A technical and economic comparison of nightsoil and sewerage systems in urban areas

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Abstract

Nightsoil systems are widely used as a means of disposal of human wastes in many urban areas in south-east Asia and elsewhere. A variety of collection, treatment and disposal methods are employed and deficiencies inherent in some of these methods are often attributed to be one of the principal causes of widespread public health problems in the communities served. This paper presents a review of the nightsoil systems currently practised in the urban areas of the Han River basin in the Republic of Korea. Data are included on nightsoil generation rates and characteristics and the paper presents an economic analysis of nightsoil systems compared to water-borne sewerage.

The evaluation shows that the vacuum cartage method of collection is hygienic and that the annualised cost of upgrading to conventional sewerage would be more than five times greater than the cost of the existing nightsoil system.

Study area

The Han River basin covers an area of about 24 000 km^2 in the north of the country and represents almost one quarter of the total area of the Republic of Korea. The climate is characterised by cold, dry winters and warm, wet summers with an average annual precipitation of about 1 300 mm/a. The average annual temperature is 11°C with typical winter and summer extremes of - 25°C and 37°C respectively.

The population of the basin is about 14 million, equivalent to one third of the total population of Korea. Seven major cities, including the capital Seoul, account for almost 85 % of the total population in the basin with the Greater Seoul area containing a population of 9,7 million. In 1982 nightsoil systems were used by about 40 % of the population in the Han River basin which may be compared to the situation in Japan where more than 60 % of the population still relies on nightsoil systems (Nakamoto, 1982).

Nightsoil collection

Nightsoil is stored in a vault, which in the cities is either a concrete or internally-rendered masonry tank, usually placed in an outhouse backing onto the street for ease of emptying. In rural areas oil drums are sometimes used. The Korean vault has a capacity ranging from 0,2 to 0,6 m^3 which is smaller than that in other countries where pour-flush toilets are used. In such cases a pour-flush water volume ranging from 2 to 6 *l* is common and the vault must be correspondingly larger, of the order of 1,7 m^3 for a family of six and an emptying frequency of every two weeks (Kalbermatten, Julius, Gunnerson and Mara, 1982).

Nightsoil collection in the cities is generally carried out by vacuum truck which is an efficient and hygienic system with very little spillage. The length of hose ranges from 30 to 100 m. In the more congested, older parts of the urban areas the streets are too narrow to permit access by vacuum truck and the traditional "pail-and-dipper" method is used. This method may give rise to spillage at the nightsoil vault, along the streets, or at the truck where the pails are lifted manually on top before pouring inside. The vacuum truck capacities generally range from 2,5 to 4,5 m^3 and in the major cities the trucks are operated by private companies. In provincial towns collection is usually by the municipality, with a small proportion being collected by farmers using a small tractor and trailer, the nightsoil being ladled from the vault into an empty oil drum on the trailer. In some towns, a tractor may also be used by the municipality to serve those areas which are not accessible to trucks.

Nightsoil treatment and disposal

The four treatment systems used in the Han River basin are heat treatment, anaerobic digestion, aerobic digestion and activated sludge as shown in Fig. 1. These are identical to the majority of those in Japan, as described by Magara *et al.* (1980). With the exception in Seoul of two Zimpro heat treatment systems each of 600 m^3/d capacity, and a two-stage activated sludge system of 400 m^3/d capacity, treatment systems are based on anaerobic digestion in the major cities and on aerobic digestion in the smaller cities and towns with the digester supernatant being treated by the activated sludge process in all cases. In locations where the installed nightsoil treatment capacity is not adequate to deal with all the nightsoil generated, the excess is discharged to protected seepage/evaporation lagoons or collected by farmers. In Seoul, however, 1 000 m^3/d excess nightsoil is discharged to the two sewage treatment plants which are designed to treat a total of 360 000 m^3/d sewage.

Aerobic digestion systems generally have a capacity of 15 to 50 m^3/d and comprise an aerated holding tank with one to two days retention followed by an aerobic digester of seven days retention, aeration being by diffused air. The supernatant has a typical BOD of 4 000 to 5 000 mg/*l* which is diluted with about 20 volumes of surface or ground water prior to treatment by activated sludge with an aeration time of 8 h. Anaerobic digestion systems generally have a capacity of around 100 m^3/d and the combined capacity of the two-stage heated digesters is one month. The gas produced during digestion is used for digester heating.

Sludge disposal in all cases is to land and in many smaller cities and towns farmers and horticulturalists collect the sludge from the treatment system for use in orchards and occasionally on rice padis. Sludge dewatering by centrifuge is the most common process in the more modern installations with filter plate presses being used at the two heat treatment systems in Seoul. Drying beds are common at the smaller installations and although these work well in the warm weather, they are not effective during the winter and sludge-holding lagoons are necessary. The most common method of dewatering raw nightsoil screenings is by drum screen with the dewatered screenings being buried on land or incinerated.

Total BOD removal rates in Japanese systems are reported to range from 84 to 98 % in aerobic systems and from 90 to 99 % in anaerobic systems (Magara *et al.*, 1980). The Korean systems generally achieve an overall BOD removal of the order of 98 to 99 % although the actual purification efficiency achieved in the

