한국환경분석학회지 제11권 (제3호) 196~206, 2008
J. of the Korea Society for Environmental Analysis

A Study on the Evaluation of Water Quality at the Sites of Water-intake between Jamsil Submerged Weir and Paldang Dam for Public Water Supply

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A study on the suitability for public water supply of the headwaters between Jamsil Submerged Weir and Paldang Dam, a 24km reach of Han-river, was carried out from June to October, 2005. To know the water quality of the headwaters 7 sampling points and a set of 23 physical, chemical and biological water quality parameters for each sampling point were chosen. Each sampling point was sampled 4 times, distinctively for dry and wet seasons. The study disclosed the water temperature ranged 18.0~24.3°C, pH ranged 6.4- 8.8, dissolved oxygen ranged 6.8~10.9 mg/L, biochemical oxygen demand ranged 0.5~2.8 mg/L, total phosphorus ranged 0.032~0.204 mg/L, and total nitrogen ranged 1.50~5.10 mg/L. Total coliforms ranged 73∼82,000 MPN/100 mL, fecal coliforms ranged 0∼12,000 MPN/100 mL, and fecal streptococci ranged 0∼3,100 MPN/100 mL. Chlorophyll-a samples were analysed to range 1.5∼12.7 mg/m^3 and algae samples showed their concentration ranged 68-1,100 count/mL. The analytical results showed that Acrylonitrile Butadiene Styrene (ABS), heavy metals, and endocrine disrupting chemicals were not detectable or below the detection limits.

Key words : public water supply, coliforms, streptococci

1. Introduction

The water quality of the headwaters between the Jamsil submerged weir and Paldang Dam, which supply 3,692 thousands cubic meters of public water per day for 10,181 thousands of pipe-water users of Seoul city, is very important not only for the consumers but also as an overall criterion for the success or failure of national water quality control policy. So far, many surveys on people's conscientiousness of public water quality were conducted by many institutions for many regions. Although there are some differences in the results among institutions and regions, they appeared to be very similar. The results of the surveys put together, population who drank the pipe water took up 80% (79.4% in a survey by Ministry of Environment in 2003 and 84.3% by Incheon city), and the population of bottled water and mountain wells recorded 10% each. However, only 2% of the city water population took the tap water as it was, and 44% of them took the water boiled and the remainder 34% used various water filtering equipments. The reason that the most of people did not drink the tap water directly was disclosed that 40% was for ambiguous uneasiness, 30% for unfavourable odor, 10% for bad taste, another 10% for aesthetic offense by visible solid pollutants such as scums, and 10% for uneasiness by mass media news.

Such a result of the investigation showed that the most important “reason that people did not drink the tap water as it is” was its inferior water qualities such as odor, taste, and visible pollutants. What can be inferred by such a result is that if the water quality of

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the tap water is improved people's confidence in city water would be built. The way to improve the quality of tap water is first of all to make the headwaters clean and to introduce an appropriate drinking water treatment process to produce clean public water. Treated drinking water should be sent to the taps of households through clean distribution system. But maintaining the high quality of headwaters, construction and operation of advanced drinking water treatment facilities, and construction and maintenance of pollution free distribution system are all difficult tasks. The purpose of this study is to investigate and analyse the water qualities of the headwaters essential for production of drinking water of high quality.

Water intake by Seoul city was 3,692 thousand cubic meter per day, of which only 296 thousands cubic meter of water were taken from the upper stream of Paldang Dam, and the remainder 3,396 thousands cubic meter of water from 5 water intake facilities in the lower stream of Paldang Dam. They are Gangbuk, Amsa, Guei, Pungnap, and Jayang water intake facility. For Seoul city, quality of Jamsil-Paldang headwaters is as important as the water quality of Paldang Dam.

In this study water quality of Jamsil-Paldang headwaters were assessed based on the results of analyses of a total of 23 parameters, including 7 physiochemical parameters such as temperature, concentration of hydrogen ion, 10 heavy metals such as Cadmium, Crome etc, 1 organic compound, 3 microorganisms including total coliforms, and 2 algae such as chlorophyll-a, and a blue algal

2. Material and Method

2.1. Investigation and Study area

The study area was the headwaters between Jamsil submerged weir and Paldang Dam in Han-river, which supplied most of the source water for city water production of Seoul City. And for the sake of comparative study, 2 water intake facilities in the upper stream of Paldang Dam, where Seoul city was extracting some headwaters, were included for the survey (Fig. 1). Han river is a National river, composed of two major branches, Nam Han river and Buk Han

