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FIELD RESEARCH ON DOMESTIC WASTEWATER FROM A SLUM IN BANDUNG CITY

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SYNOPSIS

Many metropolises in Southeast Asia have slums, where the water environment and hygiene conditions have deteriorated on account of untreated wastewater. In this study, field research on water use, wastewater, and its effect on a river in dry season was conducted at a slum in Bandung. This study showed the actual conditions in the slum where most of the domestic wastewater was discharged with no or inadequate treatment. From the comparison of pollutant flux between domestic wastewater and canal water, the runoff rate was evaluated as roughly 0.7, 0.4, and 0.4 for NH_4-N, PO_4-P, and COD, respectively. Domestic wastewater seemed as the main cause of water pollution. The pollutants originating from excreta were estimated at 16%, 44%, and 31% of the domestic wastewater in NH_4-N, PO_4-P, and COD, respectively. The improvement of the slum sanitation system appears to be of high priority.

INTRODUCTION

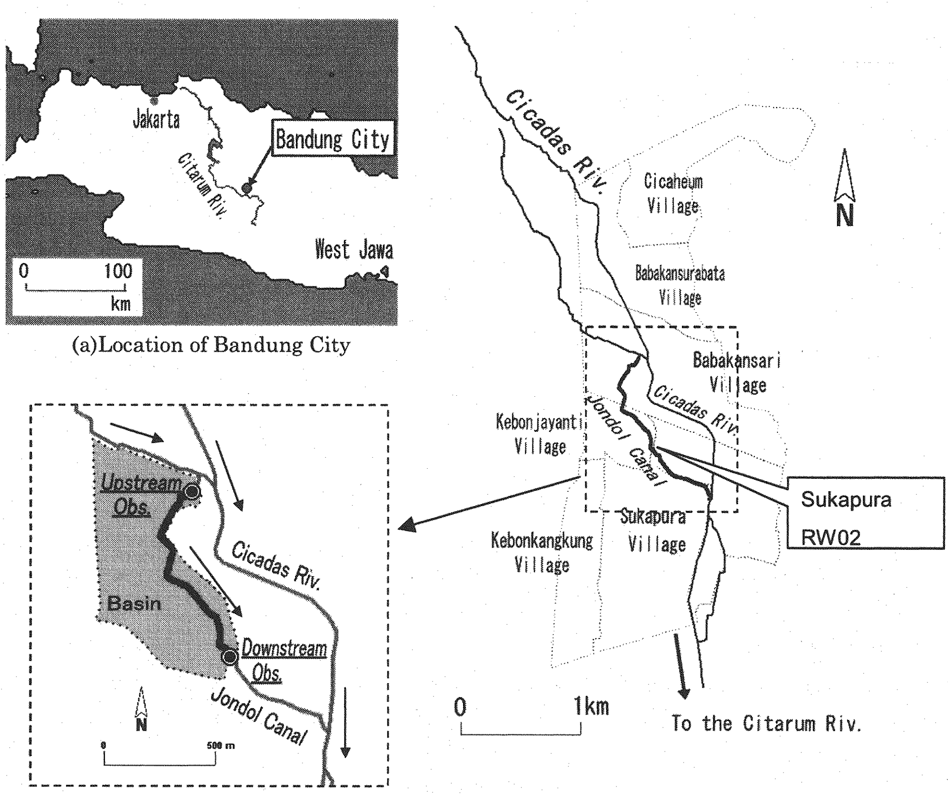
In Southeast Asian countries, the water environment of many cities has been heavily deteriorated. Overpopulation and a lack of wastewater treatment facilities are some of the reasons for this deterioration. Therefore, domestic wastewater discharge is considered to be one of main reasons (6), (10), (11). In such situations, it is considered that human excreta in domestic wastewater may discharge into rivers or groundwater, and thereby making the problem more acute with regard to water utilization and hygienics. Bandung City, which is the study site of this study, is one such city.

Slums are one of the key areas for studying the rehabilitation of the water environment in such cities. UN-HABITAT (12) estimated that 40% of the urban population in Asia lives in slums. However, the slums often do not lie under the jurisdiction of the administrative framework. Therefore, they often have local and social systems and sometimes even a self-constructed infrastructure. These aspects of slums are not reflected in official statistics. There exist only fragmentary and qualitative reports on the actual water environment in slums (8).

