CURRENT SITUATION OF GROUNDWATER ABSTRACTION IN HANOI, VIETNAM FROM THE VIEWPOINT OF SUSTAINABILITY

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1. INTRODUCTION

Since the amount of groundwater abstraction has been rapidly and continuously increasing worldwide, achieving sustainable management of groundwater resources is one of the essential objectives for the future of developing countries like Vietnam, especially when the rising demand for clean drinking water is highly considered (Mende et al., 2007). In addition, annual cycle in groundwater levels associates with those in rainfall and river water levels, but long-term trends results from increasing groundwater withdrawal (Bui et al., 2012). The Vietnamese capital, Hanoi, is the target area addressing the sustainability issue of groundwater resources because: (i) the groundwater abstraction has been rapidly and continuously increasing and the demand for clean water is becoming rather urgent; (ii) the water supply significantly depends on this valuable resources (up to almost 100%) for three main purposes such as irrigation, domestic, and industrial uses; and (iii) the rapid exploitation of the groundwater without an appropriate management system has reportedly caused a series of adverse impacts such as drying up of shallow wells, decline of groundwater level locally and seriously, and land subsidence (Bui et al., 2012; Tong, 2008). The question is that groundwater abstraction is for a better lives, but how not to make the human activities harmful to our social- environmental conditions is also essential for sustainable development (Bui et al., 2011b) of the Capital.

Therefore, taking as much as possible the advantage of the historically scientific development of the area, this paper is going to at first (i) review a number of studies regarding to the relevant issues to have better understanding about of groundwater's estimated recharge and exploitable amounts in Hanoi; secondly (ii) estimate the total amount of groundwater abstraction for three main irrigation, domestic, and industrial purposes based on The Scientific Research No.TNMT.02.33 of Ministry of Natural Resources and Environment of Vietnam; and finally (iii) value two sustainability indicators suggested by UNESCO (UNESCO, 2007) in order to provide us the general sustainability view of groundwater abstraction situation for Hanoi development.

2. STUDY AREA

Hanoi area is around 3324.5 km^2 and includes 30 separated districts. The population of about 7,095,900 habitants in 2014 accounts for the highest population density in Vietnam. Hanoi belongs to the tropical monsoonal area with two distinctive seasons in the year, the rainy season from May to October and the dry season from November to April of the following year. The annual rainfall is about 1,550 mm of which rainfall in the rainy season accounts for about 70-80%. The average humidity is about 80%, and the average temperature is around 24.3^oC. Evaporation is quite high with an annual average of 933 mm (Tong, 2008).

Hanoi also has a dense river network and is mainly supported by Red River, one of two biggest river systems, with the basin areas of 155,000 km^2, approximately, and by several Red River-linked systems such as Nhue, Duong, Tolich, Cau, and Calo. There are also 111 lakes with the total surface of up to 2180 hectares and Westlake is the biggest with the area of 526 hectares, as showed in **Fig.1**. However, the rapidly economic development and fast socialization and urbanization have put pretty much pressure on the river basin environment. This surface water system is recently polluted by organic compounds, in which, the lakes especially in this study area are significantly polluted (Tong, 2008). That is the main reason why the groundwater resources have become main water supply for the local inhabitants.

3. FORMATION OF GROUNDWATER RESOURCES IN HANOI

Hanoi's groundwater resources mainly exist in the topmost Holocene unconfined aquifer (HUA) and the shallow Pleistocene confined aquifer (PCA), while cleft and karst water exists in the Neogene water bearing layer and the Mesozoic fractured zones (Bui et al., 2011a).

In HUA layer, silty clay and various kinds of sands mixed with gravels are the main components. The HUA thickness is variously distributed, more than 35 m with an average of 15 m, approximately. The transmissivity

