Performance Evaluation of Septic Tanks as onsite Sanitation System

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Abstract

Onsite sanitation with septic tanks is popular in most of the Asian countries. The case study conducted in Hanoi and suburban area of Bangkok indicates that the septic tanks employed did not perform as required. The septic tanks just convert the suspended pollutants into dissolved form and release them to the environment due to insufficient maintenance. Thus the effluent from the septic tank is very high in COD, BOD, TKN, NH_4^+-N, PO_4^{-3} and suspended solids concentrations. Training on the operation and maintenance of septic tanks is essential if they are to be promoted as onsite sanitation systems. Community level septic tanks should be encouraged in order to facilitate post septic tank hybrid treatment systems to be installed in the future upgrades.

Keywords: Developing countries, effluent quality, onsite sanitation, septic tanks

1. Introduction

Developing countries always lack proper sanitation systems due to rapid urbanization. Decentralized onsite wastewater treatment systems could provide improvement on sanitary conditions in these countries. The simplest of such systems are septic tanks, which provide the first and very important pre-treatment. The quiescent condition inside the tank allows portion of suspended solids (SS) to settle and floatable solids to rise up and provides storage space for biological processes to occur. In some developing countries, septic tanks have become a required component in their sanitation system and appropriate authorities monitor the operation and maintenance of the septic tanks in order to manage the quality of the effluent. The effluent must meet the regional standards if discharged onto land or sewer systems (National Small Flows Clearinghouse, 2000). However, in some other developing countries, the septic tank effluent quality is not regulated and the effluent could be discharged into sewers or leached into ground. This causes serious environmental problems in those countries. The main objective of this study is to evaluate the current performance of onsite sanitation in some areas in Vietnam and Thailand in order to promote them as onsite sanitation system in developing countries.

2. Materials and Methods

In this study, the existing sewerage and sanitary system in Hanoi, Vietnam and septic tanks in Bangkok, Thailand were chosen for evaluation. The first part of the study was to collect data on the existing sanitary conditions in Hanoi. This is followed by monitoring the septic tanks in Klong 4, Pathumthani Province, Thailand. Grab samples of effluent from the septic tanks were collected to measure pH, COD, BOD, SS, NH_4^+-N, TKN and PO_4^{-3}. Analyses were conducted according to the standard methods for the examination for wastewater (APHA, AWWA, WPCF, 1998).

3. Results and Discussion

Hanoi sewerage and sanitation system

Hanoi is the capital of Vietnam with a total land area of about 927,380 km^2. Land is divided into agricultural practices (53.4%) and residential area (14%, one fifth of this is situated in urban areas). The population of Hanoi is 2.8 million and of which 1.5 million is in the urban areas. The population density is around 2,900 persons/km^2. The daily water production in Hanoi is around 600,000 to 650,000 m^3/d from nine large water treatment plants (30,000-80,000 m^3/d) and several small-scale water treatment plants (1,000 – 2,000 m^3/d). Besides, there are more than 100,000 household scale well supplying water. At present, there is about 70% of the population is served with clean water with an average consumption of 120 liters/capita/day (CERWASS, 2004). The total volume of the wastewater generated in Hanoi city is about 460,000 m^3/d.

In Hanoi, at present, single drainage system is used to collect both wastewater and storm water. This drainage system consists of rivers, canals, regulating ponds, ditches and pipes. Wastewater from domestic and other uses is discharged directly into open lakes or canals by ditches and pipes (Figure 1). The coverage of sewerage and drainage system in only about 40% of the city area (SADCO, 2003) and most part of the system is more than 100 years old. However, some parts of the system have been reconstructed or newly built by Hanoi Master Plan for sewerage and drainage project.

Hanoi has four main rivers To lich, Set, Lu and Kim nguu that are used to drain the wastewater from the city to the reservoir called Yen so. In recent years, many new drains and components have been built, especially a large system of regulating reservoirs and a pumping station to pump the wastewater directly to the Red river. Table 1 is providing the details of wastewater characteristics in selected sewer gates and canals in Hanoi.

Sanitation in Hanoi

Sanitation types in Hanoi comprises pit latrines, ventilated improved pit latrines (VIPs), single and double-vault urine-diverting toilets, pour-flush toilets with filtration pit and pour-flush toilets with septic tanks; wherein , septic tank is the most popular among all (Table 2). Since the effluent from septic tanks are directed to sewers, it is important to maintain the quality of the effluent from the septic tanks to prevent environmental pollution. Table 3 illustrates the quality of the influent and effluent of the septic tanks, which indicate that the septic tanks monitored were under performing. Almost all parameters of the effluent are higher than the Vietnamese standards stipulated for the septic tank effluents.

Figure 1 Untreated wastewater enters a canal (left); polluted canal (right)

Table 1 Wastewater characteristics in selected sewer gates and canals in Hanoi

Parameters	**Tran Binh Trong into Bay Mau Lake (SG)**	**Lo Duc into Kim Nguu River (SG)**	**Trung Tu into Lu river (SG)**	**Kim Lien (SG)**	**Hao Nam (C)**		**Khuong Thuong (C)**		**Thuy Khe (C)**	
pH	7.15	7.2	7.4	7.7	7.4	7.4	7.3	7.1	7.4	7.8
SS, mg/L	285	240	125	270	189	98	104	193	200	120
DO, mg/L	1.5	0.5	1.2	0.4	0.8	2.9	0.5	1.5	0.2	4.5
BOD_5, mg/L	85	180	46	250	180	60	135	135	156	54
COD, mg/L	182	329	72	315	256	89	1536	2080	358	102
NH_4^+, mg/L	20.2	30	12	45	20	8.6	29	26	18	6.8
PO_4^{-3}, mg/L	4.2	7.1	0.6	12.5	4.0	2.4	3.8	3.6	3.9	2.0
Cl^-, mg/L	71	125	105	105						
Coliform, MPN/100mL	5.1×10^3	1.1×10^4	6.1×10^3	1.4×10^5	5.6×10^6	3.2×10^5	1.7×10^6	1.2×10^5	1.5×10^6	8.5×10^4

Note: SG – Sewer Gate; C - Canal

At present, Institute of Standardized Construction and Ministry of Construction has promulgated a typical design for septic tank with two compartments (Table 4). This design includes 26 types of septic tanks for volumes ranging from 1.5 m^3 to 20 m^3. The first compartment, where the influent enters the septic tank is the largest (about 70% of the total volume), in order to retain almost all the solids that settles in it. The depth of water inside should not be lower than 0.75 m and should not exceed 1.8 m. The hydraulic retention time of the wastewater in the septic tank can be 1 to 3 days. Due to low velocity, almost all suspended solids will settle in the first compartment. The total solids removal efficiency can vary from 40 to 60% depending on proper operation and maintenance. The thickness of the scum layer formed on the top due to escaping gases such as methane and hydrogen sulphide, is around 0.3 to 0.5 m. Eighty per cent of the settled sludge is drawn from the first compartment once in every 1 to 2 years of operation.

According to Vietnamese standard (TCXD 51, 1984), if the volume of the septic tank exceeds 25 m^3, then multiple tanks should be constructed.

Table 2 Sanitation facilities in urban areas of Hanoi (CERWASS, 2004)

Types of on-site sanitation	**Ratio (%)**			
	1995	1998	1999	2000
Septic tank	54	56	63	68.4
Pour- latrine	2	12	10.4	9.2
Double - vault toilet	20	12	4.7	4.9
Single - vault toilet	16	9	3.8	1.8
Public Toilet				
Single-vault toilet	4	2.4	0.5	-
Double - vault toilet	2	0.7	7.3	-
Septic tank	2	7.9	10.3	15.7

Table 3 Results from the survey conducted on septic tanks in Hanoi (Most, 2000)

Parameter	**Inlet**	**Outlet**	**Standard of Vietnam**
Temperature, ^oC	20.1 – 29.4	21.1 – 29.5	ND
pH	7.32 – 8.1	6.17 – 8.5	5 - 9
TDS, mg/L	412 – 652	381 – 637	500
SS, mg/L	380 – 767	86 – 812	50
BOD_5, mg/L	240 – 376	102 – 330	20
N-NH_4, mg/L	38 – 66	20 – 43	ND
N-NO_3^-, mg/L	0 - 1,2	0.01 – 2.9	30
P-PO_4^{3-}, mg/L	3.1 - 4.1	2.79 – 33.5	6
Total Coliform, MPN/100 mL	$1.4\times10^7 – 1.5\times10^8$	$7.3\times10^5 – 1.3\times10^7$	1×10^3

Table 4 Basic design dimensions of a septic tank

Volume (m^3)	**Dimensions (meters)**			
	Length of the first compartment	Length of the second compartment	Width	depth
2.0	2.4	0.9	0.9	1.0
2.5	2.6	1.0	1.0	1.0
3.0	2.2	1.1	1.1	1.1
5.0	2.4	1.2	1.2	1.2
10.0	3.0	1.5	1.5	1.5

Septic tank monitoring in Thailand

Klong 4 located about 50 km north of Bangkok, is a suburban area in Klong Luang, Pathumthani province. The total population of this site is 8235 and its livelihood is based on agricultural activities. Land is divided equally for agriculture and residences. Clean water supply system is available for the entire community and the inhabitants have sufficient clean water for domestic purposes. However, there is no sewer system draining the wastewater from households and the wastewater is discharged directly into canals or water bodies that are closer to the residences. All households have water sealed latrines. Most of them are pour-flush latrines connected to septic tanks, which are mostly circular with one (or two) compartment(s).

Normal operational mode (no sludge withdrawal)

Table 5 compares the septic tank effluent quality obtained from this study with the literature data. During this study phase, sludge was not withdrawn from the septic tanks.

Table 5 Comparison of septic tank effluent quality data

Parameters	This study	EPA, 2002	Van cuyk, 2001	Crites and Tchobanoglous, 1998	Zhang et al., 1996
pH	7.2 – 7.8	6.4 – 7.8	-	-	7.8
SS	150 – 500	40 - 350	69	40 -140	256
COD	300 – 1500	-	386	250 - 500	-
BOD_5	50 – 300	46 - 156	227	150 - 250	576
NH_4-N	150 – 600	-	47	30 - 50	462
TKN	200 – 700	19 - 53	57	50 - 90	-
Total PO_4^{3-}-P	15 – 50	7.2 - 17	4.6	12 -20	-

Note: all values are in mg/L except pH

Generally, pH and DO were measured as soon as the samples were taken from the septic tanks. The pH was in the range from 7.2 to 7.8 and pH values differed significantly from one sampling location to another due to different water usage habits of the users. The DO was lower than 0.5 mg/L due to anaerobic conditions prevailed in the closed septic tanks. SS values varied from 25 to 720 mg/L. However, the predominant values were in between 150 and 500 mg/L, which are higher than the values reported by Zhang et al. (1996). The tanks with high SS concentrations had hard and thick scum layers. This could be due to the improper operation including late withdrawal of sludge. The values of COD were 300 to 1500 mg/L. These are higher than the results reported by Van Cuyk et al. (2001) and Zhang et al. (1996). The values of BOD varied between 50 and 300 mg/L.