We carried out field investigations in a typical slum in Bandung City, Indonesia, for the purpose of understanding the actual water environment comprehensively and quantitatively. This study shows the results in relation to water usage, domestic wastewater discharge, river water quality, and discussions on their relations.

STUDY SITE

Bandung City is the fourth biggest city in Indonesia with a population of 2.5million (2). It is in the inland part of west Java and is located upstream of Citarum river, which is a major water source of Jakarta (see Fig. 1 (a)). Therefore, water pollution in Bandung City has a direct bearing on the problem of water pollution in Jakarta.



(a)Location of Bandung City

(b)Kiaracondong Sub District

(c) Observatories and catchment

Fig.1 Location of studied area

There are public offices, health resorts, and houses of high-income families in the northern part of the city. In contrast, many low-income families live in the southern part. Only 16% of the domestic wastewater generated in Bandung City is treated in a treatment plant located in the suburbs (15). No other big treatment plant exists in the city.

Kiaracondong sub-district is located near the center of Bandung city. It is well known as the biggest slum area in the city. It has a population of 116,000 in an area of 6.1 km^2. This sub-district consists of 6 villages (see Fig. 1 (b)), and each village consists of 11 to 18 residence groups called RW in Indonesia. Furthermore, each RW consists of around 10 smaller units called "RT," which includes 10 or more families.

The field survey was conducted in Jondol Canal, which flows through the center of Kiaracondong. The canal flows into Cicadas River, a tributary of Citarum River. No house in the area was connected to sewerage system with treatment plant. During the dry season, the canal water is nearly akin to raw sewer. We thought that we could quantitatively estimate the contribution of pollutant load from the slums by the measurement of the water quality and flow rate in this canal in the dry season.

INTERVIEW SURVEY

Method

We conducted an interview survey of 62 families living near the canal. The purpose was to understand the water cycle in this area and also to obtain the data for the validation of the measurement results. The measurement cases were limited, as shown below; hence, we should check the accuracy of the measurement results in comparison to the area average. This survey was carried out in 2004.

All the interviewee families belong to RW02, Sukapura village, which has population of 1477, households of 410, and area of 0.03km^2. One of the authors has an associate in this RW; therefore, the people were cooperative, and we could carry out the survey safely and smoothly. The interview survey was conducted on the following major items: water source, water usage, type of toilet, and wastewater discharge.

We prepared a questionnaire based on preliminary research, and the researchers or collaborators visited each house to conduct the interview. With regard to water usage, we inquired regarding its amount in terms of the number of buckets or tanks and calculated it later. Most of the people in this area used water not from taps but from buckets or tanks. Therefore, the value in terms of the number of buckets or tanks appeared to be reliable.

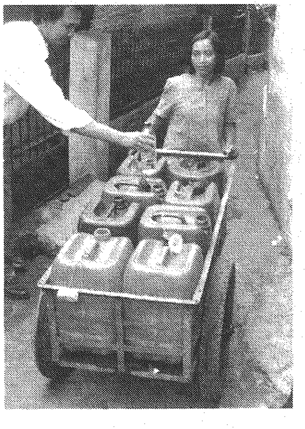


Photo 1 Water vendor

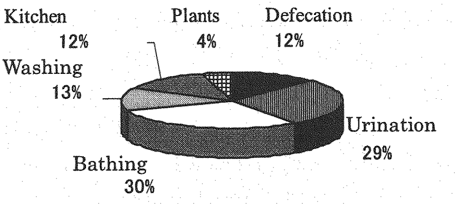


Fig.1 Water usage for each purpose

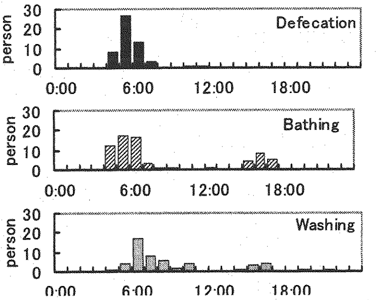


Fig.2 Time distribution of defecation, bathing and washing

Results of Water Usage

According to local statistics in 2004, the water supply coverage is 21% in RW02 Sukapura village. Families without water supply obtained water from "CORSEN," which is a type of shared tap. This tap has one owner, and people pay him/her and collect water in a plastic tank or bucket by themselves. For example, the cost of water from a CORSEN was 250 rupiah/20 liter or 5,000 rupiah/capita/month. One thousand rupiah is approximately equivalent to 0.11 US dollars. Roughly, one CORSEN exists in an RT. Also, water is available from water vendors who carry around 10 plastic tanks in a cart (see Photograph 1). They buy water from CORSEN, which is sometimes at a lower price by an agreement with the owner, and carry it to sell to the aged or families who reside far away from CORSEN or other water sources.

