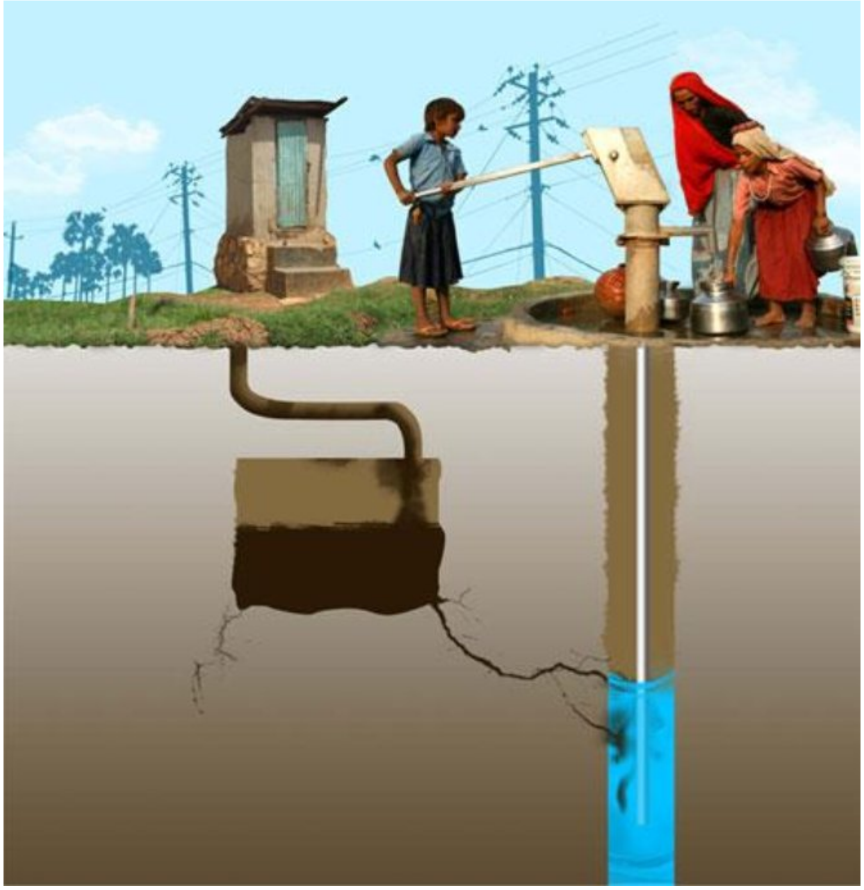
On-site Sanitation and Groundwater Contamination: A Policy and Technical Review



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1. Objectives

Going into the second decade of the 21^{st} century, the question of good sanitation is yet unresolved in most of the developing world. A variety of contributing factors dictate that on-site sanitation is still the most widespread mode of sanitation available. If properly implemented, such options could in combination with other larger scale services offer viable alternatives and complementary approaches to dominantly sewer-based sanitation systems. However, both poor design of such on-site sanitation systems, dense habitation and a combination of physical hydrogeologic factors result in threat to the contamination to fresh groundwater resources. Drinking water in both rural and urban parts of the developing world being highly decentralized and dependant critically on aquifers, this contamination of groundwater such on-site sanitation has a heavy public health burden, visible through a host of diseases, causing widespread morbidity and mortality.

The objective of this report is to first provide ways of assessing this threat of contamination to groundwater and practical means of evaluating future vulnerability at the design stage itself. The report also looks at options for adaptation with such threat especially in dense habitations where both on-site sanitation and drinking water facilities are spaced very closely. The study is based on review of literature, discussion with experts and practitioners and calibrating these with presentations in public forums. The presented “Policy Review” and “Technical Review” parts of this report attends to the needs of planners, aid agencies, researchers and practitioners to unravel through the mesh of this question and find reasonable solutions that can make headway. Presented also is a simple spreadsheet tool that summarizes the learnings and offers a method to assess vulnerability and compare alternatives.

The author urges the readers to critically look at this review and apply these learnings to planning and implementation of both on-site sanitation and drinking water systems.

2. Part A: Policy Review

The policy context of improvement in sanitation facilities for developing countries is highly intriguing. With a heavy emphasis on shifting communities away from open defecation and promoting safe sanitation, health and hygiene facilities, agencies are finding it difficult also to both culturally, technically and economically make this change happen. Though success stories of safe community drinking water, sanitation and hygiene are numerous, their scale is small and at the larger level, changes have been slow. Slippages rates of successes back to original conditions are also high.

Much of the emphasis of sanitation programmes is on construction of toilets since the initial aim is to make communities open defecation free. This in itself is a major achievement for many rural and urban areas in south Asian region countries such as India and Bangladesh. However in doing so, it is forgotten that though the mode of contamination from feces above the ground is stopped, the contamination route persists below the ground. By construction of toilets, this important point is conveniently forgotten. Also proper design of on-site sanitation structures is also not paid much attention. The maintenance of these systems, desludging of tanks and waste water disposal is also not considered much. As a result, public health problems continue to happen. Morbidity rates do not reduce. Only then does the community start thinking of second-generation solutions of disposal of sludge and waste water treatment. As evident here, the magnitude of risk from such contamination to groundwater from on-site sanitation structures is very high in dense south Asian settlements with local drinking water sources based on groundwater. Since there is almost nil treatment of such local groundwater sources, the possibility of this contamination providing a linkage to causing epidemics is huge. To avoid these issues, the minimization of groundwater contamination risk needs to be thought about right at the initial stage of planning. What will be important here is design, siting and maintenance of these On-site Sanitation Structures (OSS) and larger systems such as septage management services which need to be in place.

Then what kind of a policy should a government or policy-making agency have towards such sanitation facility, knowing that it could contaminate drinking water? Is the risk of such contamination high enough to target efforts towards promotion of safer sanitation technology, even though they would require more investment, more community cooperation and probably would be adopted slowly? Is this decision on risk uniform or would it require a more localized planning keeping into mind local risks, potential for adoption and trade-offs from longer term planning? Answering these questions require to broader thinking on water and sanitation away from formulaic approaches and tailoring solutions to community-specific contexts. As shown in this report, this decision making is not easy, so instead of following on one hand a highly precautionary principle or on the other hand a more agnostic one, it is better to build localized knowledge.

Presented here is a summary of options that are possible for stakeholders to understand and tackle this issue of contamination to groundwater from OSS. Also, we touch on current experiences from these options and expertise available. Please note that the arguments here are not intended to be comprehensive since a variety of possible options are available to address the problems.

This analysis presents the following arguments:

Main Risk Factors of OSS affecting groundwater contamination	**Strategies (not comprehensive) to counter risk:**
1. Local site specific factors such as hydrogeology 2. Varying risk from biological and chemical contamination 3. Risk due to faulty design and poor maintenance	1. National to Local regulations on OSS design, siting, maintenance and water quality standards 2. City level Septage collection and treatment 3. Community based wastewater systems 4. Protection of drinking water wells and alternative drinking water options

3. Analysis of Risks

In this section, we look at assessing the risk of contamination of groundwater from OSS and identifying factors responsible for this risk. Also, we look at context in terms of how important is this risk in different situations. These will provide us a hint towards mitigative solutions and options from technological, institutional and policy perspectives for addressing this risk.

3.1 Local site specific factors such as hydrogeology

A key determinant of risk variation is the soil and geological setting. Especially for consolidated hard rock sediments with poor soil cover and shallow water tables, the risk is higher. Given that most pathogens cannot survive in soil conditions for long period, the WHO has defined risk criteria for public health in terms of the time required for groundwater to travel from OSS to drinking water facilities.

According to WHO criteria, if the above travel time is less than 25 days, there is significant risk to contamination; low risk, if the travel time is between 25 and 50 days; and very low risk if the travel time is greater than 50 days.

This travel time depends upon a wide number of factors, most importantly:

i) Soil, geology and water table conditions
ii) Individual plot sizes and settlement density
iii) Type of drinking water sources and their distances from OSS

The current understanding from various scientific studies is that it can be broadly inferred that up to a limit there is indeed a “soil defense” happening all the time in filtering harmful pathogens and Nitrate emanating from OSS. Indeed, what can be better than continuous decentralized and natural treatment of human waste without the hazards of large infrastructure for transportation of waste and their treatment and then disposal of untreated waste? The catch here is that there is a limit up to which soil, rocks and aquifer can keep functioning as a natural filter. Beyond this limit, they in fact take on a more sinister role, that of repositories of harmful waste, multiplication, development of this toxic material into newer evolved waste and then serving it to humans through drinking water and other routes.

Away from the current thinking of what should be the safe distance between sanitation and drinking water facility; what should be ways to protect a well; how deep should be place OSS and wells; etc. <u>we instead need to be thinking on a slightly higher scale of that of the aquifer</u>. In the aquifer (including the top soil) can be thought of as having a “carrying capacity” to filter pathogens and chemicals which if exceeded can be dangerous. Defining this carrying capacity, however, is not so easy. Be it bacteria, viruses or Nitrates; what is evident is that their behavior varies with the rock type of aquifer. Therefore, one could start thinking by taking into account all these factors while deciding the carrying capacity and then consequently aquifer-specific policies on water and sanitation.

Case A: Findings by NEERI, India

In India, the National Environmental Engineering Research Institute (NEERI) has been a key government research institute that has been focusing on this aspect. The institute conducted studies in two cities – Indore and Kolkata which have very different geological settings. Indore is set on hard rock Basalt whereas Kolkata is on alluvial plains. The Indore site is also characterized by fluctuations in water table within a year with high monsoonal water tables. The results show that both coliforms and Nitrate concentrations are much higher in the Indore site than in Kolkata. Whereas fractures within the rock structure are acting as preferential pathways in the Indore site, in Kolkata a thick clay layer underlain by sand acts as a good filtration barrier. The difference of these settings on the observed quality of groundwater close to pit latrines clearly brings out the impact of geological settings. Such observations have been verified with numerous laboratory and field experiments in other countries.

These findings conclude that localized planning of sanitation and drinking water systems have to be based on the particular geological settings. Such thinking has not yet entered into policy level thinking as yet. However, experiments are being conducted by non-governmental organizations (NGOs) in this direction. An organization called Advanced Centre for Water Resource Development and Management (ACWADAM) in Pune, India is working with an NGO called CHIRAG in the hilly state of Uttaranchal and another in alluvial plains of Bihar state called Megh Pyne Abhiyaan (MPA). The issue that CHIRAG brought forward is that sanitation and groundwater contamination issues were previously not very important in this area. But recently many septic tanks have been constructed. Most of these septic tanks are poorly maintained and sludge removal is not very common. The way in which they contamination drinking water supplies is through springs which are fed by this groundwater. The spring water is used by downstream communities for drinking and domestic purposes. Also since the perception commonly is that spring water is highly pure, there is no sort of treatment done for this water. However, the organization has observed increase in bacterial and related problems mostly due to water. This is mainly attributed to the upstream locations of OSS which are contaminating groundwater. The problem that such an organization faces in properly analysis of this issue is also that no standard testing procedures are available to check the bacterial quality (except for Hydrogen sulphide strips). This makes it difficult to assert the problem and try to find solutions. As found out by detailed local studies in this area by another group called ACWADAM, it was found that the source areas contributing to the springs are not necessarily from the immediate upstream hill but also from nearby hills. Therefore even determining the appropriate OSS contributing to this contamination of groundwater and thereon to springs in difficult. The challenge therefore faces is how to prevent this contamination from happening. The current thinking in solutions is towards attempting the source communities to adopt safer on-site sanitation options which require less water use and divert urine. Till now the suggested solutions have not been tried on a larger level. In case of MPA, the sanitation and groundwater contamination linkage is very critical and important here. Due to government policies, it is now common to have drinking water sources next to households. Mainly handpumps serve this need. Open defecation is common and during monsoon, defecation practices on surface water ponds is also practiced. During flood situations the contamination from OSS is highly prevalent and the region has extreme high rates of diarrhoeal problems and child mortalities. Several solutions are being attempted to look at the problem from different angles.

The impact of local site conditions such as spring discharging groundwater, flood water affecting latrines and water supplies, etc. are present in these two sites. The manner in which local geology conditions are resulting in risk aspects is causing the organizations to think of completely different options to tackle this contamination problem, for example, as CHIRAG thinks about the septic tanks in recharge zone of the springs, MPA thinks about raising the latrines to protect them from flood waters. Such localized thinking, though difficult and expensive, can add a lot to risk perception and eventually strategies to counter this risk. Assessing the risk to groundwater contamination from OSS locally can be a very complex affair depending upon the complexities of local hydrogeology (Please refer to the "Technical Report" Section of this study for an updated review of this subject). However, one can simplify certain concepts. The authors have developed a simple Excel based program for assessing risk perception called *SanitContam* to summarize complex technical concepts taking into account findings from literature and criteria for travel times proposed by the WHO. This Excel program takes as input local site conditions such as water usage of sanitation structure, depth of pit, horizontal distance of well from sanitation pit, soil and aquifer parameters. With these parameters and monthly data on depth to water table and groundwater flow, one can assess the risk to contamination in terms of the number of days taken to flow from the sanitation structure to the drinking water well. Note that currently the program does not take into account the quality of construction. This will be an important factor which will be included in later versions.

