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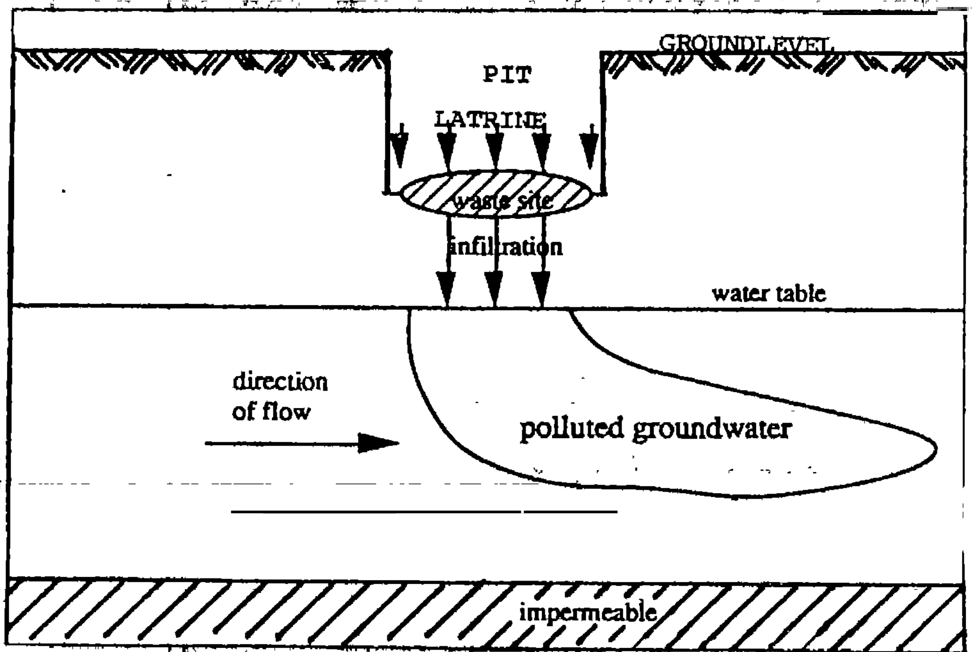

round water contamination by pit latrines

ar-es-salaam (Manzese squatter area) case study

P. Mnyanga

Sc. Thesis E.E. 39

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GROUND WATER CONTAMINATION BY PIT LATRINES

Dar-es-salaam (Manzese squatter area) case study

by

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ABSTRACT

Groundwater contamination from pit latrines is a potential health hazard especially in developing countries where shallow hand-dug wells are used to supplement conventional water supply (in cases of shortages). Analysis of the impact of groundwater contamination by pit latrines in Dar-es-salaam (Manzese squatter area) was carried out (chapter 5). Fluid and pollutant transport (chapter 2), microbial movement and survival in groundwater (chapter 3) as well as nutrient (nitrates) dynamics (chapter 4) were considered. Available data on the phenomenon were supplemented by the MFLOP model to obtain an insight into the nature of the problem.

Results from the model shows that the groundwater in Manzese area is polluted by mostltly microorganisms with low die-off rates like faecal streptococci. However, validation of the model in the field situation is essential.

ACKNOWLEDGEMENTS

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Lastly, though not least to my parents, whose prayers and blessings from a distance enabled me to complete the study successfully and to my family who missed my love during the period of study, for their understanding and patience.

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CORRECTIONS:

a) The following references should be included in the main list of references:-

67. Anonymous, 1985. EPA report 600/6-85/0026.

68. Robertson, F.N., (1980). " Evaluation of nitrate in groundwater in the Delaware coastal plain". Groundwater, 17(4).

69. Gardener, W.R., (1965). " Movement of nitrogen in soil". In W.V. Bartholomew and F.E.Clark (ed.) Soil nitrogen. Agronomy 10. Amer. Soc. of Agron., Madison, Wis.

70. Morgan, P.R. and Mara, D.D., (1982). "Ventilated improved pit latrines: recent developments in Zimbabwe". World Bank Technical paper No.3. The World Bank, Washington DC USA.

b) i. On page 69, ref. 4 should read as Van den Akker, (1983).

ii. On page 34 & 35; Walker, (1973) should read as Walker et al., (1973b)[24]. And ref. 24 should read as:-

Walker, W.G., J.Bouma, D.R.Keeney, and P.G. Olcott, (1973). "Nitrogen transformations during subsurface disposal of septic tank effluent in sands: II Ground water quality". J. Environ. Quality, Vol.2, No.4, 1973.

iii. On page 20; third line from bottom it should read:- Mirzoev, (1968)[43].

iv. On page 36; fourth line from bottom, Fig. 5.1 should read as Fig. 4.1.

v. On page 33; Equation (20) should read as below:-

$$2NH_4^+ + 2OH^- + 3O_2 - 2NO_2^- + 2H^+ + 4H_2O \qquad (20)$$

vi. On page 25; Line 5 from bottom, it should start reading as :- (> 25μm).............

Vii. Appendix III; on the tittle of the table "Figure 2.1" should be deleted.

1.0 INTRODUCTION

1.1 Problem Definition:

In the squatter areas of most cities of the developing countries, pit latrines are almost the only form of sanitation that can be afforded by the population. Unfortunately, piped water supply in these areas is not reliable (intermittent supply due to:- fuel shortage, old pumps, shortage of chemicals, low pressure due to old raising mains etc.) as such inhabitants are forced to opt for simple shallow temporary self hand-dug wells which provide individually small, untreated and unmonitored water supplies to supplement their normal water supply. Unfortunately, such sources may be vulnerable to pollution, (Foster,1985).[3]

The two solutions (sanitation and water supply) to the population's need may conflict, particularly under certain hydrogeological conditions and without adequate design and construction. The extensive use of pit latrines may cause severe contamination to shallow groundwater aquifers (pathogenic micro-organisms and biodegradation products of human excreta, such as nitrates). This may expose people to the risk of disease, and thus reduce the anticipated health benefits of providing water supply and sanitation facilities.

Pit latrines are the commonest, simplest and cheapest sanitation system. The excreta are collected in a hand-dug pit in the ground, generally located directly beneath a squatting slab or seat. Liquids soak into the ground and solids accumulate in the pit (for more details see section 5.4.2).

Most investigations on groundwater pollution by on-site sanitation are based on septic tank systems. It is important to recognise that there are significant differences between septic tanks and pit latrines. Foster, (1985)[3] gave the differences as follows:-

a) The biological active topsoil layer (2m.), while normally partly present below the septic tank soakaway, is usually removed during pit latrine construction.

b) The maximum allowable hydraulic loading for a septic tank soakaway is 30 mm/day, whereas higher loading up to 120 mm/day is inevitable for pit latrines.

c) In developing countries faecal bacterial populations and pathogen counts were found to be much higher in pit latrines than in septic tanks.

d) Septic tanks use is restricted to low density settlements, while pit latrines are being installed at high density in villages and towns/cities in developing countries.

e) Septic tanks are lined and their solid effluent, of high nitrogen content, is periodically removed, while pit latrines' sludge may remain in the ground.

There are only few reported case histories of groundwater pollution in developing countries resulting from the use of pit latrines. This is due to lack of research and reporting. Most of the literature emanates from the developed countries. Although the health and water supply problems in the developing countries are substantial, there are only limited funding available for investigation of groundwater pollution problems.

1.2 Research Objectives:

The objectives of this research project of six months duration are as listed below:-

a) review the literature related to the survival and movement of micro-organisms and movement of nitrates, through the unsaturated and saturated zones and hence,

b) identify factors which:-
i) affect the movement of the contaminants in the groundwater, and

ii) can be used to asses the pollution risks to groundwater in various hydrogeological environments likely to be encountered.

d) review the data of groundwater contamination in Dar-es-Salaam city related to physical data, social data and sanitation conditions which also can be used to asses the pollution risks (through certain practices). Thereafter,

e) study, select and use already developed computer models which are readily available in predicting groundwater contamination by extensive use of pit latrines; Dar-es-Salaam (Manzese squatter area) as a case study. And then,

f) come up with appropriate recommendation(s) for control and prevention of groundwater contamination by pit latrines considering the hydrogeological, biological and social aspects involved in squatter areas, if necessary.

1.3 Methodology:

As spelled out in section 1.2 about the objectives of the research; literature review was mainly conducted with the available books and journals from IHE library, TU Delft central library and private libraries, which were accessible to me at the time of this study.

Part of the literature review and data collection was done on the reports prepared by WASTE consultants (stationed in Gouda) and HASKONING consultants (stationed in Nijmegen). Several visits were conducted to these consultant firms in order to get data from their reports and direct interview with some of their officers. It may be said at this juncture that whoever collects data have a specific objective(s) in mind, it is not always easy for one set of data to suit two or more research objectives equally. But, despite of all that, the cooperation and help rendered to me by the two mentioned consultants firms enabled a success completion of the task. Some missing data had to be assumed or wisely and intelligently extrapolated from the available known data.

Background information was obtained by interviews with experts from DSSD; Mr. Kirango, who was by then studying at IHS Rotterdam: from HASKONING; Mr. Kok and from WASTE; Mr Rijnsburger and Miss H. Claringbould (one of my mentors) who once worked in Dar-es-salaam/Tanzania under the WASTE consultants.

MFLOP Version 2.0 model happened to be the best selection for my study on prediction of groundwater contamination by pit latrines. In chapter six (6), details of the predictions are given. The model proved to be easy to use, fast in giving results and can be acquired free of charge for study purposes from the authors. Other software proposed by TNO; CONTRANS, PHREEQM, TRABESKAS, TRIWACO and AQUA 3.0, were also studied and scrutinised, but had to be dropped due to some shortcomings here and there involved as per environment of my study.

2.0 FLUID AND POLLUTANT TRANSPORT

2.1 Fluid transport:

Groundwater flow through the soil porous media is always laminar with an exception of fractured and cavernous zones, where the flow can be laminar or turbulent depending on the flow velocities; same as in open channels. The velocity of groundwater flow can be estimated by the use of hydraulic principles or by direct measurements. Direct measurement is limited in value because it can give the velocity only at the point of measurement, whereas aquifers vary considerably in permeability within short distances (Steel and Mcghee, 1979).[23] Darcy's investigations indicated that in water-bearing sands velocity varied directly with the slope of the hydraulic gradient. His conclusion can be expressed by the equation:-

$$V = K\frac{h}{L} = KI \qquad (1)$$

in which V (m/day) is the velocity of the moving water, h (m)is the difference in head between two points separated by a distance L (m), I(unitless) is the slope of the hydraulic gradient and K(m/day) is a constant which depends upon the character of the aquifer and is determined experimentally for each type of material.

2.2 Pollutant transport processes:

The basis for groundwater transport of contaminants will be discussed in this section. The processes discussed below include advection, dispersion, diffusion, and sorption. It should be made clear at this point, that saturation zone is that zone below the watertable whereby all void spaces are filled with water, while unsaturated zone (zone of aeration) is that above the watertable with void spaces filled with water and air. Normally the two zones are separated by a transitional zone known as capillary fringe.

2.2.1 Concept:

Groundwater pollution in my study is caused by gradual dissolution of pollutants present in a pit latrine by seepage water through the unsaturated zone or the passing groundwater flow in saturated zone (Fig. 2.1).

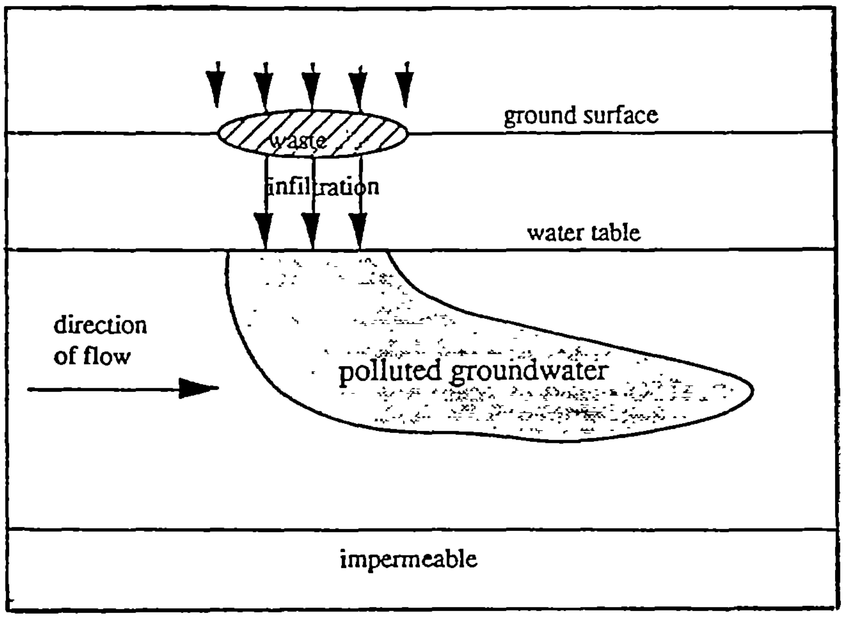


Fig.2.1. Movement of groundwater pollution

Long range spreading of pollutants is only possible when the dissolved pollutants are carried along by the prevailing flow, mainly in horizontal directions. The distance that can be covered within a certain time depends on the velocity of flow and the persistence of the pollutant (Tarrillo, 1990).[27]

2.2.2 Advection (convection):

Advection refers to the transport of contaminants at the same speed as the average linear velocity of groundwater ($\dot{V}$),

$$V = K\,I\,/n \qquad (2)$$

Where V = the average linear velocity (the average pore velocity)(m/day)
K = the hydraulic conductivity (m/day)
I = the head gradient (unitless)
n = the effective porosity (unitless)

The term **advection** is used in preference to the term **convection** because convection often carries the connotation of transport in response to temperature-induced density gradient.

2.2.3 Dispersion and diffusion:

Dispersion in porous media refers to the spreading of a stream or discrete volume of contaminants as it flows through the subsurface. Dispersion causes mixing with uncontaminated groundwater and hence is a mechanism for dilution. Moreover, dispersion causes contaminants to spread over a greater volume of aquifer than would be predicted solely from an analysis of groundwater velocity vectors.

Dispersion of a contaminant in groundwater is due mainly to heterogeneity of the medium. It is a result of the existence of a statistically distribution of flow paths and flow velocities around local heterogeneities (Tarrillo, 1990).[27]

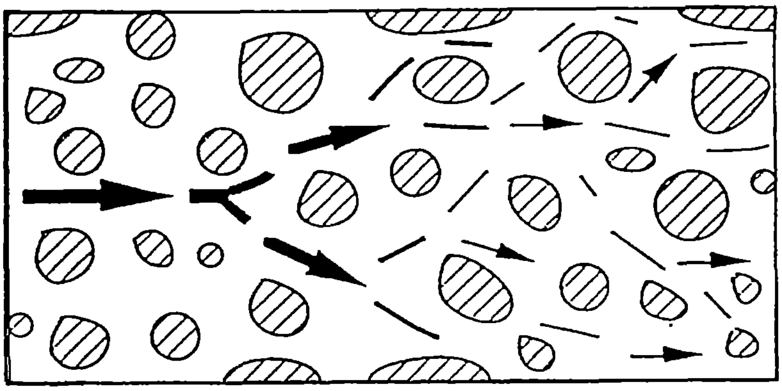


Fig.2.2. Dispersion process at a microscopic scale

Hydrodynamic dispersion:

If the migration of dissolved solutes through porous media is assumed to be only related to the seepage velocity of groundwater, a contaminant would travel through the aquifer by **plug flow** (e.g. piston-like motion). The concentration profile would resemble a step function. However, experience has shown that solutes gradually spread out from their initial point of introduction and occupy an ever increasing volume of the aquifer: hydrodynamic dispersion.

Hydrodynamic dispersion constitutes a nonsteady, irreversible mixing process. Bear (1972)[17] states that hydrodynamic dispersion is the macroscopic outcome of the solute's movement due to microscopic, macroscopic and megascopic effects. On the microscopic scale, dispersion is caused by: a) external forces acting on the groundwater fluid, b) macroscopic variations in the pore geometry, c) molecular diffusion along solute concentration gradient, and d) variations in the fluid properties, such as density and viscosity.

In addition to inhomogeneity on the microscopic scale (i.e. pores and grains), there may also be inhomogeneity in the hydraulic properties (macroscopic variation). Variations in hydraulic conductivity and porosity introduce irregularities in the seepage velocity with the consequent additional mixing of solute Finally, over large distance of transport, megascopic or regional variations in the hydrogeologic units or strata are present in the aquifer. The effect of scale on the mechanisms of hydrodynamic dispersion are shown schematically in Figure 2.3.

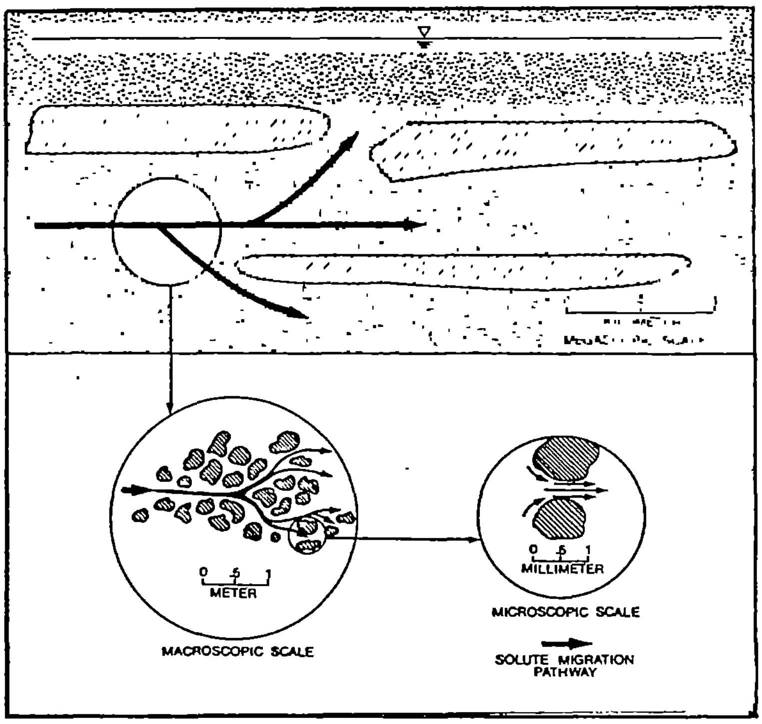


Fig.2.3. The effect of scale on hydrodynamic dispersion processes (Anonymous, 1985)

The hydrodynamic dispersion coefficient D(cm^2/s) may be mathematically expressed as the sum of two dispersion processes: mechanical dispersion D_m (cm^2/s) and molecular diffusion D^* (cm^2/s).
Thus, the sum is

$$D = D_m + D^* \tag{3}$$

Molecular diffusion D^* is a microscopic and molecular scale process that results from the random thermal induced motion of the solute molecules within the liquid phase. This process is independent of the advective motion of the groundwater and can be of significant importance at low flow velocities and very near solid surfaces. Molecular diffusion is generally specified (Sudicky, 1983)[18]. The coefficient is given equal to 10^{-6} cm^2/s.

Mechanical dispersion D_m occurs predominately on a macro and megascopic scale and is due to the " mechanical mixing" of the solutes. Such mechanical mixing is caused by : a) variations in the velocity profile across the water filled portions of a pore, b) variations in the channel size of the pore channels.

One-dimensional flow:

For one-dimensional flow, mechanical dispersion D_m (cm^2/s) is generally expressed as a function of the seepage velocity V_s (cm/s) with the relationship:

$$D_m = \alpha_1 V_s \tag{4}$$

Where α_1 = the longitudinal dispersivity of the porous medium (cm).
The hydrodynamic dispersion coefficient D (cm^2/s) is then (see equation 3).

$$D = \alpha_1 V_s + D^* \tag{5}$$

The dispersion α_1 is not constant but rather appears to depend on the mean travel distance or scale at which the measurements were taken (Sudicky, 1983)[18]. For example, laboratory experiments give values of dispersivity in the range of 10^{-2} to 1 cm, while field determined values range from about 10^3 to 10^4 cm. This shows that longitudinal dispersivity increases with scale length.