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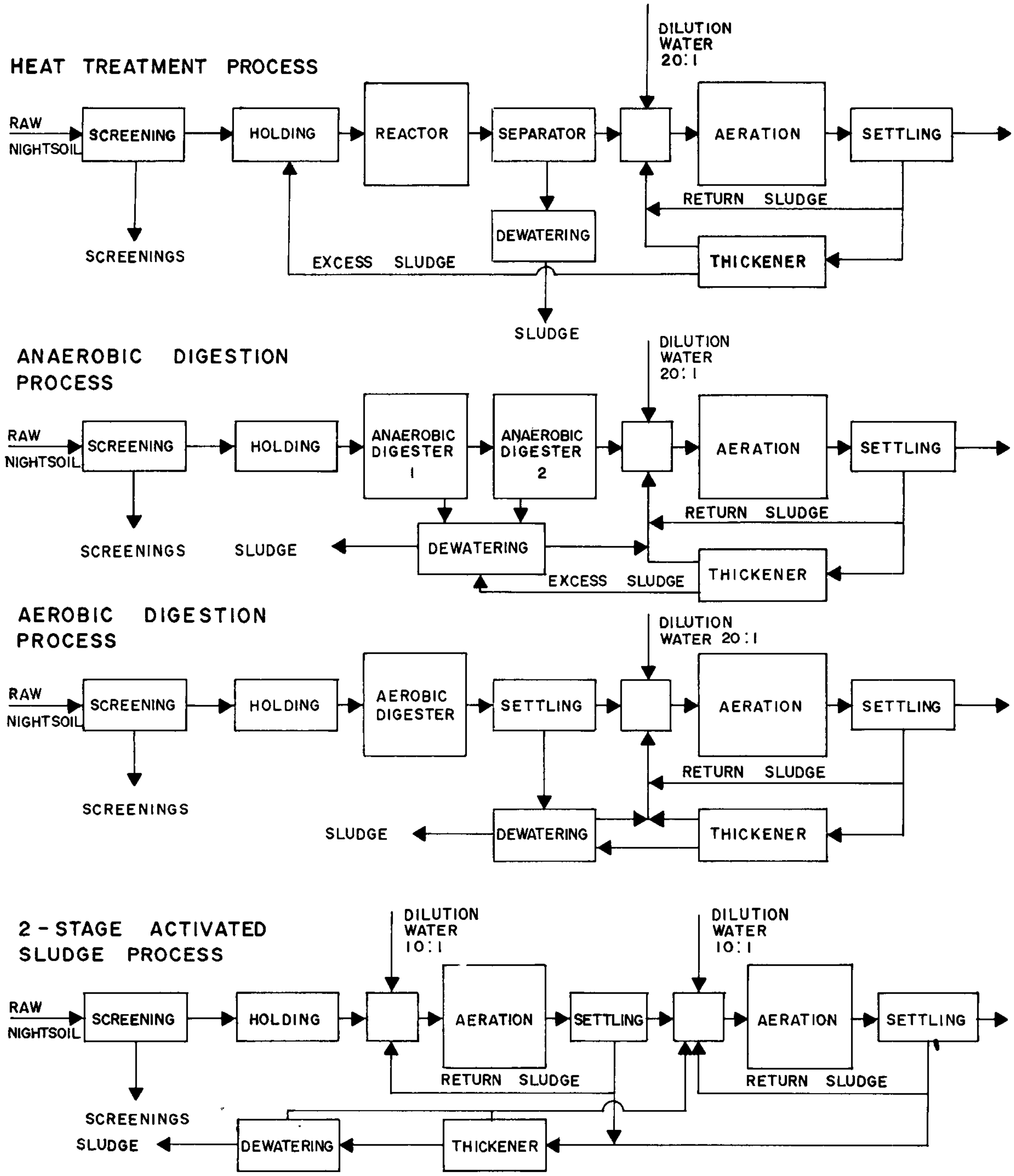

Figure 1
Schematic flow sheets of nightsoil treatment processes in Korea

supernatant treatment process to produce a final effluent BOD of 100 to 400 mg/*l* is only about 50 % assuming that the reactor, digester or aerator supernatant before dilution with clean water contains 4 000 to 5 000 mg/*l* BOD.

Samples from the heat treatment and two-stage activated sludge systems in Seoul showed a reduction of faecal coliforms from about 10^{10}/100 m*l* in the feed nightsoil to about 4×10^3/100 m*l* in the final effluent. Samples of sludge from all categories of nightsoil treatment systems were examined for viable human parasite ova. Sludge from one of the heat treatment systems in Seoul contained *Ascaris* and *Trichiuras* ova. Although studies reported by Kim *et al.* (1977) show that *Ascaris* eggs in nightsoil are completely destroyed within one month at 30° C, the Seoul results and extensive data from elsewhere (Kalbermatten, Julius and Gunnerson, 1982) indicate that *Ascaris* ova survive mesophilic anaerobic digestion for 30 d.

TABLE 1
CHARACTERISTICS OF FAECES AND URINE (based on unit per day per person)

		Faeces			Urine			Total		
Age	**Sex**	*l*	**gBOD**	**gSS**	*l*	**gBOD**	**gSS**	*l*	**gBOD**	**gSS**
3	F	0,06	4,9	17,3	0,75	1,5	0,8	0,81	6,4	18,1
7	M	0,26	19,6	56,6	1,28	4,3	1,1	1,54	24,0	57,7
19	F	0,32	13,2	56,4	1,23	3,6	2,9	1,55	16,9	59,3
25	F	0,18	9,4	15,5	0,84	2,5	1,2	1,02	11,9	16,7
32	F	0,32	32,7	64,8	1,20	2,6	0,4	1,52	35,4	65,2
36	M	0,26	16,3	36,6	2,07	6,7	2,1	2,33	23,0	38,7
62	F[a]	0,21	127,0	60,9	5,55	45,5	3,6	5,76	172,5	64,5
Rounded log mean[b]		0,25	14	36	1,25	3	1	1,5	17	37

a Diabetic
b Excludes pollution load from diabetic

TABLE 2
METAL CONTENT OF NIGHTSOIL IN SEOUL

	Raw nightsoil		Sludge[a]	
Metal	**A (mg/*l*)**	**B (mg/*l*)**	**A (mg/kg)**	**B (mg/kg)**
Zn	8,940	5,836	1 750,4	1 192,1
Cu	2,066	2,470	388,4	273,9
Cr	ND	0,112	14,3	5,5
Pb	ND	0,189	42,9	47,6
Cd	ND	0,021	3,8	4,3
Ni	0,114	0,208	34,1	199,3

a Expressed on dry solids basis at 105°C
ND Not detected.

