Current Status and Issues of Groundwater in the Mekong River Basin

Chief Editor

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PREFACE

Groundwater is an important source of freshwater that stores almost 90% of the total non-frozen freshwater on the Earth, and groundwater resources play an important role in achieving social, economic and environmental benefits in East and Southeast Asia. Recognition of the importance and the need of catchment-based groundwater management have increased in global terms in recent years, with a focus on mega-catchments such as the Mekong River system, Irrawaddy River system, and Red River system.

Assessments in the Mekong Basin have been made over the last 30 years and have revealed the great potential of the groundwater resources in the region, including trans-boundary aquifers. However, groundwater resource usage, environmental problems that emerge and priorities for water resource management differ in each country, whose level of development and populations vary significantly. A growing number of countries in the Mekong River Basin are experiencing depleted and degraded freshwater supplies because of population growth and climate change. The rapid expansion of groundwater exploitation and contamination over these countries now poses an immediate threat to water supplies, and competition over limited water resources can heighten the tension between neighbouring countries. The limited understanding of groundwater systems by the member countries restricts the sustainable management of groundwater resources. The lack of a unified hydrological map system and a common, accessible database on trans-boundary aquifers are particularly known to be major reasons for conflicts regarding groundwater and land use by stake holders, irrational water use by local peoples and inadequate management by the governments of the member countries in the Mekong region.

Current Status and Issues of Groundwater in the Mekong River Basin

The current status of the groundwater environment in the Mekong River Basin should be discussed to realize the security of water and to use groundwater resources widely in the region.

Since the establishment of the organization in 1966, the Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP) has been cooperating with 14 member countries, including almost all countries in East and Southeast Asia, i.e., Cambodia, China, Indonesia, Japan, the Republic of Korea, Lao PDR, Malaysia, Myanmar, Papua New Guinea, the Philippines, Singapore, Thailand, Timor-Leste and Vietnam. Its role in the construction of geoscientific capacities, information exchange and the coordination of cooperative technical activities, with groundwater as a major focus, contributes to economic development and the improvement of the quality of life in the region.

Within the framework of the 4-year (2013-2017) CCOP-KIGAM Project "Solution for groundwater problems in CCOP region", which was supported by the Korea Institute of Geoscience and Mineral Resources (KIGAM), Republic of Korea, the collaborative workshop between CCOP, KIGAM, UNESCO and DGR was held to create an open forum for the CCOP member countries in the Mekong Basin to contribute country reports and to discuss future collaborative work for the sustainable integrated management of trans-boundary aquifers. This collaborative work will provide a great opportunity to further our understanding of the hydrological processes throughout the Mekong River Basin, to share benefits from shared aquifers, and to provide a strategy and vision for sustainable water resource management in the Southeast Asia countries.

Dr. Kyoochul Ha
Chief Editor

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Introduction to the CCOP-KIGAM Groundwater Project

Kyoochul Ha

Korea Institute of Geoscience and Mineral Resources (KIGAM), Republic of Korea

1. Background of the CCOP-KIGAM Groundwater Project (2013-2014)

Groundwater is an important source of freshwater in CCOP region. However, a growing number of countries in Southeast Asia have suffered from serious groundwater problems both in quantity and quality such as groundwater level drawdown, subsidence of ground surface, and groundwater contamination. These problems challenge hydrogeologists to find solutions. International cooperation among CCOP countries is strongly needed to solve these water resources problems.

2. KIGAM-CCOP Project: "Solutions for Groundwater Problems in CCOP Regions"

A collaborative project between CCOP and KIGAM was launched in 2013 in an attempt to achieve sustainable management of groundwater resources in the CCOP regions by sharing information and discussing common issues between neighbouring countries. The major objectives of the project are (1) to enhance the international cooperation among CCOP countries, (2) to establish a groundwater management plan in response to the increased human activities and global climate change, and (3) to improve the technologies for solving groundwater problems in the CCOP countries. The major activities of the project over the last 2 years are summarized in the following table.

Table 1. Major activities of the CCOP-KIGAM collaborative project

Phase	Activities
Step I (year 2013)	Understanding groundwater problems in the CCOP regions - Identifying groundwater problems in each country - Trust building and enhancing reliability to cope with groundwater problems among each country - Groundwater training and workshop in KIGAM (2013. 7) - CCOP-KIGAM-DGR-DMR-AIT technical workshop in Bangkok (2013. 10).
Step II (year 2014)	Finding cooperative measures to solve groundwater problems - Establishment of the international network - Priority decision making for solving the groundwater problems in the CCOP regions. - Jeju Water Forum (2014.10)

3. Groundwater Problems in the CCOP Regions

A number of groundwater management issues have been identified from the conductive meetings and country reports. The major groundwater problems in the CCOP regions include the following:

3.1. Cambodia

- Carbonate contamination in the Mekong river
- Arsenic contamination; high amounts of arsenic in some areas
- Poor knowledge on groundwater resource management

3.2. China

- Silt & clay transport in the aquifer
- Arsenic contamination along the Yellow river
- Trans-boundary aquifers (currently, China has bilateral cooperation with Vietnam on this topic; extension to other Mekong River Countries (MRCs) should be considered)
- Continuous drop in the groundwater elevation
- Subsidence of ground surface, ground surface fissures and collapses
- Groundwater contamination: approximately 26% of the groundwater in the surficial layer has been contaminated by excessive human activities

3.3. Indonesia

- Quality of the groundwater database
- Conflict over water use
- Overlapping roles in institutional water resource management
- Limited water resources information

3.4. Lao PDR

- Assistance needed for capacity building & technique transfer
- Weaknesses and gaps in coordination and cooperation for water resource development
- Poor knowledge and capacity building of water resource management
- No long-term plan for water resource management and water usage; laws and regulations not yet clear

3.5. Malaysia

- Pollution/contamination from non-point sources (pesticides & herbicides) and point sources (mines)
- Assistance needed for an investigation of groundwater resource potential
- Fragmented policies and governance framework
- Lack of comprehensive resource evaluation (e.g., data collection, management and dissemination): lack of sustained research and development, lack of manpower and human resources

3.6. Myanmar

- Arsenic content is 50 ppb to 100 ppb from 0 to 300 ft within the aquifer in the Ayeyarwaddy region

3.7. Papua New Guinea

- Assistance needed in capacity building for, e.g., groundwater assessment and management, field-based training, groundwater geophysical surveys, and on-site pumping tests
- The issue of purification is very important for PNG, where mining activities are very popular

3.8. Thailand

- A large amount of fluoride, over 2 mg/l, is present in the western and northern regions because of the occurrence of hydro-geothermal systems
- High lead content from a former landfill in the eastern region.
- Salty water due to rock salt layers underneath the surface in the north-eastern region
- High nitrate content in groundwater from domestic animal and human waste leakage into the aquifer
- High amount of iron, salty water in upper layers, and high arsenic content in the central plain
- Assistance needed in capacity building for junior hydrological geologists

3.9. The Philippines

- Groundwater in the metropolitan area contains bacteria
- Saltwater intrusion
- Assistance needed for on-site technical training (similar to the requests by PNG)

3.10. Timor Leste

- Water shortage, saltwater intrusion in the coastline area
- Lack of water management policies

3.11. Vietnam

- Salinization of groundwater in the coastal area
- Ammonium contamination in groundwater
- Groundwater level drops in Hanoi (-1 m/yr, total 30 m drop), Ho Chi Minh City (total 30 m), and in many other places in the Mekong River Basin; groundwater levels also decreased greatly.
- Land subsidence in Hanoi because of over-extraction
- High and increasing amount of arsenic in groundwater

4. Future Plans

While the previous CCOP-KIGAM workshops (2013-2014) mainly focused on understanding groundwater problems in the CCOP regions, this year's meeting was intended to take cooperative measures to find solution to these problems. The next step of the "CCOP-KIGAM Collaborative Project" will will be taking the reliable actions to solve the groundwater issues in the CCOP region, including the hydrogeological investigations for trans-boundary aquifer management in the Mekong River Basin within the framework of the KIGAM-CCOP sub-project "Solutions for Groundwater Problems in CCOP Regions". The major research contents of the projects include (1) data collection and compilation for hydrogeological maps, (2) assessment of groundwater occurrences and water quality,

(3) construction of groundwater monitoring stations along the Mekong River, and (4) construction of groundwater database for trans-boundary aquifer management in the Mekong River Basin. Strong cooperation is required among CCOP, KIGAM, UNESCO, and DGR to achieve the abovementioned goals. With our dedicated efforts, the collaborative project will provide a great opportunity to further our understanding of the hydrological processes throughout the CCOP regions, to share benefits from the shared aquifers, and to provide a strategy for sustainable water resource management in the Southeast Asian countries.

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Introduction to the CCOP-KIGAM Groundwater Project

Groundwater Level Monitoring – Importance of Global Groundwater Monitoring Network

Groundwater Level Monitoring – Importance of Global Groundwater Monitoring Network

Ramasamy Jayakumar

UNESCO Bangkok, Asia and Pacific Regional Bureau for Education

1. Introduction

It is estimated that world-wide, almost 900 million people do not have access to an improved drinking water supply, of whom 84% live in rural areas (WHO/UNICEF 2010). The world as a whole is on track to meet the Millennium Development Goal (MDG) Target to *"halve, by 2015 the proportion of the population without sustainable access to safe drinking water"*.

We all are groundwater users, farmers use it for irrigation, industries for production and a vast majority of population uses it for drinking and domestic purposes. Groundwater, although a renewable resource, is limited in its occurrence in time and space. The mindless pursuit for extracting more and more groundwater by all the users has already started exerting tremendous pressure on this vital resource.

Because groundwater is stored underground, it is better protected then surface water from the threat of pollution from human activities. Processes such as filtration, sorption and natural reduction in the un-saturated zone (i.e. above the water table) work to reduce or eliminate contaminants to enter the groundwater system (ARGOSS 2001). Groundwater is one of the most important natural resources. In several countries groundwater is the principal source of drinking water. In addition, several countries in the semi-arid region uses groundwater for agricultural purposes.

Groundwater has an important role in the environment: it replenishes streams, rivers, and wetlands and helps to support wildlife habitat. It is therefore also a significant, but often unrecognized, component to sustain and maintain of the surface water resources. Around the world, groundwater resources are under increasing pressure caused by the intensification of human activities and other factors such as climate change. Reductions in groundwater storage have implications for the water cycle because groundwater supplies the base-flow in many rivers and it supports evapotranspiration in high water table regions. Reductions in groundwater storage also have major implications for water quality because the salinity of the extracted water frequently increases as the volume of the reservoir decreases. Groundwater resources need to be carefully protected because in many regions, withdrawal rates exceed recharge rates. Once modified or contaminated, groundwater can be very costly and difficult to restore.

2. Groundwater Monitoring

Groundwater monitoring programme includes both groundwater quantity (e.g. groundwater level and recharge rates) and quality monitoring (analysis of selected physical and chemical variables) networks. Monitoring groundwater is a continuous process. The methodology and techniques involve *in situ*, satellite and airborne observations and laboratory analysis of quality variables.

Groundwater monitoring programmes operate at the international, national, regional and local scales. Local groundwater level monitoring activities often include a great density in terms of time and space, unconfined, semi-confined and confined aquifers for quantity as well for quality.

The use of satellite and airborne observations are valuable to fill in spatial and temporal gaps in *in situ* monitoring and, although their reliability is more uncertain when high quality input data are not available.

Satellite observations are now playing an increasingly important role in global groundwater resources assessment and groundwater storage change, but only at lower spatial and temporal resolutions.

The main aims of groundwater monitoring are:

1) collecting, processing and analysing the data as a baseline for assessment of the current state, anticipating changes and forecasting trends in groundwater quantity and quality due to natural processes and human impacts in time and space;
2) providing information for improvements in the planning, policy and management of groundwater resources.

All these information types, used synergistically, can yield a consistent picture of the current state of global groundwater resources, so that in the future it will be possible to provide more accurate prediction of variations in groundwater availability.

3. Groundwater Level

Groundwater level is a term that is used in a relatively loose way, normally referring to the level, either below ground level or reference to mean sea level. This is also referred to as the water table and represents the top of the saturated zone. Above the water table lies the unsaturated zone.

3.1. Why monitor groundwater levels?

Groundwater systems are dynamic and adjust continually to short-term and long-term changes in climate, groundwater withdrawal, and land use. Groundwater level measurements from observation wells are the principal source of information about the hydrologic stresses acting on aquifers and how these stresses affect groundwater recharge, storage, and discharge. Groundwater levels reflects the amount of water in storage in the monitored aquifer. When recharge exceeds natural discharge plus abstraction, groundwater levels rise. When recharge is less than natural discharge plus abstraction, groundwater levels fall.

Long term, systematic measurements of water levels provide essential data needed to evaluate changes in the resource over time, to develop groundwater models and forecast trends, and to design, implement, and monitor the effectiveness of groundwater management and protection programs.

Comparisons of measured groundwater levels with long-term averages provide an indication of the state of groundwater resources within an aquifer. Observations over several years allows the prediction of aquifer response to current climatic and hydrological conditions. The data from the archive are used to prepare archive products such as the monthly hydrological summaries, annual summaries and the statistics volume.

The data are used for quantitative analyses, for instance of annual recharge, and provide a valuable source of data for the calibration of groundwater models.

Benefits of Monitoring Groundwater Levels:

1. Determine annual and long-term changes of groundwater in storage
2. Estimate recharge rates
3. Determine direction and gradient of groundwater flow
4. Understand how aquifer systems work
5. Gain insight for well construction and where to set pump bowls for efficient extraction

3.2. How are groundwater levels measured?

Groundwater levels are measured in several ways, manually using a dipper or automatically by a pressure transducer. Automatic readings may be stored in a data logger that is visited periodically and downloaded by field staff, or sent automatically over the phone network to a database in a data centre (telemetry).

However, there is always some components need to be addressed as indicated below:

Multiple aquifers: Where multiple aquifers are present there may be significant differences in water level between aquifers, especially if there are perched water tables or confined aquifers making it unclear which aquifers are measured.

Karstic aquifers: In karstic aquifers and other aquifers where fissure flow dominate there may be no defined water table in a regional sense, but rather each fracture system may respond independently, leading to significant variations in level over short horizontal or vertical distances.

Clays: In clays a water table may be present, but not be a useful concept, if the low permeability of the clay prevents the draining of surface water.

Seasonal variations: Seasonal variations in level range from a few centimetres in some confined aquifers to several tens of metres. Inter-annual variations show similar fluctuations in response to climatic variations.

Pumping: Levels may be artificially depressed by pumping. Where regional depressions occur it is the current depressed level that is normally of interest, although reversion to the natural 'unpumped' level is likely if pumping ceases - frequently historical data has been gathered during periods when pumping was intense, and less data may be available after pumping stops. Where unrecognised localised depression of the water table occur through pumping they may distort interpolations of regional levels that include measurements made in nearby boreholes. More rarely levels may be higher in observation boreholes due to localised recharge leading to groundwater mounding. Measurements made during or immediately after the drilling of a borehole may be affected by the injection or extraction of water as part of the drilling process.

4. Essential Components of Groundwater Level Monitoring

4.1. Selection observation wells

All groundwater level monitoring programs depend on the operation of a network of observation wells for the collection of water-level data in one or more specified aquifers. Decisions made about the number and locations of observation wells are crucial to any water-level data collection program. Ideally, the wells chosen for an observation well network will provide data representative of various topographic, geologic, climatic, and land-use environments.

Groundwater level monitoring programs for complex, multilayer aquifer systems may require measurements in wells completed at multiple depths in different geologic units. Large, regional aquifers that extend beyond country / province boundaries require a network of observation wells distributed among one or more country / province.

When the groundwater level monitoring is part of the ambient groundwater resources, or the effects of natural, climatic-induced hydrologic stresses, the observation network will require wells that are unaffected by pumping, irrigation. For further reading on many other technical considerations pertinent to the design of a groundwater level observation network are discussed in more detail in technical papers by Peters (1972), Winter (1972), and Heath (1976).

4.2. Frequency of groundwater level measurement

The frequency of groundwater level measurements is the most important components of a monitoring program. Although often influenced by economic considerations, the frequency of measurements should be determined to the extent possible to fully characterize the hydrologic behaviour of the aquifer.

Typically, collection of groundwater level data over one or more decades is required to compile a hydrologic record that encompasses the potential range of groundwater level fluctuations in an observation well and to track trends with time. The availability of long-term water-level records greatly enhances the ability to forecast future water levels. Therefore, observation wells should be selected with an emphasis on wells for which measurements can be made for an indefinite time.

4.3. Quality assurance

To maintain the accuracy and precision of groundwater level measurements, ensure that observation wells reflect conditions in the aquifer being monitored, and provide data that can be relied upon for many intended uses. The locations and the altitudes of all observation wells should be accurately surveyed to establish horizontal and vertical datum for long-term data collection. Recent advances in Global Positioning System (GPS) technology, have simplified the process of obtaining a fast, accurate survey of well location coordinates and datum.

To help maintain quality of the data, a permanent file that contains a physical description of well construction, location coordinates, the datum used for groundwater level measurements, and results of hydraulic tests should be established for each observation well.

4.4. Data reporting

The accessibility of groundwater level data is greatly enhanced by the use of electronic databases, which is compatibility with Geographic Information System (GIS) technology to visually depict the locations of observation wells relative to pertinent geographic, geologic, or hydrologic features.

Hydrographs, the graphical plots showing changes in water levels over time are particularly useful form of data reporting. Such hydrographs provide a visual depiction of the range in water-level fluctuations, seasonal water-level variations, and the cumulative effects of short-term and long-term hydrologic stresses.

5. Status of Groundwater Resources in Mekong Countries

5.1. Cambodia

Status of groundwater resources in Cambodia

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

Major issues and challenges threatening groundwater resources

- Groundwater quality problems with high arsenic and iron (Fe) contents in Mekong and Tonle Sap river basin (along the rivers)
- Saltwater intrusion in coastal aquifers (Southeast Provinces)
- Industrial zones are expanding in Cambodia; potential problems of groundwater contamination from untreated industrial wastes
- Currently, groundwater is used only for small community water supply; but trends to exploit more groundwater for industrial use and agricultural irrigation
- Potential major threat is over exploitation without legal control of groundwater administration. Groundwater management partially included in the Water Resources Law

Government interventions for groundwater issues

- Investigation and testing for Arsenic reduction technology development by MRD/NGOs and Institute of Technology of Cambodia
- Potable Iron Reduction Plants are developed and installed on high-iron content tube-wells (operated with hand pump)
- Continuation of Groundwater Study in Northeast Region (By MRD with assistance of JICA) Groundwater Database under developing (by MRD/ MOWRAM with WB assistance)
- Groundwater Water Quality Mapping by MRD in cooperation with RDI (NGO) and WHO

Challenges

- At present groundwater are extracted from shallow aquifers; there are potentials for exploration of deep aquifers (deeper than 200 meters). These deep aquifer explorations required updated technology applications.
- Groundwater, river basins and shallow aquifer areas are always replenished by rainwater and river-flood water. Climate change impact can affect to groundwater recharge in these areas
- Salt water intrusion in Coastal region is big challenges; need technology development to control of mitigate impacts.

Policy supports to increase groundwater resource sustainability

- Law enforcement on Groundwater Management Groundwater Management and Environmental Laws to protect Groundwater contaminations
- Groundwater Studies (investigation, groundwater mapping,) are essential for groundwater resource management
- Groundwater Database and Functional Monitoring System establishment (on quality and quantity) related with inter-ministerial cooperation
- Mekong River is one important source for recharging of shallow groundwater and sub-surface in Cambodia. Mekong River Management is a regional issue.

(Source: from Mr Sok Sophally, Groundwater Resources in Cambodia available at http://www.iges.or.jp/en/natural-resource/groundwater/PDF/activity20110602/S1-3_Mr.Sok-Sophally_GW_Cambodia.pdf)

5.2. Lao PDR

Status of groundwater resources in Lao PDR

Groundwater is emerging as a large and generally untapped resource. However, there is very little monitoring of groundwater quality in Lao PDR, even though it is the main source of rural water supply. There are three different aquifer systems:

- The Annamian aquifers occur randomly. These are local systems that discharge locally to the river or its tributaries. As local flow systems, they are not part of the regional flow system and will not carry pollution into the regional groundwater system. The potential water supply from groundwater in the northern part of the country is considerable in view of the high amount of recharge available. Water quality should be reasonably good and for the most part potable but will be iron rich. Yields up to 5 liters/sec can generally be anticipated.
- The Indosinian group of aquifers, which have regional flow, includes rock of the Indonisian Moyennes and Superieures and is relatively young. They are mostly freshwater sediments, although there are horizons of brackish water, and one major zone of saline water. Yields of 12-24 liters/sec can be developed.
- The alluvial aquifers associated with the sedimentary deposits of the Mekong River are not rated highly as aquifers.

(Source: http://www.wepa-db.net/policies/state/laos/groundwater.htm)

Major issues and challenges threatening groundwater resources

- Groundwater resources extent and quality largely unknown, because lack of systematic monitoring, borehole logging and yield test.
- No systematic or national approach to defining the groundwater resource means using groundwater for water supply is often a high risk option for water supply.

