GROUNDWATER RESOURCES IN VIET NAM: POTENTIAL AND CHALLENGES

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Abstract: *Groundwater is a precious resource in Viet Nam, especially in areas with a lack of other available water resources. Intensive investigation of groundwater resources has been undertaken over the past five decades and identified 26 water-bearing units in 7 regions. Groundwater resources are represented by potential reserves, classified by hydrogeological regions. The total groundwater potential reserves in the country reach nearly 133 million m^3/day, which equals 48.5 billion m^3/year. Groundwater resources are exploited for many purposes such as drinking, manufacturing, irrigating, aquacultural cultivation in Red river/aquacultural cultivation plain, in Southern plain and in the Central Highlands. During groundwater extraction, some challenges have been arise such as groundwater contamination of Nitrogen, Arsenic etc., Land subsidence as a result of overuse for example in Ha Noi, Ho Chi Minh City, Ca Mau peninsular and groundwater salinization in coastal aquifers where there is about 3,260 km coastal line with developing areas and impacts of climate change and sea level rise.*

Keywords: *groundwater resource, potential, reserve, contamination, climate change.*

1. Introduction

Viet Nam is located in South east Asia; towards the East Sea covering an area of about 329,560 km^2. Viet Nam has a tropical climate in the South and monsoonal in the North. Annual rainfall is substantial, ranging from 1,200 mm to 3,000 mm. About 90 percent of the precipitation occurs during the summer.

The whole territory of Viet Nam can be divided into 7 natural geographic regions: (I) North West, (II) North East, (III) Red River Delta (IV) North of Centre, (V) Coastal area of South of Centre, (VI) Central Highlands, and (VII) Mekong River Delta. Viet Nam has 3,260 km of coastline from the North to South with different natural characteristics (Vu, 1988).

The first almost 100 m deep production well in Ha Noi was developed in the late 19th century during French colonization period, but understanding on groundwater system was quite limited. Not until 1954 were intensive investigations on geology and hydrogeology developed. Viet Nam Geological Survey is a leading organization carring out most of the projects for exploration of groundwater resources (Vu, 2013). Since the renovation period from 1990, many consultating companies have been carrying out investigations of groundwater resources for water supply as well (Vu, 2013). In addition, national research projects and international projects have also been carried out to better understand groundwater resources in the country. This new study on groundwater's potential reserve, is based on a great deal of information from previous investigations, studies and data.

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2. Hydrogeological settings

Surveys and researches on hydrogeology in Viet Nam over the past five decades have identified 26 water-bearing units, including four porous water-bearing complexes, 15 fissured (including fissure-pore, fissure-bed, and fissure-karst) bearing complexes, and seven water-bearing zones in tectonic faulting settings (Vu, 1988). Distributions, capability and water quality of water-bearing units are diversed. Among the water-containing units, those occur in Quaternary

unconsolidated sediments, Paleozoic-Mesozoic carbonates and Neogene-Quaternary volcanic rocks are essential to socio-economic development for their spacious distribution, water abundance and of high quality (Figure. 1)

Based on the results of hydrogeological investigations carried out during more than half of a century on the territory of Viet Nam, 26 water-bearing units have been established, including 4 intergranular water-bearing complexes, 15 fissured water-bearing complexes (including fissure-intergranular, fissure-seam and fissure-karstic) and 7 water-bearing zones in tectonic faults (Vu, 1988). They have different distributive areas, water-bearing capacity and water quality that are displayed in the accompanied hydrogeological map, among them the water-bearing units in Quaternary loose sediments, in Paleo-Mesozoic carbonate beds and in Neogene-Quaternary basalts are the most important ones for the economy and people's livelihood, because they have large distributive areas, abundant water-bearing capacity and good water quality (Figure 1).