Physical meaning of dispersion coefficients:

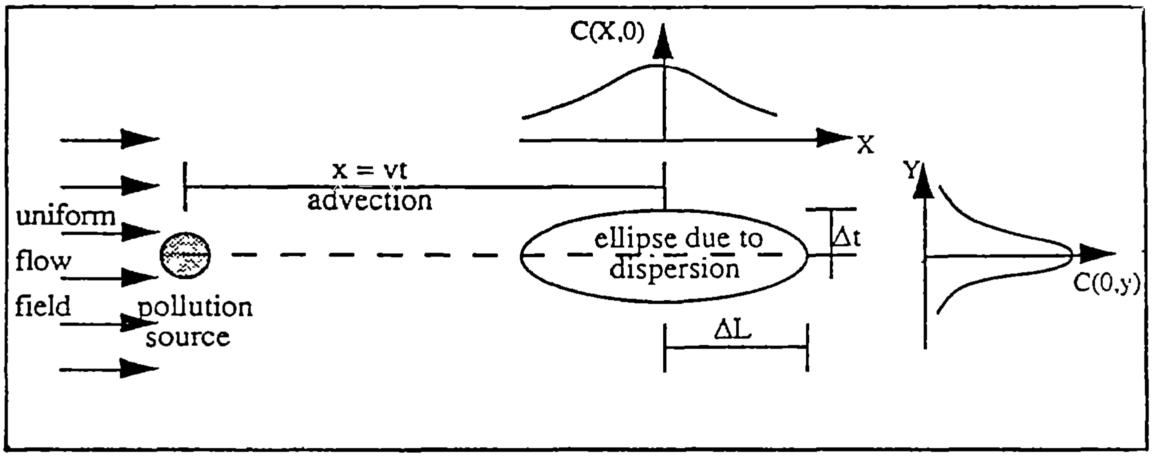


Fig. 2.4. Spreading of a definite fluid portion due to dispersion (Tarrillo, 1990)[27]

$$\Delta L = \sqrt{(2\ D_l\ t)} \qquad (6)$$

$$\Delta t = \sqrt{(2\ D_t\ t)} \qquad (7)$$

Where D_l : longitudinal dispersion coefficient

D_t : transverse dispersion coefficient

both depend upon the medium and velocity

$D_l = \alpha_l\ v$

$D_t = \alpha_t\ v$

Where α_l : longitudinal dispersivity

α_t : transverse dispersivity

The dispersivity, α, depends upon the heterogeneity of the medium and determines the spreading of a definite fluid portion.

Estimating longitudinal dispersivity:

A rough estimate of longitudinal dispersivity in saturated porous media may be made by setting α_l (cm) equal to 10% of the mean travel distance $\bar{x}$ (Gelhar and Axness, 1981).[35]

$$\alpha_l = 0.1\bar{x} \tag{8}$$

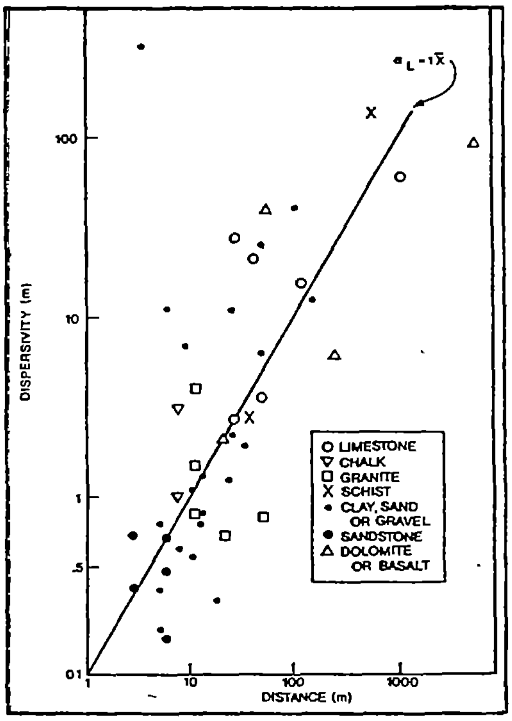


Fig.2.5 Field measured values of longitudinal dispersivity as a function of scale length for saturated porous media (Lallemand-Barres and Peaudecerf, 1978).[5]

As reported in Anonymous, (1985) in Fig. 2.5 , 48 values of longitudinal dispersivity are plotted as a function of scale length of the experiment for saturated porous media (Lallemand- Barres and Peaudecerf, 1978).[5] Note in Fig. 2.5 the line predicted by equation $\alpha_l=0.1\bar{x}$ Lallemand-Barres and Peaudecerf, (1978)[5] concluded that field-scale dispersivity was independent of both the aquifer material and its thickness. In addition, the equation suggest that longitudinal dispersivity increases indefinitely with scale length.

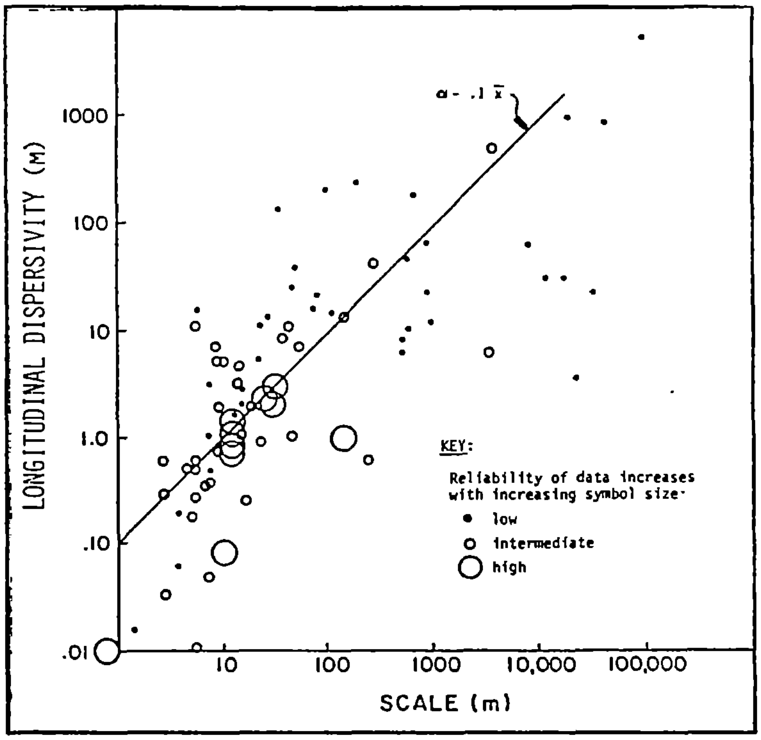


Fig.2.6 Longitudinal dispersivity Vs. scale length for saturated porous media. (Gelhar et al., 1985)[36]

A critical evaluation of saturated site data in terms of reliability led Gelhar et al., (1985)[36] to suggest that no definite conclusion could be reached concerning scales greater than 100 metres. Longitudinal dispersivity probably approaches asymptotically a constant value for very large or megascopic scale lengths (Sudicky, 1983)[48]. In addition, the 10% rule of thumb expression for longitudinal dispersivity given by equation (8) does not hold in the unsaturated zone. Rough approximation of longitudinal dispersivity for unsaturated flow can be made by using Fig 2.7, where scale means the mean travel distance or simply the distance from the origin of the contaminant.

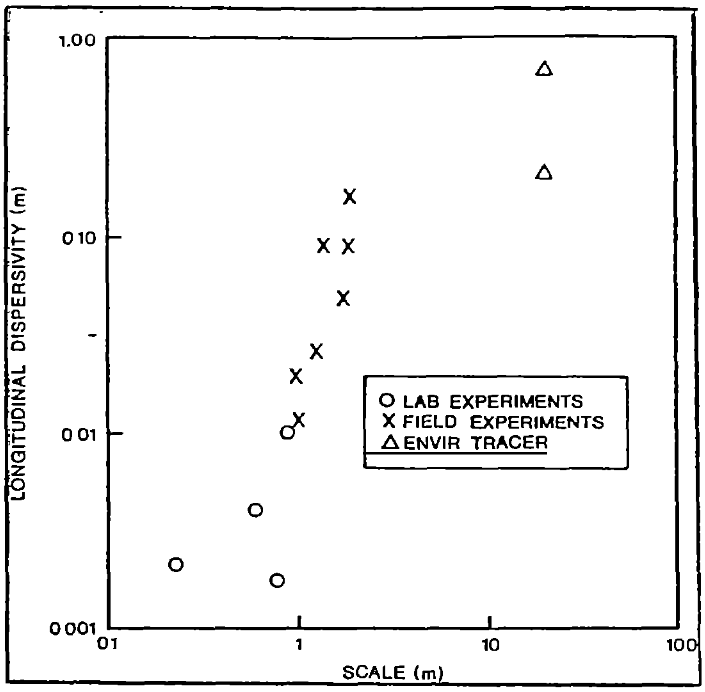


Fig.2.7 Longitudinal dispersivity Vs. scale length for unsaturated porous media. (Gelhar et al., 1985)(16)

To estimate longitudinal dispersion, an appropriate distance is determined (typically the distance from the contaminant source to the furthest point of interest). The dispersivity is then selected for the chosen distance from either equation (8) or Fig 2.6 for the saturated zone or Fig 2.7 for the unsaturated zone. Dispersion is then calculated using equation (5) or equation (4) for one-dimensional flow.

Solute transport equation:

The partial differential equation describing the one-dimensional advective-dispersive transport of non-reactive solutes in a saturated (or unsaturated) homogeneous porous medium is given by:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - V_s\frac{\partial C}{\partial x} \qquad (9)$$

Where C = the solute concentration at time t(day) and distance x(m), g/ml.
D = hydrodynamic dispersion coefficient (m^2/day)

V_s= groundwater seepage velocity (m/day)

If the aquifer is initially assumed to be solute free and if the D and V_s parameters are constant over the distance of interest, then a solution to equation (9) for a step function input (i.e. the initial concentration goes from zero to a value C_0 at t=0) can be obtained (Ogata 1970)[33]. The solution for a unit of mass, injected at the point x = 0 and t = 0, can be shown to be :-

$$\frac{C}{C_o} = \frac{1}{\sqrt{(4\pi Dt)}}\exp[-\frac{(x-V_s t)^2}{4Dt}] \tag{10}$$

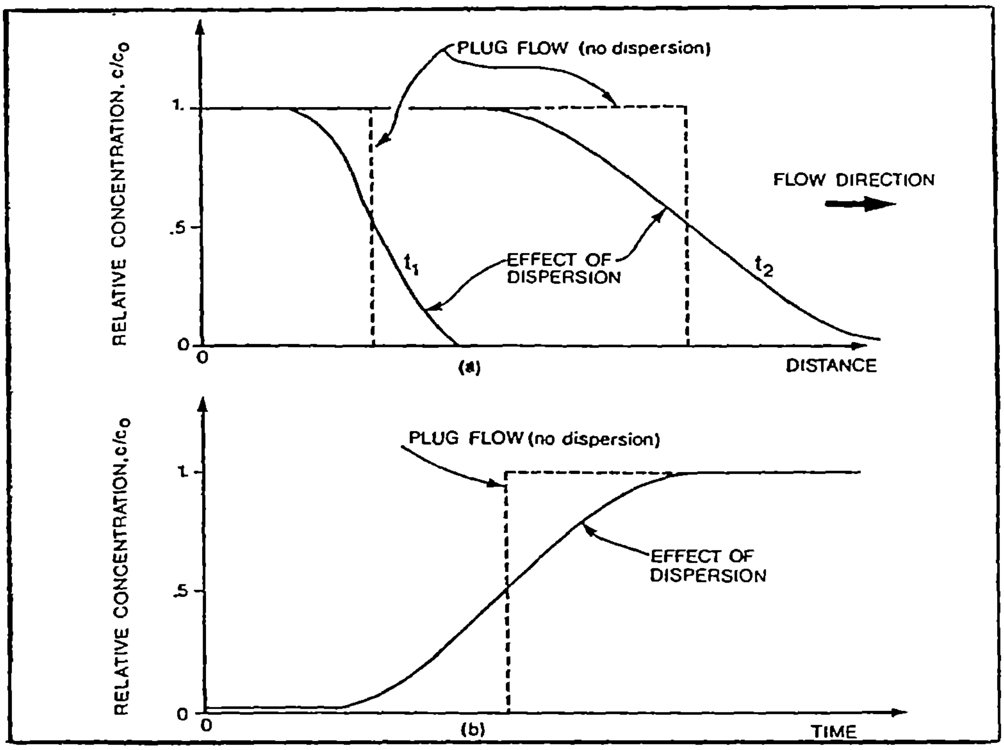


Fig.2.8 Comparison between plug flow and dispersive flow
(a) C/Co Vs distance (b) C/Co Vs time

A comparison between plug flow and dispersive flow in Fig 2.8 shows an "S" shaped curve when dispersion is considered. As time or distance increases, the

S shape flattens out (solutes in plug flow move at the seepage velocity and as a sharp front). Thus, solutes in dispersive flow are spreading out and leading portion of the solutes are moving faster than the seepage velocity. At the point C/C_0 = 0.5, the solutes move at a rate approximately equal to the seepage velocity.

Measuring longitudinal dispersivity:

The typical field method to measure longitudinal dispersivity consists of injecting a tracer into the porous media and then monitoring the arrival time of the tracer concentrations. The experimental data are then fitted or calibrated (using either an analytical or numerical solution of the dispersion equation) to obtain the longitudinal dispersivity or dispersion coefficients. It is reported in Anonymous, (1985) that many analytical methods of fitting the solute breakthrough curve are available, such as those given by Elprince and Day, (1977) and Basak and Murty, (1979).

2.2.4 Random-walk method:

The random-walk method is applied under the following assumptions:-

a) homogeneous isotropic medium
b) homogeneous continuum fluid
c) the elementary displacement of a particle is straight and of equal duration. The duration and length of each displacement take on random values, with no correlation among displacements.
d) laminar flow at each step.

It is reported by Tarrillo, (1990) that Kinzelbach, (1986 and 1988) says that simplified random walk equations are efficient in calculation but yield unrealistic results in regions of strong velocity gradients. The simplified random walk equations are of the form:-

$$x_p^{(t+\Delta t)} = x_p^{(t)} + u_x\Delta t + Z_1\sqrt{2D_1\Delta t}\; u_x/u - Z_2\sqrt{2D_t\Delta t}\; u_y/u \qquad (11)$$

$$y_p^{(t+\Delta t)}=y^{(t)}+u_y\Delta t+Z_1\sqrt{2D_1\Delta t}\; u_y/u+Z_2\sqrt{2D_t\Delta t}\; u_x/u \tag{12}$$

for a particle, p, with

$u_x = u_x(x_p^{(t)}, y_p^{(t)}, t)$

$u_y = u_y(x_p^{(t)}, y_p^{(t)}, t)$

$u = (u_x^2 + u_y^2)$

and normally distributed random numbers Z_1 and Z_2 with zero mean and unit standard deviation.

They imply unphysical heap-up of particles in stagnation points. While particles may diffuse into the vicinity of the stagnation point they have little chance to leave this region again as both convective and dispersive part of the particle step vanish at the stagnation point.

Tarrillo, (1990)[27] says that by the very nature of the random walk method results are plagued by statistical fluctuations. As the standard deviation of the particle number in a cell is proportional to the square root of this number the increase of particles does not show significantly in the increase of smoothness of the calculation results. Significant concentrations can only be obtained in cells with a large number of particles. For these reasons random walk technique should be used only for rough estimates as far as local concentrations are concerned. Smoothing of results is merely cosmetic and introduces new artificial dispersion.

Another difficulty of random walk lies in the simulation of particle capture by wells. This is usually done by defining a circle around the well such that a particle which enters the circle is considered as swallowed by the well. The arbitrariness of defining such a radius can partly be removed if discretization of the flow field is so fine that the cells surrounding the pumping well all show velocity vectors pointing radially towards the well cell (Tarrillo, 1990).[27]

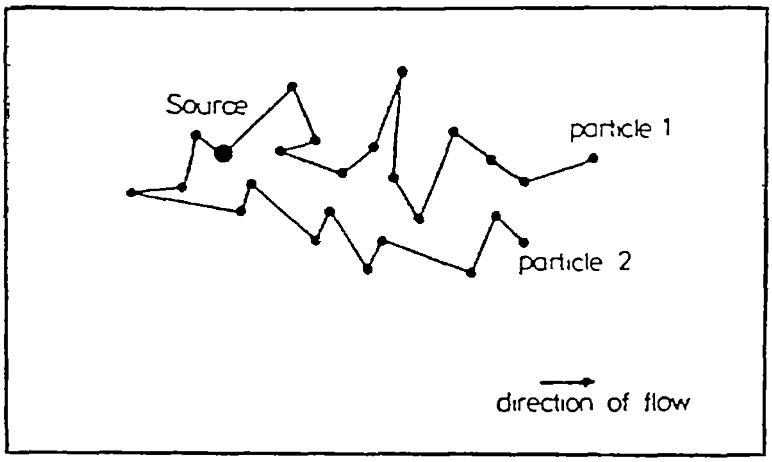


Fig. 2.8 Two individual random paths (12 steps each) starting from a point-like particle source.

2.2.5 Sorption:

Sorption can be defined as the accumulation of a contaminant in the boundary region of the soil-water interface. Sorption-desorption processes are an important determinant of pollutant behaviour in the subsurface environment. Because of the much higher solid to liquid ratios in groundwaters than surface waters, the concentration of even a moderately-sorbed pollutant can decrease significantly with distance as it migrates in the ground. Rates of reactions such as microbial degradation can be different for the adsorbed pollutant and the portion remaining in solution. In groundwater as the solid phase is immobile the adsorbed pollutant is not usually transported by advection or dispersion. However, when the concentration gradient changes, the pollutant can be desorbed over time at the same or a different rate than it was sorbed onto the soil particles.

Sorption can also affect biodegradation in groundwater. Since removal by sorption decreases the concentration in the groundwater, the biodegradation by suspended microorganisms is usually reduced.

Retardation factor:

If sorption is modeled as a linear, equilibrium process, it can be incorporated into analytical methods as a retardation factor (Anonymous, 1985). This is defined as follows:-

$$R_d = 1+\left(\frac{k_d \rho_b}{n}\right) \tag{13}$$

where R_d = retardation factor (unitless)
K_d = distribution coefficient (ml/g)
ρ_b = bulk density (g/ml)
n = porosity (decimal fraction)

If a pollutant is not sorbed, the retardation factor equals one which shows that the pollutant moves at the same speed as the groundwater. If the retardation factor is e.g. 2, the pollutant will move half as fast as the water.

The K_d term is an empirical coefficient for a specific constituent under a particular set of conditions. For linear, equilibrium sorption, K_d can be measured in the laboratory as :

$$K_d = \frac{[S]}{[C]} \tag{14}$$

where K_d = distribution coefficient, ml/g
[S] = concentration of pollutant sorbed on soil, g/g
[C] = concentration of pollutant in solution, g/ml

Effect of sorption on seepage velocity and travel time:

A solute subject to sorption will travel at the following average velocity.

$$V_s^* = \frac{V_s}{R_d} \tag{15}$$

where V_{s*} (cm/s) is the velocity of the solute, V_s (cm/s) is the seepage velocity of the groundwater and R_d (unitless) is the retardation factor accounting for sorption.

Groundwater travel time Δt is defined as the average time that it takes groundwater to travel a specified distance. In the case of a solute subject to linear, equilibrium sorption, its travel time will be:

$$\Delta t^{*}-R_d\Delta t \qquad (16)$$

where Δt^{*} (s) is the travel time of the solute, Δt (s) is the travel time of groundwater and R_d (unitless) is the retardation factor accounting for sorption. Hence, the travel time of a solute will be greater than or equal to that of groundwater. (An insignificant exception may exist for solutes like chloride, which because of anion exclusion by negatively charged soils, may move slightly faster than the groundwater itself.)

2.2.6 The effect of immobile water:

Another phenomenon that affects the movement of pollutants is that of immobile water (or almost so), often encountered in both saturated and unsaturated zones. In a saturated flow domain, immobile, or stagnant water is the water occupying dead-end pores. These are pores that, although being part of the general interconnected void space, have very narrow connections with the later, so that the water in them is almost stagnant. However, stagnant water may also be due to local zones of very low permeability. In unsaturated flow, immobile water may also occur in pendular rings of drained pores. Although (almost) immobile, the water in the immobile zones is part of the continuous water phase.

Due to its very low (or zero) velocity, it is common to assume that no advection of a pollutant, or hydrodynamic dispersion, can take place in a body of immobile water. However, these water bodies can exchange a pollutant with the water surrounding them by molecular diffusion. Thus, the behaviour of this portion of the void space is equivalent to that of sources and sinks for the pollutant. The considered pollutant will always diffuse from the portion of the water where the concentration is higher to that where it is lower (Bear and Verruijt, 1987).(16)

3.0 MICROBIAL MOVEMENT AND SURVIVAL IN GROUNDWATER

3.1 Introduction:

The fate of pathogenic bacteria and viruses in the subsurface from pit latrines will be determined by several factors which are discussed in this chapter underneath.

3.2 Factors affecting pathogen survival:

From the time of excretion, the concentration of all pathogens will usually decline due to the death or loss of infertility of a proportion of the organisms (Feachem et al., 1980).[15] Viruses and protozoa will always decrease in numbers following excretion. Bacteria may multiply, if they find themselves in a suitably nutrient-rich environment with a minimum of competition from other microorganisms. Multiplication of pathogens is very uncommon, however, and is unlikely to continue for very long. Intestinal helminths will decrease in numbers following excretion, except for the trematodes, which have a multiplication phase in their molluscan intermediate hosts (Feachem et al.,1980).[15]

3.2.1 Survival in soils:

(a) Bacteria:

Most enteric bacteria pathogens die-off very rapidly outside of the human gut, whereas indicator bacteria such as Escherichia coli persist for longer periods of time. Survival times among different types of bacteria vary greatly and are difficult to asses without studying each type individually.

Kligler, (1921)[57] investigated the survival of Salmonella typhi and Shigella dysenteriae in different soil types at room temperatures. He found that in moist soils some bacteria survived for 70 days, although 90% died within 30 days. Mirzoev, (1968) showed that low temperatures (down to -45^{0}C) were favourable for survival of Shigella dysenteriae, and he was able to detect them 135 days after they had been added to the soil. Kibbey et al., (1978)[38] found that die-off rate varied between the different soils, but were generally largest in soils maintained under cool, moist conditions.