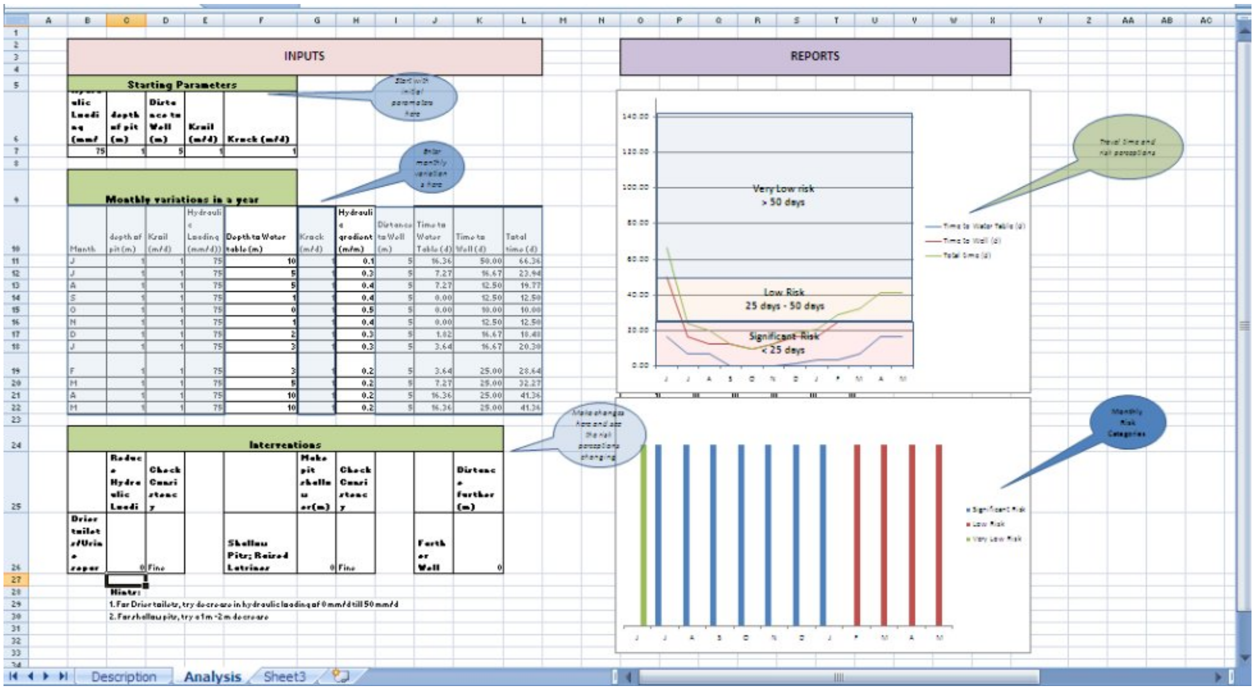
We consider a case in which a wet toilet is used (hydraulic loading = 75 mm/d), with depth to well being 5 m, depth of pit is 1 m, and both soil and rock conductivity are 1 m/d. The water table depth varies from 0 to 10 m and hydraulic gradient varies from 0.1 to 0.5. The following table summarizes the risk assessment with this base condition and after several interventions. Note that under the base condition without any intervention, 7 out of 12 months pose a significant risk to drinking water contamination and therefore to public health. This risk reduces to 3 months under two of the interventions i.e. drier toilets and a greater drinking well separation. By including all three interventions, this risk further reduces, but still there is one month when there is significant risk since this is the time when water table rises to the surface thereby connecting directly sanitation and drinking water. This cannot be avoided even with all these three interventions according to the specific site conditions and model assumptions used here.

Table 1: Risk Assessment for Groundwater Contamination from Sanitation using *SanitContam* for particular site situation

Cases	Intervention parameter	No of Months in a year with corresponding Risk category using WHO risk criteria		
		Very low risk	**Low risk**	**Significant risk**
Base Case	No changes	1	4	7
Drier Toilet	Hydraulic Loading reduces by 25 mm/d	6	3	3
Shallow Pit	Shallower by 1 m	1	5	6
Farther Well	Further distance by 5 m	5	4	3
All three interventions above	All of above	9	2	1

Note that these risk perceptions will vary a lot from one area to another. The reduction is risk achieved by any interventions will also vary. This is exactly the reason why such an assessment is useful to understand how any intervention would be useful in the future for risk reduction from contamination to groundwater.

Figure 1: Screen Snapshot of *SanitContam* Worksheet



Starting Parameters

ulic Loading (mm/	depth of pit (m)	Distance to Well (m)	Ksoil (m/d)	Krock (m/d)
75	1	5	1	1

Monthly variations in a year

Month	depth of pit (m)	Ksoil (m/d)	Hydraulic Loading (mm/d))	Depth to Water table (m)	Krock (m/d)	Hydraulic gradient (m/m)	Distance to Well (m)	Time to Water Table (d)	Time to Well (d)	Total time (d)
J	1	1	75	10	1	0.1	5	16.36	50.00	66.36
J	1	1	75	5	1	0.3	5	7.27	16.67	23.94
A	1	1	75	5	1	0.4	5	7.27	12.50	19.77
S	1	1	75	1	1	0.4	5	0.00	12.50	12.50
O	1	1	75	0	1	0.5	5	0.00	10.00	10.00
N	1	1	75	1	1	0.4	5	0.00	12.50	12.50
D	1	1	75	2	1	0.3	5	1.82	16.67	18.48
J	1	1	75	3	1	0.3	5	3.64	16.67	20.30
F	1	1	75	3	1	0.2	5	3.64	25.00	28.64
M	1	1	75	5	1	0.2	5	7.27	25.00	32.27
A	1	1	75	10	1	0.2	5	16.36	25.00	41.36
M	1	1	75	10	1	0.2	5	16.36	25.00	41.36

Interventions

	Reduce Hydraulic Loadi	Check Consistency			Make pit shallower(m)	Check Consistency			Distance further (m)
Drier toilets/Urine separ	0	Fine		Shallow Pits; Raised Latrines	0	Fine		Further Well	0

Hints:
1. For Drier toilets, try decrease in hydraulic loading of 0 mm/d till 50 mm/d
2. For shallow pits, try a 1m -2m decrease

However as pointed out from discussions with BORDA-India and GIZ-Afghanistan representatives, there are cramping practical issues in implementing distance criteria in the region. The following three reasons are of prime importance:

a) With dense settlements having both OSS and on-site drinking water source within very small compounds, it becomes impossible to allow any distance criterion that assumes filtration through the medium. As pointed out by Dr Thammarat of AIT Bangkok during discussions, in such situations, the only option is that the OSS fully contains all waste and leakage is fully prevented.

b) There is poor coordination between households of adjacent compounds. Very often, drinking water source of one household is adjacent to OSS of neighbor. Many times, this would go unnoticed during construction unless the same mason is involved.

c) Due to rapid economic boom and redevelopment activities in city outskirts, very often new houses ignore the OSS locations of previous occupants. One can end up constructing a drinking water well right into the previous occupants’ pit. This situation, not uncommon, is entirely due to lack of any records of sanitation pits in existing plots.

The above constraints make implementation of any distance criteria for OSS and drinking water sources very difficult to implement for dense settlements in the south Asian region.

3.2 Varying risk from biological and chemical contamination

The two primary contaminants from OSS are pathogens (mainly bacteria and viruses) and Nitrate. There are several reasons why the concern for Nitrates should be of lower concern, as compared to the pathogens transmitted.

a) Firstly, whereas such on-site sanitation might be the largest source for pathogens into groundwater, in case of Nitrates, the reverse is true. Often the largest contribution of Nitrates into aquifers is from cattle waste and agricultural fertilizers (in rural areas). In dense urban dense settlements, often sanitation structures could be the sole contributors of Nitrate into groundwater.

b) Secondly, the public health impact of pathogens is far greater than that of Nitrates. It has been reported that diarrhoel problems have an overall DALY > 22 million years annually in India and there are 4,25,000 deaths due to diarrhea annually, as reported by the National Institude of Chronic and Enteretic Diseases (NICED) in India. To be noted is that some fraction of this disease burden can be attributed to water related problems, but that still would be quite large. This is an enormous disease burden as compared to that of Nitrates for which no such estimated disease burden is available, mainly because it has not yet been recognized (in India) as a major public health problem. Apart from the blue baby syndrome (which does not have a high incidence), no other significant health problems have been associated with Nitrate toxicity as yet.

   Therefore Nitrate control in groundwater requires different mitigation strategies keeping into mind local public health risk.

Looking back at the history of shifting communities towards groundwater for drinking water worldwide, the risk to shallow groundwater from open defecation and on-site sanitation was recognized in the 1970s and 1980s in developing countries of south Asian region. The program to eradicate Cholera and Guinea worm tried to wean communities away from using surface water and shallow groundwater accordingly. The movement was towards accessing deeper groundwater for drinking purposes through handpumps which could be installed closer to households and offered an independent source of domestic water to women, thus reducing the drudgery for accessing drinking water.

However, these have opened up newer contamination problems in the deeper layers which take longer time to develop, but are irreversible mostly. The two problems of Fluorosis and Arsenicosis have a very high disease burden today. Estimates made for some of these water quality related health problems suggest a massive endemic nature – Fluorosis (65 million affected (reported by Dr. A. K. Susheela in “A Treatise on Fluorosis”) and DALY = 38.5 per

1000 population), Arsenicosis (5 million affected in West Bengal as reported in WHO 2002), but several magnitudes more unestimated from Assam and Bihar and more in neighbouring country of Bangladesh). The problem with Fluorosis and Arsenicosis as opposed to biological contamination problems is that they take time to cause a significant impact and by then it is too late. They are therefore far too difficult to counter.

As reported in the paper, “Contrasting influence of Geology on E Coli and Arsenic in Aquifers of Bangaldesh”, by Leber and other authors, there is an inverse relationship between Arsenic and E Coli concentration in many locations they surveyed. Similarly Geen and other authors report for Bangladesh in the paper, “Fecal Contamination of Shallow Tubewells in Bangladesh inversely related to Arsenic” report that shallow groundwater is contamination by fecal coliforms due to poor sanitation whereas deeper groundwater is affected with Arsenic. Similar vertical variation is also reported for Fluoride.

An outlook merely considering contamination from on-site sanitation will therefore hide possibly large problems in the longer run from such Fluoride and Arsenic contamination. When such kind of conditions prevail, i.e. both shallow and deeper sources are contaminated, efforts need to be made to protect both aquifers. In extreme circumstances and unfortunately in several south Asian countries today, one makes a tradeoff (which is difficult since both are significant public health problems), or one needs to have alternate strategies such as water treatment or change the source of drinking water.

3.3 Risk due to faulty design and poor maintenance

Two types of design failures can be recognized which accentuate contamination from drinking water sources:

i) Design and implementation of OSS resulting in poor containment of wastewater and sludge
ii) Design of handpumps and drinking water wells resulting in leakage of contaminants (travelling laterally) from side walls

Both of these design failures, at the source and receptor ends, can be avoided by proper care taken during construction and with good maintenance. For example, the Indian OSS design guidelines (section 3.1) recommend pit lining for pour flush latrines either with brick lining or using concrete rings with openings of maximum 12 to 15 mm thickness. Also various pit sizes are recommended depending on the family size. But this assumes that discharge only from the toilet is let out into this pit. However, in absence of sewers, it is common for the entire household water to be let out into the pit, increasing the water load highly. Given the size of plots (1000-1500 sq ft) and limited locations of OSS within a plot, having a leach pit of appropriate size becomes a practical difficulty. Moreover, contrary to design requirement, the bottom of the pit is left exposed to the soil. All these result in poor containment of waste water and sludge within the pit. Desludging services are not offered by city municipalities in countries such as India except for few cities, even for which the scale of requirement is not satisfied. Private operators carry out desludging and dispose off sludge in open locations since septage treatment plants are not available. A large city such as Bangalore has a septage treatment plant, but it used to receive sludge far above its capacity and currently it is not active. A consequence if this situation is that desludging activity is rare (5-10 years) and done in unsafe manner manually.

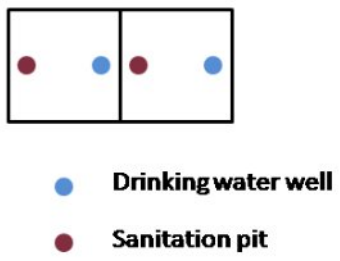
Case B: Lack of Adherence to Design of OSS, Maharashtra, India

As pointed out by Asit Nema in the note, "Sustainable options for on-site sanitation in rural Maharashtra", 50 odd pour-flush latrines constructed by the government's Total Sanitation Campaign were found to be dysfunctional due to severe scarcity of water in village Vatefal, 20 kms from Ahmednagar. One requires 3-5 litres of water after every use, which is not possible in a drought prone belt. Secondly, Nema notes that in the coastal belt of Raigarh district, there are problems of stagnation of rain water and shallow groundwater table; therefore again such latrines are not feasible due to a "backflow" problem causing groundwater contamination. As pointed out by Nema, the design recommendations for such latrines such as providing for a sand envelope, raising the pit to avoid groundwater contamination, creating a soil mound and pit lining often result in cost greater than that of just construction of the latrine; so in order to keep the cost of construction low, such design parameters are violated.

The second design failure is at the drinking water well end. For layered aquifers, the transport of pathogens to deeper layers is often very less. As explained in the "Technical Report" of this study, the horizontal transport of pathogens is much faster than vertical transport. So even if drinking water wells are located nearby, transport of contaminants can be prevented if the well accesses groundwater from deeper layers. However, the water in the well still gets contaminated if there is not protection at the well-head. This simple protection can cut off contamination through direct horizontal transport.

Case C: OSS with faulty design contaminating groundwater in Herat, Afghanistan

Herat city in Afghanistan has a water supply system with the main groundwater source located in the outskirts of the city, known as “Navin Well-field area”. Groundwater is extracted from the aquifer at 75 – 90 m below the surface through ten deep wells. The household sanitation systems found in the nearby areas are of two types – a raised-pit dry latrine or a pour-flush toilet connected to an open sewage well. The bottom base of the raised pit is open to the ground and liquid gathered in the vault can flow into the soil and ground water. The pour-flush toilet is connected to an underground, off-set sewage well (3-8 m deep), which is supposed to have vertical stacked concrete ring-walls, but many households have only one such ring, 40 cm wide. The most critical threat from the two sanitation systems found in the Navin Well-Field is the contamination of the underground water resources (a typical arrangement shown in the figure here). Both the dry pit latrine and the sewage well are open to the ground and hence pathogens and nitrates from excreta are able to migrate through the surrounding soil and water, reaching the shallow water table. The shallow drinking water wells (mostly less than 10m away from nearby OSS) found in many of the home-yards are reported by the community to have a hygienically poor water quality, and the women pointed out that children suffered from diarrhoea and stomach aches when drinking this water. This contamination has the potential to disturb the entire water supply of the Herat city now, mainly due to faulty designs of OSS in nearby areas.



4. Strategies to counter this risk of groundwater contamination from OSS

Given the background of risk of contamination to groundwater from OSS in the previous sections, we move on to understanding approaches of mitigating this risk. Here we look at solutions strategies from different levels of sanitation planning and – that of policy in terms of national, state or city levels; that of city level services; of community level solutions – and then on to options from the drinking water perspective. Note that these strategies are in no way meant to be comprehensive, but they provide us directions to explore. These options have been gathered from a wide range of discussions with stakeholders – directly, during workshops and conferences – spread across the south Asian region and involved in various sectors that are related to this issue.

