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ENVIRONMENTAL EPIDEMIOLOGY AND SANITATION

BY DAVID J. BRADLEY[1] AND RICHARD G. FEACHEM[2]

INTRODUCTION

In considering improved excreta disposal technologies the engineer, administrator and community development worker cannot consider each disease separately. Rather, they require a conceptual framework which links various types of excreta-related infections to the design and implementation of particular disposal or reuse technologies. A biological classification, which groups the viruses, bacteria, protozoa and worms together, may be less helpful in understanding the health aspects of alternative approaches to excreta disposal, than a classification of infections which is based upon their transmission routes and life cycles. Such a classification we call an environmental classification. In fact, the resemblance between a biological and an environmental classification is much closer in the case of the excreta-related infections than in the case of the diseases related to water.

The purpose of an environmental classification is to group infections in such a way that the role of different preventive measures, and the efficacy of different environmental and behavioural modifications, are made clear. The object here is to propose an environmental classification of the infections related to excreta. In devising such a classification we have encountered two major limitations. The first is, remarkably, how little is precisely known about the transmission of several infections

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and the numbers of microbes needed to pass the infections on to susceptible people. The second is that the bulk of the excreted viruses, bacteria and protozoa, differ quantitatively rather than qualitatively in their transmission characteristics and it is easy to finish up with a big category containing the majority of infections. Understanding of these infections depends on some basic parameters of transmission, especially latency and persistence in the environment, and the infective dose for man. We therefore discuss these other key concepts before setting out the classification.

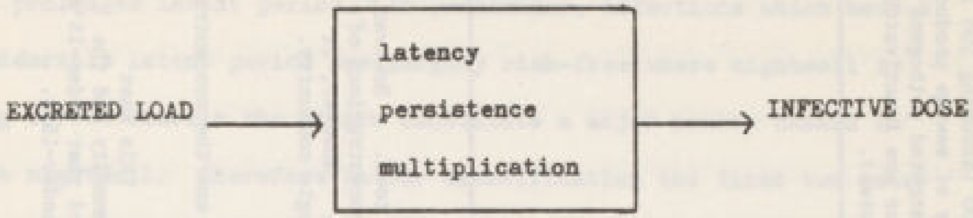
KEY CONCEPTS IN UNDERSTANDING EXCRETA-RELATED INFECTIONS

Excreta may be related to human disease in two ways (Figure 1). The agents of many important infections, escape from the body in the excreta and thence eventually reach others. These are the excreted infections. In some cases the reservoir of infection is almost entirely in animals other than man. These are not dealt with here because such infections cannot be controlled through changes in human excreta disposal practices. However we do include a number of infections for which both man and other animals serve as a reservoir.

The second way in which excreta relate to human disease is where their disposal encourages the breeding of insects. These insects may be a nuisance in themselves (flies, cockroaches, mosquitoes); they may mechanically transmit excreted pathogens either on their bodies or in their intestinal tracts (cockroaches and flies), or they may be vectors for pathogens which circulate in the blood (mosquitoes). Where flies or cockroaches are acting as vehicles for the transmission of excreted pathogens, this represents a particular case of the many ways in which excreted pathogens may pass from anus to mouth. However, where mosquitoes are transmitting non-excreted pathogens the concepts discussed in this paper have little relevance and the important factors are those which determine the breeding habits of the particular mosquitoes.

In considering the transmission of excreted infections, the distinction between the state of being infected, and the state of being diseased, must be kept in mind. Very often, the most impotant section of the population involved in transmitting an infection shows little or no sign of disease; conversely, individuals with advanced states of disease may be of little or no importance in transmission. A good example occurs in schistosomiasis, where as much as 80% of the total egg output in faeces and urine reaching water from a human population may be produced by children in the 5-15 years age group; many of these children will show minimal signs of disease. Conversely, middle-aged people with terminal disease conditions may produce few or no hatchable eggs.

If an excreted infection is to spread, an infective dose of the relevant agent has to pass from the excreta of a case, carrier, or reservoir of infection to the mouth of a susceptible person or some other portal of entry. Spread will depend upon the number of pathogens excreted, upon how these numbers change during the particular transmission route or life cycle and upon the dose required to infect a new individual. Infectious dose is in turn related to the susceptibility of the new host. Three key factors govern the probability that, for a given transmission route, the excreted pathogens from one host will form an infectious dose for another. These are latency, persistence and multiplication. Diagrammatically we can represent the concepts thus:



We will discuss these concepts in turn.

Excreted load. There is wide variation in the concentration of pathogens passed by an infected person. For instance, a person infected by a small number of nematode worms may be passing a few eggs per gram of faeces whereas a cholera carrier may be excreting more than 10^6 *Vibrio* per gram, and a case may pass 10^{13} vibrios in a day.

Where large numbers of organisms are being passed in the faeces they can give rise to high concentrations in sewage (Table 1). Thus, even in England, where water use is relatively high and salmonellosis relatively rare, raw sewage may contain 10^4 *Salmonella* per litre. At these concentrations, removal efficiencies of 99% in treatment works will still leave 10^2 pathogenic organisms per litre in the effluent, and their implications for health will depend upon the disposal method, their ability to survive or multiply and the infectious dose required.