The most common operating problems in the Korean nightsoil treatment systems are excessive foaming in the anaerobic digesters, probably as a result of inadequate mixing, blockage of air diffusers in the aerobic digestion process and freezing of dilution water and final tanks during the winter. The two heat treatment systems are subject to frequent fouling of the heat exchangers and are costly to operate and maintain. Based on the extensive local operating experience, future urban nightsoil treatment systems in Korea will probably be anaerobic or aerobic digestion with supernatant treatment by activated sludge or stabilisation lagoons.

Nightsoil characteristics

Estimates of nightsoil volume typically range from 0,8 to 1,8 *l*/d per person (Kalbermatten, Julius, Gunnerson and Mara, 1982), an average volume in Japan being 1,4 *l*/d per person (Magara *et al.*, 1980). In the Han River basin the nightsoil generation rate was determined from a survey of collection truck emptying practices and a community survey of nightsoil areas covering almost 1 000 dwellings.

The survey data showed an average occupancy of 9,3 for dwellings served by nightsoil in Seoul, compared to 7,0 in provincial cities and 4,5 in newer apartment complexes served by cistern flush toilets. The higher average occupancy in the capital city was caused by the larger proportion of extended families and lodging houses, almost 20 % of the dwellings served by nightsoil in Seoul had an occupancy of 15 or more.

The average metered water use for all premises served by nightsoil was 86 *l*/d per person, compared to an average water use of 138 *l*/d per person for houses of a similar socio-economic level with cistern flush toilets and septic tanks. This suggests that the water used for flushing toilets represented 52 *l*/d per person, 37 % of the total domestic water use.

Average nightsoil collection frequencies ranged from once every 70 d in Seoul to once every 30 d in provincial cities. On the basis of a typical average vault volume in Seoul of 0,6 m^3 per dwelling the nightsoil production was about 8 *l*/d per dwelling, equivalent to 0,85 *l*/d per person. With a typical vault volume of 0,2 m^3 in the provincial cities and an average emptying frequency of 30 d, the nightsoil generation rate was 0,89 *l*/d per person, almost identical to that calculated in Seoul.

The Korean nightsoil volume is lower than that reported in many other areas. This can possibly be explained by the fact that pour-flush systems are not common in Korea and because wage earners and students may defecate at least once daily away from home when work-places and schools are provided with cistern flush toilets. In the dwellings surveyed in Seoul, an average of 3,4 persons per dwelling were classed as potential wage earners, based on persons aged eighteen years and over and on the family composition in general. Although urine may be discharged to the storm drainage system along with sullage, particularly at night, indiscriminate dumping of vault contents into the open storm drains is rare, since the Korean population has a high level of community awareness.

Magara *et al.* (1980) report that pollution loads in Japanese nightsoil average 19 g BOD/d per person (range 11 to 21) and 29 g SS/d per person (range 25 to 34). A typical BOD load of 22 g/d per person has been suggested by Mara (1978) from surveys in a number of countries. Historical data for pollution loads in Korean nightsoil based on surveys of pollution loads from individuals are shown in Table 1 (Hyundai, 1978), the average BOD of 17 g/d per person comparing reasonably well with that from other countries. Survey data from the three Seoul nightsoil treatment plants indicated a mean BOD load of 19 g/d per person based on a volume of 0,85 *l*/d per person and an average nightsoil BOD of 22 000 mg/*l*.

The data in Table 2 show the metal content of raw nightsoil and filter press sludge at one of the heat treatment nightsoil plants in Seoul. Since the sludge is dewatered without the addition of chemicals, the metal content of the sludge represents only the metals present in the raw nightsoil. On the basis of a nightsoil generation rate of 0,85 *l*/d per person the total metal content in raw nightsoil is of the order of 8,5 mg/d per person. The average metal content in the dried sludge of 1 978 mg/kg dry solids is similar to the average of 1 800 mg/kg in UK domestic sewage sludge reported by Williams (1975).

Sullage from dwellings with nightsoil systems

Historical data on sullage from individual house surveys in Seoul are compared in Table 3 with data from other countries. The USA data in Table 3 represent houses without major water-using appliances such as automatic dishwashers and garbage disposal units.

TABLE 3
CHARACTERISTICS OF SULLAGE
(based on unit per day per person)

Waste	Seoul[a]			Seoul[b]			USA[c]			USA[d]	UK[e]	Belgium[f]	West Germany[f]
	l	gBOD	gSS	*l*	gBOD	gSS	*l*	gBOD	gSS	*l*	*l*	*l*	*l*
Kitchen	–	–	–	–	–	–	18	8,34	4,11	15	29	15	16
Dishwashing	5,6	1,87	1,24	13,2	5,85	1,59	–	–	–	–	–	–	–
Rice washing	2,7	2,37	2,18	3,0	2,95	2,23	–	–	–	–	–	–	–
Clothes washing													
Machine	–	–	–	13,2	4,48	2,08	114	14,81	10,97	38	13	11	30
Hand	9,2	2,05	1,24	–	–	–	–	–	–	–	–	–	–
Household cleaning	7,6	1,44	1,55	–	–	–	–	–	–	6	3	22	–
Personal washing	–	–	–	10,2	1,56	0,74	–	–	–	50	28	38	42
Sink	4,8	0,72	0,49	–	–	–	–	–	–	–	–	–	–
Bath/shower	18,9	4,55	2,06	23,5	3,57	1,46	49	3,09	2,26	–	–	–	–
Total	48,8	13,0	8,76	63,1	18,41	8,10	181	26,24	17,34	189	110	128	118

a. Survey of 5 houses over 7 d in 1977 (Hyundai, 1978)
b. Survey of 8 houses over 5 d in 1981 (Office of Environment, 1981)
c. Witt *et al.* (1974)
d. Ligman *et al.* (1974)
e. Rump (1979)
f. Males (1975)

The Korean houses with washing machines generate only about half of the total sullage pollution load of the USA homes primarily because the Korean batch washing machines use far less water than the fully automatic USA product. The Korean data showed a mean water use of 44 *l*/kg clothes with a pollution load of 0,012 kg BOD/kg clothes (Office of Environment, 1981). The total water use represented about 50 *l* per machine wash, compared to the typical USA use of 130 to 200 *l* per wash.