4.1 National to Local regulations on OSS design, siting and maintenance and water quality standards

In India currently, planning for the next five years under the 12th five year plan is in process. Discussions happening under a working group on "Urban sanitation" make it clear that current guidelines for urban sanitation drafted in 2008 need to be communicated to state and local bodies and implemented using local regulations. These guidelines are present in a document titled: "A Guide to Decision Making: Technology Options for Urban Sanitation in India". This document is intended as a guide for municipal agencies and also for sensitizing state governments. Regarding legal provisions the document clearly mentions that the municipal bylaws do not have any provision for safe removal, cartage and disposal of sewage in urban areas. With regard to OSS, the referring document for technical norms is the "Manual for Sewerage and Sewage Treatment" of the Central Public Health and Environmental Engineering Organization (CPHEEO) of the Ministry of Urban Development. The Chapter 21 of this manual deals with "On-site Sanitation" and it spells out many suggestions including the following:

Relevant Points from Indian OSS Guidelines, 1986

- Septic tanks should be desludged once a year
- Soak pits or dispersion trenches can be adopted in all porous soils for which soak percolation rate is below 25 min/cm and water table depth is below 2m.
- The sub-soil dispersion systems should be 20m away from nearest drinking water source
- Leach pits should be raised 300mm above the likely level of maximum water table rise
- When water table raises to 300mm below ground level, the pits should be raised above ground level
- In rocks with fissures, chalk formations, etc., serious precautions needs to be taken since pathogens can carry for long distances
- When distance between bottom of pit and water table is 2m or more, pits can be located 3m from water source when effective soil size is 0.2 mm or less; for coarser soils, bottom of pit

needs to be sealed off by impervious material
- When distance between bottom of pit and water table is less than 2m, pits should be located minimum of 10 m from drinking water source with same conditions as above for coarser soils
- Pits should be avoided in depressions and water logged areas

The guidelines also refer to criteria for different types of soils and water table conditions in order to prevent risk of groundwater contamination from OSS. Though these guidelines are not very detailed as to go into site specific situations, they still recognize the problem and recommend strict design safeguards. However, these guidelines put forward in 1986 by an expert committee constituted by the CPHEEO is yet to see the light in terms of actual implementation. In fact, the entire chapter is encapsulated in the 2008 recommendations into a single paragraph. And worse still, the 2008 recommendations have not been communicated to municipal authorities. It is therefore not possible to expect enforcement of these guidelines by local city municipalities today. What exists on the ground and pure ad-hoc "norms", for example, that pits should not benter into adjacent private or public plots or roads. Or for example, when the soak pit overflow, the households are forced to desludge, etc. The following steps could be undertaken:

i) Improve the 1986 guidelines by allowing cities to develop local risk criteria and therefore design requirements
ii) Local city regulations could be passed to implement the above guidelines
iii) City municipalities need to be trained to understand risk assessment and be able to carry out on their own or oversee such risk assessment
iv) Penalties should be decided to ensure that individuals do not violate these norms; "Free riding" and corruption is at the base of enforcement and unless they are removed, this enforcement would be difficult

Looking at the risk to groundwater contamination from OSS, apart from sanitation policy, another critical policy is that of water quality monitoring and assessment. Dense and reliable water quality data along with public health statistics could be useful tools for municipalities to raise awareness about such pollution hazards. However, as exists in the region, such data are few and lacking. Why is it so?

The Water quality assessment authority (WQAA) of India is an apex agency for the country which is responsible for assessment of water quality and laying down standards. According to the WQAA, the contamination of groundwater from on-site and also sewerage systems is the single largest contamination problem to groundwater in the country. They have produced a report on shallow groundwater contamination which discusses this issue. But the WQAA accepts that current water quality monitoring networks in the country are too less to capture the nature of this problem. Since most of these measurement are done only twice or four times a year and only a few thousand observations in the entire country, it is not possible to make an assessment of the problem from the data collected. One of the root problems cited by WQAA is that no agency is taking responsibility for assessing of water quality in the country especially for domestic purposes. One of the reasons for this is that in India, enforceable water quality standards for drinking water are not yet in place. What exists now are standards from the Bureau of Indian Standards (BIS) which are recommended, but not enforceable. No single ministry of the central government – Water Resources, Ministry of Environment and Forests, Ministry of Rural Development (housing the Department of Drinking Water Supply) - is coming forward to create such a legal standard. In absence of such legally enforceable standard, one cannot, for example hold a government program or private entity responsibly for construction of toilets which result in large scale groundwater contamination. Also, one cannot be held responsible for supply of unsafe drinking water due to no legal standards. A discussion on this aspect is happening today in policy circles in India, but progress is poor.

Another important stakeholder is the Central Groundwater Board (CGWB) in India. Currently the CGWB monitors 15,000 observation wells across the country. The water quality assessment of these wells is less towards determining risk to public health, more towards a general description of groundwater across the country. The data from these observation wells are too coarse a scale to determine whether local OSS are causing any contamination to groundwater which is of order of less than a hundred metres whereas these observation wells are on an average spread for more atleast more than 10 kilometres. Then the question is, which agency would be responsible for such assessment of risk to groundwater contamination. The response was not very clear, but the understanding was of the direction that for example if the risk assessment is for purposes of drinking water, then the Department of Drinking Water Supply (DDWS) would be responsible for such an assessment.

Multiplicity of institutions with unclear role division is leaving a large gap of water quality data monitoring unaddressed. This is a critical impediment in looking at risk of contamination since very few data is available in a country such as India.

4.2 City Level Septage collection and treatment

Desludging of septic tanks and other OSS is a major problem increasing groundwater contamination in the south Asian region. In dense settlements with narrow roads, large vacuum trucks cannot be used and narrow-based wheel trucks and UN Habitat’s Vacuutag are now being promoted. All these services require an investment which the private sector has not still made in a large manner in countries such as India. Currently private services for septage collection are available, but the manner of septage collection and disposal is highly irresponsible environmentally and also for safety of the OSS. Such services can only by provided at a scale by municipalities. But financial models that can rationalize such services and also have centralized septage treatment services that produce safe manure from sludge have not yet taken up. However, some cities in countries such as Philippines are showing the way ahead.

Some cities in the Philippines have promulgated city ordinances that penalize households which do not avail of professional desludging services once every few recommended years (usually 5 years). For such cities, common sludge treatment plants have been constructed into which sludge collected from households is transported by trucks. Several cities such as Manila and Dumaguete have implemented such programs. Discussions with Dr. Thammarat Koottatep (AIT, Bangkok) showed that most municipalities in Thailand either offer services to desludge septic tanks or subsidize such services. Around 250 Baht per cubic metre is charged for such desludging. However the practice of treating the sludge does not exist. It is just dumped on outfills. If there are systems for septage treatment also at the municipal level and it is converted into compost, then a financial model can be created where-in some tax can be imposed on the citizens for this treatment.

Case D: Septage Management in Dumaguete city, Philippines

Dumaguete is a coastal city of 3,00,000 population in Philippines. Like most other cities of the country, it does not possess a sewerage system and depends on septic tanks for domestic as well as industrial establishments. There exists around 20,000 improperly maintained septic tanks in the city and they are a severe source of contamination for sixteen deep wells and eight hundred shallow wells which supply drinking water to the city. The city identified that for a water quality management strategy, the major step to be undertaken is a septage management programme for septic tanks. The city enacted a Septage Management Ordinance in 2006. This involved a user service fee of 2 Pesos per cubic meter of water consumed, to be collected as part of water bill. The ordinance decreed that septic need to be deslidged on an average every 3 years and maximum of 5 years, or until 1/3rd of the tank is filled. Fines of 1000 pesos, 2000 pesos and 3000 esos have been suggested for violation of above principles by individual houses, private establishment and hospitals respectively. The Dumeguete city council entered into a contract with the city water district for sharing 50% of costs for the septage management system and sharing 50% of any net income. The water utility company would need to perform desludging operations and the city government operates the septage treatment facility. The system consist of vacuum trucks operating 5 days a week collecting sludge and transporting it to a centralized septage treatment facility of capacity 80 cubic metre daily load, costing 3 million pesos. Full operation began in July 2010 and by April 2011, 2842 septic tanks had been desludged with total load of 12,225 of septage. The city recognizes that more vacuum trucks need to be in place and teething problems such as collecting rainwater need to be sorted out so that treated sludge can be used as manure. But, the city government is ready to undertake these steps for protecting the groundwater resource until decentralized wastewater treatment systems or sewerage systems are in place in the future.

4.3 Community based wastewater treatment and septage management systems

Given that for the large number of teeming towns and dense settlements, on-site sanitation options by themselves are becoming impractical as a sanitation option (due to space constraints, difficulty in monitoring and lack of incentives for individuals to invest on any localized treatment), the thinking developing now is to look at community based possibilities. No wonder, community based options are no magic silver bullet. They boil down finally to a group of households coming together, taking responsibility for a common asset and maintaining it. Given the current urban south Asian context of heterogenous population with a high flux, expecting such ownership is impractical. Inspite, there have been efforts by NGOs to attempt such community based options. The community based options are all characterized by a household level sanitation system and a community level treatment facility. Not all of them have a physical transporting of waste from households to the common facility. Also, the type of common treatment facility varies.

Two approaches with some commonalities between them being implemented now are – Ecosan and DEWATS. The review of these two options is an incomplete analysis of all options available, but it is indicative of the technical analysis that communities must do before identifying the technology solution appropriate for their situation.

4.3.1 Ecosan

Ecological sanitation focuses on closing the resource loop, i.e. using the water, nutrients and organic water of human waste as a resource rather than disposing it. Ecosan practices are now encompassing a variety of safe OSS combined with recycling of waste and generation of useful energy as bio-gas and manure for fields. Overall, Ecosan aims at sustainable waste management at community levels.

Many Ecosan programmes aim at reducing the total water output from the sanitation pit. Certainly, more that water output, greater are the chances that pathogens can escape from the pit, cross the soil layer and reach the water table. Also these on-site latrines are in direct contact with the soil or rock beneath. These two factors i.e. higher risk of wet toilets and low water availability, necessitates different technology options, one of which is the form of double vault latrine, or as being promoted now as part of Ecological Sanitation (Ecosan) options in for such high risk areas.

This involves urine separation, maintenance of two separate chambers, and usage of soil/ash/dry leaves after every usage. However these require a high level of cultural change and frequent maintenance of the chambers, something which is quite difficult to bring about on an individual, distributed and household scale. Therefore Ecosan concepts are being promoted in south Asian region on a community level rather than on an individual household level.

As listed by Dayanand Panse in the note “Ecological Sanitation- A need of today. Progress of Ecosan in India”, a number of agencies are leading the effort on Ecosan through pilots across the country. Among these are Ecosolution (India), GTZ, Seecon GMBH, Gramalaya, SCOPE-Trichy, Navsarjan, BORDA, IWWA, Ecosan Services Foundation - India, ACTS, EcosanRes/SIDA, CSE, UMB, UNICEF and UNDP. However, the progress on adoption of Ecosan has been very slow. The state of Tamil Nadu has been leading on this effort, but as pointed out by Mr. Ganapathy of FIN (India), there are several bottlenecks for its progress:

i) There is not much push at the policy level till recently for Ecosan
ii) Masons are not well trained to construct and maintain such structures
iii) The user needs to have a high degree of behavioral change for proper usage
iv) Several design problems also contributed to failure at the field:
    a) The urine and washwater pipes are located inside the compost making it difficult to repair. The ash used for cleaning often clogs the urine and wash holes. While removing this block by rods, people often break the pipes leading to mixing of urine and washwater with compost. A solution has been attempted by SCOPE in Tamil Nadu by changing the location of these pipes
    b) Concrete slabs for the roof started to leak and people stopped entering the toilets. Now tin roof, asbestos or straw and reeds are used.

Case C (cont’d from section 2.3): Solutions to address groundwater contamination from existing OSS

*The Navin well field supplying drinking water to Herat city was observed to be under threat due to unsafe OSS in the nearby areas. To address this problem, preliminary discussions were held with the community of the Navin Well-Field Area to be able to gauge the existing sanitation situation. A list of criteria for the selection of alternative sanitation systems for the well-field was made based on the discussions with the community, the local context and the primary objective of water quality protection. After this discussion, a Double-vault urine-diverting dehydration toilet system (UDDT) and Fixed-dome biogas sanitation system (for toilet waste and cow manure) were decided as best acceptable options for the community***.** *Till late 2010, the project has been able to support the establishment of 37 UDDTs and two sanitation biogas systems in the target area. A progressive leadership, women’s involvement, demonstration effect and subsidy were factors considered as important in success for this project. By adopting safer OSS using urine diversion and converting sludge into manure, the possibility of protecting drinking water supply from the Navin well field into Herat city becomes higher now.*

Ecosan technologies combined with recycling of waste at a community level are a possible solution for avoiding problems causing by traditional pour-flush type on-site sanitation latrines. However, their implementation requires a higher degree of behavioral change and services for local maintenance. If these can be achieved, then a large risk to groundwater contamination from on-site sanitation can be prevented.

4.3.2 DEWATS

Beyond an individual level, solutions at a community level include DEWATS- Decentralized Wastewater treatment systems. Such systems have being built to treat wastewater up to 1000 m^3 per day using low energy technologies for sedimentation, floatation, fixed bed reactors etc. Some countries such as India have piloted this idea on a small scale – communities of less than 1000 population. In Philippines, the concept is being piloted in urban areas for specific purposes such as tanneries and market places. The Indonesian government is going ahead with this concept across the country through the SANIMAS programme.

Typically, DEWATS facilities would have a household level sanitation pit or septic tank from which wastewater is transported through simplified sewerage systems with a gradient of not more than 1 m. These pipes are simpler than small bore sewers and can be locally procured[1]. The wastewater is typically treated using an anaerobic baffled reactor and then let out into a biological filter such as a reed-bed. After this, the wastewater is expected to be safe to let out into the environment either to be re-used or for seeping as recharge or into drains. In this case the sludge that accumulates in the household pits is supposed to be of a concentrated quality and good for manure or for biogas plants. There is a separate system of sludge collection tied to this community based system.

One major constraint with DEWATS type options is availability of land. Given high real estate prices in such dense settlements, getting land for a treatment plant drives up the total cost of the project. Instead implementing agencies are toying with ideas of multiple use such as gardens and common spaces, if available. The anaerobic baffled reactor can be located underground below such a common space. But the reed bed treatment plant needs to be above the surface. Odour also can be a problem for nearby residents.

Different from the above option as practiced by DEWATS-BORDA, various other combinations are being tried also. For example, urine separating toilets are installed at the household level, the toilets are themselves communal and there are large community based septic tanks, etc. Many such options are now being attempted and they are in place in many dense settlements of cities today as an option different from individual toilets connecting to a sewerage system. Community toilets based with a pay-and-use principle are widely popular and promoted by the Sulabh agency in India. They require households to physically locate their toilets at a common facility, thereby

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[1] As yet, small bore sewerages have not found their way into larger practice. Very high-end tenement societies are experimenting with it in India and some parts of New Delhi have announced an experimentation with such small-bore systems. Otherwise, there is a teeming PVC pipe market for sewerages that already exists in the country.

avoiding maintenance issues at the household level, however, it requires a cultural change that has been overcome in many cases.

For all such type of community based measures, more than the technology, what matters is the involvement of the community at every stage of planning and implementation since in the longer run the facility has to be used and maintained by the community. At this community level, no administrative structure exists, therefore any future transfer to municipal authority becomes difficult. Therefore the bigger constraint for such a direction is community mobilization which requires a much greater awareness and imperative to act on sanitation issues.

