International Review for Environmental Strategies
Vol. 6, No. 2, pp. 361 – 372, 2006

Special Feature on Groundwater Management and Policy

Case Studies of Groundwater Pollution in Southeast Vietnam

N. P. Dan,[a] B. X. Thanh,[b] and B. D. Truong[c]

This paper focuses on issues of typical groundwater pollution caused by inadequate wastewater control systems in Vietnam, a common problem in many developing countries around the world. Two case studies are presented, one of industrial wastewater problems in the province of Tay Ninh, and the other of groundwater contamination by an unsanitary landfill in Ho Chi Minh City. Both cases have at least one thing in common: lack of impermeable liners to contain wastewater. Measures are proposed to deal with these problems and secure a safer water supply.

Keywords: Groundwater, Pollution, Industrial wastewater, Landfill, Aquifers.

1. Introduction

The main sources of water supply for cities and towns in Southeast Vietnam are the Sai Gon and Dong Nai rivers. Due to the fact, however, that the existing water supply network from surface water treatment plants is unable to meet current domestic and industrial demands, water supply is supplemented by groundwater resources in large areas of cities and towns, especially in the southeast. All residential areas and industries located in urban/rural fringe areas without piped water supply use groundwater. For example, the total amount of water use in Ho Chi Minh City is over 1,200,000 cubic meters per day (m^3/d), which includes 770,000 m^3/d from the Sai Gon/Dong Nai rivers and about 500,000 m^3/d from groundwater. An uncontrolled rate of groundwater exploitation in the developing cities and towns has resulted in a large drop in the water table, deteriorating water quality, and increasing land subsidence. At the same time, inadequate domestic and industrial wastewater control systems have contributed significantly to groundwater degradation. Typical problems with groundwater pollution can be seen in the province of Tay Ninh and in Ho Chi Minh City. This paper presents the results of studies of groundwater pollution in these two locations and proposes essential mitigation measures.

2. Case study: Groundwater pollution in Tay Ninh Province

Tay Ninh is a province in southeast Vietnam with an area of about 4,000 square kilometers that includes eight districts and one town. The eastern side of the province borders on the provinces of Binh

a. Department of Environmental Engineering, Ho Chi Minh City University of Technology, Vietnam.
b. Institute for Environment and Resources, National University of Ho Chi Minh City, Vietnam.
c. Institute for Environment and Resources, National University of Ho Chi Minh City, Vietnam.

Duong and Binh Phuoc, the southeast borders on Ho Chi Minh City and the province of Long An, and the west and northwest borders on Cambodia. Tay Ninh's terrain is relatively flat and its geographical location makes it favorable for the construction and development of basic infrastructure and industrial parks.

Tay Ninh has developed cultivation areas specialized in growing crops such as sugar cane, peanuts, and tapioca, which supply the raw materials for processing industries and for export. It has a population of about one million, with a significant proportion of young people (57 percent are of working age).[1] The main economic contributors in the province are agriculture, industrial crops (i.e., tapioca, rubber, and sugar cane), and processing industries.

The industrial crop processing industry has basically developed in Tay Ninh since 1995 and has rapidly expanded over the last few years. There are now 119 tapioca processing factories in the province, 15 of which have high production capacities ranging from 60 to 100 metric tons (tonnes [t]) of tapioca powder per day (t/d), while the small-scale ones range from 2–40 t/d of powder. The quantity of tapioca wastewater produced is about 4–15 cubic meters (m^3) per tonne of raw material processed. Thus, a medium- or large-scale facility with a capacity of 100–600 t/d discharges 800–1,000 m^3/d of wastewater.

All the factories are located in or nearby the farms where the crops are grown but far from any water distribution network. Therefore, most of them use large amounts of groundwater drawn from deep aquifers,[2] whereas nearby households draw groundwater for drinking and other domestic uses from shallow aquifers using dug wells (5–6 meters [m] deep) and boreholes (20–25 m deep) (GHUSV and DGMV 2004).

Most of the factories employ pond systems that do not have impermeable liners to treat their high organic content wastewater, which has resulted in the infiltration of wastewater into the shallow aquifer through the pond walls and bottoms. The subsequent decline of groundwater quality has caused many complaints from local residents in recent years, and they no longer use many of the shallow wells because of the foul-smelling, black water in them.