This finding was confirmed by Bouma et al., (1972)[37] in field studies on pollutant movement beneath septic tank disposal fields. Dazzo et al., (1973)[39] recorded the time for 90% reduction of E.coli as 8.5 days in soils receiving 50mm of cow manure slurry per week and 4 days in soils receiving no manure. Finally. Martin and Noonan, (1977)[40] found that faecal coliform and faecal streptococci were reduced by 90% in 28 and 22 days respectively at depths of 0-100mm, but 182 and 25 days respectively at 100-200mm depth in silt loam.

b) Viruses:

Different studies by Gerba et al., (1975)[41] and Bitton et al., (1979)[42] have shown that the nature of soils can affect virus survival characteristics. Hurst, (1979)[44] found that survival increased with the degree of viral adsorption to the soil. Hence, soils which are most effective in removing viruses would also enable them persist for the largest periods. Duboise et al., (1976)[45] showed that anaerobic condition led to a reduction in activation.

Lefler and Kott, (1974)[46] found that survival of poliovirus depend on temperature. Keswick and Gerba, (1980)[47] evaluated the factors controlling virus survival and found that inactivation was much more rapid near the surface. This is due to the detrimental effect of soil microorganisms, evaporation, and higher temperatures close to the surface. Thus, virus survival is expected to increase with depth of penetration.

3.2.2 Survival in groundwater (saturated zone):

a) Bacteria:

Mitchell and Chamberlain, (1978)[22] surveyed published data on the survival of indicator organisms in a variety of freshwater bodies and found that bacteria die-off generally follows first order kinetics, although a significant increase in coliforms is often observed in the first few Kilometres from the outfall.

Experiments conducted in New Zealand (Martin and Noonan, 1977)[40] found that hydrogen sulphide resistant strain of E.coli survived for 4 days at 11^{0}C and 2.2 days at 15.5^{0}C. Investigations on antibiotic resistant E.coli indicated that even after 32 days quite large number survived. Geldreich et al., (1968)[48] found that faecal streptococci often persist longer than faecal coliforms.

b) Viruses:

Field studies by Wellings et al., (1975)[55] suggest enteroviruses can survive for at least 28 days in groundwater. Akin et al., (1971)[49] found that between 2 and 100 days are required for various members of the enteric family to lose 99.9% of their initial infectivity when suspended in different surface waters at 20^{0}C. From these data it appears that temperature is the single most important factor in die-off, and 99% reduction may be expected at 20^{0}C within about 10 days although a few enteroviruses may survive for many months.

Several workers have noted that the observed loss of infectivity of viruses in water may be due in part to genuine damage to the virus, and in part to artefact caused by many aggregating and simulating a single infectious particle. This aggregation may involve the adsorption of viruses onto organic or inorganic suspended matter. Adsorption is enhanced at slightly acidic pH and in the presence of soluble proteins.

3.3 Die-off computations:

Mitchell and Chamberlain (1978)[22] found from literature that bacterial die-off generally follows first order kinetics. The relationship between the number of living cells per ml, C, can be expressed at any time t as:-

$$-\frac{dC}{dt} = KC \qquad \text{(Chick's law)} \qquad (16)$$

Where C = bacteria concentration at any time t

K = a constant known as specific death rate [T^{-1}]

t = the time from inoculum [T]

Integrating after rearrangement gives:-

$$C = e^{-Kt+a} \tag{17}$$

In which 'a' is Ln C at time zero, thus representing the natural logarithm of the number of cells present at the start (inoculum). Normally the equation is written as:-

$$C = C_0 \, e^{-Kt} \tag{18}$$

Where C_0 is the actual number of cells present at the start (inoculum). For conservative pollutants K = 0 and C = C_0 under steady state conditions. Decay rates are determined empirically and depend on a number of variables.

The Chick's law equation can be represented graphically as shown below:-

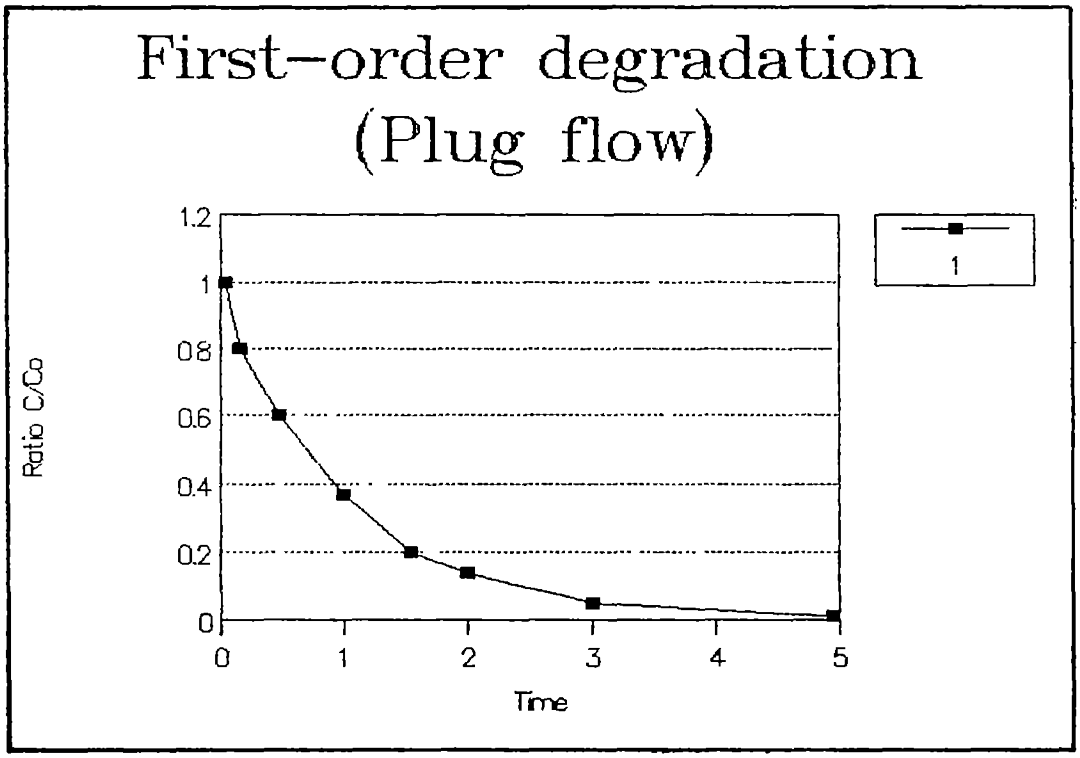


Fig.3.1 First-order degradation (plug flow)

Table 3.1. Die-off rate constants (day^{-1}) for viruses and bacteria in groundwater (Bitton and Gerba, 1984)(19)

Microorganisms	Die-off* rate(day^{-1})
Poliovirus 1	0.046
	0.21
	0.77
Coxsackievirus	0.19
avirus SA-11	0.36
Coliphage T 7	0.15
Coliphage f 2	1.42
	0.39
<u>E.coli</u>	0.32
<u>Faecal streptococci</u>	0.36
	0.03
<u>Salmonella typhimurium</u>	0.13
	0.22

* As $\log_{10} N_T / N_0$ where N_T equals concentration of organisms after 24 hrs. and No equals the initial concentration of organisms.

It should be noted that decay rates are dependent upon temperature. The values given in Table 3.2 assume a temperature of 9-12^{0}C. Variations in K values for differing temperatures are given by equation:-

$$K_T = K_{20^0} . \theta^{T-20^0} \quad (19)$$

Where K_T = decay rate at temperature T
K_{20^0}= decay rate at 20^{0}C
θ = a constant (normally between 1.03 - 1.05) (Anonymous,1985)

Indicator bacteria may grow in groundwater if sufficient nutrients are present. <u>E.coli</u> growth was observed during groundwater recharge operations in Israel. McFeters et al., (1974)(50) measured the comparative survival of various faecal indicator bacteria and enteric pathogens in well water using membrane chambers. T_{50} values (time required for a 50% reduction) of the various cultures are given in Table 3.2

Table 3.2. Half time (time of 50% reduction) of various bacterial cultures in well water, at 9-12°C, McFeters et al., 1974 [50]

Bacteria	Half time (hr)	Calculated die-off rate (hr^{-1})
Indicator bacteria		
Coliform (average)	17.0	0.040
Enterococci (average)	22.0	0.031
Streptococci (average)	19.5	0.035
Streptococcus equinis	10.0	0.067
St. bovis	4.3	0.149
Pathogenic dysenteria		
Shigella dysenteriae	22.4	0.030
S. sonnei	24.5	0.028
s. flexneri	26.8	0.026
Salmonella enteritidis ser. para-typhi A&D	16-19.2	0,042-0.035
S. enteritidis ser. Typhimurium	16.0	0.042
S. typhi	6.0	0.109
Vibrio cholerae	7.2	0.092
S. enteritidis ser. paratyphi B	2.4	0.251

3.4 Factors affecting pathogen movement:

The unsaturated zone is the most important line of defence against faecal contamination of aquifers. Maximization of effluent residence time in the unsaturated zone is, therefore, the key factor affecting removal and elimination of bacteria and viruses. The relatively large size of helminths and protozoa (>25µ) results in highly efficient removal by physical filtration in soils. It is unlikely that they would pollute groundwater, and therefore will not be considered further in this report. But, as bacteria and viruses are very much smaller (0.02 - 10 µm) and may be transported with the effluent percolating from pit latrines to the groundwater, they will be the centre of discussion in this section.

It must be noted that, when moving through soils, the great majority of bacteria and viruses are retained in the first metre and that it is only a very small fraction that are able to travel more than 10 metres.

3.4.1 Pore clogging process:

Continuous application of effluent from the pit latrine on fixed surfaces results in the growth of a biological layer which filters out increasingly more solid particles and dissolved pollutants from wastewater. A clogging layer is formed at the point of infiltration into the unsaturated soil. The clogging layer penetrates the soil; however, the major portion of the layer, 0.5 to 3cm thick, is near the infiltration surface as shown in Figure 3.2. Such clogging may reduce the rate of infiltration, cause ponding of liquid above the clogging layer(the crust or mat).

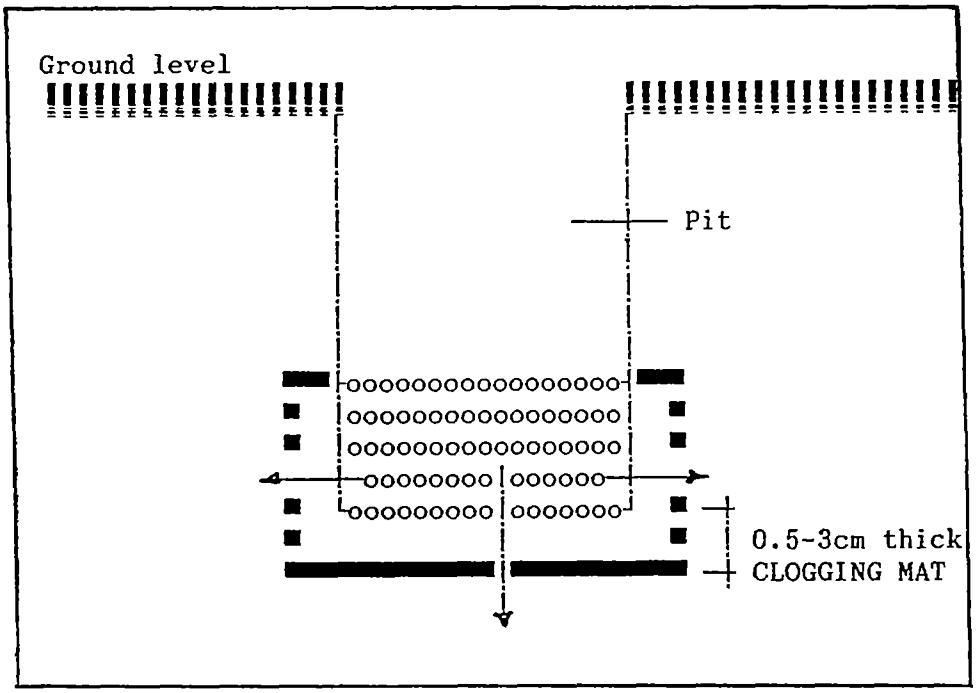


Fig. 3.2 Location of the clogging layer (mat) from a pit latrine

Several phenomena contribute to the process of pore clogging and these include:

(a) blockage of pores by solids filtered directly from the effluent;

(b) accumulation of biomass from the growth of micro-organisms;

(c) excretion of slimes by bacteria;

(d) deterioration and puddling of soil structure caused by saturation and swelling of clay minerals brought about by cation exchange;

(e) precipitation of insoluble metal sulphides under anaerobic conditions.

Clogging layer:

The clogging layer is a slimy mass consisting of wastewater solids, mineral precipitates, microorganisms (mostly falcutative bacteria, but also some protozoa and nematodes) feed on the wastewater nutrients to produce slimes and end products (polysaccharides and carbon dioxide). Filtered wastewater solids (cellulose and undigested food residues) hydrolyse and biodegrade slowly. Mineral precipitates such as ferrous sulphide and aluminium-iron-and calcium phosphate complexes can both accumulate and leach out, depending on pH, Oxygen tension and solubility.

The rate of development of the crust depends on many factors, and is believed to develop in three stages. Initially, aerobic bacteria decompose many of the organic solids filtered from the effluent, helping to keep soil pores open. However, they can only function when the infiltration surface drains, allowing the entry of air, and eventually will be unable to keep up with the flux of solids. Permanent ponding will result, leading to anaerobic conditions, where oxygen is no longer present to allow the rapid decomposition of organic matter. Clogging therefore proceeds more quickly; the reduction of sulphate by anaerobic bacteria binds up trace elements as insoluble sulphides, causing heavy black deposits. At this stage, the crust normally reaches an equilibrium state, and its hydraulic resistance stabilises (Lewis et al., 1980).(29)

The clogging layer is in continuous flux, Figure 3.3; that is, building degrading, and creeping downward into the soil as a viscous fluid where it gradually is dispersed.

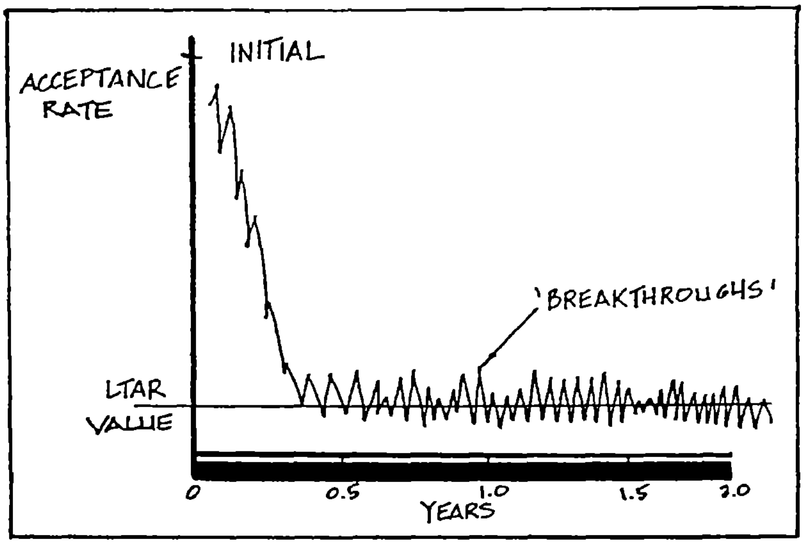


Fig. 3.3 Development of the clogging layer and its permeability changes

The clogging layer develops at a rate dependent upon the load (Otis et al., 1977)[16]. As the clogging layer matures, the infiltration rate of water decreases non-lineally (Otis et al., 1977)[16] as shown in Figure 3-3. The clogging layer's average infiltration rate, or LTAR, can be reached after a period of one to six months (Otis et al.,1977)[16].

Factors affecting the clogging layer:

The clogging layer's permeability and thickness are affected by the underlying soil type, the wastewater quality and load, and the environmental conditions.

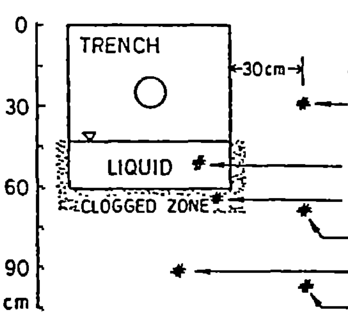
Significance of pore clogging:

Because of the partial barrier to flow created by soil clogging, the soil below the organic mat becomes unsaturated. This becomes significant when effluent is applied to the soil for disposal. Liquid flow in unsaturated soil proceeds at a much slower rate than in saturated soil because flow only occurs in the finer pores. This slows the rate of infiltration through the soil, enhances purification. The effluent is purified by filtration, biological reactions, and adsorption processes which are more effective in unsaturated soil.

3.4.2 Straining filtration:

Straining filtration refers to the immobilization of suspended bacteria that occurs when they get caught in pore openings that are smaller than their limiting dimensions.

Straining filtration of bacteria at the infiltration surface appears to be the main mechanism limiting their movement through soils. Straining filtration is an important factor in pit latrines, since build-up of biofilm may restrict pore size in porous media adjacent to the soil water interface. It has been shown that filtration is most effective at the surface of organic mat of the clogged zone (Refer to section 3.4.1). For instance, Ziebell et al., (1975b)[2] found that the bacteria population below and to the side of a septic tank seepage bed was considerably reduced to about the level of the population in a control soil sample. This abrupt drop occurred within 30cm of the clogged zone (Fig 3.4). Caldwell and Parr (1937)[31] also noted that with a newly constructed pit latrine penetrating the water table, faecal coliforms were detected 10m away. However, after clogging (3 months) pollutant dispersion was considerably curtailed. Krone et al. (1958)[58] investigated E. coli removal in sand columns, and found that the effluent concentration of bacteria gradually rose and then declined which suggested that accumulating bacteria at the soil surface enhanced the straining mechanism.



BACTERIA / 100 ml OR PER 100g OF SOIL

FECAL STREPTO-COCCI	FECAL COLI-FORMS	TOTAL COLI-FORMS	TOTAL BACTERIA ×10⁷
<200	<200	<600	0.6
160,000	1,900,000	5,700,000	3.0
54,000	4,000,000	23,000,000	4,400
<200	17,000	23,000	6.7
<200	<200	<600	3.7
<200	700	1,800	2.8

Fig.3.4 X-section of an absorption field in plain field loamy sand with typical bacterial counts at various locations (Ziebell et al., 1975b)[2]

3.4.3 Sorptive filtration:

Unlike bacteria, viruses are very small and removal appears to be dependent entirely on adsorption. Burge and Enkiri (1978)[51] studied the adsorption of bacteriophage OX-174 on five different soils in laboratory batch experiments. Good correlation was found between adsorption rates and cation exchange capacity, specific surface area and concentration of organic matter (r= 0.89, 0.85.0.98 respectively). A negative correlation (r= -0.94) was found between the rate and pH. Hence, the lower the soil pH, the more positively charged the virus particles became, and the easier it is for them to be adsorbed. A study by Green and Cliver (1975)[52] suggests that to enhance virus removal large hydraulic surges, or very uneven distribution of waste should be avoided, because the virus detention within the soil was found to be affected by the degree of saturation of the pores.

Landry et al.,(1979)[53] have demonstrated desorption of viruses. They observed that flooding soil columns with deionized water caused virus desorption and increased their movement through the columns. They also observed that different strains of viruses have varying adsorption properties. A study by Lance and Gerba (1980)[54] on the factors affecting the rate and depth of virus penetration revealed that virus adsorption in soil is increased above some breakpoint velocity, whereas flow rate changes above and below the breakpoint do not affect virus adsorption. It was postulated that the velocity of water movement through the soil may be the most important factor affecting the depth of penetration. This suggests that adsorption may not be an important factor of removal in the saturated zone, specially in formations where groundwater velocities are high.

Another study by Welling et al., (1974)[55] showed that the phenomena of desorption with decrease in ionic strength has practical implications for groundwater pollution. Previously adsorbed bacteria and viruses could be desorbed by heavy rains. Martin and Noonan, (1977)[40] also observed that rainfalls of greater than 50 mm resulted in bacterial contamination of groundwater.

3.5 Field investigations of pollutant movement:

3.5.1 Bacteria in the saturated zone:

Caldwell and Parr (1937)[31] measured pollution travel from a 5.1 m bored hole latrine in shallow (3.6 m) perched water table located in a coarse sandy stratum. A conclusion of this study was that the clogging process was an important defence mechanism limiting the extent of bacterial penetration.
A parallel study (Caldwell, 1937)[56] was conducted using a nearby dug pit latrine and it was found that the clogging process was not as effective with this type of latrine, possibly due to the greater volume per depth of penetration. Faecal coliforms were detected 18m away from the pit due to higher groundwater flow velocity which contradicts with a later study (Caldwell.,1938)[30] where no faecal contamination was found 3m away from the pit was enveloped by a layer of fine sand (0.25mm).

Based upon these findings a distance of 15m was generally accepted as a safe distance of separation. But investigations by other researchers indicated that the distance up to which bacteria can travel depends on soil condition. The longest distance reported was 920m in coarse alluvial gravels. Pollutants may be transported along preferential paths at velocities very much in excess of the average groundwater flow velocity.