2.1. Water-bearing complexes in Quaternary unconsolidated sediments

The water-bearing complexes in Quaternary unconsolidated sediments are largely distributed in the Northern, Southern and South-Central coastal plains. There are two main aquifers as follows:

Aquifer in Holocene sediments is distributed widely in all plains. Their lithological composition consists mainly of sand, clay, mixed clay and sand and mud with thickness ranging from 5-10 to 70-80 m. The water is loosed or weakly pressurized. In the dry season, the water table usually lies between 3 and 5 m deep. In rough terrains, water level may be as deep as 7-8 m. In the rainy season, the water table may rise to the surface. In low land coastal areas, groundwater level fluctuates with tides. Boreholes conducted in these areas show the specific discharge capacity varies from 0.2-0.5 to 4-5 l/sm. The permeability coefficient of the deposits changes in a wide interval, from < 1 to tens of meters/day.

The water quality of this aquifer is complicated. The water in the areas located relatively far from the sea is of good quality with the total dissolved solids (TDS) lower than 0.5 g/l, with main chemical substances being calcium bicarbonate. The water in coastal areas is usually salinized with the TDS rising up to 2-3 g/l, in some places, to 10-15 g/l or higher. However, in these areas sometimes pockets of fresh water are found withins and dunes. Due to the exposure of the water-bearing formation on the surface, the water may be easily contaminated by nitrogen compounds, bacteria and pesticides thus becoming unsafe. Another common feature is very high iron content in the water (1-2 mg/l, in sometimes up to 5-10 mg/l) that is distributed irregularly in the area.

In general, the quality of water in the Holocene aquifer is not good. Because of its large distribution, relatively abundant reserves, easy exploitation conditions it has been an important source of rural and coastal water supply; although special attention must be given to water treatment and disinfection measures.

Aquifer in Pleistocene sediments: These aquifers are widely spread in plain areas, almost covered by Holocene deposits, exposed partially in some marginal areas. The sediments are sand, pebble and gravel interceded by some clay layers. The water table occurs from 5-10 to 70-80 m deep. The thickness varies from some tens (in the Northern Plain) to 150-200 m (in the Southern Plain). The water-bearing capacity is relatively high. The specific discharge of drilling wells usually reaches 2-5 to 8-10 l/sm. In covered areas, the water is confined and the water level usually fluctuates from 5-10 m under the surface to 0.5-1.2 m above the surface.

The water quality of the Pleistocene aquifers changes rather irregularly. In the central and marginal areas, distant from the sea, the water quality is usually good with the TDS not surpassing 0.5 g/l. Its main chemical components contain calcium and sodium bicarbonates. In coastal areas, the water is salinized with the TDS increasing to 1-2 g/l, in some places, up to 5-7 g/l or higher; the chemical substances change into