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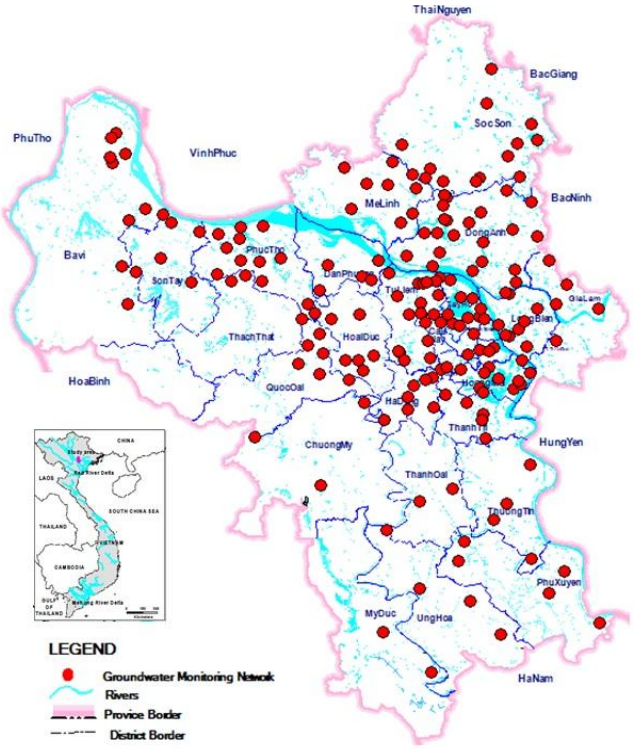

Fig.1 Study area, Groundwater and River Network.

and the specific yield of this layer ranges from 20 to 1,788 m^2/day and from 0.01 to 0.17, respectively. The HUA, thus, is distributed at a rate of about 55% in the south of the city area, and has a relatively high potential of groundwater resources, sufficient for the small to medium scale domestic water supply.

The shallow Pleistocene confined aquifer (PCA) depth is also widely distributed, less than 10m in the North of the Soc Son District, around 20m in Dong Anh District, and up to 40 m in the South of the Red River. The PCA layers have a complex components of sand mixed with cobbles and pebbles. Moreover, the PCA thickness is variously changed, with the highest value of up to 50m and the average of 35 m approximately and trend increasing from the North to the South. With a large range of transmissivity from 700 to 2,900 m^2/day, and the specific storativity from 0.00004 to 0.066, PCA is the highest potential of groundwater resources and widely distributed at a rate of about 80% in the south of the city, serving the most important aquifer for the area water supply (Bui et al., 2011a).

4. RESULTS AND DISCUSSIONS

(1) Groundwater recharge in Hanoi

The term "*recharge*" has been defined as "*as the downward flow of water reaching the water table, adding to groundwater storage*" in the book of "*Estimating Groundwater Recharge*" (Richard, 2010). The author mentions that the definition does not include water flow to an aquifer from adjoining groundwater system such as water movement from an unconfined aquifer to an underlying aquifer. This paper, thus, considers the recharge to Hanoi groundwater resource is the same as recharge to the HUA from precipitation.

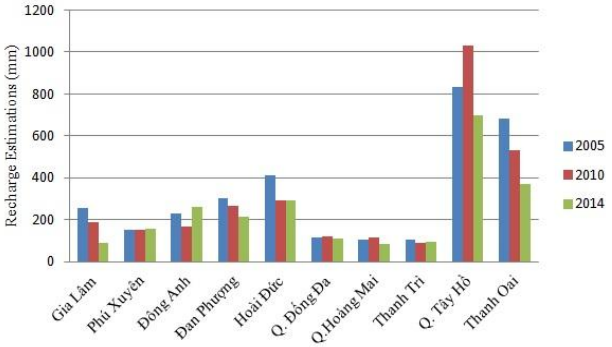

Fig.2 Recharges in 2005, 2010, and 2014.

Based on the data from national water resource monitoring and investigation projects of National Center of Water Recourses Planning and Investigation in period of (1995-2014), the recharge amounts is various from region to region with the minimum of 85 mm/year (at monitoring no.Q65 in Hoang Mai District in 2014) and the maximum of 1,028.52 mm/year (at monitoring no.Q67 in Tay Ho District in 2010). The average recharge estimation for Hanoi is about 276 mm/year (**Fig.2**).