3.5.2 Bacteria in an unsaturated zone:

Kligler (1921)[57] was one of the earliest researchers to investigate the relationship between pit latrines and the spread of waterborne infectious diseases. He concluded that pit latrine and septic privies, if properly constructed, are unlikely to cause the spread of bacterial intestine infections. Baars (1957)[32] investigated dispersion from a pit latrine at a camping site in the Netherlands and he found that bacteria may penetrate some distance into soil. The conclusions that can be drawn from these early studies is that at least 2m of sandy soil is required beneath a pit latrine to prevent pollution of any underlying water.

A more recent study (Scalf et al., 1977)[59] concluded that soils in many areas are not suitable for conventional septic tank soil absorption system, such as the areas where groundwater table is high.

3.5.3 Movement of viruses:

Little data exists on virus contamination of groundwater from on-site sanitation. Virus determinations are expensive, requires specialised laboratory facilities and highly trained personnel. Furthermore, methods are only available for less than half of all the viruses known to be present in human wastes (Keswick and Gerba, 1980)[47], for example it is not possible to detect Hepatitis A virus.

In the past, demonstration of viruses in potable groundwater supplies were essentially confined to those where an outbreak of illness had occurred. For example, Neffe and Stikes (1945)[60] described an extensive outbreak of infectious Hepatitis at a summer camp in the USA. Also, Wellings et al., (1975)[20] detected poliovirus in water collected 3m below a cypress dome receiving secondary sewage effluent. A recent study in Israel (Marzouk et al., 1979)[61] indicated that 20% of 99 shallow groundwater samples (3m) analyzed contained enteric virus.

Viruses are much smaller than bacteria and removal is dependent almost entirely on adsorption, thus, of all the pathogens present in sewage, viruses are the most likely to find their way into groundwater during land application (Gerba, 1979).[62] Wellings et al., (1974)[55] recovered viruses from groundwater after spray irrigation of secondary sewage effluent onto a sandy soil. In contrast, Gilbert et al., (1976)[63] did not recover any viruses in groundwater samples collected 6m beneath sewage spreading basins composed of fine loamy sand underlaid by coarser sand.

Vaughn et al., (1978)[64] conducted a survey of human virus occurrence in groundwater recharged with sewage effluent, virus concentrations between 0-2.8pfu/l (plague forming units) were reported in 20-33% of 40 litre samples collected. Edworthy et al., (1978)[65] recovered viruses in groundwater 15m beneath a sewage effluent and disposal site. virus concentrations were 63 pfu/l at the groundwater table, but zero in boreholes 100m away.

4.0 NITRATE AS A CONTAMINANT:

4.1 Introduction:

Extensive use of pit latrines may lead to elevated concentrations of nitrate in underlying groundwater, eventually to drinking water wells. A high consumption of nitrate (WHO recommended limit of 45 mg/l for drinking water) is thought to cause infantile methaemoglobinaemia, a blood poisoning which reduces the oxygen transport capacity of the blood of young infants and may cause death. High consumption of nitrate has also been related to an increased risk of stomach cancer.

From pit latrines effluents nitrate is formed by a process known as nitrification and can be removed by conversion to a gaseous nitrogen species by a process known as denitrification. The two processes of nitrification and denitrification are described below:-

4.1.1 Nitrification:

Nitrification is an aerobic biological process that occurs in at least two steps to form nitrate. Nitrification can occur in the soil in unsaturated zones only, where aerobic conditions exist. The first reaction is carried out by <u>nitrosomonas</u> and produces nitrite.

$$2NH_4^+ + 2OH^- + 3O_2^- = 2NO_2^- + 2H^+ + 4H_2O \qquad (20)$$

The second reaction is accomplished by **nitrobacter** and, to lesser extent, by other bacteria.

$$2NO_2^- + O_2 = 2NO_3^- \qquad (21)$$

The nitrification bacteria are referred to as chemoautotrophic bacteria because carbon dioxide is used as a carbon source and ammonia is used for energy. Under aerobic, warm conditions and at a load rate of a few centimetres of pit latrine effluent per day, about one meter of soil thickness can convert ammonia to nitrate. Nitrification does not occur in waterlogged soils where anaerobic conditions prevail.

4.1.2 Denitrification:

The biological process of denitrification involves the conversion of nitrate nitrogen to gaseous nitrogen species. Gaseous nitrogen is relatively unavailable for biological growth, thus denitrification converts nitrogen which may be in an objectionable form to one which has no significant effect on groundwater quality.

$$C_5H_7O_2 + 4NO_3^- \xrightarrow[bacteria]{Dinitrifying} 5CO_2 + 2N_2\uparrow + NH_3 + 4OH^- \quad (22)$$

As opposed to nitrification, a relatively broad range of bacteria can accomplish denitrification, including Pseudomonas, Micrococcus, Archrobacter and Bacillus. These groups accomplish nitrate reduction by what is known as a process of nitrate dissimilation whereby nitrate or nitrite replaces oxygen in the respiratory process of the organism under anoxic conditions. Because of the ability of these organisms to use either nitrate or oxygen as the terminal electron acceptors while oxidising organic matter, these organisms are termed as facultative heterotrophic bacteria.

4.2 Movement of nitrate within groundwater:

On entering the soil, nitrogen may undergo mineralization, nitrification, adsorption, ion exchange, fixation, volatilization biological uptake and eventual denitrification. There are two processes by which unreactive solutes such as NO_3-N, move within groundwater aquifers (Gardener, 1965). These are: i) Advection due to the mass flow of the groundwater and ii) molecular or ionic diffusion due to the concentration gradients (Walker, 1973). The relative contributions of these two processes to the distribution of NO_3-N in groundwater adjacent to subsurface seepage beds are difficult to establish by investigating heterogenous natural flow systems. Therefore, field studies usually report analytical results of periodic sampling of observation wells, placed at different distances from the nutrient sources and at different depths into the aquifer. Conclusions applying to the entire flow system are derived from these point sources using hydrogeologic data and assumptions applying to the aquifer (Walker, 1973).

The location of wells in relation to nutrient sources is very important. Highest NO_3-N concentrations may be expected in wells that are a short distance down gradient from a disposal system, while dilution by groundwater flow will result in decreasing concentrations farther away from a pit latrine. Lowest NO_3-N concentration may be expected in wells constructed at up-gradient locations. Complications may arise in areas with many latrines where groundwater entering the flow system adjacent to seepage bed may have a relatively high No_3-N content (Walker, 1973).

Nitrogen in the groundwater occurs predominately as NO_3-N and concentrations approximates the NH_4-N in the seepage-bed ponded effluent. Denitrification is the only process that could significantly reduce the NO_3-N content during downward percolation. However, significant denitrification is unlikely to occur in the well-aerated sandy subsoil or in the carbon-deficient groundwater. Therefore, relatively high NO_3-N concentrations can be expected in groundwater beneath crusted seepage beds in sands.

Presence of NH_4N as the major N species in the groundwater is due to soil being saturated and resultant lack of nitrification. Ammonium-N concentrations decreases rapidly with increasing distance from the pit latrine because of NH_4N absorption to the soil colloids.

4.3 Field investigations:

Individual pit latrines are significant point source of nitrate-N (NO_3-N) to groundwaters. Nitrogen excreted per capita is 8 to 16g; Cleaning compounds and food waste add another 10 to 15%. It is reported that Walker et al.,(1973)[24] conducted in-situ monitoring of soil profiles below sub-surface disposal beds of five septic systems. Their results indicated that essentially complete nitrification of NH_4-N from septic tank effluent occurred in the area of unsaturated flow in well-aerated soil below the crusted seepage bed. Nitrate removal by denitrification was highly unlikely, and significant local ground water contamination may be anticipated. Excessive concentration of nitrates in drinking water may cause a bitter taste. Water from wells containing more than 45 mg/l of nitrates has been reported to cause methaemoglobinaemia in infants (Canter and Knox, 1985).[18]

Walker et al., (1973b)[24] calculated that in Wisconnsin, USA, the average nitrogen input reaching the groundwater per year was 7.5 Kg. for a family of four people discharging septic tank effluent into sandy soils. His data suggested that the only active mechanism of lowering the nitrate content was by dilution with uncontaminated groundwater. Relatively large areas were needed before concentrations in the top layer of groundwater were lower than 10 mg NO_3-N/l. Nitrate contamination of groundwater was also found to be a particularly severe problem in densely populated low-income residential area in Delaware (Robertson,1980). The area was not sewered, and relied entirely on septic tanks; 28% of the supplies tested in the area had a nitrate concentration exceeding 17 mg NO_3-N/l. Recharge in the sandy, well drained soils was estimated to be approximately 535mm/year.

Hutton et al., (1976)[66] attributed widespread and severe nitrate contamination of shallow village groundwater supplies in eastern Botswana to pollution emanating from pit latrines (nitrate concentrations of 50 mg NO_3-N/l and higher commonly observed in groundwater supplies located within village limits). Lewis et al., (1980)[29] conducted a hydrogeological study in the vicinity of a severely polluted village water supply borehole which had a nitrate concentration in excess of 135 mg NO_3-N/l. The results of this study (Fig.5.1) show that pit latrine cause a major build-up of nitrogenous material in the surrounding soil and weathering rock, from where nitrate is leached intermittently by infiltrating rainfall.

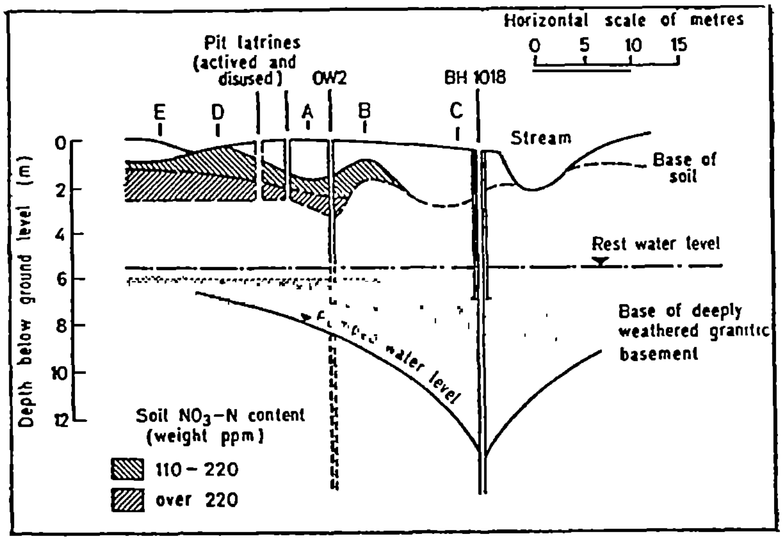


Fig.4.1 Hydrogeological section of study area showing build-up of nitrates in soil around a pit latrine (Lewis et al., 1980)(29)

The authors calculated that the total mass of readily oxidizable nitrogen in a column of soil from the surface to the bedrock for the sites in the immediate vicinity of the pit latrine (auger holes A-E, Fig.5.1) was 0.1 -0.5 Kg N/m^2.

Thus it is apparent that nitrate contamination of shallow groundwater is likely to be a problem where the density of on-site sanitation facilities, including pit latrines is high, and where nitrogen removal and groundwater recharge is moderate to low.

Nitrogen not removed by the soil will eventually reach the groundwater as either nitrate or ammonium ion, depending on the amount of oxygen available. The more important nitrogen removal process are biological denitrification, volatilization of ammonia by aeration, adsorption of ammonium ions, fixation by organic matter, and incorporation into microbial protoplasm.

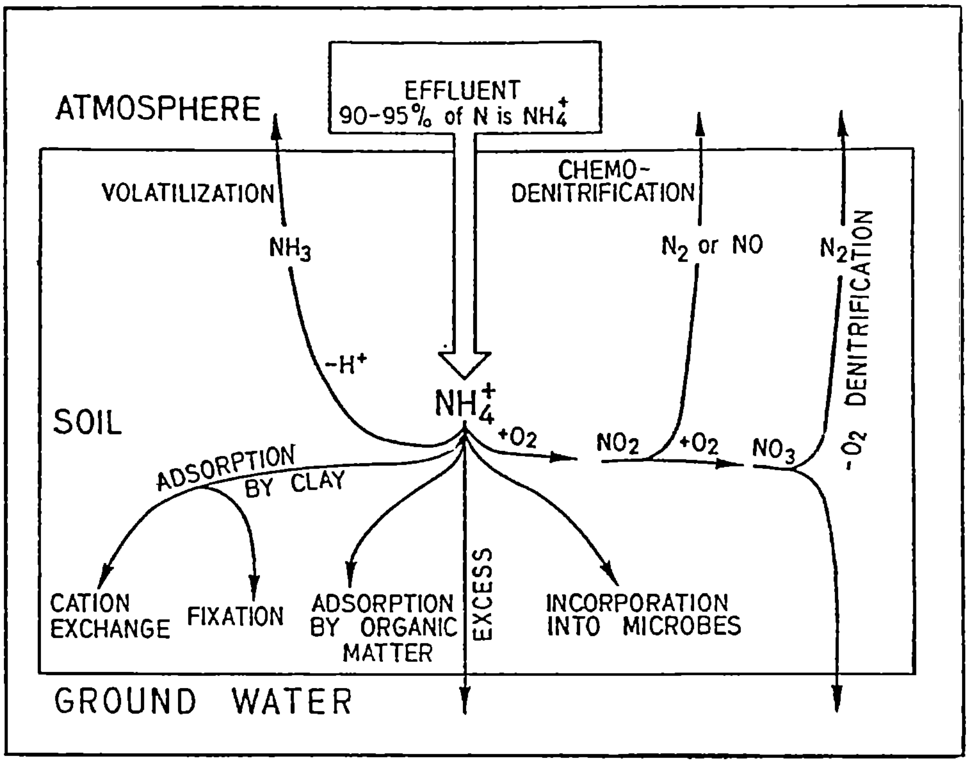


Fig.4.2 Nitrogen transformation in a pit latrine

4.3 Severity of nitrate contamination in groundwater:

Nitrates, once they enter a groundwater body, will remain there for a very long time. The overall factors controlling the severity of nitrate contamination are:

a) the population using pit latrines and the density of the pit latrine in the concerned area,

b) dilution by local recharge and regional aquifer through flow. where this has a lower nitrate concentration,

c) efficiency of the nitrogen removal process beneath the latrine. This will depend on many factors, such as the soil's hydraulic conductivity, the hydraulic loading of the latrine, whether anaerobic conditions favourable for denitrification are established, and the clay/organic content of the sub-soil,

d) denitrification in the saturated zone. However, groundwater conditions giving rise to denitrification may be associated with other problems, for example, high concentration of iron, manganese and other metals (Lewis, 1980).[21]

5.0 DATA INFLUENCING GROUNDWATER CONTAMINATION IN DAR-ES-SALAAM

5.1 Introduction:

In order to be able to write a scenario on the groundwater contamination caused by extensive use of pit latrines in Dar-es-Salaam a description of the area will be given in this chapter. A number of factors which are of major influence to the groundwater pollution problem in Dar-es-Salaam will be discussed. But, as it is always the case in many cities, more than one pollutant contribute to the contamination of groundwater. Dar-es-Salaam is not an exception, but due the restriction of the subject, data on other pollutants like industrial waste etc., won't be discussed here. The data has been grouped into two; physical and social data.

Physical data are: Location of the city, its topography (which influences the groundwater movement), climate (temperatures, wind and rainfall which affect the groundwater table and hence the movement of contaminants from the pits as well as the influence on pit construction) and the soil type and structure which play a key role on groundwater contamination movement.

Social data are: The city population with its future projections, ward administration and the population density as these factors determine the amount of waste and sullage produced and the amount of water supply required which at times forces the population to dig shallow temporary borehole wells to supplement their water supply. The shortage of housing is described as it leads to overcrowding under one roof and hence, high hydraulic loading from the pit latrines.

A separate paragraph has been spend on sanitation. The sanitation situation is treated separately due to its great influence to the problem concerned. The chapter is finalised with conclusions to be used in the modelling in chapter six (6).

5.2 Physical data:

5.2.1 Location and topography:

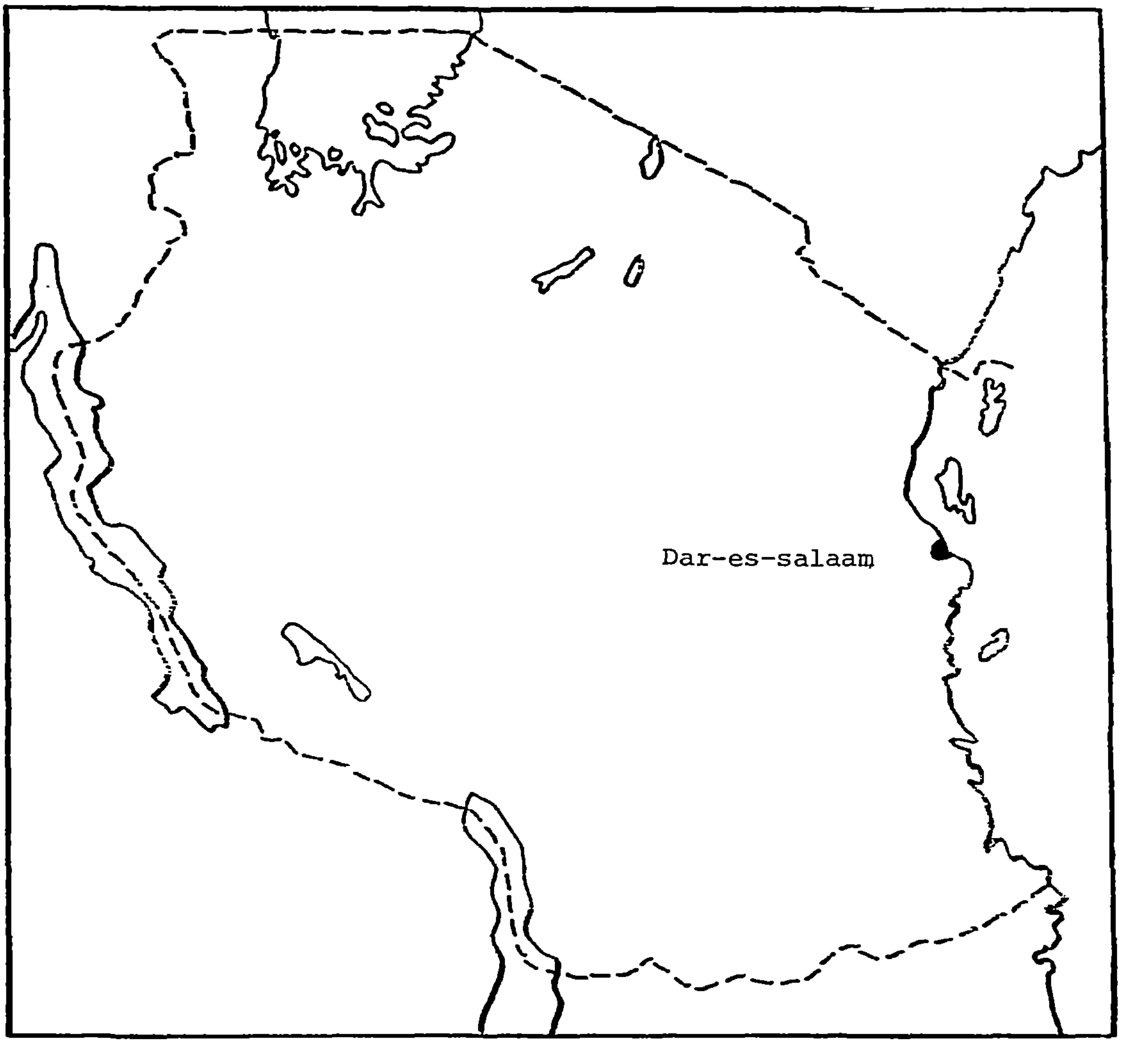


Fig. 5.1 Map of Tanzania showing location of Dar-es-salaam city

Dar-es-salaam (harbour of peace-"bandari ya salama"), is the largest city in Tanzania which until 1973 used to be the capital of the country before Dodoma Municipality assumed that role. This did not have any effect on the role of Dar-es-salaam as the main point of business activities. The total area of Dar-es-salaam city is about 1350Km.^{2} covering a coastal zone of some 10 to 20Km. wide.

The morphological features of Dar-es-salaam can be summarised to be uneven with many streams, some of them have water only during rainy seasons. See contour map on Appendix (I). Normally for shallow aquifers the groundwater level goes parallel to the morphology of the land surface. Its land boundaries are formed by rivers and watersheds. Its territory is confined by river Mpiji in the North East, by the rivers Mzinga and Makosi in the centre, and by river Mbezi in the South; comprising the catchment area's of the rivers between them, such as those of the Nyakasamwe, Msimbazi, and Mnguria rivers (Haskoning, 1988).[7]

There is always linkage between groundwater and river water. During periods when the groundwater level is higher than the water level in the river (Fig.5.2), water will flow from the groundwater into the stream channel, and the river is considered effluent, draining the surrounding area. For the situation that the water level in the stream is higher than the groundwater level, water will flow from the river into the soil and the stream is considered influent (Fig.5.3). This phenomena explains the Dar-es-salaam situation. Most of the streams are effluent during dry season and influent during rainy season, therefore exchanging the water quality between the two waters; groundwater and surface water.