One item in the Korean sullage which is not readily identifiable in sullage in the USA and Europe is rice washing, which represents almost 20 % of the total Korean sullage BOD and almost 30 % of the SS load. The water used for rice washing averages 3 *l*/d per person, equivalent to 14 *l*/kg rice. Since it is common for Koreans to visit public bath houses and saunas the personal washing pollution loads in Table 3 underestimate the total water used for this activity.

A 24-hour survey of a low-income nightsoil housing area with a contributory population of about 5 000 persons showed that sullage represented 12 g BOD and 11 g SS/d per person, with an average flow of 45 *l*/d per person. This load is comparable to the typical range of 10 to 18 g BOD/d per person derived from Kalbermatten, Julius and Gunnerson (1982) for developing countries and is almost identical to that of 13,0 g BOD/d; 8,76 g SS/d and 48,8 *l*/d per person shown in Table 3 for houses without washing machines.

Public health aspects

The public health level in the Republic of Korea is good when compared to health indicators in many other countries (World Bank, 1980). It is unlikely that the provision of water supplies has any significant effect on health levels in Korean housing served by nightsoil systems since domestic water use is generally well in excess of the threshold minimum of about 50 *l*/d per person below which water-supply related health problems become noticeable. The average use in houses with nightsoil systems and piped water supplies was 86 *l*/d per person, even in urban areas in provincial cities where the supply was from public standposts, the surveyed average use was as high as 62 *l*/d per person.

Although it is generally considered that nightsoil systems are less hygienic than cistern flush toilets, and that public health risks are greater as a result, it is difficult to establish a direct measure of health improvements resulting from improved excreta-disposal facilities when the level of service has improved beyond that where the community, particularly if it is urban, must no longer rely on indiscriminate defaecation. The use of vacuum cartage reduces the risk of spillage considerably and direct contact with faecal matter is therefore unlikely to be a common occurrence. One aspect which could have a detrimental effect on hygiene levels in houses served by nightsoil systems is the common lack of a tap or water container in the room containing the nightsoil vault, a factor which does not encourage hand washing after defaecation. However, this potential disease transmission pathway is not restricted to houses with nightsoil systems since reduction of the health risk is related to cultural as much as to technical factors.

Nightsoil is often a causative factor in the spread of parasite infestation if raw or partially-treated nightsoil is dumped on food crops. The role of contaminated fields and vegetables in the spread of *Ascaris* has been emphasised from studies in Korea, Taiwan and Japan (Feachem *et al.*, 1983). Although such dumping may be carried out occasionally in some rural areas of Korea, the national parasitic infestation rate is relatively low at about 10 % positive and is decreasing rapidly as a result of a steady improvement in overall hygiene levels and a programme of biannual mass chemotherapy treatment of the school population (Korean Society for Parasitology, 1981), (Soh *et al.*, 1973). The dramatic reduction in *Ascaris* infestation is compared in Fig. 2 with data from Taiwan (Korean Society for Parasitology, 1982) and Japan (Hayashi *et al.*, 1981), both countries where nightsoil systems and mass chemotherapy are widely used. In general, parasitic infestation rates tend to be lower in the Korean cities, 6 to 10 % positive, compared to 15 to 20 % positive in the small towns. These rates compare favourably with recent data reported by the Korean Society for Parasitology (1982) for rural and semi-rural areas of other Asian countries, for example Indonesia (positive rate 75 %); Philippines (68 %); Sri Lanka (80 %); Bangladesh (81 %) and Malaysia (25 %).

Differences in health levels between houses using nightsoil and those using septic tanks in Seoul were evaluated by analysing health records from school clinics in a number of residential areas. Socio-economic indicators such as housing type, occupancy, population density, elevation, air pollution level, etc., and gastrointestinal disorders (reported as stomach-aches) were matched against respiratory problems (reported as headaches) in an attempt to establish a control. The health records of about 40 000 students for 1981 and 1982 showed a frequency of about 16 000 complaints

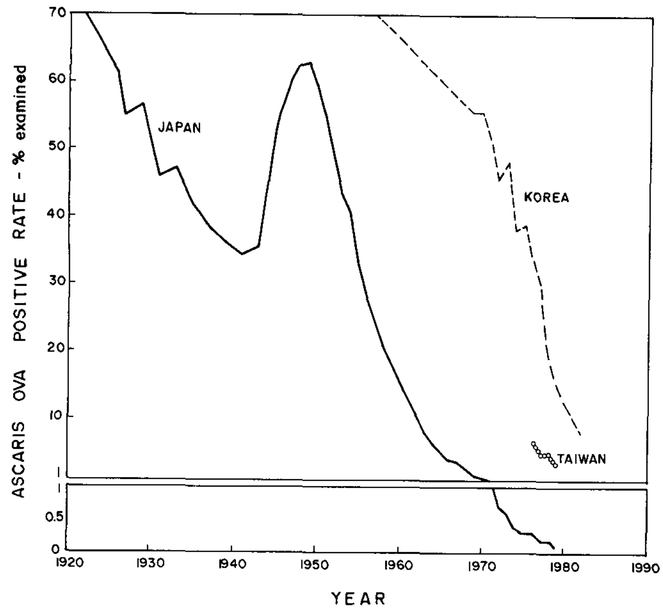

Figure 2
Annual Ascaris *infection rates in student groups in Korea, Japan and Taiwan*

of stomach-ache and 10 000 complaints of headache each year. Highest frequencies of stomach-aches were about 3,3/1 000 students in a middle class septic tank area, the lowest frequencies were recorded in a nightsoil area at about 0,7/1 000 students. Parasite levels, however, were higher in the nightsoil area at 7,6 % positive, compared to 3,8 % positive in the septic tank area. A similar result was reported by Soh *et al.* (1973) in a study of *Ascaris* rates in Seoul nightsoil and sewered areas. The school records showed similar frequency distributions in 1981 and 1982, suggesting that there may be some relationship between the incidence of stomach-ache and the general characteristics of the local community. However, the differences were slight and the study showed no statistically discernible health differences between houses with nightsoil or septic tank systems. In general, it can be concluded that with the exception of the smaller towns where some nightsoil may be collected on a relatively irregular basis by farmers, the nightsoil collection and disposal systems in Korea are efficient and are being carried out in a hygienic manner. The public health risks with the vacuum collection system as it is currently operated are negligible.