Latency. By latency we mean the interval between the excretion of a pathogen and its becoming infective to a new host. Some organisms, including all excreted viruses, bacteria and protozoa have no latent period and are immediately infectious when the excreta are passed. The requirements for the safe disposal of excreta containing these agents

TABLE I

POSSIBLE OUTPUT OF SOME PATHOGENS IN THE FAECES AND SEWAGE OF A TROPICAL COMMUNITY (a)

PATHOGEN	Typical Prevalence of infection in developing country (b)	Typical Average number of organisms per gram of faeces (c)	Total Number Excreted per infected person per day (d)	Total Number Excreted per day in town of 50,000 pop.	Concentration per litre (c) in sewage from town of 50,000 (assuming 100 litres per capita per day of sewage produced and that 90% of excreted pathogens do not enter the sewers or are inactivated in the first few minutes).
Enteroviruses	5%	10^6	10^8	$2.5x10^{11}$	5000
Salmonellae	7%	10^6	10^8	$3.5x10^{11}$	7000
Shigellae	7%	10^6	10^8	$3.5x10^{10}$	7000
Vibrio cholerae	1%	10^6	10^8	$5x10^{10}$	1000
Path. E. coli	?	10^8	10^{10}	?	?
Entamoeba histolytica	30%	$15x10^4$	$15x10^6$	$2.25x10^{11}$	4500
Ascaris	60%	10000 (e)	10^6	$3x10^{10}$	600
Trichuris	60%	2000 (e)	$2x10^5$	$6x10^9$	120
Hookworms	40%	800 (e)	$8x10^4$	$1.6x10^9$	32
Schistosoma mansoni	25%	40 (e)	$4x10^3$	$5x10^7$	1
Taenia saginata	1%	10^4	10^6	$5x10^8$	10

NOTES:

(a) This table represents an entirely hypothetical situation and the figures are not taken from any real town. However, for each pathogen the figures are reasonable and in line with those found in the literature. The concentrations of each pathogen in sewage, derived in the table, are in line with the higher figures in the literature. However, it is unlikely that all these infections at these relatively high prevalences would occur in any one single community.

(b) The prevalence figures quoted in this column refer to infection and not to morbidity.

(c) It must be remembered that the pathogens listed have different abilities to survive outside the host and the concentration of some of them will rapidly decline after the faeces have been passed.

(d) To calculate this figure it is necessary to estimate a mean faecal weight for those people infected. This must necessarily be the roughest estimate because it depends on the age-specific faecal weights in the community and the age distribution of infected people. It was assumed that over-15 year olds excrete 150 g per day and that under-15's excrete, on average, 75 g per day. It was also assumed that two-thirds of all infected people are under-15's. This gives a mean faecal weight for infected individuals of 100 g.

The distribution of egg output among people infected by these helminths is extremely skewed and some people are putting out very high egg concentrations.

are far more stringent than for those helminthic infections where there is a prolonged latent period. In particular, infections which have a considerable latent period are largely risk-free where nightsoil is being carted whereas the others constitute a major health hazard in fresh nightsoil. Therefore in our classification the first two categories where no latency is observed are separated from the remaining categories where a definite latent period occurs.

Among the helminthic infections only three have eggs or larvae which may be immediately infectious to man when passed in the faeces. These are Enterobius vermicularis, Hymenolepis nana, and sometimes Strongyloides stercoralis. The remaining excreted helminths all have a distinct latent period, either because the eggs must develop into an infectious stage in the physical environment outside the body, or because the parasite has one or more intermediate hosts through which it must pass to complete its life cycle.

Persistence or survival of the pathogen in the environment is a measure of how quickly it dies after it has been passed in the faeces. It is the single property most indicative of the faecal hazard in that a very persistent pathogen will create a risk throughout most treatment processes and during the reuse of excreta.

A pathogen which persists outside the body only for a very short time needs to find a new susceptible host rapidly. Hence transmission cannot follow a long route through sewage works and the final effluent disposal site back to man but will rather occur in the family by transfer from one member to another as a consequence of low personal cleanliness.

More persistent organisms can readily give rise to new cases of disease further afield, and as survival increases so also must concern for the ultimate disposal of the excreta. In addition, pathogens which tend to persist in the general environment will require more elaborate processes if they are to be inactivated in a sewage works. Methods of sequestering them, as by sedimentation into a sludge which receives special treatment, are often needed.

While it is easy to measure persistence or viability of pathogenic organisms by laboratory methods, to interpret such results it is necessary to know how many are being shed in the excreta (relatively easy to determine) and the infective doses for man (extremely difficult).

Multiplication. Under some conditions certain pathogens will multiply in the environment. Thus, originally low numbers can be multiplied to produce a potentially infective dose (see below). Multiplication can take the form of reproduction by bacteria in a favoured substrate (e.g. *Salmonella* on food) or of the multiplication by trematode worms in their molluscan intermediate hosts.

The former case is a mechanism whereby light faecal contamination may build up bacterial numbers to reach the rather high minimal infective doses needed by many excreted bacterial pathogens. The need for this may determine the usual mode of infection, since multiplication in water is limited compared with the massive increases possible in food. Viruses and excreted protozoa do not multiply outside their animal hosts.

Among the helminths transmitted by excreta, all the trematodes infecting man undergo multiplication in aquatic snails. This introduces a prolonged latent period of a month or more while development is taking place in the snail, followed by an output of up to several thousand larvae into the environment for each egg that reached a snail. Category V of the classification is used for infections of this sort where excreta have to gain access to the appropriate snail habitat, but once this happens great amplification is possible.

Infective dose. In a tidy world, from knowing the output of pathogens in the excreta of those infected, the mean infective dose, and the extractive efficiency of the excreta treatment process, it would be a matter of simple calculation to assess risk. The real world is much less predictable than this because of the variable infective dose of most pathogens and the uneven distribution of infection in the environment. While the minimal infective dose for some diseases may be a single organism, or very few, the doses required in most bacterial infections are much higher. Data bearing on this are very hard to acquire, since they involve administering a known dose of a pathogen to a volunteer. Information is scanty, concerned with doses required to infect say half those exposed, rather than a minute proportion, at a single exposure. The volunteers have been well-nourished adults and usually from non-endemic areas. Such results have therefore to be applied with great caution to malnourished peasant children continually exposed to infection. It has been found that changes in the manner of administration, such as preceding a dose of cholera vibrios with an alkaline substance to temporarily reduce free gastric acid, may lower the mean infective dose of such organisms by a factor of 10^3.

