland Province

At the request of the local Water Project Committee at Emirau Island, New Ireland Province, MRA Geological Survey conducted a preliminary groundwater investigation on the Island. At present, no water supply system is in place; hence, the islanders rely mostly on surface water in the form of springs, and rainwater catchments. These spring seepages occur all around the coastline of the island, but no seepages occurred on the main part of the island. The island comprise of mostly coralline limestone which may be a very good reservoir.

Figure 5 – Top: One of the springs observed on the island. Right: Senior hydrogeologist, third from right, going with the locals to the island.

At the time of visit, American wells were observed on the island, but are currently not in use.

A second phase investigation is yet to be carried out, specifically on geophysical methods; however this will depend on funding available. There is great possibility that groundwater may be extracted on the island; however, measures should be taken for coastal zone management, in order to avoid salt water intrusion.

2.5 Hydrogeology Database

The Mineral Resources Authority, PNG lacks data on groundwater around PNG. Hence, a hydrogeology database is to be created, which will be important for our records. MRA will need to piggy-back on the Water PNG wells to collect some data, since we do not have an observation system in place. Furthermore, MRA does not have a drilling rig of its own; hence drilling is done by a lot of contract companies. Because of this, most reports didn’t give enough data needed; they covered only areas such as the well name, brief descriptions on the location, pumping test results, and borehole design. Information such as the temperature and the chemical composition of the groundwater were not stated.

MRA proposes to collect GPS points of groundwater wells and boreholes around Papua New Guinea in order to have quality data to set up a database. Other necessary information such as downhole temperature measurements, downhole geology, TDS and pH levels, groundwater chemistry, may all be attributed to this database. From this, we will produce quality groundwater maps, which will also outline the groundwater basins in PNG. This project is still ongoing at present.

2.6 Effect of El Nino on PNG

Around mid-last year, 2015, the country started to experience extreme dry weather conditions due to the El Nino. These extreme dry conditions caused a lot of food shortage as well as water shortage throughout PNG.

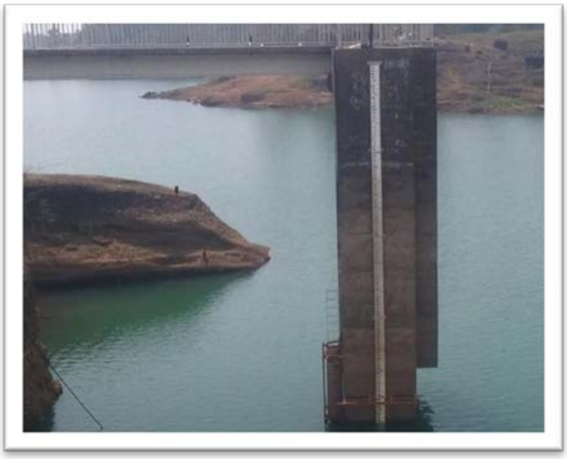

Figure 6 – Photographs showing present water level at the Sirinumu Dam.

Water levels at the Sirinumu Dam, which provides water for consumption and hydro-electricity for the whole of Port Moresby city continues to drop at a consistent rate on a daily basis. However, compared to the El Nino experienced back in 1997, Mr. Laun. Medakou, PNG Power Limited Water Management Team Leader said the current levels are slightly worse, however, can be managed. Late October 2015, the water level at the dam was said to be approximately 129 million m^3. Acting CEO of PNG Power Limited has stated that once the water levels at the dam drop to the 100 million m^3 mark, all hydro electricity generation using this source will cease.

3. Action study for the groundwater issues

For the above projects, it was recommended that a test drilling/ shallow well construction program should be conducted at the Walium Usino site. As for the Wau site investigations, it was recommended that a borehole of 250mm diameter be drilled to 100m depth and screened. Since the Kivori site is in an inaccessible location, borehole drilling has been disregarded. Hence, a shallow well should be constructed and tested.

For the Emirau water project, the community has raised some funds for further investigations, especially for Geophysical investigations. However, more funding is needed, and since funds are limited at this time, the project has been put on hold.

At present, we have started to collect data from existing reports on groundwater data around PNG. However, there is no proper software that can be used to enter this data. Until we find a suitable software for this purpose, we are storing data into excel spreadsheets. Funding would also be needed, to go through training of using the new groundwater data software.

Since the El Nino dry period has very much affected the water level at the Sirinumu dam, water rationing has been carried out in the capital city of PNG, Port Moresby. Water rationing will continue, until there is enough rainfall to recharge the Sirinumu dam.

4. Conclusions

PNG has a lot of potential for groundwater development; from the projects worked on in the past two years, most of the strata that host the aquifer/ groundwater are unconsolidated sediments, colluviums or alluviums, while limestone is the main rock type that hosts the aquifer on coastal zone areas. Some parts of PNG do have wells constructed, however some have been abandoned, and some in a state that needs to be maintained, or reconstructed.

Proper technical expertise is also needed in order to properly investigate groundwater conditions and give proper recommendations. PNG lacks hydrogeologists, who have the knowhow to carry out these tasks. More training may be needed to equip our current hydrogeologist to properly carry out their duties.

While site investigations may be carried out to locate potential groundwater sites, we must consider the costs of the operations and necessary equipment needed to finish the task. That being said, funding is one major area that needs attention, and must always be considered when carrying out groundwater investigations/ projects.

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Thailand: Recent Groundwater Issues and Their Action Study

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Abstract

Economic and population growth has resulted in expansion of infrastructure to support increasing urban, industrial and agricultural areas. Needs for water to sustain various types of activity have continuously risen, while the shortage of water supplies becomes social crisis in many areas during dry season. The urgency and importance of seeking additional and alternative water supplies is therefore widely accepted.