The highest value observed for TKN was 842 mg/L. However, almost all the values of COD were in the range between 200 and 700 mg/L. They are higher than 60 mg/L reported by Van Cuyk et al. (2001) and Crites and Tchobanoglous (1998).Ammonia content in the septic tank were also high. The highest and lowest values of ammonium nitrogen were 720 and 30 mg/L, respectively. The results indicate that the ammonium nitrogen concentration is 70 to 100 % of the TKN. The total phosphate was varying from 15 to 50 mg/L. These results were much higher than the results reported in the literature (Charles et al., 2005; EPA 2002; Van Cyuk et al., 2001). Water used to flush the pour-flush latrines contained phosphate detergents that led to high concentration and variation of phosphate in the effluents of the monitored septic tanks.

When compared the performance of septic tanks in Hanoi and Bangkok, it was found that the effluent quality of septic tanks was poor in both places. The effluents contained higher values of SS and BOD. Similar values and variations were found for BOD in both places. However, variations in pH and SS in the effluents of septic tanks in Hanoi were wider than that in Klong 4. In addition, SS in the septic tanks of Hanoi is quite high compared to the values observed from Klong 4 septic tanks. High concentrations of ammonia were found in the effluent of Klong 4 septic tanks and it varied widely. On the contrary, ammonia concentrations in the effluent of Hanoi septic tanks were low and varied within a small range. These differences in effluent quality may be due to different geometries used for the septic tanks in Hanoi and Klong 4. Also, the septic tanks in Hanoi have 2 compartments while the septic tanks in Klong 4 have only one. The type of latrine, amount of water used for each flushing and the quality of flushing water are the other factors that could affect the quality of the effluent from those septic tanks.

Sludge withdrawal model

Variation in pH before and after the withdrawal of sludge was not significant in the two septic tanks monitored in Klong 4. But after withdrawing the sludge the SS concentration decreased by 100 mg/L in both septic tanks. The decreasing trend continued up to 4 weeks; and after 8 weeks from the day of sludge withdrawal, the SS increased slightly in both tanks and varied by small amounts on the following weeks.

The COD did not change much after sludge withdrawal. It increased slightly after 2 weeks from the day of sludge withdrawal and then decreased in the following weeks. The BOD values before sludge withdrawal was lower and it took 8 weeks for the microorganisms to grow after the sludge withdrawal in order to reduce the BOD values in the effluent (Figure 2). Therefore, when cleaning the septic tanks, the sludge should not be removed 100% from them.

Figure 3 presents the variation of NH_4^+-N in the septic tank effluents. The concentrations were very high (above 350 mg/L) compared to the values observed in other studies (Table 5). Similarly, the TKN values were also high throughout the period of monitoring and the septic tanks did not remove TKN. After sludge withdrawal, phosphate concentrations in two septic tanks were lower than 20 mg/L. However, the phosphate concentration started to increase from 4 weeks after the sludge withdrawal.

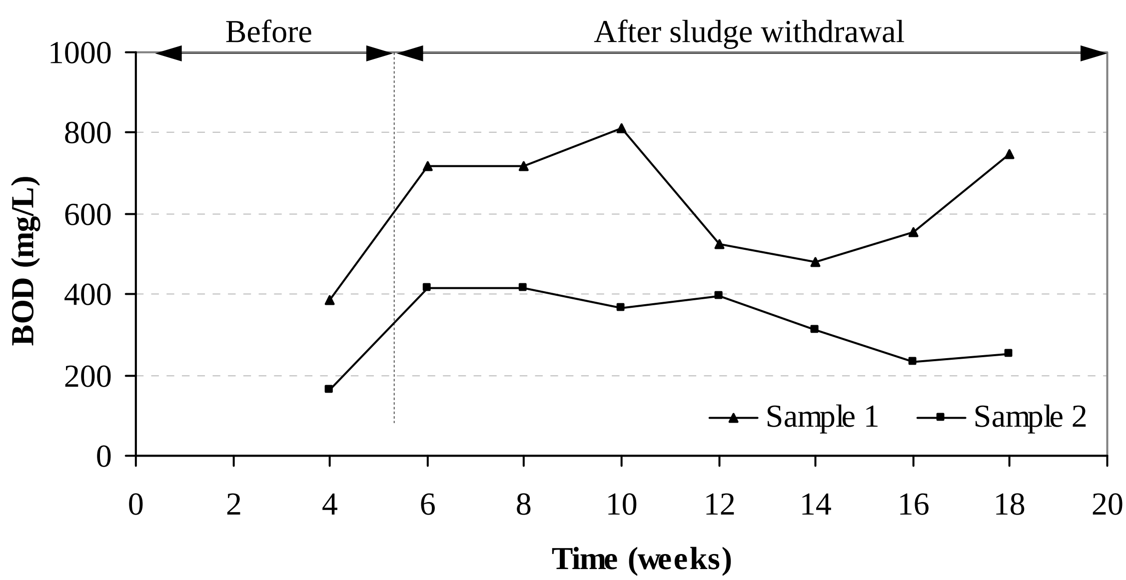

Figure 2 BOD concentration in the septic tank effluents (sample 1 is from septic tank 1 and sample 2 is from septic tank 2)

In order to compare and quantify the settleability of suspended solids in the septic tank with that in the raw wastewater, samples were taken from the physical plant of Asian Institute of Technology (domestic wastewater) and a Vietnamese Restaurant (septic tank effluent). Table 6 provides the SS concentration, particle size distribution in those samples along with specific resistances. It could be noticed that the raw wastewater and septic tank effluent were similar in terms of SS concentrations and the mean particle size of the raw wastewater was higher than that of the effluent from the septic tank. Thus, the septic tanks allow the particles above 50 μm to settle still letting the particles smaller than this size to escape. The better uniformity of particles was observed for the wastewater that is settled for 4 hours. Septic tank effluent did not show better uniformity when compared to domestic wastewater that is settled for 2, 3 and 4 hours. The specific resistance of septic tank effluent was twice as high as that of raw wastewater. It is possible that the septic tanks monitored in Hanoi and Klong 4 convert the parameters analyzed from solid phase to dissolved phase. Then due to insufficient retention time in the septic tanks, these pollutants are discharged with the septic tank effluents without any removal occurring in the septic tanks.

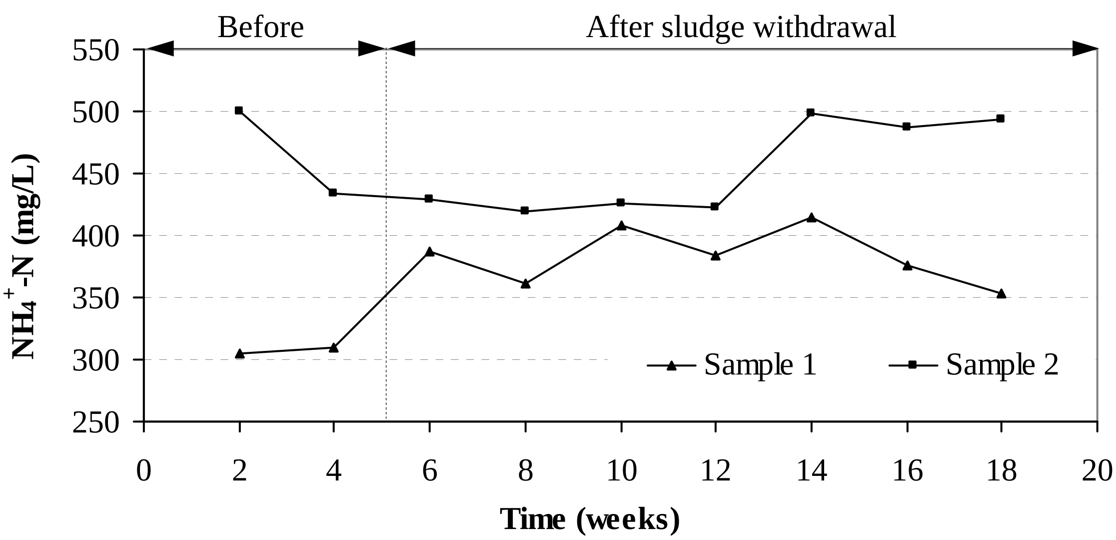

Figure 3 NH_4^+-N concentration in the septic tank effluents (sample 1 is from septic tank 1 and sample 2 is from septic tank 2)

Table 6 SS and mean particle size diameter in different wastewaters along with specific resistance

Sample	**SS**	**Mean diameter (standard deviation)**	**Uniformity of particle sizes**	**Specific resistance**
	(mg/L)	(μm)		(m/kg)
Raw wastewater	73	76.18 (1.75)	1.45	3.74×10^9
Wastewater after 2h settling	54	36.63 (1.48)	0.97	6.01×10^9
Wastewater after 3h settling	46	26.05 (0.48)	0.78	5.54×10^9
Wastewater after 4h settling	44	24.70 (0.66)	0.70	5.06×10^9
Effluent septic tank	76	52.32 (1.50)	1.18	7.19×10^9

4. Conclusions

Effluent quality data from septic tanks in Hanoi and Bangkok were collected to evaluate their performance as onsite sanitation systems. The study reveals that in general, the septic tanks did not perform as required. This may not be due to the faults in design but due to improper operation and maintenance. Currently, the septic tanks are just converting the pollutants from solid phase to dissolved phase, which escape with the septic tank effluent due to insufficient retention time. For example, the concentrations of COD, BOD and NH_4^+-N in the effluent septic tanks are as high as 1500, 300 and 600 mg/L. If the septic tanks have to be promoted as effective onsite treatment system, proper training on the operation and maintenance is essential. Also, small community level septic tanks rather than individual household septic tanks should be built to incorporate hybrid treatment systems in the future.