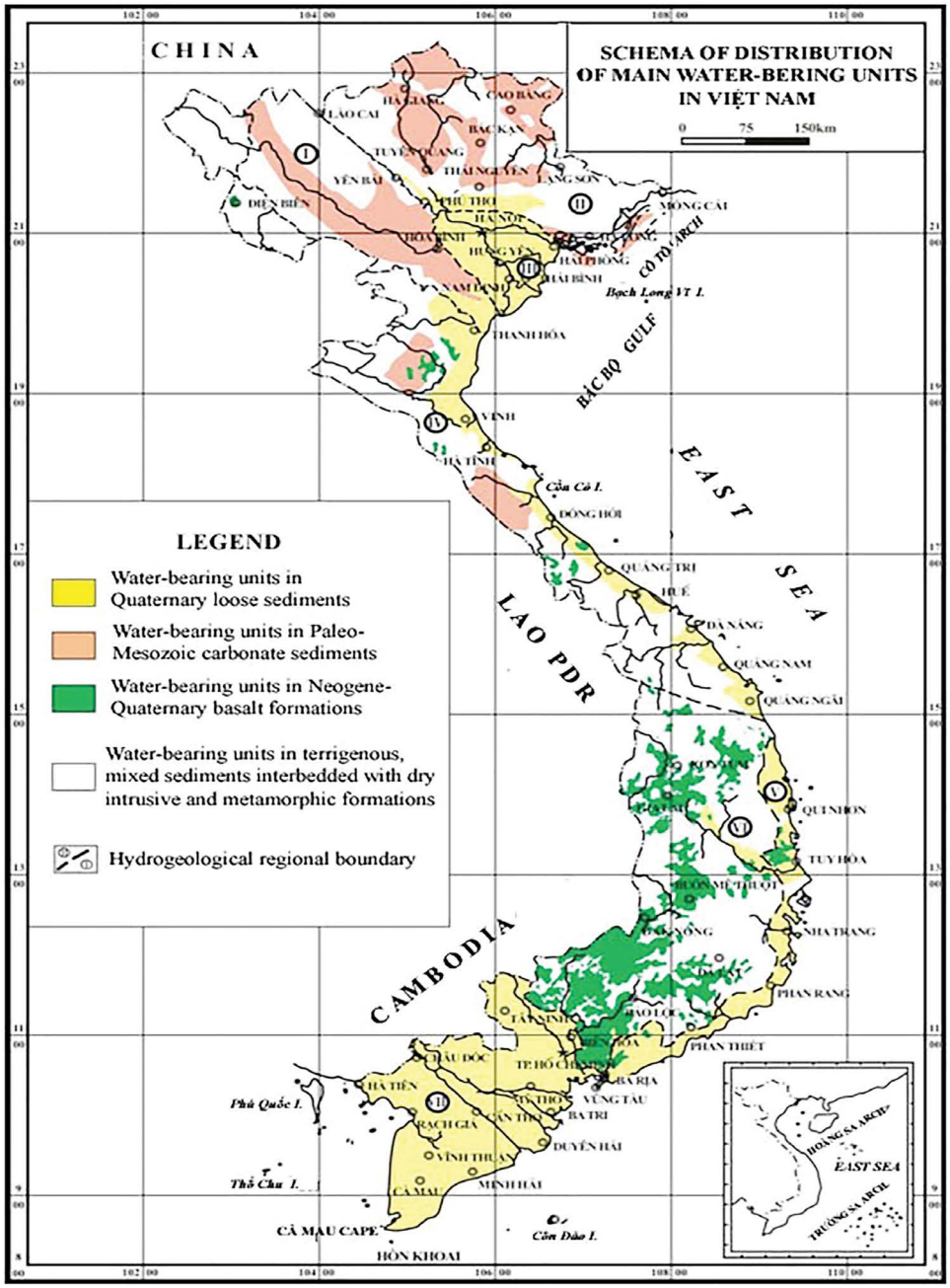

Figure 1. Distribution of main water-bearing units in Viet Nam (Source: Vo Cong Nghiep et al., 1995)

sodium chloride or sodium-magnesium chloride-bicarbonate. However, similar to the Holocene aquifer, in these areas, there are pockets of fresh water of good quality as found in the Northern (Red River) Plain. In Thai Binh - Nam Dinh area, the groundwater is salinized, but 2 freshwater strips are found there: the first extends from Hai Hau to Giao Thuy districts, having an area of 800 km^2; the second spreads from Hung Ha to Diem Dien districts, where the water has the TDS not exceeding 0.4-1.5 g/l. In the Duyen Hai, Cau Ke, Tra Cu areas (Tra Vinh province), in the Southern (Nam Bo) Plain regardless of being located near the sea, the groundwater has the TDS usually about 1 g/l or lower.

In general, this is the aquifer of great significance, especially for large water supplies. The water-supply plants of the Ha Noi City extract mainly its groundwater. Many other cities, such as Phuc Yen, Dap Cau, Da Nang, Quy Nhon, Ba Ria, Ho Chi Minh City (Binh Chanh, Hoc Mon Dist.), Thu Dau Mot, Vinh Long, etc. use mainly the water from just this aquifer.

2.2. Water-bearing complexes in Paleozoic-Mesozoic carbonate sediments

The Paleozoic-Mesozoic carbonate formations occur mainly in the Northeastern, North-Central, Southeastern and Southwestern regions. Their lithological composition consists mainly of bedded or massive limestone; usually fractured, strongly karstified, forming large caves and underground rivers and streams. The total thickness of the formation reaches thousands of meters.