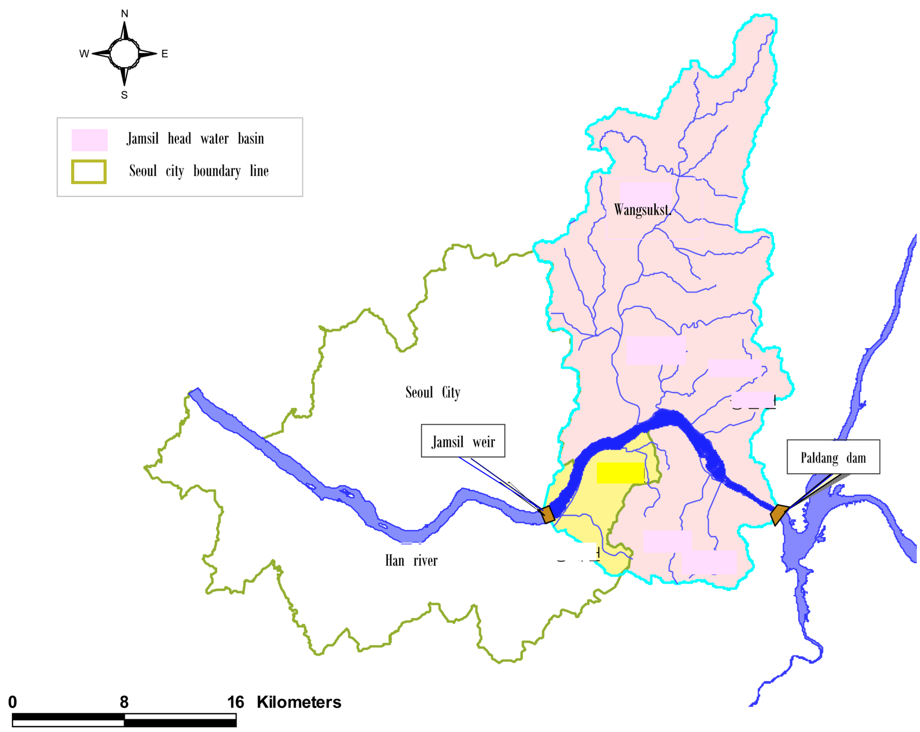

Fig. 1. The study area, the headwaters between Jamsil Underwater Weir and Paldang Dam.

river. Nam Han river is originating in Mt. Ohdae, Jinboomyun, Pyungchanggun, Kangwondo and joined by Nam Han river at Yangsoori, Yangsuhmyun, Yangpyunggun, Kyungkido, and runs 375 km, draining a watershed of 2,577 km^2. Buk Han river is originating in Mt. Keumgang, running through the Hoiyang and the Chuncheon and joined by Nam Han river at Yangsuhmyun, Yangpyunggun, Kyunggido. Nam Han river runs 391 km, draining a watershed of 10,719 km^2. After the two major branches joined, Han river flows north-westward through Seoul city and Kimpo plain and is emptied in Yellow Sea.

The river width of the study area was maximum 937 m and minimum 645 m, and the average annual flow rate was 554 m^3/sec. The water intake of Seoul city from the headwaters amounted to 7.1% of its annual average flow rate. Daily average water intakes by drinking water treatment plants were 296 thousands cubic meter by Gwangam, 560 thousands cubic meter by Guei, 572 thousands cubic meter by Tukdo, 433 thousands cubic meter by Youngdeungpo, and 1,049 thousands cubic meter by Gangbuk (Table 1).

2.2. Investigation Methodology

The flow rates and samples taken 4 times for each of 7 points in the study area were investigated and analysed. The flow rate data collected at the point of Paldang Grand Bridge by the Han river Flood Control Office, Ministry of Construction and Transportation, were used for the flow rates for the study area.

Table 2. Sampling points by date and water intake facility

Sampling point \ date	06/01/2005 (1st)	06/30 (2nd)	09/05 (3rd)	10/06 (4th)
Paldang WIF[1] #2	10:40	10:30	10:30	11:30
Paldang WIF #1	11:00	10:40	10:50	11:45
Gangbuk WIF	11:40	11:10	11:15	12:10
Amsa WIF	12:55	12:30	13:15	13:30
Pungnap WIF	13:25	12:55	14:00	13:50
Jayang WIF	13:45	13:10	14:10	14:10
Guei WIF	14:05	13:30	14:25	14:30

[1] Water Intake Facility

2.2.1. Sampling dates

Samples were taken 4 times in 2005 on June 1 (dry season), June 30 (wet season), September 5 (in-between season), and October 6(in-between season) (Table 2).

2.2.2. Sampling points

Seven sampling points in the survey area, Guei, Jayang, Pungnap, Amsa, Gangbuk, Paldang No.1, and Paldang no. 2 Water Intake Station, were chosen. For the better representation of the water quality, water samples were taken at the mouth of water intake station or at a point prior to the pre-treatment process of water treatment plants (Fig. 2).