Moreover, many wells also exist. People also use these wells for water; however, they do not use them for drinking and cooking because the water in such wells contains too much iron and is also contaminated by E-coli (9).

The results of the interview on water usage are as follows. Total water usage was 89 liter/capita/day on an average. The averaged water use for each purpose is shown in Figure 2. The largest proportion of the used water was consumed for toilet purposes (41%), including urination and defecation. The next largest was for "bathing" (30%), followed by "washing" (13%) and "kitchen" (12%) activities. The result that toilet consumption of water is the largest is similar to the results obtained in our research in the slums at Metro Manila, Philippines (14).

Figure 3 shows the summary with regard to water use time for three purposes: "defecation," "bath," and "wash." The total volume of these waters corresponds to 55% of the total water usage, as shown in Figure 2. Water for other purposes was distributed on the basis of time, and a clear answer was not obtained.

Types of Toilets

According to the local statistics in 2004, 87% of the houses had private toilets and the others used shared toilets.

Photo 2 Toilet with ceramic stool

Photo 3 Toilet with cement step only

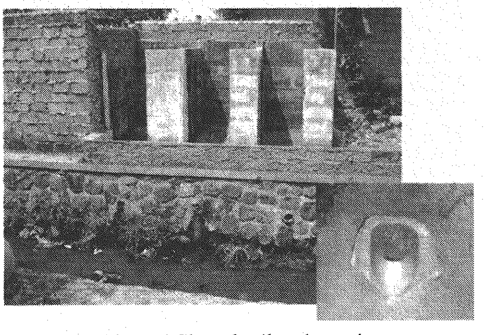


Photo 4 Shared toilet along river

A typical type of Indonesian toilet has been reported as a pour-flush-type squatting toilet (4). The observed domestic toilets were basically the same, but some had only steps without a bowl, and some toilets only had a hole (see Photographs 2 and 3). All these toilet types are categorized as toilets. Indonesians usually clean up their anus or urethral opening with water after defecation or urination. They use a pail (1 - 2 liter) to pick up water from bucket or tank. This pail is used for flushing the toilet as well as bathing. The toilet and bathroom are not separate in most of the houses.

In 53% of the houses of the respondent families, wastewater from the toilet or bathing activities was directly discharged into the natural water body. In the remaining 47%, the wastewater was treated using a septic tank. However, in this case, the septic tank was simple type and the treatment efficiency was originally low (13). Furthermore, it required regular sludge removal. With regard to this, we interviewed a worker who was involved in sludge removal in this area and found that all the removed sludge was thrown into the canals. Wastewater, except that from the toilet and bathing, was directly discharged from all the respondent houses.

Shared toilets were located beside the Jondol canal or ditch, and their wastewater was directly discharged (see Photograph 4). Some of these toilets were constructed by the residents and some by the local government. The quality of construction is rather low in comparison to the private toilets; however, they are sufficiently clean inside because the users pour water after use.

FIELD MEASUREMENTS

We measured domestic wastewater and canal water for the purpose of studying the water balance and pollutant balance in the slum. The catchment area under this study is occupied by houses and little farms; factories or other large facilities are not included in this area. Therefore, the side-inflow to the canal appears to contain only domestic

Table 1 Wastewater observed families

Family Type	Family size	Water supply	Toilet	Measurement period
1. Four person	4	private	private / water flush / no treatment	24 hours from 11:00 a.m 11st Aug. 2004
2. Live alone	1	shared	private / water flush / no treatment	24 hours from 10:00 a.m. 1st Sep. 2005
3. Tenement	11	shared	private / water flush / no treatment	24 hours from 10:00 a.m. 24th Aug. 2006