5. References

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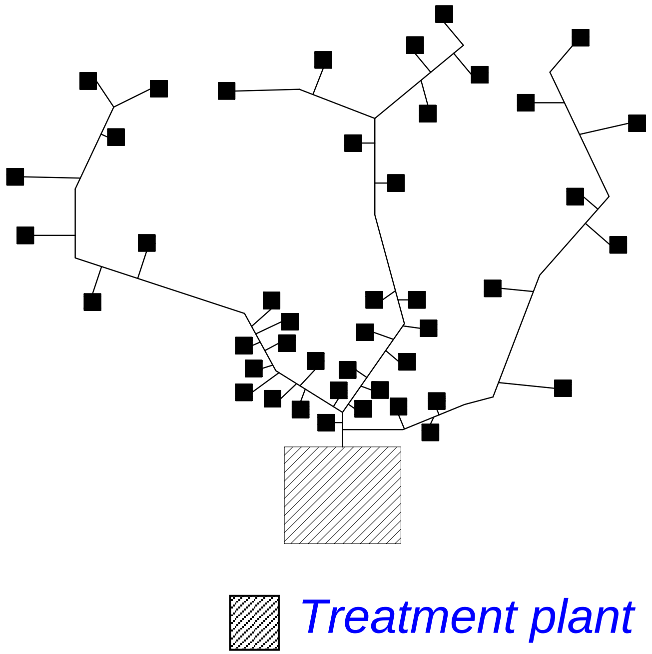
- Methodology
- Results and Discussion
- Conclusions and Recommendations

Introduction

Centralized Treatment System



Advantages

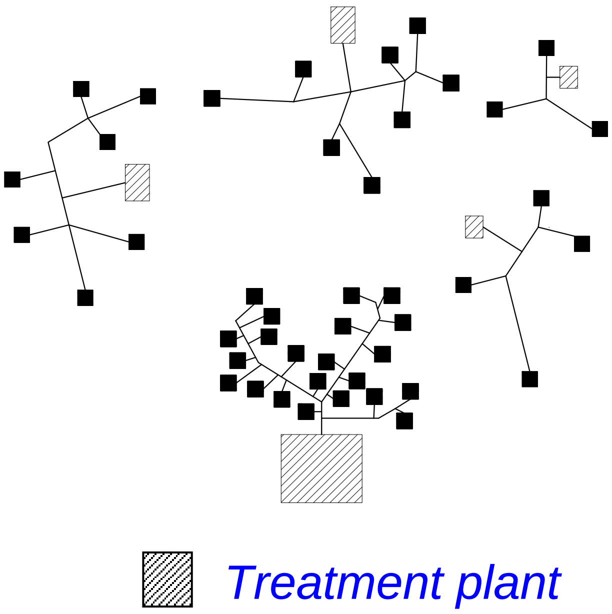
- ✓ Easy to manage in terms of effluent quality and operation
- ✓ Successfully applied in areas with high population densities

Disadvantages

- ➢ High cost in terms of operation and maintenance
- ➢ High investment cost
- ➢ Large area requirement

Introduction

Decentralized treatment system



- Rapid growth of urbanization
- Discharge of untreated wastewater into environment

Advantages

- Less investment cost
- Effective for communities with sparse populations
- Suitable for different site conditions
- Allows more flexibility for community planning

Introduction

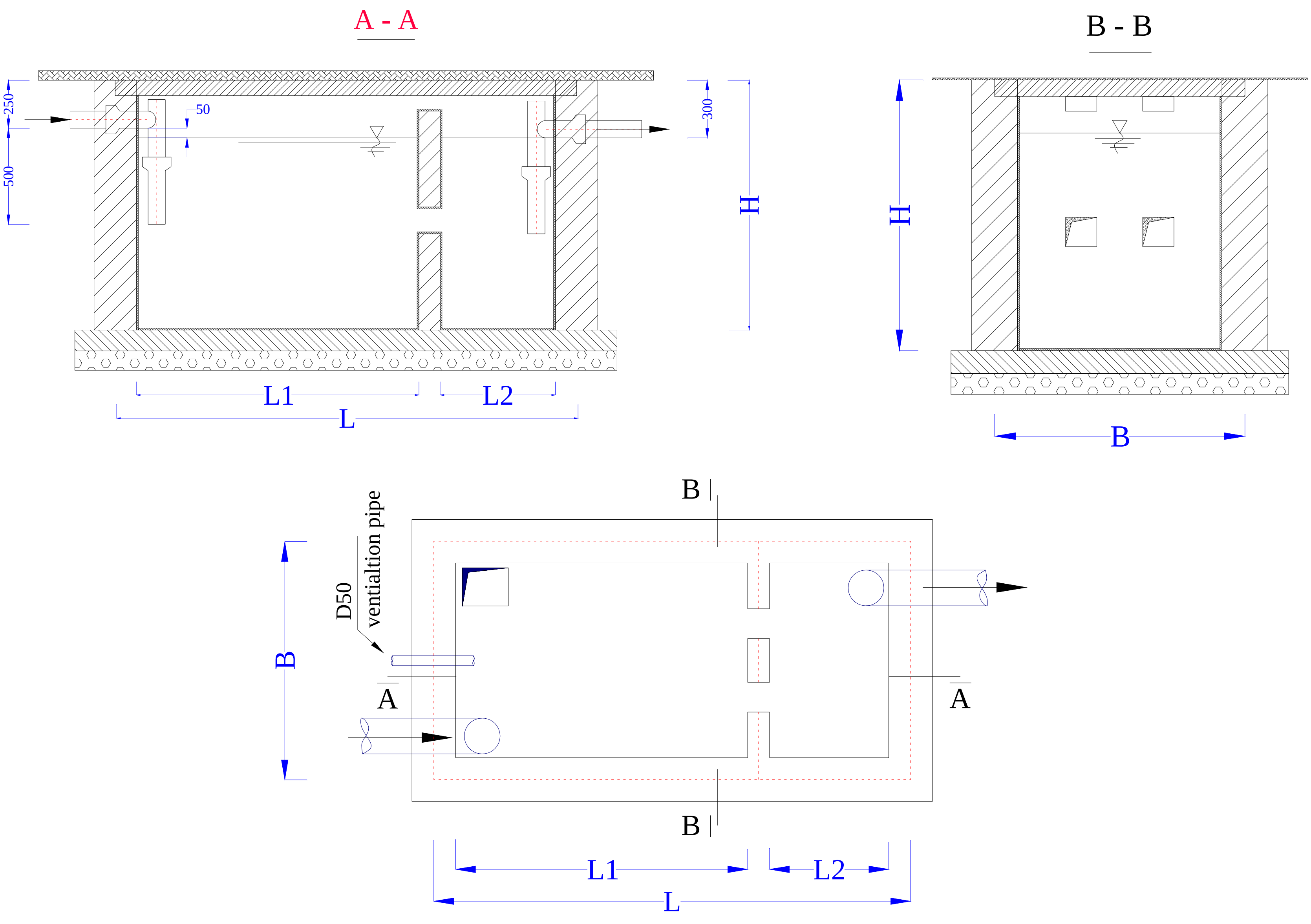
Septic tank

- ✓ Single or multi chamber
- ✓ Circular or Rectangular
- ✓ Treatment of wastewater by anaerobic process
- ✓ Removal of pathogenic organisms
- ✓ Removal of settleable & floatable substances

Problems

- Effluent contains high of SS, BOD, COD and TKN
- Effluent is discharged directly to sewage or water bodies
- Leach to soil with or without leaching system

Septic Tank Design



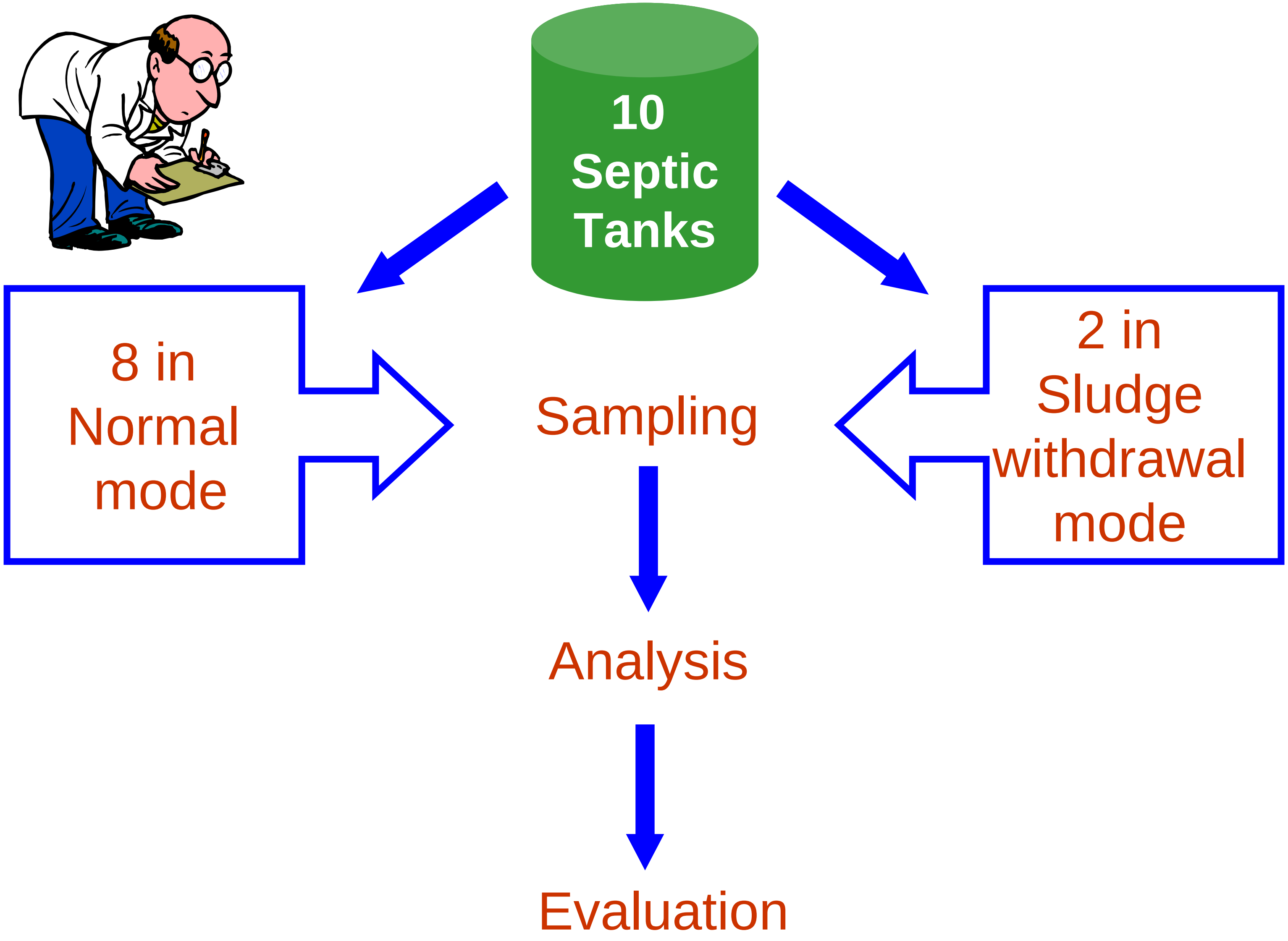
Scope of Study

- Review of sewerage, sanitation system and septic tank in Hanoi Vietnam
- Review of septic tanks in suburban area of Bangkok Thailand
- Measurement of filterability of various wastewaters
- Measurement of treated wastewater properties