2.2.3. Sampling methods

To minimize the measurement error due to the difference of sampling times, a sequential sampling practice was employed in the order of Paldang no. 2, Paldang no. 1, Gangbuk, Amsa, Pungnap, Jayang, and

Table 1. Water intake and treatment capacity by water treatment plant

	water intake capacity (1,000 m^3/day)	water treatment capacity (1,000 m^3/day)	production rate (1,000 m^3/day)	water supply population (person)	location of head water (Paldang Dam site as reference point)
Total	6,670	5,400	3,692	10,181,350	-
Gwangam WTP[1]	800	800	296	721,847	upstream
Guei WTP	960	650	560	1,762,000	downstream
Tugdo WTP	1,450	750	572	1,088,683	downstream
Yongdeungpo WTP	700	600	433	1,531,692	downstream
Amsa WTP	1,710	1,600	1,049	2,720,000	downstream
Gangbuk WTP	1,050	1,000	720	2,357,128	downstream

[1] Water Treatment Plant

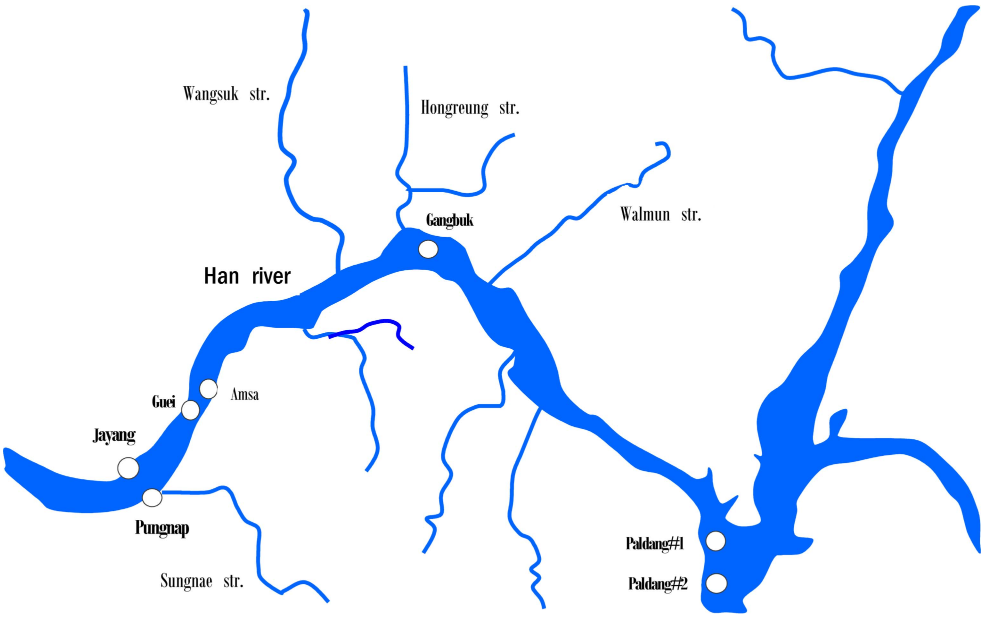

Fig. 2. Sampling (water intake) points.

Guei in downstream wise. Four-liter water sample was taken for each of sampling point. Hydrogen ion concentration, water temperature, and dissolved oxygen concentration were measured immediately at site, and water samples taken were kept in refrigerator before analysis and the parameters which needed immediate analysis were tested in four hours. The water samples were taken and analysed by the Water Assessment Team, Environmental Health Research Center, Korea University.

2.3. Analytical Methods

2.3.1. Physiochemical parameters

Of the 9 physiochemical parameters, such as water temperature, hydrogen ion, dissolved oxygen (DO), biochemical oxygen demand (BOD), suspended solid (SS), total nitrogen (T-N), total phosphorus (T-P), nitrates nitrogen, and phosphates phosphorus, some were measured at site and the others were analysed in laboratory. Winkler-Azid Method with a quantity scope of 0.1 mg was used for the analysis of BOD, and Glass Fiber Filtering Method with a quantity scope of 5 mg was employed for the analysis of SS. Photoelectric photometer measurable at 220 nm with quantity scope of 0.005-0.05 mg N was used for the analysis of T-N. Photoelectric photometer measurable at 710 nm with quantity scope of 0.001-0.025 mg P/mL was used for the analysis of T-P.