- Climate change - abnormally fluctuating shallow groundwater levels can have a significant impact on iron and manganese content of shallow groundwater, need further studies.
- Lack of a water quality data base means that for example 'arsenic hotspots' on the plains of Southern Lao are now just being recognized as an issue. Problem is that in many cases there is no alternative to the existing, inexpensive shallow dug wells.

Policy barriers towards groundwater resource sustainability

- Policies need to be supported with timely Decrees in order to implement the Regulations and Decisions.
- Need all kinds of resources to support the policies and inter-ministerial cooperation is required.

(Source: Phouvong CHANTHAVONG, Groundwater for Water Supply in Laos http://www.iges.or.jp/en/natural-resource/groundwater/PDF/activity20110602/S1-3_Ms.Phouvong_CHANTHAVONG_Laos.pdf)

5.3. Myanmar

Status of groundwater resources in Myanmar

- On the basis of stratigraphy, there are 11 different types of aquifer in Myanmar.
- Depending on their lithology and depositional environments, groundwater from those aquifers has disparities in quality and quantity
- Out of those, groundwater quality of Alluvial and Irrawaddian aquifers is more potable for both irrigation and domestic water use.
- In the water scarce regions, groundwater from Peguan, Eocene and Plateau limestone aquifers, though not totally suitable for drinking purpose from hygienic point of view, are extracted for domestic purpose.
- Water use in Myanmar has been on the increase particularly in the agricultural and industrial sectors.
- It is found out that as much as 89% of water use is tapped for irrigation purpose, about 8% is for domestic consumption and 3 % is for industry

Major issues and challenges threatening groundwater resources

- Groundwater is the principal source of domestic water supply in Myanmar.
- Between 1952 and 1976, RWSD (predecessor of WRUD) constructed 6,261 tube wells serving some 4.5 million rural populace. (These works were funded by the government.)
- Negotiations initiated in 1976 with resulted in the formulation of a tube well program in the dry zone of central Myanmar which comprised the construction of 3100 tube wells for the three regions of Sagaing, Magway and Mandalay. (implemented in 1977-1978 with the combined resources of the Government and external agencies, namely WHO. UNICEF and ADAB.)
- So far, WRUD has completed a total of 38,320 tube wells in different types and sizes for drinking water supply throughout the country.

(Source: U Aung Khaing Moe, Sustainable Development and Management of Groundwater in Myanmar: http://danishwater.dk/wp-content/uploads/2013/09/Ministry-of-Agriculture-and-Irrigation-Department-of-Water-Resources-Utilization-Sustainable-Development-and-Management-of-Groundwater-in-Myanmar.pdf)

Experts warn of groundwater depletion dangers

While some areas of Myanmar suffer from dwindling water supplies during summer, it is not unusual at this time of year to see water dripping from overflow pipes set outside high-rise buildings in Yangon.

(Source: http://www.mmtimes.com/index.php/national-news/10304-experts-warn-of-groundwater-depletion-dangers.html)

5.4. Thailand

Status of groundwater resources in Thailand

- The stress on water in the main development regions is especially heavy, and groundwater has become an important resource for industrial use and urban water-supply. Moreover, as a consequence of recent droughts, it has become more widely exploited for irrigated agriculture to insure dry-season cropping.

- Thailand needed a soundly-based and effectively-implemented management system to ensure sustainable and efficient use of its valuable groundwater resources. In general terms it can be said that all of the major alluvial aquifers possess very large reserves of freshwater in storage, but their rates of active replenishment (while very significant) are still subject to a large degree of uncertainty.

Major issues and challenges threatening groundwater resources

- Careful monitoring of the aquifer response to existing or new pumping, and to already-existent pollution plumes, is the cost-effective way of confirming conceptual models, and calibrating numerical models, used as the basis for groundwater management.
- A particularly important need is to assess shallow aquifer recharge mechanisms and rates, together with evaluation of shallow-deep aquifer interactions, in typical alluvial aquifer situations. This is related to the field assessment of hydrogeological sustainability and socioeconomic benefits of existing informal conjunctive use of groundwater for supplementary agricultural irrigation.
- There was also a need to rationalise data basing, including establishment of a computerised linkage system (with joint numbering and agreed location) between well-based entries in the scientific hydrogeologic database and the abstraction regulation database, and also widening the data-capture up-grading and completion of the computerised regulation database.

(Source: GW·MATE Briefing Note Series Sustainable Groundwater Management Lessons from Practice - Thailand: Strengthening Capacity in Groundwater Resources Management - http://www.un-igrac.org/dynamics/modules/SFIL0100/view.php?fil_Id=178)

5.5. Vietnam

Status of groundwater resources in Vietnam

The Vietnamese territory can be divided into 6 hydrogeological regions (HGR).

- West Bac Bo HGR located in folded mountain structure in West Bac Bo. This is a complicated hydrogeological region.
- East Bac Bo HGR belonging to formation of mountainous area in East Bac Bo.
- Bac Bo Delta HGR including the whole delta plain in North Vietnam, which extends from Viet Tri City to the East Sea. This delta is built up by Red and Thai Binh River systems.
- North Trung Bo HGR including coastal plain provinces in the north of Central Vietnam such as Thanh Hoa, Nhge An, Ha Tinh, Quang Binh and Thua Thien – Hue.
- South Trung Bo HGR including coastal plain provinces in the south of Central Vietnam such as Tuy Hoa, Binh Thuan and Nha Trang – Khanh Hoa.
- Nam Bo Delta HGR including the whole delta plain of Mekong and Dong Nai River systems.

Groundwater on the Vietnamese territory exists in following formations:

- Groundwater in loose sediments is distributed mainly in two large delta
- Groundwater in basalts is distributed mainly in the Tay Nguyen plateau belonging to the Kon Tum, Gia Lai, Dac Lak, Lam Dong Provinces and some provinces of South Trung Bo and East Nam Bo
- Groundwater in carbonate (karst aquifer) occupies an area of 50,000 km^2
- Groundwater in crushed formations (terrigenous sediments, effusives, intrusives and metamorphic rocks) usually has good quality and satisfies the water use demands. However, because of small reserve, its exploitation is scattered with each well of only some cubic meters per day of output.

Major issues and challenges threatening groundwater resources

Issue of quality management is an urgent problem not only at present but also in the future. To manage and control the quality of water sources, we need to perform the following works:

- Obeying strictly protective requirements for water sources during the time of exploitation and use;
- Establishing protective areas and belts to protect aquifers;
- Managing successfully and controlling strictly waste and pollutant sources that lead to the degradation of water quality.
- Building monitoring systems for the fluctuation of groundwater;
- Assessing the environmental impact to factors causing pollution and exhaustion of water sources, such as annulation of natural recharge sources (forests, rivers, streams…), exploitation of water with large output and in long time, mineral exploitation causing serious influence to groundwater quality and reserves.

Solutions for managing and protecting groundwater resource

To well perform the task of management and protection of precious groundwater resource, we need to realize the following works:

- Seriously designing a law for water resource protection;
- Strictly realizing guides, decretes and under-law documents. Managing successfully the works of drilling for groundwater exploitation. Listing water exploitation works to establish database for different works;
- Propagandizing broadly to people the ways to exploit and use water effectively and economically. By late years of this decade, all people should have good sense in the protection of water resource;
- Building protecting zones for water sources, especially in present exploiting areas of Ha Noi, Ho Chi Minh Cities and other urban areas;
- Modernizing water management work. It is necessary to have immediately courses on water management for individual, community and organizations related to the exploitation and protection of groundwater;

- Processing pollutant and toxic waste sources which there influence on water sources;
- Planning and building water exploiting centres to manage and supply with water more effectively to minimize catastrophes during exploiting process.

(Source: BUI HOC, PHAM KHANH HUY, HOANG THI MINH THAO, Groundwater Management in Vietnam, http://www.idm.gov.vn/nguon_luc/Xuat_ban/2005/B25/b26.htm)

6. Global Groundwater Monitoring Network (GGMN)

Groundwater is monitored in many parts of the world by measuring groundwater levels, groundwater abstraction rates, spring discharge and groundwater quality. Groundwater level point measurements are often interpolated and combined with other data (e.g. remote sensing and modelling) to assess the state of groundwater resources.

There is however, a lack of information on groundwater monitoring at the regional and global scales, which hampers assessment and informed water management. Recognizing the need for a systematic collection of groundwater data, IGRAC took initiative to establish the Global Groundwater Monitoring Network (GGMN). The GGMN is a programme in which groundwater data from a global network of groundwater professionals is gathered, processed and made accessible to a range of stakeholders. The GGMN Programme combines groundwater experts and technological services into an online portal that facilitates the assessment of changes to groundwater resources globally. The GGMN Programme consists of two components: the GGMN Portal and the GGMN People Network.

6.1. The GGMN Portal

The GGMN Portal enables users to produce online maps showing groundwater changes over time on a regional scale. A web-based software application assists in the analysis of monitoring data and gives insights into changes occurring in groundwater levels worldwide. The simplicity of the application and clear information ownership (it remains with the data supplier) ensure the essential support and commitment of the global groundwater community for the GGMN Programme.

6.2. Country workspace

Groundwater specialists, who are members of the GGMN People Network, can access the country-dedicated workspace of the portal. This workspace allows users to upload, interpolate, aggregate and analyse the groundwater data from their country using the following steps:

1. Representative groundwater point measurements are uploaded. Alternatively, the measurements can be transferred from a national system via web services.
2. Point data are spatially aggregated per grid cell using customised grid overlays. Automatic interpolation can be used as a first step to interpolate available point data.
3. Final adjustments are made manually, using available proxy information and personal expertise.
4. Time series analysis can be performed for each point measurement location. This functionality is currently being extended to also allow for the optimisation of monitoring frequency.

6.3. Public view

The GGMN portal has a public view mode that is meant for the general public, including researchers, consultants, teachers, policy makers and NGOs. Changes in groundwater level point measurements can be calculated and visualised over time on a regional and a global scale. It also allows simultaneous display of the country-based spatial aggregations to create a regional or a global picture of the state and changes of groundwater levels. With permission from countries and data owners, the data sets can be used for calibration and verification of numerical models and remote sensing data.

6.4. Future database connections

Many countries already have online databases but currently only few provide open-access to groundwater data. In collaboration with the countries championing international data sharing, IGRAC is establishing automated data flows between these countries' national databases and the GGMN. Other countries are encouraged to follow these examples. In the meantime, they can join the People Network and upload measurements into the GGMN portal themselves via the country workspace.

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Groundwater Level Monitoring – Importance of Global Groundwater Monitoring Network

Country Report of Cambodia

Groundwater Issues and Hydrogeological Survey of the Mekong River Basin in Cambodia

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1. Introduction

The kingdom of Cambodia is a downstream riparian country in the Mekong River Basin. Of the estimated 475 billion m^3/yr that flow from Cambodia towards the sea, perhaps 400 billion m^3/yr flow from upstream countries. The remainder is generated within Cambodia's borders or in the headwaters of tributaries that reach the Mekong within Cambodia. Hence, the water quantity, water quality, and sediment load in the Mekong River as it flows through Cambodia are strongly controlled by the conditions in the upstream catchments. The water flows and levels in the lower Mekong Delta, which is located upstream of Cambodia's southern border with Vietnam, can be influenced by downstream conditions as a result of backwater effects that are associated with, for example, drainage or flood control works.

Approximately 86% of Cambodia's land area is included within the Mekong River Basin. This area includes the most densely populated and highly developed part of the country, along the floodplain of the Mekong, Bassac, and Tonle Sap system. The 14% of the country that drains directly into the Gulf of Thailand is lightly populated and is predominantly covered in forests. Water resources are almost wholly undeveloped, and the principal resource management issues in this area relate to forest and wildlife management and conservation.

A number of sub-basins in Cambodia's part of the Mekong River Basin are sufficiently large to be managed as distinct entities, if necessary. These sub-basins include the Prek Thnaot, Pursat and Battambang River Basins. The whole Tonle Sap Basin is also sufficiently large, in principal, to be worth managing as a unit. However, its hydrology is very strongly linked to the Mekong River because of its "reverse flow regime", so managing the Tonle Sap separately from the Mekong system would present unique challenges.

2. Current Status of Water Resources

Cambodia is considered one of the most water-abundant countries in the region. Rivers and streams, lakes, aquifers and marine water are important sources for national economic development in many sectors, such as agriculture, manufacturing and small-scale industries, hydropower, navigation, tourism, environmental protection and daily life.

Two types of water are available in Cambodia: approximately 75,000 million m^3 of annual surface water runoff and 17,600 million $m^3$of aquifer groundwater. Precipitation varies from 1,400 mm to 3,500 mm annually, depending on the areas and number of rainstorms.

The Mekong and Tonle Sap Rivers and their systems play vital roles in maintaining aquatic ecosystems and provide natural resources for national economic and social development. Agriculture and fisheries are the main sources of national and family incomes. Agriculture alone generates some 31.4% of the country's annual GDP.

Water is used for households, agriculture, industries, hydropower, navigation and tourism. The maximum quantity of annual water consumption is estimated to be 750 million m^3 (10% of the country's total available water), of which 95% (710 million m^3) in used for irrigated agriculture. No reliable data exist regarding the water quantity that is used for other purposes. Cambodia's economy highly depends on water. The importance of water for food production, rural livelihoods and economic development is recognized in the Government's Rectangular Strategy on Growth, Employment, Equity and Efficiency, the NSDP Update (2009-2013), and the SAW (2009-2013). It has been accepted that climate change will increase water management challenges; less rainfall is anticipated during the dry season and more during the wet season, with more extreme weather events and potentially worse seasonal water shortages and floods. These challenges are more threatening to a developing country such as Cambodia, where meteorological systems are not yet able to forecast extreme weather such as flash floods and unpredicted droughts, which have often occurred in Cambodia.

Water quality is determined by natural processes, particularly by the dilution effects of water runoff from heavy rainfall, which normally occurs during the wet season. At this time, the bacteriological and chemical water quality is generally high, although the physical water quality may be reduced because of heavy sediment loads. However, when river flows decline, the water quality may deteriorate remarkably because contaminants are diluted to a much lesser extent. In addition, the water quality has become increasingly threatened, especially during the dry season and during years of less rainfall, because of human population growth and socio-economic development.

3. Hydrogeological Characteristics and Groundwater-related Issues

The lowlands are underlain by thick piles of alluvial deposits (>160 m in some areas). "Young alluvium" surface deposits are up to 10 m thick and silty, with poor aquifers and poor water quality (arsenic, iron). "Old alluvium" contains multiple aquifers and has high quality but is spatially variable. Potential aquifers in the upland areas are as follows:

- Tertiary basalts (eastern and central Cambodia)
- Permian limestones (Battambang, Kampot)

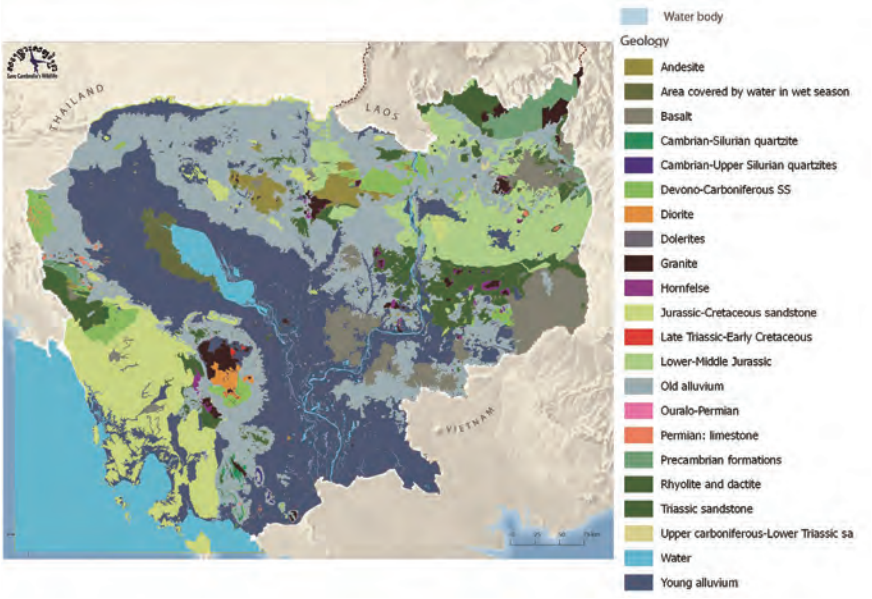

Fig. 1 Geology map of Cambodia
(Data sources: Province center/Province and International boundary:
Department of Geography (DoG), 2005, http://www.naturalearthdata.com Water body:
Aruna Technology Ltd. Geology: Atlas Data 2006)

Groundwater is available almost everywhere in the plains area, except for the dry zone in the central and north-western regions. Groundwater is major source of the drinking water supply in Cambodia. 53% of Cambodian households drink from groundwater sources in the dry season. No data are currently available for groundwater exploitation in Cambodia. Approximately 270,000 tube-wells with hand pumps are functioning for drinking water purposes. Groundwater is generally suitable for irrigation use, but high level of arsenic, iron, manganese, fluoride and salt are observed in some areas. Over 15% of wells tested nationally had arsenic levels above the provisional national limit of 50 μg/l.

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

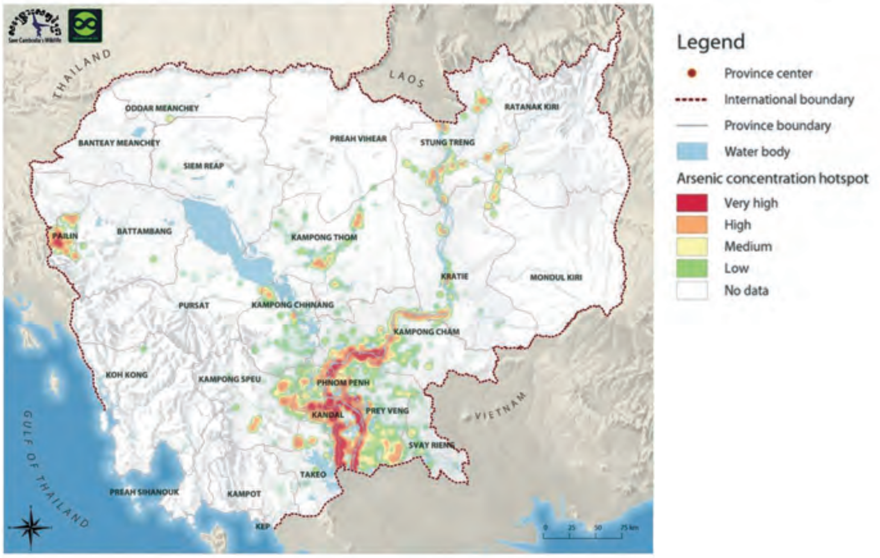

Fig. 2 Arsenic concentration hotspot map of Cambodia
(Data source: Cambodia Well Map database 2013 http://www.cambodiawellmap.com/
http://arunatechnology.com, Department of Geography (DoG), 2005)

3.1. Major issues and challenges that threaten groundwater resources

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

3.2. Potential consequences of groundwater issues

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

4. Hydrological Monitoring Network

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

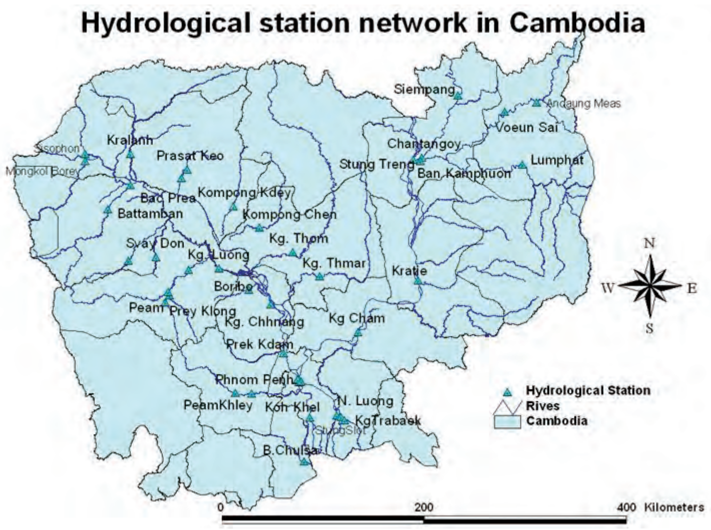

Fig. 3 Hydrological station network in Cambodia

5. Future Challenges & International Cooperation

- A regional knowledge-hub can provide cooperation and networking opportunities for regional issues, including saltwater intrusion in Lower Mekong and coastal areas and Mekong River system management for groundwater recharging in lower Mekong areas
- Regional cooperation for the development and updating of appropriate technology is needed.
- Studies and mitigation strategy should also be developed in response to the impacts of climate change on groundwater.
- Sharing information on groundwater data and regional monitoring is also important.
- Groundwater data and parameters should be surveyed for future prediction and related research.