The water presents in fissured or fissured-karstic forms, practically not forming a continuous hydraulic system, but existing as bands or zones. Due to the heterogeneity of water-bearing character, the water-bearing capacity changes both horizontally and the vertically. The depth of the water level changes from first meters to 20-30 m or more in some places. A number of water springs are exposed, but the density of occurrence is different. The spring discharge changes from about 1 l/s to hundreds of liters per second. The specific discharge of drilled wells changes from 0.01 l/sm to 50 l/sm, usually greater than 0.5 l/sm. The hydraulic conductivity coefficient varies strongly, usually from 10 to 50 m/day.

The TDS of water is usually less than 0.5 g/l. Only in coastal areas, affected by the tide fluctuation and distributed along some large faults, highly mineralized water originated from deep levels the TDS may be as high as tens of g/l. The main chemical components of the water are calcium bicarbonate or calcium-sodium chloride-bicarbonate. The water quality, in general, is good, except for salinized and residential areas, industrial and agricultural areas and livestock farms where the water is easily polluted due to the presence of many karstic funnel caves exposed on the surface. In some mountainous areas (such as Cao Bang, Ha Giang), the water has very low TDS (super fresh), a factor affecting the people's health (e.g., causing calcium and magnesium deficiency diseases). In general, the carbonate water-bearing complexes play an important role, but the investigation and exploitation of this resource are still feeble.

2.3. Water-bearing complexes in Neogene-Quaternary basalts

Basalt formations are distributed mainly in the Central Highlands and Southeastern regions, and scattered in some other areas (such as Northwestern, Phu Quy, Vinh Linh, Quang Ngai, Phu Yen). The thickness of the basalt cover varies from tens to several hundreds of meters, especially in the Pleiku plateau the total thickness reaches up to 400 m. Basalts occurred in a number of episodes and eruption phases, clearly observed in some cross-sections. The basaltic stratigraphy includes intercalated layers of porous and massive lavas, weathering and fresh products. This lithological variety forms a heterogeneous water-storage capacity (the most abundant container is porous and sub-weathered lava flows).

The water level in the basalt changes from few meters to 30-40 m or more. Elsewhere water ejects from drilled wells to the surface. At a well in Dak Mol (Dak Nong province) water spouts up to 18 m into the air. Water is more abundant in the central area of basalt center or inproximity of volcanic craters as compared to marginal sites. The discharge of exposed springs and wells varies from a few to 30-40 l/s. The Co Dam springs in Buon Ma Thuot city show the discharge rate up to 80 l/s. The specific discharge of boreholes normally varies from 0.1-0.5 l/sm to 6-7 l/sm. The hydraulic conductivity changes in an interval between 0.1 and 10 m/day. In some areas (such as Pleiku, Buon Ma Thuot, Xuan Loc), it is noticeable that basalt formation, regardless of having high water storage capacity, due to the complete draining of water when boreholes are drilling through fractured zones, still causes water loss from upper fractured zone down to deeper one.

The quality of groundwater in basalts is generally good. The TDS is usually lower

than 0.5 g/l. The water consists of sodium bicarbonate, sodium and sodium-magnesium bicarbonate-chloride.

The groundwater in basalts is essential for economic development, especially for the irrigation of industrial plantations in the Central Highlands and Southeastern regions.

Apart from the above-mentioned water-bearing complexes which have great significance in the large-scale water supply to wide areas, in the Southern Plain, the Pliocene and Miocene aquifers also play an important role.

Terrigenous sediments and complex formations have lesser water abundance, but appear to be significant as small- and medium-scale water suppliers. In metamorphic and intrusive formations, groundwater exists limitedly only in fractured and tectonically deformed zones; thus may be considered as a small-scale water supplier.

3. Groundwater potential

Many hydrogeologists, using different methodologies and achieving different results, have evaluated the groundwater resources in Viet Nam.

According to the National Research Project *"Evaluating the sustainable character of the extraction and use of the groundwater resource on the territory of Viet Nam: Strategic orientation of the rational extraction and use and preservation of the groundwater resource to 2020"* completed by the University of Mining and Geology (Pham et al., 2005), groundwater potential reserves in Viet Nam were ever determined.