2.3.2. Heavy metals

For the analyses of heavy metals, Korea Standard Method for the Examination of Water were used. Inductively Coupled Plasma-Mass Spectrometry (ICP-MS, Agilent 7500a, U.S.A) was used for the analysis of all heavy metals but mercury (Hg), for which absorptiometric analysis was used. The quantity scopes of Cadmium, Chrome, Zinc, Copper, Lead, Manganese, Arsenic, and Ferrous were 0.04~10 μg/L, 0.2~50 μg/L, 4.0~1,000 μg/L, 4.0~1,000 μg/L, 0.4~100 μg/L, 1.6~400 μg/L, 0.4~100 μg/L and 1.6~400 μg/L, respectively. Mercury was analysed with a quantity scope of 0.04~10 μg/L. Table 3 shows the operating condition of ICP-MS.

2.3.3. Organic compounds

Anion surfactants were analysed by Absorption Spectrophotometry Method provided in Korea Standard Method for Examination of water. Absorption Spectrophotometer measurable at 650 with a quantity scope of 0.002~0.05 mg was used for the analysis of anion surfactants.

Table 3. ICP-MS Operating Conditions

Item	Conditions
RF power	1,200W
RF matching	1.64V
Sampling depth	9mm
Carrier gas	1.6 L/min
Plasma gas flow rate	15.0 L/min
Aux gas flow rate	1.0 L/min
Nebulizer	Babington type
Sample uptake rate	0.4 mL/min
Skimmer cone	Nickel
Spray chmber temperature	2°C
Mass range	8-240 amu

2.3.4. Microbes

The three bacterial groups, total coliforms, fecal coliforms, and fecal streptococcus, were analysed by Korea Standard Method for Examination of water and Standard Method. Particularly, the mEndo Method of Membrane Filtering Method for total coliforms and mFC method for fecal coliforms were employed respectively. Fecal streptococcus was analysed by Membrane Filtering Method.

2.3.5. Algae

Analyses for Chlorophyll-a and blue algae were conducted. For the analyses of chlorophyll-a and blue algae, Acetone Extraction Method and Mirror Assay Method were used respectively.

3. Result and Discussion

3.1. Flow Rates

Annual average flow rate for the period of 2000 to 2003 was disclosed to be 554 cubic meter per second (CMS). The monthly minimum value was 172 CMS of January, and the maximum value was 2,519 CMS of August. the maximum and minimum values differed by 14.6 ratio (Table 4). The relationship between the flow rate and water quality appeared to be different among water quality parameters. Concentrations of total coliforms and fecal coliforms were disclosed to be inversely proportionate to the flow rate, and the concentration of total phosphorus was shown to be proportionate to flow rate (MOE, 1999-2003). The concentration of chlorophyll-a and biochemical oxygen demand was inversely proportionate to flow rate. And it was investigated that suspended solid was proportionate to and dissolved oxygen was inversely proportionate to flow rate.

3.2. Result of the Analyses

3.2.1. Water temperature

For the water sampling period, water temperature in the study area ranged 18°C-24°C (Fig. 3). Water temperature had close relationship with concentration of dissolved oxygen. Saturated dissolved oxygen concentration was decreasing with increasing tem-

Table 4. Flow rates of the study area (unit: m^3/sec)

month \ year	2000	2001	2002	2003	Average
January	230.34	144.03	153.80	159.89	187.19
February	195.06	146.56	141.39	152.39	170.81
March	220.23	192.73	152.53	205.59	206.48
April	189.13	171.53	168.11	350.27	180.33
May	169.53	139.06	332.76	814.45	154.29
June	298.77	233.79	309.12	493.63	266.28
July	439.42	1,036.27	405.00	1,271.14	737.85
August	1,202.82	964.88	6,152.62	1,754.45	2,518.69
September	1,190.05	161.65	932.32	1,954.72	675.85
October	337.07	156.70	302.46	302.71	246.88
November	298.62	135.42	226.26	275.92	217.02
December	237.63	157.72	156.84	163.35	197.68
Average	417.76	306.05	818.70	673.13	553.91

perature. At 20°C the saturated DO concentration was roughly 8.84 mg/L. And DO in water, which was consumed by oxidation of organic matters and metabolism of microorganisms in water, could be used as a barometer for water pollution. On the contrary, because DO could be oversaturated by photosynthesis of algal, DO, together with hydrogen ion, was known to provide basic information about the over-all quality of the water.

3.2.2. Dissolved oxygen

The DO for the points of Paldang 1 and Paldang 2 in the 3rd and 4th water samples appeared to be oversaturated and for the other points DO were almost saturated. It seemed that DO concentrations of Paldang 1 and Paldang 2 were affected by algal, and it was considered that the decrease of DO in the 2nd water samples was due to the increase of flow rate by the rainfall of low DO contents (Fig. 4).