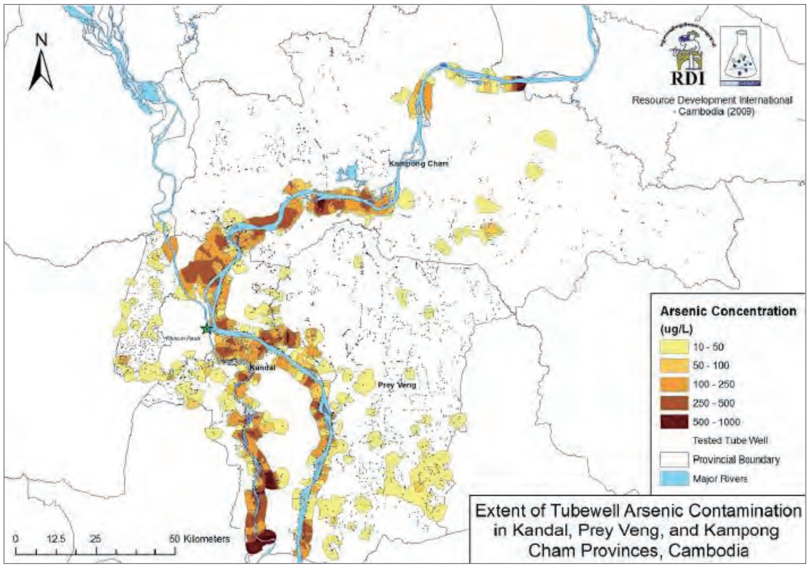

Fig. 4 Arsenic concentration in Kandal, Prey Veng, and Kampong Cham

6. Special Issues of Groundwater Problems in the Mekong River Basin

- At present, arsenic contamination is a significant problem.
- Approximately 1,607 villages in 7 provinces along the Mekong River Basin and Tonle Sap Basin, which have a total population of 2.25 million surfers, experience this problem.
- 38% of the tube-wells in these 7 provinces are contaminated with arsenic (above 50 ppb).
- High-iron content is not a health issue, but people are reluctant to use groundwater with high iron content.
- Fluoride contamination is present in some areas but further detailed studies are needed to elucidate this problem.

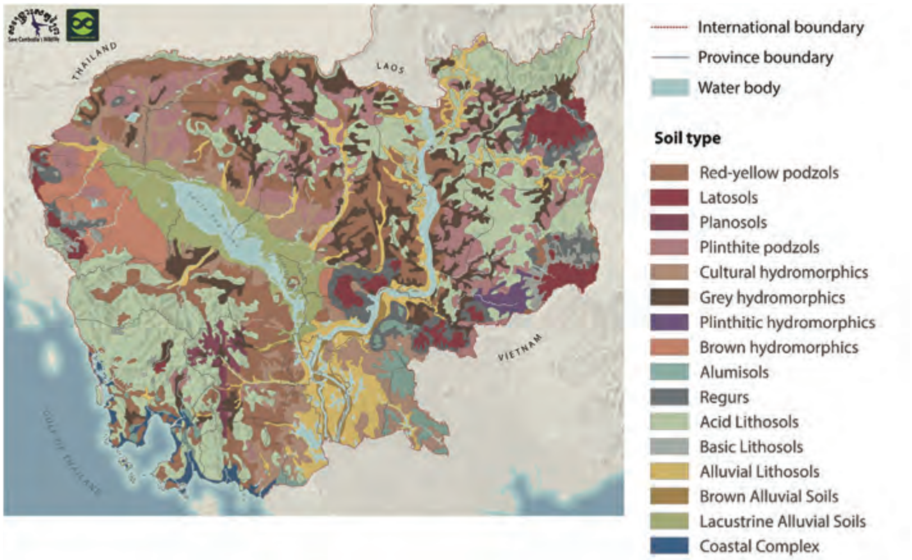

Fig. 5 Soil type map of Cambodia

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Groundwater Issues and Hydrogeological Survey of the Mekong River Basin in China

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1. Introduction

1.1. Profile of Lancang-Mekong River

The Lancang-Mekong River is an international river that originates from the western side of Zhajiarima, along the northern side of Tanggula Mountain in Zadoi County, Qinghai Province, China. The river is called the Lancang River, after it runs southward and meets Ngom Qu near Changdu County, Tibetan Autonomous Region, and the river is called the Mekong River, after the Lancang River runs south-eastward into western Yunnan, southern Xishuangbanna Dai Autonomous Prefecture and finally outside China. The river runs through 6 countries, including Myanmar, Laos, Thailand, Cambodia and Vietnam, with a total catchment of 8.1×10^5 km^2 and a total length of 4,880 km. The catchment in China covers 1.8×10^5

km^2 with a length of 2,179 km, accounting for 21% of the total basin and 16% of the total water quantity.

1.2. Previous research

The Chinese government has paid great attention to the investigation and research of the water resources and hydrogeology of the Lancang-Mekong River, and the following research results have already been achieved: a hydrogeological survey at 1:200,000 scale was completed in the 1980s; the related geographical elements (runoff & sediment variation, distribution & utilization of water resources) were researched in the 1990s; and the key project "*Study on Multi-purpose Coordinative Development and Management of Water Resources in International Rivers (1997-2000)*", which was funded by the National Natural Science Foundation of China (NNSFC), promoted geographical research on the Lancang-Mekong River. Since the 21st century, the Great Development of Western China, which has been undertaken by the Chinese government has helped vigorously promote regional economic cooperation in the Mekong River and geo-cooperation between China and 5 Central Asian countries, advance the comprehensive development of an international river in China, and enhance the rapid development of geo-cooperation with surrounding countries. The strategy has also promoted interdisciplinary research on the cooperative utilization of the water resources in this international river, geo-cooperation strategies, regulations of trans-boundary ecosystems, and management and coordination mechanisms. In 2000, the Internationally Shared Aquifer Resources Management (ISARM) was initiated by UNESCO during Phase VI of its International Hydrological Programme (IHP), which mainly included the definition and analysis of trans-boundary aquifer systems, the encouragement of cooperation with mutual benefits among different countries who share the same groundwater resources, aquifer protection, and the sustainable utilization of groundwater. Research on the trans-boundary aquifers of the Lancang-Mekong River Basin is an integral part of the ISARM. The Mekong River Basin has 4 trans-boundary aquifers in total, 1 of which is located in the

Lancang River Basin. This aquifer is located between China and Myanmar, downstream of the Lancang River. The aquifer covers an area of 39,508 km^2, with 78% (31,167 km^2) of its area located in China. To promote research on these trans-boundary aquifers and create hydrogeological maps of international rivers, scientists from related Chinese institutions have conducted hydrogeological investigations, research and mapping of the Lancang River Basin in recent years. The data and achievements that are mentioned in this paper are mainly from the abovementioned research.

1.3. The importance of groundwater resources for the Lancang River Basin

Groundwater is the major water source for most people in this basin. Statistically, 340 million people live on water from the trans-boundary aquifers; thus, the groundwater environment of these trans-boundary aquifers is closely linked to plenty of lives. With the increasing population and rapid socio-economic development, the exploitation of groundwater has gradually increased, which has resulted in a series of environmental problems (lower water table, seawater intrusion, and water pollution), which threaten the safety of the domestic water supply and hamper socio-economic development. Various countries in the basin will study how to maintain the ecological balance and ensure the safety of the water supply to maintain the sustainable development of the trans-boundary aquifers in this region.

2. Current Status of Water Resources

2.1.Characteristics of the groundwater resources

The morphology and stretch of the water system of the Lancang-Mekong River Basin are complex and related to the control of the latitude & longitude tectonic system. The terrain of the Lancang River is high in the north and low in the south and extends as a strip from north to south.

The main geomorphic types in the upstream area (from the headstream to Changdu) include alpine mountains, gorges, mountain glaciers and mountain valleys, which have an average altitude of 4,500 m. The distribution of the groundwater resources in the Lancang River Basin indicates that fracture water dominates the groundwater, followed by karst water and interstitial water. Although fracture water is distributed extensively, large or intermediate water sources are difficult to form because the water is scattered and only concentrated in blocks where fractures have developed. Karst water is concentrated irregularly with great differences, especially in regions that are dominated by conduit flows, which brings more difficulties to the exploitation and utilization of groundwater. Therefore, despite the abundant groundwater resources in this region, developing these resources with lower utilization is difficult.

The overall characteristics of the groundwater distribution in this basin include the following: interstitial water is mainly distributed in the southern delta plains, valley basins and mountain valleys; karst water is distributed along the Hengduan Range and Tenasserim Range; and fracture water is extensively distributed in the middle of the entire basin. The distribution of the groundwater resource reserves of the entire basin is shown in Table 1.

2.2. Contribution of groundwater resources to the Lancang-Mekong River Basin

The Lancang-Mekong River Basin supplies plenty of water to the surrounding countries. For example, the upstream delta region (located in Cambodia) has groundwater exploitable reserves of approximately 17.3×10^9 m^3/yr, accounting for over 50% of Cambodia. Vietnam has abundant groundwater resources, and the national exploitable reserve is estimated to be approximately 60×10^9 m^3/yr. However, the exploitable groundwater reserve in the downstream delta region of the Mekong River is 25.1×10^9 m^3/yr, accounting for 42% of the groundwater resources in Vietnam.

The natural groundwater recharge area in the Lancang River Basin is 90,714 km^2, the natural groundwater recharge volume is 268.53×10^8 m^3/yr, and the exploitable groundwater reserve is 80.64×10^8 m^3/yr, accounting for 30% of the natural recharge volume. Groundwater resources are relatively abundant, and protecting the groundwater resources and the environment in the basin is very important.

Table 1. Groundwater resources of the Lancang-Mekong River Basin

Region	**Natural Recharge Volume (10^8 m^3/yr)**			**Exploitable Reserve (10^8 m^3/yr)**		
	Interstitial water	**Fracture water**	**Karst water**	**Interstitial water**	**Fracture water**	**Karst water**
Lancang River	10.77	207.78	49.98	3.21	59.80	17.63
Mekong River	343.90	234.02	57.60	86.22	65.63	23.04
Subtotal	354.67	441.80	107.58	89.43	125.43	40.67
Total	904.05			255.53		

2.3. Existing groundwater resource problems

Water resources are one of the fundamental strategic resources for socio-economic development. In recent years, south-western China and many surrounding countries have suffered from a severe arid climate. Reduced rainfall has resulted in an acute shortage of water resources in the region and has greatly influenced economic development and local residents. China has fought against drought in its south-western region for four years with many groundwater surveys and exploitations, which effectively relieved the drought in south-western China and ensured a normal water supply for residential and agricultural purposes.

3. Hydrogeological Characteristics and Groundwater-related Issues

3.1. Hydrogeological characteristics of trans-boundary aquifers

Studies on the trans-boundary aquifers in the basin have been conducted based on analyses of the groundwater systems. Four trans-boundary aquifers can be defined in the Lancang-Mekong River Basin with a total area of 4.65×10^5 km^2, accounting for 57.41% of the total area of the basin. The 4 trans-boundary aquifers include the *Lancang River downstream aquifer, Mekong River midstream aquifer, Khorat Plateau aquifer and Mekong River delta aquifer.*

The main hydrogeological characteristics of trans-boundary aquifers are shown in Table 2.

Table 2. Trans-boundary aquifer characteristics and water resources

Name	**Countries**	**Area (km^2)**	**Type**	**Groundwater Recharge Estimate (10^8m^3/a)**
Lancang River downstream aquifer	China, Myanmar	39508.5	Massive rock single structure fracture aquifer	35.68
Mekong River midstream aquifer	Thailand, Laos, Vietnam	106976	Dual-layer structure interstitial-fracture aquifer	126.97
Khorat Plateau aquifer	Thailand, Laos	95510	Multi-layer structure fracture aquifer	82.92
Mekong River delta aquifer	Cambodia, Vietnam	223422	Multi-layer structure interstitial aquifer with loose sediments	278.7

3.2. Quantity and quality

The aquifer in China and its junction with Myanmar is called the Lancang River downstream aquifer. This trans-boundary aquifer between China and Myanmar belongs to clastic rocks with a fracture-interstitial water aquifer. Its area is 39,508.50 km^2, and that of the part in China is 31,167.50 km^2, accounting for 78% of the total area. The annual rainfall in this region is 1,000~1,500 mm, which improves the recharge, with the natural recharge modulus ranging from 15×10^4 $m^3/km^2\cdot yr$ to 20×10^4 $m^3/km^2\cdot yr$. The natural groundwater recharge reserve is approximately 35.68×10^8 m^3/yr, with an exploitable groundwater reserve larger than 20×10^8 m^3/yr. Slightly hard water that contains HCO_3-Ca·Mg and HCO_3-Ca, dominates this region, with a mineralization degree of 0.15~0.4 g/L. According to groundwater quality evaluations, those out of specification (OOS) mainly include 0.56 mg/L of Mn, 0.06 mg/L of Cd, and high fluoride and low iodine in some regions.

The main lithology of the aquifer in the region includes Triassic acid intrusive granite, Jurassic shale that is intercalated with argillaceous limestone, Cretaceous sandstone that is intercalated with mudstone, and conglomeratic mudstone that is intercalated with siltstone and packs. Intrusive stones are mainly distributed from Lincang to Jinghong. Because of the effects of fracture zones and the development of structural fissures, gathering groundwater in positions where acid intrusive stones contact adjacent rocks is favourable. Such positions are often large and intermediate sources for centralized water supplies.

4. Hydrogeological Map Status

Under the unified organization and leadership of the China Geological Survey, the Institute of Hydrogeology and Environmental Geology at the Chinese Academy of Geological Sciences (CAGS) formulated the *Asia Hydrogeological Map*, the *Asia Groundwater Resource Map* and the *Asia Geothermal Map*, which are formally listed in the IAH mapping plan and are highly commended by the UNESCO. The map series divided Asia into 11 groundwater systems and 36 secondary groundwater systems. As a secondary groundwater system, the Lancang-Mekong River mountain and plain groundwater system is classified into a tropical humid groundwater system in the mountains and hills of the Indo-China Peninsula.

In February 2015, UNESCO's Thailand Office entrusted the Institute of Hydrogeology and Environmental Geology, CAGS through mutual negotiations to edit and publish the following maps based on already published map series: *Mekong River Groundwater Resource Map, Mekong River Groundwater Environment Map, Mekong River Geothermal Map, Greater Mekong River Groundwater Resource Map, Greater Mekong River Groundwater Environment Map, Greater Mekong River Geothermal Map, ASEAN Groundwater Resource Map, ASEAN Groundwater Environment Map, and ASEAN Geothermal Map*. Currently, the agreement has been signed and mapping has commenced.

The *Compilation Programme for Geological Map Series of Karst Environment in China and Southeast Asia*, which was funded by the China Geological Survey and led by the Institute of Karst Geology, CAGS, was launched in 2013 based on discussions in the Geological Environment Protection of Mines, China-ASEAN Mining Cooperation Forum and cooperation between China and six countries in ASEAN; the *Sketch for Karst Distribution Characteristics in Southern China and Southeast Asia, the Sketch for Hydrogeology in Southern China and Southeast Asia* and mapping guidelines have already been completed. In 2015, mapping works will be further improved.

5. Hydrological Monitoring Network

Fifty-four hydrological monitoring points and 22 monitoring sections are set in the Lancang River system. Among the monitoring sections, 6 are for the main river and 16 are for 11 branch rivers. Twenty-two monitored items include pH, SS, GH, COD, COD_{Mn}, BOD_5, NH, nitrite nitrogen, nitrate nitrogen, volatile phenol, cyanide, TAs, THg, Cr^{6+}, TPb, TCd, petroleum, electric conductivity, TN, TP, fluoride, and Cu. The monitoring frequency is six times per year, specifically, 2 times each for the wet season, normal season and dry season.

Currently, the groundwater monitoring network of China is still under construction. Only a few national groundwater dynamic monitoring works in the Lancang River Basin have been conducted in Dali, Yunnan Province, and in Jinghong, Xishuangbanna.

6. Future Challenges & International Cooperation

6.1. Existing problems and future challenges

With the increasing water demand for residential, agricultural and industrial purposes and the imbalance between water supply and demand, countries with trans-boundary aquifers are attempting to occupy more groundwater. Hence, interstate natural, social and economic issues from the unreasonable utilization of groundwater have already become a major international focus. Another significant problem is that downstream regions are badly affected by exploitation activities in upstream regions in intensively exploited aquifers; in particular, groundwater pollution moves across borders, which is the ultimate reason for interstate conflicts.

Moreover, karst developed better in the Greater Mekong sub-region, such as Myanmar, Laos, Cambodia, Vietnam, Thailand, and Yunnan Province, China. A series of environmental geological problems exist in karst regions because of the special geological processes of karstification, e.g., abundant rainfall but still severe drought. Despite abundant rainfall in mountainous karst areas, the well-developed karst underground causes atmospheric precipitation to rapidly transform into surface water and then to groundwater, leading to descriptions such as “plentiful flowing groundwater but little surface water” and “flood everywhere after a heavy rain and drought everywhere after ten days with no rain”. Predatory damages to surface vegetation and unreasonable land development by humans have exacerbated rocky karst desertification and further weakened surface water conservation and storage capabilities, worsening these drought and flood disasters. In the meantime, floods, water loss, soil erosion, karst sinkholes, groundwater pollution, rock collapses and landslides and other geological environment problems are also very serious in the mountainous karst areas in this region, damaging local national economic construction and the lives of residents and destroying the ecological environment.

6.2. International cooperation

Following the "One Belt and One Road" strategy of China, political, economic and cultural cooperation between China and other countries in the Greater Mekong sub-region has commenced, and cooperation regarding the protection of the geological environment has been a common aspiration in the region. China has rich experience in studies on trans-boundary aquifers, the carbon cycle in basins, global changes in the karst environment, and the joint control of surface water & groundwater. China plans to promote the harmonious development of the groundwater environment in the Lancang-Mekong River Basin through the following cooperation activities:

(1) Organizing joint research and training for the sustainable development of the groundwater environment in the Greater Mekong sub-region

  - Due to the IHP and interstate scientific and technological cooperation, the joint control of trans-boundary aquifers, surface water and groundwater and research into the quality standards of surface water and groundwater have been conducted. The main issues that were discussed in the seminars include standards, policies, and cooperation for the protection of the geological environment protection in the Greater Mekong sub-region. The training contents mainly include groundwater exploitation technologies, groundwater resource investigation and evaluation theories and technologies, key technologies for the reasonable utilization of groundwater and protection of the environment, and technologies for geological environment protection and geological disaster prevention and control.

(2) Establishing a monitoring network for groundwater, karst processes and the carbon cycle in the Mekong River Basin

- The karst environment in the Mekong River Basin has been mapped thanks to the support of the International Research Center on Karst under the auspices of UNESCO (IRCK). Monitoring stations for groundwater, karst processes and the carbon cycle have been built into key hydrologic stations and typical small basins to monitor groundwater, karst processes and carbon sink fluxes. At present, monitoring stations have already been construction in China, Thailand, Vietnam and Indonesia.

(3) Research on the impacts of the exploitation of resources on the geological environment in China-ASEAN countries

- This topic mainly includes the following: 1) investigating and evaluating the impacts of the exploitation of resources on the environment in China-ASEAN countries; 2) researching the impacts of the exploitation of resources on the geological environment in typical regions; and 3) researching the impacts of the exploitation of resources on the geological environment in key regions.

(4) Investigation of ASEAN karst landscapes and geoparks and related training

- With the support of IRCK, China plans to conduct international comparisons, investigations and research of typical karst landscapes in the Mekong River Basin, establish a model and formulate technical regulations for the protection and management of karst landscapes and geoparks in the Mekong River Basin, and organize related training.

Groundwater Issues and Hydrogeological Survey of the Mekong River Basin in Lao PDR

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1. Introduction

Recognition of the importance of groundwater in achieving a broad range of social, economic and environmental benefits has increased in global terms in recent years. Consequently, a good deal of attention has been directed towards groundwater governance as a paradigm by which to manage groundwater resources more holistically and inclusively (Foster and Garduño, 2013). Governance serves as a vehicle to improve the planning, development, operation and management of groundwater. Governance processes work well when they consider the views of all stakeholders with an interest in resource development and sustainability issues and are translated into actions that seek to be effective, transparent and equitable (Foster and Garduño, 2013). The converse is, of course, equally true.

Although the overarching goals of this groundwater governance approach are obviously worthwhile, a clear emphasis has been placed on problems that are related to the consequences of overdevelopment, which are shaped by thinking that has emerged from well-documented cases. However, many of the basic requirements to achieve an adequate level of governability are usually limited or absent, and a different set of perspectives and priorities may emerge for those who are actively engaged with groundwater issues in the world's most underdeveloped countries, which are somewhat removed from the possibility that extreme development will emerge as a major issue over the foreseeable future. Of the world's 193-odd countries, 49 have been categorized by the United Nations as Least Developed Countries (LDCs), which have a combined population of 851 million people (UNDESA-PA, 2011), or almost 10% of the global population. LDCs are characterized by their low incomes, poor state of human welfare and high economic vulnerability. The LDC that is the subject of this paper is the Lao People's Democratic Republic (otherwise simply known as 'Laos'). Groundwater has historically been highly under-represented in the field of water resources and related sectors in Laos, although this is gradually changing. This report is an attempt to consolidate and document the current state of knowledge, current challenges, gaps and pathways forward for the country. The report is intended not only to serve to inform policy and decision making within the country but also to provide some level of guidance and perhaps a useful point of reference for other LDCs.