Methodology

- **Survey** → Collect data → Evaluate
- **Monitoring** → Sampling → Analysis → Evaluation
- **Experiment** → Filtration test

Monitoring

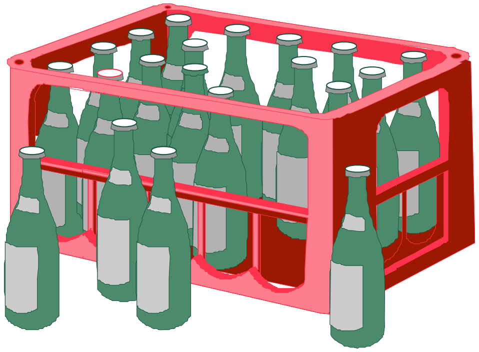

10 Septic Tanks
8 in Normal mode
Sampling
2 in Sludge withdrawal mode
Analysis
Evaluation

Methodology

Filtration test

- Tested samples
  - ✓ Raw wastewater
  - ✓ Wastewater after settling for 2, 3 and 4 hours
  - ✓ Effluent septic tank

- Measured parameters
  - ✓ Particle size distribution
  - ✓ Specific resistance
  - ✓ Capillary suction time

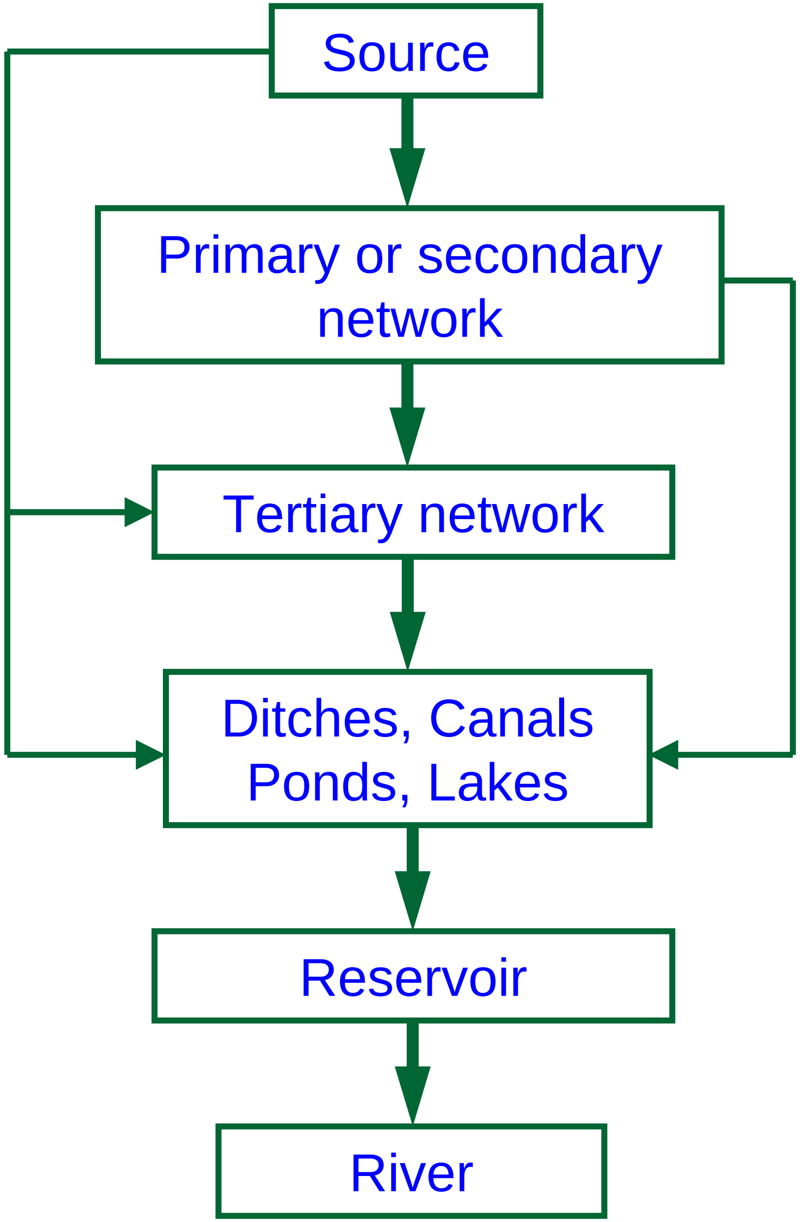


Results and Discussion

Hanoi sewerage and sanitation

The sewerage and drainage system

- Covers only 40% of area
- Very old
- 0.3 m/person



- Total volume 460 000 m^3/day including domestic and industrial wastewater
- Untreated wastewater is discharged to open canals, lakes and ditches

Some Pictures

Water quality in some canals in Hanoi

Parameter	Hao Nam	Khuong Thuong	Thuy Khe
pH	7.4	7.3	7.4
DO, mg/L	0.8	0.5	0.2
SS, mg/L	189	104	200
BOD_5, mg/L	180	135	156
COD, mg/L	256	1536	358
NH_4^+, mg/L	20	29	18
PO_4^{-3}, mg/L	4.0	3.8	3.9

Sanitation facilities in urban areas of Hanoi

Types of on-site sanitation		Ratio (%)			
		1995	1998	1999	2000
Septic tank		54	56	63	68.4
Pour- latrine		2	12	10.4	9.2
Double - vault toilet		20	12	4.7	4.9
Single - vault toilet		16	9	3.8	1.8
Public Toilet					
	Single-vault toilet	4	2.4	0.5	-
	Double - vault toilet	2	0.7	7.3	-
	Septic tank	2	7.9	10.3	15.7

(CERWASS, 2004)

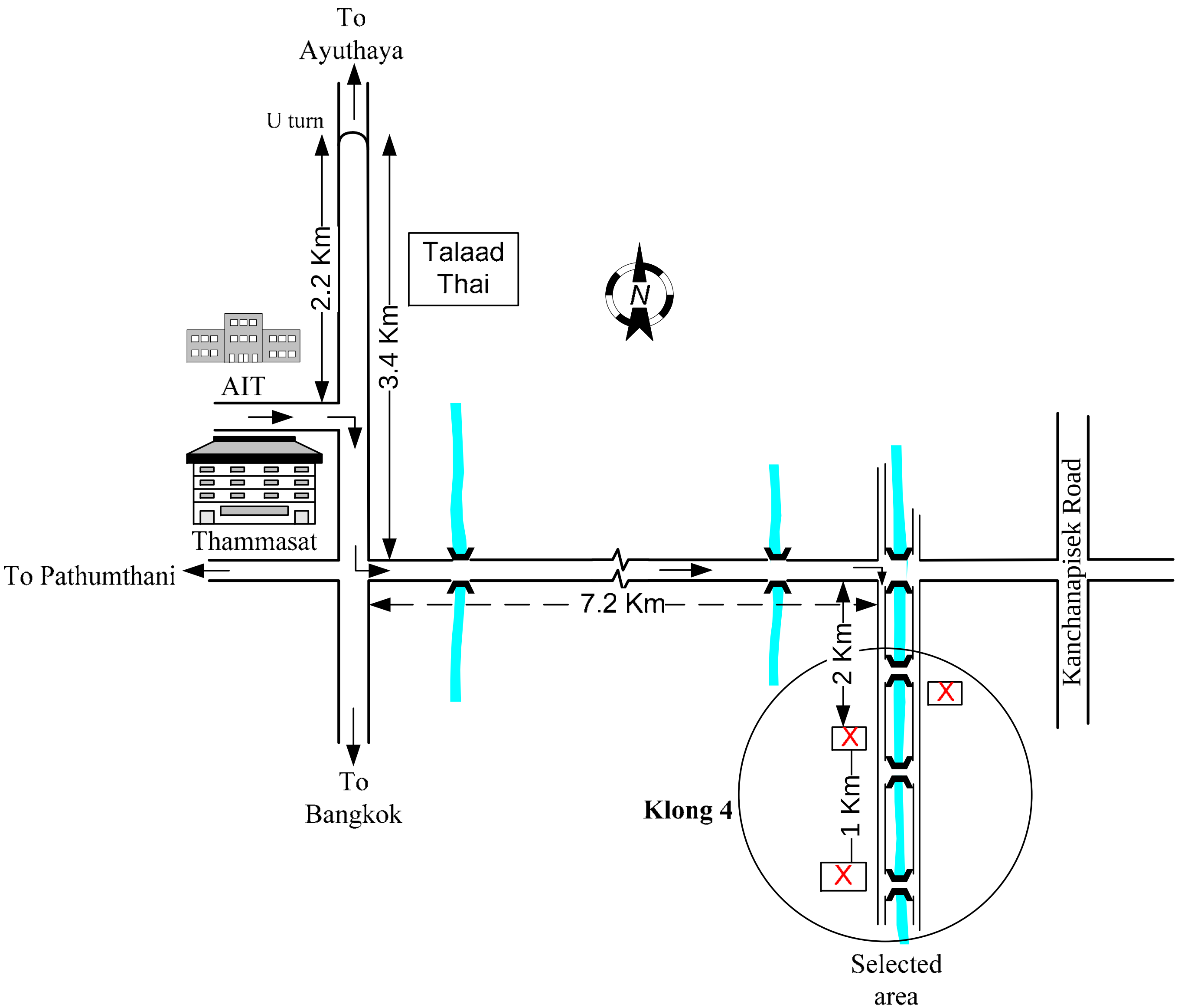
Effluent septic tank in Hanoi

The monitoring of treatment efficiency from 3 septic tank effluent by Centre for Environmental Engineering of Towns and Industrial Areas

