Groundwater Pollution in the Hanoi Area, Vietnam

Dr. Nguyen Van Dan[1], *Ms. Nguyen Thi Dzung*[2]

Abstract

Water supply in Hanoi is mainly from groundwater. Exploitation of groundwater for domestic and industry use in Hanoi started in 1909. From an initial use of some 20,000 m^3 d^{-1} the volume of water extracted has steadily increased to over 500,000 m^3 d^{-1} at present. It is estimated that in 2010 the volume will be close to 1,000,000 m^3 d^{-1}. The pumping of large volumes of groundwater has negative impacts such as the lowering of the groundwater level, the enlargement of the cone of depression, land subsidence and groundwater pollution. Groundwater pollution in the general Hanoi area occurs in the two main aquifers, the Holocene aquifer and the Pleistocene aquifer, the latter being the main production aquifer. The pollutants are nitrogen compounds, biological and organic matter and toxic elements such as arsenic and mercury. Pollution by nitrogen compounds has been studied since the 1990's. The results show that the main contaminant is ammonia. The polluted area and the concentration of pollutants increase with time.

Introduction

Hanoi is located in the Red River delta it has an area of 900 km^2, 7 urban districts and 5 sub-urban districts and a population of 2.7 million inhabitants. Most of the Hanoi area is flat with elevations below 20m, but in the north the Tam Dao hills are up to 462 m high. Annual rainfall in the Hanoi area is 1600mm. The rainy season from May to October accounts for 85% of annual rainfall. The Red River is the largest river in the northern part of Vietnam. It passes through Hanoi and in the center of the city is joined by the Duong River. The average volume of water transported by these two rivers through Hanoi is 3500 m^3 s^{-1}.

Groundwater resources in the Hanoi area

Most of the groundwater under the Hanoi plain is contained in quaternary sediments, in two main aquifers. The Holocene aquifer or upper aquifer is distributed widely over an area of 530km^2. The upper part consists of clayey and sandy layers and has a thickness of up to 10 m. The lower part is made up of various sands, at times mixed with gravel. The average thickness of the aquifer is between 9.2m in the north and 13.3m in the south of the Red River delta area.

The transmissivity for the Holocene aquifer is from 20 to 800 m^3 d^{-1}. The water level is in general 3-4m below the surface however in the south of the Red River the water level is lower due to groundwater pumping. The specific capacity in test wells is from small to 4.5 l s^{-1}. The recharge sources are rainfall, irrigation and river water. Groundwater losses occur through discharge into the river in the dry season and through evaporation and percolation into lower aquifers. The groundwater is fresh the TDS, mainly calcium carbonate is below

[1] Hydrogeology & Geological Engineering Div., Dept. of Geology & Minerals of Viet Nam, Ministry of Natural Resources & Environment, Hanoi, Vietnam.
[2] Department of Geology & Minerals of Viet Nam, Ministry of Natural Resources & Environment, Hanoi, Vietnam.

0.5 g l^{-1}. The iron concentration in most areas is between 0.4 to 10 mg l^{-1}, manganese is from 0.2 to 2.0 mg l^{-1}, ammonia is from very low to very high in the south of the city. In the Thanh Tri district this concentration can go up to100 mg l^{-1}. The Holocene aquifer is sufficient for small-scale water supply. Producing groundwater from this aquifer is done by dug wells and small diameter shallow wells.

The Pleistocene aquifer is situated lower in the stratigraphic sequence. The depth to the top of this aquifer is 2-10m in the north, 5-22m in Gia Lam and 10-35m in the south. There is a weakly permeable layer between the upper aquifer and the lower aquifer. Between the Red and Duong rivers this layer thins out so that the two aquifers are overlying each other directly creating a "hydrogeological window". The Pleistocene aquifer is made up of sand mixed with cobbles and pebbles and has a thickness of 10-35m. The transmissivity is from 200 to 1600 m^3 d^{-1}. The specific capacity in the tested wells in most cases is over 1 l s^{-1}. The aquifer has a significant potential for the supply of groundwater. The groundwater is fresh, the TDS, mainly calcium carbonate, is up to 0.78 g l^{-1}. The iron concentration is high from 0.4 to 50 mg l^{-1}, the manganese concentration ranges from 1.0 mg l^{-1} to 4-5 mg l^{-1}. Ammonia concentration in the Thanh Tri district, in the South of city is very high with an area of 80 km^2 having over 10 mg l^{-1}. The lower aquifer has been used for the main water supply of Hanoi since the beginning of the last century. Groundwater pumping from the wells at Yen Phu began in 1909. Since then the amount of groundwater pumped has been increasing with time, from 20,000 m^3 d^{-1} in 1954 to the present rate of well over 500,000 m^3 d^{-1}.