In order to solve water shortage groundwater resources have been exploited more and more nationwide, unfortunately without integrated planning, usage and resources management, and pollution control. Negative impacts to groundwater, both in terms of quality and quantity, seem inevitable unless proper plan and strategies are in place timely.

Department of Groundwater Resources the sole government agency dealing with all kind of groundwater related issue, has to develop strategic plan and implement several project that meet the high need of groundwater data and consumption.

Keywords: groundwater investigation, mapping, baseline

1. Introduction

Thailand’s groundwater resources are of significant economic values to the nation. It is an integral part of Thailand’s economy because it is essential for industries, agriculture, and livestock farming. Groundwater also plays an important role in the Thai people’s daily life because it is a clean water source for domestic consumption. Large-scale groundwater development in Thailand began more than 50 years ago under the jurisdiction and guidance of the Groundwater Division, Department of Mineral Resources. Owing to the growth of population and economic bases during the past decade leading to a significant rise in groundwater demand, the areas of responsibilities of the Groundwater Division and its staff have also grown accordingly. In order to reflect the growth, in 2002 the Groundwater Division was elevated to the departmental status, thereby becoming the Department of Groundwater Resources under the Ministry of Natural Resources and Environments. The Department’s current mandates are: to oversee the development and regulation of national groundwater resources and to provide leadership in integrated management of the nation’s groundwater resources in such a way that is consistent with the national socio-economic development goals and policies.

2. Recent Groundwater Issues in Thailand

The Department of Groundwater Resources has formulate the groundwater resources management master plan and main strategies which address the following issues

2.1) Quantitative Aspect

Groundwater availability and potential: The master plan requires that a study of groundwater availability and potential in aquifers be conducted to provide necessary information for future planning and development of groundwater resources for supporting community expansion and urban development.

2.2) Qualitative Aspect

Groundwater quality: The master plan requires that groundwater quality data collection be undertaken for all groundwater basins to delineate the national distribution of groundwater quality. The data will be used to assist in the determination of future trends in potential impacts - due to natural and anthropogenic factors - on groundwater quality in respective groundwater basins so that appropriate groundwater management plans and necessary mitigation measures may be formulated.

2.3) Demand-side Management and Economics

Groundwater demand: The master plan requires that a study of groundwater demands for all relevant sectors, e.g., agriculture, industry, and public and domestic consumption be conducted. The study should address present and future demands in accordance with the national economic and infrastructure development plans.

Water and groundwater use: This study will identify ways to manage effective contemporaneous uses of interdependent water and groundwater resources. The study will also identify appropriate use and storage methods of water and groundwater resources for given areas, and seasons. In addition, water exchange rates to maintain naturally sustainable balances between the two resources will also be identified.

Economics: The master plan requires that a plan to develop a methodology to assess economic values of groundwater resources be formulated. Groundwater resources values based on true and justifiable socio-economic bases will become an essential element of resources management in the future.

Groundwater Prices: A methodology to assign justifiable prices based on the resources' economic values and costs to all stakeholders in terms of environmental and socio-economic impacts as related the amount of extracted groundwater will be developed. Groundwater prices will be used as a means to manage and control groundwater demands and to promote highly effective and sustainable use of groundwater resources.

Improvements of Policy and Regulations: The master plan suggests that existing rules, regulations, and/or environmental laws be enhanced and additional rules, regulations and environmental laws be legislated to facilitate equitable groundwater resources distribution, allocation, and management. The rules, regulations, and necessary laws must be based on the current and anticipated future trends in the use and management of national groundwater resources.

2.4) Conservation and Restoration

Safe Yields: The master plan requires that a study of safe yields for using groundwater in a sustainable manner without adverse impacts be conducted. Criteria and factors of the study, according to hydrologic, hydrogeologic, environmental, and socio-economic conditions, include available groundwater quantity, economic values of groundwater resources development and intended use, and environmental impacts.

Groundwater Quality Protection: The master plan requires that a study to protect groundwater resources from pollution be conducted. The study will identify suitable areas for aquifer storage recovery systems, water sources, and high- risk areas that are subject to pollution due to anthropogenic and natural sources. The study will also address preventive measures for mitigating groundwater pollution as well as plans to establish nationwide networks for groundwater monitoring.

Defining Measures by Priority: The master plan requires that a plan for groundwater development and restoration based on priority, e.g., construction of groundwater dams or aquifer storage recovery systems, etc., be developed.
Research and Development Financial Support: The master plan requires that various forms of groundwater research and development support be established, i.e., research funding or groundwater research fund.

2.5) Groundwater Development

This study addresses all aspects of groundwater development including: water sources survey, drilling, pumping, reduction of water losses, and adopting innovative technologies for development purposes.

2.6) Technical Tools

The framework proposed in the master plan will lay a foundation for the structure of the Department's groundwater information technology system. The structure will include necessary elements for database types, data collection plans, database improvements, and data links. Accurate, fast, and easy to use information technology should be selected for the implementation, development, and management of the Department's information technology system.

3. Action study for the groundwater issues

3.1 Groundwater mapping project

Department of Groundwater Resources (DGR) is the only core agency whose mission is to provide a unified groundwater resources management at maximum efficiency. The duties and responsibilities included the preparation, compilation, and update groundwater information to ensure that both Hydrogeological and Groundwater maps are accurate and current at all times. All this information is to be used, by private and government organizations as well as the general public, as the basic for the development and management of groundwater resources of the country

DGR as a core agency responsible for preparing such inforn1ation needs to create a groundwater resources database and groundwater maps for each groundwater basin throughout the country. The studies should explore groundwater potential for each groundwater basin both in quantity and quality. This is because the original groundwater resources database used in provincial groundwater maps scale 1:100,000 does not have enough detailed information. Recently, the groundwater information has increased substantially. Due to academic studies and researches, as well as the drilling and construction of new groundwater wells by DGR, local administrations, and other agencies.