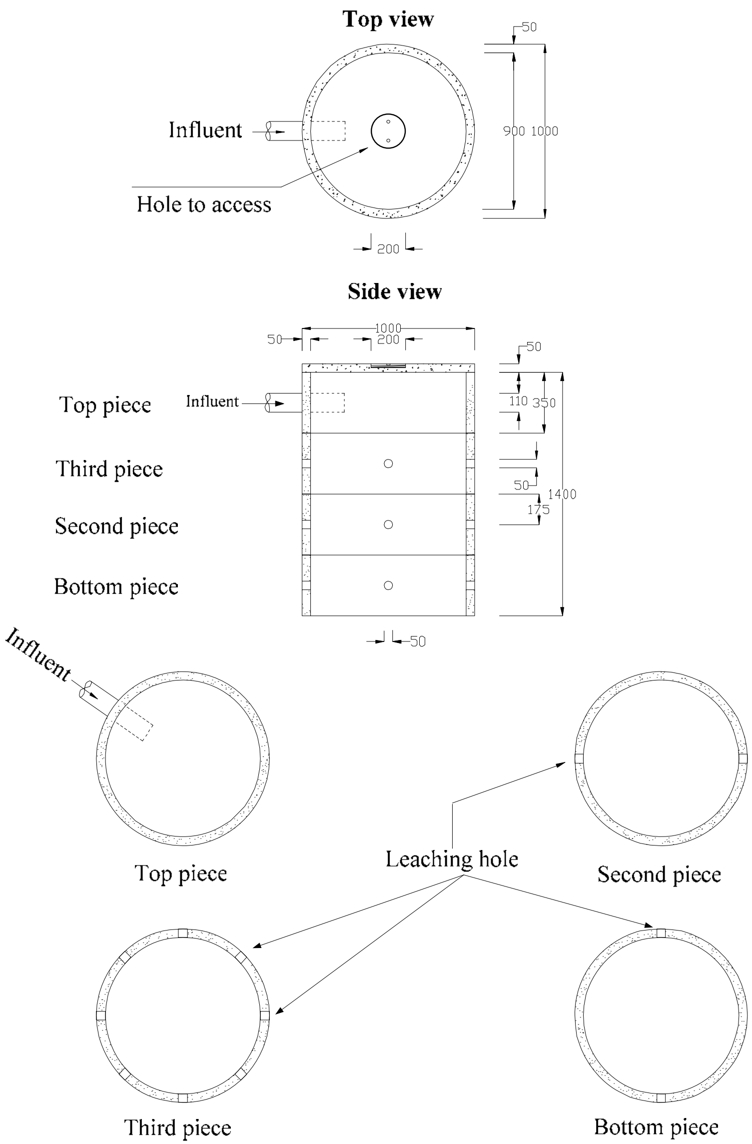
Parameter	Inlet	Outlet	standard of Vietnam
pH	7.32 – 8.1	6.17 – 8.5	5 - 9
SS, mg/L	380 – 767	**86 – 812**	50
BOD_5, mg/L	240 – 376	**102 – 330**	20
$N\text{-}NH_4$, mg/L	38 – 66	20 – 43	Not Defined
$N\text{-}NO_3^-$, mg/L	0 - 1,2	0.01 – 2.9	30
$P\text{-}PO_4^{3-}$, mg/L	3.1 - 4.1	**2.79 – 33.5**	6