2. Country Overview

Laos is situated within the Indochinese Peninsula in Southeast Asia and is home to approximately 6.5 million 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 who live in upland villages that are far 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 alleviation of poverty and improvement in general health and wellbeing, as indicated by declines in both child infant mortality and the prevalence of communicable diseases.

Laos, which is located within the tropics, has high amounts of rainfall, which 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 approximately 50% of the native forest still retained and covered and only 9% of the land under agriculture. These and other resources provide the engine for socio-economic development and a means to lift many out of entrenched poverty and malnutrition. 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 demand for electricity in Laos and neighbouring countries such as Thailand and Vietnam.

Developing water resources effectively to achieve short-term socio-economic development targets while simultaneously 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 and also at the wider Mekong level.

3. Water Supply System of Lao PDR

The following map that was 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. The data were derived from the 2010 census. A summary of the categories in terms of areal coverage is provided in the table below:

Table 1. A summary of water supply situation of Lao PDR in terms of areal coverage

Source	Area (m^2)	% 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	< 0.1%
Other sources	151,439	0.7%

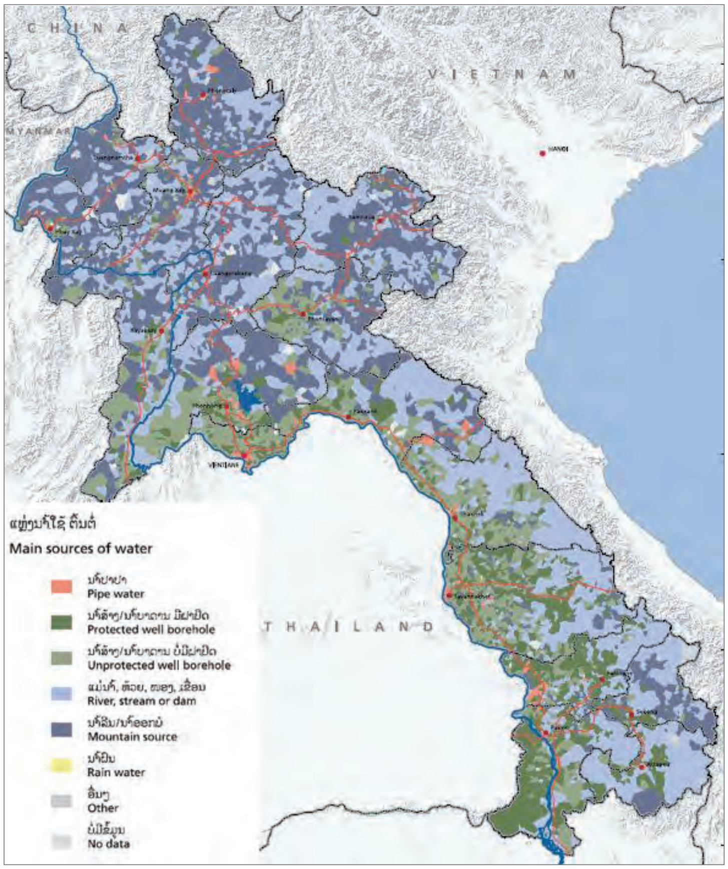

Fig. 1 Water supply situation of Lao PDR

4. Domestic Use of Groundwater

Areas that use groundwater from drilled boreholes cover only 13.2% of the country, which is approximately 20% of all villages according to the census survey. These wells are chiefly used to meet domestic needs. Currently, these wells are provided by the Nam Sa-at unit of the Ministry of Public Health, with funding mainly from UNICEF. An additional 23% of all water sources come from dug wells, which are usually constructed by individual households; thus, the total estimated groundwater usage is approximately 41%.

Dug wells generally tap water at depths of 10 m or less. Wells that rely on this shallow water are rarely producing during the entirety of the dry season and are easily contaminated. Dug wells are assumed not to be reliable or biologically safe sources, and the same can be said for most surface water sources that are not part of piped schemes, which comprises 11,668,533 km^2 or 55% of the country. In terms of the number of villages and total population, nearly 50% of the population does not have access to safe water.

The census results are arranged by villages. If we add the populations of the villages that use a particular water source, we obtain the following results for the number of groundwater users:

Population that uses groundwater in Loa PDR

Population that uses drilled boreholes	1,186,252
Population that uses dug wells	1,301,346
Total users	2,487,598

By using a figure of 100 litre per capita per day, we can estimate that approximately 90 million m^3/yr is extracted in the whole of Laos. This statistic, although interesting, has limited use for planning purposes. On the level of a province or a river basin, water use assessment is essential for resource management. An example is given for the Nam Ngum Basin in the next sub-section.

The borehole coverage that is derived from the map is likely overestimated because many boreholes may be non-functional. Some of these boreholes can be rehabilitated, whereas others may have to be abandoned. Records that were collected from local authorities in the Nam Ngum River Basin on a field trip by in August 2012 were incomplete in terms of the current operational status. This notes the need for a monitoring and evaluation program that is tied to an Operation and Maintenance (O&M) database to track this problem. However, estimates from the fragmentary information that were collected suggest that as much as 30-40% of hand-pumped wells are non-functional.

Another aspect that needs to be examined is the use of bottled water. Commercial bottled water is available even in large portions of the rural countryside. In some places, this water is produced by small- and medium-scale enterprises, which raises the question of whether the construction of water supply systems will undermine them and force them out of business, a negative consequence for the local economy. One argument against this reasoning could be that this water is expensive for the poor, and therefore the socio-economic benefits would outweigh this loss. However, the current price of such water is 4000 kip (0.5 USD) for a 20 litre container, or only 200 kip per litre. If a proper O&M program is set up, would the costs of maintaining a water supply system (e.g., hand pump wells) incur less cost? If a community cannot afford the O&M costs, then that supply is not sustainable anyway.

In the Republic of Ghana, intensive water supply programs have had a minimal impact on these small-scale water producers, although no formal studies have been conducted. Many of these producers have actually invested privately in wells themselves to be used as the source of the packaged water. This approach may not apply to Laos because surface water supplies are more readily available to the producers, which raises the issue of water quality.

The water that is sold may be of sub-standard quality, even in the capital city of Vientiane (reported by the Vientiane times).

4.1. Example of groundwater use appraisal for Nam Ngum Basin

The Vientiane Basin and north-eastern headwater areas are dominated by the use of dug wells, and the central area obtains its water from mountain springs. Borehole coverage is limited.

Table 2. Groundwater usage status of Nam Ngum Basin, Lao PDR

	Number of villages	Number of people	% of total villages	% of total population
Boreholes	175	165,840	21%	26%
Dug wells	366	281,272	43%	45%
Total groundwater used	541	447,112	64%	71%

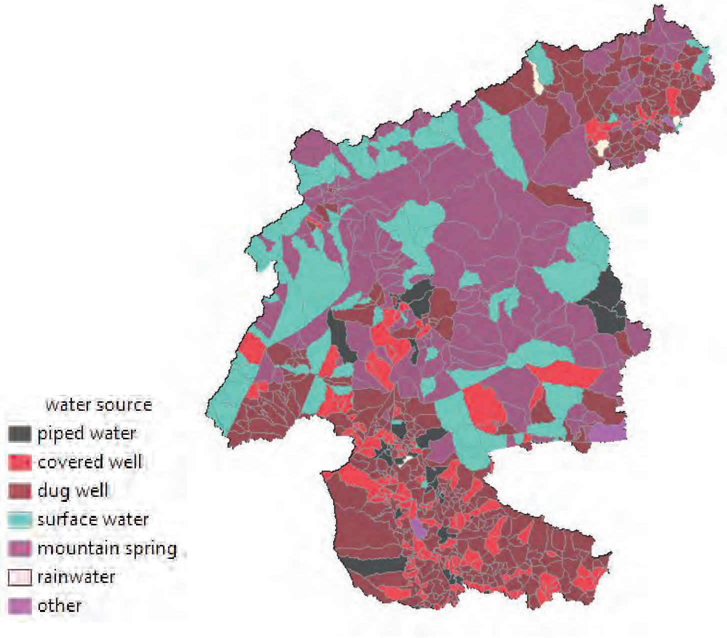

Fig. 2 Water use map of Nam Ngum Basin, Lao PDR

5. Groundwater for Irrigation

There is no irrigation scheme in Laos that utilizes groundwater on a large scale. Small homestead gardens are often watered by using hand-dug wells and boreholes. Pumping from surface streams is the practice that is used for major irrigation projects. Many of these systems are old and often perform poorly during periods of low river flows. An attempt to compare costs per hectare for both stream-supplied systems and typical groundwater-fed systems should be conducted by utilizing data from the Khorat Plateau in Thailand and by linking to the World Bank Hydro-Agro-Economic Model study. Information from the Khorat Plateau is particularly relevant because both the climate and the geology are quite similar to those of central Laos (e.g., in Savannakhet).

Surface water usage can potentially switch to groundwater abstraction during times of low flows and/or poor water quality, thereby safeguarding against water shortages, with particular application to irrigation. The management of such systems may benefit from a conjunctive use policy that allows the use of groundwater during the dry season. Furthermore, the possibility of a two crop system in drought-prone areas such as the Plain of Jars in the headwaters of the Nam Ngum River Basin or in the Champone District in Savannekhet Province is a realistic objective if groundwater abstraction becomes a viable option.

One encouraging development is occurring in the Hadxaifong District in Vientiane. Irregular and insufficient precipitation in some years has led to poor crops, and farmers have been unable to meet market demand more often than not during the past decade. In response, technical staff members from the Had-dokkeo Horticulture Research Centre have shared techniques to access groundwater to enable the growing of vegetable crops for more successful harvests since 2006. Currently, almost 95% of the area's farmers have expressed interest in using the underground aquifers to expand the growth period.

Given the current rate of expansion of agricultural development and the uncertainty of climate change, the idea that food security can be increased by supplementing rain-fed crops with groundwater-sourced irrigation has stirred some interest. A research project that is funded by the Australian

Centre for International Agricultural Research (ACIAR) and led by the International Water Management Institute (IWMI) will be investigating the value of this strategy.

Furthermore, ACIAR holds the belief that even domestic wells can increase agricultural production because of the increased productivity of individuals, i.e., improved health and less time fetching water increases agricultural activity. As mentioned previously, well water is used in many cases for garden plots, strengthening the linkage between domestic and agricultural uses.

A full treatment of the cost/benefits of developing groundwater for irrigation is not attempted in this paper. Instead, the results of projects such as the ACIAR/IWMI project LWR/2010/081 should result in a clear and detailed evaluation of this application.

In summary, all of the considerations that have been made thus far indicate that a national program of groundwater development will, in all likelihood, lead to a greater level of socio-economic welfare for the country.

6. Commercial/ Industrial Use

Information concerning the quantities of groundwater that are extracted for commercial/industrial use is not easily accessible. These stakeholders feel that they are the owners of this information and are not obligated to share these data. Details regarding well construction (total depths, occurrence of water strikes, water levels) are also not known outside these owners. Regulation and permitting may be required to facilitate access to this critical information. The fact that the government authorities do not have access to this information forms a major obstacle to the strategic planning and management of groundwater.

Most industries, however, prefer locations next to major rivers and use surface water. The most notable example of the industrial use of groundwater in Laos is the Lao Beverage Company, who are the makers of Lao Beer and Tigerhead bottled water. Although their plant in Champassak still uses groundwater as a source, the plant in Vientiane has switched to the city supply from the Mekong, which occurred as an attempt to improve the yield of existing wells by deepening them. Halite (rock salt) was encountered during this attempt, which subsequently ruined their wells.

7. Challenges in Managing Groundwater Resources

Groundwater is a largely invisible resource that is seen only by those who know or make the effort to consider it. Thus groundwater is easily neglected, misunderstood, mismanaged or simply taken for granted. The ease of access and the lack of differentiation in the legal entitlements for land and water in many countries can create tension between the perceptions that private, individual access equates to a sense of outright ownership of groundwater, which is incompatible with the practicality that groundwater must be a common pool resource. Problems can thus emerge with falling water levels, higher pumping costs, reduced water quality and competition or even conflict amongst competing water users.

Well-known and documented examples of such issues include those in the densely populated and agriculturally productive plains of India and North China (Giordano, 2009). Even within the Lower Mekong River Basin (LMRB), localized and less well-known examples emerge. In parts of southern Cambodia, recent rapid and unregulated growth of small-scale groundwater irrigation has raised concerns about competition with domestic supplies (IDE, 2005). In the Mekong Delta region, over-pumping for irrigation, industrial and domestic uses is resulting in a lower water table and saltwater intrusion (IUCN, 2011).

8. Water Resource Management and Policies

- Despite the Lao government's effort to develop laws and regulations, water resource management in Laos has not matched the rapid socio-economic development throughout the country. Weaknesses and gaps exist in the understanding and application of regulations for effective and integrated water resource management. The purpose of National Water Resource Stragety of Lao PDR is to provide guidance for the participating government agencies and investors in the water sector to conduct appropriate and well-coordinated water management and utilization activities.
- The National Water Resource Policy reflects the government's direction and vision in water resource management to ensure equitable water use, the sharing and utilization of benefits from water development to contribute to poverty reduction, the protection and restoration of the water environment and increased water security.
- The National Water Resource Strategy will be a reference for the improvement of the Law on Water and Water Resources and other legislations. This strategy will also contribute to national socio-economic development planning and private sector investment management at the central and local levels. The National Water Resource Strategy is an important foundation to define the water resource action plans for every five-year period.

9. Water Resource Problems

- No Coordination and cooperation for water resource development with line agency
- Poor knowledge and capacity building of groundwater management
- No long-term plans for groundwater management and water usage
- People do not understand water resource management
- Laws and regulations not yet clear

10. International Water Resource Management and Cooperation

River basins are diverse in terms of water quantity and the human activities that occur both within river basins and in their downstream areas. Thus, water management has been changed to river basin-based management, which is a more effective approach. In the United States of America, relevant organizations are attempting to protect water quality by establishing a monitoring and evaluation system for a maximum daily amount of a chemical that is allowed in water based on conditions and the capacity of the river basin to absorb contaminated substances. The European Union also uses water resource management plans to improve the water quality of all rivers through well-coordinated river basin management.

After the International Conference on Water and Environment in Dublin and Rio de Janeiro in 1992, integrated water resource management received special interest, although no clear definitions or answers on its application were provided. Four Dublin principles, which were agreed upon by the UN conference on Environment and Development in Rio de Janeiro, Brazil in 1992 and accepted by the world community as a direction for integrated water resource management, include the following:

1) Freshwater is a finite and vulnerable resource that is essential to sustain life, development, and the environment.
2) Water development and management should be based on a participatory approach that involves users, planers, and policy-makers at all levels.
3) Women play a central part in the provision, management, and safeguarding of water.
4) Water has an economic value in all its competing uses and should be recognized as an economic good based on equitable standards and affordability by the poor.

11. Regional Cooperation

Water resource management in Laos has been conducted in cooperation with the region for a long time. Such cooperation has several forms, specifically, becoming a member of the South East Asian Nations (ASEAN) and cooperating with the Mekong sub-region.

Cooperation with ASEAN countries in water resource management has been conducted since 2002 with the following vision: "achieve sustainable water resource management to ensure sufficiency and acceptable water quality and quantity to assure and meet the needs of people in ASEAN countries in terms of health, food, economy and environment".

The cooperation in the Mekong sub-region, particularly under the agreement in 1995 among four countries, namely, Laos, Vietnam, Cambodia and Thailand, has covered all aspects in terms of the sustainable development, utilization, management, and protection of water and related resources in the Mekong River Basin, including irrigation, hydropower, boat transportation, flood protection, fishery, river logging, recreation and tourism, through the optimal use of many models, along with mutual benefits among the party countries and impact mitigation from natural phenomena and man-made activities. The agreement agreed to establish the Mekong River Commission, where the current secretariat is located in Vientiane, Laos, and in Phnom Phen, Cambodia.

12. National Cooperation

- Develop coordination mechanisms for effective and efficient water resource management and development.
- Ensure the management, development, conservation and rehabilitation of water resources nationwide to meet needs while ensuring management of benefits and sustainability, which also includes protection, mitigation and the addressing of hazardous issues to reduce impacts on society and the ecosystem.

- Improve the management and conservation of water and water resources by using the basin for worthwhile and sustainable economic production, and ensure the protection of the river basin environment and social benefits.
- Improve water resource management to meet water needs both in terms of quantity and quality in the river basin and increasing measures to protect drought-, flood-, erosion- and subsidence-prone areas in the river basin.
- Increase production values from using natural resources such as land, water, forests, minerals and others.
- Renovate and develop meteorological stations and early warning systems nationwide to facilitate agricultural production and climate change adaptation.

13. Conclusions

Groundwater management and national water resources are crucial to the sustainability of the economic activities of people in rural areas. Likewise, these resources determine the pace and extent of industrial development in urban and commercial centres in Laos. The wise management and utilization of water resources provides a guide for all stakeholders to cooperate and collaborate together to achieve a sound international water resource management for greater societal benefits.

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Country Report of Myanmar

Groundwater Issues and Hydrogeological Survey of the Mekong River Basin in Myanmar

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1. Introduction

Myanmar, similar to other nations in Southeast Asia, is now facing industrialization and urbanization and is increasingly demanding both surface and groundwater resources. With a sudden upsurge in population flow to urban areas and the establishment of new satellite towns, the demand for water has been inevitably increasing for both domestic and industrial uses.

To protect the health of the population and prevent saline water encroachment, land subsidence and disputes among groundwater users, the Burma Underground Water Act of 1930, along with some updates, provides control measures on the use of groundwater.

The current population of Myanmar is 51,419,420 million (2014 Census), and most cities and towns are located on the banks of its major rivers, which provide access to navigation for trading and water supply for domestic usage. The length of continuous frontier is 5,858 km, sharing 2,185 km with China, 238 km with Laos, 1,799 km with Thailand, 233 km with Bangladesh and 1,403 km with India. The total length of coastline to the west and east is 2,267 km.

Water is the most basic requirement and demand, and an issue that influences and effects social, economic, cultural, political and religious heritages of different communities. Water must not only be available in abundance but also be safe for consumption. The need for plentiful supplies of water is universally perceived and demanded, but the perception of the importance of water quality is low, especially among the rural community.

Myanmar can be identified as a low water stress country. No serious issues exist in terms of water quality or wastewater management. However, several agencies under their respective ministries remain responsible for the supply and management of water for agricultural, industrial, domestic and sanitation purposes. With mounting pressure on the availability of fresh water from ever-growing demands to serve population growth, industrialization, agriculture and their related populations, cooperation and coordination have become more urgent and essential. Meanwhile, the Myanmar Water Vision, a follow up programme that was funded by ESCAP & FAO to implement and realize the World Water Council's water vision, was launched in 2003 to attain sustainable water resources and ensure sufficient quantities of acceptable water to meet the needs of people of the country in terms of health, food, the economy and the environment by 2030.

2. Water Resources

Because of favourable climatic conditions in the widespread river basin, which covers 90% of the country's area, Myanmar can be identified as a low water stress country. Myanmar can be divided into 10 major basins, which comprise 102 sub-basins.

The total area coverage of 10 major river systems and their tributaries is approximately 737,800 km^2, and the total surface water potential in Myanmar is approximately 708 million acre-ft.

3. Groundwater Resources

Groundwater potential largely depends on the hydrogeological conditions of the area and is the principal source of domestic water supplies in Myanmar. Groundwater is being exploited not only for domestic water supplies but also for irrigation purposes in areas where conditions are favourable. The total estimated groundwater potential in Myanmar is 23 million acre-ft (494,713 km^3/yr).

3.1. Water quality protection

Major activities for water quality protection in Myanmar include:

1) To control the direct discharge of wastewater from factories into rivers and streams
2) To ban the use of some toxic pesticides and encourage the utilization of conventional bio-fertilizers as a substitute for chemical fertilizers

Arsenic and other parameters have been tested in collaboration with the Water Resources Utilization Department (WRUD), Department of Development Affairs (DDA) and United Nations Children's Fund (UNICEF). The Environmental and Sanitation Division under the Ministry of Health is implementing a programme on water supply systems with health institutions and conducting a Water Quality Surveillance and Monitoring System Pilot Project in Yangon.

3.2. General nature of the groundwater in Myanmar

The occurrence of groundwater in urban areas is generally classified into two types according to the geologic conditions: unconfined aquifers and confined aquifers. In particular, hand-dug wells are tapped from shallow unconfined aquifers, whereas deeper tube wells reach into confined aquifers. The replenishment of groundwater in Myanmar occurs in the following two ways:

1) By means of natural recharges from precipitation, storm sewages and influent seepage from drainage (rivers and streams);
2) By means of artificial recharge, that is, the aquifer is artificially recharged from the waters of the Chindwin River through wells in the Monywa ara.