The research outcomes have incorporated previous results as well as updated information using newly published literature and calculation methods for the entire territory. The results achieved are highly reliable. Groundwater resources are represented by potential reserves and classified by hydrogeological regions (Table 1). As calculated above, the total potential reserves of groundwater in the country reaches nearly 133 million m^3/day, which is 48.5 billion m^3/year, plus about 870 billion m^3/year of surface water, the total renewable water resources of Viet Nam are 918.5 billion m^3/year. According to data published in 2002-2003 by the World Water Resources Institute (WRI), the amount of renewable freshwater resources of Viet Nam is 11.189 m^3/person, folding 1.7 times the world average (6,537 m^3/person/year).

Table 1. Groundwater potential reserves in Viet Nam

No	Hydrogeological region	Symbol	Area (km^2)	Important water bearing formations	Potential reserves (m^3/day)
1	Northwestern	I	35,530	Carbonate, terrigenous formations	15,521,338
2	Northeastern	II	66,434	Carbonate, terrigenous formations	27,995,374
3	Northern (Red River) Plain	III	8,204	Quaternary unconsolidated sediments; carbonate and terrigenous rocks (marginal)	17,191,162
4	North-central	IV	51,095	Quaternary unconsolidated sediment (plain); carbonate and terrigenous rocks (mountainous); basalt (locally)	15,830,784
5	South-central coastal region	V	44,245	Quaternary unconsolidated sediment (plain); terrigenous formations (mountainous); basalt (locally)	12,839,864
6	Central Highlands	VI	54,701	Basalt, terrigenous formations	18,009,388
7	Southern Plain	VII	44,789	Quaternary unconsolidated sediments; terrigenous rocks, basalt (Eastern)	25,486,080
	Total		**304,998***		**132,873,990**

** Not to mention the areas of the islands (Pham et al., 2005)*

Over the past five decades, the Viet Nam Geological Survey and Consultation Companies have been carrying out the exploration of groundwater in over 200 sites, mainly urban areas and important economic zones, with the developed reserves reaching the industrial categories (A+B) of nearly 2 million m^3/day, C_1 category=2.8 million m^3/day and C_2 category=18.5 million m^3/day. These are the insufficient synthetic data taken from reports on groundwater exploration serving the centralized water supply.

Nowadays, most groundwater (over 80%) is extracted for water supply. At present, the water source supply to Ha Noi City is almost from groundwater with the total abstraction of about 712,222 m^3/day (not including rural water supply and private production wells). In each region, there are updated statistical of Groundwater abstraction such as in North-West and North-East: 356,274 m^3/day, Red River Delta: 1,799,892 m^3/day (not including Ha Noi City), North Central coast: 201,984 m^3/day, South Central coast: 185.445 m^3/day, Central Highlands: 170.642 m^3/day, South-East: 268,346 m^3/day and Mekong River Delta: 483,759 m^3/day (not including Ho Chi Minh City with 1,270,700 m^3/day). The groundwater is used effectively also in agricultural production, especially in provinces in Central Highlands and in the South Eastern in the irrigation of industrial plantation crops.

4. Challenges

Viet Nam has been facing major challenges associated with contamination of groundwater resources by industries, agricultural pesticide and fertilizer, aquaculture activities, mining, and waste disposal. While no detailed scientific assessment has been undertaken, the areas most "vulnerable" to the effects of groundwater pollution and salt intrusion are places where the aquifers are unconfined, where there are many potential polluting activities, and where communities and cities are dependent on groundwater as the main source of drinking water supply. In many places, the groundwater shows signs of contamination of pollutants (such as Nitrogen, Arsenic, Heavy metals, Bacteria, Organic compounds) caused by households, industrial waste, the use of fertilizers and insecticides in agriculture.