2.1. Methodology

Sample wells for this study were situated 20–500 m from the wastewater ponds of selected industries (medium-scale tapioca, sugar cane, and rubber processing factories). Control wells were selected where water quality was not expected to be influenced by wastewater and were based on two additional criteria: (1) they share the same aquifer, and (2) there were no complaints from nearby households about water quality. These were situated 1,000–1,500 m from the ponds, and all analyses were conducted using methods defined in *Standard Methods for the Examination of Water and Wastewater* (APHA et al. 1995).

1. Working age is 15–55 years and 15–60 years for females and males, respectively.
2. There are two deep aquifers used for water supply in Tay Ninh Province: the Holocen Aquifer (2–6 m deep) and the Upper-middle Pleistocen Aquifer (9–53 m deep).

2.2. Results

The survey showed that 90 percent of the tapioca processing factories in the survey area had wastewater stabilization ponds with no proper impermeable liners (HPDE sheets) in place. Most of these ponds were overloaded and the effluents did not meet Vietnam's effluent standards (see below). The others (10 percent) were mainly small-scale factories that did not have any wastewater treatment system at all, which discharged their wastewater directly into canals or earthen soaking pits. Most of these facilities had not obtained a business license from the local government.

The results of the survey of wastewater quality of five large-scale tapioca processing factories that employed a stabilization pond system are presented in table 1, which shows that 40–80 percent of biological oxygen demand (5 days at 20 degrees Celcius), or BOD5, was removed by the ponds. The effluent quality of all these facilities, however, did not meet Vietnam's industrial effluent standards. The BOD and total Kejdahl nitrogen (TKN) levels in the effluents from the stabilization ponds were still very high, although cyanide was significantly removed.

Table 1. Wastewater characteristics of five large-scale tapioca factories

Parameter	Factory 1		Factory 2		Factory 3		Factory 4		Factory 5		Vietnam's effluent standard
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	
pH	5.3	7.6	4.57	6.8	6.5	4.7	3.1	6.6	5.8	8.0	6–9
COD, mg/L	8,650	5,850	8,590	3,028	6,990	3,345	2,430	729	970	300	≤ 100
BOD_5 mg/L	5,800	3,500	5,900	1,700	4,600	2,100	1,600	430	620	105	≤ 50
BOD removal, %		39.7		71.2		54.3		73.1		83.1	
CN^-, mg/L	5.3	0.5	4.16	0.08	3.1	0.02	2.3	0.1	0.01	No data	≤ 0.1
TKN, mg/L	453	190	202	250	—	—	—	—	94	49	≤ 60
Total P, mg/L	0.39	—	17.5	3.8	—	—	—	—	7.4	4.19	≤ 10
SS, mg/L	2,010	700	3,880	7.5	1,075	690	—	—	340	175	≤ 50

Note: COD = chemical oxygen demand; BOD_5 = biological oxygen demand (5 days, 20°C); BOD = biological oxygen demand; CN^- = cyanide; TKN = total Kejdahl nitrogen; Total P = total phosphorous; SS = suspended solids; mg/L = milligrams per liter.

Tay Ninh Province also has three large-scale sugar cane processing factories, each with a capacity of 4,000 t/d of raw material. The one surveyed produced 6,500 m^3/d of wastewater, which was treated by a set of large stabilization ponds that had no impermeable liners. The characteristics of the raw wastewater and the treated effluent are shown in table 2.

The table shows that the stabilization ponds of the factory had a high level of wastewater treatment efficiency, but the COD and BOD levels of the effluent still did not meet Vietnam's effluent standards (COD ≤ 100 mg/L, BOD_5 ≤ 50 mg/L). The anaerobic ponds followed by facultative ponds had no impermeable liners in place, which caused groundwater pollution of nearby shallow wells.

Table 2. Wastewater characteristics of one sugar cane processing factory

Parameter	Influent	Effluent	Removal, %
pH	7.6	8.0	
COD, mg/L	9,050	380	95
BOD_5, mg/L	6,350	150	96
TKN, mg/L	65	15	77
Total P, mg/L	10	1.5	85
SS, mg/L	1,050	300	71

Eighteen wells that draw from the shallow aquifer, located about 1,000 m from the stabilization ponds of the various factories surveyed, were chosen as control wells because they might not be influenced by wastewater discharges. Table 3 shows that the water quality of all the control wells was suitable for domestic uses, because the levels of BOD_5, COD, TKN, ammonia-N, nitrite-N, and nitrate-N concentrations met Vietnam's drinking water quality standards. Only two wells contained high iron concentrations ranging from 0.3 to 1.6 mg/L, a little bit higher than the drinking water standard value of 0.3 mg/L. Note that low pH and relatively high levels of iron can be easily removed by simple aeration followed by filtration.