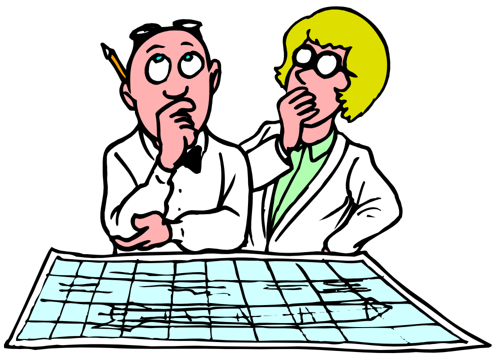
Some Photos

Monitoring in Bangkok



Septic Tank Design in Thailand





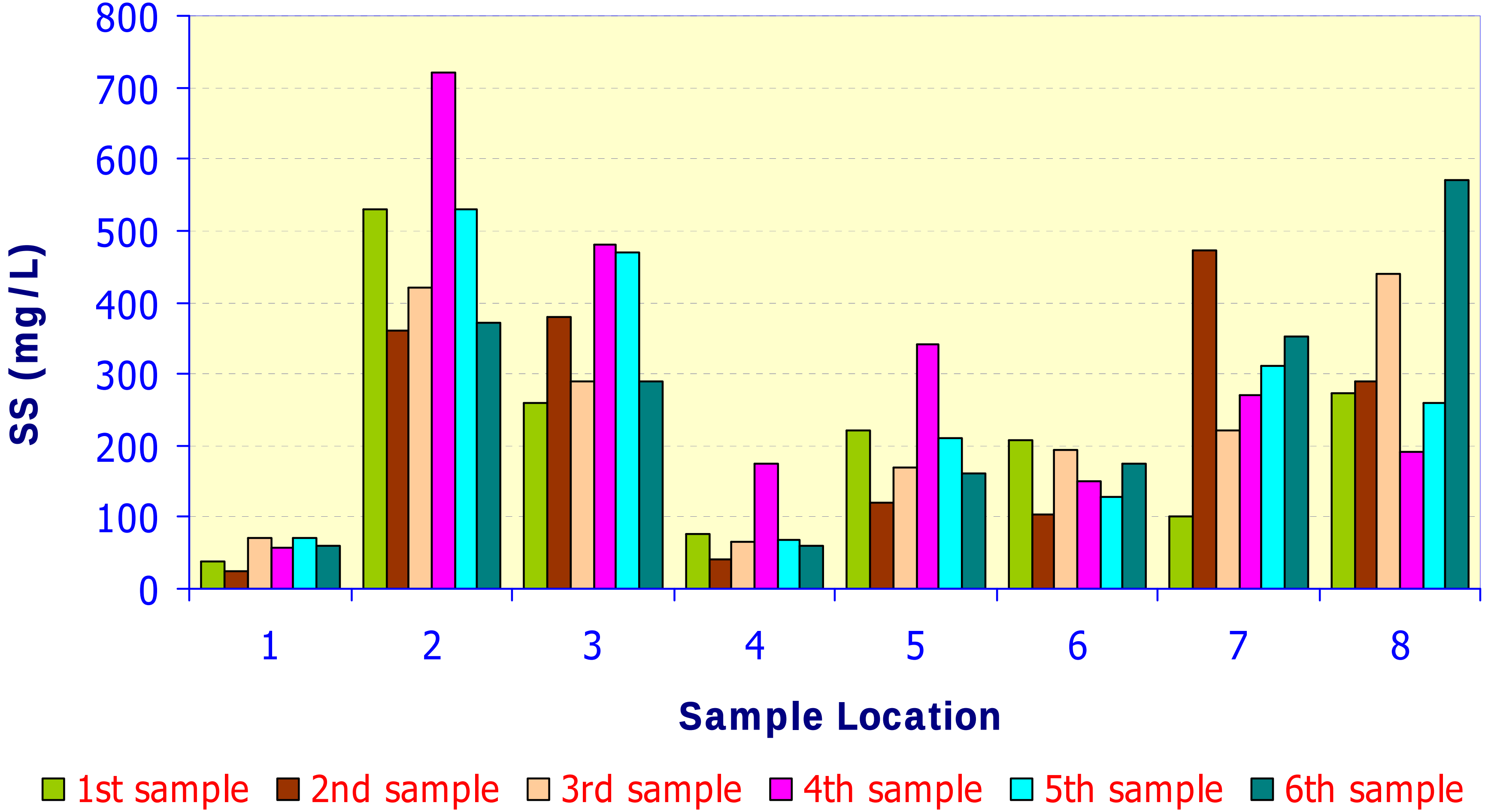
Some Photos

Some Photos

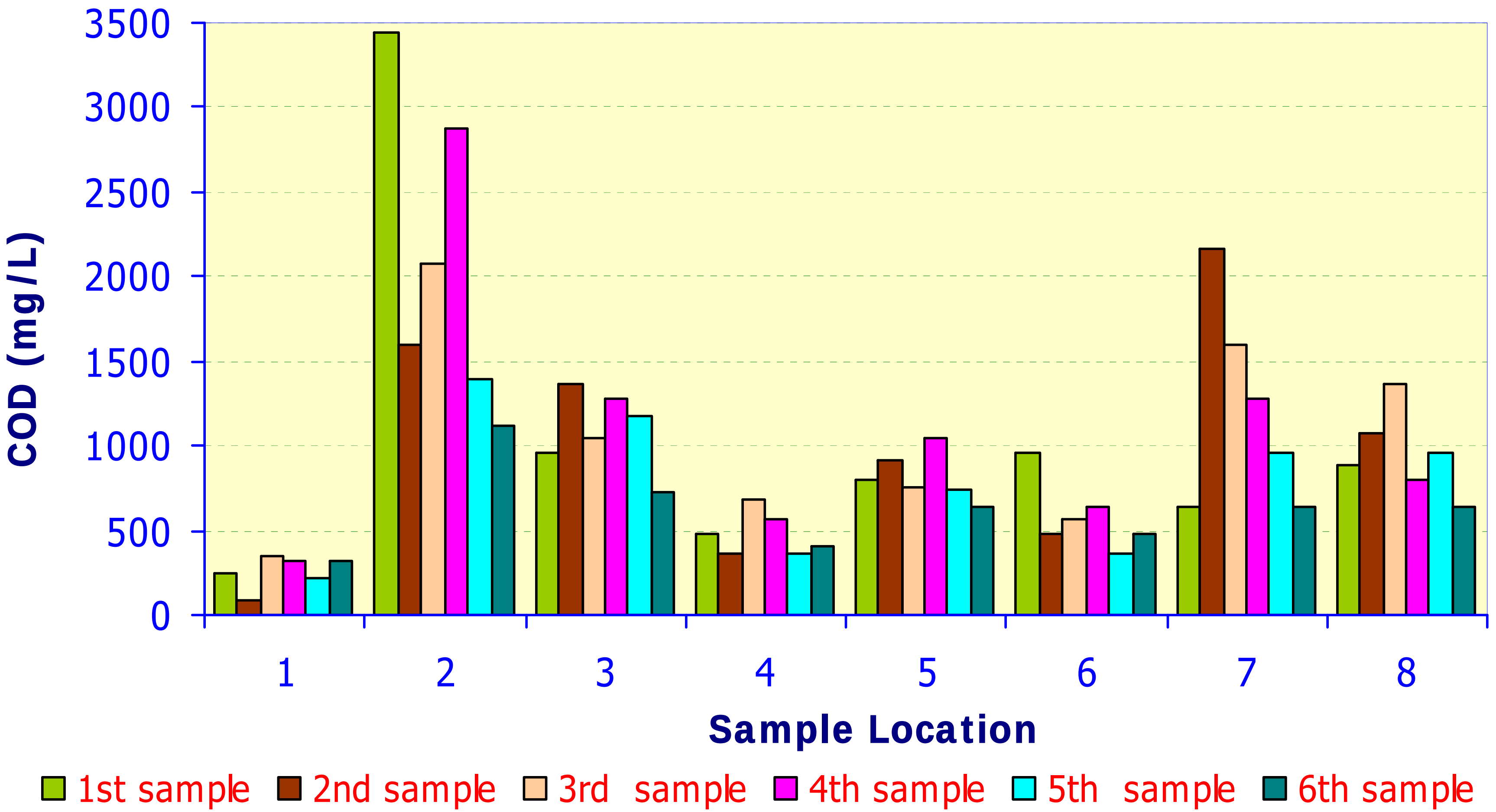
Some Photos

Monitoring septic tanks in suburban area of Thailand

Normal mode

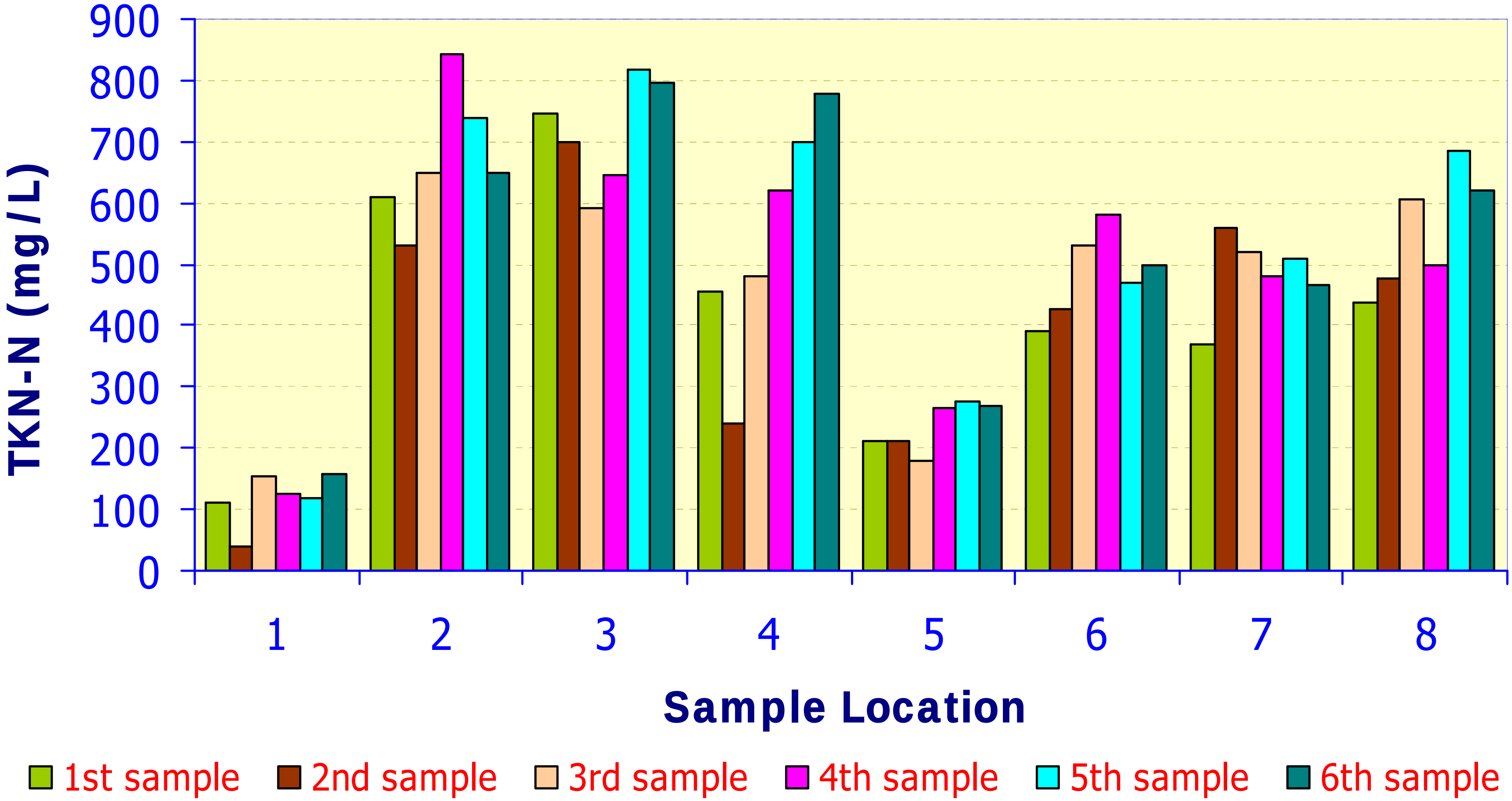


Normal mode



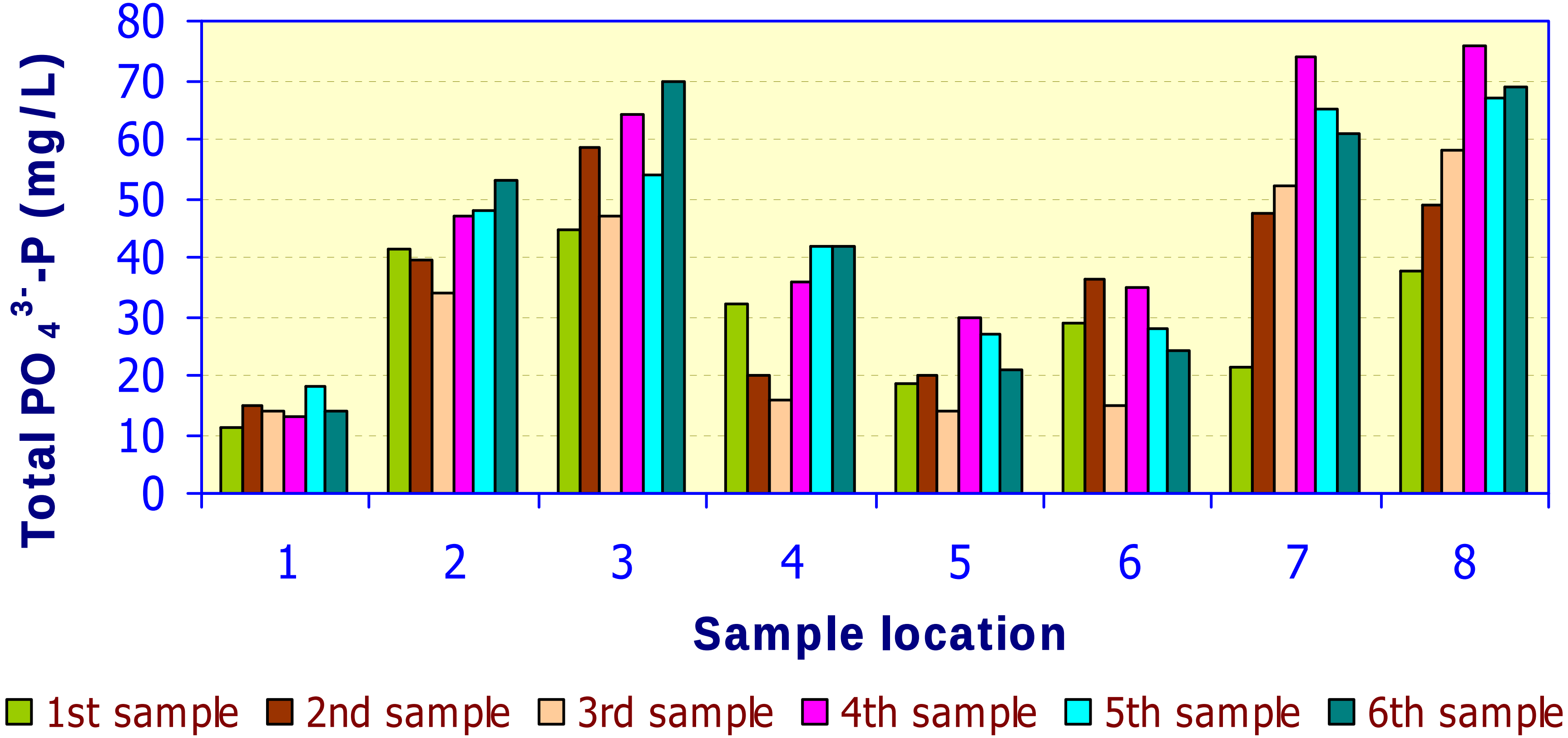
3500
3000
2500
2000
1500
1000
500
0
COD (mg/L)
1
2
3
4
5
6
7
8
Sample Location
1st sample
2nd sample
3rd sample
4th sample
5th sample
6th sample

Normal mode



900
800
700
600
500
400
300
200
100
0
TKN-N (mg/L)
1
2
3
4
5
6
7
8
Sample Location
1st sample
2nd sample
3rd sample
4th sample
5th sample
6th sample

Normal mode



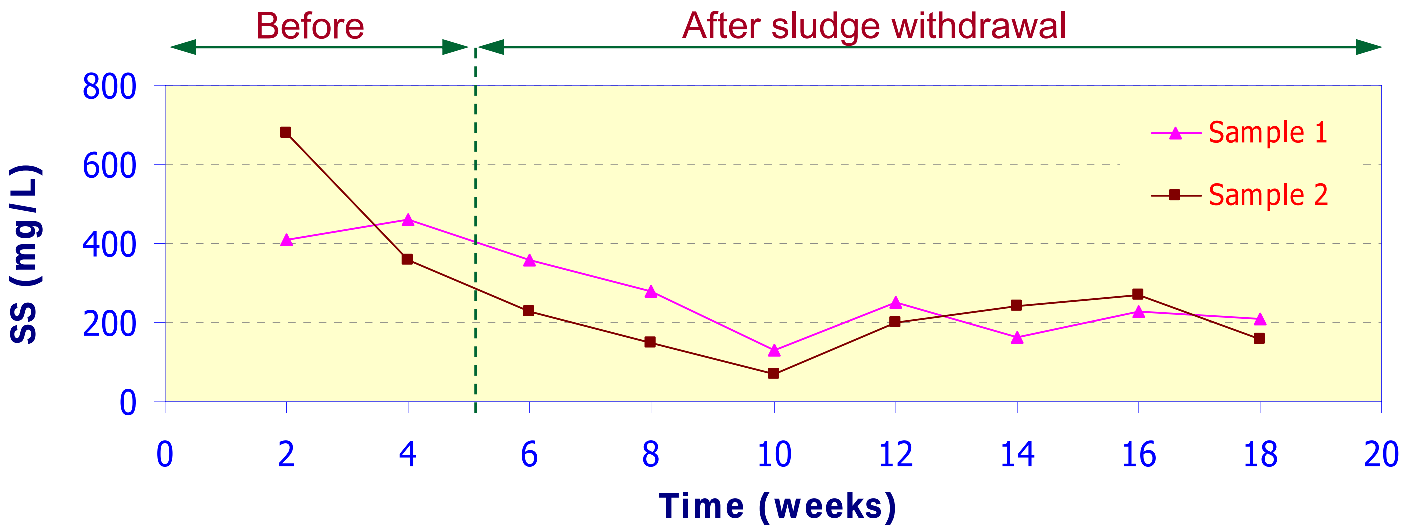
Total PO_4^{3-}-P (mg/L)
0
10
20
30
40
50
60
70
80
1
2
3
4
5
6
7
8
Sample location
1st sample
2nd sample
3rd sample
4th sample
5th sample
6th sample