Thus, DGR has established the Project to Study, Exploration, and preparation of Groundwater Maps detail scale at 1:50,000 for all 27 groundwater basins across the country. The Khorat Plateau is known as the droughtest area of the country, since topographically not suitable for construct neither dam nor large reseviors, therefore, the irrigated area is only about 8% of total area. Groundwater is then considered as an important water resource for especially, during drought period. The Project of Groundwater and Hydrogeological Details Mapping of the Upper Khorat Plateau is selected as a pilot project area for the plateau. The task for preparation the map included hydrogeological data verification, Groundwater Well Inventories, geophysical prospecting, aquifer test, drilling of exploration wells, and compilation of all related data.

3.2 The Investigation of Heavy Metal Background in Groundwater: Rayong and Chonburi Groundwater Basins

There are many industrial estates located on East-Coast Gulf watershed and Rayong and Chonburi groundwater basin. These areas are economical zone of Thailand due to its rapidly industrial sector expansion so that, inevitably, the demand of groundwater has been extreamly increasing. Groundwater is potential resources supplied to those activities. In 2005, Groundwater Resources Department (DGR) carried on the project of eastern area drought relief. Then, groundwater could be consumped continueously up to present leading to both qualtity and quality impacts.

From 2005, groundwater in Rayong and Chonburi basins has been deteriorate, and non-potable. In 2007, The Pollution Control Department has authorized ad hoc committees to investigate heavy metal and VOCs contamination aspects from 75 wells The result found that some heavy metal and VOCs were dectected such as lead, manganese and arsenic and VOCs like Benzene, Dichloromethane and Tetrachloroethylene in Ban Bon and Map Cha Lut communities. Those substances are poison matters in health impact concern according to Announcement of National Environmental Board B.E 2543. Futhermore, their persistence are quite high and could be harm from groundwater abstraction. However, VOCs is definitely claimed to “human made” substance, but heavy metals are still suspicious because they could be induced from both human activities and natural processes.

At present, DGR has attempted to reform groundwater regulations in order to enhance DGR’s authorization which could cover the penalties for groundwater contamination culprits. Unfortunately, those process has been stucked in the consideration stage by the Council of State because our country still lacks of heavy metal background values data
Heavy metals concentration in groundwater could be induced by natural processes or human activities so that it too hard to defied the origin of those substances. By that reason, DGR actualized project “The investigation of heavy metal background in groundwater: Rayong and Chonburi groundwater basin” to identify sources or causes of heavy metal in groundwater. This is an urgent issue for related agencies who responsible to national health risk assessment and to impose groundwater reclaimation, prevention and preservation guidelines in sustainable groundwater management program.

For technical point of view, this projected studies relationship of hydrogeology and geochemistry mechanism along groundwater circulation, defined sources of pollution and heavy metal induced in groundwater, and evaluate contamination trend in future from geochemistry data and measured groundwater age in this project. The study showed that different chemical and groundwater quality variation was the result by alteration of groundwater age, redox potential, dissolved oxygen content and depth to water. Natural processes were main factors affected to heavy metal in groundwater such as water-rock reaction, which depended on specific local area, especially in consolidated aquifer which contained higher or in range background value. Unconsolidated aquifer somewhere might be influenced by human development activities. The result of water chemical study indicated that a large amount of heavy metal were in solid form which adsorped on soil and aquifer surface. If system balance was interrupted, heavy metal would had been dissolute into groundwater particular in unconsolidated aquifer that more sensitive to human activities and landuse. Therefore, regularly groundwater quality monitoring would be needed.

Furthermore, this project also aimed to acknowledge scientific understading to local people and stakeholder and enhanced their awareness of groundwater quality situation at this present including motivated them to participate and corporate in groundwater protection program. Then, suitable media was invented to transfer these objectives to them such as questionares for willing to pay study.

As mention above, it could be concluded that local people had willing to pay to preserve groundwater quality so that these values could be used as reference values in annual budgeting to support groundwater preservation and management policy which was suggested in this study in law, economic and environment dimensions goal like “Effective groundwater resources management for the best quantity, quality, price and justice”.

3.3 Advanced Airborne Time-Domain Electromagnetic Survey, ATDEM

DGR has a mission for development on geophysical investigation techniques with advanced technology that could provide the surveyed data rapidly, for which more detailed and completed data covering the whole consecutive area are achievable. As a result, the size shape, and aquifer distribution characteristics as well as their stratigraphic pattern could be accurately interpreted; the result of which would enhance groundwater management planning. As a consequence, DGR has established the pilot project on groundwater exploration with an advanced geophysical survey method: Airborne Time-Domain Electromagnetic Survey (ATDEM), with the project area of 1,000 sq. km. in the sedimentary basin. The result of the survey the geological model and hydrogeological model both 2D and 3D images processing by computer program has been achieved. And the detailed hydrogeological map at the scale 1:50,000; as well as development on standardized geophysical database for DGR have also been accomplished accordingly.