Table 3. Water quality of the control wells

Parameters	Value	Limit value
PH	5.95 ± 0.48	
Iron, mg/L	0.9 ± 0.7	0.3
Chloride, mg/L	17 ± 4	
NH_4-N, mg/L	No data	3
NO_3-N, mg/L	0.03 ± 0.03	10
COD, mg/L	0.8 ± 0.5	4
BOD_5, mg/L	0.1 ± 0.2	2
Total coliform, MPN/100mL	0	
CN^-, mg/L	Not detected	
Well depth, m	20 ± 10	

Note: MPN = most probable number.

In contrast to the study at the sugar cane factory, the water of 28 shallow wells (5–30 m deep) located 30–100 m from the tapioca processing factories surveyed contained 25–90 mg/L COD and 8–52 mg/L BOD_5. Residents had stopped using all these wells as a source of water for drinking and washing. Cyanide concentration, which is generally high in tapioca processing wastewater, ranged from 0.0018 to 0.003 mg/L, less than the limit value of the water quality standards. Thus, cyanide was effectively degraded under the ponds and in the soils. Nitrate-N (NO_3-N) was not detected in any of the wells, and the ammonia-N (NH_4-N) concentration was also very low (less than 1 mg/L), maybe due to nitrogen

uptake by bacteria living in the pond water and the soil. This is illustrated by the low BOD_5 to nitrogen ratio of the raw wastewater (BOD:N = 100:1).

Fifteen shallow wells (less than 30 m deep) neighboring the stabilization ponds of five rubber processing factories were also surveyed, and it was found that, as with the tapioca processing wastewater, the water in these wells was contaminated with organic matter. BOD and COD concentrations were 5–16 mg/L and 12–21 mg/L, respectively, but TKN concentration was low (0.4–1.0 mg/L as nitrogen).

A survey of four shallow wells (5–7 m deep) located near the stabilization ponds with no liners of two sugar cane processing factories showed that these wells were also polluted with organic matter. COD and BOD concentration was 14–20 mg/L and 25–30 mg/L, respectively.

Comparisons of the water quality of wells at various distances from the stabilization ponds of selected tapioca, rubber, and sugar cane processing factories in terms of COD and BOD_5 are shown in figures 1, 2, and 3, respectively.

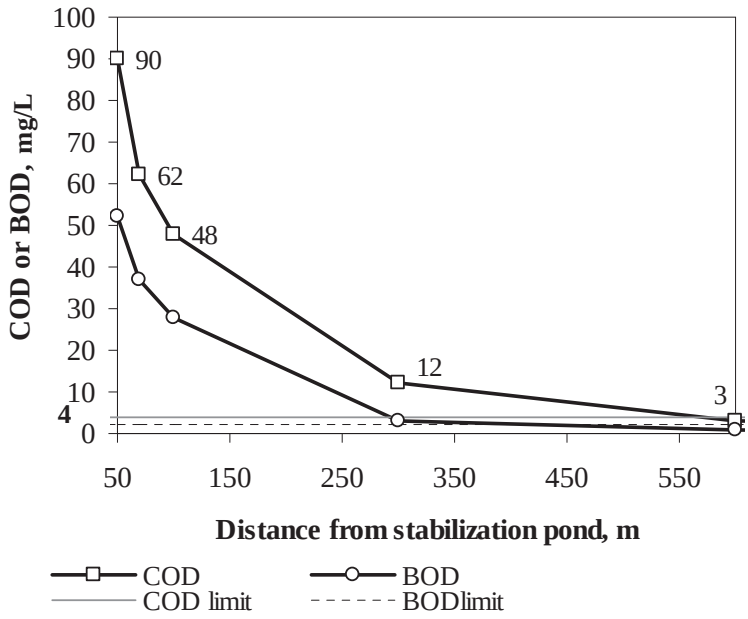


Figure 1. COD and BOD levels in wells at varying distances from the stabilization ponds of a tapioca processing factory

Figure 1 shows that most of the shallow wells located within 500 m of the unlined stabilization ponds of the tapioca processing factory were polluted with organic matter. COD concentration steeply declined within a distance of 100 m, but the wells at a distance of less than 600 m still showed evidence of contamination. The COD concentration of these wells was higher than allowed by Vietnam's

groundwater quality standards.[3] It was discovered, however, that there was less impact on the water quality of shallow wells by the sugar cane and rubber processing factories surveyed than by the tapioca processing factories.