Also, in human experimental studies, the infective dose for half the people exposed is the most reliable result but in natural transmission the dose infective for 5% or less of the population may be more relevant.

The consequent uncertainties over the size of the minimal infective dose in nature makes allocation of diseases between the first two categories of our classification uncertain. These difficulties are greatest for the major excreted bacterial infections, and for protozoa. For viruses there is evidence of low infective doses in experiments, and in human populations for some but not all virus infections. Among the helminths a single egg or larva can infect if ingested though a high proportion of worms can fail to develop to maturity, especially where immunity is present.

<u>Host response</u>. Host response is important in determining the result of an individual receiving a given dose of an infectious agent. In particular, acquired immunity, and the relation of age to pathology, are important for predicting the effects of sanitation. At one extreme would be a short-lived parasite to which little immunity developed and in which the relation between infection and disease was not age-dependent. Then a close, tending to linear, relationship between exposure and disease might be expected with improvements in the appropriate aspects of sanitation giving health benefits proportional to effort. <u>Ascaris</u> closely approximates to this model.

At the other extreme would be a viral or bacterial infection which gives rise to long-lasting immunity and where the chance of overt disease in those infected rose with increasing age. An example is infection with poliomyelitis virus. Under very bad sanitary conditions all are infected at a young age, older children and adults are immune and disease is limited to a few of the youngest children who may suffer chronic paralysis. If sanitation improves, infection is deferred and its pathological consequences later in life are more serious. Thus, although poliovirus <u>transmission</u> may be reduced by improving sanitation, reduction in <u>disease</u> is in practice achieved by immunization. Does this apply to any other excreted infection? Possibly to infectious hepatitis and it has been argued in the case of typhoid. However, there are probably several infections where human immunity is of importance in regulating the amount of disease. This will tend to reduce the health significance of moderate sanitary improvements, and may in part explain the disappointing impact of some sanitary programmes.

The balance between exposure to infection and host response to it will determine the pattern of excreta-related disease. If transmission, creating exposure to a particular infection, is low then most people will not have encountered the infection. They will be susceptible. If a sudden increase in transmission of the disease occurs, it will affect all age groups in epidemic form. Improvements in sanitation will have a big effect under these circumstances by reducing the likelihood and/or the magnitude of an epidemic.

By contrast, if transmission is very high all the people will be repeatedly exposed to infection and first acquire it in childhood. Subsequent exposures may be without effect if immunity is acquired from the first attack. Or immunity may be cumulative from a series of attacks. The infection will always be present and is described as

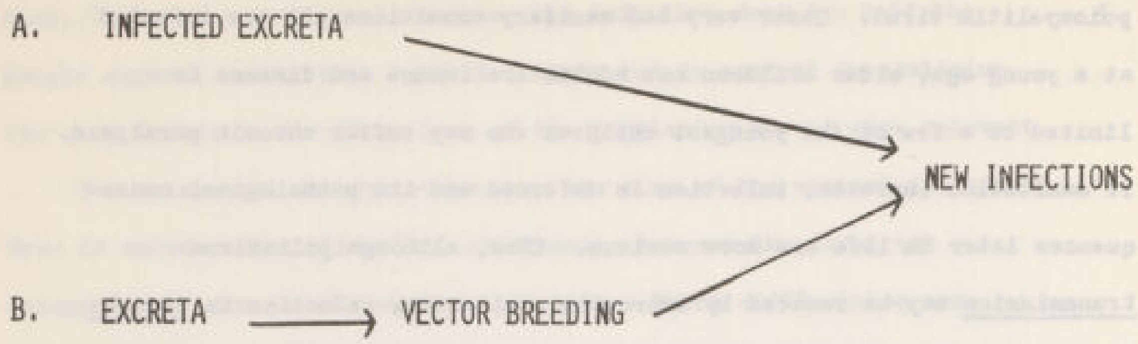


Figure 1: The two main ways in which excreta is related to ill-health. In A, the excreta itself contains the pathogens which may be transmitted by various routes to a new host. In B, the excreta or sewage permits the breeding of certain flies and mosquitoes which may act as vectors of both excreted, and other pathogens.

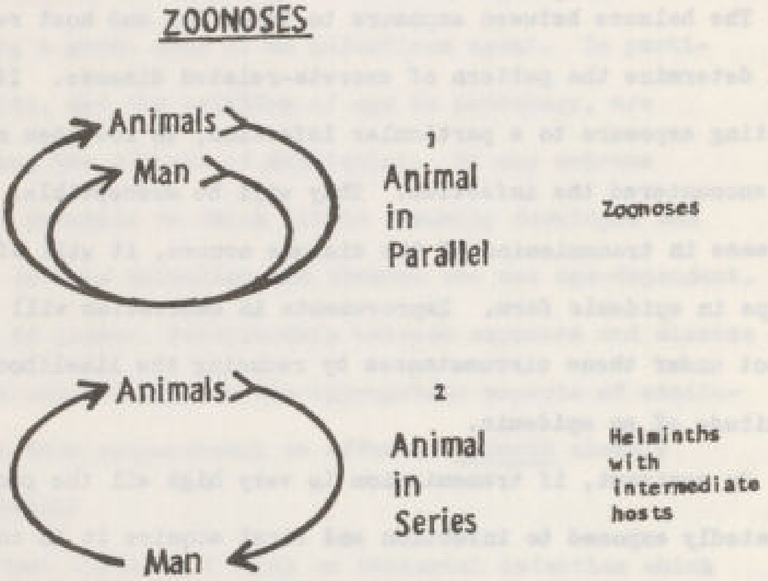


Figure 2: Two ways in which animals are involved in the tranmission of excreted infections.