Water supply for domestic purposes and drinking and for industry and manufacturing is mainly derived from groundwater. Public groundwater supply is managed by Clean Water Business Companies. Water is drawn from 10 well fields and other small stations from a total of 150 wells approximately. The average daily withdrawal from these wells is 420,000 m^3. The whole volume is drawn from the lower aquifer. Companies, economic units and organizations (Schools, hospitals, institutes.), also withdraw groundwater. This is done from about 500 wells drilled into the lower aquifer with an approximate production of 150,000 m^3 d^{-1}. Rural groundwater is produced from shallow small diameter wells pumping water from the upper aquifer. The treatment and extraction equipment in use is very basic. The number of these wells is increasing with time. In 1999, 150,000 m^3 d^{-1} was produced from 150,000 rural wells. The demand for drinking water and for water for domestic uses is increasing. According to the Water Master Plan for Hanoi this demand may reach 700,000 m^3 d^{-1} in 2010 and 1,400,000 m^3 d^{-1} in 2020.

Negative impacts caused by groundwater pumping

Most production wells' capacities are designed on the basis of exploration results. But some private wells are drilled randomly, therefore groundwater pumping will have some negative impacts such as land-subsidence, the lowering of the water table and pollution.

Land subsidence

The study of land subsidence in the Hanoi area is still preliminary, but land subsidence has been discovered. In 1988, the Hydrogeological and Engineering Geological Division No 2 constructed 32 benchmarks South of the Red River for the measurement of land subsidence. From 1991 to 1995 the Transportation Public Work Service managed these benchmarks with sponsorship from the Finnish Government, and added 13 benchmarks. The results of the studies in the period 1988-1995 show that most of the urban area and its vicinity suffer from land subsidence. The highest land subsidence of over 10 mm yr^{-1} is in the center and to the South of Hanoi city. The rate of land subsidence is highest in Giang Vo – Thanh Cong and Phap Van with a value of 20-44 mm yr^{-1}. Since 1997 the Institute for Technical Science and Construction has been studying land subsidence at 6 stations in and around Hanoi with similar results. From the results some conclusions can be drawn as follows;

- Areas from where large volumes of groundwater are withdrawn, and which are underlain by weak, soft strata (mud, peat, organic matter) have the highest rate of land subsidence.
- Land subsidence velocity is reduced with time.
- The reasons for land subsidence can be many, but groundwater pumping is the main reason.

Lowering of the groundwater level

Intensive pumping of groundwater has affected the groundwater equilibrium, especially south of the Red River. The cones of depression beneath the city and in surrounding areas have become very large, with the largest cone having an elliptic cross section of which the long axis extends from Co Nghue to Ngoc Hoi and the shorter axis, perpendicular to the Red River, from Ha Dong to Yen Phu. In this large cone there are many smaller cones, reflecting the location of the well fields. The cones of depression exhibit several different levels of intensity between areas where the water table is almost at 0 meters and areas where the drawdown is at –14 meters. Not only the size of the cone of depression grows over time, the drawdown itself becomes larger over time. This is not so much in evidence near the Red River itself, as the aquifers get replenished there, but away from the direct influence of the river, water table levels of –32 meters have been measured.

Groundwater pollution

The groundwater pollution in Hanoi has been studied over a long time, but those studies have not been systematic and the results are not yet complete. However some conclusions can be drawn from the results available. Nitrogen compounds, organic and bacterial matter and pollution by heavy metals have been studied at different levels.

Groundwater pollution caused by Nitrogen compounds

Pollution of groundwater by nitrogen compounds in the southern part of Hanoi, has been studied by the Northern Hydrogeological Engineering Geological Division since the early 1990s. Water samples were taken twice per year once each in the dry and rainy seasons. The studied nitrogen components are NH_4^+, NO_2^- and NO_3^-. Table 1 below shows the standard limits (STLs) that were applied for the degree of pollution of groundwater by nitrogen compounds.

Table 1. Standard limits for the degree of pollution of groundwater by nitrogen components.

Compound	STL for drinking water, mg l^{-1}	Degrees of pollution, mg l^{-1}			
		Clean	Light pollution	Moderate pollution	Serious pollution
NH_4^+	3	<0.5	0.5-3	3-10	>10
NO_2^-	0.1	<0.1	0.1-0.5	0.5-1	>1
NO_3^-	5	<5	5-10	10-50	>50

The results of the studies show that there is serious ammonia pollution of groundwater. The concentrations of this compound are high and are increasing over time; they are distributed over a large area. Nitrite and nitrate are rarely found in elevated concentrations. Table 2 below illustrates the results obtained for ammonia over the years.