Figures 2 and 3 show that the wells over 100 m and 200 m from the rubber and sugar cane processing factories, respectively, were not affected by wastewater. Of course, the area influenced by wastewater pollution depends significantly on the characteristics of the wastewater, the discharge flow rate from the factory, and the specific geological conditions of the survey area, etc.

In 2004, the provincial government of Tay Ninh made it a requirement that factories must upgrade their wastewater stabilization ponds by installing an impermeable liner, but not many have done this in the short term because of the huge cost. In fact, the government has allowed factories to use new boreholes into the deep aquifer to access water for their processing activities rather than using the water from already polluted wells.

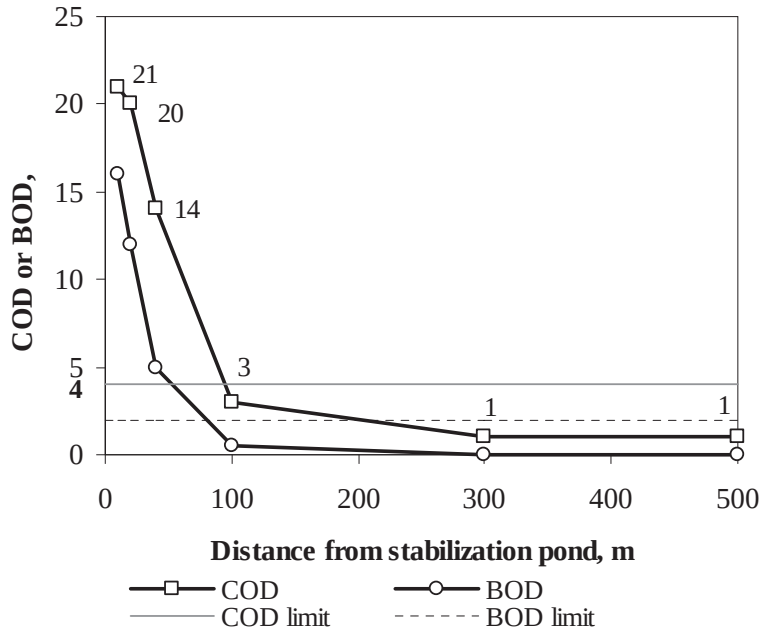


Figure 2. COD and BOD levels in wells at varying distances from the stabilization ponds of the Hiep Truong rubber processing factory

3. TCVN 5944:1995: Code name of Vietnam's underground water quality standards for water supply.

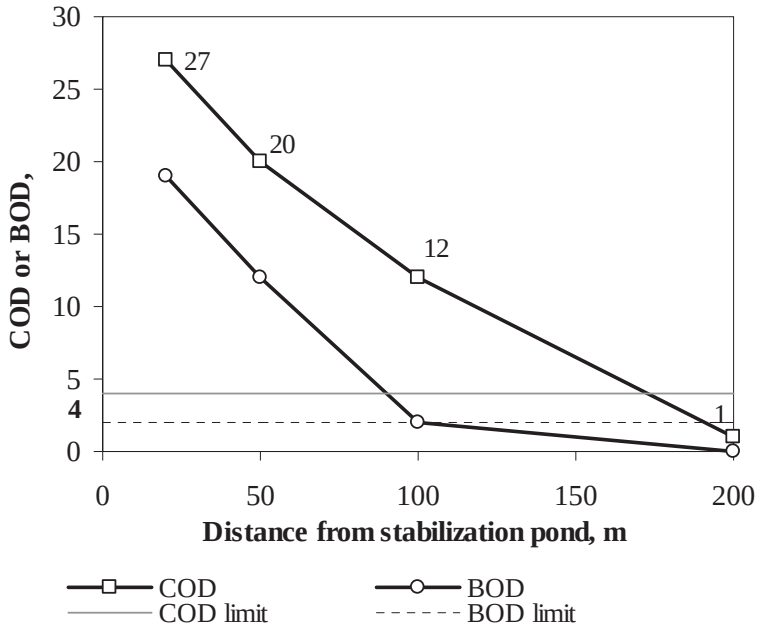


Figure 3. COD and BOD levels at varying distances from the stabilization ponds at the Bien Hoa sugar cane processing factory