The quality of groundwater in natural conditions is, in general, good, but in many places, the Fe and Mn contents are very high (especially, in the water in Quaternary deposits of the Red River and Mekong Plains), unfavorable for the water supply to livelihood and industry. According to the study results in recent years, the groundwater in many densely populated areas contains a high concentration of Arsenic and Ammonia, surpassing many times the maximal permissible concentration by National Standards. The current drinking water guidelines in Viet Nam are set at 10 µg As/L and at 1.5 mg NH4/L. Arsenic and Nitrogen contamination in groundwater in Red River Delta and Mekong River Delta is very severe due to anthropogenic and geogenic sources (Postma et al., 2012; Jenny et al., 2008). Some areas in Red River Delta and Mekong Delta, Arsenic concentration ranges from 27-264 µg/L. Groundwater heavy metal contamination is due to industrial activities and handicraft villages while pesticide and fertilizer contamination in groundwater is due to agricultural activities in rural area (Water Sector Review, 2017)

In Ha Noi, where the groundwater is most strongly withdrawn, there have been formed large cones of depression around pumped wells of some tens of meters deep (Phap Van, Ha Dinh, Mai Dich, etc. wellfields), that causes the land subsidence with the rate of some centimes and more by year.

Excessive groundwater pumping makes groundwater level decrease and consequently land subsidence. In Ha Noi and Mekong River Delta, this issue is happening at different level impacts. In inner Ha Noi area, there are 12 water plants with the total of 200 pumping wells. Total groundwater extraction flow is about 580,000 m^3/day. Since 1991, 10 land subsidence monitoring stations have been built by Ha Noi Institute of Technology and Economics of Construction. Land subsidence speed is high in some areas such as Thanh Cong

(41.02 mm/year), Ngo Si Lien (27.14 mm/year), Phap Van (22.02 mm/year), and low in some others such as Ngoc Ha (1.80 mm/year), Mai Dich (2.28 mm/year), Dong Anh (1.41 mm/year). In Ha Noi by InSAR analysis, land subsidence was from 30 cm to 80 cm (Tran et al., 2016). In Ca Mau peninsula, up to 2008, groundwater level has dropped from 10 m to 20 m. Land subsidence analysis showed that total subsidence might reach up 30-80 cm by the end of 2012 and the rate ranges from 3-7 cm/year (Karlsrud et al., 2016).

Viet Nam is considered as one of countries most affected by climate change and sea level rise. As a prediction (IMHEN, 2016) with a scenario of high emission (A1F1), sea level will rise up to 100 cm by the end of the year 2100. Extreme climate and sea level rise have been impacting salinization phenomena in coastal aquifers. Beside it, groundwater extraction although is in limited capacity, but in many places, it has been causing negative impacts, such as excessive lowering of water level, degradation of well discharge and consequently causes the saltwater intrusion in coastal aquifers. This impact is severe now in many coastal aquifers in Red river delta, Mekong River Delta and along the coastal line (Pham, 2017).

5. Conclusions

Over the past five decades of investigation, study and development on groundwater resources in Viet Nam, 26 water-bearing units in 7 regions have been identified. Characteristics of water-bearing units were also determined with different level. Some aquifers are very productive such as Pleistocene aquifers in the Red River Delta plain, Basaltic aquifer in the Central High land, Karstic aquifers in the North East and North West, Pleistocene and Neogene aquifers in the Southern plain. Groundwater resources are represented by potential reserves, classified by hydrogeological region. The total groundwater potential reserves in the country reach nearly 133 million m^3/day, which is 48.5 billion m^3/year. Groundwater resources are abstracted for many purposes such as drinking, manufacturing, irrigating and aquacultural cultivating especially in Red river plain, in Southern plain and in Central Highlands.

During groundwater abstraction, some challenges have been recognized such as groundwater contaminations of Nitrogen, Arsenic, etc. land subsidence in intensive pumping areas for example in Ha Noi, Ho Chi Minh City, Ca Mau Peninsula; groundwater salinization in coastal aquifers where there is about 3,260 km coastal line with developing areas and impacts from climate change and sea level rise. Some areas in Red River Delta and Mekong Delta, arsenic concentration ranges from 27-264 µg/L, which is over current drinking water standard in Viet Nam at 10 µg As/L. In Ha Noi by InSAR analysis, land subsidence was from 30 cm to 80 cm. In Ca Mau Peninsula, up to 2008, groundwater level has dropped from 10 m to 20 m. Land subsidence analysis showed that total subsidence might reach up 30-80 cm by the end of 2012 and the rate ranges from 3-7 cm/year. There is also severe salinization now in many coastal aquifers in Red river delta, Mekong River Delta and along the coastal line.

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