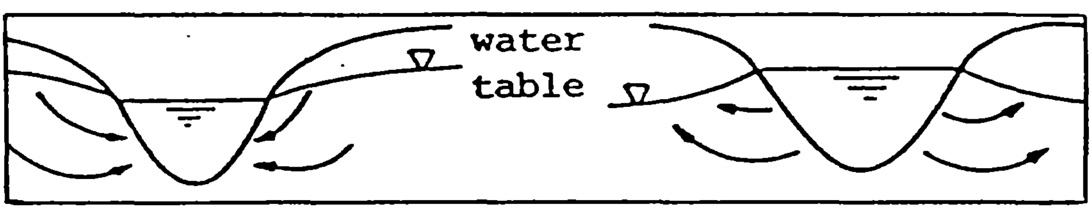


Fig.5.2 Effluent river

Fig.5.3 Influent river

5.2.2 Climate:

The climate of Dar-es -Salaam, a coastal city, is generally influenced by the south to south east monsoon from April to October and by the north east monsoon between November and March (Haskoning, 1988).[7]

Precipitation is concentrated mainly during the long rains-"masika" from March to May, and during the short rains-"vuli" in November and December. However, rainfall may also occur in the dry seasons. Most of the total rainfall occurs in short downpours. Total yearly precipitation may vary considerably.

The rainy seasons are also the most humid periods. Maximum humidity occurs around dawn, minimum in the afternoons. Precipitation surpasses potential evaporation only in 2 to 3 months of the year, leading to a local water surplus only during the long rains (in order of some 100mm. on a monthly basis). For the rest of the year the potential evaporation is greater than rainfall, exceeding on average the actual rainfall with a factor two, indicating the relatively dry conditions of the climate.

During the long rainy season almost all streams of Dar-es-salaam are normally flooded and some of the houses will be under water and as a result of this most pit latrines in these areas will be flooded. Mounded pits and those at a higher elevations will be safe from floods.

The groundwater table in Dar-es-salaam in an average can be said its depth varies between 0.0 m (in swampy areas) and 3.0 m, in elevated areas. The gap being narrowed during rainy seasons. See map on appendix (II).

The air temperature is closely related to the sea water temperature; cooler from May to August than during the rest of the year. Seasonal variations are slight. Temperature drop at night and may reach occasionally 13^0 C at dawn. Maximum temperature may reach 35^0C during afternoons (Haskoning, 1988).[7] Climate data are presented in appendix (III).

As from section 3.2.1, temperature is detrimental to the survival of pathogens, but as the latrines are covered and some are roofed, the temperatures in the latrines will be a little lower as compared to the air temperatures. This condition may give a better chance for the pathogens to survive longer as compared to a situation of surface application.

5.2.3 Soils:

Referring to chapter 2, it is clear that the soil structure determines the groundwater movement and transportation, adsorption, dispersion, diffusion, filtration and survival of the contaminants.

The performance of pit latrines depends primarily upon the ability of the soils of the unsaturated zone to accept and purify effluent; functions which may be in conflict under certain site conditions. Both functions relate, directly or indirectly, to the regime of groundwater movement which, in ,turn, is largely controlled by the hydraulic characteristics of the soil. It will be apparent that these hydraulic characteristics will determine the moisture content, flow path and residence time of pollutants (Lewis et al., 1980)[29].

As most of the aquifer parameters were not available in detail for this research, a number of them have been tentatively estimated from known data, or otherwise assumed in comparison to soil characteristics available in The Netherlands. The parameters are as listed below:-

Type of soil..................Medium sand
Porosity......................40%
Aquifer thickness.............25m
Permeability..................0.5-5m/day
Regional slopes...............0.01-1%

5.3 Social data:

In the social data Dar-es-salaam city population, administration, ward population, housing, water supply and sullage disposal are described. To restrict the subject; political, economical, and historical subjects as well as uses considering subjects like solid waste disposal are hardly mentioned here.

5.3.1 City population:

The 1988 census put the population at 1,360,850 indicating an average growth rate of 4.8 percent due to growth of the city population itself and due to migration (Tanzania population census, 1988). For the sake of future projections the average rate of 4.8 percent will be used for the forthcoming decade, this report will entirely be on this bases. See population projections on Table 5.1.

TABLE 5.1 POPULATION PROJECTIONS FOR DAR-ES-SALAAM CITY

YEAR	POPULATION
1988	1,361,000
1990	1,495,000
1991	1,567,000
1995	1,890,000
1998	2,175,000

5.3.2 Dar-es-salaam administration:

The area administered by the Dar-es-Salaam city council, is subdivided in three districts: Kinondoni, Ilala, and Temeke (Haskoning,1988)(7). Each district is subdivided into wards. See Appendix (IV) for Districts and wards in Dar-es-salaam.

5.3.3 Ward population:

Usually urban growth follows a logical path. Wards closest to the city centre fill fastest. Subsequent growth follows along main access roads with infilling as secondary roads are constructed. Dar-es-Salaam city is exactly following this broad pattern of growth.

The rate of construction of new dwellings has not increased to meet the higher growth rate, with the result that population densities and the number of families per dwelling have exceeded projections.

Accurate population figures per ward are available following the 1978 and 1988 population census. Comparison of the results of the two census (1978 and 1988) allows a calculation of possible current ward growth rates.

Appendix (V)-(VII) indicates the population of the wards in 1978 and 1988 with the associated growth rates. Wards are sorted according to district and distance from the city centre. The area of each ward is indicated along with the gross population density in 1988. It is noted that actual population densities can be very different from gross population densities due to the occurrence of open spaces, in rural wards, especially where villages are involved. Though from calculations the gross population density of Manzese is 102, but due to the reasons discussed above the figure of 400 will be adopted as the actual population density of the area.

5.3.4 Housing:

Most housing development in the city now takes place in unplanned areas, also termed as squatter areas. The quasi-total housing production in unplanned areas is carried out by individual families, largely through self-management. Formal housing production by state, employers, or private developers, only caters for a small portion of the total demand, and that mostly in the medium-high income range. Even in surveyed and planned areas(as per city plan), most housing has thus been developed by individual residents.

The authorities, however, have not been able to provide sufficient plots in planned areas for housing development over the past decade or more, which partly accounts for the rapid increase in squatters. Also due to financial constraints little building activity takes place. More people are crowding under the same roof using the same facilities including sanitation. As pit latrines are used as the sole means of sanitation, the increase in number of people using a single unit house, will mean more people per latrine and more request for water supply facilities. As a result an increase in hydraulic loading from each latrine. Hence, more contamination to the groundwater is expected.

5.3.5 Water supply:

Dar-es-Salaam city population gets their water supply from three major sources namely; Ruvu Juu and Ruvu Chini, both from Ruvu river, and Mtoni. Unmonitored shallow self-dug borehole wells are used to supplement the water supply for domestic use when the taps are dry.

At this juncture it should be made clear that the self hand-dug wells are an initiative of the population when all other means of getting clean and safe water are exhausted: A situation of "do or die". This situation occurs mostly in the squatter areas and the far ends of the distribution systems.The main cause of this can be explained as the old raising main, old distribution system, old pumps, shortage of fuel etc. of the water supply industry.

As the wells are dug in the residential areas where there is an extensive use of pit latrines, there is a danger of faecal contamination. See Table 5.2 for diseases caused by faecal pathogens in water.

TABLE 5.2 WATER-BORNE DISEASES CAUSED BY FAECAL PATHOGENS (modified Macoun,1987)[6]

	Pathogen	Disease
1.	Virus	
	Polioviruses....	Poliomyelitis; paralysis and other conditions
	Enchoviruses......................	Numerous conditions
	Coxsackieviruses..................	Numerous conditions
	Reoviruses........................	Numerous conditions
	Adenoviruses	Numerous conditions
	Hepatitis A virus	Infectious hepatitis
	Rotaviruses	Diarrhoea or gastroenteritis

2. Bacteria

Salmonella typhi	Typhoid fever
Salmonella paratyphi	Paratyphoid fever
other salmonellae	Food poisoning and other salmonellosis
Shigella	Bacillary dysentery
Vibrio cholerae	Cholera
Other vibrios	Diarrhoea
Pathogenic E.coli	Diarrhoea or gastroenteritis
Campylobacter	Diarrhoea

3. Protozoa

Entamoeba histolytica	Colonic ulceration, amoeba dysentery, and liver abscess.
Giardia lamblia	Diarrhoea and malabsorption
Balantidium coli	Mild diarrhoea and colonic ulceration

4. Helminths (worms)

Roundworm	Ascariasis
Pinworm	Enterobiasis
Hookworm	Hookworm
Threadworm	Strongy/oidiasis
Tapeworm	Taeniasis
Whipworm	Trichuriasis

The National Urban Water Authority (NUWA) is the sole governmental parastatal organisation responsible for the tapping, treating and distribution of the water in the city. Reportedly 90 percent of the population is served by public water supply. It is being assumed that this service level will increase by 0.2 percent per annum, resulting in a service level of 94.2 percent in the year 2009. Total water supply must therefore increase by 7.6 per annum (Haskoning, 1988).[7]

The number of house connections for public water supply in 1988 has been assessed at 60,000, covering a population of 420,000 (7 people per connected house). It is being assumed that the number of house connections will increase by 2.5 percent per annum (Haskoning, 1988).[7]
The difference between the total served population and the population served by house connections, is the population served with stand pipes and/or plot

taps. Street vendors also collect water from the stand pipes and sell to those who needs the service. At the moment water from a stand pipes is free of charge to anybody. Public water-points have been installed at a rate of about 1 to 50 plots. In many locations, these water points are no longer working due to vandalism and lack of maintenance.

The population relying on its own water supply in urban and rural areas of Dar-es-Salaam can be accounted for, being the difference between the total population and the served population.

Due to availability of piped water supply with a flat rate system of charging the water, there will be a tendency of people using more water more than necessary. More sullage (See further chapter 5.4.9) will then be produced which will likely end up in pit latrines; thus increasing the depth of seepage, and depending on the content of the sullage deeper groundwaters may be contaminated in this way.

5.4 Sanitation in Dar-es-salaam:

5.4.1 General:

Dar-es-Salaam is unusual and fortunate by comparison with many capital cities in Africa today in having relatively well-developed sanitation systems. It is therefore appropriate that it is leading the way forward with the implementation of an integrated sewerage and sanitation master plan where the goal is not, as so often elsewhere, the installation of sewerage system for the fortunate few, but rather, the general improvement of excreta and sullage disposal facilities for the whole community by the most technically and economically feasible means. This policy reflects not only Tanzanian socialist principles but also the acknowledgement that the public health hazard from poor excreta and sullage disposal practices can only be tackled effectively on a community-wide basis (Humpreys,1982).[10]

The central business area of Dar-es-Salaam and the high- and medium-density residential areas around the city centre are served by a sewerage system; this reaches 12.8 percent of the city's population. The sewage is discharged through an ocean outfall which is defective and short (Yhdego, 1989).[12] The large quantity of untreated sewage has generated a high biological pollution in Tanzania's coastal waters, and reports of fungal infections caught by people bathing along the polluted beaches of Dar-es-Salaam are wide spread (Bryreson, 1982).[13]

During the mid-1960s and the beginning of the 1970s waste stabilization ponds were constructed to treat wastes from semi-urban residential areas, industrial sites and institutions such as university of Dar-es-Salaam and army camps. There are now nine ponds in the city (Yhdego, 1989).[12] No data is available accounting for their pollution due to leakage contribution to the groundwater.

Nevertheless, in Dar-es-Salaam, pit latrines are the main form of sanitation in the major residential areas: the unplanned or squatter areas. An estimated 0.8 Million people live in this areas. The people in these areas make use of an estimated 80,000 pit latrines, each plot having its own latrine(s) with up to 20 users for each latrine (Humphrey, 1982).[10]

In this chapter some explanation will be given on latrine construction, and improvements in construction on uses concerning latrines, on filling and emptying, on problems encountered. Finally something about sullage, shallow hand-dug wells and waste disposal are described.

5.4.2 Pit latrine construction:

Conventional pit latrines are the most common, simple and cheap sanitation facility used in developing countries. In its simplest form, a pit latrine has three components: a pit, a squatting plate (or seat and riser) and foundation, and a superstructure. A typical arrangement is shown in Fig.5.4, the pit is simply a hand-dug hole in the ground into which excreta fall. Liquids soak into the ground and the solids accumulate in the pit. After a certain filling time, some emptying methods are employed (see section 5.4.7), normally when the pit is about two-thirds full. Conventional Pit latrines with squatting slabs often smell. If they smell they may not be used and thus cannot achieve any potential benefits in improving health.

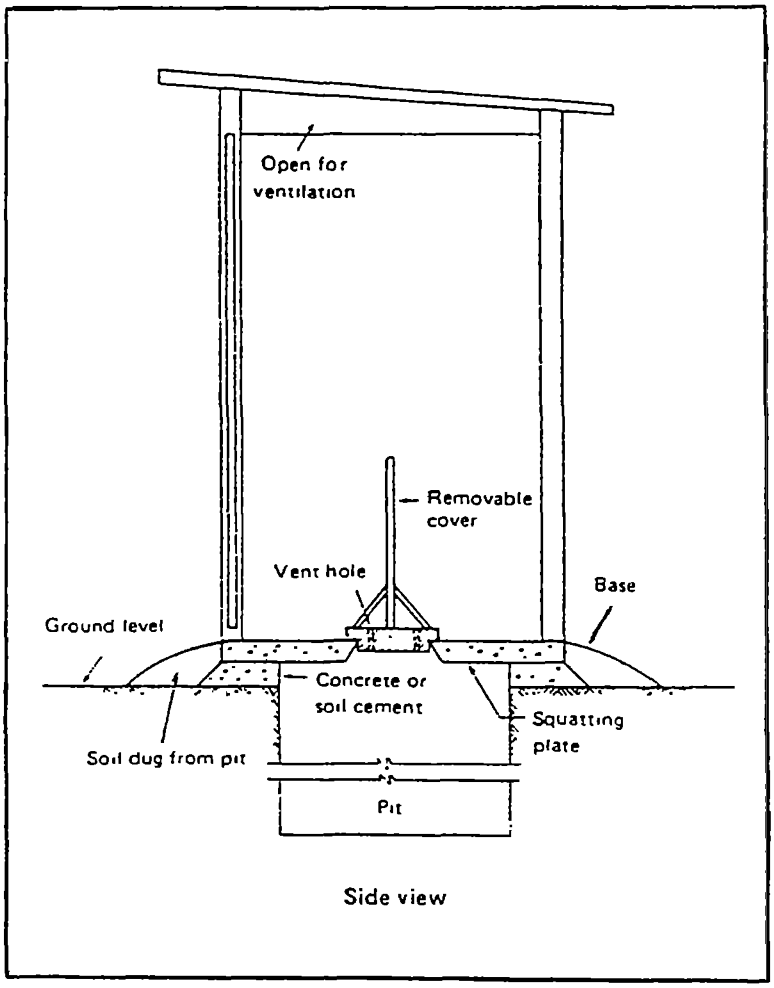


Fig. 5.4 Section of a Pit Latrine

Smell can be virtually eliminated by fitting a vent pipe to the pit. This pipe should be at least 100mm in diameter, (preferably 150-200mm), painted black, fitted on the sunny side of the latrine so it can heat and so create an updraught (Feachem et al., 1980)(15). Such latrines are called Ventilated Improved Pit (VIP) latrines (see Fig.5.5).

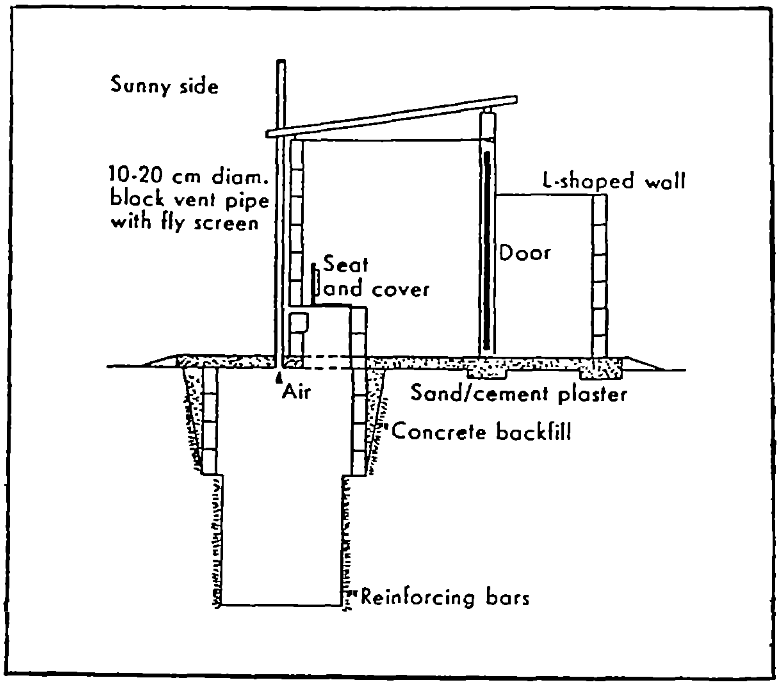


Fig. 5.5 VIP Latrine

The latrines are presently constructed by individual skilled labourers hired by house owners. The basic design and target cost is set by the house owners, whilst details of the design are left to the builder. About 40 percent of the houses in Dar-es-Salaam have separate male and female latrines (Humphrey, 1982)[10]. There is usually a single pit with the superstructure divided into two by a partition wall.

Latrines without lining on the sides as well as the bottom and those which are constructed with perforations (not water tight) leads to infiltration of faecal matter into permeable soils. Apart from the house-owners who are unable to afford the cost of lining, others are doing this purposely to encourage the infiltration into the ground so that the pit don't fill up quickly. This has the advantage of being less demanding for pit-emptying exercise; although after sometime the clogging effect (see section 3.4.1) will decrease the infiltration and increase the filling of the pit. The odds to this way of construction is that it pollutes the groundwater and during the rainy season water will infiltrate into the pit latrine causing it to flood/overflow.

The groundwater table, which is high in many parts of Dar-es-Salaam is an important factor in pit latrine design/construction. This high groundwater level condition influences the overtopping of the pits. Due to this factor quite a number of pit latrines in Dar-es-Salaam are mounded.

The mounding is provided because a certain amount of head is required inside the pit latrine to overcome the hydraulic resistance of both clogging mat (composed mainly of organic floc and bacterial Polysaccharide slimes) formed at the interface between pit and soil and of the soil itself. Saturated soils have the advantage of possessing a higher hydraulic conductivity than unsaturated ones , but under conditions where the water table reaches the surface during wet season, extra head will be required to disperse liquors.

5.4.3 Pit Latrine Use:

The most appropriate form of low cost sanitation system for Dar-es-Salaam is the pit latrine and it may be noted that they have been in use in the East African coast for the past 500-600 years. The technology is thus familiar and acceptable, and, in principle, technically appropriate (Humphreys, 1982).[10] But with the increasing population, faecal contamination increase via the pit latrine is a point of concern as it degrades the groundwater. Hence, improvements of pit latrine construction and emptying methods are necessary, as well as proper use.

Pit latrines are the simplest of all on-site disposal systems. Excreta fall into a hole in the ground and a new pit is dug or the pit is emptied when it is about two-thirds full.

About 80 percent of the Dar-es-salaam population who live non-sewered areas (1,255,850) rely on on-site sanitary facilities; pit latrines or septic tanks are being used by 1,004,680 people. The remaining population lack elementary sanitary facilities.

5.4.4 Cleaning and waste disposal:

Normally latrines are cleaned once a day by the women of the house by using water and broom. Soap and disinfectants are rarely used due to economic situation but also do not appear to be very necessary. On top of that it is better not used to safe guard groundwater from contamination. Women in Dar-es-Salaam feel responsible for the task of cleaning; It is part of their roles as housewives to ensure that the house, the latrine, and the campus (house and its compound) etc. are kept in good order. They feel proud if everything is clean, and they feel ashamed if, for example, the latrine is in a messy and smells bad, as this reflects on their identity and capacity of being a housewife (WASTE , 1989)[8].

Most people are aware that it is unwise to put refuse into the pit because this fills their pit quickly. The refuse can also stuck the vacuum tankers when emptying the latrine with a hosepipe. Garbage can include serious contaminating materials for the groundwater such as heavy metals etc. Still many of the pits in Dar-es-salaam have at least some cans, bottles, rags etc. inside. This seems inevitable and any emptying service must be prepared to contend with this materials and educate the people.

It appears that both paraffin and salt are sometimes put under use for maintenance of latrine hygiene. Paraffin is mostly used as disinfectant (16% of the surveyed latrines) and salt against smell (30% of the surveyed latrines) (WASTE, 1989)[8]. This may pollute the groundwater.

Children generally start using the latrine at the age of 4 years. Over 70 percent of the children are using the latrine by the end their fourth year. This implies a fairly high awareness amongst mothers of the importance of latrine use, and that the squatting slabs (see Fig 5.4) they are presently used, are satisfactory for children. When children defecate in the yard it is picked-up and thrown with papers into the latrine.

Normally rubbish is burned, buried, put in open-pit (not necessarily latrine) or put in drain. Mensuration cloths are washed or burned, not thrown into latrine.