endemic. Under these conditions much transmission is ineffective because of human acquired immunity, and reduced transmission, as through improved sanitation, will only delay the date of infection somewhat so that older children are seen infected. Very large sanitary improvements, will either render the infection very rare or, if the disease was originally very highly transmitted, make it an adult disease. Examples are tyhoid, which by management of excreta and of water supplies, can be completely prevented in the community, and poliomyelitis virus infection which requires extreme hygienic precautions to prevent, and in practice improved sanitation increases the disease problem by deferring infection to an age where the clinical course is more severe.

Consequences of a juvenile age-prevalence are that, not only do children suffer chiefly from the diseases, but also they are the main sources of infection, so that the acute need for better community excreta disposal is among young children, the group perhaps least inclined to use any facilities that may be available.

Other hosts besides man. Some excreted diseases are infections exclusively or almost exclusively of man. Others involve animals either as alternatives to man as host or as hosts of other stages in the life cycle (Figure 2). In the first case, where wild or domestic vertebrate animals act as alternative hosts (such infections are called zoonoses), control of human excreta is likely not to suffice for complete prevention of the infection, while if the infection under consideration is strictly anthroponotic (e.g. shigellosis) then it is the control of human excreta which is of importance. In the second case, some excreted helminthic infections have intermediate hosts. They will therefore be controlled if:

(a) excreta are prevented from reaching the intermediate host;

(b) the intermediate hosts are controlled;

(c) people do not eat the intermediate host uncooked or do not have contact with the water in which the intermediate host lives (depending on the particular life cycle).

These infections (animals in series, Figure 2) fall into Categories IV and V of the classification below. In Category IV the intermediate hosts are domestic vertebrate animals and control of either human excreta or the animal infection will suffice to prevent disease. By contrast, with the vertebrates 'in parallel' (Figure 2) it is necessary to control both human and animal excreta, or tackle the problem in some other way.

Some details on the factors discussed above are provided in Table 2, for the excreted infections being considered.

ENVIRONMENTAL CLASSIFICATION OF EXCRETA-RELATED INFECTIONS

There are many ways in which the excreted infections could be grouped on the basis of the information presented in Table 2. We have searched for a classification which is most relevant to the effect of excreta disposal per se and which is most helpful in considering the impact of changing excreta disposal facilities and technology. Table 3 presents this classification. We have distinguished six categories of infection.

There is a clear difference between the first five categories of excreted pathogens and the last which contains the excreta-breeding insect vectors of disease. A variety of sanitation methods will control the insects and there are additional specific measures that can be directed

TABLE II

CATEGORY (Table 3)	PATHOGEN	LATENCY Typical min. time from excretion to infectivity	PERSISTENCE Anticipated max. life of infective stage at 20-30°C	CONCENTRATION typical average number of organisms per gram of faeces	MULTIPLICATION Outside human host	MEDIAN INFECTIVE DOSE High > 10^6 Medium 10^4 Low < 10^2	SIGNIFICANT IMMUNITY	MAJOR RESERVOIR OTHER THAN MAN	INTERMEDAITE HOST
V (f)	*Clonorchis*	3 months (c)	life of fish	10^2	Yes (d)	Low	No	Yes	snail and fish
	Diphyllobothrium	4 weeks (c)	life of fish	10^4	No	Low	No	Yes	copepod and fish
	Fasciolopsis	10 weeks (b)	?	10^2	Yes (d)	Low	No	Yes	snail and aquatic plant
	Paragonimus	4 months (c)	life of crab	?	Yes (d)	Low	No	Yes	snail and crab or crayfish
	Schistosoma mansoni	4 weeks (b)	2 days	40	Yes (d)	Low	?	No	snail
	Schistosoma haematobium	5 weeks (b)	2 days	40/10 ml urine	Yes (d)	Low	Yes	No	snail
	Schistosoma japonicum	7 weeks (b)	2 days	40	Yes (d)	Low	Yes	Yes	snail

Notes: (a) Leptospirosis does not fit into any of the categories defined in Table 3

Leptospira	0	7 days	? (urine)	No	Low	Yes (?)	Yes	none

(b) Life cycle involves one intermediate host. Latency is minimum time from excretion by man to potential reinfection *of man*. Persistence refers to maximum survival time of final infective stage.

(c) Life cycle involves two intermediate hosts. Latency is minimum time from excretion by man to potential reinfection *of man*. Persistence refers to maximum survival time of final infective stage.

(d) Multiplication takes place in intermediate snail host.

(e) The large number of serotypes (> 1000) makes immunity epidemiologically irrelevant.

(f) *Fasciola*, *Gastrodiscoides*, *Heterophyes* and *Metagonimus* are also located in Category V.