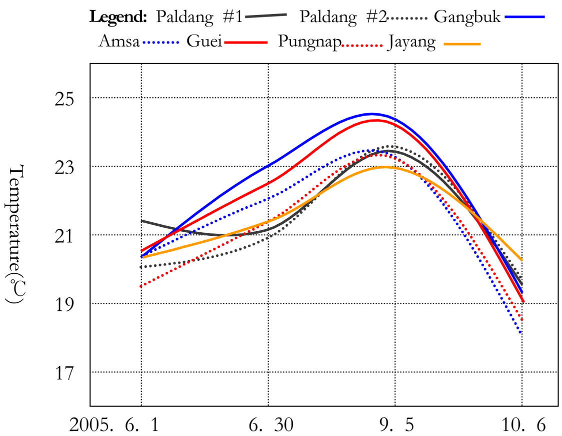

Fig. 3. Variation of water temperature.

3.2.3. Hydrogen ion

Hydrogen ion concentration of surface water is generally determined by the amount of carbonates and carbon dioxides dissolved in water. With high concentration of carbonates the solution tends to become alkaline, and acidic for high concentration of carbon dioxide, and usually the surface water tends to become neutral or weak alkaline. In lentic water system, such as lakes, algae flourishes and the water becomes alkaline because of consumption of free carbonates by photosynthesis of algae. Influent of wastewater into a water body changes it to be acidic by the carbon dioxide and a sort of organic acids released by the metabolism of organic matter decomposing microbes. In this study, that the hydrogen ion concentration in the 1st water samples was high in general seemed due to algal activity. And that the hydrogen ion concentration in the sample taken after rainfall fell to the neutral zone seemed due to the effect of neutral rainfall (Fig. 5).

3.2.4. Biochemical oxygen demand

As an organic indicator of the water quality, BOD has been widely used. Organic matters impose direct impact on DO concentration in water when microbes in water consume DO in the course of aerobic decomposition of the organic matters. As the 2nd, 3rd and 4th

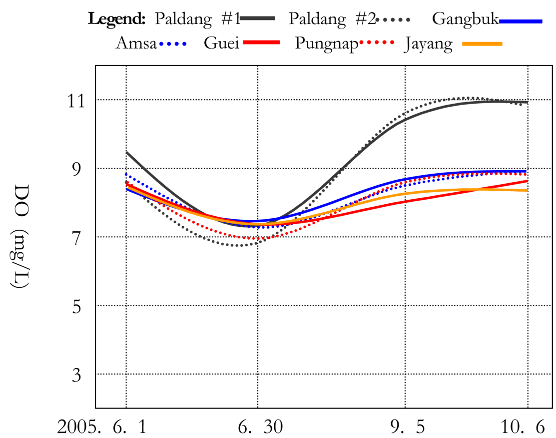

Fig. 4. Variation of DO concentration.

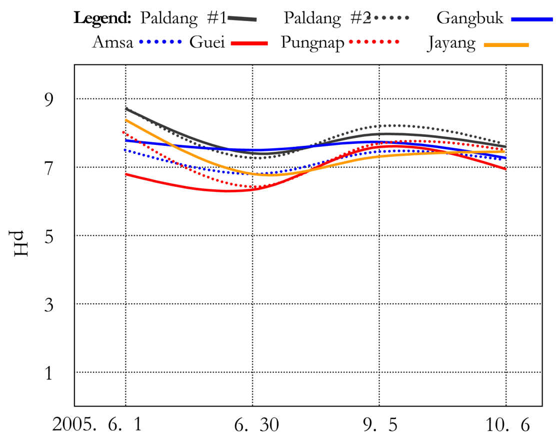

Fig. 5. Variation of pH.

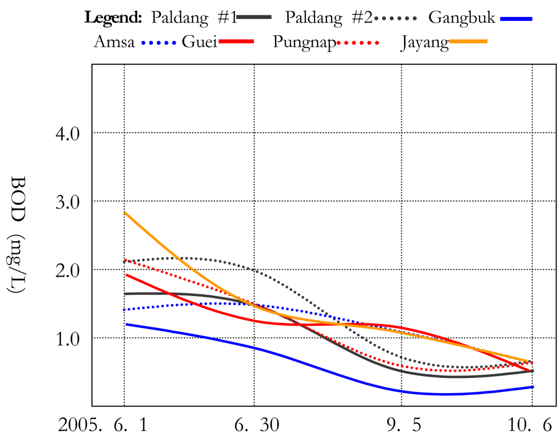

Fig. 6. Variation of BOD concentration.