Average groundwater recharge =

$= 276[mm/year] \times 10^{-6}[km/mm] \times 3324.5[km^2]$

$\approx 917{,}562 \times 10^{-6}\ [km^3/year]$

$= 917{,}562{,}000[m^3/year]$

(2) Exploitable groundwater resources

The term "*exploitable*" means the amount of water that can be annually abstracted from a given aquifer under current socio-economic constraints, political priorities and ecological conditions (UNESCO, 2007). The latest estimation is carried out by The National Center of Water Recourses Planning and Investigation in 2015. The amount of 6,199,140m^3/day, combines natural dynamic storage, elastic static storage, a part of gravitational static storage, and the entrained storage, as the following formula:

$$Q_{kt} = Q_{tn} + \frac{Q_{dh}}{t} + \frac{\alpha V_{tl}}{t} + Q_{ct} \qquad (1)$$

where:

Q_{kt}: the exploitable groundwater resources, m^3/day

Q_{tn}: the natural dynamic storage, m^3/day

V_{dh}: the elastic static storage, m^3

V_{tl}: the gravitational static storage, m^3

Q_{ct}: the entrained storage, m^3

α: the coefficient associating with natural and gravity static storage, %

t: exploitation time, 27 years (10^4 days) as usual.

(3) Groundwater abstraction

The amount of groundwater abstraction for different uses such as agricultural, industrial and domestic uses, have been reported by Scientific Research No.TNMT.02.33 of Ministry of Resources and Environment (NAWAPI, 2015) (**Table 1)**.

Table 1 Hanoi Groundwater Abstractions (*Sources:* The Scientific Research of MONRE, No.TNMT.02.33) (NAWAPI, 2015)

Group 1. List of abstraction amounts from The Groundwater Supply Companies

No	The public exploitation wells managed by 25 Clean Water Supply Companies (Group 1)	Abstraction (m^3/day)	Note
1	Mai dịch	55,000	Currently exploited
2	Ngọc Hà	43,000	Currently exploited
3	Ngô Sĩ Liên	45,000	Currently exploited
4	Pháp Vân	26,000	Currently exploited
5	Tương Mai	26,000	Currently exploited
6	Lương Yên	62,000	Currently exploited
7	Yên Phụ	80,000	Currently exploited
8	Hạ Đình	27,000	Currently exploited
9	Hà Đông	48,500	Currently exploited
10	12 trạm cấp nước khác	66,200	Currently exploited
11	Cáo Đỉnh	30,000	Currently exploited
12	Nam Dư Thượng	30,000	Currently exploited
13	Thượng Cát	30,000	Currently exploited
14	Bắc Thăng Long	60,500	Currently exploited
15	Long Biên	60,500	Currently exploited
26	Đông Anh	15,500	Currently exploited
17	Sóc Sơn 1	20,700	Currently exploited
18	Sóc Sơn 2	14,200	Currently exploited
19	Sóc Sơn 3	9,000	Currently exploited
20	Mai Lâm	51,000	Currently exploited
21	Gia Lâm	36,000	Currently exploited
22	Sài Đồng	13,700	Currently exploited
23	Giang Biên	60,500	Currently exploited
24	An Khánh	15,500	Currently exploited
25	Phù Đổng	51,800	Currently exploited
Abstraction by Group 1		977,600	Currently exploited

Group 2. List of main groundwater abstraction locations

No	The private exploitation wells managed by Institutes, Schools, small factories, and so on (Group 2)		Abstraction (m^3/day)	Note
1	Xí nghiệp thuốc thú y		650	
2	Trung tâm 75		320	
3	Sơn Cầu Diễn		240	
5	Nhà máy in quân đội		100	
6	XN. A34 QC Phòng không		180	
7	Ướp lạnh Cầu Diễn		640	
8	Liên đoan 10		120	
9	NM Bộ tư lệnh Thông tin		330	
10	XN bê tông XL Bưu điện		150	
11	Viện hoá CN cầu Diễn		360	
12	Công ty giống gia súcCầu Diễn		120	
13	NM gạch Hữu Hưng		375	
14	Trung đoàn 220		120	
15	TT thể dục thể thao Nhổn		240	
16	Đơn vị 144		120	
17	Đơn vị 2910		240	
18	Trường ĐH NN Quân đội		120	
19	Viện công nghệ CN QP-KT		210	
20	Viện bảo vệ thực vật		288	
21	Trường ĐH Cảnh sát		240	
22	CT sản xuất bao bì		180	
23	TrườngĐH Mỏ-Địa chất (K.B)		400	
24	XN LH hoá chất		180	
25	Trại giam Hà Nội		400	
26	Trường ĐH Mỏ-Địa Chất(K.A)		500	
27	Cục Hậu cần- Tổng cục 2		1,040	
28	Đại học Tài Chính		400	
29	Ct dịch vụ giống gia cầm		480	
30	NM Sợi Hà Nội	G1	1,600	
		G2	1,600	
		G3	4,800	
		G4	1,600	
31	Công ty Bia Hà Nội	G1	840	
		G2	840	
		G3	840	
		G4	2,400	
32	Công ty cao su sao vàng	G1	1,440	
		G2	1,440	
		G3	4,800	
		G4	1,200	
33	Viện Địa chất khoáng sản		150	
34	Công ty xà phòng Hà Nội		700	
35	Trường nội trú Ng. Viết Xuân		180	
36	Viện Y học dân tộc Q.Đội	G1	90	
		G2	300	
37	Nhà máy pin Văn Điển	G3	4,800	
		G4	4,800	
38	Bệnh viện y học dân tộc		240	
39	Xí nghiệp khảo sát điện 1		120	
40	Nhà máy bê tông Thịnh Liệt		210	
41	NM cơ khí xây dựng L.Minh		160	
42	XN. ôtô 210		250	
43	Nhà máy chế tạo biến thế		210	
44	Nhà máy sành sứ Thanh Trì		400	
45	Nhà máy giày da xuất khẩu		160	
46	Viện điều tra quy hoạch LN		480	
47	Others		43,553	
	Abstraction by Group 2		88,946	