TABLE II

SOME BASIC FEATURES OF EXCRETED INFECTIONS (a)

CATEGORY (Table 3)	PATHOGEN	LATENCY Typical min. time from excretion to infectivity	PERSISTENCE Anticipated max. life of infective stage at 20-30°C	CONCENTRATION typical average number of organisms per gram of faeces	MULTIPLICATION Outside human host	MEDIAN INFECTIVE DOSE High > 10^6 Medium 10^4 Low < 10^2	SIGNIFICANT IMMUNITY	MAJOR RESERVOIR OTHER THAN MAN	INTERMEDIATE HOST
I	Enteroviruses	0	6 months	10^6	No	Low	Yes	No	none
	Hepatitis A virus	0	?	10^6 (?)	No	Low	Yes	No	none
	Rotaviruses	0	1 year (?)	10^6 (?)	No	Low	Yes (?)	No	none
	Entamoeba histolytica	0	20 days	$15x10^4$	No	Low	No	No	none
	Giardia lamblia	0	3 months	10^5	No	Low	No (?)	No	none
	Balantidium coli	0	1 month (?)	?	No	Low ?	No	Yes	none
	Enterobius	0	7 days	not usually found in faeces	No	Low	No	No	none
	Hymenolepis	0	a few weeks	?	No	Low	Yes (?)	No	none
II	*Salmonella typhi*	0	60 days	10^6	Yes (food)	High	Yes	No	none
	Other *Salmonellae*	0	1 year	10^6	Yes (food)	High	Irrelevant (e)	Yes	none
	Shigella	0	40 days	10^6	Yes (food)	Medium	No	No	none
	Vibrio Cholerae	0	30 days	10^6	unlikely	High	Limited	No	none
	Path. E. coli	0	1 year	10^8	Yes	High	Yes (?)	No	none
	Yersinia	0	6 months	10^5	?	High	No	Yes	none
	Campylobacter	0	?	?	?	?	?	?	none
III	*Ascaris*	9 days	several years	10^4	No	Low	No	No	none
	Trichuris	3 weeks	1½ years	10^3	No	Low	No	No	none
	Hookworms	7 days	20 weeks	$8x10^2$	No	Low	No	No	none
	Strongyloides	3 days	5 weeks (free living stage very much longer)	10	Yes	Low	Yes	No	none
IV	Taenia	8 weeks (b)	2 years	10^4	No	Low	No	No	cow/pig

TABLE III

A CLASSIFICATION OF EXCRETED INFECTIONS

CATEGORY	FEATURES	INFECTIONS	DOMINANT TRANSMISSION FOCI	MAJOR CONTROL MEASURES
I	Non-latent, low infectious dose	Enterobiasis Enteric viruses Hymenolepiasis Amoebiasis Giardiasis Balantidiasis	Personal contamination Domestic contamination	Domestic water supply Health education Improved housing Provision of toilets
II	Non-latent medium or high infectious dose, moderately persistent and able to multiply	Typhoid Salmonellosis Shigellosis Cholera Path. E. coli Yersiniosis Campylobacter	Personal contamination Domestic contamination Water contamination Crop contamination	Domestic water supply Health education Improved housing Provision of toilets Treatment prior to discharge or reuse
III	Latent and persistent with no intermediate host	Ascariasis Trichuriasis Hookworm Strongyloidiasis	Yard contamination Field contamination Crop contamination	Provision of toilets Treatment prior to land application
IV	Latent and persistent with cow or pig intermediate host	Taeniasis	Yard contamination Field contamination Fodder contamination	Provision of toilets Treatment prior to land application Cooking, meat inspection
V	Latent and persistent with aquatic intermediate host(s)	Clonorchiasis Diphyllobothriasis Fascioliasis Fasciolopsiasis Gastrodiscoidiasis Heterophyiasis Metagonimiasis Paragonimiasis Schistosomiasis	Water contamination	Provision of toilets Treatment prior to discharge Control of animal reservoirs
VI	Excreta-related insect vectors	Bancroftian filariasis (transmitted by Culex pipiens), and all the infections listed in Categories I-V which may be transmitted by flies and cockroaches	Insects breed in various faecally contaminated sites	Identification and elimination of suitable breeding sites

against them.

The excreted infections are divided on the presence (Categories III-V) or absence (I and II) of a latent period so that health problems with fresh faeces or nightsoil are particularly in the first two categories. The distinction between Categories I and II on the one hand, and Categories III-V on the other, is fundamental and clear cut. It also corresponds closely to the biology of the pathogens, in that all infections in Categories III-V are helminthic.

The sub-divisions of the infections with latency (Categories III-V) are also clear cut, with Category III for the soil-transmitted worms, IV for the tapeworms which depend on access of faeces to stock, and V for the trematodes and other worms requiring aquatic intermediate hosts. However, the subdivision of Categories I and II is difficult, and somewhat arbitrary, because the various concepts discussed above split the infections in these categories in different ways. For instance, if we divide Categories I and II on the basis of median infectious dose, stressing as we do so the grave limitations of the available data on infectious dose, we arrive at the following approximate ranking:

	Enteric viruses	$< 10^2$
increasing median infectious dose	*Enterobius*	
	Hymenolepis	
	Entamoeba histolytica	
	Giardia lamblia	
	Balantidium coli	

Shigella	10^4
Salmonella typhi	$> 10^6$
Salmonellae	
Yersinia	
Path E. coli	
Vibrio cholerae	

If, on the other hand, we list the infections according to their persistence outside their animal host, we arrive at approximately the following ranking:

	Enterobius	< 1 month
	Entamoeba histolytica	
	Hymenolepis	
increasing	Balantidium coli	
	Vibrio cholerae	
persistence	Shigella	< 6 months
	Giardia lamblia	
	Salmonella typhi	
	Yersini a	
	Enteric viruses	< 1 year
	Salmonellae	
	Path E. coli	

Another important factor in predicting the impact of improved excreta disposal facilities may be whether or not there is a significant non-human reservoir of infection (Figure 2). Considering the Category I and II infections, there are only two (the salmonellae and *Balantidium coli*) which have a significant animal reservoir.