4.4 Protection of drinking water wells and alternative drinking water options

4.4.1 Sanitary Dug wells

However, if the contamination of groundwater by OSS cannot be prevented, one option left out would be to protect the drinking water well from contamination by proper casing and protection. The first aspect that needs to be kept into account here is the distance of the drinking well from a source of contamination. Next, direct horizontal movement of the contamination from the sanitation pit to the well can be preventing by casing till a depth below that of the latrine pit. In case of boreholes, a cement seal (altleast 5 cm thick) needs to be used as casing. However, since many of the shallow dug wells are constructed by hand drilling or blasting, such practice is difficult to follow.

Case E: Sanitary Dug Wells for Drinking and Domestic Purposes

In areas where alternate drinking water sources are not available, such protection of the dug well is in practice calling it a protected sanitary dug well. For example the Centre for Science and Environment in New Delhi, India reports about an NGO, Vasudha Vikas Sanstha working in Dhar district of Madhya Pradesh. Here the NGO has involved women's groups through the Village Water and Sanitation Committee (VWSC) and energized the community to protect this dug well as the drinking water well. This involves several rules:

- *a) To provide proper casing for the well to avoid direct contamination from sanitation structures*
- *b) Siting of this well to be as far as possible from on-site sanitation and open defecation areas*
- *c) Complete closing of the well head and providing a handpump instead of direct contact for withdrawing water*
- *d) Avoiding excess pumping of other wells nearby for irrigation purposes to sustain the water during the dry season also*

To be noted is that this option of a protected sanitary dug well is more suitable at a community level (rather than at an individual household level). All these have resulted in self-sufficiency for the community in terms of sufficient and safe drinking water even in a village with on-site *sanitation and open defecation. Many NGOs and government programmes across the region are advocating such protection of sanitary dug wells as means of ensuring safe drinking water. This has also resulted following from the next point mentioned below i.e. harmfulness of deeper groundwater.*

4.4.2 Rainwater harvesting

Traditionally, storing rainwater during monsoon available from the roof-top within cisterns below a household have been a practice in many arid and semi-arid parts of India. In the past few decades this practice has been revived under the name of roof-top rainwater harvesting (RRWH). The Centre for CSE was instrumental in popularizing this idea in the 1990s and today many agencies such as Arghyam Foundation actively promote this idea throughout India. RWH can be an excellent option for safe drinking water in areas with no alternative safe drinking water source that can be protected from contamination. However, experiences show that this collected water during monsoon needs to be conserved throughout the year and also one needs to prevent this water from getting contaminated. In urban areas, many private services are today being provided for RRWH and the city of Chennai in India has a regulation for every new building to have RRWH. Widespread adoption of this concept is yet slow due to several reasons:

i) Water availability per household is low for high rises where the same roof is shared by large number of households

ii) A well paved roof is not available to many rural houses, making it trickier to trap the rainwater

iii) A high (for poor households) initial investment of around Rs 2-3 per cubic metre needs to be made to construct the underground tank

iv) Adequate protection of stored rainwater has to be made throughout the year

If all these are followed, many areas with as less as 300 mm average rainfall every year can adopt this ideas as described by Indukath Ragade in his book, “Self-Reliance in Water”.

4.4.3 Water treatment

In areas where one has to choose between either of the two evils (Biological or Chemical contamination) and scarcity of water is not a problem, an option is that of water treatment. However, for most rural households in India, water treatment is not practiced widely except for simple filtration by cloth. In very few states a culture of boiling water exists. Apart from that, the general culture is to directly consume water without treatment. During monsoon, public health agencies adopt chlorination of water supplies at the community level and chlorine tablets are distributed at the domestic level.

In this context, a lot of options are being created today for water treatment at the domestic and at the community level. Several organizations such as Nandi foundation in Andhra Pradesh are practicing community based water treatment where the entire cost of O and M is met by the community. Many of these are Reverse Osmosis (RO) plants which are also effective in removal of some types of contaminants such as Fluoride. However, RO technology is expensive, has high maintenance costs and is high on water usage since the concentrated waste water needs to be rejected. At the domestic level, a lot of development has been happening in India recently. Two major industries the Tatas and Hindustan Level (Indian arm of UniLever), have developed low cost filters (less than Rs 1000) which run without electricity and aim to remove a reasonable bacterial load. Several other filters are also available such as Terrafil (made from Terracota, produced by IMMT – Institute of Minerals and Materials Technology), iron removal filters made of clay and rice husk in eastern India, Activated alumina based filters for Fluoride and Arsenic removal, use of Moringa Olifera for removing turbidity and bacteria, Bio-sand filters for bacterial removal.

Inspite of the low cost and ease of use, widespread adoption of domestic water filters has yet not picked for most of rural India.

4.4.4 External Water Supply

In the broader context, beyond distance requirements between on-site sanitation and drinking water facilities, more critical is to look at overall sanitation, hygiene and health and be able to see trajectories that the community can take with various evolutionary technology options in a public, subsidized or private mode.

As Asian cities are developing, newer satellite areas get permission first for land construction, then for water supply and lastly after long period for sewerage. Therefore a significant time passes by when both sanitation and drinking water facilities are on-site for many of these communities. This is true for majority of rural areas where absence and failure of public delivery systems has forced household to depend on nearby drinking water sources and sanitation is either open defecation or a household sanitation pit. Within this context, it is apt to view Table 2 as a matrix of possibilities between on-site and off-site drinking water and sanitation facilities. This decision needs to be made everywhere – in rural and urban settlements, and very much pertinently now, when investments on both these aspects are taking place on a large scale. In this report we discuss the on-site/on-site option with respect to risk. But where such risk is very high, one might have to consider the other options i.e. making either or both of these as off-site facilities.

Table 2: On-site and Off-site Conundrum of Drinking Water and Sanitation Facilities

Drinking Water → **Sanitation ↓**	**On-site**	**Off-site**
On-site	Safe distance criteria and depth of well become important; Currently in Less Densely Populated Rural Areas	Cost and maintenance of external drinking water supply
Off-site	Investment costs; Flow and maintenance of sewerage; Centralized treatment	High investment and high maintenance option; Currently in High Population Density urban areas

This last option as is happening in several parts of south Asian region is to totally discard local sources of water for drinking and depend instead on external water sources supplied through pipes. Slowly as a response to drinking water crisis, such piped water supply schemes are being demanded by urban and even rural areas and being met by governments. The source of water is often a reservoir which is also used for irrigation, and urban/industrial/hydropower uses. The water supply within a village/town is supposed to be met by local community based organizations or municipal bodies and a nominal per capita charge charged. However this cost recovery is very poor for most such schemes, therefore the operation and maintenance of the schemes depend totally on government grants. The status of such schemes is very often in disrepair after few years of operation leading to intermittent water supply especially during summer months.

The critique for such external piped water schemes has been that communities often start to depend on these schemes, neglecting the maintenance of local water sources. Thereby if the external scheme fails, the community has to recourse to a poorer local water supply source.

The trend across the region, irrespective, is that of political promise of such pipe water supply schemes and the future might see more development on this front.

5. Conclusions to Part A

Most developing country sanitation programmes have maximum attention on toilet construction leaving critical issues such as disposal of sludge and waste water treatment to second-generation solutions. After eradicating open defecation, the risk of contaminating groundwater from OSS is not paid much attention and remains a public health problem. A key determinant of risk variation is the soil and geological setting. Due to small houshold plot sizes and high settlement density and lack of coordination between adjacent households, this risk gets amplified. Also important is the type of drinking water sources and their distances from OSS. But instead of focusing on individual OSS and the risk emanating from them, we need to be thinking on a slightly higher scale of that of the aquifer. At this level, one needs to have a localized planning of sanitation and drinking water systems and they have to be based on the particular geological settings. To aid such planning, a simple Excel based program for assessing risk perception called *SanitContam* (available for use) has been developed to summarize complex technical concepts taking into account findings from literature and criteria for travel times proposed by the WHO. When comparing risk from Nitrates and that of Pathogens, still, the disease burden from pathogens is considerably higher and should be given more importance. However, contamination of shallow groundwater has opened up newer contamination problems in the deeper layers which take longer time to activate, but are irreversible mostly. For example, the two problems of Fluorosis and Arsenicosis have a very high disease burden today in the south Asian region.

The field level implementation of OSS and drinking water wells also contribute to this risk. Faulty design and implementation of OSS results in poor containment of wastewater and sludge Also the design of handpumps and drinking water wells results in leakage of contaminants (travelling laterally) from side walls onto the well.

Looking at strategies to counter this risk of groundwater contamination from OSS, a range of steps need to be carried out. At the policy level, guidelines need to be framed so that technical frameworks for risk assessment are easily available. The city municipalities need to have capacities to develop local risk criteria and therefore adopt design requirements locally. City municipalities need to be trained to understand risk assessment and be able to carry out on their own or oversee such risk assessment. Once such criteria are developed, local city regulations need to be passed to implement the above guidelines. Penalties should be decided to ensure that individuals do not violate these norms; “Free riding” and corruption is at the base of enforcement and unless they are removed, this enforcement would be difficult.

To assess the problem, dense and reliable water quality data along with public health statistics could be useful tools for municipalities to raise awareness about such pollution hazards. Multiplicity of institutions with unclear role division is leaving a large gap of water quality data monitoring unaddressed. This is a critical impediment in looking at risk of contamination since very few data is available in a countries in south Asian region.

At the city level, we need systems for septage treatment at the municipal level. By converting treated sludge into compost, a financial model can be created where-in some tax can be imposed on the citizens for this treatment. Some countries such as Philippines have already proceeded in this direction.

Given that for the large number of teeming towns and dense settlements, on-site sanitation options by themselves are becoming impractical as a sanitation option (due to space constraints, difficulty in monitoring and lack of incentives for individuals to invest on any localized treatment), the thinking developing now is to look at community based possibilities. Two approaches with some commonalities between them being implemented now are – Ecosan and DEWATS. Ecosan technologies combined with recycling of waste at a community level are a possible solution for avoiding problems causing by traditional pour-flush type on-site sanitation latrines. However, their implementation requires a higher degree of behavioral change and services for local maintenance. If these can be achieved, then a large risk to groundwater contamination from on-site sanitation can be prevented.

With regards to DEWATS type options, one constraint is availability of land at a community level. Given high real estate prices in such dense settlements, getting land for a treatment plant drives up the total cost of the project. For all such type of community based measures, more than the technology, what matters is the involvement of the community at every stage of planning and implementation since in the longer run the facility has to be used and maintained by the community. At this community level, no administrative structure exists, therefore any future transfer to municipal authority becomes difficult. Therefore the bigger constraint for such a direction is community mobilization which requires a much greater awareness and imperative to act on sanitation issues.

In areas where alternate drinking water sources are not available, such protection of the dug well is in practice calling it a protected sanitary dug well. Many NGOs and government programmes across the region are advocating such protection of sanitary dug wells as means of ensuring safe drinking water. This has also resulted following from the next point mentioned below i.e. harmfulness of deeper groundwater.

Where protection of groundwater with proper design of OSS and protection of drinking water well is not possible, options such as rainwater harvesting and water treatment need to be undertaken. Rainwater harvesting is increasingly becoming popular in cities, especially fort low storeyed houses. The practice is also getting support from cities through ordinances. In areas where one has to choose between either of the two evils (Biological or Chemical contamination) and scarcity of water is not a problem, an option is that of water treatment. A lot of low-cost domestic purifier are now entering the market and households in the region either have such purifier or directly buy such purified bottled water for drinking. Eventually, with all local sources getting contaminated, governments are opting for piped drinking water supply after treatment or from exported surface water. This becomes the last resort in the face of increasing contamination of fragile groundwater aquifers.

6. Part B: Technical Review

The technical challenge of studying on-site sanitation on groundwater contamination is fraught with methodological difficulties. First, is the hugely complex subject of unsaturated zone hydrology, considered to be the most sensitive and technically tough subject within groundwater hydrology. Next, the transport of pathogens (and Nitrate) through this vadose zone and then the saturated aquifer is another complexity layer which makes field-based measurements more difficult. Consequently, a lot of studies have been done under laboratory conditions with soil conditions of an ideal type. With regard to field conditions, approximations need to be made on the structure of geology beneath and also on the type of pathogens that can be detected. These approximations could be especially important since, for example, the formation of a water trough beneath a wet or partially wet sanitation system can help in having a hydraulic connection to the saturated aquifer beneath. In case of pathogen detection, often the approximation of indicator pathogens are adopted. Most often, the detection is performed by presence of Fecal coliform, specifically, Escherecia coli which can ferment lactose at 44^0C. Most studies therefore follow an experimental design with an idealized subsurface, detection of indicator pathogens and assumptions about the source of these pathogens. Inspite of these assumptions, however, experiments have revealed a lot about sanitation-groundwater linkages which guide current thinking on this subject.

On-site sanitation can be of risk to polluting groundwater resources mainly from two aspects – pathogens and Nitrates. Both pathogens and Nitrates can also reach human beings through routes other than that of the sanitation-groundwater linkages. Pathogens, broadly transmit through the Fecal-Oral Transmission route by food, touch, water, soil and flies. Nitrates similarly can reach humans in excessive amounts from water and food and also through agricultural fertilizers and also waste from animals, especially cattle. The release of pathogens and Nitrates (oxidation of Ammonia and Nitrites) from the sanitation pit occurs through

a) The biologically active crust layer which acts as a “soil defense” mechanisms. Beyond this crust, the surrounding soil – saturated or unsaturated – is a key factor
b) Unsaturated unconsolidated soil provides the best medium for decay of pathogens. Transport still occurs in unsaturated soil,
c) The key step is contact with saturated soil and then transport of pathogens occurs.
d) The process of attenuation then begins where the specific pathogen – bacteria, virus, protozoa or worms – has a different decay behavior ranging from hours to tens of days of survival within the soil media,
e) Next, the source-receptor dynamic comes in where the receptor is mostly some type of well (dug well, bore well, hand pump etc) or springs and ponds. The design of the receptor, location, depth and screening adopted in construction decides the ease with which pathogens can enter through the receptor and then on into drinking and domestic water.

f) Once pathogens reach the receptor well, it can be transmitted further by directly drinking or in food preparation; through bathing by skin contact; and also through food by irrigation. Upon reaching humans, the cycle of pathogen transmission can continue through this same or other route.

In case of Nitrates, oxidation of Ammonium/Nitrite into Nitrogen or vice-versa could be achieved under different oxidation/reduction regimes. These depend on the soil conditions when Nitrates are released from the crust of the sanitation pit. Travel of Nitrates through aquifers and residence times are much larger than those of pathogens. However, the health consequences are mostly less immediate and less noticeable by public health officials, therefore less reported.