These results show that the average ammonia concentration in groundwater is higher than the standard limit for drinking water. The ammonia concentration in the upper aquifer is higher than in the lower aquifer, indicating that the pollutants migrate downward. In addition, the ammonia concentration in both aquifers is increasing with time. Further, the ammonia concentration in the upper aquifer is changing strongly with time, influenced directly by the sources of pollution and by climate factors. The lower aquifer does not show such variation. The northern part of the city does not show similar ammonia pollution.

Table 2. Ammonia concentration in groundwater in the south of the Red River 1992-2002

Year	Season	Holocene aquifer (qh)			Pleistocene aquifer (qp)		
		No of samples	Concentration, mg l^{-1}		No of samples	Concentration, mg l^{-1}	
			Max	Average		Max	Average
1992	Dry	41	58.1	7.1	43	58.1	4.2
	Rainy	42	64.5	8.7	46	51.6	4.7
1993	Dry	42	34.6	5.2	43	24.2	4.4
	Rainy	45	48.4	5.1	48	19.3	4.1
1994	Dry	43	84.7	7.6	48	33.6	5.1
	Rainy	49	51.7	4.3	51	17.4	3.7
1995	Dry						
	Rainy	50	100.0	11.9	52	80.0	7.4
1996	Dry						
	Rainy	40	128.0	16.8	47	128.0	7.6
1998	Dry	30	144.0	11.1	42	100.0	8.9
	Rainy	27	151.5	11.2	42	42.0	8.5
1999	Dry	31	168.0	16.1	42	44.0	8.7
	Rainy	29	157.2	16.2	40	45.5	9.3
2000	Dry	31	178.0	18.7	41	50.4	7.5
	Rainy	27	118.0	14.7	39	30.5	6.9
2001	Dry	36	204.0	14.6	18	32.0	7.5
	Rainy	38	56.4	8.1	37	39.2	5.2
2002	Dry	34	92.4	16.9	46	72.4	11.1
	Rainy	32	135.2	17.5	47	64.0	9.54

Groundwater pollution caused by organic matter.

Total organic matter content is studied at the same time as the nitrogen compounds, by determining the level of oxidation. The results, in mg l^{-1} O_2, are presented in the Table 3.

Table 3. Oxidation of groundwater south of the Red River 1992-2002 (mg O_2 l^{-1})

Year	Season	Holocene aquifer (qh)			Pleistocene aquifer (qp)		
		No of samples	Concentration, mg l^{-1}		No of samples	Concentration, mg l^{-1}	
			Max	Average		Max	Average
1992	Dry	41	16	3.79	43	11.36	2.7
	Rainy	40	25.6	5.99	46	67.2	4.14
1993	Dry	42	13.44	3.98	43	10.88	2.56
	Rainy	45	21.12	4.46	48	12.8	3.71
1994	Dry	43	21.76	3.52	48	11.2	2.77
	Rainy	49	16.2	3.10	51	64	4.79
1995	Dry						
	Rainy	50	132	12.05	52	14.72	4.16
1996	Dry						
	Rainy	42	46.4	9.28	46	17.6	5.83
1998	Dry	30	26.6	9.10	41	20,8	7.22
	Rainy	26	31.6	8.91	41	24	7.89
1999	Dry	31	28.8	10.52	41	22.8	8.92
	Rainy	29	31.2	10.94	39	68	10.31
2000	Dry	31	33.2	9.16	41	31.2	8.32
	Rainy	27	31.6	10.05	39	34	9.07
2001	Dry	35	38.4	9.87	18	19.2	6.24
	Rainy	38	19	6.32	37	13.7	4.62
2002	Dry	34	21.84	7.24	46	14.32	5.49
	Rainy	32	23.2	7.26	47	13.2	4.76

These results are similar to the results for ammonia. The average value in groundwater is higher than standard limit for drinking water. The oxidation values in the upper aquifer are higher than in the lower aquifer indicating that the pollutants percolate from surface downward. The values are, in both aquifers, increasing with time. The polluted area is in the south of the city. Preliminary studies in 2000 by Pham Hung Viet of the Center for Chemistry and Environment of the University for Natural Sciences on concentrations of volatile organic substances - benzene, toluene, chloride derivatives - in groundwater are so far incomplete and inconclusive.

Groundwater pollution by microbes.

Microbe pollution by *coliform* (Standard limit 3 100ml^{-1}) and *fecal coliform* (Standard limit zero) was studied in 1993 by Do Trong Su of the Research Institute for Geology and Mineral Resources. The results are presented in Table 4.