3.4 Large Scale Groundwater Resources Development Using Modern Riverbank Filtration Technology

At present, water supply problem for domestic and industrial consumptions has been increasingly important in Thailand. This is due to the problem of raw surface water quality deterioration. In general, it is found that the discharge of waste water from the community and large urban areas into water bodies caused the contamination so as to increase the cost of water supply production. In Thailand, in addition to water quality problem, severe water shortage for domestic, irrigation, and industrial uses as well as ecological system sustainability will be encountered in the near future. There are many conditions and aspects that cause problems and difficulties in water resources development. Every river basin seems to have the limitation. Many river basins cannot be further developed for additional water supply using the conventional development methods. The influencing factors include: the raw water quality deterioration; continuing and increasing surface water sources contamination; problems in land use and community relocation; environmental impact and natural conservation problems; and problems in natural groundwater resources contamination such as that from salinity, arsenic, fluoride, and iron oxides derived from the existing nearby waste disposal sites or mining areas. The Department of Groundwater Resources (DGR) recognizes such above-mentioned problems. And therefore, “Large Scale

Groundwater Resources Development Using Modern Riverbank Filtration Technology **“**project is proposed. The target areas are initially focused along the main river courses in Thailand so as to: formulate the master plans for systematic and sustainable groundwater management, study and research on the modern techniques and methods, and conduct the demonstrating appropriate water management system to provide adequate good quality water to meet the increasing public water demand in the near futureThe RBF system would be useful for domestic and industrial water shortage mitigation in the future. The investigations and design of the RBF system consist of the selection of the potential areas from the existing river basins in Thailand. The results of field investigations and analysis of various data groups show that the twelve (12) potential areas for the RBF system development are located mainly in the North Region and Upper Central Region. The results show that the RBF system development in Amphoe Muang, Chiang Rai Province, would provide water production capacity of 1200 cu. m/hour for water users of 19,200 households. The saving costs for the construction of the RBF system and system operation comparing to the existing water production has shown. The results of the economic feasibility evaluation show high cost-benefit with the benefit/cost ratio of 2.11 and the water supply fee at the break-even point of 3.07 Baht/cu.m. The development of the RBF system is the conjunctive pumping of groundwater and surface water through the natural filtration. The system could save the cost of water supply production and that is the systematic water resources management to provide adequate clean water for domestic consumption in every part of the country.

3.5 Exploring Corrective Means for Solving Flood and Drought Problem by ASR Method in the Northern Part of Chao Phraya River Basin

The Exploring Corrective Means for Solving Flood and Drought Problem by ASR Method in the Northern Part of Chao Phraya River Basin (phase 2) was carried on Sukhothai province. A hydrogeological feature of this area was unconsolidated confined aquifers which could be classified into 2 main layers; namely, the shallow aquifer (approximately 40 meters below earth’s surface) and the deep aquifer (approximately 80 meters below earth’s surface). The study included the conduct of aquifer storage and recovery study through cycle testing of water injection and extraction, assessment of changes in aquifers due to water injection and geochemical changes of water, development of conceptual and mathematical models for analyzing the potential of water injection and extraction, assessment of economic feasibility, and dissemination of knowledge gained from study results.

The experiment of with recharge rates of 19-22 cbm/hour in each recharge well were performed. Study results showed that water injection could be performed continuously for more than 50 days without clogging problem. Water injection into aquifer resulted in water levels of shallow monitoring wells located at the distance of 22-66 meters from the shallow recharge well being drawn up from their static levels about 2.1-1.9 meters respectively based on the distance from the recharge well, and water levels of deep monitoring wells located at the distance of 21-65 meters from the deep recharge well being drawn up from their static levels about 1.5-1.3 meters respectively. The overall picture of the injection testing in this project showed that the recharge efficiency was 470 cbm/day for shallow aquifer and 383 cbm/day for deep aquifer.

With regard to geochemical study, it was found that when dissolved ions precipitated as minerals through chemical reactions, it did not pose any significant clogging problem. According to geochemical classification, there were 2 types of clogging; that is, aquifer pore space clogging and recharge well clogging. Aquifer pore space clogging was not evident during the project time frame as study results revealed that the concentration of calcium, which was the main constituent of calcite mineral that might clog the aquifer pore spaces, was relatively low in the mixture of groundwater and recharge water. The water mixture was thus undersaturated with respect to calcite, and this was the reason for negligible calcite precipitation and the absence of aquifer pore space clogging. When considering recharge well clogging, on the other hand, it was found that iron played an important part when iron in water combined with oxygen (oxidation process) and precipitated as a scale around the recharge well, which would clog the well screen.

Through the quantitative and qualitative assessment of aquifer recharge, about 85% of extracted water was found to possess similar quality as that of the recharge water, while the quality of the rest resembled that of the native groundwater. This fact helped ascertain that aquifer recharge did not have environmental impact on the native groundwater. Conceptual and mathematical models were developed as the study was underway to analyze the groundwater flow directions, to estimate the volume of water that could be injected into aquifers and the resulting elevated water levels in each well at different injection rates at the end of each specified periods, and to estimate the volume of water that could be extracted plus the resulting drawdowns in the associated monitoring wells.

The subsequent economic analysis illustrated that, with the project indicators that fully met the required criteria. This project was found to be economically viable and suitable for further development. The concluding activity was the dissemination of knowledge gained from this study, where trainings and technology transfer sessions were arranged for officials of the Department of Ground Water Resources, while a number of seminars were organized to publicize the launch and progress of this project among local administration officials and civilian stakeholders to develop their awareness and increase participation, which were met with highly satisfactory response.