3. Case study: Groundwater pollution caused by an unsanitary landfill in Ho Chi Minh City

The Dong Thanh open dumpsite is located in Ho Chi Minh City in the north of Hoc Mon District and borders the district of Cu Chi. It measures 43.5 hectares, and before it was closed its maximum capacity was 4,000 tonnes of solid waste per day and it generated about 600 m^3/d of leachate. It was closed completely in 2003 when it contained up to 6.5 million tonnes of dumped solid waste. Earthen ponds without impermeable liners were used to contain over 100,000 m^3 of leachate, but they caused a decline of water quality of shallow wells used by households near the landfill. Table 4 shows that the leachate contained high levels of organic matter and nitrogen concentration, which resulted in the contamination of shallow wells nearby with TOC and N-ammonia.[4]

4. Data presented in this section were collected from periodic reports on groundwater monitoring by the Ho Chi Minh City Environmental Protection Agency (HEPA), Geology and Hydrology Union for South Vietnam.

Table 4. Characteristics of leachate from the Dong Thanh dumpsite

Parameters	Unit	Value
pH		7.9–8.2
COD, mg/L	mg/L	1,079–2,507
BOD_5, mg/L	mg/L	735
SS, mg/L	mg/L	250
Org-N, mg/L	mg/L	196–470
NH_4-N, mg/L	mg/L	790–1,100
NO_3-N, mg/L	mg/L	2.5–2.9
Total P, mg/L	mg/L	14.9–21.5
Hardness, mg/L	mg $CaCO_3$/L	2,000

Source: CENTEMA 2002.

Monitoring wells located over 1,000 m from the Dong Thanh landfill were used as control wells for the study. The pH of the water in the shallow control wells ranged from 5.3–6.3, and N-nitrite (NO_2^-) and N-ammonia concentrations were quite low, ranging from 0.004–0.288 mg/L of nitrate and from 0.18–0.74 mg/L of ammonia (figure 4). In general, the groundwater quality in Ho Chi Minh City was good in terms of NH_4^+, NO_2, NO_3^-, and met the TCVN 5501-1991 drinking water standard.[5] Table 5 shows the groundwater quality of the wells near the Dong Thanh dumpsite. It shows that, in comparison to the groundwater quality of the control wells, the wells near the landfill were contaminated with ammonia and TOC, which were 10.4–32 mg/L and 56–153 mg/L, respectively. This contamination was due to infiltration from the leachate ponds and landfill cells without impermeable liners.

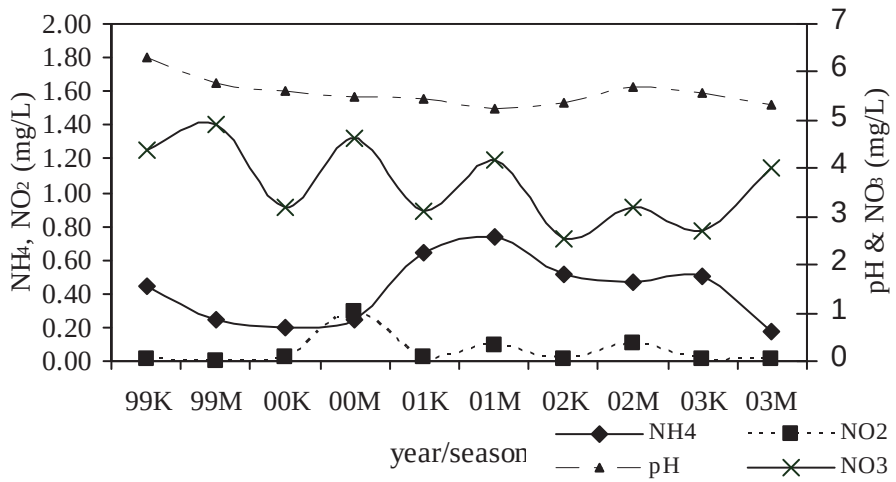


Figure 4. Variation of nitrogen and pH levels in the control wells over time, 1999–2003

Note: K = dry season; M = rainy season.

5. pH = 6–8.5; NH_4+ = 3 mg/L; NO_2– = 0.1 mg/L; NO_3– = 5 mg/L.