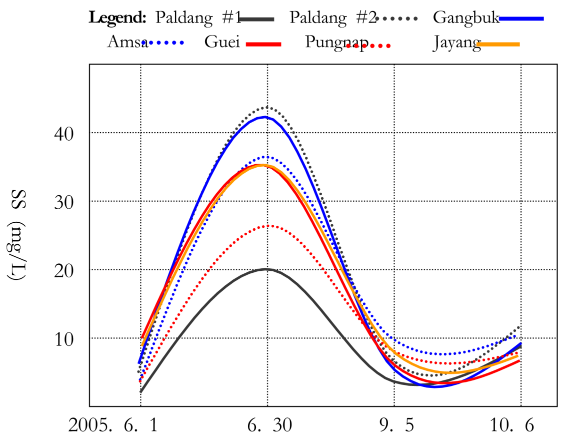

Fig. 7. Variation of SS.

samples showed, in comparison with the 1st sample, a tendency of decreased DO concentration seemed due to the dilution and decomposition of organic matters in water column by the increased flow rates (Fig. 6).

3.2.5. Suspended solid

Suspended solids are colloids of organic and inorganic matters, which is 0.1 μm-2 mm in size and insoluble in water. Suspended solids are turbidity inducing matters, disturbing the photosynthesis of phytoplankton, and killing fishes by stuffing the gills, thus imposing malignant impact on aquatic ecosystem. Moreover, in relation to water treatment processes, as the suspended solid is acting as a shield against disinfection for pathogenic microbes, it becomes the cause of overdose of disinfectants or ultraviolet radiation necessary in the process. In general, rainfall was followed by a soil erosion and run-offs of suspended solids into water bodies, thus increasing the concentration of suspended solids in the headwaters. The sample taken on June 6, 2005, just after the rainfall, recorded the highest of suspended solid concentration among others (Fig. 7).

3.2.6. Total phosphorus and Total nitrogen

T-P and T-N were major nutrients for eutrophication of lakes. In a water body of low flow speed there was a high probability of algal growth. The concentration of the T-P and T-N of the samples taken on June 30, 2005, just after the rainfall, showed the highest ones, being considered because of run-offs of the eroded soil and the nitrogen and phosphorus accumulated on the surface of earth (Fig. 8, Fig. 9).

3.2.7. Total coliforms

To know the quality of water, together with the analysis of physiochemical indicators, the analysis of micro-biological indicator is necessary as well. Because of its analytical easiness, rapidity and economics, total coliforms has been widely used as a bacterial indicator. The sample taken on June 6, 2005, just after the rainfall, recorded the highest of total coliforms among others (Fig. 10). That is considered because of run-offs of the bacteria loaded excretion accumulated on the surface of earth.

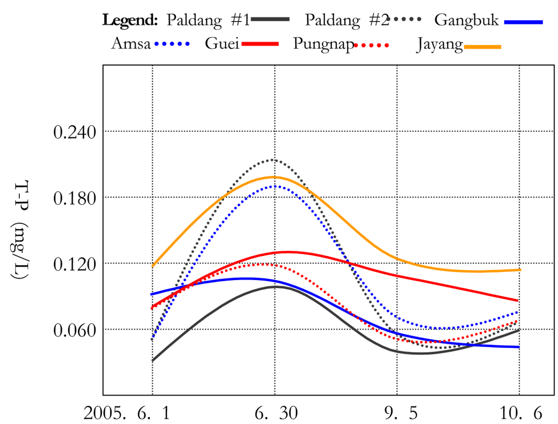

Fig. 8. Variation of T-P concentration.

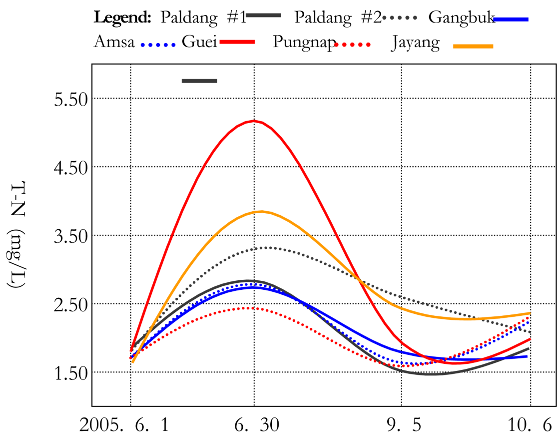

Fig. 9. Variation of T-N concentration.

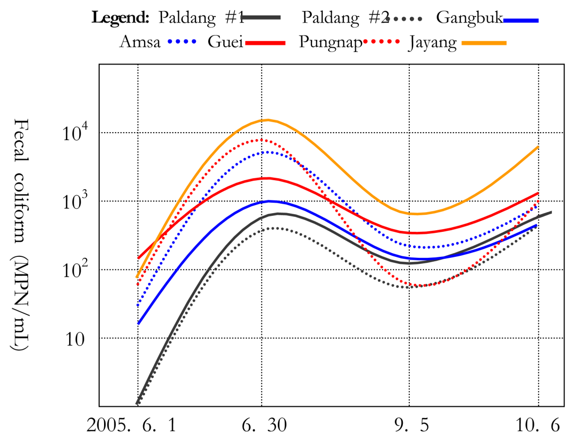

Fig. 11. Variation of Fecal coliforms concentration.