Economic evaluation of nightsoil and sewerage

There is a general trend in developing countries, particularly in urban areas, to convert traditional methods of excreta disposal to cistern flush toilets and sewerage. The Republic of Korea is no exception to this trend and the Government has placed a major emphasis on the early conversion of nightsoil systems to waterborne sewerage systems in the major cities. In addition to an increased preference for cistern flush toilets, the demand for nightsoil as a fertiliser has fallen. For example, a survey of nightsoil practices in Japan, Taiwan and Korea reported by Julius (1978) showed that although the demand was highest in Korea, it was considerably less than in earlier years, the reduction probably being attributable to rising farm incomes and the country's self-sufficiency in chemical fertiliser.

The conversion of nightsoil systems to sewerage has a significant economic impact since nightsoil systems are consistently less expensive than sewerage. For example, McGarry (1978) compared the cost of a number of excreta disposal systems in a hypothetical urban area and showed that nightsoil systems using vacuum cartage with treatment in oxidation ponds was consistently cheaper than sewerage and pond treatment, regardless of population density or interest rate. The total annual cost of the sewerage alternative was approximately three times greater than the nightsoil alternative at a discount rate of 11 % and a 20-year repayment period.

The results of a detailed comparison of excreta disposal costs using different systems have been reported by Kalbermatten, Julius and Gunnerson (1982). Based on field data from a number of countries the results showed that with the exception of Japan, the total annual cost per household of sewerage systems averaged about 10,5 times that of a vacuum-truck nightsoil system. Nightsoil systems in Japan were reported to be much more costly, generally equivalent to about 50 % of the sewerage cost because of the more elaborate house plumbing and higher water use. The same survey reported master plan costs for the City of Malacca in Malaysia indicating that a sewerage system would cost about 4,5 times that of nightsoil with vacuum cartage.

The following economic evaluation is based on actual nightsoil and sewerage costs in the Han River basin area and considers a typical small provincial town of 15 000 persons with 2 500 dwellings. At present, 85 % of the dwellings are assumed to be on a nightsoil collection system, with sullage discharged directly through drains to surface waters. The remaining households are on septic tank systems for toilet wastes, with the septic tank effluent and all household sullage ultimately discharged into surface waters without further treatment.

Existing situation

The present waste flows and BOD loads based on field surveys carried out in similar areas are shown in Fig. 3. Basic cost data are summarised in Table 4. All the costs relate to June 1982 and have been converted to US Dollars at a rate of 750 Won to US$ 1,0. Assuming a constant population, the pollution loads in year 2001, a typical planning horizon, would be 1 472 m^3/d and 263 kg BOD/d. For a discount rate of 11 % and a 20-year repayment period, the existing system has a total present value and annualised cost of $1,2 million and $0,15 million respectively. Costs per dwelling amount to $107 and $63/a for septic tank and nightsoil dwellings respectively.

Upgrading options

Three options are considered for upgrading as shown in Fig. 4. All three options are designed to remove approximately comparable