3.6 Pilot Study and Experiment on Managed Aquifer Recharge Using Ponding System inthe Lower North Region River Basin

The Groundwater Research Center (GWRC), Khon Kaen University, was awarded a contracted research by the Department of Groundwater Resources (DGR) to study on the project “Pilot Study and Experiment on Managed Aquifer Recharge Using Ponding System in the Lower North Region River Basin. The project duration was between April, B.E. 2552 and April, B.E. 2554. The project objectives are to: 1) study and experiment on the artificial groundwater recharge using recharge pond system or other artificial recharge methods; 2) study the physical processes, hydraulic characteristics, and chemical processes in artificial recharge; 3) provide guidelines for integrated mitigations of drought and flood hazards; 4) apply the research results to provide guidelines for the project operation; and 5) generate the knowledge body and transfer of technology. The project activities consist of the essential tasks such as the study on hydrogeology of the study areas, groundwater uses, selection of suitable project site, experiment on artificial recharge using recharge pond, study on economic feasibility, study on the guidelines for groundwater artificial recharge master plan formulation for the mitigation of the groundwater level decline, training seminar for the related DGR personnel and interested people, and project conference for dissemination of research results.

The results of the study show that the large shallow aquifers in the Lower North Region River Basin consist of layers of sands and gravels of the River Yom and Nan. Farmers extract shallow groundwater from shallow aquifers- ranging in depths from 10 -15 meters from ground surface for rice growing at about 7,500 million cubic meters per year and generate income of about 25,000 million Baht per year. During the last decade, groundwater levels have been continuously declined at the rates of approximately 10 – 25 centimeter per year resulting in the occurrence of approximately (10,560 sq. kilometers) of the groundwater critical areas with groundwater levels deeper than 8 meters from the surface. If the groundwater pumping is continued at the same rate without any mitigation measures, the groundwater critical areas would increase approximately 160 sq.km and the groundwater levels would be 1.0 -2.5 meters deeper than the initial levels within the next 10 years.

The success of the development of the artificial recharge system in the future would be based on the project implementation according to the recharge master plans and systematic recharge development established from various aspects of researches. These include raw water quality treatment, groundwater hydraulics, groundwater quality, selection of suitable artificial recharge methods, prevention of clogging of recharge ponds, operation and maintenance, and feasibility of project economy and environments.

4. Conclusion

The Department of Groundwater Resources has made the strategic plan to meet the national needs. Several projects have been implemented in both full scheme and pilot scale. The demand of high precision data with the rapid acquisition is so high to serve the fast dynamic of national planning. DGR has to improve the technology of exploration and acquiring groundwater with the need of capacity building for the new coming personnel.

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OVERVIEW OF TRANSBOUNDARY WATERS IN VIETNAM

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Summary

Water is vital for life, In Vietnam water sector is receiving more and more attention and investment from the Party, State and Government. Since 2003, under the united management of the Ministry of Natural Resources and Environment (MONRE), water resources management been strengthened and fortified. As a country with over 3260km of stretched coastline, Vietnam is currently facing many challenges related to water resources and water transboundary. According to the criteria of International Water Resources Association, Vietnam is among the country that lack of water, with up to 60% of surface water generated outside of Vietnam. In actuality, water resources including surface water and ground water in most river basins are at risk of degradation and depletion. Moreover, the impacts of climate change and sea level rise, socio-economic development, urbanization and rapid population growth has increased pressure on water resources, which resulted in water shortages occur regularly and conflicts happen between water-consuming sectors and regions, threatens water security of the nation and region.

Keyword: water resources, water transboundary, NAWAPI

I. INTRODUCTION

The term “Water is vital for life” was sum up and replicated countless times in many important documents around the world when mention about water. This shows the increasing attention toward the role of water in socio-economic development. As well as many countries around the world and in the region, Vietnam is currently facing many challenges related to water resources. According to the criteria of International Water Resources Association, Vietnam is among the country that lack of water, with up to 60% of surface water generated outside of Vietnam. In actuality, water resources including surface water and ground water in most river basins are at risk of degradation and depletion. Moreover, the impacts of water transboundary, climate change, sea level rise, socio-economic development, urbanization and rapid population growth has increased pressure on water resources in Vietnam. Recent years, water sources problems and water scarce have been happened with increasing density and intensity and insisting the need of water investigation, monitoring and planning (distribution, protection and water-borne national disaster).

II. OVERVIEW OF SURFACE WATER RESOURCES

Vietnam has a dense and complex network of rivers and streams with 2.360 rivers of more than 10km in length, 109 of which are major rivers. There are 16 river basins larger than 2.000 km^2, among them are 9 which have catchments areas of over 10.000 km^2. The total area of river basin in Vietnam measures approximately 1.167.000 km^2, the catchment’ area lying outside the country occupies for 72% of the total area.

This rivers and streams network was distributed along the nation and borderland areas from Quang Ninh province in the North to Kien Giang province in the South. The international rivers present in all 25 border provinces of Vietnam. Among them, there are 126 rivers originated from the foreign countries, 76 rivers and streams originate from Vietnam and 4 passing through Vietnam. 68 rivers are found along the Vietnam-China borderline, 85 and 54 in Vietnam-Laos borderland and Vietnam-Cambodia borderland, respectively. In these international rivers, there are 89 continuous flow rivers, streams and channels which are over 10km in length. Most of the river systems are originate form 15 majors river basins (Fig. 1), 9 of which are basins with huge discharge including Hong river basin in Northern region; Ma, Ca river basins in North Central region; Vu Gia-Thu Bon, Se San, Srepok, Ba river basins in Central Highlands and South Central Coast region; Dong Nai, Cuu Long in Southern region.

Aforementioned, the mean annual discharge of surface water in Vietnam[1] is about 830 billion m^3 (BCM). The Cuu Long river basin accounts for 57% of the total discharge while Hong (Red)-Thai Binh and Dong Nai river basin occupies 16% and 4%, respectively. These whole river basins, therefore, are now supporting for most of the economic-socio development activities.