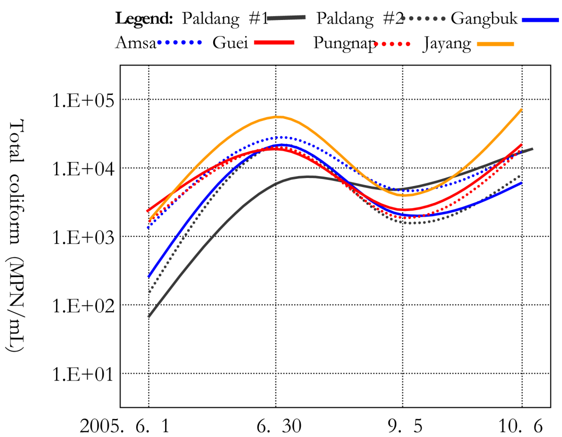

Fig. 10. Variation of Total coliforms concentration.

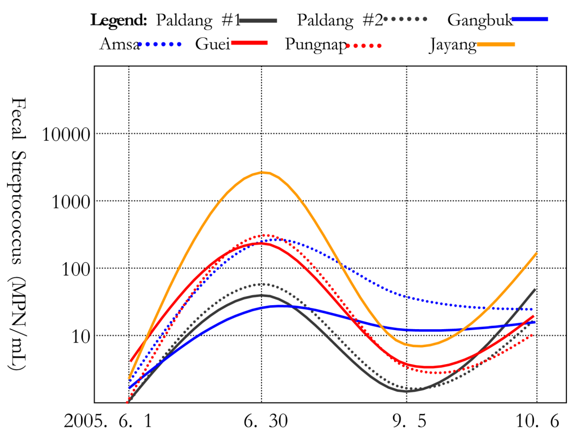

Fig. 12. Variation of Fecal streptococci concentration.

3.2.8. Fecal coliforms

Although fecal coliforms are often found in places which have no direct relation with excretion of warm blooded animals, they are more reliable than total coliforms as an indicator for pathogenic microbes. As that of total coliforms is, the concentration of fecal coliforms is higher after rainfall and in lower stream. This infers that the major sources of fecal coliforms are Gungchonchun, Wolmunchun, Hongreungchun, Wangsukchun, and Godukchun, which flow into the upper stream of the study area (Fig. 11).

3.2.9. Fecal streptococcus

Fecal streptococcus is a gram-positive coccus, facultatively anaerobic, ball-shaped bacterium. In comparison with fecal coliforms, it occurs in low concentration in excretion. However, because it survive the water treatment processes well, does not breed, and have short life span in water, it has been used as a complimentary indicator for fecal coliforms for water pollution by excretion. As been seen, the concentration of fecal streptococcus after rainfall rapidly increased (Fig. 12).

3.2.10. Chlorophyll-a

At most of the sampling points the concentrations of Chlorophyll-a were measured less than 10 mg/m^3. In the 1st survey, it was shown that the concentration of chlorophyll-a increased gradually along the stream downward, but in the 2nd survey, with the increased flow rate and higher concentration of suspended solids, it was disclosed the concentration in lower stream was lower than that in upper stream (Fig. 13). When the concentration of chlorophyll-a exceeds 15 mg/m^3 and 25mg/m^3, algal alert and algal warning are issued respectively.

3.2.11. Algae

The blue-green algae of phyto-plankton classification group occurs massively in eutrophied waters and many toxic species like mycrocystine are included. In case of such toxic matter being included in headwaters, some of its harmful effects on human health can be realized through water treatment processes and distribution systems. When the number of blue-green algae cells exceeds 500 counts/mL and 5,000 counts/mL, algal alert and algal warning are issued respectively. In the 1st, 2nd, and 4th survey, maximum concentration of

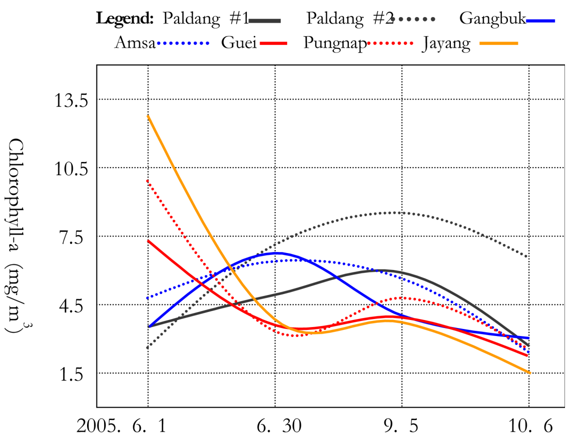

Fig. 13. Variation of Chl-a concentration.