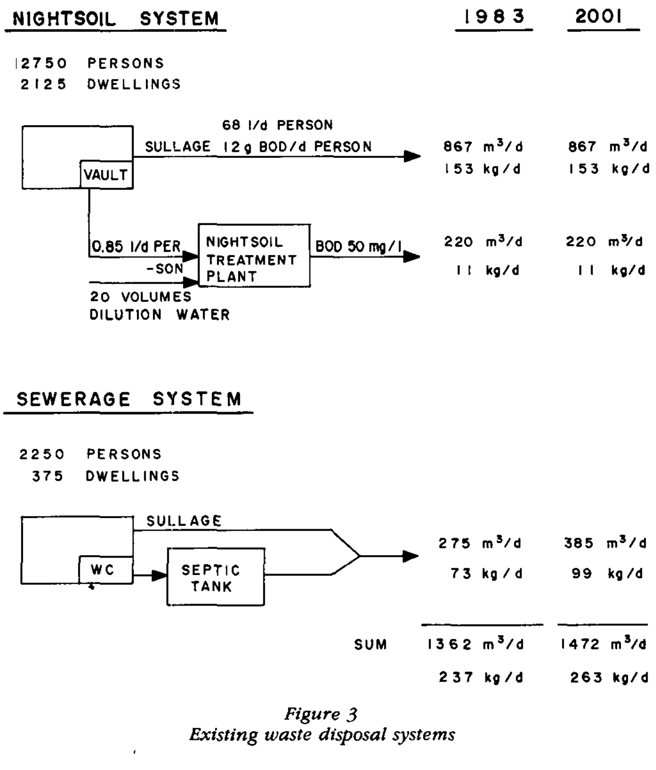

Figure 3
Existing waste disposal systems

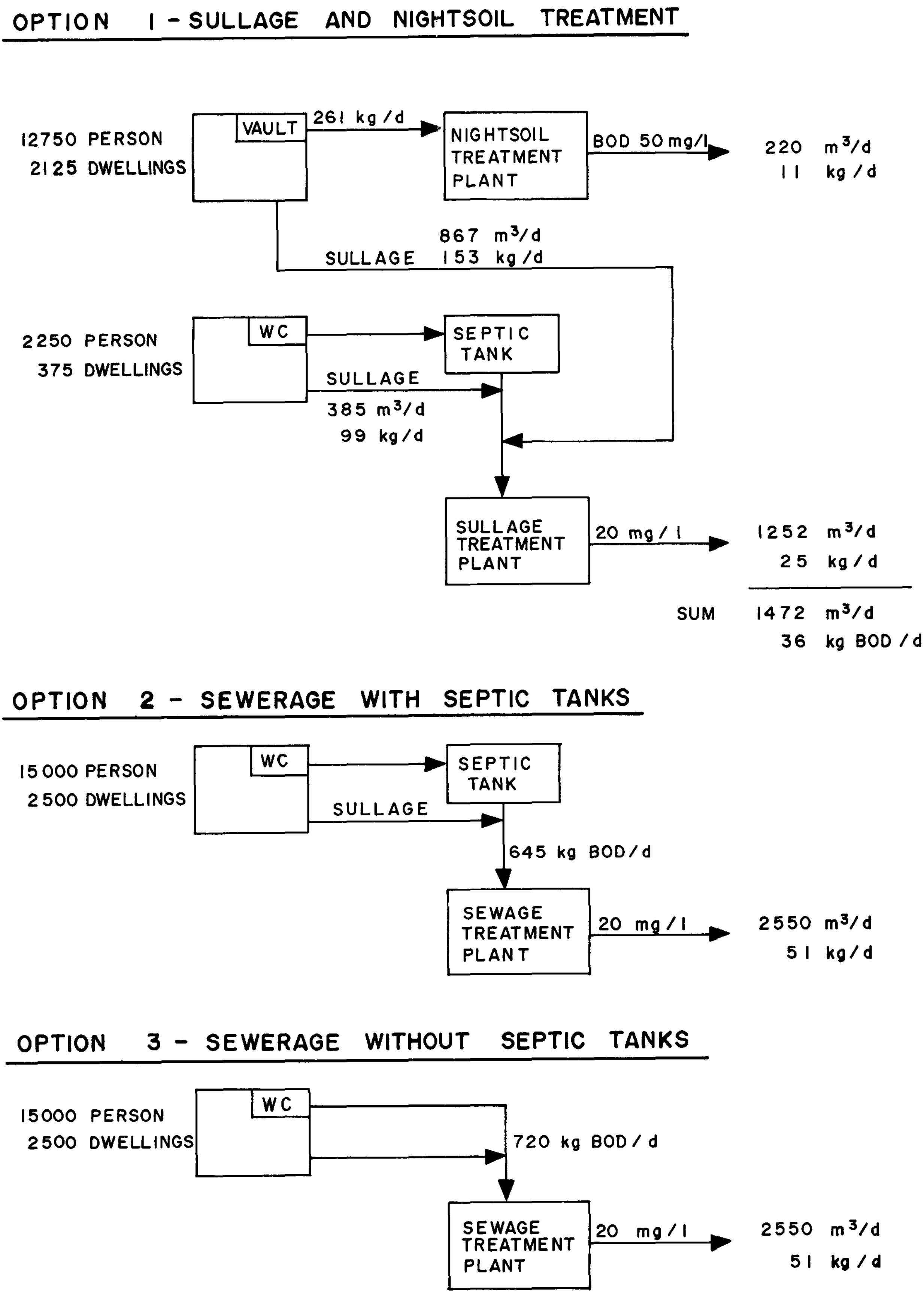

Figure 4
Upgrading options

amounts of BOD, of the order of 80 to 85 % compared to the existing system on the basis of year 2001 loads.

In Option 1 the nightsoil system is retained but the sullage is intercepted from both nightsoil and septic tank dwellings, together with the septic tank effluent, and treated in an extended aeration activated sludge system to produce a final effluent BOD of 20 mg/*l*. No primary settling would be necessary because of the relatively low SS level in sullage. Some upgrading of the storm drainage system would be required in order to improve hydraulic characteristics. This analysis assumes that it is environmentally expedient to reduce the pollution load in the receiving streams by treating the sullage. In many cases the health hazards of discharging sullage to drainage systems are relatively low (Bradley, 1983), and improvement measures could perhaps be limited to covering open drains and diverting flows to less environmentally-sensitive locations.

Options 2 and 3 involve the elimination of nightsoil collection and treatment. In Option 2, all dwellings now with nightsoil collection systems would be converted to cistern flush toilets with septic tanks. The septic tank effluent, along with sullage from each dwelling, would be transported through a partially upgraded drainage system to a sewage treatment plant based on activated sludge.

TABLE 4
BASIC COST DATA FOR ECONOMIC EVALUATION

Septic tank	
Construction	$127/dwelling
Desludging	$ 19/a per dwelling
Nightsoil conversion	
With septic tank	$467/dwelling
Without septic tank	$347/dwelling
Cost includes vault filling or removal, WC installation, water supply pipe inside house to WC and foul sewer to street.	
Increased water use cost	
Based on 50 *l*/d. person for WC flushing and house occupancy of 6, using current water tariff.	$16/a per dwelling
Nightsoil collection and treatment	
Collection	$17/a per dwelling
Treatment plant construction	$0.27 million
Treatment O and M	$64 000/a
Treatment based on aerobic digestion with sludge drying on beds. Assumes new plant, O and M costs exclude debt charges.	
Sewerage	
Separate sewerage (total replacement)	
Construction	$ 16 000/ha ($2,4 million)
O and M	$120 000/a
Separate sewerage (partial upgrading at 20 % of total replacement)	
Construction	$ 0,48 million
O and M	$24 000/a
Based on average plot density of 20/ha to give total sewered area of 150 ha.	
Sewage treatment	
Conventional activated sludge	
Construction	$0,67 million
O and M	$56 000/a
Extended aeration (for sullage)	
Construction	$0,8 million
O and M	$33 300/a

Because of adverse winter conditions and land constraints, oxidation ponds are not considered for either sewage or sullage treatment. With this option, dwellings now on nightsoil collection systems need to have the vaults converted to cistern flush toilets, septic tanks installed and connected, and must also pay for a share of the sewage treatment plant cost.

Option 3 is identical to Option 2 except that septic tanks are removed and a completely renovated sewerage system is provided to ensure that the network is capable of carrying raw sewage without undue maintenance problems.

The present value and annualised costs of the options are compared with those of the existing situation in Table 5. The annualised cost of a complete sewerage system (Option 3) is about 5,3 times greater than that of the existing nightsoil system for dwellings currently served by nightsoil collection systems. This cost difference is similar to that reported in studies for other south-east Asian countries.