The processes (a) till (f) vary and depend on many field conditions and several deciding factors within each step. As explained by Table 3, a variety of critical factors come together in deciding the risk from contamination of groundwater due to on-site sanitation. The problem is that the determining factors align together in many cases therefore bringing about this linkage and therefore contamination. Also, these factors need not be independent from each other, in fact propagating too. An example: Areas with sufficient groundwater availability conditions and a high water table (important for c) above) are often also places where residents can afford to have their own shallow well drinking water facility within the house complex (important for e) above). This decreases the distance between the household sanitation and drinking water well. The high water availability (important for a) above) also means that the possibility of larger hydraulic load into the sanitation pit is more. In this condition the connections, b) and d) are bypassed, therefore creating a very high risk of sanitation-groundwater contamination linkage. This particular situation given here is highly prevalent in the alluvial plains of eastern Indian state of West Bengal where dense settlements further aggravate this situation, however, high clay content of soil in many places also acts as an effective filtration barrier for some bacteria.

Table 3: The Key Steps in Transmission of Pathogens and Chemicals from Sanitation to Humans

Sr No	Steps in Pathogen-Oral Transmission	Factors in each step
a)	Transmission through crust of sanitation pit	Type of on-site sanitation pit, Quality of crust formed in pit, total hydraulic load in sanitation pit, lining quality of pit, total pathogen load
b)	Movement through Unsaturated Soil	Soil moisture, nature of pathogen, interaction with soil medium – sand/silt/clay content, temperature, organic load, thickness of unsaturated zone
c)	Reaching saturated Medium	Depth to water table, transmissivity of soil layers,
d)	Attenuation in saturated Medium	Decay rate of pathogens, velocity of

		groundwater, interaction with soil medium - Adsorption, size of pathogens vis-à-vis size of soil particles, temperature
e)	Source-Receptor Pathway	Spatial density of sanitation pits and wells, Relative location of well, depth of well, screening in well construction
f)	Transmission from wells to humans	Type of usage of water – drinking/cooking/other domestic use; type of food crops grown; Treatment mechanisms used

The decision matrix of on-site versus off-site drinking water supply and sanitation as a combination of possibilities is something which water and sanitation planners face frequently. Within this decision matrix, there are further details as to what type of on-site sanitation or what depth for on-site water supply, etc. All these decisions involve a trade-off. The trade-offs can be between risking water contamination at the cost of better sanitation; good quality water supply for one water quality parameter versus another; investing in high resource intensive community based sanitation to avoid risk of contamination from on-site sanitation, and so on. Ultimately, these decision need to be based on several criteria: resource investments, improvements in health, social values, community acceptance, economic cost recovery, etc.

7. Methodological Issues

The main methodological issues in understanding the linkages of sanitation-groundwater contamination linkages are two- the science of modeling pathogen and chemical transport in soil and rocks; and secondly, the science of detection of microorganisms, specifically pathogens of interest to fecal contamination.

7.1 Modeling Pathogen and Chemical Transport through Porous Media

A key problem with any pathogen or chemical transport problem is the applicability of laboratory scale results to the field (Ginn et al, 2002). Termed as the "Pore scale" to "Darcy scale" issues, this involves averaging of various processes and parameters which are poorly understood and act very differently at the pore scale being studied in the laboratory and the field scale where Darcy's law holds for averaged parameters. As a result, heterogeneity in the field is seldom captured in laboratory experiments, leading generally to more predictable results in the laboratory. Secondly, key processes related to adsorption of pathogens on soil surfaces are not easily replicated in numerical models. Thirdly, the aspect of nutrients and organic matter influencing pathogen growth, survival and transport is very poorly replicated in such models. Fourth, the interaction between bacterial and soil surfaces, especially in clay and silt media where the comparative sizes of soil and bacteria are similar are difficult to model. Lastly, the impact of preferential flow paths created by microbes affecting flow and vice-versa are highly complex and currently only observed empirically (Morales et al, 2010).

7.2 Detecting Pathogens through Indicator Micro-organisms

Though fecal matter will contain pathogens, water directly may or may not contain the pathogens one would be looking for. For example, if the viral load of fecal matter from a patient is 10^6/g, then say the total roughly 10^8 excreted virus of the individual gets distributed in groundwater of say, a 10^9 litres, thereby reflected in just 1 pathogens per 10 litres which is hard to detect. Instead, if one looks for other indicators which are also present in fecal material in higher quantity (but may or may not be harmful), then there is an indirect indicator of infection. The most useful such indicator is Eschericia Coli (Hutton, 1985).

However, this particular choice of indicator organism dates back from 1914 when the US Public Health Service stipulated that no drinking water sample should contain any Coliform (Yates 2007). This standard was also dictated by the instrumentation and scientific knowledge available during that period, but also the fact that E Coli is a fecal Coliform which can provide a good indication of contamination. An indicator should be a microbe which is abundantly present enough to detect, must sufficiently indicate risk of a pathogen, grow readily on simple media, be more resistant to disinfection than the pathogens, and should also be of low risk to the analyst, be cost effective, speedy to detect etc. Looking at these criteria, the current Coliform criteria is grossly inadequate and has often lead of erroneous deductions about contamination linkages. Especially Coliform presence has very less to say about presence of many Viruses, which have very different residence and decay behavior in soil media. Therefore, many new indicators are being proposed including, Fecal Enterococci (indicating enteretic pathogens), Heterotrophic plate count bacteria (high organic content of water; not indicating pathoges), Bacteriophages (virus that infects bacteria). However, none of these are substitutes for direct pathogen monitoring which is highly expensive and also difficult to detect. The science of pathogen monitoring therefore is now looking at newer techniques (related pathogen monitoring, detection of chemicals released in growth of pathogen, etc.), however, still the use of indicator organisms is a weak substitute in the search for contaminants.

8. Issue no 1: Release of Contaminants from the Sanitation pit

8.1 Impact of hydraulic loading

A key distinctive factor for transporting contaminants from a sanitation pit is the quantity of flow from the pit. Here the distinction between "dry" and "wet" sanitation comes out strongly. Especially if bulk of household wastewater gets into the same pit, then it further acerbates the problem.

Table 4: Hydraulic loading from on-site sanitation systems (ARGOSS, 2001)

	dry on-site sanitation	**wet on-site sanitation**
low hydraulic loading (< 50 mm/d)	simple VIP composting urine separation	pour-flush (low usage <10 people) ; 10-15 litres/per capita/day (Carr, 2001)
high hydraulic loading (> 50 mm/d)		septic tanks aqua privies ; 20-30 litres per capita per day (Carr, 2001)

A hydraulic loading of the soil below a pit of 50 mm/d is considered as a cutoff for a high rate of water flow. (Note that hydraulic loading of 1 mm/d is equivalent to 1 litre/m^2/day). The rate of hydraulic loading is also related to breakthrough of certain pathogens through the sanitation pit. Experiments performed by Green and Cliver (1975) in which samples from a septic tank (50 mm/d) were applied to a sand column for the duration of a year. This effluent was inoculated with Polio Virus type 1. It was found that the virus breakthrough occurs at a loading rate of 500 mm/d which applies more to septic tank type loading.

8.2 Trough formation linking to water table

Even though the water table might be far below the sanitation pit, formation of a water trough below the pit can form a hydraulic link between the pit and the water table. This is especially important in case of wet sanitation systems and also in cases where other domestic fluids waste gets deposited close to the pit thereby forming this trough. Romero (1970) surmises the the zone of saturation between the lowest and highest levels of water table during different seasons is the most risky zone to have disposal of contaminant waste. This zone of saturation can be artificially created by this trough.

8.3 Biologically Active crust layer or “Soil Defense”

Research in laboratory and field settings confirms that a biologically active crust layer of bacteria and fungi gets formed just below the sanitation pit. The crust is stable and large enough mostly in relatively drier sanitation pits with hydraulic loading less than 50 mm/d. For such systems, a gelatinous mat of predatory micro-organisms gets formed creating a barrier to the groundwater system. The barrier gets formed because of (a) changes in soil structure caused by cation exchange and swelling of clay minerals, (b) blockage of soil pores with filtered solids, (c) deposition of bacterial slimes and (d) precipitation of insoluble metal sulphides (Kreissl 1978 referred from Lewis 1981). The layer acts in two ways: one, crust micro-organisms predating on pathogen bacteria, and secondly, allowing an increased attenuation (decay) period for pathogens. It acts as a filtration medium for fecal bacteria (of sizes 0.5 – 5.0 µm). Also it reduces the infiltration rate of the unsaturated zone.

Studies show that this crust layer develops within 3 to 7 months of construction of sanitation pit and ensuring relatively dry conditions of the soil during this period (Caldwell and Parr, 1937). If that is achieved, most of the fecal bacteria can get filtered (under low pathogen load), but viruses still get through this layer. Bioclogging or microbial clogging of soil pores can reduce the hydraulic conductivity by more than 90% (Morales, 2010). In fact, such bioclogging below sanitation structures can totally alter the water flow and create preferential flow paths. If basic survival criteria are met, these layers can offer a suitable barrier for further penetration of contaminants into the aquifer.

The oldest and influential study in this regard has been that of Caldwell (1937, 1938a and b) where the impact of pit latrines of Coliform presence in soil was studied at 3 sites of Covington country, Alabama. Observations were done for a minimum period of a year in each of these 3 sites. It was observed uniformly that from the pit construction date, Coliforms were initially observed at 10-15 feet and also traces up to 35 feet. But after 2-4 months, the Coliform made a retreat back to the Latrine pit. This was observed uniformly in all three cases leading to coining of the term “Soil Defense”.

Numerous studies record effective filtration, especially of bacteria at this infiltration surface due to crust formation or bioclogging. The following evidences from different studies are summarized in Lewis et al, 1981:

- Looking at bacterial population of fecal coliforms within 30cm of the clogged zone, the bacterial population below and to the side of a septic tank seepage bed fell close to the population level in a control soil sample.

- Measurements of coliform bacteria in sandy soils used to dispose of settled sewage showed a dramatic reduction in coliforms in the first 50mm of soil and a subsequent build-up of bacteria at lower levels.

Table 5 shows the rate of removal of different microorganisms through various soil media and the time required for 1 log removal in concentration.

Table 5: Time for 1 log removal of Bacteria, Bacteriophage and Viruses from Groundwater (Pavelic et al (1996) quoted from Dillon (1997))

Microorganism	**Decay rate[a] ($^{-1}$days)**	**Removal time[b] (days)**
Poliovirus 1	0.046 0.21 0.03-0.09 0.04-0.08	22 4.8 11-33
Adenovirus 40	0.04-0.05	??
Adenovirus 41	0.04-0.05	??
Coxsackievirus	0.11 0.05	9.1 20
Echovirus 6	0.11	9.1
Echovitus 11	0.10	10
Echovirus 24	0.05	20
Rotavims SA-11	0.36	2.8
Coliphage f2	1.42 0.39	0.7 2.6
Coliphage T2	0.17	5.9
Coliphage 17	0.15	6.7
Escherichia coli.	0.32 0.36 0.16 0.26 0.32 0.05-0.11[c]	3,1 2.8 6.3 3.9 3.1 9.1-20
Fetal Streptococci	0.23 0.24 0.03 0.12	4.3 4.2 33 8.3
S. Fecalis	0.31 0.23	3.2 4.3
Salmonella Typhimurium	0.13 0.22	7.7 4.5

Note:

- [a]: Expressed as $\log_{10}(C_t/C_0)$ where C_t is the concentration of organisms after 24 hours and C_0 is the initial concentration of organisms
- [b]: time for one log removal of organisms
- [c]: fecal coliforms

8.4 Quality of construction

One key aspect of construction quality which matters in leakage of contaminants from a sanitation pit is whether the pathogens and Nitrate leach out from the bottom or the side walls also. In case of poor lining, the leakage can be from the side walls, thereby causing additional pathways for contaminants to leak out.

8.5 Pathogen load

There is a self-propagating cycle in the sanitation-contamination linkage. An area with no Polio virus carriers or patients will not have any pathogen to carry from feces. Similarly an area suffering from an epidemic of Ameobiosis will have dense concentration of carriers whose feces would carry the pathogens. In effect the pathogen load is also determined by the existing carriers in the community. If the pathogen load is very high (count of 10^9/litre), then even the unsaturated zone crust layer is not effective, nor is a dry pit. In that case, some part of this load will get transmitted into the aquifer.

The Nitrogen loading depends on specific factors such as type of food intake, weather etc. However, the person specific nitrogen load daily excreted can be taken as amounting to 11-12 g (Howard et al, 2006).

Seasonal variation in pathogen and Nitrate loading can also occur to seasonal outbreaks of diseases or food patterns in the community. These can also lead to variation in pathogen and Nitrate loading, thereby impacting the risk of contamination.

8.6 Containment comparisons between on-site sanitation options

An important point to be noted is the scale at which a certain sanitation option is effective in containment of waste. For example, ejecting out waste from off-site sanitation can cause contamination to a faraway community. The impact of containment has been divided into 3 levels: Household (specific to one home), Community (nearby houses also), Society (general larger community or village/town) (Carr, 2001). In the case of the VIP latrine it is easy to see that the containment acts at a household level. However, poor design or inappropriate location may lead to migration of waste matter and contamination of local water supplies putting the community at risk. In terms of waterborne sewage, the containment may be effective for the individual and possibly also the community, but effects may be seen far downstream of the original source, hence affecting 'society'.

Table 6: Containment at levels by different sanitation options (Carr, 2001)

Sanitation option	**Containment and Protection Levels**		
	Household	**Community**	**Society**
Pit latrine	Good	Poor	Good
VIP Latrine	Good	Some	Good
No-mix double vault	Some	Good	Good
Pour-flush latrine	Good	Some	Good
Septic tanks	Good	Some	Some
Sewerage	Good	Some	Poor

This sort of a classification though useful to compare between sanitation options and decide at what levels they serve, could also be misleading since there are site-specific factors which come into play. Therefore, to generalize this classification would not be very useful.

9. Issue no 2: Pathogen and Nitrate transport through soil and rock media

9.1 Type of pathogens and their sizes versus soil particle sizes

The main types of pathogens of interest from fecal contamination are

1. Bacteria
2. Viruses
3. Protozoa
4. Worms

On an average fecal material contains 10^9 bacteria/g (not necessarily pathogenic) and in infected individuals up to 10^6 virus/g. **Table 7** shows the diseases transmitted through groundwater and particular bacteria and virus causing the disease.