Water that is collected from natural springs on Mount Popa is also used to supply the town water in Kyaukpadaung (Central Myanmar). Water for Taunggyi (Southern Shan States) is supplied in a similar fashion. The infiltration and percolation of surface water into groundwater varies from place to place with respect to the underlying geology, vegetation cover, geomorphology, and thickness of the covering layer. In Myanmar, groundwater aquifers are recharged during the rainy season (end of May to September), although replenishment in some towns that lie in the dry zone of Central Myanmar is obvious only during the late period of the rainy season, i.e., during the months of August and September. During the rainy season, the replenishment of groundwater is very significant because rainfall exceeds evapotranspiration. This phenomenon is evident by the uprising of groundwater levels in wells that are tapped from both confined and unconfined aquifers.

After the rainy season, the groundwater levels in the wells start to decline, and the lowest levels are reached at the end of the dry season (mid-May).

4. Description of the Main Aquifers in Myanmar

In general, thirteen main aquifers can be recognized in Myanmar, which are classified according to their lithology and stratigraphy. These aquifers are (from oldest to youngest) the Chaungmagyi, Cambrian-Silurian, Leyin-Merqui, Plateau Limestone, Kalaw-Pinlaung-Lashio Basins, Cretaceous Limestone, Arakan-Naga Flysch, Eocene, Peguan, Irrawaddian, Alluvial-Proluvial, Crystalline Rocks and Igneous aquifers.

Table 1. Types of aquifers and rocks and the general quality of groundwater in the major cities and urban areas in Myanmar (source: U Tin Maung Nytunt)

	Locality	Type of Aquifer	Type of Rock	General Quality of Groundwater
1	Yangon	Unconfined Confined	Alluvium (unconsolidated fluvialtile deposits) Irrawaddian Formation (consolidated)	Good Good to moderately saline (Iron concentration in somewhat higher)
2	Pathein	Unconfined Confined	Alluvium (unconsolidated) Alluvium	Good Good
3	Thazi	Unconfined Confined	Continental alluvial deposits Irrawaddian Formation (consolidated)	Good Slightly saline
4	Meiktila	Unconfined Confined	Alluvium Peguan Formation	Good High EC and pH
5	Mandalay	Unconfined and confined	Alluvium (river-laid deposits)	Good
6	Akyab (Sittway)	Unconfined	Alluvium	Saline
7	Taunggyi	Unconfined	Brecciated dolomite (Plateau limestone FM)	Good
8	Sagaing	Unconfined Confined	Alluvium Irrawaddian Formation (consolidated)	Good Good
9	Myingyan	Unconfined Confined	Alluvium Irrawaddian Formation (consolidated)	Slightly saline Slightly saline

The groundwater resources of Myanmar by administrative region can be summarized as follows.

4.1. Kachin State (Northern areas)

Groundwater is found mainly in Oligocene- mid- Miocene and Eocene rocks. It is mainly brackish and rarely fresh. In the valley areas, groundwater from alluvial deposits is fresh and yield may be high, but it is found only in localized areas.

4.2. Sagaing Region (North-Western area)

In the northern part of the Division, groundwater is situated in Oligocene to mid- Miocene rocks and is brackish in quality. Groundwater in the Chindwin Basin is of mid-pliocene age and occurs in a contained area. The water is suitable for drinking and irrigation purposes. Groundwater in the southern part of the Region is suitable mostly in alluvial beds of Quaternary age, mainly fresh water, and has a good yield. The water is also suitable for drinking and irrigation purposes.

4.3. Shan, Kayah, Kayin and Mon States and Tanintharyi Region (East and South-Eastern area)

Groundwater occurs mainly in limestones of the Carboniferous-Permian age. In the eastern part of the area, it lies in beds of Mesozoic and Precambrian ages. Groundwater in volcanic rocks is found in the southeastern part. Generally, it is fresh and mostly suitable for drinking and irrigation. To exploit economically, drilling method may be limited.

4.4. Rakhine and Chin States (Western area)

In the eastern part of the states, groundwater occurs in Eocene rocks. The groundwater is mainly brackish and fresh water is rarely encountered in this area. On the Western side groundwater is of Oligo to mid-Miocene and is brackish in quality. Natural reserves of fresh water are limited and seawater intrusion may be encountered along to Rakhine coastal line.

4.5. The Central Area (Mandalay and Magway Regions)

Fresh groundwater is found in Quaternary and Mio-Pliocene rocks. But salinity of groundwater in Mio-Pliocene beds increases with depth. It is suitable for drinking and irrigation purpose. Small supplies of groundwater have been achieved from boreholes tapped in Upper and Lower Peguan in some areas. They are of Miocene and Oligocene ages. Groundwater in these sediments is mostly saline and rarely fresh.

4.6. The Delta Area (Yangon and Ayeyarwady Region)

Groundwater occurs in alluvial beds of Quaternary age. It is mostly fresh and in some parts brackish and suitable for drinking and irrigation purposes. In coastal area the water quality may be saline.

4.7. Bago Region (Southern area)

The central area of the Region is Bago Yoma and it has the rocks of Oligo-Miocene age bearing mainly brackish water. Natural reserves of fresh water are limited. In the eastern and western parts of the Region, groundwater of alluvial beds is exploited. Groundwater reserves are considerable and suitable for drinking and irrigation purposes.

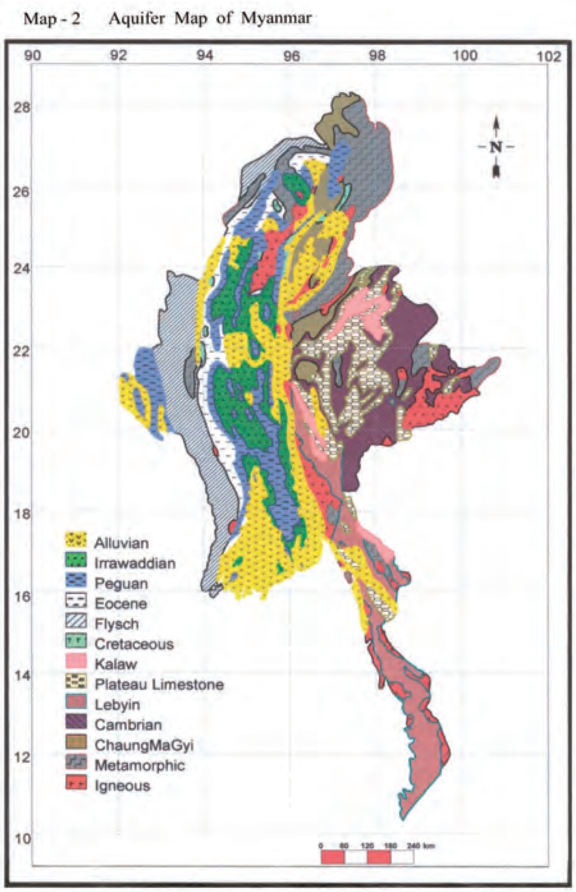


Fig. 1 Status of hydrogeological map

5. Utilization of Groundwater

(a) Municipal water supply. The capital city of Yangon is the only city that receives its water supply from groundwater resources as a supplement to the surface water supply. The daily amount of water that is supplied from groundwater sources is approximately 15 million gallons.

(b) Rural water supply. By the end of 1983, 10,000 tube wells were located in villages in the six divisions of Magwe, Mandalay, Sagaing, Pegu, Irrawaddy and Yangon, serving approximately 5.3 million people, or 24 % of the rural population.

(c) Tourism. Tourism is still under development, and the cities of Mandalay, Pagan and Sand Away have hotel facilities that are supplied with water from groundwater sources.

(d) Industry. The main industries that utilize groundwater sources are ceramics, pulp and paper, textiles, pharmaceuticals, timber, and rice mills. These industries are still under development.

(e) Irrigated agriculture. At the moment, irrigated agriculture does not utilize groundwater resources. Investigations of groundwater resources for irrigated agriculture are now being conducted in the four alluvial basins of Monywa-Chaung-U, Pale-Yinmabin,Yamethin-Tatkon and Thegon-Nattalin, with assistance from the UNDP/World Bank. The results of these investigations are very promising for all these areas.

(f) Cattle. Cattle are part and parcel of the rural population and will not be treated separately.

6. Groundwater Resource Problems

Major problems related to groundwater resource in Myanmar include:

(a) Overdraft exists in parts of the city of Yangon (especially in highly populated sectors), in which groundwater utilization has been dated back several decades.

(b) Saltwater intrusion has occasionally occurred in the city of Yangon along the Pazaung Creek and Hlaing River.

(c) Drainage problems have occurred in the Yinmabin area in the dry zone of Myanmar, where water from the flowing wells has been allowed to flow without control since 1952.

(d) Groundwater in Myanmar is contaminated by fertilizer, pesticides, road salt, chemical spills, septic systems, landfills and many other human activities. As a result of rapid urbanization, urban flooding has recently become a major potential disaster in term of its social and economic impact.

7. Future Challenges and International Cooperation Constraints

- Limited budget
- Insufficient human resources (skilled professionals in the field of groundwater)
- Insufficient groundwater engineering technology
- Limited groundwater survey equipment, exploration machines and monitoring equipment
- Weak country-wide data compilation and data sharing
- Groundwater acts/laws need to be established for the sustainability of groundwater resources.

8. Future Plans

- Country-level, basin-wide estimation of groundwater potential
- Volume estimation for country-level groundwater extraction
- Water quality monitoring in groundwater irrigation areas
- Revision of previously established hydrogeological map for central dry zone of Myanmar
- Preparation of hydrogeological maps for the whole country
- Searching for new groundwater prospect areas
- Establishment of a groundwater database management system by using geospatial technology

9. Conclusions

- Among the three types of groundwater, the water in the Alluvial and Irrawaddian aquifers has been found to be promising for future utilization in agriculture. These aquifers are extensive and lie at shallow depths below the surface, and their waters are generally of good quality.
- The groundwater in the Peguan aquifer is more or less saline and can be used for livestock and domestic use.
- Myanmar is endowed with water resources. Effectively managing these resources will require water management to be integrated into national economic and social policies, including the planning of land use, the utilization of forest resources and the protection of mountain slopes and river banks.
- Better water management will require innovative technologies, including the improvement of indigenous technologies to make full use of limited water resources and to safeguard the water from pollution.
- The management of water resources should be delegated to the lowest appropriate level. It should include full public participation, including that of women, youth, indigenous people and local communities, in water management and decision making.

Current Status and
Issues of Groundwater
in the Mekong River Basin

Groundwater Issues and Hydrogeological Survey of the Mekong River Basin in Myanmar

Country Report of Thailand

Groundwater Issues and Hydrogeological Survey of the Mekong River Basin in Thailand

Mahippong Worakul, Arissara Painmanakul, Warangkana Larbkich

Department of Groundwater Resources, Royal Thai Government

1. Introduction

Systematic groundwater development in Thailand began approximately 60 years ago and focused on the north-eastern region of the nation, which has been known as the most drought-prone region of Thailand. The first technical aids came from the United State Geological Survey (USGS) during October-December 1954. The geological, hydrological, and geophysical exploration was performed in north-eastern Thailand by the geologists from UGSG in collaboration with Department of Mines in Thailand. Some years later, the Department of Mines changed its name to the Department of Mineral Resources (DMR). The Groundwater Division was one of the principal divisions that belonged to the DMR and was responsible for groundwater development to serve people in rural areas nationwide.

As a result of the Government Reformation Scheme in 2003, all of the organizations that had dealt with groundwater development have been merged together into the Department of Groundwater Resources (DGR). Currently all groundwater development and advanced studies have been proceeding efficiently by DGR.

2. Current Situation of Water Resources in Thailand

Only 40,000 million cubic metres (M.m^3) comprise the surface water resources in Thailand in the forms of, e.g., rivers, lakes, and dams, whereas 1.1 million M.m^3 have been stored as different groundwater resources beneath Thailand territory (Figure 1).

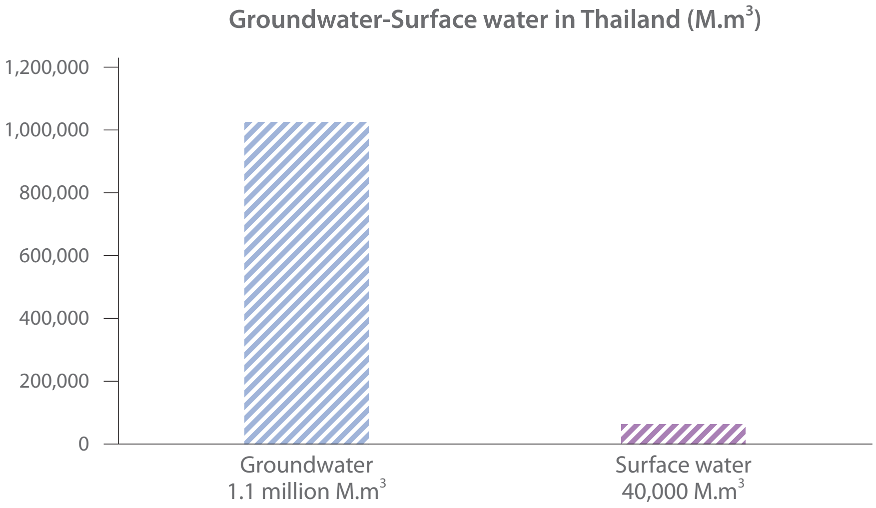
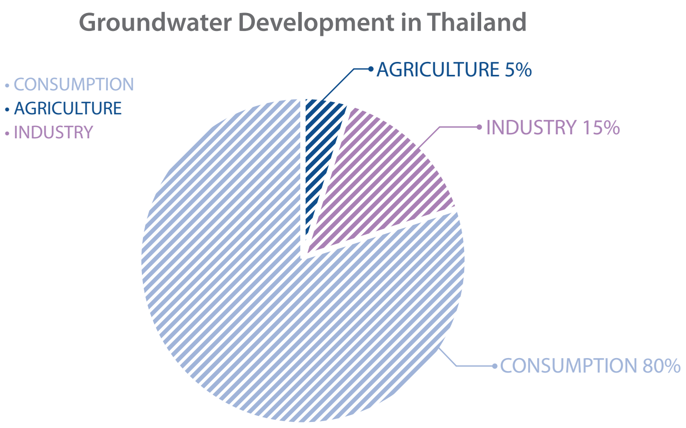


Fig. 1 Diagram that shows the approximated groundwater and surface water quantity in Thailand

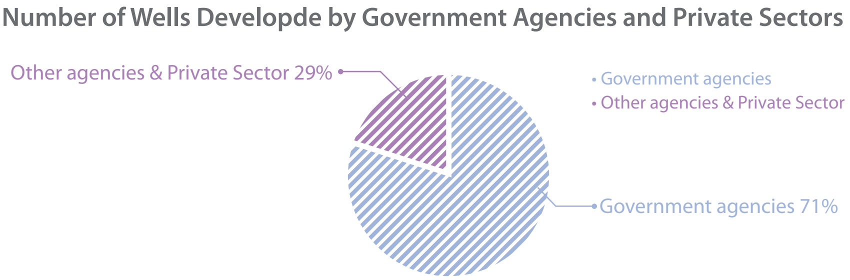
Groundwater utilization in Thailand has been categorized into three main groups: groundwater for consumption, agriculture, and industry. Figure 2 illustrates the percentage of groundwater use for each category with the approximated groundwater utilization of 8,000 M.m^3 per year.



ESTMATED TOTAL GROUNDWATER UTILIZATION IS 8000 M.CU.M./YR

Fig. 2 Groundwater utilization categories in Thailand

As mentioned above, groundwater wells have been drilled by several government agencies for a span of 5-60 years ago for consumption as the first priority and then allocated for agriculture, but later on some private sectors have drilled their own groundwater wells for industrial utilities. The current total number of groundwater wells in Thailand is almost 350,000 wells for all these categories (Figure 3).



Implementing Agency	No. of Well Drilled	No. of Pump Installed			
		Hand Pump	Submersible Pump	Engine Pump	Rural Piped Water Supply System
DMR	90,132	37,771	40,019		12,342
ARD	50,102	42,257	2,521		5,324
PWD	52,790	40,621	810		11,359
DOH	39,867	27,362	-		12,505
NSC	9,475	5,914	-		3,561
Other Agency & Private Sectors	98,592		28,592	70,000	-
total	340,958	153,925	141,942	70,000	45,091

Fig. 3 Picture that illustrates the numbers and percentages of groundwater wells in Thailand

3. Hydrogeological Settings in Thailand

Several types of water-bearing rocks or aquifers are present in Thailand and are closely related to geologic units with ages from the Precambrian to the present. These units are categorized by using the International Association of Hydrogeologist's (IAH) standards, such as groundwater in porous formations, groundwater in jointed or fissured formations, and groundwater in igneous rocks.

Porous formations consist of the Alluvium, Colluvium, Low Terrace, and High Terrace aquifers, which roughly cover twenty percent of the nation. Fissured or jointed aquifers consist of Tertiary semi-consolidated rocks in the upper part and consolidated rocks in the middle and lower parts, which are fresh water limestone, mudstone, lignite, sandstone, and shale. Triassic to Cretaceous continental sedimentary rocks, which are represented by shale, siltstone, sandstone, and conglomerate, are dominantly found in the Khorat Plateau, which covers one-third of Thailand and is located in the north-eastern and northern regions of the country.

Triassic marine sedimentary aquifers are also found in minor areas to the south. Permian and Ordovician carbonate aquifers are also dominant, covering about one-fourth of the nation. Additionally, we found some Permian to Carboniferous meta-sedimentary aquifers, and the last one for this category is a metamorphic aquifer, which is Precambrian to Devonian in age. The last category is represented by igneous rocks, which is subdivided into 2 groups, namely, volcanic aquifers, which are represented by basaltic and rhyolitic aquifers, and intrusive rocks, which are granitic aquifers.

Trans-boundary aquifers are located to the north in Laos and the Union of Myanmar. In Laos, the trans-boundary aquifers are represented by concealed, high terrace aquifers of Tertiary to Lower Pleistocene age. Thailand shares the Permian limestone aquifer to the northwest and Permian-Carboniferous sedimentary aquifers to the west of Myanmar.

To the south, Thailand shares a granitic aquifer with the Kedah State of Malaysia. Thailand and Cambodia share a Permian limestone aquifer and Permian-Carboniferous meta-sedimentary aquifers. In the northern region, Thailand and Laos share a sandstone aquifer, though the boundary is bordered by the Mekong River.

The major problems that are related to groundwater resources in Thailand are not very prevalent. These problems occur in local areas, for example, the leakage of landfill leachates into municipal areas, but all sites have been monitored closely by installing monitoring wells around each site. Another important problem is seawater intrusion into the upper three aquifers in Bangkok and its vicinity, where groundwater wells have been drilled by private sectors, and their over-exploitation lowered the static water levels and induced seawater to come further beneath the land. Another phenomenon that was caused by over-exploitation was land subsidence, but this problem has been solved by designating limits to the drilling and pumping rates.

4. Hydrogeological Map Status

Hydrogeological mapping has been conducted with various scales, starting with 1:500,000 and then compiled into 1:1,000,000 in the year 1983. 1:100,000 Provincial Groundwater Maps had been produced nationwide to be used as decision-making tools for drilling groundwater wells and have been very helpful for several sources of users.

Since 2012, Groundwater Maps and Hydrogeological Maps at a scale of 1:50,000 have been prepared to cover the entirety of Thailand by the year 2020. These maps will be very helpful for both academic and non-academic users. Those maps have been constructed altogether with 3-D images of hydrogeological cross-sections and eventually can serve people through the Application of 3-D Hydrogeology of Thailand.

5. Hydrological Monitoring Network

The Bureau of Groundwater Conservation and Restoration, Department of Groundwater Resources, is responsible for the establishment of groundwater monitoring networks in Thailand. In total, 1,408 groundwater monitoring wells have been installed in every region in Thailand, and more wells have been planned to cover all the major aquifers in the nation. Figure 4 illustrates the locations and distribution of monitoring wells in Thailand. These wells have been monitoring both the groundwater level and quality twice a year in the dry and wet seasons.

6. Future Challenges & International Cooperation

The Department of Groundwater Resources has international cooperation with many countries and international agencies. The DGR has been studying isotope hydrogeology, which has been supported by the International Atomic Energy Agency (IAEA) over the last three decades. The DGR has signed a Memorandum of Understanding (MOU) with the Geological Surveys of Denmark and Greenland to conduct airborne geophysical surveys and use the Geocene3D software. The DGR has signed a Memorandum of Understanding (MOU) with the Chinese Academy of Geological Sciences (CAGS) for the purposes of co-researching karst hydrogeology and performing hydrogeological mapping in China and Southeast Asia.

7. Special Issues of Groundwater Problems in the Mekong River Basin

Special issues that are related to groundwater problems in the Mekong River Basin include the detailed study of trans-boundary aquifers between Thailand and Laos and between Thailand and Cambodia, which requires cooperation with the CCOP and UNESCO.