Cost-effectiveness analysis

The cost-effectiveness of the various options is presented in Table 6 in terms of BOD removal. The cost-effectiveness ratio is calculated by dividing the change in annual BOD loadings by the difference in annualised costs of each option relative to the existing system. The annualised costs represent the total annual operation and maintenance costs, plus the capital recovery (debt payment) on all initial construction and conversion outlays (calculated over a 20-year period at 11 % interest). The annualisation of capital outlay is appropriate, regardless of whether loans are used to finance all capital expenditure, since it accounts for the opportunity cost of the capital. That is, even if a household paid cash for converting a vault to a cistern flush toilet and installing a septic tank, this outlay would otherwise have been saved or invested (earning interest), and/or spent on other items.

It is apparent from Table 6 that upgrading to Option 1 is the most cost-effective, at $2,6/a per kg BOD removed, compared to $5,9 and $8,7 for Options 2 and 3 respectively. Therefore, as long as nightsoil is properly collected and treated, so that health risks and BOD removals are comparable to cistern flush systems and sewage treatment, it is economical to retain nightsoil systems in the towns.

Benefit-cost analysis

Benefit-cost analysis may be applied to the waste disposal options in order to address two issues. The first is whether it is worth expending an extra $2,1 million (in present value terms) in order to eliminate nightsoil entirely by upgrading from Option 1 to

TABLE 5
COSTS OF NIGHTSOIL AND SEWERAGE OPTIONS

Option	Present value cost ($ million)	Annualised cost($) per dwelling per year: Dwelling currently on nightsoil	Dwelling currently on septic tank
Existing	1,2	63 (1,6)	107 (2,7)
1. Nightsoil and sullage treatment	2,9	121 (3,0)	318 (8,0)
2. Sewerage with septic tanks	5,0	260 (6,5)	187 (4,7)
3. Sewerage without septic tanks	6,9	337 (8,4)	312 (7,8)

Based on 20a period, 11 % discount rate
Figures in ( ) are per cent annual dwelling income which is taken as $4 000/a per dwelling.

TABLE 6
COST-EFFECTIVENESS ANALYSIS

Option (moving from existing to)	Reduction in BOD load[a] (kg/a)	Increase in annualised cost ($ million)	Cost effectiveness ratio ($/kg)
1. Nigthsoil and sullage treatment	82 900	0,22	2,6
2. Sewerage with septic tanks	77 400	0,46	5,9
3. Sewerage without septic tanks	77 400	0,67	8,7

a 80 000 kg/a used for analysis

Option 2. The second issue is whether it is worth $1,7 million (in present value terms) to upgrade from the existing system to Option 1.

Where nightsoil is properly collected and treated, the benefits of conversion are a slight reduction in health risk because of the virtual elimination of the possibility of direct contact with faecal matter in the home, the added convenience of a cistern flush toilet, and the prestige of possessing a cistern flush toilet rather than a nightsoil vault. The increase in total cost per dwelling of conversion and treatment is $139/a (Table 5), hence the benefits of conversion would have to be at least that great in order to justify community-wide implementation.

Monetary benefits of eliminating illnesses should take into account not only direct medical expenses but also pain and suffering and loss of earnings. Assuming an average annual episode length of one week for those infected persons showing symptoms of parasitic infestation, loss of earnings would be about $45 per full-time worker. Studies in the USA have shown that direct medical costs for infective and parasitic diseases are about 18 % greater than earnings losses (Cooper and Rice, 1976). Assuming a similar proportion in Korea, and equating pain and suffering to direct medical costs results in a total cost of $143 per case. Assuming half the affected population are workers (including housewives and others who perform tasks for which they do not receive financial reimbursement), the other half being too young, old, or unable to work, the average value per case avoided is $120.

Typical parasitic infestation rates in the towns range from 15 to 20 %. Upgrading from an improved nightsoil and sullage treatment system (Option 1) to a septic tank and sewerage system (Option 2) should reduce the incidence rate to zero. This reduction is undoubtedly an overstatement since if the nightsoil treatment and disposal system were fully effective the incidence rate would probably be much less than 15 to 20 %. On the basis of 80 % of infections typically being symptomless (Feachem *et al.*, 1983), a reduction of 525 cases/a results for the population of 15 000. The annual incremental costs of moving from Option 1 to Option 2 are $240 000 from Table 5, implying a cost per case avoided of $457.

It is apparent that even in this particular case study where the benefits are probably considerably overestimated, the costs of nightsoil system conversion exceed the likely health benefits by a substantial amount ($457 compared to $120 per case avoided). The conversion costs represent an additional 3,5 % of total annual household income to realise a minute reduction in health risk and an unquantifiable increase in convenience and prestige (moving from Option 1 to Option 2). Option 1 therefore, is recommended over Option 2 (and implicity over Option 3) for towns of this approximate size.

Given the desirability of Option 1 relative to the other upgrading options, the next consideration is whether it is worth changing from the existing system to Option 1, the treatment of sullage. The benefits of such a move are reflected in the additional 80 000 kg/a of BOD removed. The value of this reduction in pollution load is unquantifiable in this hypothetical case study, but the reduced BOD discharge could lead to improved water quality which in turn might enhance recreation possibilities and aesthetic values, reduce drinking water treatment costs if the water intake was located downstream of the town, and perhaps improve commercial fisheries. Each of these benefits would have to be assessed on a site-specific basis.

Another factor which could be considered is the improvement within the existing system of waste disposal. Although the cost estimates herein are based on the complete and proper collection and treatment of nightsoil, in smaller communities a portion of the nightsoil is sometimes collected for a fee by farmers, who then use it on their fields. Although this practice provides some nutrient value to the soil, it also increases the likelihood of parasitic infestation. The programme to deworm Korean school-age children through administering chemotherapy twice each year has undoubtedly contributed to the marked reduction in the incidence of parasitic infestation in recent years as shown in Fig. 2. However, improving nightsoil collection and treatment could serve as an alternative to the application of chemotherapy.