Majority of the people, about 84 percent (Buguruni experience) (Gauff, 1980)[14] who live in the squatter areas of Dar-es-Salaam, where pit latrines are widely used, use water for anal cleansing. Few use toilet papers and the rest use all kinds of paper including magazines/news papers etc. The practice of using water for anal cleansing, makes the pit to be wet a condition which is favourable for the infiltration of faecal matter into the soil.

As a conclusion it can be said that the influence of pit latrine use on groundwater pollution is effected by the quantity of pit latrines, the type of latrines (how much leakage is going to the ground), the retention time of the material before the pit is full and emptied and the way of disposal (new pit in the same yard), see section 5.4.7. Also the use of anal cleansing and cleaning materials and disposal of solid wastes in the pit.

5.4.5 Filling of pits:

As the groundwater level in Dar-es-Salaam is very high, a number of the pits will be full during rainy season because of exfiltration of groundwater into the pit latrines. This condition will easy-off during dry season. But, as described by Winbland and Kilama, (1985)[25] a periodic increase in groundwater level may have a beneficial effects on a pit. The pit walls are declogged (see further in section 3.4.1) and the absorptive capacity of the soil is restored.

With the very large pit capacity, 1 metres wide, 2 metres long and 3-4 metres deep (Winblad and Kilama, 1985)[25] which seems to be convectional in Dar-es-Salaam the useful life of a pit may be very long. There are many pits which are more than 15 years old and had not been emptied during that time. Local practice is favourable for minimum solids accumulation because water is invariably used for anal cleansing and bathing, wastewater is often added maintaining the excreta in a wet condition (Humphrey, 1982).[18]

About 60 percent of latrines in Dar-es-salaam are used as disposal for bathing water and as a bathing room, since they provide privacy and a cement or well rammed earth floor (Haskoning, 1988).[7] This practice is beneficial in so far as it ensures regular cleaning of the squatting slab with water. Bathing water disposal within the pit has always been encouraged in Dar-es-salaam, since a wetter sludge has higher rate of volume reduction thus it will reduce the rate of sludge accumulation. If there is a separate shower, bathing water will be directed to the latrine through a pipe. This is not the case with some of the house-owners who believe that any addition of water to their pit latrines will fill them quickly as such it is uncalled for.

If a pit is wet, the rate of accumulation of faecal solids is 40 litres per adult per year; while if is dry, the rate increases to 60 litres per adult per year (Wagner and Lanoix, 1958).[1] This is because the wet condition is favourable for the exfiltration of faecal matter from the pits. Some authors (Morgan and Mara, 1982) claim that pit latrines should be wet and even recommended that people use VIP-type latrines as wash/bath rooms.

No data are available on the effects of sludge compaction in pit latrines but experience indicates that with the passage of time the accumulated sludge becomes more difficult to remove from pits using a vacuum-tanker.

5.4.6 Excreta generation per capita:

Excreta consist of faeces (solid matter) and urine (liquid matter) (Winblad and Kilama, 1985).[25] Volumes, composition and consistency of faeces depend on such factors as diet, climate, and state of health. Individual wet faecal weights vary from under 20 grams daily to 1.5 Kilograms daily. People in developing countries have average wet faecal weights of 130-520 grams daily (Feachem et al., 1980);[15] Dar-es-salaam population falls under this category. Water content which normally varies with the faecal weight will be between 75-90 percent in this case.

Most adults at an average produce between 1.0 and 1.3 Kilograms of urine per day, but this depends on how much they drink and sweat, which in turn depends on diet, occupation, climate, and other factors (Feachem et al., 1980).[15]

In order to get an idea of the excreta produced in the squatter areas of Dar-es-salaam, a faecal weight of 250 grams per capita daily with a water content of 80 percent is assumed. Further assume a urine production of 1.2 litres per capita per day and 0.35 litre of water used for anal cleansing. Then the excreta of one individual will contain 50 grams of solids in 1.8 litres of excreta, in other words, a solids content of 2.8 percent. If paper is used for anal cleansing, solids content may go up to 5 percent. Refer to section 5.4.9) for the amount of sullage produced per capita per day.

5.4.7 Emptying of pit latrine in Dar-es-salaam:

Various alternative practices for dealing with filled pits are being employed in Dar-es-Salaam for years up-to now. The different methods have different impact on the groundwater contamination. These includes the following methods:-

a) traditional emptying methods,
b) addition of locally readily available coagulants,
c) allowing latrine contents to overflow,
d) building a new pit,
e) municipal vacuum tanker service, and
f) newly introduced **MAPET** (MAnual Pit Emptying Technology) service.

a) Traditional emptying methods:

For years people in the unplanned areas in Dar-es-Salaam have resorted to other solutions in coping with their full and overflowing pit latrines. They hire casual pit emptier who empty the pits by hand and bury the sludge in pits dug in the compound. Two traditional ways of emptying are applied; the digging method and the flushing method, in both methods extra pit is dug which increases the chance of groundwater contamination.

i) Digging method:

In this method the traditional emptier break away the squatting slab and dig out (scoop out with a bucket, depending on the water content) the contents and burry them in pits dug in the compound. See Fig. (5.6) .

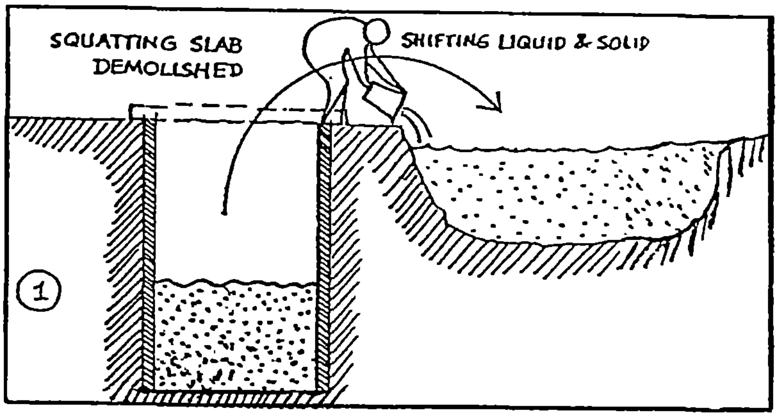


Fig.5.6 Digging method (WASTE, 1989)[8]

ii) **Flushing method:**

In this method an adjacent pit deeper than the latrine pit is dug. The sludge is then thoroughly mixed with water and then by drilling a hole through the wall of the full latrine pit, the contents are flushed into the freshly dug pit. See Fig.(5.7) below:-

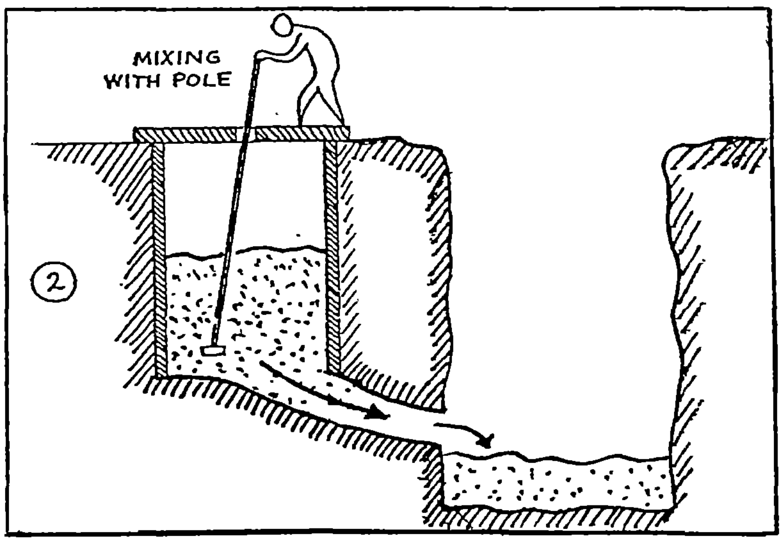


Fig.5.7 Flushing Method (WASTE, 1989)[8]

b) Addition of locally readily available coagulants:

Salt and ashes (5-10 Kg.) are used and may cause some compaction of solids by an electrolytic destabilisation and flocculation of the organic solids. This tends in the long run to make solids removal more difficult since the solids then become less tractable when they do have to be removed and the salinity reduces the permeability of the surrounding soil. This method makes longer storage possible which has the effect on groundwater as described in the introduction. The coagulants added may also contribute to the pollution of the groundwater.

c) Allowing latrine contents to overflow:

Latrine walls are often built slightly above ground level (even if not fully mounded) and can thus be breached via a shallow channel to a ditch or water course. This is often adopted as a temporary expedient but becomes permanent as the months slip by. As the wastewater will be flowing through open channels it will infiltrate into the soil and may pollute the shallow groundwaters.

d) Building a new pit latrine:

The construction of new pits to replace full ones is common in the rural areas and the newer squatter settlements in the urban area, but space constraints in the dense, established areas make this difficult. Even if space is there it is not a favourable alternative economically, as it will require a new pit lining and superstructure in case of permanent ones. The influence on contamination depends on the lining of the pit (see section 5.4.2). If the linings are closed and the pit closed, the faecal matter will decompose and can be used after 2 years as fertilizer.

e) Municipal vacuum-tanker services:

To prevent on-site dumping a relatively cheap municipal service is set up. The Dar-es-salaam city council, through Dar-es-salaam sewerage and sanitation department (DSSD) and the health department of the council, runs two fleets at present of pit latrine emptying service with vacuum-tankers. They dump the contents in controlled oxidation ponds and into sea overfall. Also private vacuum-tankers exist, catering mainly for their private institutions. Due to lack of proper dumping place for them (private), they sometimes dump along the road e.g. in the swamps of Buguruni. This causes contamination of the environment and indirectly of the groundwater.

f) Newly introduced MAPET service:

Since 1988 a combined project of DSSD, private emptier and a Dutch Consultant Company (WASTE), known as MAnual Pit Emptying Technology (MAPET) is under progress in Dar-es-salaam. The aim of the project is to develop a pit emptying service for the unplanned areas so as to improve the living conditions for the customers and the emptier. Two routines for sludge disposal have been proposed under the MAPET project:-

i) **On-Site Disposal:**

This is the traditional way of disposal. Digging a pit in the yard of the customer in which the sludge is buried. On-site disposal in Dar-es-Salaam is acceptable only in areas with a low groundwater table (WASTE,1989)[8]. The method is not favourable as it tends to spread the contaminant over a wider area (See Fig.5.8).

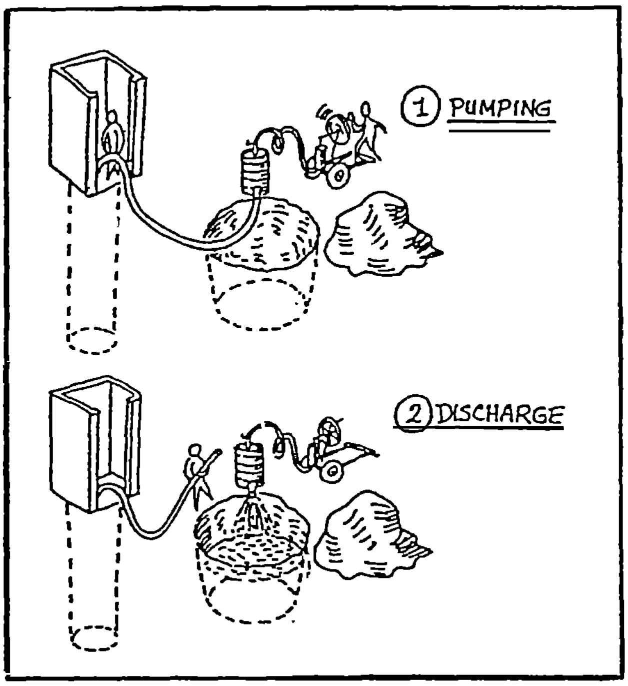


Fig.5.8 On-site disposal (WASTE, 1989)[8]

ii) **Disposal in transfer stations:**

In areas with a high groundwater table the sludge has to be transported from latrine (by 400 litres pushcart) to a transfer station. Transfer stations are concrete vaults of about 10,000 litres constructed near feeder roads, which can be reached by vacuum tankers. See Fig.5.9. These transfer-stations act as temporary storage for sludge. Transfer-stations will be emptied by DSSD vacuum tankers that dispose the sludge in the sewage treatment ponds (WASTE, 1989).[8] In case of no leakages in the stations and ponds and high efficient DSSD vacuum tankers, this method can cause no extra groundwater contamination.

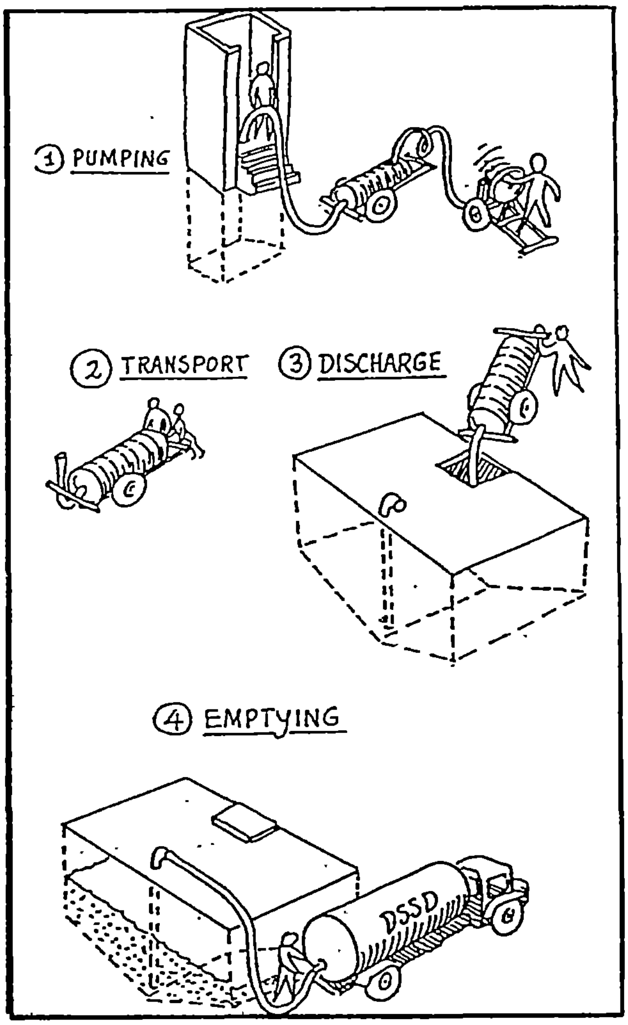


Fig.5.9 Disposal in Transfer Stations

So, considering the different emptying methods on the impact on groundwater pollution the less contaminating are the municipal vacuum-tankers, "Mapet"(ii) or building a new pit with a water-tight lining.

5.4.8 Problems experienced with existing pit latrine:

Problems demanding attention on groundwater pollution which are being experienced with the existing latrines in Dar-es-salaam are as follows:-

a) lack of exfiltration from pits => overflowing due to quick filling.

b) oversize pits, which because of their large size (2.5m X 1m X 3-4m), store sludge for a long time and therefore more time for the contaminants to infiltrate into the groundwater but also after sometime there will be less infiltration because of sludge thickening and clogging effect.

c) different access for pit emptying, and

d) inadequate superstructures (Humphrey, 1982).[10]

e) overflowing pit latrines => the over-flowing material will leach into the groundwater (WASTE consultants, 1989).[8]

5.4.9 Sullage disposal:

Sullage (grey water), as used here, refers to all domestic wastewaters not containing excreta. It is the wastewater from baths, sinks, and the like which may be expected to contain considerably fewer pathogenic microorganisms than sewage. The volume of sullage generated normally depends upon water consumption. The problem of sullage disposal, therefore is most prominent in those households not connected to sewerage or septic tank soakaway systems i.e. those using low-cost sanitation system. The volumes, in case of pit latrine use will be lower in those households obtaining water from public standpipes than in those with a single water tap on site (Njau, 1980).[9] The contamination of groundwater will mainly depend on the volume and disposal method applied. In broad terms there are six sullage disposal methods used in Dar-es-Salaam:-

i) disposal on the ground within the house compound
ii) disposal on the ground outside the compound of the house
iii) On-site disposal, into ground soakaway pits
iv) On-site disposal into pit latrines
v) disposal into open drains, and
vi) disposal into covered drains or sewers (Njau,1980)[9]

Sullage disposal on the ground creates nuisance and promotes favourable conditions for mosquito breeding. While disposal of sullage into pit latrines through a "karo" (washing platform connected to the pit by a pipe) , increases the groundwater contamination. Disposal of sullage into water tight closed drains / sewers presents no health problems but is always expensive and requires a lot of organization for operation and maintenance and therefore so far did not appear to be an appropriate alternative for the unplanned areas of Dar-es-salaam. Typical volumes of sullage water products as per different sources as given by Cairncross, (1988) ,are:-

Community wells and hand pump	10 L/ person/day
Communal stand post	15 L/ person/day
household wells, yard tap	30-50 L/ person/day
multiple-tap private connections	50-300 L/ person/day

5.4.10 Care of the shallow wells:

In Dar-es-salaam, the unmonitored self-dug shallow wells are normally taken care by the owners (can be one person or a community), though anybody is allowed to draw water from them. Much interest will be invested on these wells when the piped water supply is inadequate. During the periods when there is enough supply these wells are abandoned, and nobody takes care of them. In the worst cases the wells are being used as garbage pits. This will be a direct contamination of the groundwater as well as the water which will be extracted from these wells when the problem of shortage of water supply resurfaces. Water drawn from these wells is used without any treatment.

6.4.11 Domestic wastewater generation per capita:

For the assessment of daily domestic pollution in Dar-es-salaam the following per capita generation data have been used, Table 5.3.

Table 5.3 DOMESTIC WASTEWATER GENERATION PER CAPITA IN DAR-ES-SALAAM

	Range	Values adapted for Dar-es-salaam	Units
BOD_5	30-60	(40)	g/cap/day
COD	70-150	(100)	g/cap/day
Tot. Nitrogen	8- 12	(8)	g/cap/day
Tot. Phosphate	1- 3	(1)	g/cap/day
Faecal coliform Number/cap/day	$2x10^{10}$	$2x10^{10}$	

As already discussed in section (5.4.6)., that volumes, composition, and consistency of faeces depends on such factors as diet, climate and state of health. The above figures have been established for industrialised countries, out of them estimates put in brackets are estimated to fit with Dar-es-salaam conditions. Using the population census of 1988 (4.8 percent growth per annum) the scenario leads to the following projections for the domestic pollution load for Dar-es-salaam, Table 5.4.

Table 5.4 PREDICTED DISTRIBUTION LOADS OF DAR-ES-SALAAM

PRESENT	SANITATION	SYSTEMS	1988	1993	1998
Total	Population		1,360,850	1,721,100	2,175,000
Daily pollution	Domestic per capita				
$-BOD_5$	40g/day	(Kg.)	54,434	68,840	87,000
-COD	100g/day	(Kg.)	1,360,850	172,100	217,500
-Tot.N	8g/day	(Kg.)	10,887	13,768	17,400

-Tot.P	1g/day	(Kg.)	1,361	1,721	2,175
_Faecal coli	X10[10]	Number	2,721,700	3,442,000	4,350,000

5.5 Concluding remarks:

1) The groundwater table is very high in Dar-es-Salaam. Its depth varies between 0.0 m and 3.0m in average.
2) There is a linkage between the Dar-es-Salaam groundwater and her surrounding streams. Most of the streams are effluent during dry season and influent during rainy season, therefore, exchanging water quality between the two waters; groundwater and stream water.
3) From the 1988 census, the population growth rate of the City of Dar- es-Salaam was established to be 4.8 percent.
4) Aquifer parameters which are going to be used in this Thesis report are as stated earlier in section 5.2.3 and listed again below:-

   Type of soil.................Medium Sand
   Porosity....................40%
   Aquifer thickness...........25m
   Permeability................0.5-5m/day
   Regional slopes.............0.01-1%
5) Due to occurrence of open spaces in rural and semi-urban wards, especially where villages and squatters are involved, actual population density will be different from gross population density. The gross population density of Manzese is 102, but the actual population density in built areas is higher. As an estimate on the basis of the above discussed reason a figure of 400 will be used in this report.
6) As little building activity takes place in Dar-es-Salaam, more people are crowding under one roof using the same pit latrine(s) and more requests for water facilities. As a result more contamination of the groundwater is expected via the pit latrines.
7) As the unmonitored self hand-dug shallow wells are constructed in the residential areas where there is an extensive use of pit latrines, danger of faecal contamination of the well water through the latrine is expected.

8) Pit latrines which do not have lining on any of its parts leads to accelerated infiltration of faecal matter into the permeable soils.
9) Saturated soils have the advantage of possessing a higher hydraulic conductivity than unsaturated ones. But under conditions where the water table reaches the surface during wet season, extra head will be required to dispose off liquors.
10) Emptying practices of pit latrines if properly chosen i.e. water tight oxidation ponds, can minimise the problem of groundwater contamination.
11) Finally it can be said that the influence of pit latrine use on groundwater pollution is effected by the quantity of pit latrines, the type of latrines (how much leakage is going to the ground), the retention time of material before the pit is full and emptied and the way of disposal (new pit in the same yard, illegal dumping or legal controlled pond). Also, effects on groundwater pollution may be due to cleansing methods and solid waste disposal into the pits. Further research for this statement is necessary.