A quite different approach to the division of Categories I and II is to consider affluent communities in Europe (for instance), which enjoy high standards of sanitary facilities and hygiene, and examine which of the Category I and II infections are commonly transmitted in these privileged communities. We might expect that infections which continue to be transmitted amongst people living in good housing, with indoor plumbing and flush toilets, will not be readily reduced by the introduction of limited sanitary improvements amongst poor people in the less developed countries. A division on this basis is approximately as follows:

Enteric viruses *Enterobius* *Giardia* Path. *E. coli* *Salmonellae*	Pathogens commonly transmitted within affluent communities
Balantidium coli *Entamoeba histolytica* *Hymenolepis* *Salmonella typhi* *Shigella* (other than *sonnei*) *Vibrio cholerae* *Yersinia*	Pathogens rarely transmitted within affluent communities in Europe

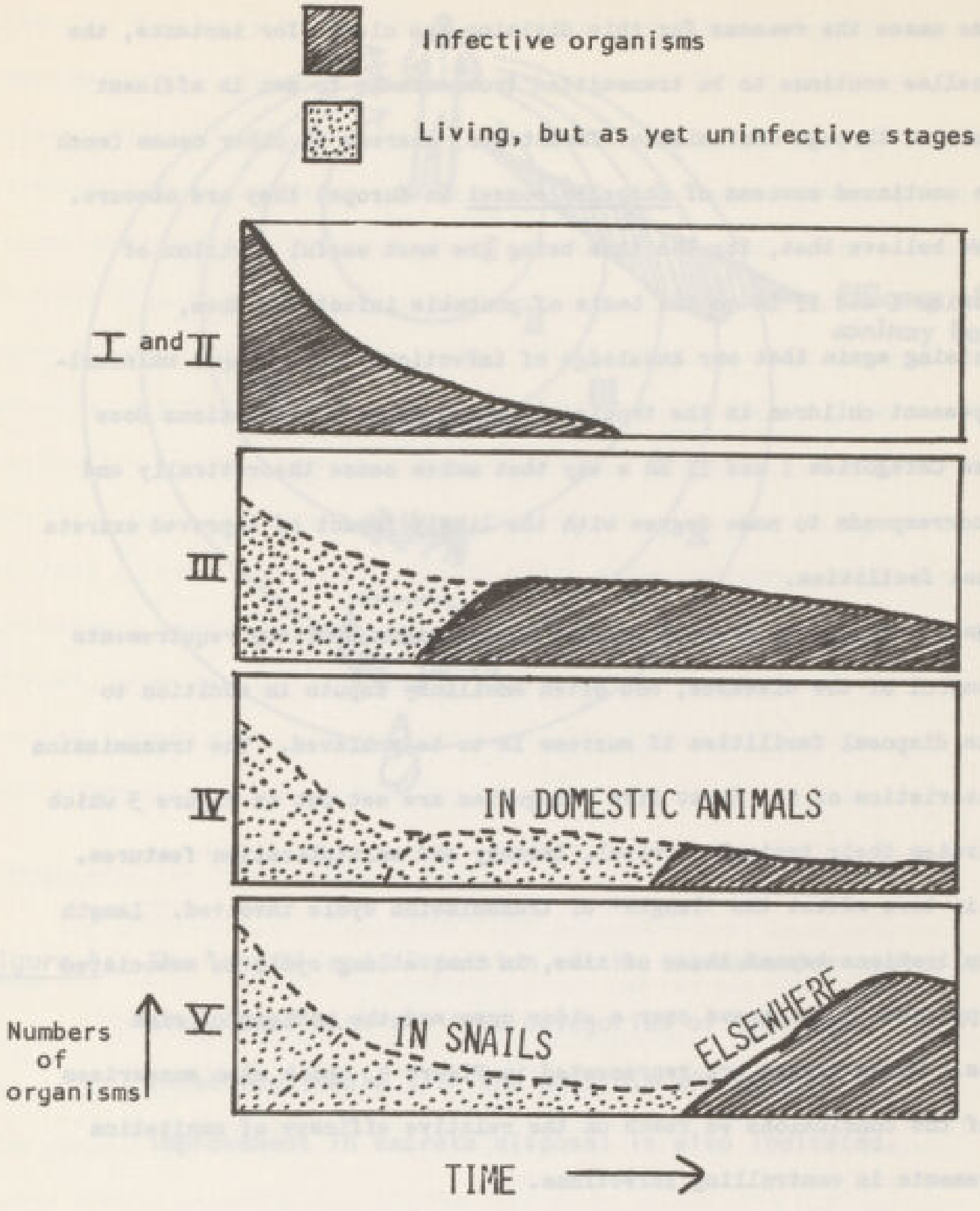


Figure 3: The survival of pathogens over time, outside their definitive hosts, for each category of infection.

(see Table 3).

In some cases the reasons for this division are clear (for instance, the salmonellae continue to be transmitted from animals to man in affluent communities through contaminated foodstuffs) whereas in other cases (such as the continued success of Shigella sonnei in Europe) they are obscure.

We believe that, for the time being the most useful division of Categories I and II is on the basis of probable infectious dose, recognising again that our knowledge of infectious dose amongst malnourished peasant children in the tropics is non-existent. Infectious dose divides Categories I and II in a way that makes sense theoretically and also corresponds to some degree with the likely impact of improved excreta disposal facilities.

Each category in Table 3 implies some minimum sanitary requirements for control of the diseases, and often ancillary inputs in addition to excreta disposal facilities if success is to be achieved. The transmission characteristics of the first five categories are set out in Figure 3 which illustrates their typical survival, latency and multiplication features. These in turn affect the 'length' of transmission cycle involved. Length has implications beyond those of time, in that a long cycle is associated with opportunity to spread over a wider area and the pattern of risk changes. These issues are represented in Figure 4, which also summarises some of the conclusions we reach on the relative efficacy of sanitation improvements in controlling infections.