The "over-the-counter" cost of chemotherapy is about $1,0/treatment, based on biannual applications and excluding administration costs. Assuming three children per dwelling, the basic chemotherapy cost for the hypothetical town is $15 000/a. This cost is much less than that required to operate a modern nightsoil treatment facility as shown in Table 4. However, improved nightsoil treatment has additional benefits such as reduced adverse water quality impacts and elimination of potential side-effects from regular exposure through childhood to chemotherapy. In addition, mishandled nightsoil may expose persons far removed from the original source and the evaluation should take into account the local food supply trading area rather than just the nightsoil-producing community.

Conclusions

The study of nightsoil practices in urban areas in Korea has shown that the system is generally operated efficiently with the attainment of a high standard of hygiene. For a typical Korean small town, the annualised cost of a conventional sewerage system would be about 5,3 times greater than that of the existing nightsoil system.

The economic analysis of excreta collection and treatment options shows that provided that the nightsoil is collected and disposed of efficiently using vacuum cartage, with no spillage or indiscriminate dumping of sludge, then the most cost-effective option assuming that it is desirable to reduce local water pollution from sullage discharges, is to retain the nightsoil system for current users and treat the sullage from all households together with septic tank effluent from those dwellings served by septic tanks in a sewage treatment facility.

This option is between two to two and a half times as cost-effective as the next best option of universal conversion to cistern flush toilets with septic tanks, partial sewer upgrading and sewage treatment. The water quality benefits of each option would be identical and the difference in health risks minimal. For houses on nightsoil systems the improved system involving treatment of sullage would effectively double the annual household cost to represent 3 % of the household income.

Although there is an understandable desire to eliminate nightsoil systems, conversions to sewerage systems usually must be carried out gradually in accordance with economic constraints. Investment in widespread sewerage systems at an early date could give rise to wasteful use of resources, based on experience elsewhere. For example, in Japan there is often a time lag of up to ten years between the commissioning of a sewerage system and voluntary connection to it by a significant number of households (Kalbermatten, Julius and Gunnerson, 1982). These constraints are recognised in Korea and the conversion to sewerage is being implemented in a phased manner, in conjunction with prior nightsoil treatment plant upgrading in some of the urban areas.

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References

BRADLEY, R.M. (1983) The choice between septic tanks and sewers in tropical developing countries. *J. Instn. Public Health Eng.* **11** (1) 20-28.

COOPER, B.S. and RICE, D.P. (1976) The economic cost of illness revisited, *Social Security Bulletin,* February. 21-36.

FEACHEM, R.G., BRADLEY, D.J., GARELICK, H. and MARA, D.D. (1983) *Ascaris* and Ascariasis. *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management,* John Wiley and Sons. 375-399.

HAYASHI, S., SUEMITSU, T. and KUNIL, C. (1981) Soil-transmitted helminthiasis control programme in Japan. *Bol. Child. Parasit.* **36** 2-5.

HYUNDAI ENGINEERING CO. LTD. (1978) Report on Regional Water Quality Management Plan for Greater Seoul, December.

JULIUS, D.S. (1978) Urban wastes as an economic good. *Sanitation in Developing Countries,* John Wiley, Chichester. 194-200.

KALBERMATTEN, J.M., JULIUS D.S. and GUNNERSON, C.G. (1982) Appropriate sanitation alternatives: A technical and economic appraisal, *World Bank Studies in Water Supply and Sanitation* **1** Johns Hopkins, Baltimore.

KALBERMATTEN, J.M., JULIUS, D.S., GUNNERSON, C.G. and MARA, D.D. (1982) Appropriate sanitation alternatives: A planning and design manual, *World Bank Studies in Water Supply and Sanitation* **2** Johns Hopkins, Baltimore.

KIM, D.C., LEE, O.Y., KIM, S.H., HAN, E.J. and KIM, N.S. (1977) *National Institute of Health Annual Report.* **14** 189.

KOREAN SOCIETY FOR PARASITOLOGY, (1981) Assessment Report of National Parasite Control Programme, December.

KOREAN SOCIETY FOR PARASITOLOGY, (1982) Assessment Report of National Parasite Control Programme, December.

LIGMAN, K., HUTZLER, N. and BOYLE, W.C. (1974) Household wastewater characterization. *J. Environ. Engng Div. Am. Soc. Civ. Engrs.* **100** (1) 201-213.

MALES, D.B. (1975) Household use of water. Technical Note No. 7, Central Water Planning Unit, Reading, UK.

MAGARA, Y., SUGITO, D. and YAGOME, K. (1980) Design and performance of nightsoil treatment plants. *J. Wat. Pollut. Control Fed.* **52** (5) 914-922.

MARA, D.D. (1978) Collection and treatment of nightsoil. *Sewage Treatment in Hot Climates,* John Wiley, Chichester, 137-141.

McGARRY, M.G. (1978) Waste collection in hot climates: A technical and economic appraisal. *Water Wastes and Health in Hot Climates,* John Wiley, Chichester. 239-263.

NAKAMOTO, I. (1982) Fifth five-year program for sewerage construction. *Sewage Works in Japan,* Japan Sewage Works Association. 14-16.

OFFICE OF ENVIRONMENT (1981) Report on Basic Data for Major Rivers Environmental Study, Volume **2**, December.

RUMP, M.E. (1979) Demand management of domestic water use. *J. Instn. Wat. Engrs. Scientists.* **33** (2) 173-182.

SOH, C.T., KIM, S.J., CHANG, B.P., YOUN, B.B. and LEE, J.H. (1973) Faecal pollution in relation to soil-transmitted helminthic infections. *Korean Journal of Parasitology* **11** 133-136.

WILLIAMS, R.O. (1975) A survey of the heavy metal and inorganic content of sewage sludges, *Wat. Pollut. Control* **74** (5) 607-608.

WITT, M.D., SIEGRIST, R. and BOYLE, W.C. (1974) Rural household waste characterization, *Proc. Am. Soc. Ag. Eng.* 175 December.

WORLD BANK (1980) Health Sector Policy Paper, IBRD, Washington, D.C.