Table 4. Microbe concentrations in groundwater in Hanoi area, 1993

Season	Holocene aquifer (qh)			Pleistocene aquifer (qp)		
	Number of study samples	Number of samples - higher value than standard	%	Number of study samples	Number of samples - higher value than standard	%
Dry	36	28	77	31	15	48
Rainy	14	7	50	20	9	45

These results indicate that microbe values in groundwater in both aquifers are higher than the standard limit. The groundwater in the upper aquifer is more seriously polluted than in the lower aquifer. Microbe pollution in the dry season is more intense than in the rainy season. The main microbe elements are *fecal coliforms*.

Groundwater pollution by heavy metals.

Heavy metal pollution has been studied, though not yet in a very coherent manner. To date the best results are available for arsenic contamination. In 1994 relatively high arsenic concentrations were reported from the Hanoi area and in 1999 from Hai Ba Trung district. Subsequently UNICEF sponsored a study on arsenic levels in production wells. The results showed that 25% of the collected samples had concentrations of arsenic that were higher than the standard limit. A later study of arsenic in groundwater, also sponsored by UNICEF, was executed by the Northern Hydrogeological Engineering Geological Division. A large number of samples was collected from locations all over Hanoi in the dry season of 2000 and in the wet season of 2001 (Table 5). The results indicate that in the north of the Red River and the Duong River in Soc Son and Dong Anh districts the samples are taken only in the lower aquifer. The number of samples having a concentration higher than the STL is small. In the south of the Red River and the Duong River, 1.8 to 59.7% of samples have As concentrations higher than STL. In the Gia Lam area, the number of samples having an As concentration greater than STL in the upper aquifer is larger than in the lower aquifer while in the Tu Liem district, this is the other way around and in Thanh Tri and in the urban area the degree of As pollution in both aquifers is the same. In all study areas groundwater is heavier polluted in the dry season than in the rainy season.

Table 5. Arsenic in groundwater, Hanoi area.

Area	Holocene aquifer		Pleistocene aquifer		Max. value mg l^{-1}
	Dry season 2000	Rainy season 2001	Dry season 2000	Rainy season 2001	
Dong Anh					
No. of samples			78		0.105
No. of samples with concentration > STL			6		
Percentage %			7.7		
Soc Son					
No. of samples			37		0.196
No. of samples with concentration > STL			1		
Percentage %			2.7		
Gia Lam					
No. of samples	20	19	72	72	0.274
No. of samples with concentration > STL	8	2	13	2	
Percentage %	40	10.5	18.1	2.8	
Thanh Tri					
No. of samples	72	72	24	23	0.292
No. of samples with concentration > STL	43	29	13	9	
Percentage %	59.5	40.3	54.2	39.1	
Tu Liem					
No. of samples	55	55	25	25	0.216
No. of samples with concentration > STL	8	1	9	3	
Percentage %	14.5	1.8	36	12	
Urban area					
No. of samples	47	46	42	43	0.331
No. of samples with concentration > STL	18	12	17	8	
Percentage %	38.3	26.1	39.5	19	

Summary

Intensive groundwater pumping can be a direct cause of pollution as it causes lowering of the groundwater table creating a cone of depression and a large hydraulic gradient. Environmental pollution in Hanoi is very serious. Domestic and industrial wastewaters are not treated and in most cases are allowed to flow untreated into the natural drainage. Landfill and large cemeteries in some areas can be sources for microbes, nitrogen and organic matter. This is considered the main reason for the serious ammonia and organic matter pollution in the South of Hanoi. The urban area has been over-drilled for groundwater and there has been exploitation of clay for the manufacture of bricks and tiles, big areas have been excavated for waste dumps, construction work is ongoing on a large scale. All these can be causes of pollution, especially pollution that will trickle downwards from the surface. Composition and origin of sediments can be causes of pollution. Organic matter in soils, mud, peat can be sources for nitrogen compounds. Fine sediments high in organic matter can be sources of arsenic pollution.

References

Vu Nhat Thang, Nguyen Van Dan et al 2001, Geology and Mineral Resources of the Hanoi Area. (Stored in Geological section)- Hanoi

Do Trong Su et al 1993. Assessment of groundwater pollution and proposed protection methods for groundwater resources in important areas of the Red River delta plain (Stored in Geological section)- Hanoi

Pham Hung Viet et al 2002. Groundwater quality in the Hanoi area (Conference on groundwater in the Ministry of Planning and Investment) – Hanoi

UNICEF Viet Nam 2002, Mitigating arsenic pollution in Vietnam (Conference on an action plan for arsenic problems – MARD) – Hanoi.