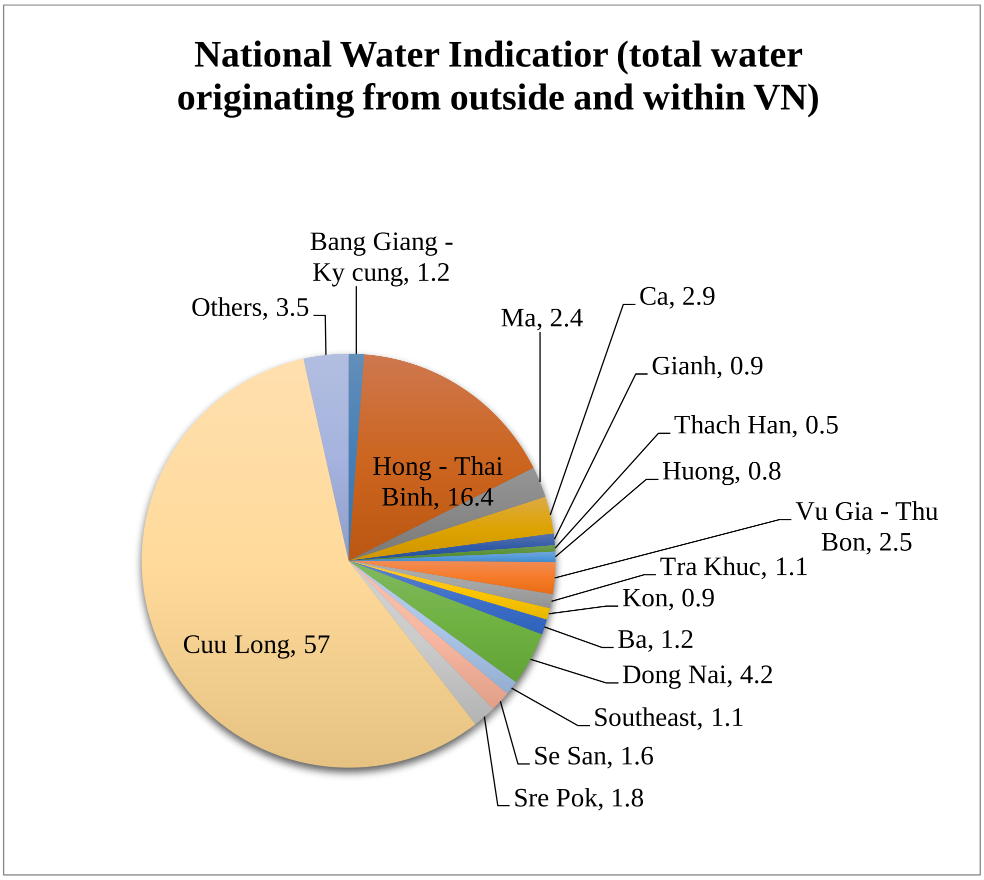

Figure 1. Water resources distribution follow river basin

[1] The river basins which included in this research have total annual discharge over 800 billion m3 for years, account for 96% of the total country.

Among the 9 biggest river basins in Vietnam, 6 of them are depending on the outwardly flows: Hong-Thai Binh river in the North; Bang Giang - Ky Cung river in the Southwest; Ma river in the North Central; Se San - Srepok in Central Highlands and; Dong Nai, Cuu Long river in the South. The major flow of these rivers originate from foreign countries, the Cuu Long river for i.e. has 95% of the annual flow comes from the upstream Mekong river. Approximately 40% of Hong-Thai Binh river flow is rooted from China, nearly 30% of Ma river flow and 22% of Ca river flow are coming from Laos, about 17% of Dong Nai river flow is originates from Cambodia. The only 2 major rivers which running from Vietnam to the outside are Bang Giang - Ky Cung river which originated from China, after passing through Vietnam territory it again flows back to China; and the Se San - Srepok river which came up in Vietnam and running toward Cambodia and contributes for around 50-75% of the total flow in this country.

The total length of rivers and streams which running along the borderline between Vietnam and Laos, Cambodia and China is measured about 1136 km, accounts for 24.7% the length of borderline.

Every year, international rivers and streams contribute over 500 BCM, stand for 60% of total river discharge of the country. In which, the Cuu Long river is the biggest rivers with annual flow of 400 BCM, accounts for 84% of the outwardly flow; Hong river (Red river) annual flow is about 50 BCM, accounts for 10%; Ma river has 8 BCM (7 BCM from Ma river in Thanh Hoa province and the other 1 BCM from Chu river); Ca river flow is about 4 BCM; Dong Nai river has about 3.5 BCM; Bang Giang - Ky Cung brings 1.7 BCM annually after running back to China, etc.

Table 1. Water balance of major river basins

No.	Country and river basin	Precipitation		Total annual flow		Surface water flow		Ground water flow		Evaporation		DC coefficient
		km^3	mm	km^3	mm	km^3	mm	km^3	mm	km^3	mm	
1	Vietnam	647	1957	331	974	232	704	99,3	270	316	983	0,50
River basin networks												
2	Cuu Long	134	1919	54,4	779	38,1	545	16,3	234	72,6	1140	0,37
3	Hong	142	1925	69,7	1137	48,8	796	26,9	341	48,3	788	0,58
4	Dong Nai	76,6	2052	30,4	814	19,8	529	10,7	285	46,2	1238	0,40
5	Ca	33,9	1912	19,8	1117	14,9	838	4,95	279	14,1	795	0,58
6	Ma	30,9	1756	14,7	836	10,3	585	4,41	251	16,2	920	0,43
7	Ba	22,4	1625	9,39	680	7,99	578	1,41	102	13,0	945	0,42
8	Thai Binh	20,0	1577	9,19	725	7,35	680	1,84	145	11,0	852	0,46
9	Ky Cung	15,5	1422	7,19	660	5,39	495	1,80	165	8,30	762	0,50
10	Thu Bon	29,0	27,6	20,0	1915	14,0	1341	6,00	575	8,90	848	0,66