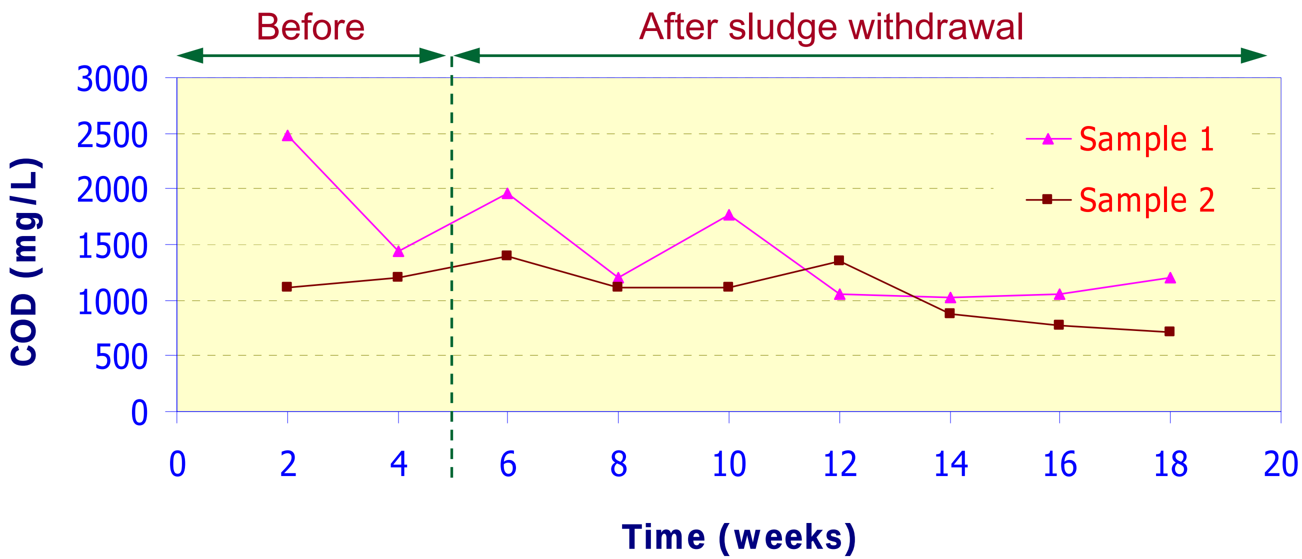
Comparison of Monitoring results with other reports

Parameters	This study	EPA 2002	Van cuyk 2001	Crites and Tchobanoglous 1998	Zhang et al 1996
pH	7.2 – 7.8	6.4 – 7.8	-	-	7.8
SS	150 – 500	40 - 350	69	40 -140	256
COD	300 – 1500	-	386	250 - 500	-
BOD_5	50 – 300	46 - 156	227	150 - 250	576
NH_4-N	150 – 600	-	47	30 - 50	462
TKN	200 – 700	19 - 53	57	50 - 90	-
PO_4^{3-}-P	15 – 50	7.2 - 17	4.6	12 -20	-