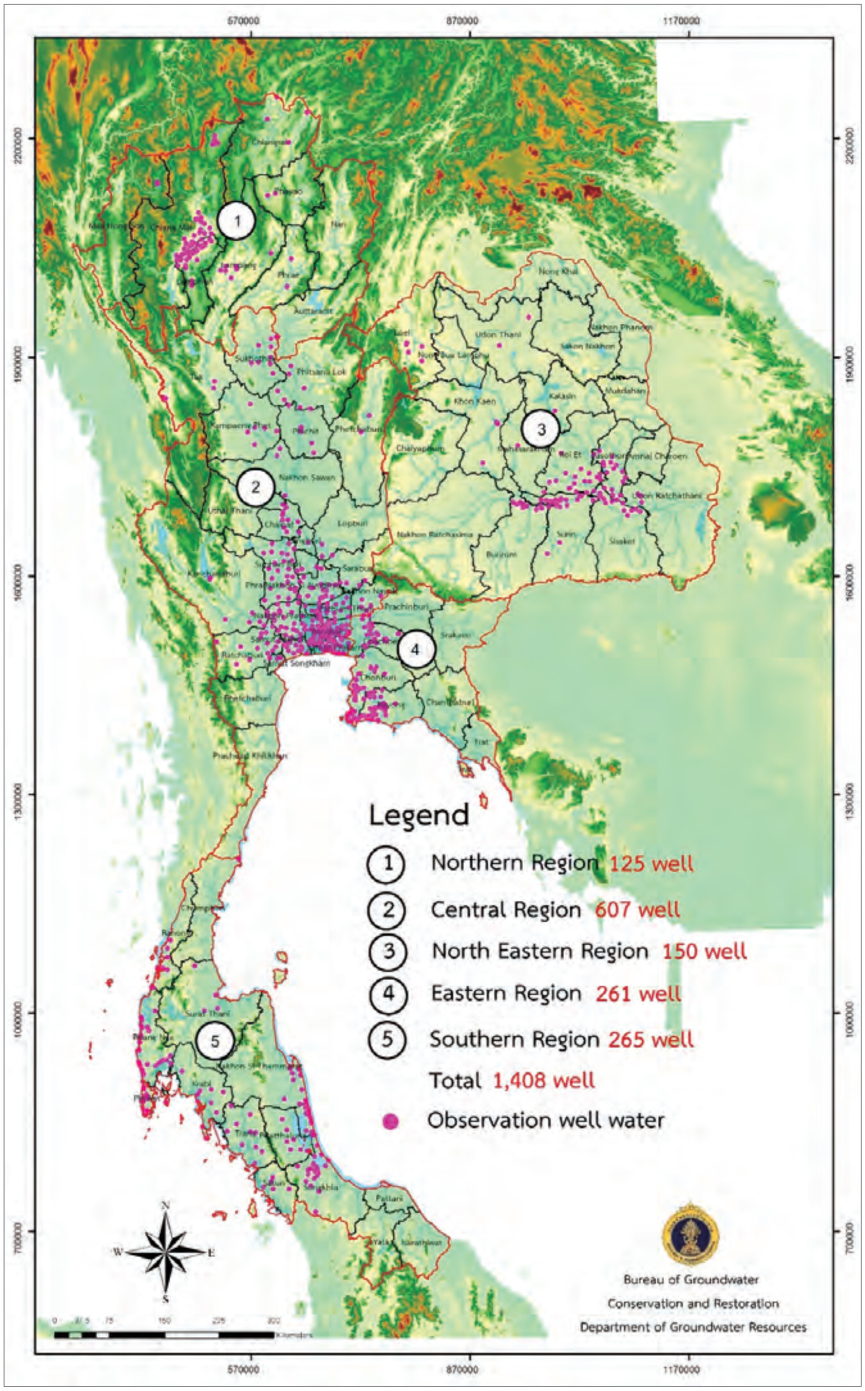


Fig. 4 Groundwater monitoring wells in Thailand

Country Report of Vietnam

Groundwater Issues and Hydrogeological Survey of the Mekong River Basin in Vietnam

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1. Introduction

The Mekong Delta (MD) in Vietnam forms a triangle of 39,734 km^2, stretching from Tien Giang in the east to An Giang and Dong Thap in the northwest, Ca Mau at the southernmost tip of Vietnam, the Gulf of Thailand to the southwest, the East Sea to the south and southeast, and Cambodia to the north. Within Vietnam, the delta is divided into 13 provinces (Long An, Dong Thap, An Giang, Tien Giang, Ben Tre, Vinh Long, Tra Vinh, Hau Giang, Soc Trang, Bac Lieu, Kien Giang, Ca Mau provinces and Can Tho – see Fig. 1); the city of Can Tho could be considered the centre of the delta.

Fig. 1 Map of the Mekong Delta (Google Maps)

With approximately 17 million people (nearly 20% of the Vietnamese population), the Mekong Delta is, similar to many deltas, densely populated. In 2012, only approximately 25% of the population lived in urban areas (compared with the national average of 32%), and 75% of the population was rural.

The Mekong Delta river system consists of natural river systems and man-made canal systems. The main natural river systems are the Tien River and Hau River system; the Vam Co River system; and the Cai Lon and Cai Be River system.

- The Tien and Hau Rivers transfer large amounts of water, with a total annual flow of 325.41 billion m^3 at the Tan Chau station and 82.43 billion m^3 at the Chau Doc station. Both the Tien River and Hau River are wide and deep, with an average width of approximately 1000-1500 m and an average depth of 10-20 m (in some locations, the depth is over 40 m). However, near the mouth, the river widens and the riverbed is raised by siltation. Many elongate islands have formed within the two rivers.

- The Vam Co River system consists of two branches, namely, Vam Co Dong and Vam Co Tay, which are derived from Cambodia and flow east through the Mekong Delta.
- The Cai Lon-Cai Be Rivers are tidal rivers that originate from the centre of the Ca Mau Peninsula and flow to the sea through the Cai Lon River mouth. The estuary is very wide but not deep.

The system of man-made canals in the Mekong Delta was developed primarily during the past century, with the primary purpose of developing agriculture and transportation. The canal system has currently developed into a dense network with 3 levels of major, primary and secondary canals. The primary and secondary canal systems have a high density, with some 80-10 m/ha, and a total of 30,000-40,000 km of canals in the entire Mekong Delta (Mekong Delta water resource assessment studies, 2011).

2. Surface Water Resources

2.1. Hydrological regimes

The hydrological regimes in the Mekong Delta (MD) are directly affected by the river flow, the tidal regime of the East Sea (South China Sea) and, for some parts of the delta, by the tidal regime in the Gulf of Thailand (West Sea). The East Sea has a semi-diurnal and irregular sea-tide regime, whereas the West Sea is diurnal.

Based on the influence of these diverse tidal patterns and cycles, the MD can be divided into three hydrologically different sub-regions: (A) the upper delta sub-region (fresh floodplain zone), which is impacted by floods (Fig. 2); (B) the estuary sub-region (intertidal/mixed zone), which is impacted by both floods and tides; and (C) the coastal sub-region (coastal zone), which is impacted by tides.

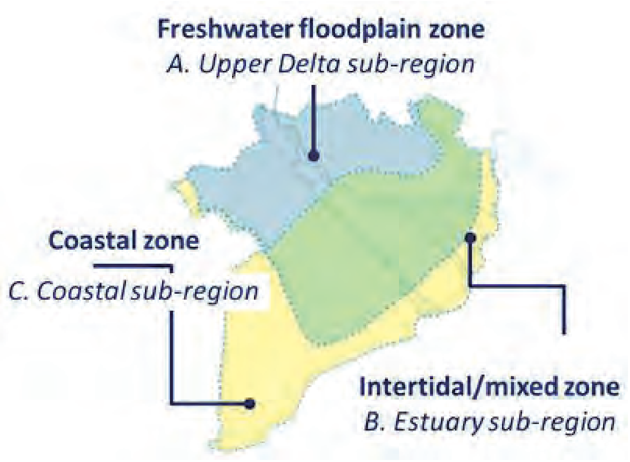


Fig. 2 The three hydrologically different sub-regions
(source: Southern Institute for Water Resources Planning)

Seasonal flooding in the Mekong Delta usually begins in the months of June to July and ends in the months of November to December, with an average peak flow that enters the delta of approximately 28,000-30,000 m^3/s. This flow is followed by an average dry-seasonal flow of approximately 3,000-5,000 m^3/s. Both high and low flood regimes prevail for approximately 6 months.

The total annual average river flow in the Mekong Delta in the upstream parts of the Tien River and Hau River is ~408 billion m^3 (according to data that were measured from 2000 to 2008 at the Tan Chau and Chau Doc stations). During the flood season, the border region accounts for 14-18% of the total floods into the territory of Vietnam (estimated 57 billion m^3), and surface water from rain on the plains accounts for 11% of the whole water volume (estimated 45 billion m^3).

2.2. Surface water quantity

First, the stations in the main tributaries (stations on the river) or primary river/canals (tributary channels) were identified. Second, statistical analysis were performed on the monthly flow data from these stations to obtain the hydrological characteristics. The dry year (80%), medium-water year (50%) and wet year (20%) can be calculated by using the log-normal distribution $R = e^x$. If filling gaps in the data is required, the monthly average runoff and monthly rainfall correlation will be established.

Only five stations are present along the main river courses in the Mekong Delta, namely, the Tan Chau and My Thuan stations (on the Tien River), the Chau Doc and Can Tho stations (on the Hau River) and the Vam Nao station (on the Vam Nao River).

The My Thuan and Can Tho stations have continuous data from 2003 to the present. The Tan Chau, Chau Doc and Vam Nao stations have continuous data from 2000 to the present. The Vam Nao River is a short connection between the Tien River and Hau River in An Giang province.

Tan Chau and Chau Doc are the most important stations for measuring the flow of the entire basin, i.e., the upstream Mekong River, to the Mekong Delta. The Vam Nao station quantifies flow from the Tien River to the Hau River. The My Thuan and Can Tho stations quantify the flow of the Tien and Hau Rivers after flowing through the Plain of Reeds area (POR) and the Long Xuyen Quadrant (LXQ), which are subject to the distribution of water through main channels in the POR and LXQ regions. These last two stations are influenced by sea tides.

The Mekong Delta contains some local hydrological stations that measure the water level in the main river/channels and other stations that measure water in coastal estuaries. Estuarine coastal stations and local stations in the coastal provinces measure the salinity. Most local hydrological stations have no flow data, so the water quantity in sub-basins such as POR, LXQ, and CMP is assessed by using a river hydraulic model simulation.

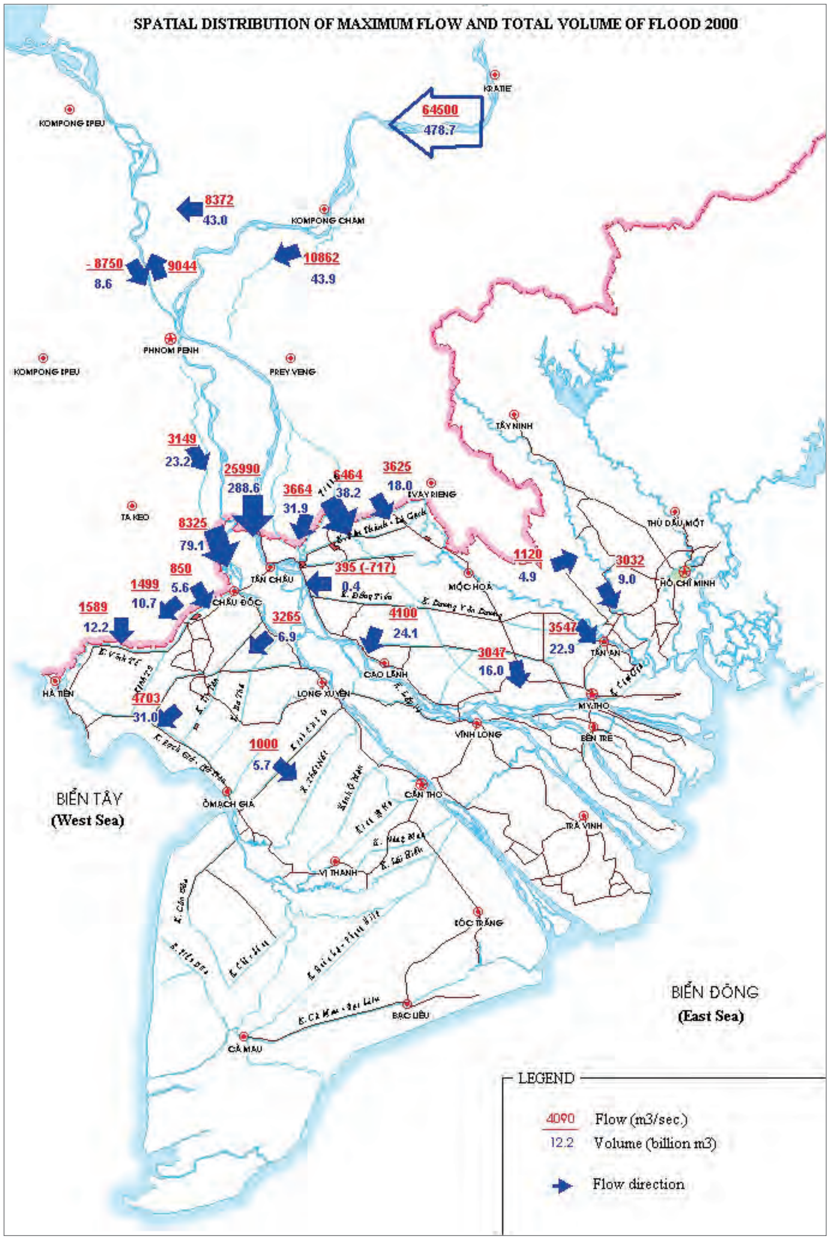


Fig. 3 Spatial distribution of the maximum flood flow and total volume of the 2000 flood from a VRSAP model simulation (source: Southern Institute for Water Resources Planning)

2.3. Saltwater intrusion

Saltwater intrusion in the Mekong Delta is a complex process that depends on the magnitude of floods in the previous year, the ability to supply fresh water in the upstream part during the dry season, the summer-autumn paddy production status and the timing of the rainy season. In general, the amount of rainfall at the beginning of the summer–autumn crop season is small in late-raining years. Abundant water is needed for the irrigation of summer–autumn rice, but the water flow from the upstream part to the MD is less than 70% of the average. If the rainy season appears later, the saltwater will intrude very far inland, which occurred in 1977, 1993, 1998 and 2004-2005.

Every year, the highest salinity occurs at the end of the dry season, usually in April or in early May during late-raining years. The length of 1 g/l salinity intrusion is 40 - 50 km inland, which is shorter in branches of the Mekong River and longer in branches of the Vam Co River. During the flood season, flood flow from upstream is large, so saltwater is quickly pushed back to the estuaries. During the mid-flood season (September and December), the 1 g/l salinity mark is usually only located in the estuaries.

In the Plain of Reeds, saltwater intrusion occurs along the Tien River and Vam Co Tay River. Saltwater intrusion along the Tien River depends on the flow from the upstream Mekong River. After years with large flood flow, the dry flow is often large, and saltwater is quickly pushed back to the estuaries. In contrast, after years with small flood flow, saltwater intrudes far inland in the rivers and canals.

The Ca Mau Peninsula is an area with serious and complex saltwater intrusion in the Mekong Delta. The peninsula is bordered by the East Sea and West Sea, which have two different tidal regimes, complicating the flow in the rivers and canals in the Ca Mau Peninsula and limiting the transfer of fresh water from the Hau River inland to interior fields.

The Long Xuyen Quadrant area is directly affected by saltwater from the West Sea. The main canals from Tri Ton to Cai San take water from the

Hau River and discharge to the West Sea to supply irrigation and prevent salinity intrusion. Most coastal ends of the main canals (22 of 24 canals, except for the Cai San and Vam Rang canals) have sluice gates to control saltwater.

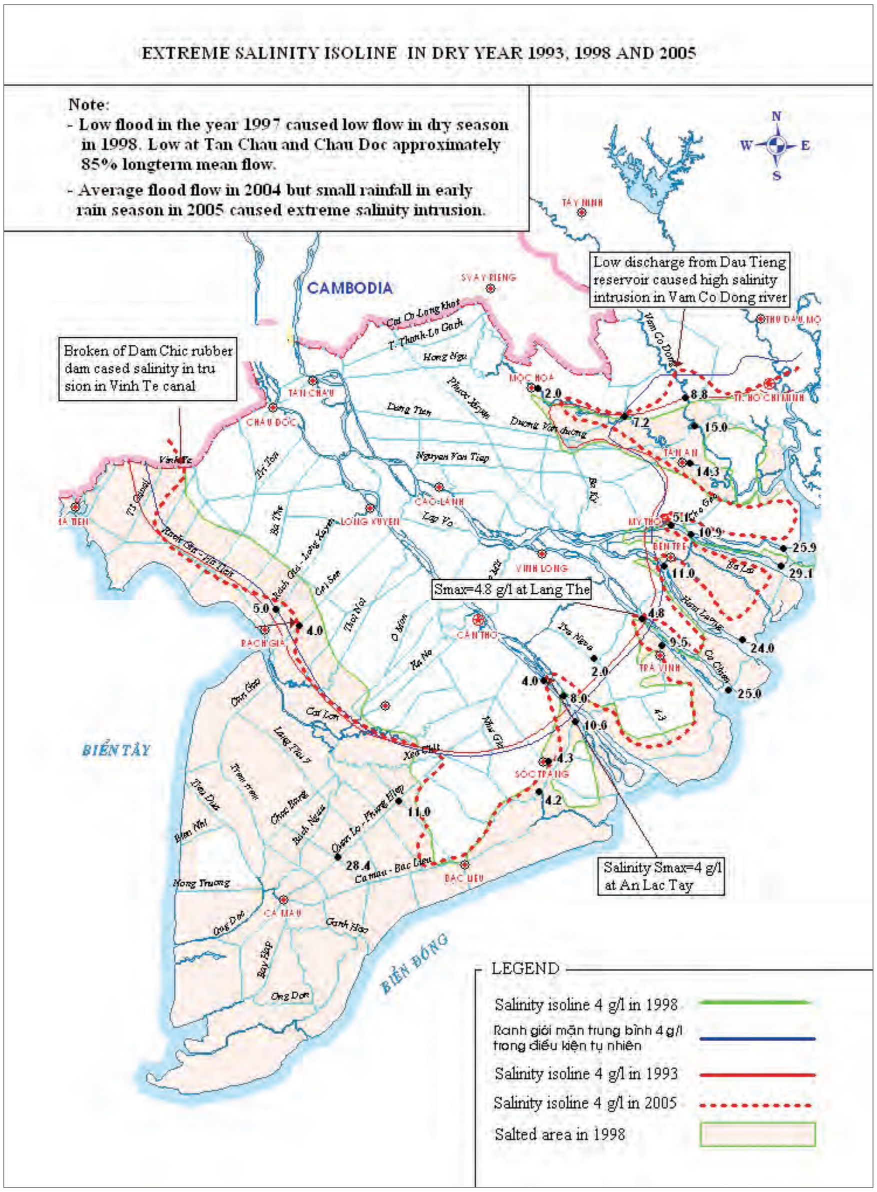


Fig. 4 Salinity intrusion isolines in some dry years
(source: Southern Institute for Water Resources Planning)

2.4. Surface water quality

The rainwater supply in the Mekong Delta is plentiful and of good quality, and it can be used for drinking and as irrigation water for crops. Monitoring and analytical data on the quality of the rainwater in the Mekong Delta in recent years show that the rainwater in the Mekong Delta can generally be used as a water supply source, although some data indicate the increasing occurrence of acid rain. This source is important for people who work in areas that still have difficulty obtaining a water supply or have poor surface water resources and where the groundwater is contaminated, especially in flood seasons. Rainwater also plays an important role in agricultural production, aquaculture, and forest fire prevention in coastal areas because of the limited sources of fresh water from rivers.

The water quality in the main river courses varies markedly with the seasons. The amount of soluble substances is higher during the dry season and lower during the flood season. Floods are loaded with silt, especially during the first months of the rainy season. Annually, the Mekong Delta receives approximately 150 million tons of silt; this process has shown an increasing trend in recent years. At Tan Chau, the average concentration of silt in the flood season is approximately from 800 to 1,000 g/m^3 in August.

The variation in the water quality in the flooded Mekong Delta region is complicated; the area is dominated by several modes of climate, hydrology and human activities. The Na, K, Ca^{2+}, Mg^{2+}, Fe^{2+}, Al^{3+}, $SO4^{2-}$, Cl^-, and HCO_3^- contents vary with season, with the dry season values usually being higher than those during the flood season, but generally still below critical thresholds.

In general, surface water pollution in the Mekong Delta is characterized by high concentrations of coliforms, with 300,000-1500,000 units/100 ml on average. The main sources are human waste and waste from livestock and poultry. In interior fields (“polders”), the water quality situation is usually more serious. According to research results, pesticide pollution is not widespread in the delta, but contamination has certainly affected aquatic ecosystems in some places.