Meanwhile, river network in Vietnam has also transport approximately 43 BCM of water discharge from Vietnam across the borderline to China, Laos and Cambodia. The Bang Giang - Ky Cung and Quay Son rivers (in Cao Bang and Lang Son) annually discharge 9 BCM through Vietnam-China borderline. Rivers of Mekong river network transport nearly 29 BCM of annual water flow to Laos and Cambodia then flow back to Vietnam territory through Tien and Hau river (about 1.6 BCM from Nam Rom river, 13 BCM from Se San river, nearly 14 BCM from Srepok); the Ma river brings about 4 BCM water flow to Laos through Son La province after flow back in Thanh Hoa.

II. OVERVIEW OF GROUNDWATER RESOURCES

Vietnam has a variety of ground water resources. The total ground water reserves calculated for about 63.000 mil m^3/yr but unevenly distributed. A dynamic reserve of the entire territory (excluding islands) is 2.000 m^3/s. This amount, however, was measured quite apart of long-term sustainable development. Underground water exploitation per capital varies from 3.770 m^3/capital/yr in the Northwestern to the lowest 84 m^3/capital/yr in Mekong river delta.

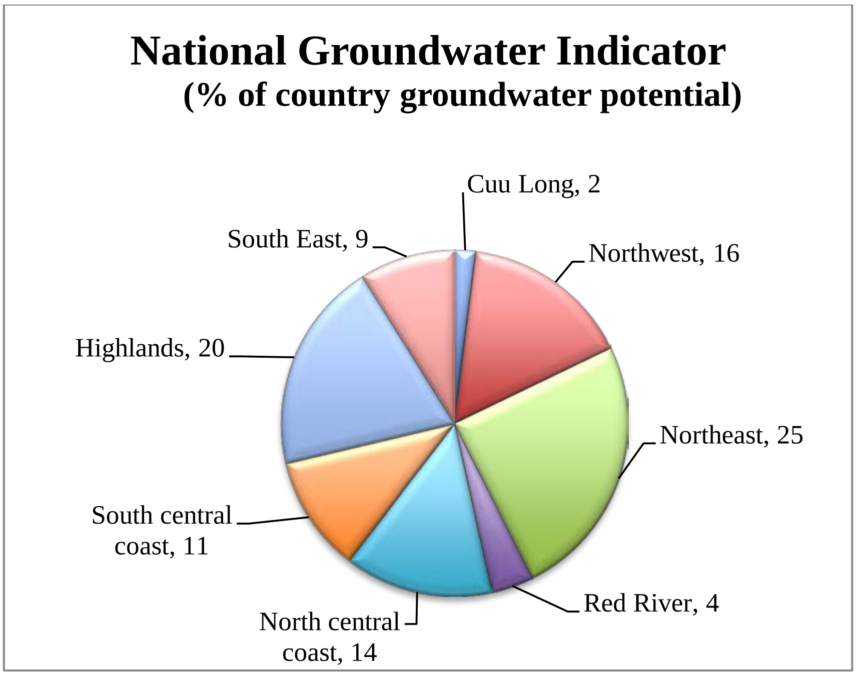

Figure 3.12. Underground water distribution throughout the country

The Northwestern and Northeastern in Vietnam have a high potential amount of groundwater, unevenly distributed but mostly in limestone formation which is a problem for exploitation. In Hong River Delta (Red River Delta), Southeastern region, Mekong River Delta and other coastal delta, the best water-bearing formations are seen in sedimentary rock containing sand, gravel and pebble in quaternary sediment. These formations are usually placed in shallow depth which is cheaper for groundwater exploitation but sensitive to pollutants. In Central Highlands and high regions in the Southeastern, sediments found in igneous volcanic rock are also containing a potential amount of groundwater.

The major water-bearing complexes and aquifers in Vietnam which are essential in Vietnam including:

- *Pore-water bearing complexes in Quaternary sediment and Neogene*

Pore-water bearing complexes in Quaternary sediment and Neogene vastly distribute in Northern Delta, Central Coastal region and South Coastal regions. These aquifers are some dozen meters up to 400 - 500 m (Southern Region) in depth. They divide into 2 - 3 aquifers in Central Coastal Delta or up to 8 aquifers in Southern Delta. These water-bearing zones contain numerous amount of water; water transmissibility coefficient fluctuates in the range of 100 - 2000 m^2/day. Exploitation capacity of drilled well can reach from dozens to hundreds cubic meters per hour.

These water-bearing complexes play an extremely important source for drinking water, municipal use and industry in Northern Delta, Central and South Coastal regions.

- *Karst water bearing complex*

The Karst water-bearing complexes (in limestone) distribute primarily in the Northern areas. These complexes hold 1/3 of the natural area of the North with average underflow module varies from 10 - 12 l/s.km^2. Karst topography is lack of surface water, as the result, groundwater is vital for water supply. The municipal areas which are using water exploited from karst the most are Ha Giang, Cao Bang, Lang Son, Son La, Thai Nguyen, etc.

- *Pore-water bearing complex in Basalt*

This type of complex mostly seen in Central Highlands with thickness ranges from couple dozen meters do maximum of about 500 meters. Water containing ability of this layer is from medium to rich, average underflow module of 80-100 l/s.km2. Potential exploitation reserve can goes up to 100 m3/hr. Currently, water containing complex in Basalt is the main supply source for domestic use of people in Central Highlands and for irrigation. Coffee, pepper, rubber tree and so as other terrestrial crops in Central Highlands are depending on this water supply sources for growth.