Table 7: Diseases and Pathogens transmitted through Groundwater (Lewis, 1981)

Bacterial Disease	**Particular Pathogen**	**Viral Disease**	**Particular Pathogen**
Cholera Typhoid fever Paratyphoid fever Bacillary dysentery Diarrhoeal diseases	Vibrio cholerae Salmonella typhi Salmonella paratyphi Shigella spp. Enterotoxigenic E. coli Enteroinvasive E. coli Enteropathogenic E. coli Salmonella spp. Campylobacter petus spp. Jejuni	Infectious hepatitis Poliomyelitis Diarrhoeal diseases, Varied symptoms and diseases	Hepatitis A virus Poliovirus Rotavirus, Norwalk agent, other viruses Echoviruses and Coxsackievirus

Disease transmission by these pathogens depends on two sets of factors (Carr, 2001):

A: Pathogen related

i) The ability of the pathogen to survive and multiple in the environment (here subsurface unsaturated and saturated medium)
ii) Latent Period of the pathogen
iii) Ability to infect the host (millions or just few thousands)

B: Host related

i) Immunity
ii) Nutritition

iii) Health status
iv) Age
v) Gender
vi) Personal Hygiene
vii) Food Hygiene

Here we are primarily interested in the factor A i) i.e. the ability of the pathogen to get transmitted from a sanitation system and survive, multiple, transport and reach the drinking water or irrigation water system. The first key factor towards this understanding is that of the sizes of these pathogens vis-à-vis the sizes the particles of the soil media.

There is a high variation in sizes of these pathogens. Figure 2 shows the relative sizes of the pathogens. Especially, crucial is the fact that viruses are much smaller (µm to nm scale) compared to bacteria which are mostly in the µm scale.

Figure 2: Comparative sizes of Fecal Pathogens present in Groundwater (Cave and Kolsky, 1999)

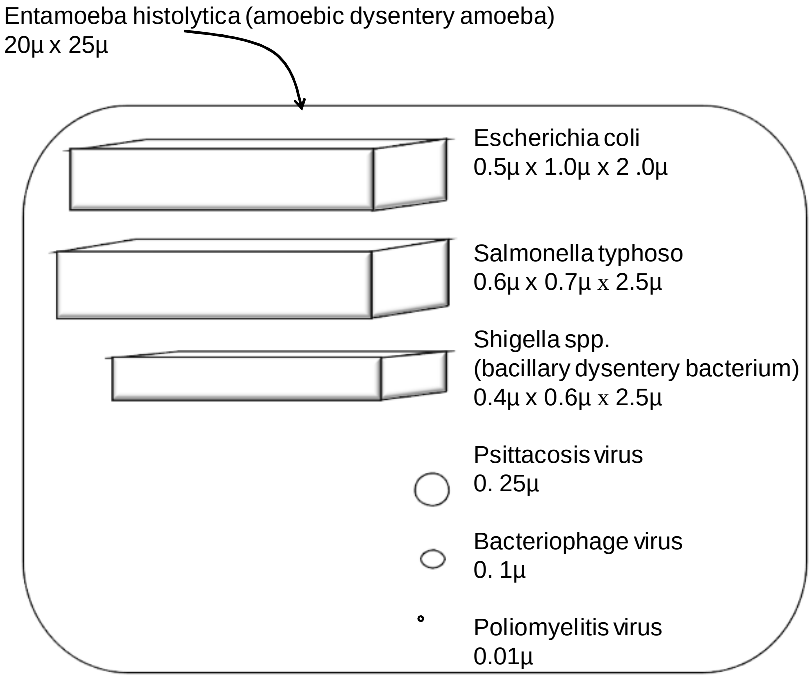
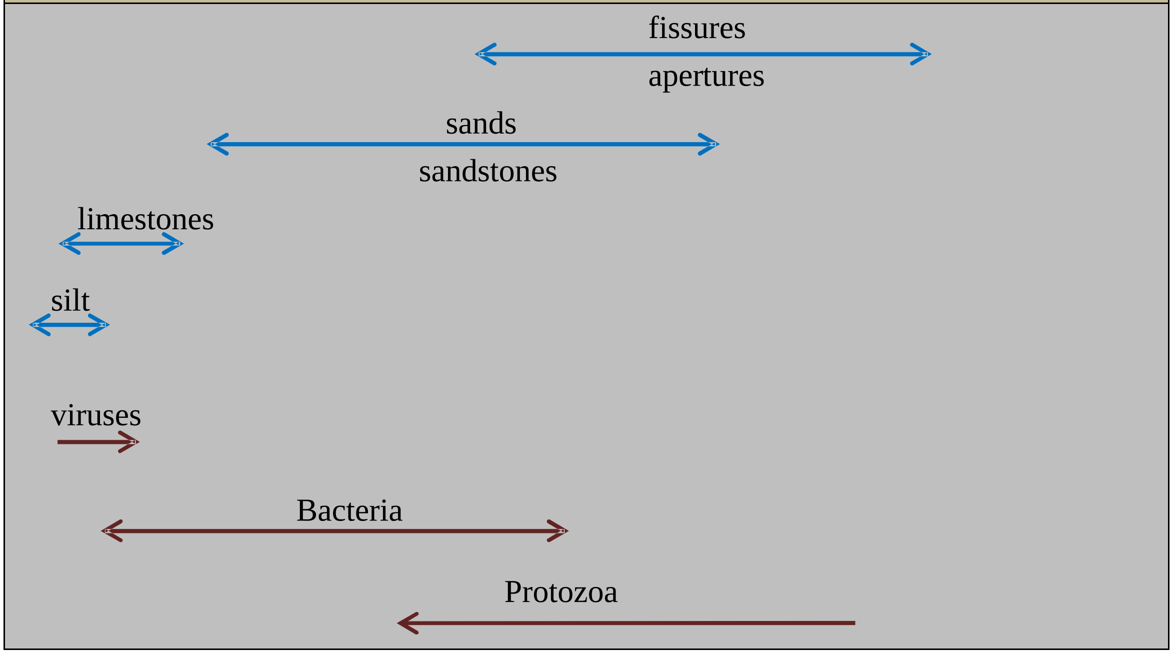


Figure 3 shows the classification of soils and comparison with standard pathogen diameters and aperture sizes for various aquifer types. As can be seen here, viruses are much smaller than most aperture sizes, therefore less prone to filtration through the soil media. In contrast, large Protozoa have a high chance of filtration through most media. Therefore, in the context of looking at risk of contamination, one needs to keep in mind strongly the effective particle size of soil and the size of the pathogen. For example, if we are dealing with a problem of Ameobiosis (particle size given in Figure 2), for an unsaturated soil media with high clay content, then a high trust should be placed on the filtration capability of this medium, just taking into account the factor of direct filtration by the soil medium.

Figure 3: Soil classification compared with sizes of Pathogens and classification of broader aquifer group (modified from Cave and Kolsky (1999) and ARGOSS(2001))

ISSA	Clay	Silt			Fine sand				Coarse sand				Gravel
USDA	Clay	Silt				Very fine sand		Fine sand		Medium sand	Coarse sand	v. coarse sand	Gravel
BSI	Clay	Fine silt	Medium Silt		Coarse silt		Fine sand		Medium sand		Coarse sand		Gravel
(1 nm) 2000	**(1 μm)**	**2**		**5**	**10**	**20**		**50**		**100 200**		**500**	**1000**

Particle size diameters



(Note: ISSS: International Society of Soil Science; USDA: US Department of Agriculture; BSI: British Standards Institutions

Important also to see is that most Bacteria can get filtered through particles of small sizes of 1 μm and whereabouts. But key here is also the total bacterial load and hydraulic loading that pushes it through. Both these factors have been discussed in previous sections of this report. The lower part of

Figure 3 compares microbial sizes with relative ranges of different aquifer types. The role of geological heterogeneity becomes important here. Also there is an interesting trade-off as far as geology comes into play. On one hand, unconsolidated sediments with small particle sizes can act as a good filtering medium, but these sediments generally also have a well established regional groundwater gradient allowing those microbes which are not filtered to travel long distance (up to tens of metres in a month). On the other hand, hard-rock type aquifer offering less soil media cannot act as a good filter, but (except in cases with regional fractures, dykes etc), the groundwater gradients are not so regionally well established, thereby reducing the chances of carrying pathogens to faraway distances.

9.2 Processes Responsible for Pathogen Migration through Soil and Rocks

The migration of Bacteria and Viruses through soil and rocks is guided by several physical, biological and bio-chemical processes. These together decide as to decay, growth, residence, transportation and extinction of pathogens within the soil media. Many factors such as aerobic/anaerobic conditions, temperature, nutrient availability for pathogens in the form of organic matter, host availability for viruses, presence of predatory micro-organisms, pH conditions, flow paths within the soil, water table fluctuations, flow directions of groundwater; combine to cause this movement. Though there are variations and differences, studies have documented ranges of behavior specific to pathogens and specific to field conditions. These ranges of distances travelled, time taken for travel, decay rates, etc. give us some indications of risk and possible hints for design of sanitation and nearby water supply systems.

Table 8: Comparison of Consolidated and Unconsolidated Sediments for Risk of Contamination

	Unconsolidated Soil/Clay	**Consolidated (hard rock)**
Filtration	With a thick unsaturated zone, can filter out many bacteria	If there is a thin soil cover, can be a poor filter for bacteria
Transport	Could have a regional groundwater gradient, therefore transport unfiltered pathogen to longer distances	Unless there are fractures/dykes, regional groundwater gradient is not established, so transport to far distances is minimal
Risk of Contamination	Locally safe; But regionally Unsafe	Locally Unsafe; But regionally Safe

9.3 Adsorption behavior on soil

Adsorption on the surface of soil particles is a key retardation mechanism of pathogen transport. The drivers of adsorption are quite complex and being understood currently through numerous micro-scale experiments at the laboratory. For example, current thinking is not about the interaction between actual pathogen and soil particles, but between macromolecules on the pathogen cell surface interacting with the surface of soil particle (Ginn et al, 2002).

Since viruses are much smaller than bacteria, their transport and removal are influenced by different mechanisms, different from direct filtration which is possible for larger sized bacteria in fine soil. Viruses, being one of the the smallest excreted pathogens, they are also different behavior by (i) Not being able to replicate outside a living host, (ii) the dosage required for infection can be of orders of magnitude lesser than that of bacteria, and (iii) filtration is difficult in soil media. Therefore retardation of virus in solid media is almost always due to adsorption on soil surfaces.

Though removal of Virus appears to depend almost entirely on adsorption, which is a reversible process eg. Onset of rains can wash down the adsorbed virus into groundwater. However, retention of Virus by adsorption can sometimes also mean higher life-spans if local conditions are favourable for survival. Following factors are critical to adsorption (Cave and Kolsky(1999)), as compiled from different case studies:

- As the pH falls the virus particles become more positively charged and are more easily adsorbed
- Changes in ionic strength can reverse the process of adsorption
- Large reductions (99.9% or more) of viruses could be expected if secondary effluent is passed through expected if secondary effluent is passed through 0.25m of calcareous sand at rates of up to 550 mm/d . Viruses would only move through calcareous sand if heavy rains fell within one day of applying the sewage
- The number of viruses mobilized by simulated rainfall ranged from 24% to 66% and depended upon the strain of the virus different strains of viruses have varying adsorptive properties
- Rate and depth of virus penetration virus adsorption in soil is increased above some breakpoint velocity. Flow rate changes above and below the breakpoint do not affect virus adsorption

9.4 Nutrient availability and Chemotaxis

Nutrient availability in groundwater is key to survival and growth, especially of bacteria. This nutrient availability can be in the form of organic matter infiltrating into groundwater as part of household waste or from fecal matter. In such nutrient-rich environments, survival of pathogens can be much above generally observed durations in laboratory conditions. In the absence of nutrients, a prime process controlling movement of microbes can be Chemotaxis, which is the control of microbe movement due to chemical gradients (Ginn et al, 2002). These chemical gradients could be inherently linked to signals nutrient availability. Such processes also determine the direction of pathogen transport once they are transmitted into the saturated zone.

9.5 Survival Time in Saturated Zone

The survival and then transport of pathogens in the saturated zone, therefore depend on a variety of factors. The

Table **9** shows summaries of pathogen survival in different media – fresh water, salt water, soil and crops (Carr, 2001). Note that survival in fresh water and salt water for different pathogens do not follow any regular trend. Any studies show, some viruses have greater ability to survive longer in salt water medium too.

Table 9: Pathogen and Indicator Survival in Different Media (Carr, 2001)

Organism	**Pathogen Survival (Time in days, unless otherwise indicated)**			
	Fresh water	**Salt water**	**Soil**	**Crops**
Viruses	11-304	11-871	6-180	0.4-25
Salmonellae	<10	<10	15-100	5-50
Cholera	30	+285	<20	<5
Fecal Coliforms	<10	<6	<100	<50
Protozoan Cysts	176	1 yr	+75	ND
Ascaris Eggs	1.5 yrs[1]	2[1]	1-2 yr	<60
Tapeworm Eggs	63[1]	168[1]	7 months	<60
Trematodes	30-180	<2	<1[1]	130

(Note: [1]: Not considered an important pathway)

The survival time of pathogens are influenced in many ways:

i) Moisture content: Survival is generally higher in greater moisture content

ii) Temperature: Survival increases significantly at lower temperatures
iii) Adsorption: Greater ability to adsorb, especially in case of viruses
iv) pH: Survival is shorter in acidic soils
v) Sunlight and evaporation: Generally bacteria have shorter lifespan at the soil surface where these factors dominate
vi) Soil microflora: Nutrient availability is important for growth; Aerobic microorganisms can thwart virus survival; Also predatory microorganisms could be present in soil

Some deduction can be made here from the published studies:

i) Fecal Coliforms (which are often used as indicator organisms) generally survive less than 60 days (Lewis et al, 1981), and normally less than 15 days. However, suitable conditions as above can help in their longer survival
ii) Survival of bacteria greater than 100 days can been rarely recorded
iii) Comparing virus and bacteria: Though virus would not be higher in number and grow, their survival ranges are higher. Therefore, utilizing Coliform as an indicator sometimes in misleading.
iv) In dense settlements with poor solid waste management (apart from sanitation latrines), excellent environment for pathogen survival in terms of nutrient availability is provided

9.6 Maximum Horizontal and Vertical Distance Movement through Soil

Once pathogens are released from the sanitation pit, and manage to get through the biologically active unsaturated zone, they survive by multiplying, going into dormancy, adsorption etc. But as they get into the saturated zone by infiltration mainly and also diffusion processes, they can get transported along the main direction of groundwater flow. The distance to which they can travel is determined by the groundwater flow velocity and also to how much time the pathogen can survive in such conditions. Here two processes take control, namely attenuation (due to decay) and dilution within the saturated zone.

Though the survival times for bacteria vary a lot, some thumb rules could be used, for example according to Lewis et al (1981), one can take this maximum distance as that travelled by groundwater in about 10 days within which most bacteria would decay to about 90% or lesser concentration. But as shown in Table 10, studies on different bacteria in soil media of varying types such as sand, gravels, etc. show for example that up to 30 m distance had been reached by Coliforms in just 33 hours in one case and in another case Bacillus Coliform had reached a distance of just 20 m in a long time of 27 weeks. The maximum distance travelled in these set of studies was 830 m for Coliforms in sand and gravel.