Monitoring the water quality in the Mekong Delta is extremely important to assess pollution levels and water use options. Since 1999, the Ministry of Agriculture and Rural Development has assigned the Southern Institute Water Resources Planning (SIWRP) to monitor the surface water quality in the Mekong Delta through a monitoring network in the rivers to serve the requirements of sectoral development and water management. Since July 2004, this has become a regular monitoring network. Samples were taken on the 15th from January to December during the peak and lowest water levels of the day. Monitoring parameters were selected to meet the monitoring water quality goals, including silt composition, nutrition components, components that are indicative of organic pollution, and micro pollutants. In 2008, the monitoring indicators included the following groups:

- Physical and chemical characteristics of the water: pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), Na, K, Cl, Ca, Mg, SO4, alkalinity/acidity, and hardness ($CaCO_3$).
- Nutrients: total phosphorus, total nitrogen, ammonia (NH_3), nitrate (NO_3), nitrite (NO_2), and phosphate (PO_4).
- Level of organic pollution, specifically, micro-organisms in water: COD, BOD_5, DO, coliforms and E. coli.
- Analysis methods: the standard method of Vietnam or international standards that are used around the world.

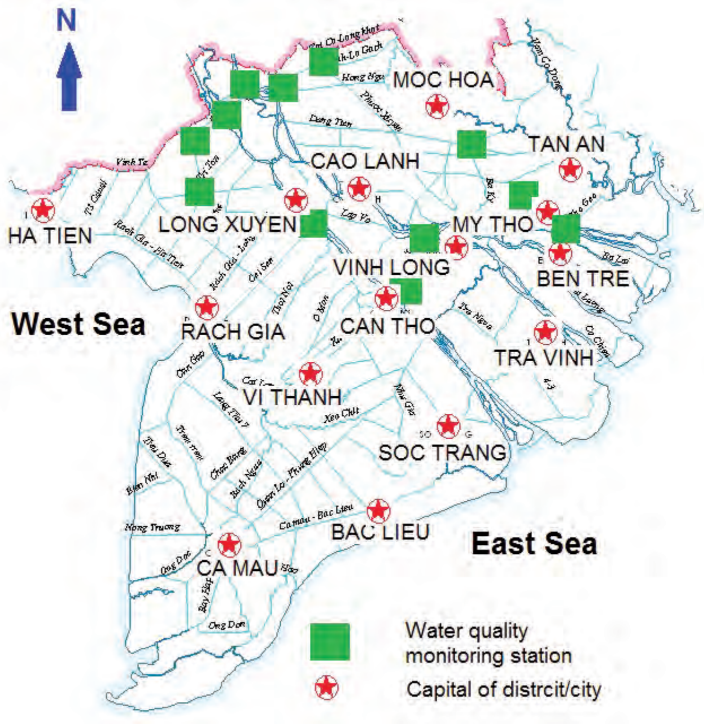


Fig. 5 Water quality monitoring network
(source: Southern Institute for Water Resources Planning)

In 2007, the water quality in the lower Mekong River Basin was monitored at 12 stations, including positions along the Tien River, Hau River, a channel region of the POR and the LXQ. Some analytical results are as follows:

- In 2007, the alum water on the channel in Nguyen Tan Thanh at Long Dinh was more acidic than in 2006, with a minimum pH value of 4.95 in August. In previous years (2002-2007), the water was less acidic, but the alum content fluctuated more, and the trend line did not change (coefficient = 0 and angular coefficient p = 0.982).
- Saltwater intrusion in 2007 was not high. In My Tho, the maximum conductivity value was 1680 μS/cm in April, with a lower salinity of approximately 1.3 g/l. In recent years, saltwater intrusion did not show fluctuations, and 2004 was the year with the highest saltwater intrusion.

- The silt content in the main streams and the internal canals tended to increase from 2002 to 2007.
- The amount of organic matter, such as nitrogen and phosphorus, increased during heavy rains (July). During the dry season, the nutritional composition of the canals was higher than that in the mainstream. From 2002 to 2007, the components tended to increase (nitrogen) or decrease (phosphorus), but not significantly.
- The organic matter content (BOD_5) was quite low; however, COD components tended to increase from 2002 to 2007. Dissolved oxygen was low in the channels during the dry season.
- The water in the main streams had good quality (meets TCVN 5942:1995 standard) based on most water quality indices, except for suspended solids. The water in most canals was polluted. All the water bodies had good quality for fresh aquatic life, except for a few months of acid sulphate soil exposure in the Long Dinh area.
- Some local stations were polluted by acid water in May and June by acid leakage from soil in the early rainy season.

3. Hydrogeology and Groundwater Resources

3.1. Aquifer system in the Mekong Delta

Eight distinguished aquifers are present in the Mekong Delta, namely, Holocene (qh), Upper Pleistocene (qp_3), Upper-Middle Pleistocene (qp_{2-3}), Lower Pleistocene (qp_1), Middle Pliocene (n_2^2), Lower Pliocene (n_2^1), Upper Miocene (n_1^3) and Upper-Middle Miocene (n_1^{2-3}) aquifers. Generally, the lithology of each aquifer consists of fine to coarse sand, gravel, and pebbles.

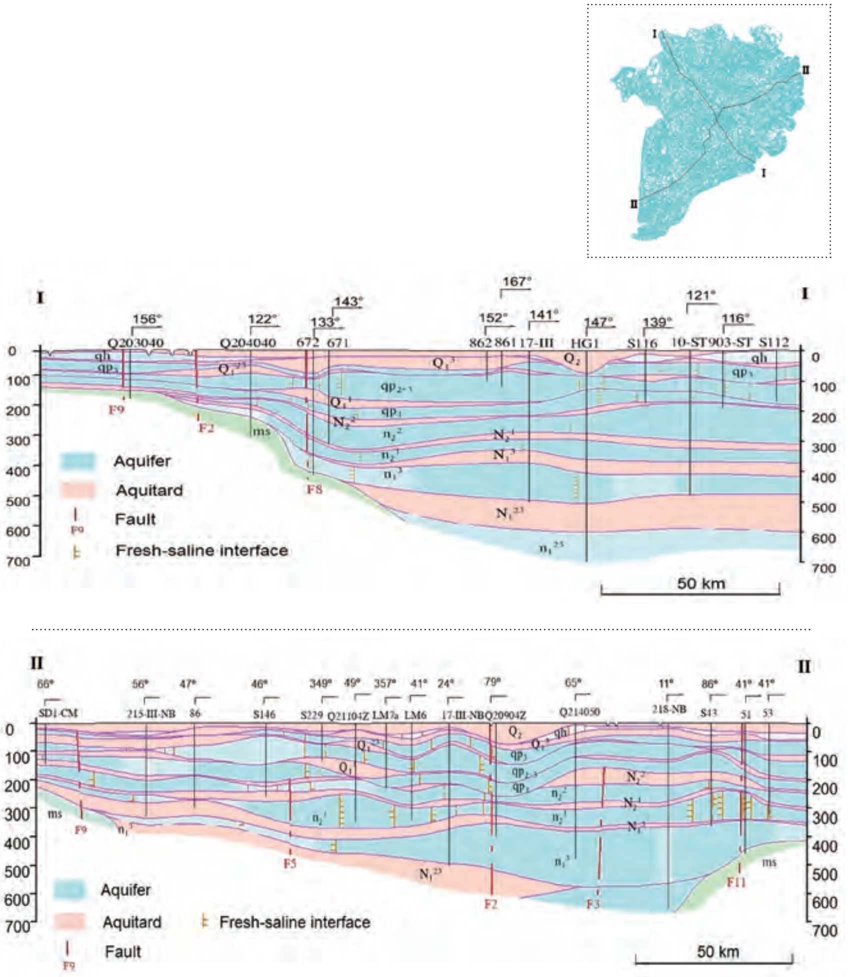


Fig. 6 Hydrogeological cross-section I-I & II-II (source: Vuong B.T. (2014))

3.1.1. Holocene aquifer, qh

The Holocene aquifer outcrops over an area of 17,676 km^2 but is absent along the Vietnam-Cambodia boundary and in the north-western part of the MD.

The aquifer consists of various sediments of different origins: Lower to Middle Holocene sediments (Q_2^{1-2}) of alluvial and marine origin mainly consist of clayey silt and fine sand and are rich in organic matter. Middle-Upper Holocene sediments of alluvial, marine and eolian origin (Q_2^{2-3}) include 5- to 10-m-thick remnants of sand dunes from paleo-sea shores, which can be found in the Mo Cay, Ba Tri, Tra Cu, and Long Toan districts of Tra Vinh Province. Upper Holocene sediments (Q_2^3), which accumulated in river valleys and flood plains, consist of clay silt and fine sand.

The depth to the top of the aquifer varies from 0.00 m to 61.50 m, with an average of 16.87 m. The depth to the bottom of the aquifer ranges from 2.80 m to 89.00 m, with an average of 32.89 m. The thickness is from 0.90 m to 72.00 m, with an average of 15.48 m. The groundwater levels are generally between 0.5 and 3.0 m above sea level. The area of fresh groundwater (TDS<1 g/l) is 2,889 km^2, and that of saline groundwater is 14,788 km^2. The amount of groundwater that was abstracted in 2010 was 17,851 m^3/day.

3.1.2. Upper Pleistocene aquifer, qp_3

The Upper Pleistocene aquifer is distributed widely over an area of 39,468 km^2 but is absent in Tri Ton, Tinh Bien, Chau Đoc, Thoai Sơn (An Giang Province), Hon Đat, Ha Tien, and Kiên Lương (Kiên Giang Province).

The aquifer is composed of Upper Pleistocene sediments of alluvial and marine origin (amQ_1^3). The depth to the top of the aquifer varies from 0.00 m to 115.40 m, with an average of 47.96 m. The depth to the bottom of the aquifer ranges from 11.50 m to 154.00 m, with an average of 76.36 m. The thickness is from 2.00 m to 84.00 m, with an average of 29.14 m.

The permeability varies from 0.22 m/day to 65.82 m/day, with an average of 20.62 m/day. The groundwater levels are between -6.36 m and 0.99 m above sea level.

The area of fresh groundwater is 10,494 km^2, and that of saline groundwater is 28,974 km^2. The amount of groundwater that was abstracted by 2010 was 114,945 m^3/day.

3.1.3. Upper - Middle Pleistocene aquifer, qp_{2-3}

The Upper-Middle Pleistocene aquifer covers an area of 39,279 km^2 but is absent in Tri Ton, Tinh Bien, Chau Đoc, Thoai Sơn (An Giang Province), Hon Đat, Ha Tien, and Kiên Lương (Kiên Giang Province). The aquifer is composed of Upper-Middle Pleistocene sediments of alluvial and marine origin (amQ_1^{2-3}) that consist of fine to coarse sand and gravel.

The depth to the top of the aquifer varies from 9.70 m to 178.00 m, with an average of 86.88 m. The depth to the bottom of the aquifer ranges from 24.50 m to 207.00 m, with an average of 129.13 m. The thickness is from 2.00 m to 100.30 m, with an average of 41.45 m.

The permeability varies from 0.89 m/day to 55.07 m/day, with an average of 21.24 m/day. The area of fresh groundwater is 14,941 km^2 and that of saline groundwater is 24,338 km^2. The amount of groundwater that was abstracted by 2010 was 997,514 m^3/day.

3.1.4. Lower Pleistocene aquifer, qp_1

The Lower Pleistocene aquifer is distributed widely over an area of 39.340 km^2 but is absent in Tri Ton, Tinh Bien, Chau Đoc, Thoai Sơn (An Giang Province), Hon Đat, Ha Tien, and Kiên Lương (Kiên Giang Province). The aquifer is composed of Lower Pleistocene sediments of alluvial (aQ_1^1) and alluvial-marine origin (amQ_1^1).

The depth to the top of the aquifer varies from 62.00 m to 221.00 m, with an average of 146.53 m. The depth to the bottom of the aquifer ranges from 69.50 m to 298.00 m, with an average of 185.98 m. The thickness is from 3.50 m to 92.60 m, with an average of 38.08 m.

The permeability varies from 0.76 m/day to 53.28 m/day, with an average of 24.73 m/day. The groundwater levels are between -7.37 m and -0.04 m below sea level. The area of fresh groundwater is 13,647 km^2 and that of saline groundwater is 25,693 km^2. The amount of groundwater that was abstracted by 2010 was 130,077 m^3/day.

3.1.5. Middle Pliocene aquifer, n_2^2

The Middle Pliocene aquifer is distributed widely over an area of 36,267 km^2 but is absent in Tri Ton, Tinh Bien, Chau Đoc, Thoai Sơn (An Giang Province), Hon Đat, Ha Tien, and Kiên Lương (Kiên Giang Province). The aquifer is composed of Middle Pliocene sediments of alluvial (aN_2^2) and alluvial-marine origin (amN_2^2).

The depth to the top of the aquifer varies from 42.60 m to 318.90 m, with an average of 206.47 m. The depth to the bottom of the aquifer ranges from 125.00 m to 415.40 m, with an average of 258.92 m. The thickness is from 4.00 m to 147.00 m, with an average of 51.33 m.

The permeability varies from 0.17 to 67.20 m/day. The groundwater levels are between -20.14 m to -7 m above sea level. The area of fresh groundwater is 14,014 km^2 and that of saline groundwater is 22,253 km^2. The amount of groundwater that was abstracted by 2010 was 477,395 m^3/day.

3.1.6. Lower Pliocene aquifer, n_2^1

The Lower Pliocene aquifer is distributed widely over an area of 34,546 km^2 but is absent in the western and north-western parts of the study area. The aquifer is composed of Lower Pliocene sediments of alluvial (aN_2^1) and alluvial-marine origin (amN_2^1).

The depth to the top of the aquifer varies from 134.00 m to 432.20 m, with an average of 274.77 m. The depth to the bottom of the aquifer ranges from 180.00 m to 435.10 m, with an average of 330.16 m. The thickness is from 2.00 m to 131.00 m, with an average of 53.78 m.

The permeability varies from 1.05 m/day to 48.14 m/day, with an average of 13.63 m/day. The groundwater levels are between -1.37 m and -5.89 m above sea level. The area of fresh groundwater is 16,269 km^2, and that of saline groundwater is 18.277 km^2. The amount of groundwater that was abstracted by 2010 was 87,652 m^3/day.

3.1.7. Upper Miocene aquifer, n_1^3

The Upper Miocene aquifer is distributed widely over an area of 39,468 km^2 but is absent is absent in the western and north-western parts of the study area. The aquifer is composed of Upper Pliocene sediments of alluvial (aN_1^3) and alluvial-marine origin (amN_1^3).

The depth to the top of the aquifer varies from 215.00 m to 444.00 m, with an average of 360.58 m. The depth to the bottom of the aquifer ranges from 220.50 m to 508.00 m, with an average of 391.96 m. The thickness is from 2.50 m to 200.10 m, with an average of 58.79 m.

The permeability varies from 1.05 m/day to 48.14 m/day, with an average of 9.01 m/day. The groundwater levels are between -6.36 m and 0.99 m above sea level. The area of fresh groundwater is 10,494 km^2, and that of saline groundwater is 28,974 km^2.

3.2. Usable groundwater storage

Natural accumulations of organic and inorganic substances in the Earth's crust that can be effectively tapped and used for material production are generally referred to as "useful minerals". By virtue of this definition, groundwater resources that are tapped as water supplies and for other purposes are also considered "useful minerals".

Table 1. Natural storage (Vn) in the MD (Vuong B.T., 2014a)

aquifer		**qp_3**	**qp_{2-3}**	**qp_1**	**n_2^2**	**n_2^1**	**n_1^3**	**Sum**
Gravity storage (m^3/day)	Fresh GW	1,808,992	4,043,805	3,075,374	4,324,231	5,045,585	2,985,195	21,283,182
	Saline GW	5,892,479	6,004,019	5,974,966	7,449,900	5,475,699	5,915,494	36,712,557
Elastic storage (m^3/day)	Fresh GW	193,114	397,837	527,047	74,424	18,533	18,852	1,229,807
	Saline GW	516,710	649,651	1,061,648	125,920	23,035	34,804	2,411,768
Natural storage (m^3/day)	Fresh GW	2,002,106	4,441,642	3,602,421	4,398,655	5,064,118	3,004,047	22,512,989
	Saline GW	6,409,189	6,653,670	7,036,614	7,575,820	5,498,734	5,950,298	39,124,325

- The usable fresh groundwater storage is approximately 22.5 Mm^3/day.
- The usable saline groundwater storage is approximately 39.1 Mm^3/day.

3.3. Groundwater resource development and management

The results of an investigation in 2010 in 13 provinces/cities in the MD pinpoint 553,135 exploitation wells with a total amount of groundwater abstraction of 1,923,681 m^3/day.

Most of the exploitation wells have a capacity less than 200 m^3/day (552,203 wells); only 932 wells have a capacity greater than 200 m^3/day. The number of exploitation wells that are used for domestic purposes and agriculture is 551,507 wells. These exploitation wells are distributed unevenly in the aquifers. In total, 417,010 exploitation wells are present in aquifer $qp_{2\text{-}3}$, 986 are present in aquifer n_1^3, 30,000 to 50,000 are present in aquifers qp_3, qp_1 and n_2^2, and 1,000 to 10,000 are present in aquifers qh and n_2^1.

Groundwater is abstracted primarily in the $qp_{2\text{-}3}$ (977,514 m^3/day) and n_2^2 aquifers (477,359 m^3/day); in the qp_3, qp_1, n_1^2, n_1^3 aquifers, groundwater abstraction varies from 87,000 to 130,000 m^3/day.

Groundwater is exploited mainly for domestic use (801,730 m^3/day, or 41.68% of the total groundwater abstraction), agricultural use (769,619 m^3/day, or 40.01% of the total groundwater abstraction), and industrial use (352,332 m^3/day, or 18.32% of total groundwater abstraction).

3.4. Major groundwater problems

Because of the rapidly increasing population and very fast economic development in the MD, the demand for water resources has also rapidly increased. However, the surface water resources are unable to meet these demands, groundwater was over-abstracted. Resulting groundwater depletion and saline water intrusion are the main problems that threaten drinking water supplies, farming systems, and livelihoods in the delta.

3.4.1. Groundwater depletion

Continuous decrease in groundwater level has been observed in the Mekong Delta Region. The $qp_{2\text{-}3}$, qp_1, n_2^2 and n_2^1 aquifers show larger decreases in their groundwater levels than the other aquifers.

In the qp_3 aquifer, parts of the Ca Mau, Bac Lieu, Kien Giang and Tra Vinh Provinces show larger decreases in their groundwater levels than the other provinces: the maximum groundwater level decrease is 5.0 m and the rate of the groundwater level decrease at the centre points of the cones of depression is 0.50 m/year.

In the $qp_{2\text{-}3}$ aquifer, parts of the Bac Lieu, Kien Giang, Tra Vinh and Can Tho Provinces show larger decreases in their groundwater levels than the other provinces: the maximum groundwater level decrease is 17.6 m and the maximum rate of the groundwater level decrease at the centre points of the cones of depression (at Vinh Thuan District) in Kiên Giang Province is 1.76 m/year.

In the qp_1 aquifer, parts of the Bac Lieu and Ca Mau Provinces show larger decreases in their groundwater levels than the other provinces: the maximum groundwater level decrease is 12.5 m and the rate of the groundwater level decrease at the centre points of the cones of depression is 1.25 m/year.