- *Other water-bearing formation besides these major complexes (Metasedimentary and meta-igneous formations)*

Despite of the limited water bearing - water transmissibility abilities, these horizons are still valuable for small scale domestic use, irrigation and breeding, especially in water scarce areas in Centre, Central Highlands and Northern mountainous regions.

II.3. Major Challenges

Firstly, population growth, economical growth and urbanization are increasing in recent years. In 1986, the whole country has 480 urban areas, to 2012 has increased to 755 urban areas and estimated to double that number in 2020. On national scale, we have 301 industrial zones, hundreds of small-scale industrial zones and about 2.000 handcrafted village in various regions, in which 70% of the industrial zones do not have a qualified wastewater treatment system; more than 90% production, business and service facilities do not treat wastewater; more than 4.000 facilities causes serious water pollution; about 55 - 70% the number of enterprises do not comply to the regulation about creating evaluating report about impacts on water sources or commit to protect water sources; 98% of enterprises have violation on discharged wastewater which do not meets the regulated standards; 100% of enterprises emit emssions without facilities to treat toxic substances.

Secondly, compared to the world, Vietnam does not have abundant water resources, combine with many risks due to natural geographic characteristics, all of which cause many hindrances to our country in active exploitation of the water sources. More than 60% of surface water in Vietnam have originated from outside of the country. In recent years, the upstream countries are increasing exploitation of water for the purpose of socio-economic development, therefore the amount of water flows to Vietnam is increasingly diminished and polluted, especially the Mekong River and Red River basins. On the other hand, Vietnam has low stretched coastline, which make the impacts of climate change and sea level rise more serious, salt-instrusion is more and more complicated, especially in the Mekong River basin.

Thirdly, water resources of Vietnam do not contribute evenly in space and time, 75-85% of total water amount yearly focus mainly during 3 months of flood season, meanwhile there is very little amount of water during dry season for the rest of the year. At the heavily populated regions or regions with heavy production, service facilities, such as coastal delta, urban areas…the water sources is very limited. The demand for water use increases, coupled with the lack of a system that cooperates, shares and distributes water sources between industries and regions, leads to conflict of interests, conflicts in exploitation of water.

Fourthly, other than reasons mentioned above, the pollution and exhausted situation of water sources also caused by the awareness of users, many people still do not have a full awareness of the problem and their responsibility, still have not changed their daily life habits. For instance, the thought “water is from the sky, it is unlimited” is still embedded deep inside the conscious of the majority of the population, which leads to low awareness in using and protecting water resources; and that causes a waste of clean water sources. Or another habit, the habit of throwing domestic wastes into rivers and channels, even with strong criticism and disagreement, this habit until now is still popular, which turns many rivers to solid waste dump river.

IV. Primary missions and major solutions

IV.1. Strengthen investigation and researching ability, technique development

- Strengthen the human and material resources and investigation technical equipment for effectively accomplish the fundamental investigation and planning on water sector.
- Speed up the construction and effective exploitation of information system, database for investigation, monitoring and planning.
- Concentrate on modernize water monitoring, apply digital technology in monitoring, projection and warning.
- Improve international cooperation for researching, technology transfer and master the modern technique for better services on water resources projection, warning in all over the country, focus on major river basins.
- Mobilize the international capital investment, socialized capital for water sector planning, building the water supply, water distribution works for water scarce regions, mountainous regions and frontier islands.

IV.2. Oriented solution

Firstly, continue to complete the legistration system and strengthen the inspection on enforcement of policies, legistration in management and protection of water resources. First, build the sharing, coordinating and supervising mechanisms, complete the operation process of important reservoirs system to ensure harmony between multiple goals of water consumers and regions.

Secondly, strengthen regional and international cooperation, enlisting the international support and assistance to protect national water security. Establish a mechanism for cooperation and dialogue to ensure the fair exploitation of water sources of international rivers, and build plans to actively address the arising issues.

Thirdly, promote the basic survey, monitoring, observation, forcasting and warning to catch up with the condition of national water resources. Early complete baseline survey of the country from which define the roadmap for implementing the investigation and evaluation of water resources, develop the monitoring system, automated and online monitoring including baseline monitoring, fluctuation monitoring and exploitation monitoring, use and operate the reservoirs and the waste discharge into water sources. Establish and implement water resource planning for the whole country, water resources planning for large river basins, intercity and planning of water resources in each locality, provide the basis to address shared issues, distribute and protect water resources and prevent the harmful effects caused by water.

Fourthly, promote information, communication, and education to improve the social awareness about water transboundary not only for Asian countries but also for provinces in the country; the responsibility to protect and use water sparingly, effectively. Consolidate and strengthen the apparatus, improve capacity of science, capacity in water resources management at all levels and strengthen the socialization of public service in the field of water resources.

IV. Conclusion

Vietnam lacks of diversity in water resources. Under the increasing pressure of population growth, effects of urbanization and climate change with intensifying complications, the dangers of water security on socio-economic development have been growing seriously day-by-day. The situation raising the needs of response plans to protect, maintain and develop national water resources for present and future.

We have to do more for best water transboundary management, it very importance for ensuring water security of each country, ensuring living condition for human, an important contribution in social stability, enhancing the process of economic development. In contrast, when water transboundary is breached, it will have a direct impact on people interests of each countries, reduces social conflicts between country and country; people and the business; between the people and their government. We are doing for ensuring water shared-interests countries to be equitable.

We are doing for ensuring harmonized water sharing among countries and user groups of common interests.

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