Group 3. Household wells in the rural areas

No	Districts	Number of Wells for Residents in Rural Areas (Group 3)	Abstraction (m^3/day)
1	Ba Đình	NA	NA
2	Cầu Giấy	NA	NA
3	Đông Anh	NA	NA
4	Đống Đa	50,441	3,745
5	Gia Lâm	37,023	3,637
6	Hai Bà Trưng	NA	NA
7	Hoàn Kiếm	NA	NA
8	Hoàng Mai	12,937	1,847
9	Long Biên	13,512	620
10	Sóc Sơn	29,564	3,509
11	Tây Hồ	6,778	2,745
12	Thanh Trì	12,749	2,072
13	Thanh Xuân	1,868	557
14	North and South Từ Liêm	19,245	2,437
15	Ba Vì	55,278	79,007
16	Chương Mỹ	59,792	64,246
17	Đan Phượng	30,832	37,662
18	Hà Đông	NA	NA
19	Hoài Đức	7,528	8,405
20	Mê Linh	40,418	40,437
21	Mỹ Đức	34,826	42,451
22	Phú Xuyên	NA	NA
23	Phúc Thọ	34,945	60,659
24	Quốc Oai	39,265	4,439
25	Sơn Tây	156,982	196,342
26	Thạch Thất	38,458	39,803
27	Thanh Oai	3,771	44,903
28	Thường Tín	35,303	43,689
29	Ứng Hòa	38,203	49,804
Abstraction by Group 3			733,016

Hanoi groundwater abstraction mainly includes (i) public exploitation wells managed by 25 Clean Water Supply Companies, (ii) private wells managed by approximately 47 schools, institutes, factories, small industries, communities, and so on, and (iii) 793,657 household wells. The sub-total groundwater abstraction estimations of group (i), (ii), and (iii) are 977,600 m^3/day, 88,946 m^3/day, and 733,016 m^3/day, respectively.

Total groundwater abstraction is:

= 977,600 + 88,946 + 733,016

= 1,799,562 [m^3/day]

The percentages of the abstraction with respect to the recharge and exploitable are calculated. According to the classification of the Groundwater Indicators Working Group (UNESCO, 2007), the percentage of abstraction with respect to the exploitable is falling into the first scenario of less than 90%. The percentage of 29% shows that the groundwater resource is '*underdeveloped*' and the use could probably be further developed. The result also shows that Hanoi Capital still has a substantial potential in groundwater exploitation. There is a definite need to improve economic performance in groundwater investigation and exploitation for the Capital.

In addition, the other sustainability indicator is about 72%, less than 90%, also in the first scenario of the abstraction with respect to groundwater recharge presenting that the abstraction situation in Hanoi is generally toward sustainable development.

5. CONCLUSION

Groundwater abstraction situation in Hanoi is assessed in the viewpoint of sustainability by valuing two basic sustainability indicators. The results indicate that Hanoi groundwater development is toward sustainable in general and still has a potential on groundwater resources, which has not been utilized for the rapid expansion of the city. There is a basic need to comprehensively investigate with the purpose of having a well distributed monitoring network. The appropriately effective approaches and the high quality data available are needed for further research on sustainability assessment of groundwater resources.

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