Category I. These are the infections which have a low infective dose ($<10^2$) and which are infective immediately on excretion. We argue that these infections may be spread very easily from person to person whenever personal and domestic hygiene are not ideal (Figure 4). Therefore, it is

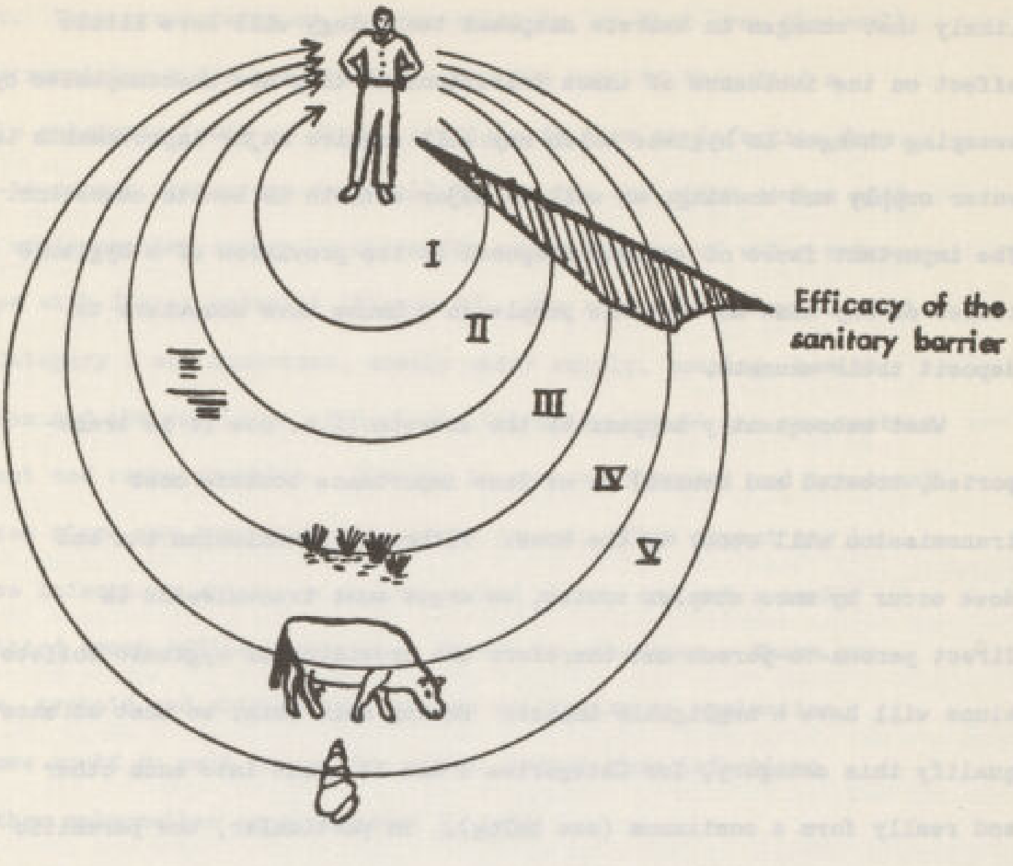


Figure 4: The 'length' and dispersion of the transmission cycles associated with the five categories of excreted infection (Table 3). The possible efficacy of improvement in excreta disposal is also indicated.

likely that changes in excreta disposal technology will have little effect on the incidence of these infections if they are unaccompanied by sweeping changes in hygiene which may well require major improvements in water supply and housing, as well as major efforts in health education. The important facet of excreta disposal is the provision of a hygienic toilet of any kind so that the people in a house have somewhere to deposit their excreta.

What subsequently happens to the excreta (i.e. how it is transported, treated and reused) is of less importance because most transmission will occur in the home. Although transmission can and does occur by more complex routes, we argue most transmission is direct person-to-person and therefore the provision of hygienic toilets alone will have a negligible impact. Having said this, we must at once qualify this category, for Categories I and II grade into each other and really form a continuum (see below). In particular, the parasitic protozoa have some features of each group. The extreme example of a Category I parasite is the pin-worm, <u>Enterobius</u>, whose sticky eggs are laid by emerging females on the anal skin so that transmission is by way of scratching fingers without depending much on eggs in the faeces. At the other extreme, <u>Giardia</u> has been associated with well-documented water-borne diarrhoea outbreaks, and therefore is presumably in part subject to control by excreta management.

<u>Category II</u>. The infections in this category are all bacterial. They have medium or high infective doses ($>10^4$) and so are less likely than Category I infections to be transmitted by direct person-to-person

contact. They are persistent and can multiply, so that even the small numbers remaining a few weeks after excretion can, if they find a suitable substrate (such as food), multiply to form an infective dose. Person-to-person routes are important but so too are other routes with longer environmental cycles, such as the contamination of water sources or crops with faecal material (Figure 4). The control measures listed under Category I are important, namely water supply, housing, health education and the provision of hygienic latrines, but so too are waste treatment and reuse practice. Changes in excreta disposal and treatment practices alone may have some but little impact. This impact may be on those infections which, as we have noted above, are not normally transmitted among affluent groups in Europe or elsewhere. These are cholera, typhoid and shigellosis and any monitoring or evaluation programme would do well to examine these, rather than infections with other salmonellae or pathogenic E. coli.

Characteristics of Categories I and II

The criteria used to separate these categories have been infective dose and 'length' of the environmental cycle and our aim has been to predict efficacy of sanitation as a control measure. The reason they do not form tidy groups is the variable persistence of the pathogens involved. The extreme type I situation with a low infective dose and environmentally fragile organism will clearly tend to be spread in a familial or other tight pattern and depend for its control more on personal cleanliness and less on sanitation. (An extreme example, though not excreta-transmitted,is given by venereal diseases which do not survive in the environment and depend on intimate contact for their spread).