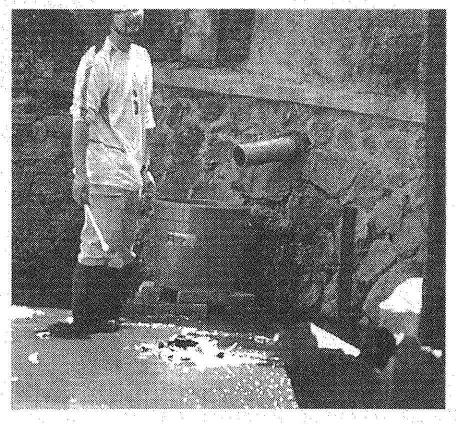


Photo 5 Domestic wastewater measurement

wastewater and natural components such as rainfall. Our objective in this study is to discuss the effect of domestic waste water on river water. Hence, the observation was conducted at the end of the dry season in order to avoid the unsteady effect of rainfall. With regard to other components, there is considerable water usage before prayers in the Islamic society. We will discuss this "religious component" in the next section. Feces and urine are the key sources of pollutants; hence, we measured them independently.

Domestic wastewater

We observed three cases, as shown in Table 1. All the houses are facing the Jondol canal, and the outlet pipes directly protruded from the canal wall. We placed a large bucket just below the pipe (see Photo 5). The measurement and samplings were conducted using this bucket at regular one hour intervals for 24 hours. Thesampled water was analyzed using a portable water-quality analyzer (Lambda 8022: Kyoritsu Chemical-Check lab. Corp.). These samples were analyzed as composite sample weighted by amount, except for "live-alone family". The reason why we prepared a composite sample was that the unstable fluctuation was assumed to occur due to the random urine inflow. In fact, the results of the "live-alone family" showed an unstable pattern; therefore, the following discussion uses only the total pollutant load in a day.

The analyzed components were NH_4-N, NO_2-N, NO_3-N, PO_4-P, and COD by the indophenol method, naphthylethylenediamine method, naphthylethylenediamine method with deoxidization, molybdenum blue method, and alkaline potassium permanganate method, respectively. The supernatant of the sample was analyzed by following the instruction manual of the water-quality analyzer. This measurement could not include the solid component of the pollutant load.

Following are the results of the measurement. Figure 4 shows the per capita domestic wastewater measurement results. The "4-person family" shows a sharp peak at night because water was used for washing the motorcycle by the husband of this family on the measurement day; this is an irregular component of the measurement.

The "live-alone family" shows a sharp peak at noon because all the meals were cooked around noon. Even though this is a routine, it was not very typical. Although these three cases show irregular patterns, a common trend of increased water usage was observed in the mornings and evenings.

The total per capita water use was 124.5 liter/day by the "4-person family," 95.0 liter/day by the "live-alone family," and 46.2 liter/day by the "tenement house." However, the usual water use of the "4-person family" was estimated to be 111.1 liter/day without considering the amount of water used for washing the motor cycle. On the other hand, the interview indicated that the water use was 89 liter/day/capita ranging between 44 and 231 liter. Summarizing these results, the representative amount of water use appeared to be roughly 100 liter/day/capita, and the observed water use of the "live-alone family" was the closest to the representative value in the three cases. The amount of water usage for a "4-person family" appeared to be rather large. On the other hand, "tenement houses" showed a very small usage, but it was included in the range of the interview survey results.

Table 2 shows the averaged water quality for a day. For a "live-alone family," the maximum and minimum values are also shown. NO_2-N and NO_3-N were ignored here because their amounts were considerably lower than that of NH_4-N.

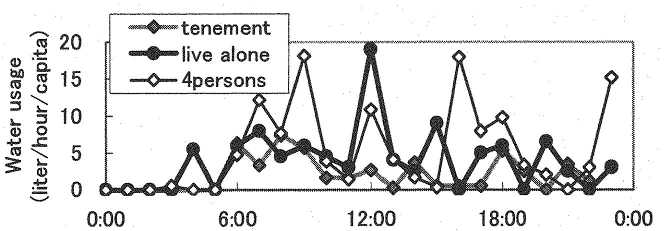


Fig. 4 Time series of water usage per capita

Table 2 Water quality of domestic wastewater

Family Type	Water usage (liter/day/capita)	NH_4-N (mg/l)	PO_4-P (mg/l)	COD (mg/l)
1. Four person	111	12.5	17.4	203.1
2. Live alone	95	83.1 (1.6 – 439.0)*	64.5 (7.7 – 276.5)*	377.5 (103.3 – 1503.5)*
3. Tenement	46	25.6	16.6	62.4

* ( ) shows minimum and maximum in 24 hours.