Table 10: Summary of studies on Bacterial Transport through Soil (Crane and Moore (1984) quoted from Dillon 1997)

Organism	**Medium**	**Measured Distance (m)**	**Time of travel**
Bacillus Coli	Fine Sand	19.8	27 wks
Coliforms	Fine and Coarse Sand	70.7	-
Bacillus Coli	Fine and Coarse Sand	24.4	-
Bacillus Coli	Sand and Sandy Clay	10.7	8 wks
Bacillus Coli	Fine and Medium Sand	3.1	-
Coliforms	Fine Sandy Loam	0.6-4	-
Coliforms	Aquifer	30	33 hrs
Escherecia Coli	Sandy Dunes	3.1	-
Enterococci	-	15	-
Coliforms	Sandy Gravels	0.9	-
Fecal Coliforms and Fecal Streptococci	Coarse Gravels	457.2	15 days
Coliforms	Sand and Pea Gravel Aquifer	30.5	35 hrs
Fecal Coliforms	Fine to Coarse Sand Aquifer	30.5	-
Coliforms	Sand and Gravel	830	-
Bacillus Stearathermophilis	Crystalline bedrock	28.7	24-30 hrs
Coliforms	Fine to Medium sand	6.1	-
Fecal Coliforms	Fine loamy sand to gravel	9.1	-
Fecal Streptococci	Silty Sand and Gravel	183	-
Fecal Coliforms and Fecal Streptococci	Fine Loamy Sand	9	-
Total Coliforms and Fecal Coliforms	Fine Loamy Soil Fine Loamy Soil	6.1 13.5	- -
E Coli	Silty clay loam	20	5 hrs

In the siting of drinking water wells, however, crucial is also the vertical distance travelled by pathogens. A major policy debate ongoing in Asian countries today is the balance between biological and chemical contamination. In the 1980s and 1990s, deeper wells and handpumps were promoted in many countries as an attempt to alleviate the impact of biological contamination. But this is turn has led to newer water quality problems such as Fluoride and Arsenic, which not necessarily, but in many aquifers seem to be higher concentrated at lower depths (Beg et al, 2001 and van Geen at al, 2011). Also there is a problem of availability and sustainability of drinking water sources at deeper depths. In this context, the maximum vertical distance that can be traversed by pathogens and be of possible interest from a public health perspective is pertinent.

Table 11: Migration of Bacteria in Subsurface (Yates and Yates (1988) quoted from Dillon (1997))

Microorganims	Medium	Maximum Distance Travelled (m)	
		Vertical	Horizontal
Bacillus stearorhermophilus	Fractured rock		29
Bacteria	Fine sand		457
	Medium to coarse sand		21
	Alluvial gravel		90
	Pea gravel + sand		30
	Coarse gravels		457
	Gravel		920
	Sandy clay		15.25
	Fine to coarse sand		30.5
	Fine to medium sand		6.1
Clostridium welchii	Fine + medium sand		15.5
Coliform	Loam + sandy loam		
	Sand + gavel	10-12	850
	Fine sandy loam	4	1.2
	Fine sand	4	2
	Pebbles		850
	Weathered limestone		1000
	Stony clay + sand	0.91	
	Stone + clay	0.61	
	Firm clay	0.3	
	Coarse sand + gravel		55
	Sandy clay loam	2	6.1
	Sandy clay loam	4.3	13.5
	Sandy loam	0.64	28
Escherichia coli	Sand		3.1
	Fine + coarse sand	4	24.4
	Fine + medium sand	0.15	
	Fine + medium sand		3.1
	Sand + sandy clay	1.5	10.7
	Silt loam		3
	Silty clay loam		1.5
	Medium sandy gravel		125
	Fine sandy gravel with cobbles	1	50 IS
	Silty clay loam		19.8
	Fine sand	0.3	70.7
	Fine sand		
Fetal coliforma	Fine loamy sand + gravel		9.1
	Stony silt loam		900
	Fine to medium sand		2.4
	Gavel with sand + clay		9
	Saruraled gravels		42
	Sandy clay + clay	0.85	
	Sandy clay	1.2	
Salmonella enteriditis	Clay	0.1	
S. typhi	Limestone		457
Streptococcus fecalis	Silty clay loam		0.5
	Silt loam		5

Strep. symogenes	Sandy Gravel	0.15	15.2

For deeper penetration of pathogens, the vertical alignment of geological layers is the key factor. Also key is whether there is any hydraulic gradient in the vertical direction, within and between aquifers. It is also possible, although to a lesser degree that pathogens infiltrate through separating layers between aquifers though evidences for those are lesser. As shown in Table 11 and Table 12, the comparison between horizontal and vertical distances travelled by bacteria and viruses have been tabulated. Let us first focus on horizontal distance travelled by the bacteria Bacillus stearorhermophilus in different soil and rock media. A maximum of 920 m (maximum ever recorded) and 457 m were observed in gravel like media. A minimum of 6.1 m and 29 m were observed in fine to medium sand and in fractured rock. This is evidence to show the geological control of pathogen movement. Next let us observe the bacteria Clostridium welchii for which both horizontal and vertical distances travelled have been recorded. Here we see that the vertical distances travelled are much lesser (0.3 m – 10 m) as compared with horizontal distances (1 m – 1000 m). Weathered limestone shows the maximum transportation (1000 m here), whereas sandy loam and sandy clay loam have least distances travelled (1 m-2 m).

Table 12: Migration of Viruses in Subsurface (Yates and Yates (1988) quoted from Dillon(1997))

Microorganims	**Medium**	**Maximum Distance Travelled (m)**	
		Vertical	**Horizontal**
Bacteriophage	Sand	45.7	400
	Sandy clay	1.2	
	Clay	0.85	
	Boulder clay		510
	Sandstone		570
Coliphage f2	Silty sand	29	183
Coliphage T4	Karst		1600
Coxsackievirus B3	Fine loamy sand	18.3	
	Sand	22.8	408
Echovirus	Coarse sand + tine gravel	11.3	45.7
Enterovirus	Sandy loam	3.5	14.5
Poliovirus	Loamy sand	0.4	
	Medium sand		0.6
	Loamy sand	1.6	
	Sand	0.2	
	Silt loam		46.2
	Medium to fine sand		9
	Loamy medium sand		6
	Sand	9.1	
	Coarse sand + fine gravel	10.6	3
	Coarse sand + fine gravel	7.62	
Viruses	Sand	6	

	Sandy clay	3	
	Sand	38	
	Sand + coarse gravel	16.8	250

These same patterns hold true for other bacteria as well i.e. vertical distances travelled being much lesser and the fine grained aquifers transporting lesser than the coarse grained ones. However, on the geological aspect one needs to keep in mind that they dynamic aspect which is especially key in Asian context with constant dynamic withdrawals from the irrigation wells cause high hydraulic gradients in the aquifer. Therefore, design of travel distances need to be made keeping into mind such local conditions.

Table 13: Aquifer properties for a range of rock types and possibility of horizontal separation (ARGOSS 2001)

Rock Types	**Typical Porosity**	**Typical Kh:Kv ratio**	**Range of likely permeability (m/d)**	**Feasibility of using horizontal Separation**	**Lateral Separation to reduce pathogen arrival at water supply to low risk**
Silt	0.1-0.2	10	0.01-0.1	Yes	Up to several metres
Fine Silty Sand	0.1-0.2	10	0.1-10	Yes, should be generally acceptable	Up to several metres
Weathered basement (not fractured)	0.05-0.2	1-10	0.01-10	Yes	Up to several metres
Medium Sand	0.2-0.3	1	10-100	Uncertain, will need site specific monitoring	Tens-hundreds of metres
Gravel	0.2-0.3	1	100-1000	Not feasible	Up to hundreds of metres
Fractured rocks	0.01	1	High variability	Not feasible	Up to hundreds of metres

A striking difference is noted when we look at transport of viruses as compared with bacteria. As mentioned in the previous sections, the key difference is that viruses can also get retarded mainly by adsorption on the soil particles. Even if lesser in number, they can thrive for long time outside a host and survive in tougher environments. Especially important is that as compared with bacteria, viruses can have more vertical penetration since they cannot be filtered by the larger size soil particles (see Figure 3), therefore there is a possibility of penetrating through layers into deeper aquifers.

Table 12 shows the horizontal and vertical distances travelled by viruses in different media. The horizontal distances travelled are in the same range as that of bacteria. Similar as to that of bacteria, the vertical distances travelled are lesser, but note that the ratio of horizontal/vertical distance is high here. The vertical distances travelled here are much greater than those of bacteria: 45.7 m for bacteriophage in sand and 29 m for Coliophage f2 in Silty sand. Also the horizontal distance travelled by Coliophage T 4 is maximum of 1600 m in Karst limestone aquifer.

As is evident from this section, i) geological heterogeneity, ii) local hydraulic conditions, iii) type of pathogen, iv) biochemical environmental for pathogen survival come together to cause variations in distances travelled and time of survival. However, as a policy thought can we have such variable criteria? For example, we cannot have a policy for Bacteriophages in Karst aquifers. One possible direction for thinking could be as shown in Table 13 where the possibility of having horizontal separation criteria between sanitation and drinking water facilities is thought of for different aquifer conditions.

Surely keeping sanitation-drinking water distances subject to such criteria would be very difficult. How can one account for a Cholera free area to be suddenly affected by the Virus during a flood situation? And how can we prepare for newer strains which keep evolving? These questions will become more important as we go on to the next sections.

9.7 Nitrate transport and risk

Table 14: Proportion of Nitrates leaching into Aquifer for different Rock types (ARGOSS 2001)

Hydrogeological Environment		**Fraction of Nitrate likely to be leached**
Unconsolidated sedimentary aquifer	Clay, silt, fine sand	Up to 0.3; could be very low especially where water table is shallow and sediments clayey
	Fine-medium sand	0.3
	Medium sands and gravels	0.3-0.5
Weathered	Thick weathered layer	Up to 0.3; but could be very

basement aquifer		low especially where water table is shallow and weathered material clayey
	Thin or highly permeable weathered layer	0.3-0.5
Fractured consolidated sedimentary aquifer		Up to 1.0

High amount of Nitrates ingestion can lead to methaemoglobinemia, and could be triggers for cancer, increased infant mortality, abortions, birth defects, recurrent diarrhoea, changes in cardiac muscles, alveoli of lungs and adrenal glands (Gupta et al, 2008). When inhaled, Nitrates can cause unconsciousness, vomiting and nausea. Many of these effects lie undetected due to problems in causation and good epidemiological studies.

Different studies point out to around 12-16 grams/per capita of Nitrogen released in human waste. Lewis et al estimates around 5 kg/per capita/year of Nitrogen material. This is in the form of Ammonium and complex organic compounds which then gets converted into Nitrites, Nitrates and Nitrogen gas through Denitrification. Nitrate is formed from human waste by the sequential, microbially catalyzed oxidation of Ammonia to Nitrite and then to Nitrate. In oxidizing environments within the subsurface, this Nitrate is preserved and transported through groundwater. In high density areas where a lot of organic matter also gets infiltrated into shallow groundwater, reducing conditions are created thereby reducing the risk to Ammonium conversion into Nitrates. Interestingly, in dense dense settlements the development of such reducing conditions is more difficult. Therefore, the more favourable conditions for Nitrate formation and sustenance is in somewhat less dense rural conditions. Also in such settlements, the possibility of Nitrate leaching from cattle waste and also from agricultural fertilizers is high. The combined risk of Nitrates in sparse rural settlements from all these sources can be very high.

As in the case of pathogens, the amount of Nitrate that will leach through to the aquifer depends on different aquifer types. As given in Table 14, general thumb rules can be provided for the maximum possible proportion of Nitrates leaching into the aquifer. Note that this proportion can be very high (close to 1) for fractured consolidated sedimentary aquifers.

9.8 Difference between Pathogen and Nitrate pollution

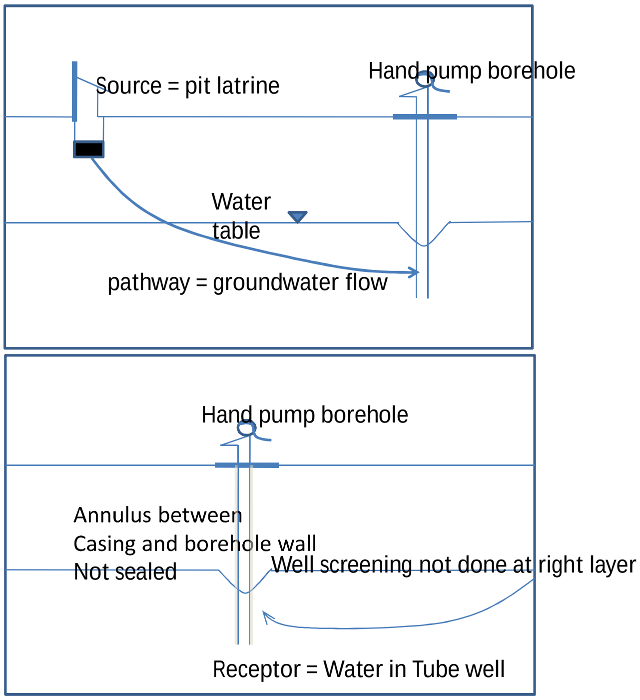
Significant differences lie between Pathogen and Nitrate pollution, some of which can be summarized here:

1. Fecal pathogens of harm need not be present all the time. It is more for infected individuals. Therefore the quantity of harmful pathogens in feces varies a lot. In contrast, Nitrogenous material are always present in feces. There is variation in the amount of this material, but this variation is not very large as for pathogens.
2. Pathogens carry on their own form from the source to the receptor. Nitrate need to be formed by oxidation process and sustained through this route.
3. The decay and attenuation process for pathogens is a more rapid one, whereas Nitrates once they enter the saturated zone accumulate over time.
4. Distance criteria are more important for pathogens, less for Nitrate which have higher diffusion potential through the aquifer
5. The health impact of pathogens is relatively in shorter time frame and more clearly detected. For Nitrates, the health impact is not observed mostly and could affect in relatively longer time duration.
6. The entry of pathogens into groundwater is mostly from fecal material, whereas for Nitrates it can be relatively from a larger variety of sources eg. Cattle waste, agricultural fertilizers, etc.

10. Issue no 3: Source –Receptor Pathways

In the previous two sections, we have discussed about release of pathogens and Nitrates from the onsite sanitation facilities and then transport of these contaminants through unsaturated and the saturated zones. Ultimately they become of risk to humans, when they enter humans come into contact with this contaminated water. For that the connection between source and receptor needs to be made through different pathways.