However, a low infective dose in an environmentally persistent organism will lead to an infection very difficult to shift either by sanitation or by personal and domestic cleanliness. Many viruses fall into this category and pose very major problems of control so that induced immunity may be the best approach, as discussed above for poliomyelitis. In Category II the role of sanitary improvements is to reduce the efficacy of the longer cycles and thus have a greater overall benefit than for Category I pathogens where these longer cycles are of little significance.

Category III. This category contains the soil-transmitted helminths. They are latent and persistent (Figure 3). Their transmission has little or nothing to do with personal cleanliness since the helminth eggs are not immediately infective to man. Domestic cleanliness is relevant only as it affects incoming infective stages by food preparation methods or the maintenance of latrines in a tolerable state so that eggs do not remain on the surrounds for the days or weeks of their latent period. If ova are not deposited in soil, or other suitable development sites, transmission will not occur. Therefore, any kind of latrine which contains or removes excreta, and does not permit the contamination of the floor, yard or fields, will limit transmission. Because persistence is so long (see Table 2) it is not sufficient to stop fresh faeces from reaching the yard or fields. Any faecal product which has not been adequately treated must not reach the soil. Therefore, in societies which reuse their excreta on the land, treatment is vital prior to application. Effective treatment for the removal of these ova requires waste stabilization ponds or thermophilic digestion, though prolonged storage will remove many species.

Category IV. Category IV is for the beef and pork tapeworms. Any system which prevents untreated excreta being eaten by pigs and cattle will control transmission of these infections (Figure 4). Cattle are likely to be infected in fields treated with sewage sludge or effluent. They may also eat faeces deposited in the shippen. Pigs are likely to become infected eating human faeces deposited around the home or in the pig pen. Therefore, the provision of toilets of any kind to which pigs and cattle do not have access, and the treatment of all wastes prior to land application, are the necessary control methods. It is also necessary to prevent birds, especially gulls, from feeding on trickling filters and sludge drying beds and subsequently depositing tapeworm ova in their droppings on the pastures. Personal and domestic cleanliness are irrelevant, except insofar as the use of toilets is concerned.

Category V. These are the water-based helminths which have an obligatory aquatic host or hosts to complete their life cycles. Control is achieved by preventing untreated nightsoil or sewage from reaching water in which the aquatic hosts live (Figure 4). Thus any land application system or any dry composting system will reduce transmission. There are two complications. Firstly, in all cases, except Schistosoma mansoni and S. haematobium, animals are an important reservoir of infection

Therefore any measures restricted to human excreta can only have a partial effect. Secondly, in the case of Schistosoma haematobium it is the disposal of urine which is of importance and this is far more difficult to control than the disposal of faeces. Because multiplication takes place in the intermediate hosts (except in the case of the fish tapeworm - Diphyllobothrium) one egg can give rise to many infective larvae. A thousandfold multiplication is not uncommon. Therefore effective transmission may be maintained at low contamination levels and the requirements of adequate excreta disposal in terms of the percentage of all faeces reaching the toilet may be demanding.

Category VI. The excreta-related insect vectors of disease comprise three main groups. Among the mosquitoes there is one cosmopolitan species Culex pipiens fatigans which preferentially breeds in highly contaminated water, and is medically important as a vector of the worms which cause filariasis. The other two groups, flies and cockroaches, proliferate where faeces are exposed. Both have been shown to carry numerous pathogenic organisms on their feet and in their intestinal tract, but their importance in actually spreading disease from person to person is controversial though their nuisance value is great. Flies have also been implicated in the spread of eye infections and infected skin lesions.

The implied control measures are to prevent access of the insects to excreta and may be achieved by many sanitary improvements of differing sophistication. In general, the simpler the facility the more care is needed to maintain it insect-free. Cockroaches, flies and Culex mosquitoes have numerous breeding places other than those connected to excreta disposal and will never be controlled by excreta disposal improvements alone.

The way in which the categories correspond to the length of transmission routes is shown in Figure 4. The discussion has emphasised the importance of complementary inputs for control of most diseases. If excreta disposal is improved in isolation, likely control of each category is as follows:

Category I	negligible
Category II	slight - moderate
Category III	great
Category IV	great
Category V	moderate
Category VI	slight - moderate

The outstanding difference is between Categories I and II together, which depend so strongly on personal and domestic cleanliness, and the other categories which do not. If one considers the changes necessary to control Categories III and IV they are relatively straightforward - namely the provision of toilets which people of all ages will use and keep clean and the treatment of faecal products prior to land application. The reason why the literature on the impact of latrine programmes often does not show a marked decrease in the incidence of Category III and IV infections is because, although latrines were built, they were typically not kept clean, not used by children, nor by adults when working in the fields.

excreta disposal improvements whereas

The way in which the categories correspond to the length of transmission routes is shown in Figure 5. The discussion has emphasised the importance of complementary inputs for control of most diseases. If excreta disposal is improved in isolation, likely control of each category is as follows:

Category I	negligible
Category II	slight - moderate
Category III	great
Category IV	great
Category V	moderate
Category VI	slight - moderate

The outstanding difference is between Categories I and II together, which depend so strongly on personal and domestic cleanliness, and the other categories which do not. If one considers the changes necessary to control Categories III and IV they are relatively straightforward - namely the provision of toilets which people of all ages will use and keep clean and the treatment of faecal products prior to land application. The reason why the literature on the impact of latrine programmes often does not show a marked decrease in the incidence of Category III and IV infections is because, although latrines were built, they were typically not kept clean, not used by children, nor by adults when working in the fields.