6.0 "MFLOP Version 2.0" AS A PREDICTIVE GROUNDWATER MODEL:

6.1 Introduction:

Originally the FLOP (Flow Pattern) programs were developed by Dr. Ir. C. Van den Akker and were run on mini and main-frame computer systems. In 1984 Prof. A. Verruijt wrote a simple MICROFLOP program in BASIC for Commodore-64 for teaching purposes. In 1986 this program was made suitable for interactive use on MS-DOS microcomputers (GW-BASIC) by Mr. C.J. Hemker at the request of I.H.E.(Delft). The present version, MFLOP version 2.0 (in Turbo Pascal by now) is the most recent extension.

The extension of the various versions of microcomputer FLOP-programs exclusively concern the type of computer, the speed of calculation, the ease of operation and the like. The most important improvement in MFLOP version 2.0 compared to version 1.0 is the maximum number of streamlines which has been extended from 100 to 250.

All microcomputer versions are concerned with a solution to the same problem, viz. drawing streamlines in case of horizontal two-dimensional groundwater flow in a homogeneous and isotropic porous medium. In addition to one or more (not more than 50) discharge and recharge wells, a regional (uniform) groundwater flow can also be taken into account.

6.2 Background of the 'FLOP' model:

The 'FLOP' (FLOw Pattern) computer programme by Van den Akker, (1982) [4] is making use of the following two major velocity equations for m wells:-

$$\frac{dx}{dt} = V_x = - \sum_{i=1}^{m} \frac{Q_i}{2\pi\bar{n}H} \frac{(x-x_i)}{(x-x_i)^2+(y-y_i)^2} \qquad (23)$$

$$\frac{dy}{dt} = V_y = -\sum_{i=1}^{m} \frac{Q_i}{2\pi nH} \frac{(y-y_i)}{(x-x_i)^2+(y-y_i)^2}$$

(24)

Where V_x = velocity in x-direction

V_y = velocity in y-direction

n = aquifer porosity

H = aquifer thickness

Q_i = pumping rate

m = number of wells

x_i and y_i are coordinates of the wells

x and y are the coordinates of the point where velocity is being computed.

If natural groundwater flow is also present the equation (23) and (24) becomes:-

$$V_x = -\sum_{i=1}^{m} \left(\frac{Q_i}{2\pi nH} \frac{(x-x_i)}{(x-x_i)^2+(y-y_i)^2}\right) + \frac{q_{nat.x}}{n} \quad (25)$$

$$V_y = -\sum_{i=1}^{m} \left(\frac{Q_i}{2\pi nH} \frac{(y-y_i)}{(x-x_i)^2+(y-y_i)^2}\right) + \frac{q_{nat.y}}{n} \quad (26)$$

Where $q_{nat.x}$ and $q_{nat.y}$ are the components of the natural groundwater flow in respectively x and y direction.

At each point P(x,y), the velocities can be computed. From this, also the movement of a water particle in a time step Δt can be calculated, giving the new position of the that particle. Then again the velocities are determined. Repeating the calculations, results in the flow line and the summation of the time steps gives the travel times.

With the help of the 'FLOP' computer program it is possible to calculate the stream lines and travel times of water particles in a confined aquifer with a number of sources and sinks and with a natural groundwater flow. The method uses the well-known Runge-Kutta integration scheme (Van den Akker, 1982). In the case of steady flow in a confined aquifer the path lines of water particles are identical to the stream lines.

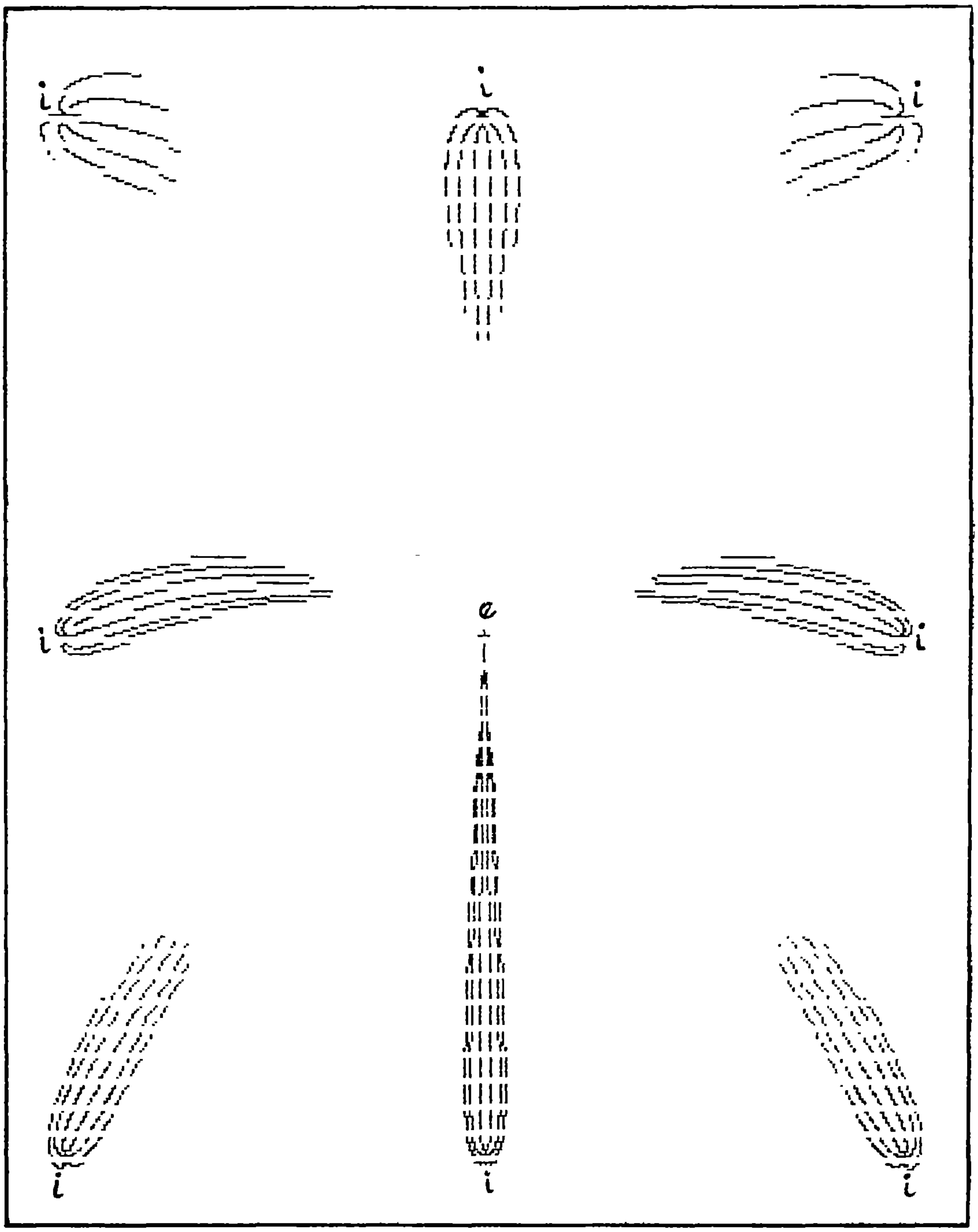


Fig. 6.1 Flow lines from eight (8) infiltration wells to an extraction well

6.3 Assumptions in the Model:

In order to simplify the computations and to reduce the data input requirement for the software, the following assumptions are used:-

i) Steady state flow,
ii) homogeneous and isotropic porous medium,
iii) confined groundwater,
iv) single aquifer of constant thickness,
v) fully penetrating wells.

In principle only a very simple situation can be modelled because of the large number of assumptions stated above.

In practice, however, the streamline pattern in the neighbourhood of a well-field is not susceptible to slight departures from the supposed ideal situation. The most important uncertain factor is often the heterogeneity and it is difficult to obtain enough information about this factor in particular. Therefore the simple analytical approach that has been applied can still be used in many cases as the most suitable method to determine the flow pattern.

As the distance from the well-field increases, the modelled pattern becomes less reliable, however, especially when vertical flow components (seepage, infiltration) play a part. Consequently the original FLOP-programs have been extended to calculate situations with semi-confined groundwater, phreatic aquifers and/or multilayer systems.

6.4 Use of the model for Dar-es-salaam (Manzese) case study:

6.4.1 Sensitivity of the Model:

Before doing the actual modelling of the case study area it is important to check the sensitivity of the model and know precisely the sensitive parameters which need much attention.

The sensitivity tests were based on the following parameters:-

i) aquifer thickness
ii) aquifer porosity
iii) well discharges
iv) regional slopes
v) groundwater flow components (x and y-components)
vi) well distances (x and y-coordinates), and
vii) Permeability.

In order to check the sensitivity of the model a simple case of eight houses was assumed, each having its own pit latrine (infiltration wells). The houses have been placed surrounding an extraction well. Each house is having six rooms and in each room lives a family of average 4.2 people (Anonymous, 1988).[11] Consumption of water per capita per day is taken to be 50 litres in the squatter areas.

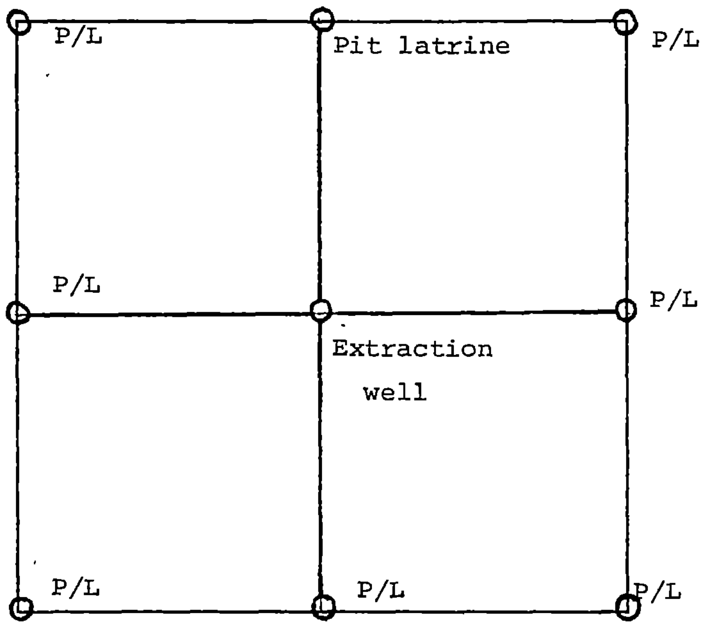


Fig. 6.2 Wells arrangement in the sensitivity test

Discharge calculations:

From the data which has been dealt with in the preceding chapters and sections the following calculations can be made:-

-Total number of people using a well = 8 X 6 X 4.2 = 201.6 (say 200)

-Total amount of water extracted from the well =200 X 50=10,000litres ($10m^3$/day)

-Total number of people using a latrine = 6 X 4.2 = 25.2 (say 25)

From section 5.4.6., it is reported that an adult produces 1.8 litres of excreta per day and about 10 litres of sullage. This gives :-

-Total waste produced = 11.8 X 25 = 295 litres/day = 0.295 m^3/day.

It has been stated in section 5.4.5 that if a pit is wet, the rate of accumulation of faeces is 40 litres per adult per year.

Thus amount accumulated in the pit per day = (40 X 25)/(365 X 1000)= 0.0027 m^3/d

Therefore, amount of sewage which will infiltrate into the ground will be equal to:- 0.295 - 0.0027 = 0.2923 m^3/da (say 0.29 m^3/day).

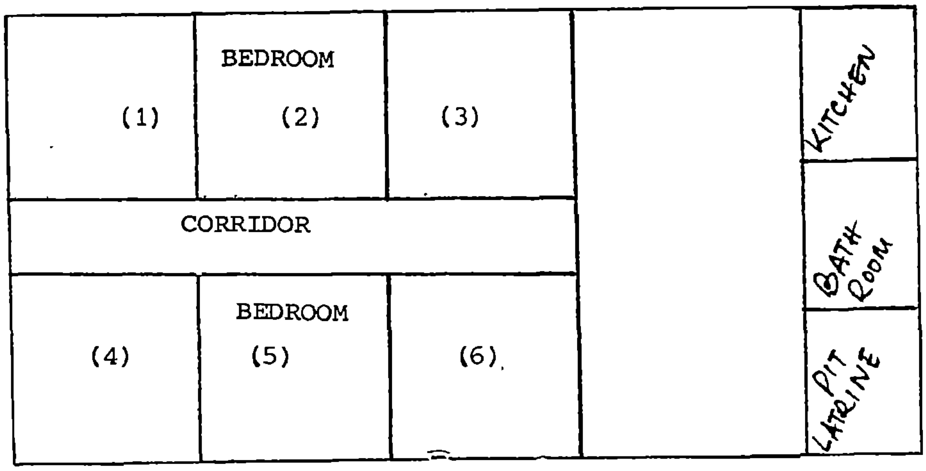


Fig.6.3 Plan of a six bedroomed house found in Manzese

Porosity changes:

Different porosity values (10%, 20%, 30%, 35%, 40%, and 45%) were used in the model. Flow time values taken by the first streamline to reach the well were recorded (see Appendix VIII). A graph of flow time against porosity was plotted (see Fig. 6.4).

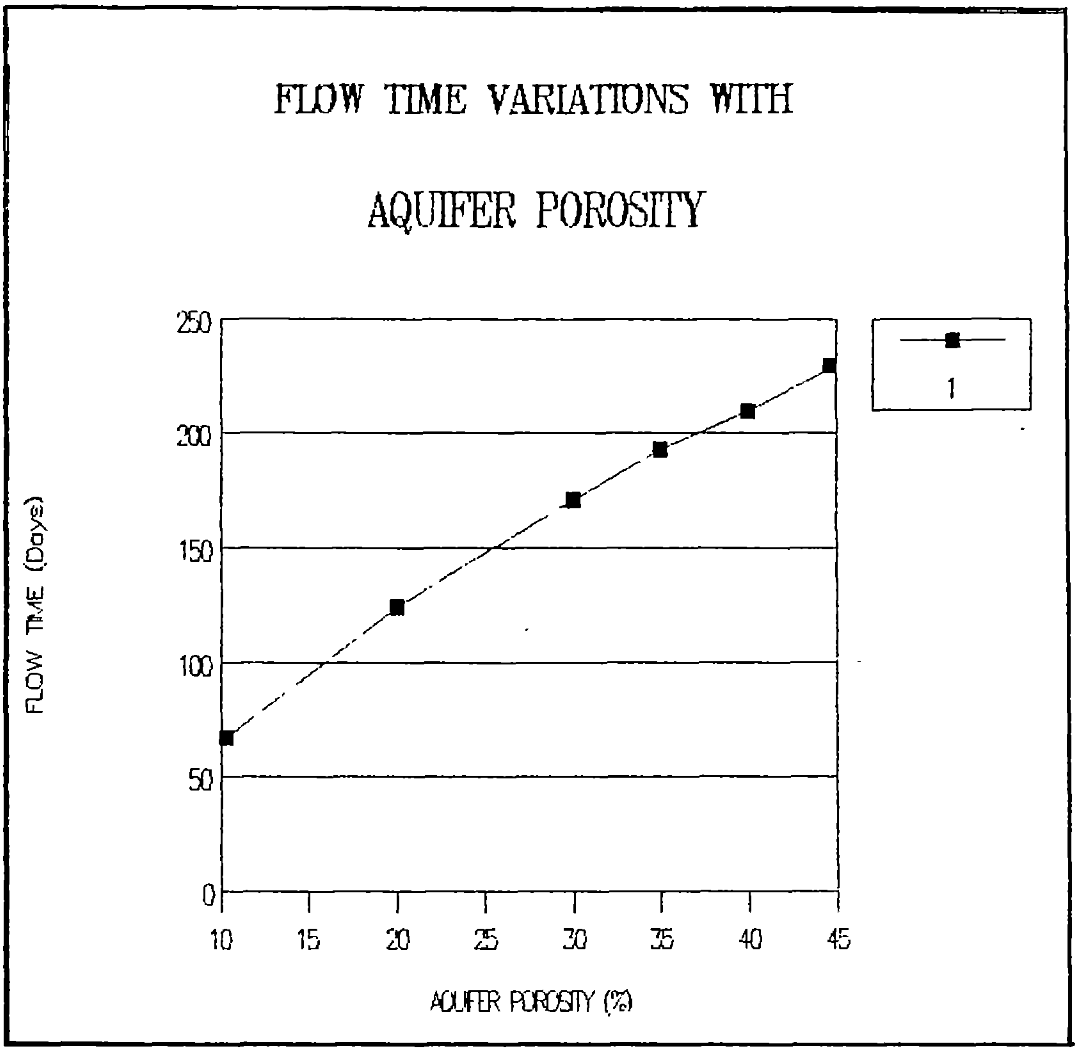


Fig.6.4 Flow time variations with aquifer porosity

The curve shows that flow time increases as aquifer porosity increases. The curve is almost a straight line indicating nearly same degree of sensitivity; for the tested range porosity does not seem to be a very sensitive parameter to pay much attention to in the modelling.

Aquifer thickness:

Different aquifer thicknesses (10m, 15m, 20m, 25m, 30m, 35m, and 40m) were fed into the model. Flow time values taken by the first streamlines to reach the well were recorded (see Appendix IX). A graph of flow time against aquifer thickness was plotted (see Fig. 6.5).

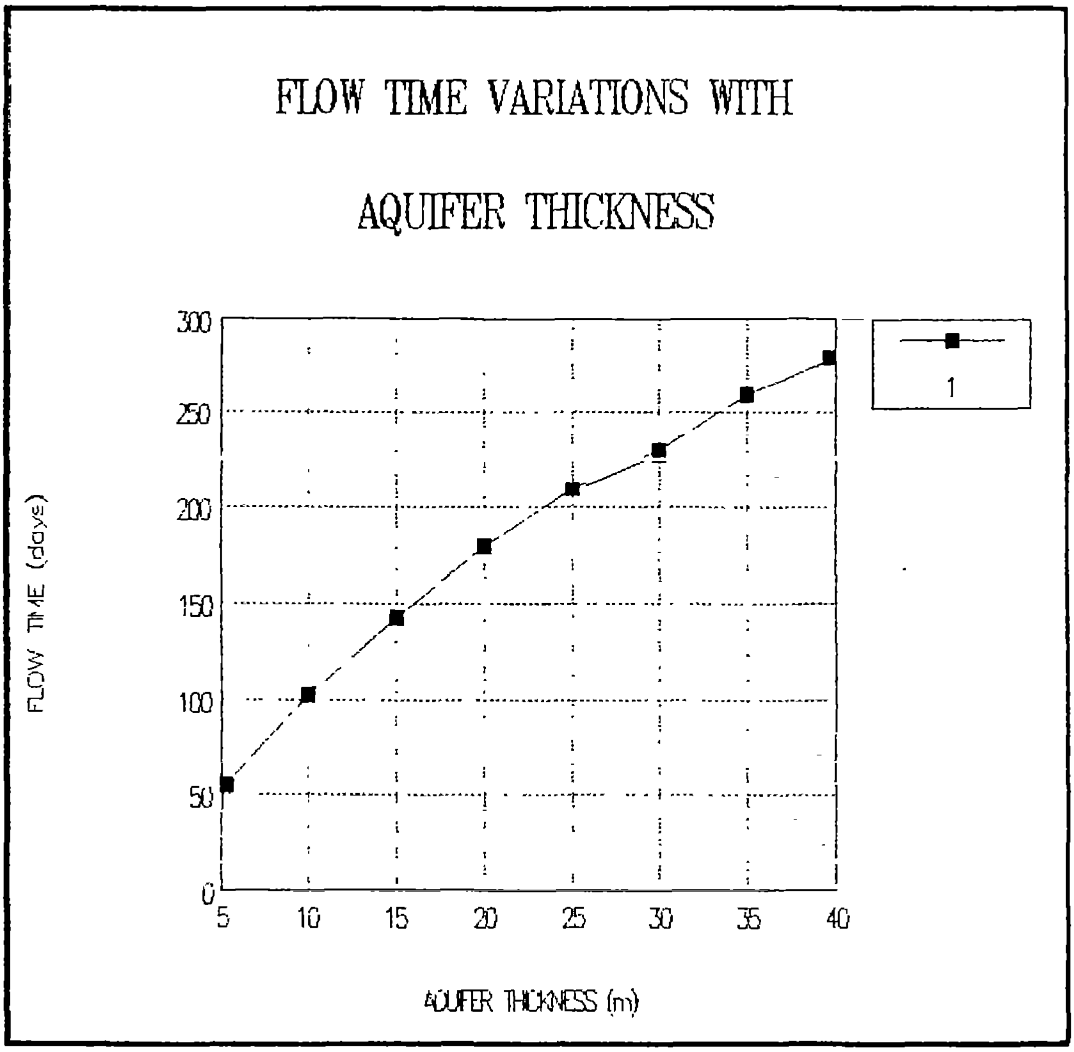


Fig. 6.5 Flow time variations with aquifer thickness

The curve shows a trend which can be concluded that the model is more sensitive at low aquifer thicknesses (less than 20m); at high aquifer thicknesses the curve flattens showing less sensitivity. To my opinion aquifer thickness is a sensitive parameter to pay attention to in the modelling.

Distance between wells:

Same procedure as above was used only that in this case distance between the wells was the variable. The pit latrines are being considered as infiltration wells (negative discharge) and the wells for water supply as extraction wells. Values of 5m, 10m, 15m, and 20m were introduced. See Appendix X, for the streamlines and travel time. A graph of flow time against distance between wells was plotted (see Fig. 6.6).