Table 3 Results of excrement analysis

	Urine(mg/l)			Feces(mg/g)		
	Male	Female	Average	Male	Female	Average
NH_4-N	1277	842	1060	0.27	1.59	0.93
PO_4-P	3046	1460	2253	2.14	2.73	2.44
COD	11286	7080	9183	44.76	44.10	44.43

Human Excrement

We measured the urine and feces of residents in RW02, Sukapura village. We asked 10 women and 10 men to provide urine and feces the day before the analysis. Thus, we obtained urine samples from 8 women and 6 men and feces samples from 6 women and 3 men. All these samples were analyzed immediately after weighing. The analyzed items and methods were the same as those of domestic wastewater. In the case of feces, 1.2-1.6 g of samples were homogenized in 0.5 liter of distilled water and analyzed. The analysis of four composite samples were conducted; the samples were grouped according to women/men and the urine/feces of each. The results are shown in Table 3. NO_2-N and NO_3-N were ignored here because their amounts were considerably lower than that of NH_4-N.

Jondol Canal

Figure 1(c) shows the measurement locations and catchment of this section of Jondol canal. The distance between the two observatories was 960 m. We examined the catchment area to be 0.41 km^2 with a population of 16,240 and 3,585 households; these values are based on previous investigations and local statistics. All the three abovementioned families were included in this catchment.

We placed the water-level gauge (Uizin Corp.: UIZ-WL100) at each observatory, and it automatically recorded the depth at regular 10 min intervals. On the other hand, we measured the flow rate by intermittently using an electromagnetic current meter (Alec Electric Co., Ltd: ACM-100D) in the observation period. As a result, we obtained the correlation curve between depth and flow (see Fig. 5) to convert the depth data to flow data.

Figure 6 (a) and (b) show the cross section of each observatory. At the downstream observatory, we made the cross section narrower with sand bags (see Fig. 6 (b)) because it was too shallow. The observation period was from August 31, 2005 to September 2, 2005. The canal water was sampled at each observatory at regular 1 h intervals for 24 h from 10:00 onwards on September 1, 2005. They were analyzed with respect to the same items and methods that were used in domestic wastewater measurement

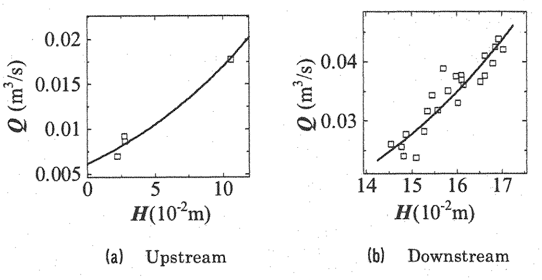


Fig. 5 Depth-flow correlation curve

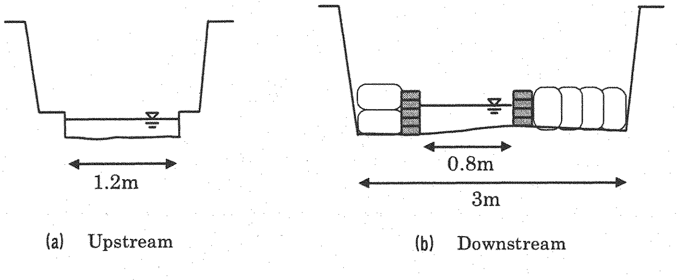
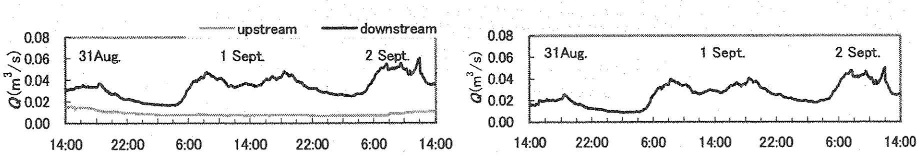
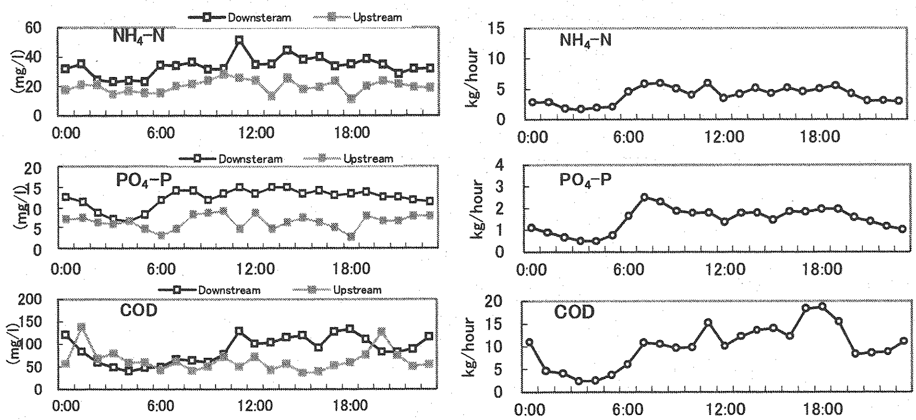