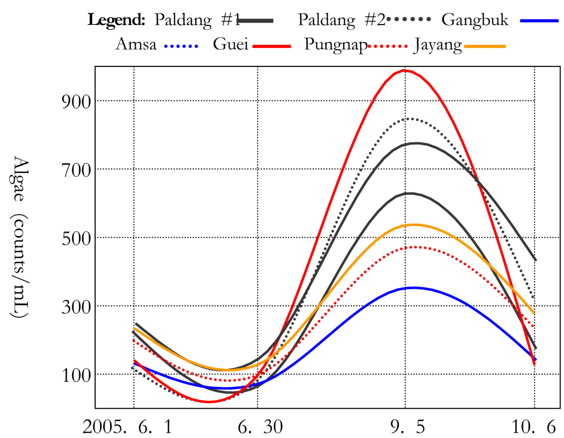

Fig. 14. Variation of Algae counts.

algae was 430 counts/mL, well under the count for algal alert, but in the 3rd survey, maximum concentration of algae was 1,100 counts/mL, and the average for the 7 points was 673 count/mL (Fig. 14).

3.2.12. Heavy metals and Anionic surfactants

In this survey, almost no heavy metals such as cadmium, arsenic, mercury, lead, and chrome, and organic compounds such as anionic surfactants, were detected. Other metals analysed in this survey such as ferrous, zinc, copper, and manganese, showed concentration range of 0.004 mg/m^3-0.730 mg/m^3, except copper, which was not detectable. For heavy metals, such as cadmium, and mercury, that should not exist in headwaters, were not detected. However, in the 1st and 2nd survey, the variations of concentrations of inorganic matters such as ferrous, manganese, etc., which were widely distributed in natural environment, was remarkable. The higher concentrations of them for the 2nd survey than for the 1st one was considered that the inorganic matters in soil were eluted and washed out by the rainfall into the river or the heavy metal ions in the sediment of the river bed moved up to the water column through mixing exercise of the water body.

4. Conclusion

To know the water quality of the 25km reach of the headwaters from Jamsil Submerged Weir to Paldang Dam in Han river, water samples for 7 sampling points were taken for 4 times for each of them and analysed for each of samples for 23 water quality parameters, which were related directly or indirectly with some of the criteria water pollutants of drinking water provided in Drinking Water Management Law. The results of the analyses were as follows;

1. Water temperature ranged 18.0-24.3°C and the pH ranged 6.4-8.8.
2. DO concentrations were measured to be in the range of 6.8-10.9 mg/L. Concentrations of BOD showed a range of 0.5-2.8 mg/L, the high concentration values for the dry season, and the concentration value of as

low as 0.5 mg/L for the rainy season due to the increase of flow rate after rainfall and its assimilative effects.

3. Suspended solids, except for the event of rainfall, did not exceed a concentration of 12 mg/L, but in the event of rainfall, the concentration values rose as high as 44 mg/L.
4. Total phosphorus showed concentration values ranging 0.032-0.204 mg/L. The concentration values for all of the points in the event of rainfall exceeded 0.100 mg/L. Total nitrogen showed concentration values, ranging 1.50-5.10 mg/L. Total nitrogen concentrations were also high after rainfall, showing excess of 2.50 mg/L for all points.
5. Concentration of total coliforms showed a range of 73-82,000 counts/100 mL. Although its values rose up greatly after rainfall, a high concentration value for the non-rainy season in the 4th survey was also checked. Fecal coliform concentration ranged 0-12,000 counts/100 mL, showing high concentration values for the rainy season and for the dry season in the 4th survey. Fecal streptococci concentration ranged 0-3,100 counts/100 mL, showing a variation of concentrations between the events of rainfall and no rainfall, similar to those of total coliforms and fecal coliforms.
6. Chlorophyll-a concentration showed a range of 1.5-12.7 mg/m^3, and algae a range of 68-1,100 organisms/mL.
7. Anionic surfactants and heavy metals were not detected or under detection limits.

As summarized above, water temperature, hydrogen ion, dissolved oxygen, and biochemical oxygen demand all showed the concentration values well below the water quality criteria of headwaters. But for the suspended solids, in the event of rainfall, the concentration values rose drastically as high as those interfering with the water treatment process. The concentrations of chlorophyll-a and blue-green algae affected by influx of plant nutrients such as total phosphorus and total nitrogen, appeared to be under water quality criteria for source water, and those of heavy metals and organic compounds were also under water quality standards. However, microbes, such as total coliforms, fecal coliforms, and fecal streptococci, well exceeded the source water quality criteria. Particularly, samples taken at Am-sa, Guei, Pungnap, and Jayang water intake station were all over 1,000 counts/100 mL of fecal colifoms. Fecal streptococci showed a concentration exceeding 77 organisms/100 mL.

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