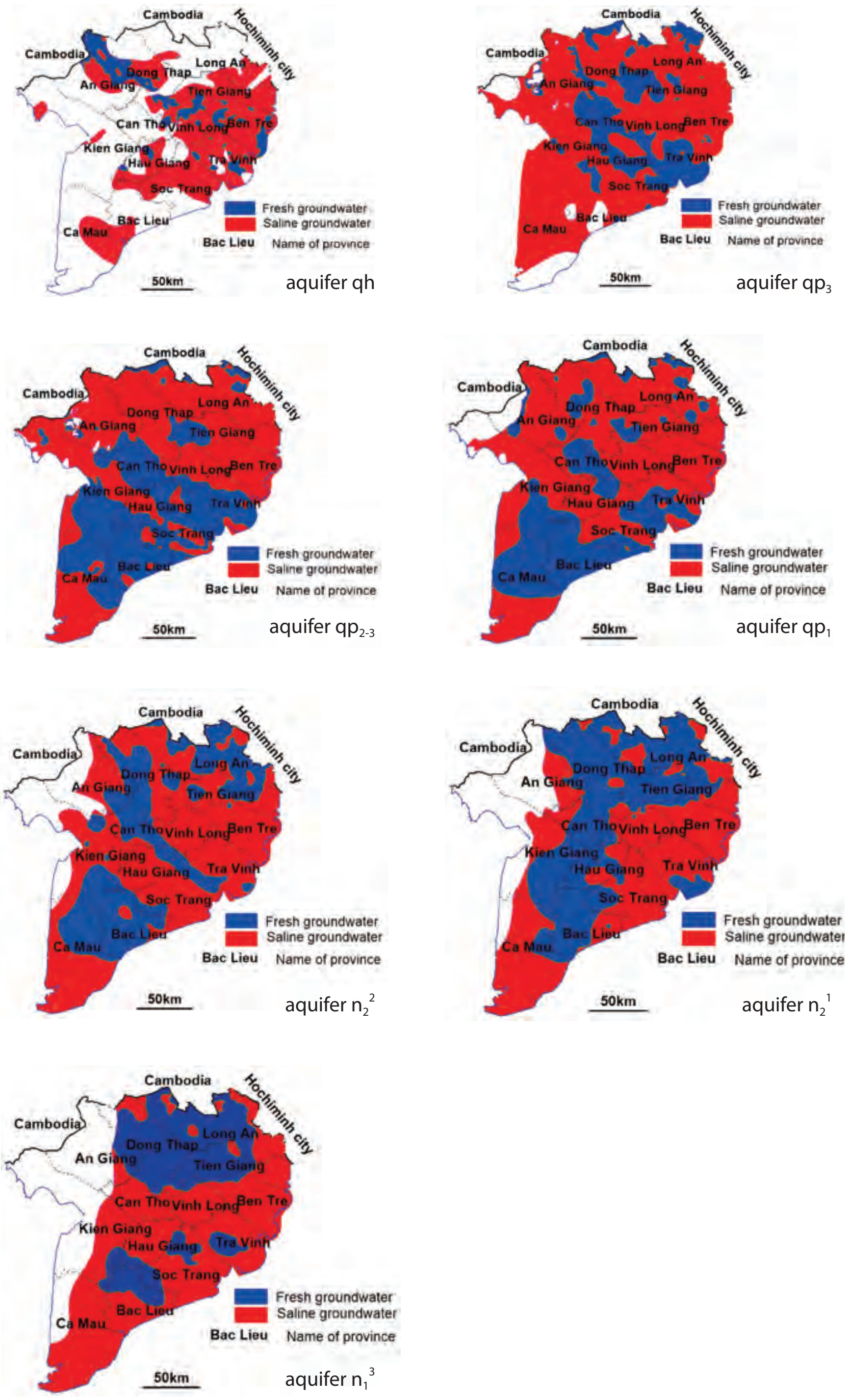
In the n_2^2 aquifer, parts of the Ca Mau, Đồng Thap, and Can Tho Provinces show larger decreases in their groundwater levels than the other provinces: the maximum groundwater level decrease is 19.8 m and the rate of the groundwater level decrease at the centre points of the cones of depression is 1.98 m/year.

In the n_2^1 aquifer, parts of the Ca Mau and Soc Trang Provinces show larger decreases in their groundwater levels than the other provinces: the maximum groundwater level decrease is 14.2 m and the rate of the groundwater level decrease at the centre points of the cones of depression is 1.42 m/year.

In the n_2^1 aquifer, parts of the Long An and Tien Giang Provinces show larger decreases in their groundwater levels than the other provinces: the maximum groundwater level decrease is 25.8 m and the rate of the groundwater level decrease at the centre points of the cones of depression is 2.8 m/year.

3.4.2. Saline water intrusion

The distribution areas of fresh and saline groundwater in each aquifer are illustrated in Fig 7.



aquifer qh

aquifer qp_3

aquifer $qp_{2\text{-}3}$

aquifer qp_1

aquifer n_2^2

aquifer n_2^1

aquifer n_1^3

Fig. 7 Distribution areas of saline and fresh groundwater in aquifers (source: Vuong B.T, 2014a).

3.4.3. Land subsidence

Hydraulic heads have declined significantly throughout much of the Mekong Delta in recent years. Monitoring the wells indicated a drop of over 15 m at Ca Mau since the mid-1990s, leading to a cone of depression that is now nearly 20 m below sea level. The current rate of hydraulic head decline among the delta's wells averages 26 cm yr^{-1} (range: 9–78 cm yr^{-1}), which has caused widespread regional drawdown in a ~100 km-wide swath that trends NE from Ca Mau towards Ho Chi Minh City.

The magnitude of drawdown diminishes in wells with increasing proximity to the international border, owing to minimal groundwater extraction in Cambodia, reduced development density in the north-eastern areas of the Vietnamese Delta adjacent to Cambodia, and bedrock outcropping in the north-western corner of the delta. Subsidence rates from compaction-based calculations follow a similar pattern (Laura E Erban, 2014), which is modified by the highly variable thicknesses of compressible subsurface layers. Compaction-based subsidence rates average 1.6 cm yr^{-1} (range: 0.28–3.1 cm yr^{-1}).

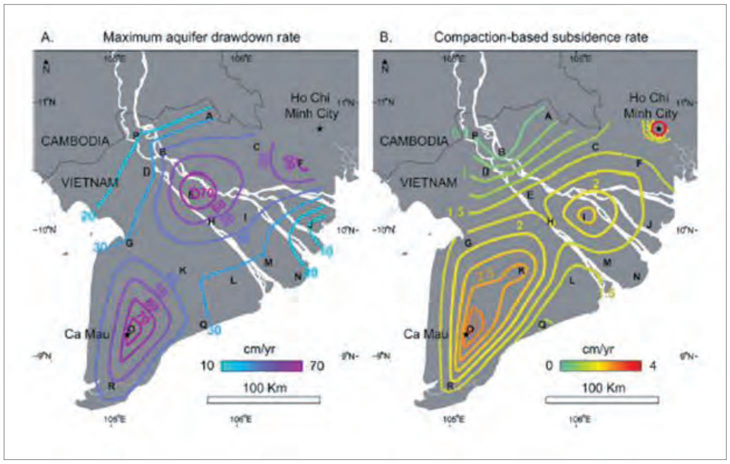


Fig. 8 Hydraulic head decline and subsidence rates from compaction-based calculations in the MD (source: Erban et al. 2014)

4. Hydrogeological Map Status

At present, a hydrogeological map of the whole country on a scale of 1:500,000 has been completed. A hydrogeological map of Nam Bo (covering 54,000 km^2 and including the Mekong Delta) on a scale of 1:200,000 has also been completed. Hydrogeological maps at a scale of 1:50,000 have been completed in 4 areas, covering an area of 6,621 km^2.

In additional, 13 projects have investigated urban geology, in which hydrogeological maps on a scale of 1:25,000 have been made.

The locations of all of the hydrogeological projects are shown in Fig. 9.

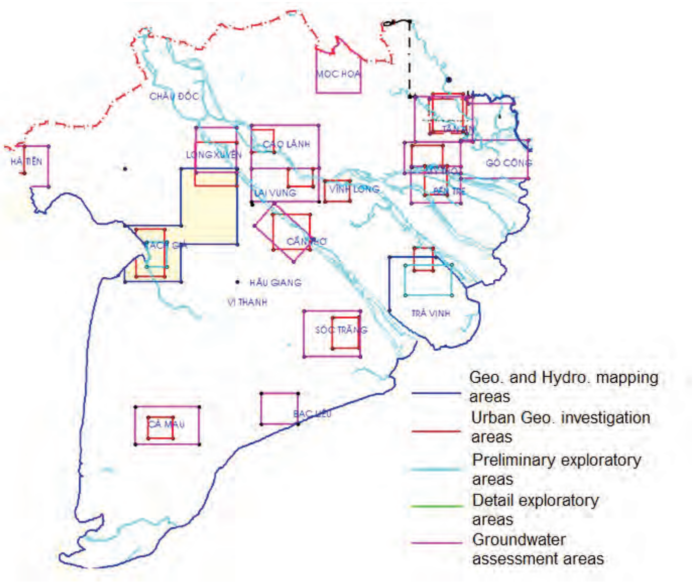


Fig. 9 Location map of the hydrogeological project in the MD

5. Hydrological Monitoring Network

Seventy-one stations with 220 monitoring wells (Fig. 10) are present in Nambo (southern Vietnam):

- 10 stations for surface water monitoring
- 1 station for rainfall monitoring
- 60 stations (210 obs. wells) for groundwater monitoring

Of these 210 monitoring wells, 24 obs. wells are present in the Holocene aquifer, 44 obs. wells in the qp_3 aquifer, 31 obs. wells in the qp_{2-3} aquifer, 27 obs. wells in the qp1 aquifer, 30 obs. wells in the n_2^2 aquifer, 29 obs. wells in the n_2^1 aquifer, 12 obs. wells in the n_1^3 aquifer, 1 obs. well in the n_1^{2-3} aquifer, 10 obs. wells in basalt rock, and 2 obs. wells in Mesozoic bedrock.

The Mekong Delta contains 94 observation wells that recorded time series of the groundwater level from 1999 to 2010. Among these wells, the number of observation well in the aquitard Q_2 and the aquifers qh, qp_3, qp_{2-3}, qp_1, n_2^2, n_2^1 and n_1^3 are 6, 10, 13, 18, 11, 14, 14 and 8, respectively.

Water sampling and analysis were performed at an interval of twice per year (in April and October). Five types of water samples were taken and analysed.

- Complete sample: Na, K, Ca, Mg, NH_4, Fe^{2+}, Fe^{3+}, HCO_3, Cl, SO_4, NO_3, NO_2, CO_3, CO_2, pH, and hardness
- Iron sample: Fe^{2+} and Fe^{3+}
- Micro-element sample: As, Cd, Pb, Cr, Cu, Zn, Mn, Hg, Se, F, and COD
- Phenol cyanide: Phenol and cyanide
- Contaminated sample: NH_4^+, NO_2^-, NO_3^-, and PO_4^-

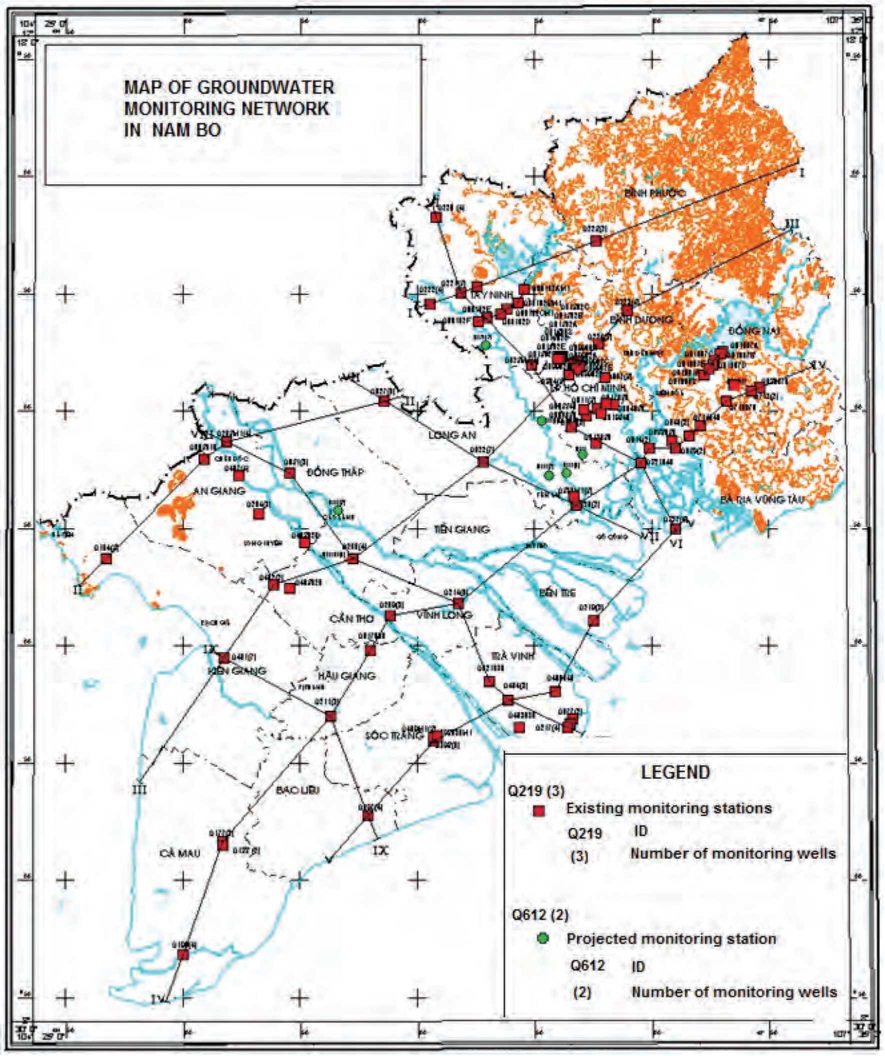


Fig. 10 Location map of the monitoring stations in Nambo (source: DWRPIS (2010))

6. Future Challenges & International Cooperation

6.1. Future challenges

The increasing overexploitation and salinization of deeper aquifers raises questions regarding the origin and recharge of deep fresh groundwater and new exploration strategies.

The relationship between low sea level and the origin of deep fresh groundwater, which has been demonstrated previously, suggests that the recharge of this finite groundwater resource is limited.

Detailed case studies need to quantitatively assess the groundwater side flows that feed the low saline aquifers in the MD, if any exist. However, the current exploitation status obviously already exceeds the aquifers' capacities. Further exploration of other fresh groundwater lenses may only temporarily improve this situation.

Obviously, proper management and mitigation strategies are urgently needed for more sustainable solutions. Thus, a close connection between water policy and science and engineering and strong cooperation between different groundwater users, such as water supply companies, agriculture, other industries and domestic households, are crucial.

Some challenges that can potentially lead to more sustainable groundwater usage in the MD include the following:

- Reducing extraction: High-quality groundwater is a finite resource and should only be used for the domestic drinking water supply:
    - Identifying the sources of groundwater loss or misuse, together with the design and approval of mitigation strategies, is necessary. Leaking wells, pipes and tubes are some common causes of wasted groundwater.
    - Alternatives must be found for groundwater usage with lower priority, such as (i.) the application of saline-tolerant crops in agriculture and (ii.) the treatment and usage of surface water for industry and both aqua- and agriculture.

- Optimizing extraction: The salinization of remaining fresh groundwater lenses can be minimized by applying appropriate exploitation strategies. This can only be achieved based on detailed knowledge about the local subsurface structure and its hydraulic characteristics.
- Conjunctive usage: Mixing high quality water with poorer quality water may increase the available amount of water while still maintaining an acceptable water supply quality.
- Increasing recharge: Potential areas where technologies can be applied to increase groundwater recharge with artificially infiltrated precipitation and low saline surface water must be identified. To minimize long-term risks, feasibility studies need to carefully assess the hydrogeological and hydrogeochemical impacts on the subsurface environment and develop appropriate geotechnical and monitoring strategies.

6.2. Special focus on requests regarding international assistance to solve groundwater-related issues

Upgrade and improve the national monitoring network of groundwater resources in the Mekong Delta to perform the following:

- Increase the density of monitoring wells
- Collect data automatically
- Ensure that monitoring stations will operate over the long term

Design, build, operate and maintain a monitoring network of the land surface subsidence in the Mekong Delta to perform the following:

- Assess existing land surface subsidence
- Understand the drivers of land surface subsidence
- Monitor land surface subsidence
- Propose measures to minimize land surface subsidence

Conduct feasibility studies and pilot the implementation of artificial groundwater recharge schemes in coastal areas of the Mekong Delta to perform the following:

- Test the effectiveness of using artificial groundwater recharge in restoring depleted aquifer storages and sustaining urban water supplies
- Select the best sites and suitable technology for artificial recharge as part of a comprehensive feasibility study
- Pilot the implementation of artificial recharge schemes where feasible
- Learn from implementing artificial groundwater recharge schemes in different physical and social environments
- Develop knowledge bases for artificial groundwater recharge in Vietnam

Design, build, operate and maintain an information system on groundwater resources for the Mekong Delta to perform the following:

- Assess the existing data availability on water resources for management in the Mekong Delta (data catalogue)
- Propose a structure for sharing data in the Mekong Delta
- Transfer websites and data catalogues for service in Vietnam
- Support the preparation of suitable maps for management plans
- Recommend the development of a national information system for water resources

7. Special Issues of Groundwater Problems in the Mekong River Basin

Several special problems in the field of groundwater are worth examining. In brief, these problems are mentioned below:

- Isotope analysis (C-14 dating) has, to date, concentrated primarily on the absolute age of the groundwater in the top aquifers of the Mekong Delta and its general flow patterns. However, more isotopes can be tested to provide specific information about recharge from, e.g., rainwater or river water. A project could be established to determine the origin of this water in selected areas.
- Groundwater chemistry has not been studied in detail. Subjects to be studied in this context are the cation exchange capacities of the clays, the ion balances in the clays and the relationship with the results of the isotope analysis.

- Present procedures for the assessment of groundwater reserves in Vietnam are not acceptable in terms of sustainability – they are not considered feasible or realistic. Modern literature is now available on groundwater reserve calculations. This literature can be studied by a panel of specialists and new guidelines for reserve calculations can be formulated.
- The groundwater levels are dropping in certain areas. A study on the application of suitable artificial recharge methods could be useful for sustainable groundwater development in the MD.
- Based on the population per province, growth rates, present number of wells and availability of other water resources, an estimate of the future water demand from groundwater is necessary. Wells were planned and designed in outline, and the total number of required wells was determined based on the locations of the inhabitants. Based on these prognoses, the potential locations of wells and well fields should be investigated by modelling. The result could support the master planning of the water supply for the entire Mekong Delta.

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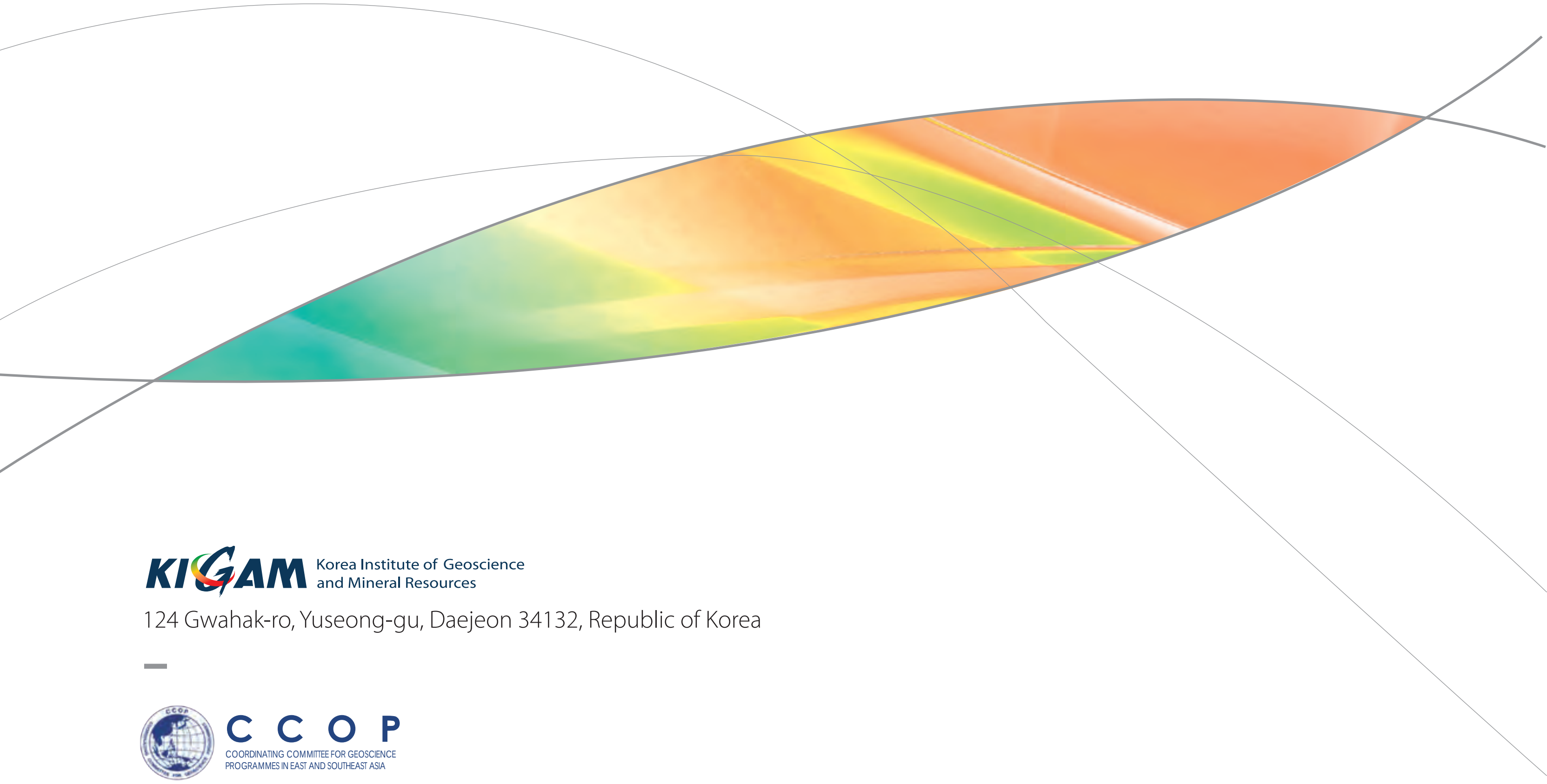

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