Table 5. Groundwater quality of wells near the Dong Thanh landfill, March and August 2004

Well depth	TDS, mg/L		NO_3^-, mg/L		NH_4^+, mg/L		TOC, mg/L	
	Mar. 2004	Aug. 2004	Mar. 2004	Aug. 2004	Mar. 2004	Aug. 2004	Mar. 2004	Aug. 2004
15–21 m	1,112	1,280	0.4	3.1	10.4	32	121	56
30–36 m	1,532	1,736	0.6	0.8	25	25	153	86

Note: TDS = total dissolved solids; TOC = total organic carbon.

Figures 5 and 6 show that the ammonia concentration of the monitoring wells near the Dong Thanh dumpsite was quite high in the year 2000, up to 155 mg/L in the shallow wells and 36 mg/L in the deep wells. The concentration of ammonia tended to decrease over time after the landfill was closed.

Figure 5. Variation of ammonia concentration over time in the deep aquifer at 15–21 m at the Dong Thanh landfill

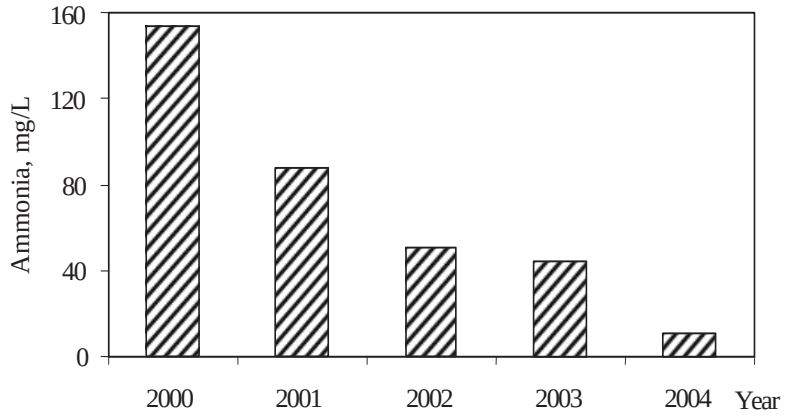
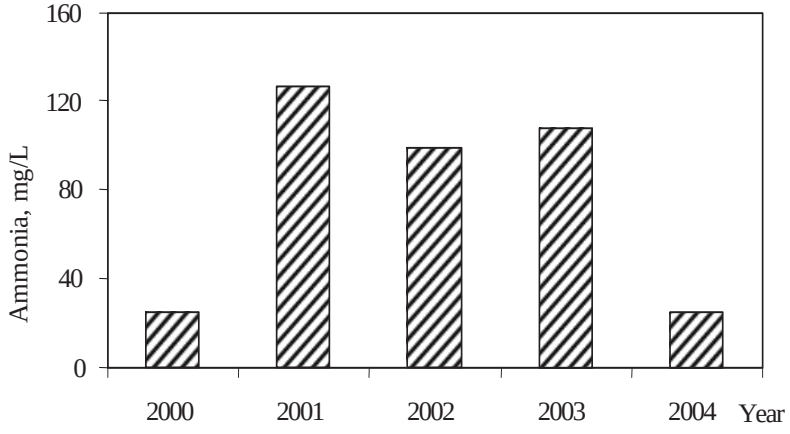


Figure 6. Variation of ammonia concentration over time in the deep aquifer at 30–36 m at the Dong Thanh Landfill



Figures 7 and 8 show that TOC contamination also occurred in the wells near the landfill site, where the TOC was about 20 times greater than that in the control wells.

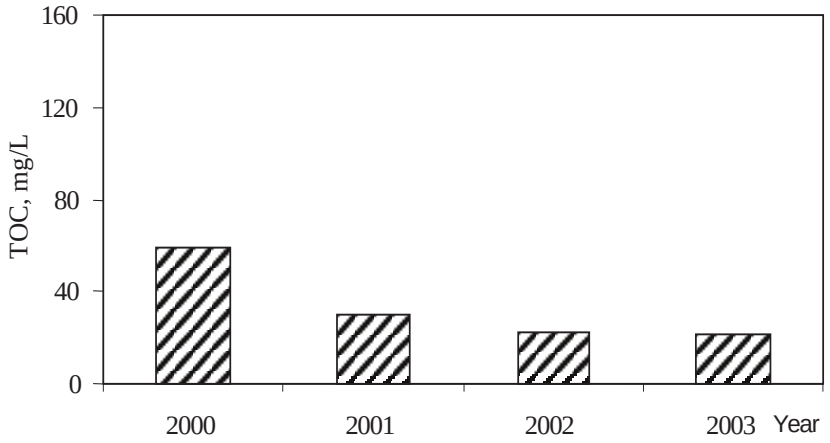


Figure 7. Variation of TOC over time in the deep aquifer at 15–21 m at the Dong Thanh Landfill