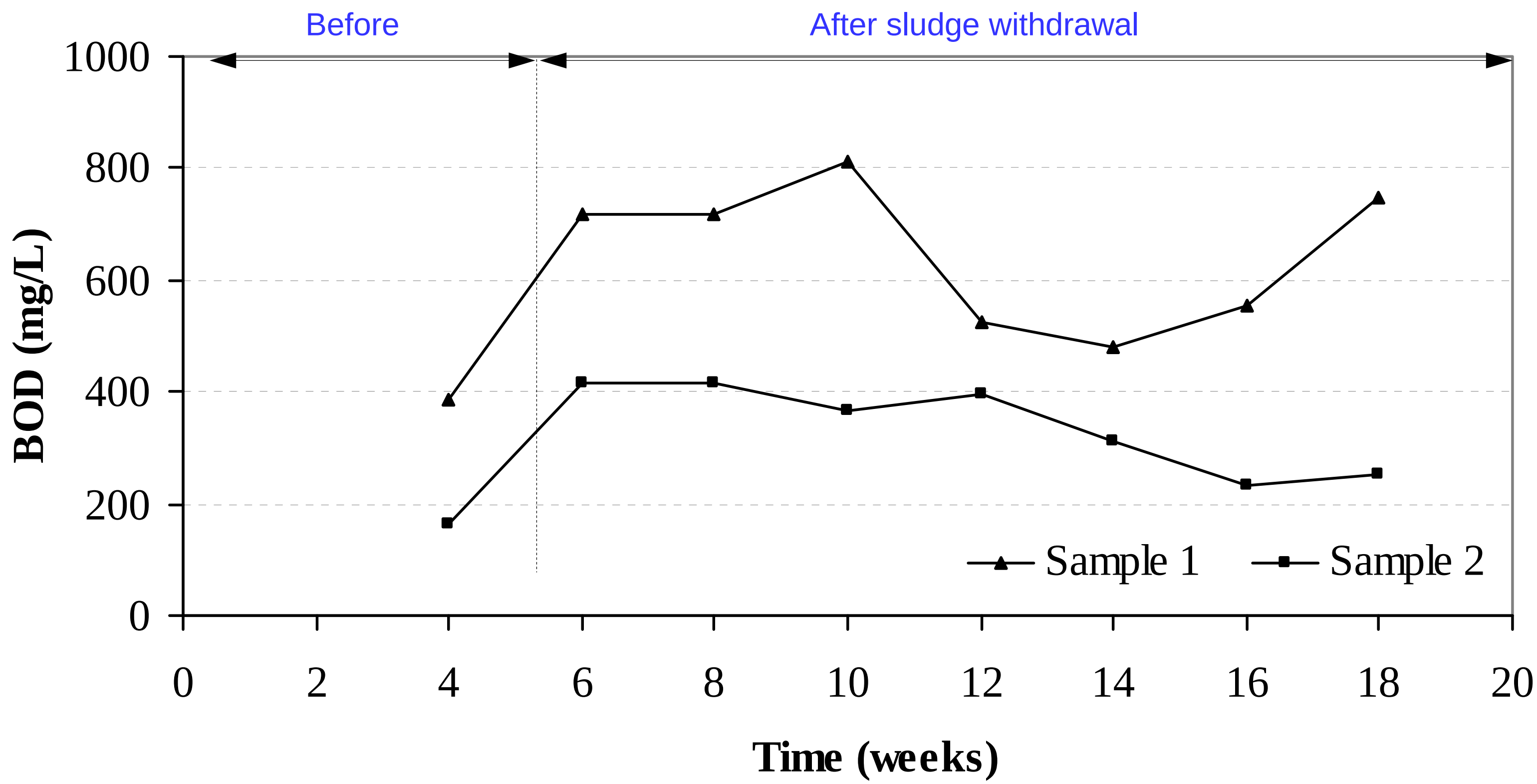
All values are mg/L except pH

Sludge withdrawn mode

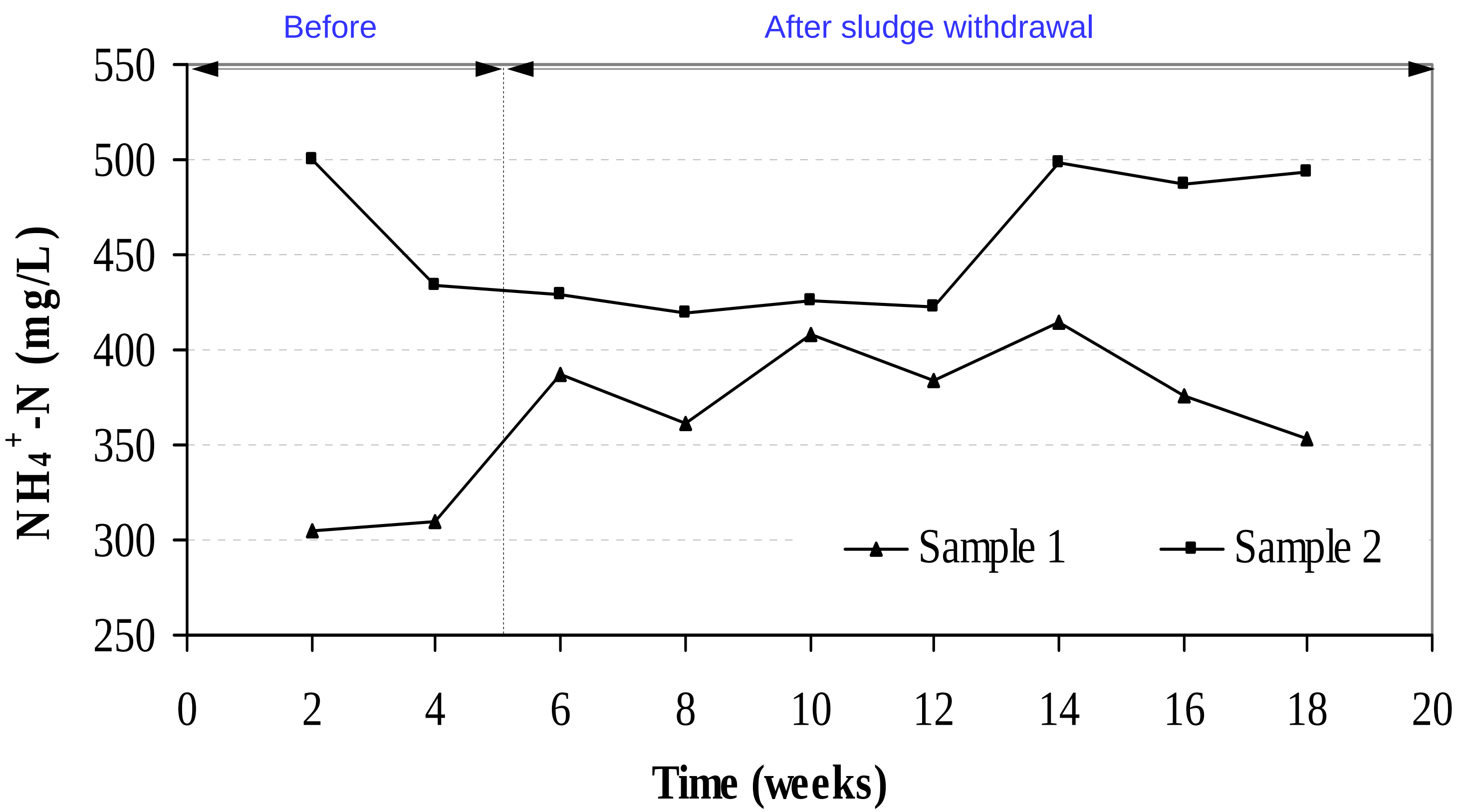




BOD concentration in the septic tank effluents



NH_4^+-N concentration in the septic tank effluents



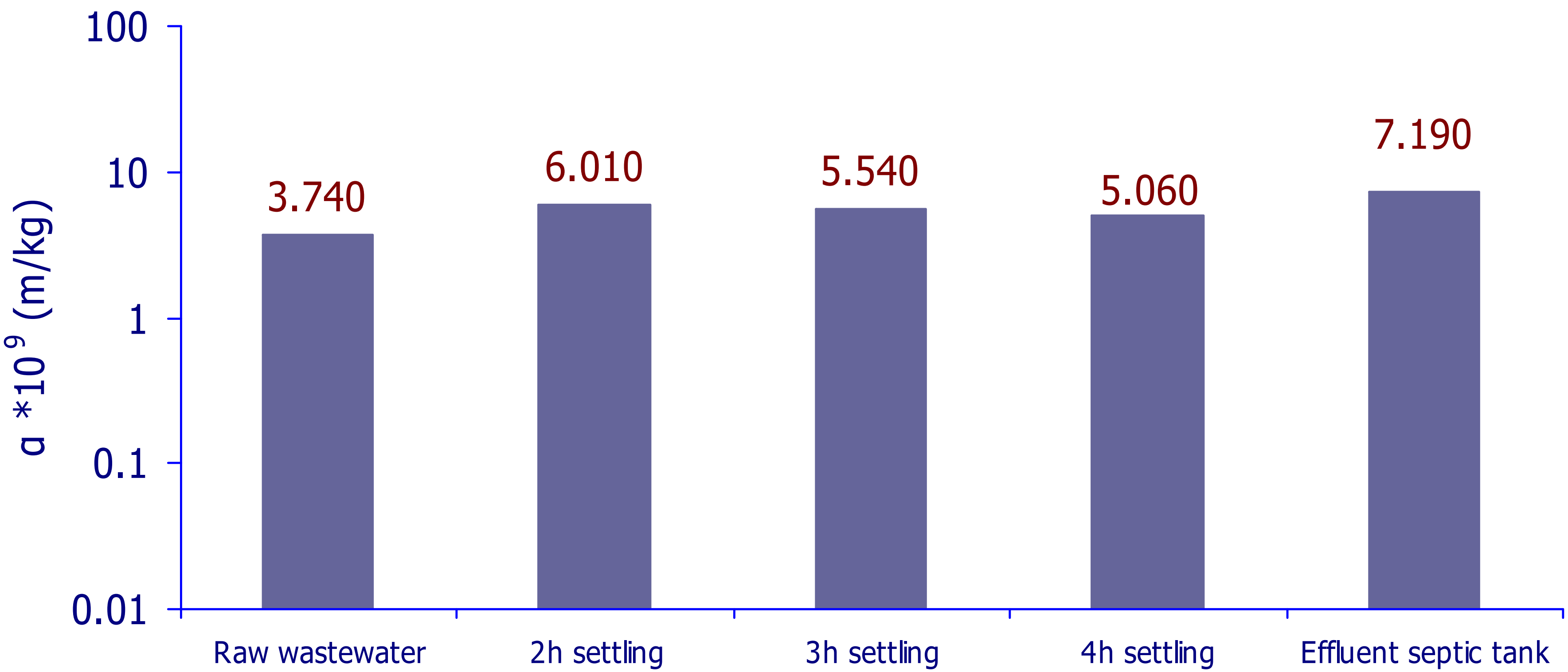
After sludge withdrawal

- pH was stable around 7.6 to 7.8
- SS was reduced and reached a steady state after 8 weeks
- COD increased slightly and decreased afterward
- BOD increased and reached a stable value; after 8 weeks it started to decrease
- TKN increased and reached a steady state after 10 weeks

Filtration Test

Samples	Mean diameter (µm)	Uniformity
Raw wastewater	76.18	1.45
Wastewater after 2h settling	36.63	0.97
Wastewater after 3h settling	26.05	0.78
Wastewater after 4h settling	24.70	0.70
Effluent septic tank	**52.32**	1.18

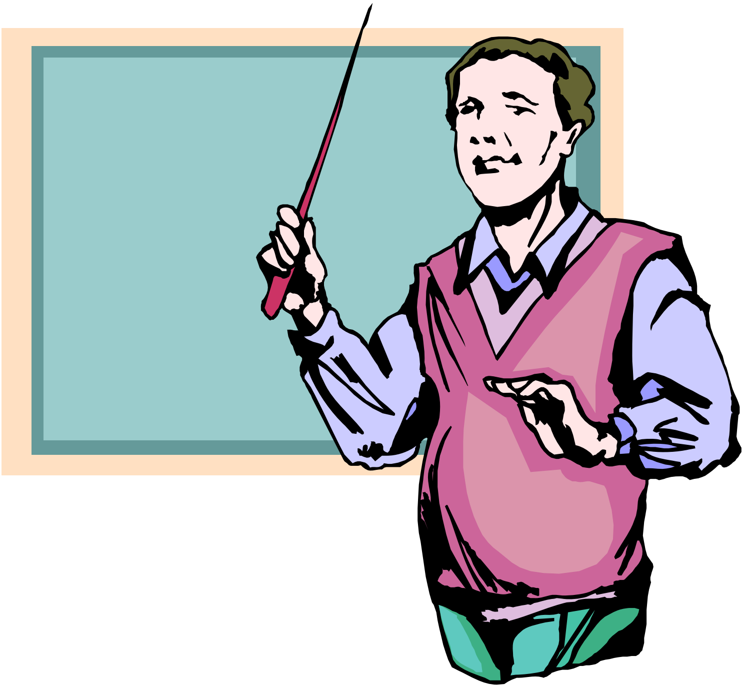
Filtration Test



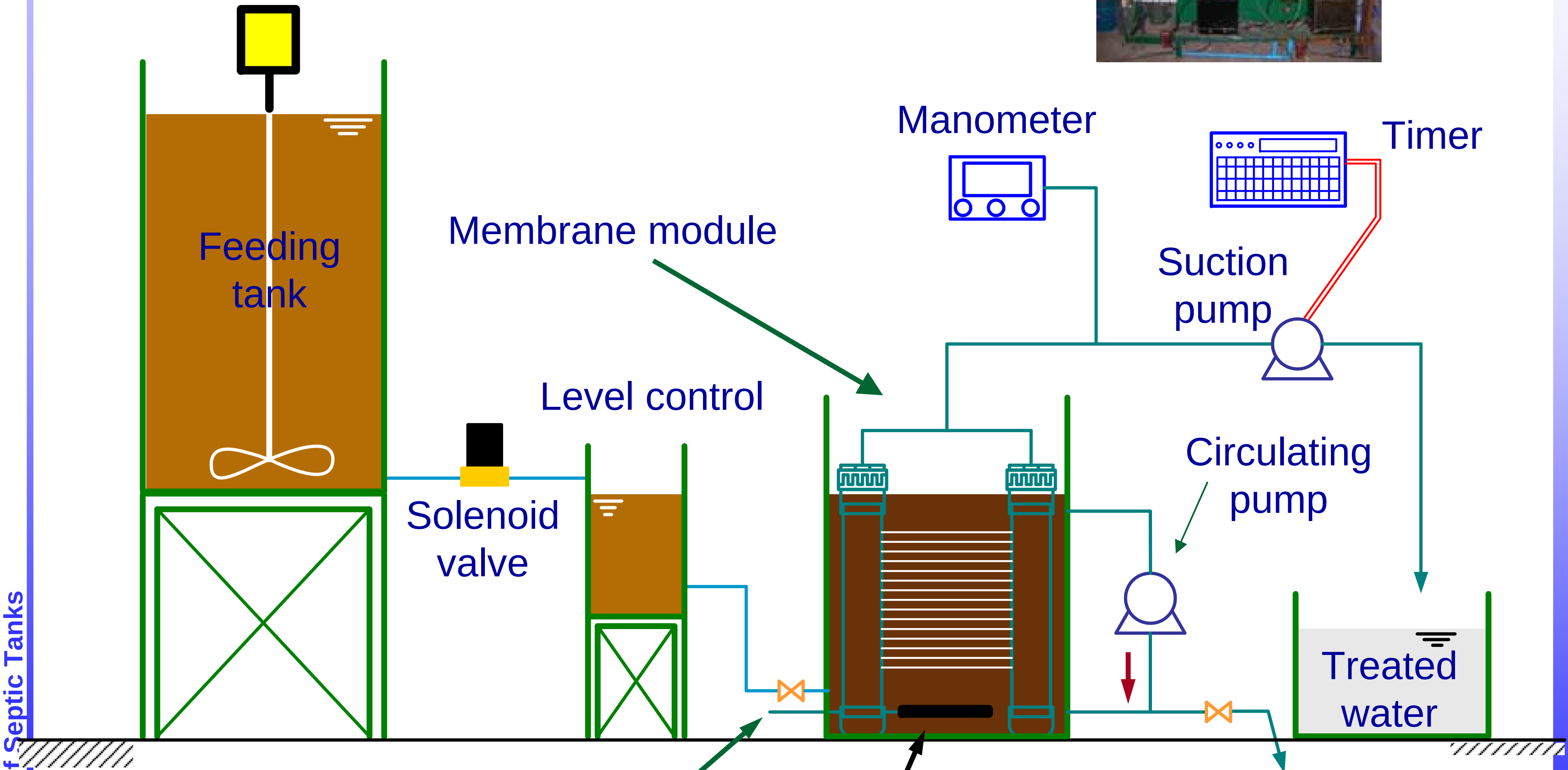
Conclusions

- Canals and lakes in Hanoi are polluted by untreated wastewater.
- Quantity of septic tank is increasing and its effluent was high in term of SS, BOD, TKN, although its dimensions were standardized.
- Monitoring of septic tanks indicated wastewater is high in term of SS, COD, TKN and ammonia. For example, the concentrations of COD, BOD and NH_4^+-N in the effluent septic tanks are as high as 1500, 300 and 600 mg/L, respectively.
- The monitoring results indicated that wastewater quality did not meet required effluent standards.
- After sludge withdrawal: SS decreased, COD, TKN and ammonia did not vary much (same as before sludge withdrawal)
- If the septic tanks have to be promoted, proper training on the operations and maintenance is essential.

Thank you all



Sketch of Experimental setup



Wastewater quality after treatment

Parameter	HRT = 16 hours		HRT = 8 hours		Reuse options	
	Aerobic	Anaerobic	Aerobic	Anaerobic	Agriculture	Aquaculture
pH	6.0 – 7.0	7.4 – 7.8	4.6 – 5.9	7.4 – 7.5	-	-
COD, mg/L	29 – 40	129	13 – 35	98 - 114	< 30	< 30
TKN, mg/L	33 – 42	126	30 – 47	123	Not defined	Not defined
NH_4^+, mg/L	30 – 42	120	30 – 33	117 – 120	-	-
PO_4^{3-}, mg/L	6.2 – 13.0	10.2	8.0 – 9.0	9.5 – 10.0	No Defined	< 0.5

Higgins et al, 2003