Fig. 6 Cross section of observatories



(a) Time Series of flow (b) Remainder of Downstream and Upstream

Fig. 7 Time series of flow rate in Jondol canal



(a) Water quality in Jondol canal (b) Flux increment in Jondol canal

Fig.8 Water quality and flux increment in Jondol canl

Figure 7 (a) shows the time series of the flow rate at each observatory. Figure 7 (b) shows the difference between downstream and upstream at each instant as a rough estimation of the side inflow. The graph shown in Figure 7 (b) shows two apparent peaks: one around 9:00 and the other around 18:00. This tendency corresponds to that of the observed domestic wastewater (Fig. 4). Figure 8(a) shows the time series of the concentration of NH_4-N, PO_4-P, and COD at each observatory. The results of NO_2-N and NO_3-N were not taken into consideration here because their values were significantly lower than that of NH_4-N. Each concentration was higher downstream; hence, the water quality appeared to have been deteriorated after flowing through the slum.

NH_4-N and PO_4-P showed high concentrations, except in the period between midnight and early morning. On the other hand, COD showed a low concentration from midnight to around 10:00, and it became high from noon to midnight. These fluctuation patterns appear to depend on the water usage pattern shown in Figure 3.

DISCUSSION

Water Balance

Before discussing the pollutant load balance, the water balance has to be checked. Table 4 shows the integrated result with regard to the water balance. In Table 4, (a) is the per day flow increment between two observatories, and (c) is the estimated total generation of domestic wastewater. The latter was estimated by multiplying each result of the measurement or interview survey with the catchment population. The scale of (c) is similar to (a), but it is rather small. The natural component is included in (a), and it is difficult to ignore this component. We assumed that the observed minimum flow rate is the nearest value to the natural component. This flow rate was observed in the early morning of

Table 4 Summary of water balance

		m^3/day
(a)	Increment in the Canal	2581
(b)	(1)− (Minimum flow)	1856
(c)	Domestic sewage × Population	
	i Interview	1445
	ii 4person family	1804
	iii Live-alone family	1543
	iv Tenement house	750
	v 100 litter/capita/day	1624
(d)	(c)i + Religous water	1815

September 1, 2005. The estimated "human activity component" is given by (b) after the deduction of the minimum flow rate from (a).

On the other hand, the probable component that is not included in (c) is religious water. Muslims pray five times a day, and they have to clean up their hands, face, and feet before each prayer. Muslims form 97% of the total population in Kiaracondong; hence, the amount of water used for prayer purposes appeared to be significant. We measured this water at one Mosque after installing a flow meter on the pipe for water supply. As a result, the water usage was estimated to be 4.7 liters / prayer / capita. Therefore, the total amount of water used in the catchment is estimated to be 370 m^3/day; this is obtained by multiplying the frequency of prayers among Muslins (= 5 times/day) with the Muslim population (= 15,753). This activity is held in both at homes and the mosque; therefore, it seems to be partially included in (c)-ii, (c)-iii, (c)-iv, and (c)-v. Only (c)-i excludes this activity since "religious water" was not an item in the interview survey. When we add this religious component to (c)-i, good correspondence is observed with (c). Moreover, if we add this amount as the maximum of the religious component to (c)-ii, (c)-iii, (c)-iv, and (c)-v, the total amount becomes roughly the same as (b). Thus, the water balance estimated by the observation results appears to correspond approximately.

Pollutant Load Balance

Figure 8(b) shows the time series of the net pollutant flux, which is derived as follows: the concentration and flow rate are multiplied with each other and are integrated over 1 h; finally, the upstream flux is deducted from the downstream flux for each hour. The results show a pattern similar to that of the concentration (see Fig. 8(a)).