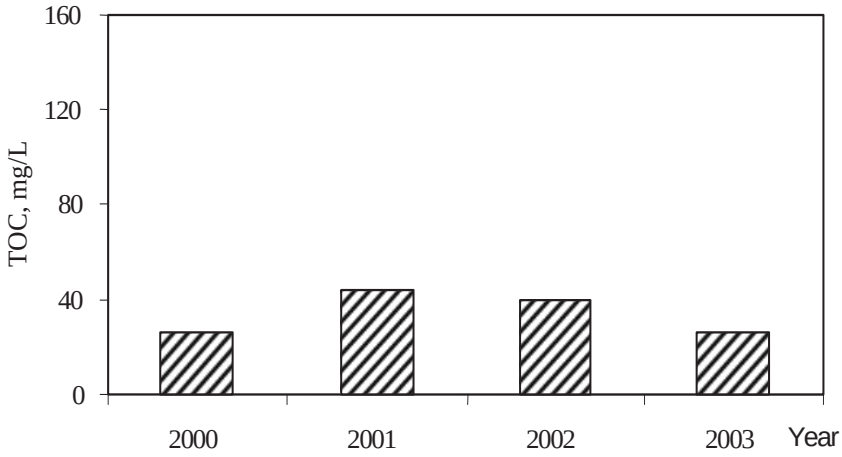


Figure 8. Variation of TOC over time in the deep aquifer at 30–36 m at the Dong Thanh Landfill

As occurred in Tay Ninh Province, the households near the landfill site stopped using groundwater and bought bottled water for drinking and cooking. Now most of them use tap water delivered through a distribution network installed by the water supply company in 2004.

Two landfills presently operating in Ho Chi Minh City—the Go Cat and Tam Tan landfills—(built in 2002) are sanitary landfills with impermeable liners. So far, no contamination of the monitoring wells has been detected (HEPA 2004).

4. Conclusion

The contamination of groundwater from stabilization ponds without impermeable liners is a serious issue worldwide. In the case of Tay Ninh Province, high COD and BOD concentrations were found in shallow wells near improperly constructed stabilization ponds used for treating the wastewater of tapioca, rubber, and sugar cane processing factories. Similarly, groundwater contamination with high ammonia and TOC concentrations was recorded in the wells surrounding the Dong Thanh landfill, where dumping cells and leachate ponds were not lined with impermeable materials.

At present, the Tay Ninh provincial government has no plans to deal with the contaminated aquifers due to the very high cost. In order to systematically protect the aquifers, however, the existing government requirement for factories to have impermeable liners surrounding stabilization ponds and sanitary landfills should be enforced for any present and planned projects.[6] Economic tools such as fines for non-compliance, national and international support funds, and tax reduction for investors should also be established and applied without delay.

Acknowledgements

The authors wish to thank the following research partners for data provision: Ho Chi Minh City Environmental Protection Agency (HEPA) and the Department of Science Technology and Environment (DoNRE) of Tay Ninh Province (which also provided financial support).

References

American Public Health Association (APHA), American Water Works Association (AWWA), and Water Pollution Control Federation (WPCF). 1995. *Standard methods for the examination of water and wastewater*. 18th ed. Washington, DC: APHA.

Center for Environmental Technology and Management (CENTEMA). 2002. Report on Go Cat Leachate Treatment Plant. Ho Chi Minh City: Department of Science Technology and Environment, Van Lang University.

Geology and Hydrology Union in the South of Vietnam (GHUSV) and Department of Geology and Minerals of Vietnam (DGMV). 2004. Report on "Groundwater monitoring in Ho Chi Minh City."

Ho Chi Minh City Environmental Protection Agency (HEPA) 2004. Ho Chi Minh City. Periodical report on groundwater monitoring in Ho Chi Minh City. Department of Natural Resources and Environment (DoNRE).

6. The government of Tay Ninh Province has not yet issued any regulation on fines for non-compliance with the order to use impermeable liners. It has only commented on this requirement in the EIA report on current and future projects.