Figure 4: Source Receptor Pathways: Aquifer and Localized



Two main pathways have been distinguished (ARGOSS, 2001):

a) The route through the soil and fissures in rock within the aquifer (aquifer pathway)
b) Manmade pathways such as construction and location of a handpump, well, spring head (localized pathway)

The localized pathway can occur when the contaminated water comes into direct contact with the water delivery structure due to rains and raising or water table; or could be due to problems of ineffective sanitary protection of the receptor or fault in design.

In case of handpumps and boreholes, screening at appropriate levels can be made to minimize direct infiltration of contaminated water. It is also possible to pack dug wells with filter media that can cause some filtration at the receptor end also.

However, most such protection measures are difficult at an individual level. There are successful cases at the community level where protection of dug wells for drinking water have led to sustainable and safe drinking water supplies.

The last point in the source receptor pathway and in Oral disease transmission is the actual contact of the pathogens and Nitrate with humans. This depends on how the water from the receptor is being used. Here community practices become important. For example, in many places in rural India where electricity availability is poor, it is common for communities to use deeper (50 ft-100 ft) handpumps for drinking water and shallow (10 ft-30 ft) dug wells for irrigation through Diesel operated pumps. In such a case, pathogens such as bacteria which would be in the shallow zone could get into the food cycle through irrigation. Virus, if they get through deeper layers can get directly into drinking water. Nitrates would possibly be more in the shallow zone, thereby being of lesser risk to drinking water supplies. Also direct contact of certain pathogens with skin is possible by bathing and other domestic uses. Often communities can also depend on different water supplies for varied uses, possibly coming from different groundwater layers. These factors can be kept in mind when looking at what type of pathogens and chemicals would be present at which layers and enter humans through which route (direct contact, drinking, food etc.).

10.1 Deciding Safe distances for On-site Sanitation and Drinking Water Facilities

Finally, when it comes to designing sanitation systems a decision needs to be made keeping into mind what is acceptable and what is possible. Looking at various studies presented here it is evident that perfect safety is never possible within current habitation densities existing in developing countries. Morever, if we look at monsoonal rainfall countries such as India, the inter-seasonal fluctuations and water velocity changes is very high. In such conditions, coming with generalized criteria is difficult.

But looking at some evidences, one can consider the current western European criteria of 50 day travel time based distance criteria as a possible ‘high standard’. This means that the safe distance between an on-site sanitation source and a drinking water source should be such that groundwater takes no less than 50 days to traverse between these two points. Such a criteria automatically translates into a geologically based definition since this travel time would vary widely across local settings.

However, with dense habitations, it could possibly be reasonable to think of 25 day travel times that could reduce fecal contamination to acceptable levels. One could have three levels of risk (ARGOSS, 2001) as shown in

Table 15.

Table 15: Risk Levels for Achieving Safety in Risk From Sanitation to Drinking Water

Risk Level	**Requirement for Groundwater flow**	**Possibility of Achievement**
Significant risk	less than 25 day travel time	This is true in most cases where the household has an on-site sanitation facility as well as a drinking water facility (handpump, dug well) close to the household
Low risk	between 25 and 50 days travel time	Possible for on-site sanitation if drinking water facility is at the community level and isolated
Very low risk	greater than 50 days travel time	Mostly not possible for on-site sanitation facilities unless external drinking water is made available

This similar concept has been extended well by a Public health Engineer from Colarado, US is a less known report document with the US NGWA (Romero 1970). In this report, Romero has extended the distance concept into such 3 similar risk categories, not as travel time, but as distances, by translating the travel times into effective particle sizes of the aquifer medium. For a public health and sanitation engineer, such thinking would be more suitable since such standard soil curves are generally available locally. Synthesizing from many studies on pathogen transport conducted in laboratory and field settings,

Figure 5 and Figure 6 define categories of Prohibitive, Hazardous and Probably Safe for variety of distances from the sanitation structure. For example, if one resides in an area of shallow water table, with effective particle size of 2 mm, then the sanitation-drinking supply distance up to 20 ft will be Prohibitive and beyond that will still be hazardous. Instead in the same area if water table is far below, then just a separation distance of 3 feet will take it more prohibitive to hazardous, but still not safe. Along with these figures, if one can bring in local conditions of settlement distributions, type of pathogens and their behaviour, groundwater use patterns from drinking and irrigation, and types of on-site sanitation options available, then an appropriate decision could probably be made on design of this entire system.

Figure 5: Classification of soil particle sizes into safe distances in case of unsaturated medium (Romero 1970)

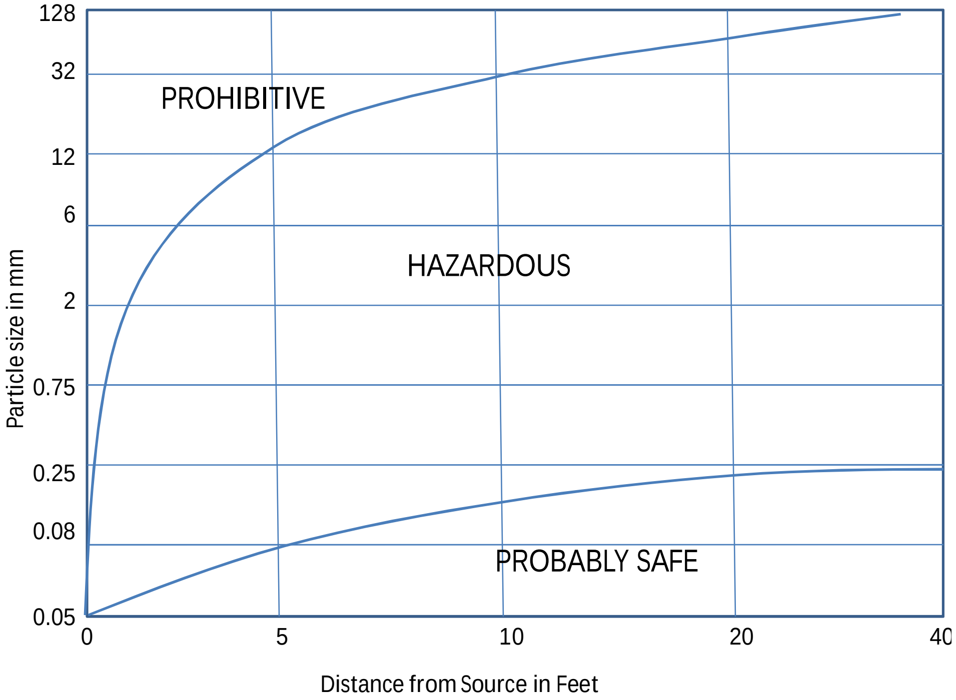
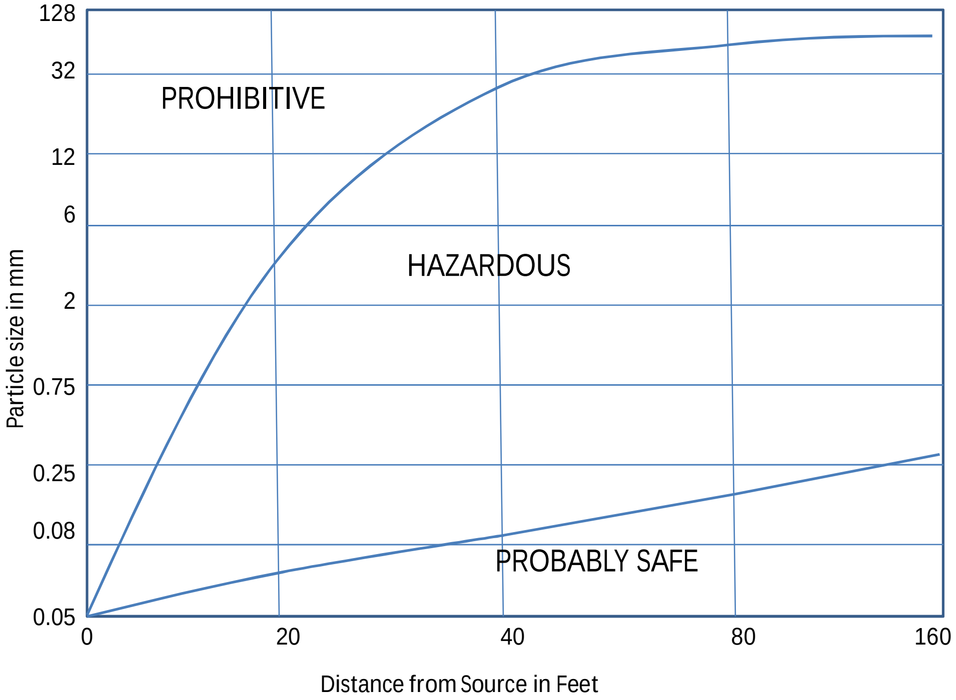
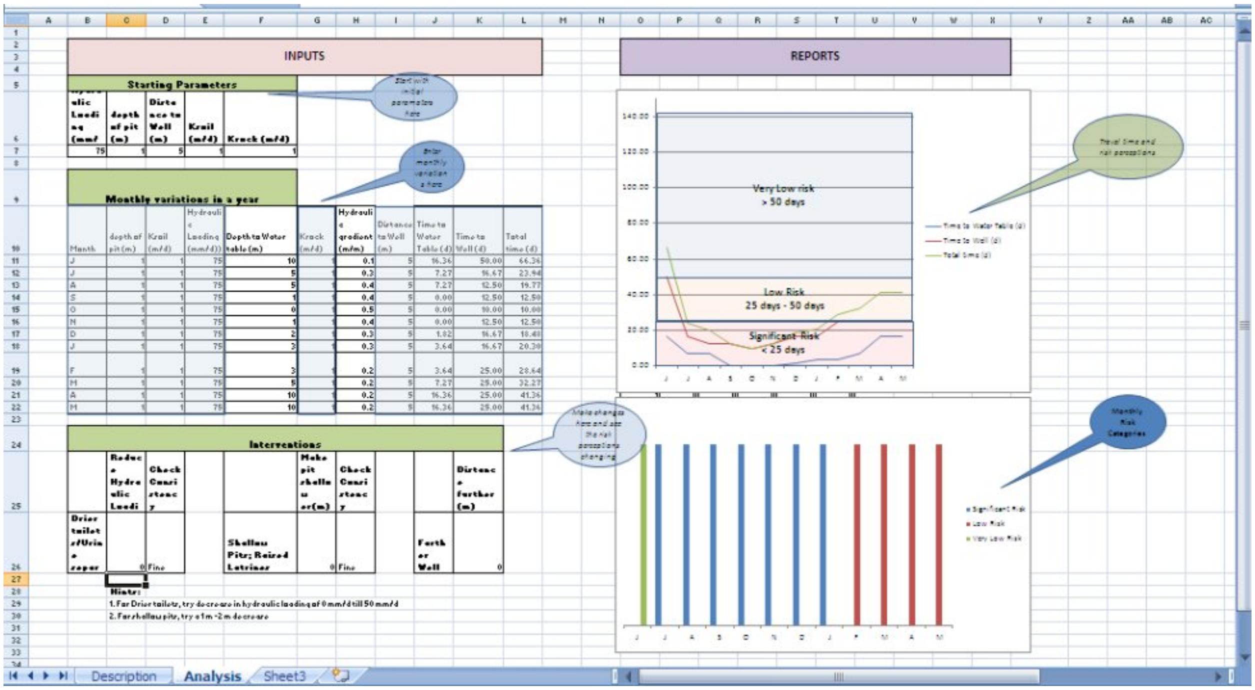


Figure 6: Classification of soil particle sizes into safe distances for Saturated medium (Romero (1970))



11. SanitContam: A simple Program for Risk Assessment

Figure 7: Screen Snapshot of *SanitContam* Worksheet



INPUTS

Starting Parameters

Hydraulic Loading (mm/d	depth of pit (m)	Distance to Well (m)	Ksoil (m/d)	Krock (m/d)
75	1	5	1	1

Monthly variations in a year

Month	depth of pit (m)	Ksoil (m/d)	Hydraulic Loading (mm/d))	Depth to Water table (m)	Krock (m/d)	Hydraulic gradient (m/m)	Distance to Well (m)	Time to Water Table (d)	Time to Well (d)	Total time (d)
J	1	1	75	10	1	0.1	5	16.36	50.00	66.36
J	1	1	75	5	1	0.3	5	7.27	16.67	23.94
A	1	1	75	5	1	0.4	5	7.27	12.50	19.77
S	1	1	75	1	1	0.4	5	0.00	12.50	12.50
O	1	1	75	0	1	0.5	5	0.00	10.00	10.00
N	1	1	75	1	1	0.4	5	0.00	12.50	12.50
D	1	1	75	2	1	0.3	5	1.82	16.67	18.48
J	1	1	75	3	1	0.3	5	3.64	16.67	20.30
F	1	1	75	3	1	0.2	5	3.64	25.00	28.64
M	1	1	75	5	1	0.2	5	7.27	25.00	32.27
A	1	1	75	10	1	0.2	5	16.36	25.00	41.36
M	1	1	75	10	1	0.2	5	16.36	25.00	41.36

Interventions

	Reduce Hydraulic Loadi	Check Consistency			Make pit shallower(m)	Check Consistency			Distance further (m)
Drier toilets/Urine separ	0	Fine		Shallow Pits; Raised Latrines	0	Fine		Further Well	0

Hints:

1. For Drier toilets, try decrease in hydraulic loading of 0 mm/d till 50 mm/d
2. For shallow pits, try a 1m -2m decrease

Following from the 6 steps of contamination described above, a very simple program called SanitContam has been developed in Microsoft Excel in order to bring out interlinkages and tradeoffs in decision-making. This simple model allows for looking at inter-relationships between various risk factors that contribute to contamination from on-site sanitation. The user can provide estimated values of controlling parameters such as depth to water table, depth of pit, distance to well. The output is in the form of the time taken to travel from sanitation to well. Interpretation of this time as risk is provided. In this example, parameters have been set to look at a 12 month cycle in which the depth to water table and groundwater gradient are varied. The situation is typical to a monsoonal type rainfall and a hard rock aquifer with very short distance to drinking water. One can view the individual time taken to reach the water table, to reach the well and the total time taken.

The user has options of 3 interventions 1. Using drier latrines, 2. Raising the latrine pit and 3. Having the drinking water well farther. The travel time to the well can be seen by making variations on these interventions and see which of them has greater impact.

Assumptions: The model is a simple one in which homogenous aquifer conditions are taken. Also, the unsaturated hydraulic conductivity is estimated by assuming it as a function of hydraulic loading from the sanitation structure. A 100mm/d loading is considered to lead From

500 mm/d to 100 mm/d the hysteresis factors is varied from 0.1 to 1 linearly. It is varied from 0 to 0.1 linearly with loading of 0 to 50 mm/d.

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