Table 5 (b) shows the pollutant load of the domestic wastewater per capita per day estimated from the results of domestic wastewater measurement (see Table 2). As reference data, the reported values of the case in England (1) and Japan (7) were shown. The values obtained by the different methods are written in parentheses. The estimated values for the three families varied greatly. Therefore, we focus on the "live-alone family," which seemed to be the closest to the typical condition based on the discussion of water volume. Although the pollutant load from the "live-alone family" was larger than the other two families with regard to every item, they were roughly the same as that of the reference data with the exception of NH_4-N. With regard to the amount of NH_4-N, it was probable that NH_4 was generated by the degradation of urea. In fact, the amount of NH_4-N for the "live-alone family" is less than Japanese data, which is the total amount of nitrogen. We should have measured it along with the total nitrogen content. However, we were not able to do so because the analysis had to be carried out at the site.

On the other hand, Table 5 (a) shows the estimated pollutant flux in the canal; this value was converted to per capita per day. By utilizing the data of the "live-alone family," the runoff rate was estimated to be 0.7, 0.4, and 0.4 for NH_4-N, PO_4-P, and COD, respectively.

Contribution of Human Excrements

Table 5 (c) shows the pollutant load by excrement per capita per day. It was estimated from the excrement analysis (see Table 3). The daily amounts of urine and feces were assumed to be as follows. With regard to the feces, almost all the respondents (96%) reported the frequency of defecation to be once a day in the abovementioned interview survey. Therefore, we regarded the averaged weight of the feces sample (90.3 g) as the daily amount of defecation. As for urine, there were no actual data on the urine amount in the area. We considered 1.2 liter/day/capita as a reasonable average, as reported by Franceys et al. (3). In comparison to the reference data, as same as Table 5 (b), the estimated values were in a range similar to that of the reference data.

We estimated the contribution rate of pollutant load by excrement in domestic wastewater. Because the analysis of the canal water was carried out only for the dissolved part, this estimation includes the only the urine part. The contribution of NH_4-N, PO_4-P, and COD was estimated at 16%, 44%, and 31%, respectively. As for NH_4-N, the actual contribution seemed to be larger because of the additional NH_4-N from the degradation of urea in urine, as mentioned above. Furthermore, in the actual situation, the feces also seemed to release soluble pollutants while flowing. This part is supposed to be added to the estimated contribution. Thus, the contribution of excrement to domestic wastewater was considerable, and it seemed to considerably affect the water quality of the Jondol canal. The improvement of the sanitation system appears to be a high-priority issue with respect to the water environmental as well as hygiene.

Table 5 Estimated pollutant flux per capita per day

	NH_4-N (g/capita/day)	PO_4-P (g/capita/day)	COD (g/capita/day)
(a) Flux increase in the canal	5.90	2.18	14.86
(b) Living sewage flux			
i. 4person family	1.55	2.17	25.32
ii. Live-alone family	7.89	6.13	35.86
iii. Tenement house	1.18	0.77	2.88
Almeida et al. (1999)	2.38	6.68	(111.88)*
Nakanishi et al. (1986)	(11-14)**	(1.5-2.1)***	26-37
(c) Urine and feces flux			
i. Urine	1.27	2.70	11.02
ii. Feces	0.07	0.22	4.01
Almeida et al. (1999 UK) (urine + feces)	2.27	5.24	(48.33)*
Nakanishi et al. (1986 Japan) (urine + feces)	(9-11)**	(0.9-1.2)***	10-15

* COD by potassium dichromate method **Total Nitrogen *** Total Phosphorus

CONCLUSION

The findings of this study indicate that domestic wastewater was assumed to be the main cause of water pollution in the river flow through slum area. Pollutants form excreta were a measurable part of the domestic wastewater, and it was assumed to have considerable influence on the river environment. The improvement of sanitation systems is of vital importance in slum areas.

Although many developing countries have sewerage construction projects, many of them are stagnating or being delaying because of low budgets and other problems. Moreover, slum areas are always a low priority or not a target of these projects because many slums do not come under the jurisdiction of the administrative framework. However, the effect of domestic wastewater, especially of excreta, is seems to be relatively large in slums because they are overpopulated and have no effective treatment facilities, as this study showed.

Under the abovementioned circumstances, improvement of sanitation system, other than centralized sewerage system, becomes priority in slum. A septic tank or Jokaso is one such system. In terms of sustainability or effective recycle of materials, recently, composting toilet system becomes also prospective method (5). For the solution of water environment in slums, a feasible sanitation system should be introduced and applied.

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