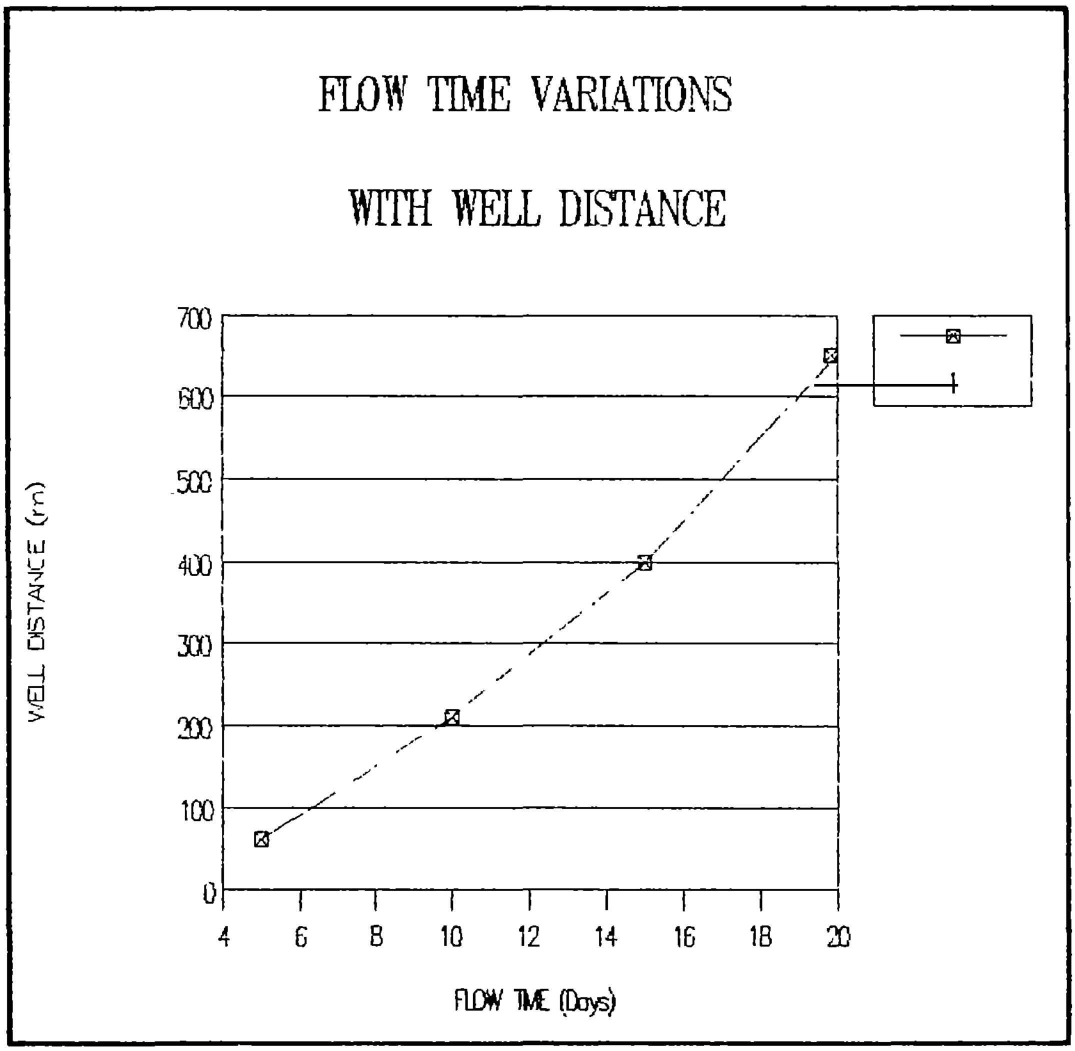


Fig. 6.6. Flow time variations with distance between wells

In general flow time increases as the distance between wells increases, the trend showed that the model is very sensitive from well distance of 15m and more as compared to short distances.

Well discharges:

Seven well discharges were investigated (0, 1, 3, 5, 10, 15 and 20m^3/day) in the model. Flow time values were taken for the first streamline to reach the well (see Appendix XI). Flow times were plotted against well discharges (see Fig.6.7).

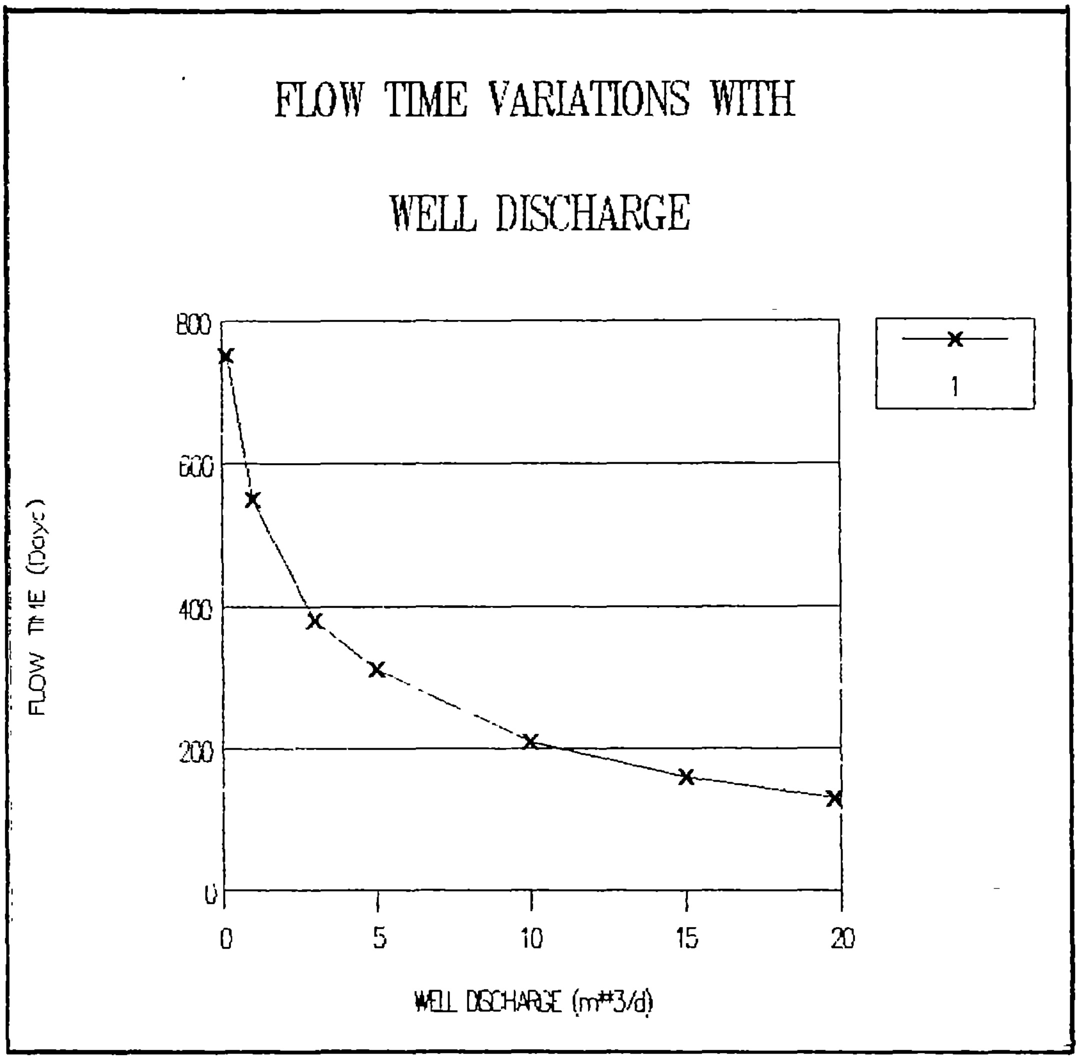


Fig. 6.7. Flow time variations with extraction well discharges

From the plot well discharge shows to be a very sensitive parameter to be considered in the modelling. Flow time decreases as the extraction well discharge increases. The decrease is fast at low discharges up-to $5m^3$/day after that the curve flattens.

Regional groundwater velocities:

The regional groundwater velocities were calculated using the formula V = KI/n as defined in section 2.2.2 and three different permeabilities (K= 0.5, 1, and 5m/day). Six regional groundwater velocities (0.000125, 0.00025, 0.00125, 0.0025, 0.0125, 0.025, and 0.125m/day) were tried in the model. Flow time values were taken for the first streamline to reach the well (see Appendix XII). A curve of flow time variations with the regional velocities was plotted

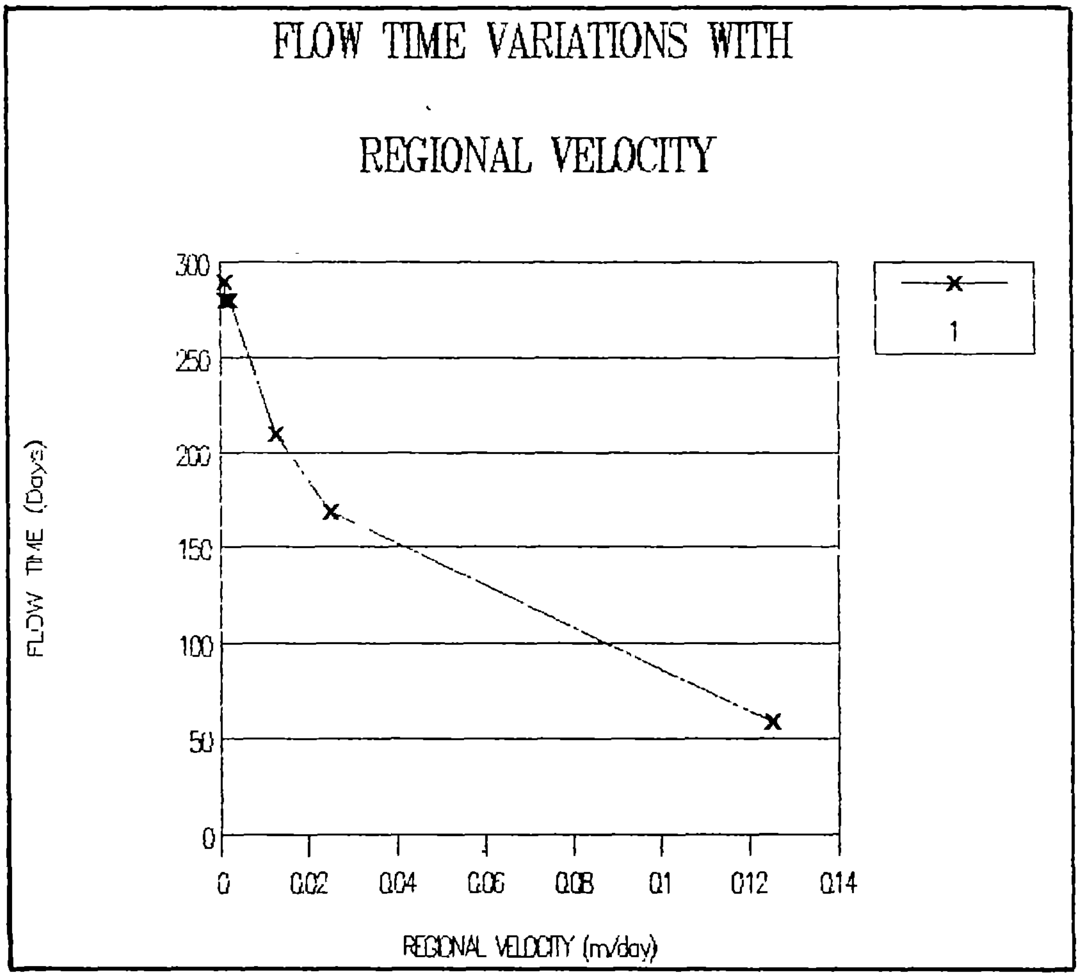


Fig.6.8 Flow time variations with regional velocities

This also shows to be a sensitive parameter which needs attention in the modelling exercise. The model is very sensitive at low regional velocities up-to 0.025m/day, thereafter the curve flattens showing little change in flow time with increase in regional velocity.

Regional slopes:

A comparison of groundwater velocity changes with regional slopes at different soil permeabilities are shown in Fig. 6.9

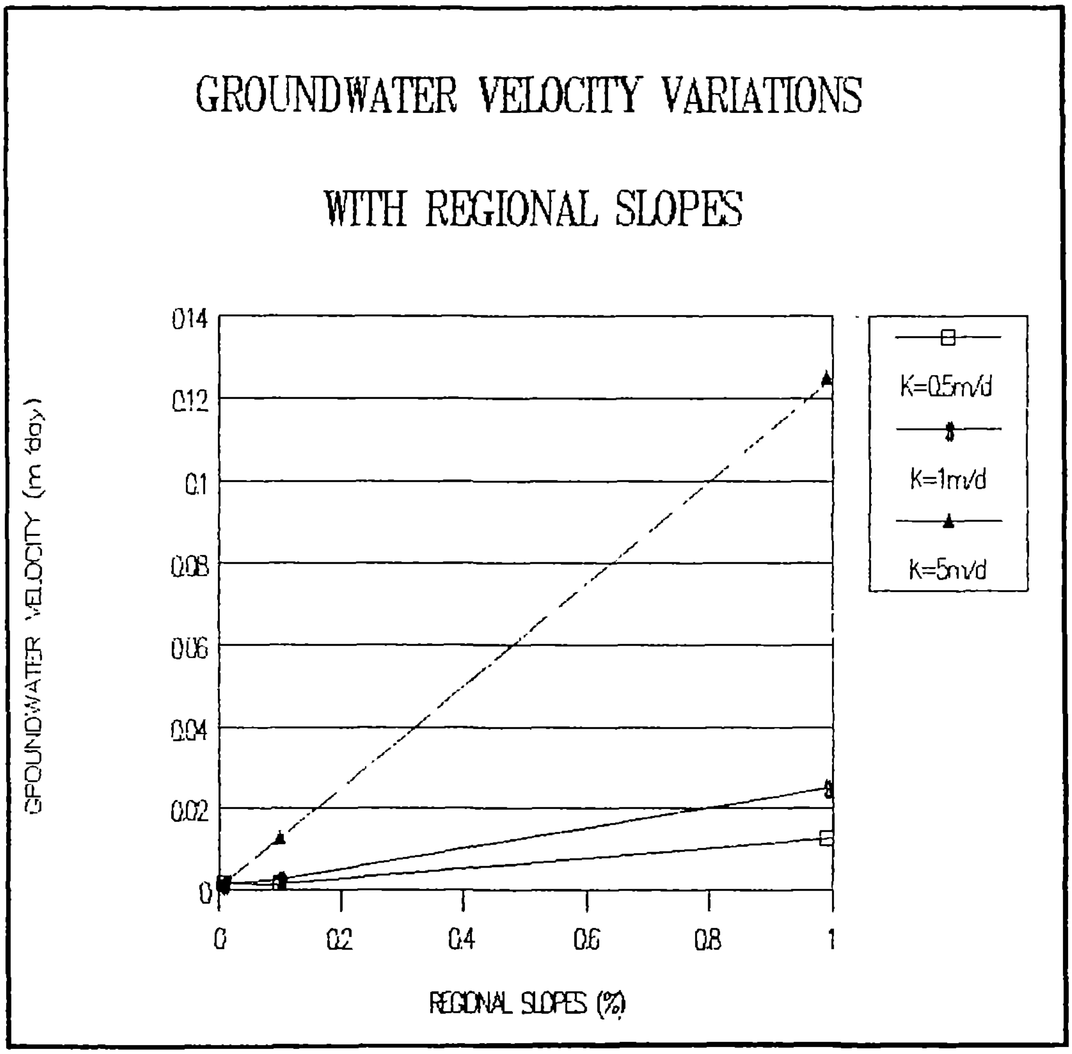


Fig. 6.9 Groundwater velocity variations with regional slopes

From the plot of Fig. 6.9 it can be concluded that permeability is an important parameter to be considered. The line showing permeability of 5m/day has a steeper slope as compared to the other two of 0.5m/day and 1m/day.

6.4.2 "Manzese model":

Introduction:

Planned and unplanned residential areas are scattered all over the city of Dar-es-salaam. In order to minimise locational differences, Manzese including Tandale is selected to be the study area. Manzese is the biggest unplanned area of Dar-es-salaam, with 112,912 inhabitants according to the 1988 census, or 8.3% of the population of the whole city. Apart from having the biggest area, its extensive use of pit latrines as the sole means of sanitation is an important reason for selecting the area for this study. The area is sufficiently representative of the squatter areas in Dar-es-salaam.

The primary cause of concern in this model are the excreted pathogens and of secondary concern is the nitrate. These are the parameters which are going to be dealt with hereunder.

Data input:

Type of soil	medium sand
Aquifer thickness	25m
Porosity	40%
Uniform flow x-component	0.125m/day
	0.0125m/day
	0.00125m/day
Uniform flow y-component	0m/day
Total number of wells	27 (25 infiltration & 2 extraction)
Number of free streamlines	0
Resolution	low

See Fig. 6.10 for the data input file

Filename : vitty2

Aquifer thickness	(m)	25	Aquifer porosity	(%)	40
Uniform Flow X-comp.	(m/d)	0.013	Uniform Flow Y-comp.	(m/d)	0.000
Total Number of Wells	(<51)	27	Number of Free Streamlines		0
Pumping Period	(days)	4745	Resolution		Low

Well Nr	X-coord.	Y-coord.	Discharge
1	0.00	12.50	9.00
2	0.00	-12.50	9.00
3	-50.00	50.00	-0.29
4	-25.00	50.00	-0.29
5	25.00	50.00	-0.29
6	50.00	50.00	-0.29
7	-50.00	25.00	-0.29
8	-25.00	25.00	-0.29
9	25.00	25.00	-0.29
10	50.00	25.00	-0.29
11	-50.00	0.00	-0.29
12	-25.00	0.00	-0.29
13	25.00	0.00	-0.29
14	50.00	0.00	-0.29
15	-50.00	-25.00	-0.29
16	-25.00	-25.00	-0.29
17	25.00	-25.00	-0.29
18	50.00	-25.00	-0.29
19	50.00	-50.00	-0.29
20	-25.00	-50.00	-0.29
21	25.00	-50.00	-0.29
22	-50.00	-50.00	-0.29
23	0.00	50.00	-0.29
24	0.00	25.00	-0.29
25	0.00	0.00	-0.29
26	0.00	-25.00	-0.29
27	0.00	-50.00	-0.29

Fig. 6.10 Data input file for Manzese model

Regional groundwater velocity calculations:

Table 6.1 REGIONAL GROUNDWATER VELOCITIES

S.No.	K (m/day)	I	n	V = KI/n (m/day
1	0.5	0.0001 0.001 0.01	0.4 0.4 0.4	0.000125 0.00125 0.0125
2	1.0	0.0001 0.001 0.01	0.4 0.4 0.4	0.00025 0.0025 0.025
3	5.0	0.0001 0.001 0.01	0.4 0.4 0.4	0.00125 0.0125 0.125

From the above table 6.1, critical velocities are obtained with case 3; hence will be opted in the modelling.

Discharge calculations:

-The discharge of sewage infiltrating from pit latrine into the soil was calculated in section 6.4.1 as 0.29 m^3/day. The same value will be used here.
-Retardation factor tells how the pollutant lags behind the water movement. Taking a critical case, it will be taken equal to one (1), meaning moving together with the water.
-Taking a hectare as the area to be modelled, the actual population density of Manzese is equal to 400 though gross population is 102 as already discussed in 5.3.3.
-Taking average size of houses to be four bed-room with 4.2 per household (in a room), we get

4.2 X 4 = 16.8 (say 16 people per house)

-This means that in a hectare there are 25 houses in average in order to get the population density of 400c/ha., and each house has a pit latrine.

-Water consumption per capita is taken to be 50l/c/d but it is assumed that 10% of it is being supplied by the normal water supply (critical case), thus, from the well the requirement will be 45l/c/d.

$$45 \times 400 = 18000 l/d = 18\ m^3/d$$

It is assumed that there are two wells to meet this demand for the population each supplying $9m^3/d$.

-Total number of wells will be 27 (25 infiltration well with negative discharge in the model and 2 extraction well with positive discharge).

-Taking case 3 above in the regional groundwater velocity calculations, three velocities are used in the model; 0.00125, 0.0125 and 0.125 m/d.

-The other parameters as porosity, and aquifer thickness were kept constant in the model.

Data output:

Taking Q_0 as the total discharge expected at the extraction well from the infiltration wells and Q being the discharge a particular time, the following results were obtained:-

Table 6.2 MANZESE MODEL OUTPUT RESULTS

Case	V (m/day)	Time (days)	Q/Q_0
1	0.00125	0	0
		360	0
		1200	0.20
		1800	0.33
		2500	0.60
		3650	0.87
		4015	1.00
		4380	1.00
		4745	1.00

2	0.0125	0 420 1040 2190 2920 3650 4015 4380	0 0 0.25 0.50 0.75 1.00 1.00 1.00
3	0.125	0	0

In case 3 due to high velocities streamlines were running parallel to the wells. a different case could have happened if the well were directly downstream of the latrines. This case has been left out because it is not likely in practise.

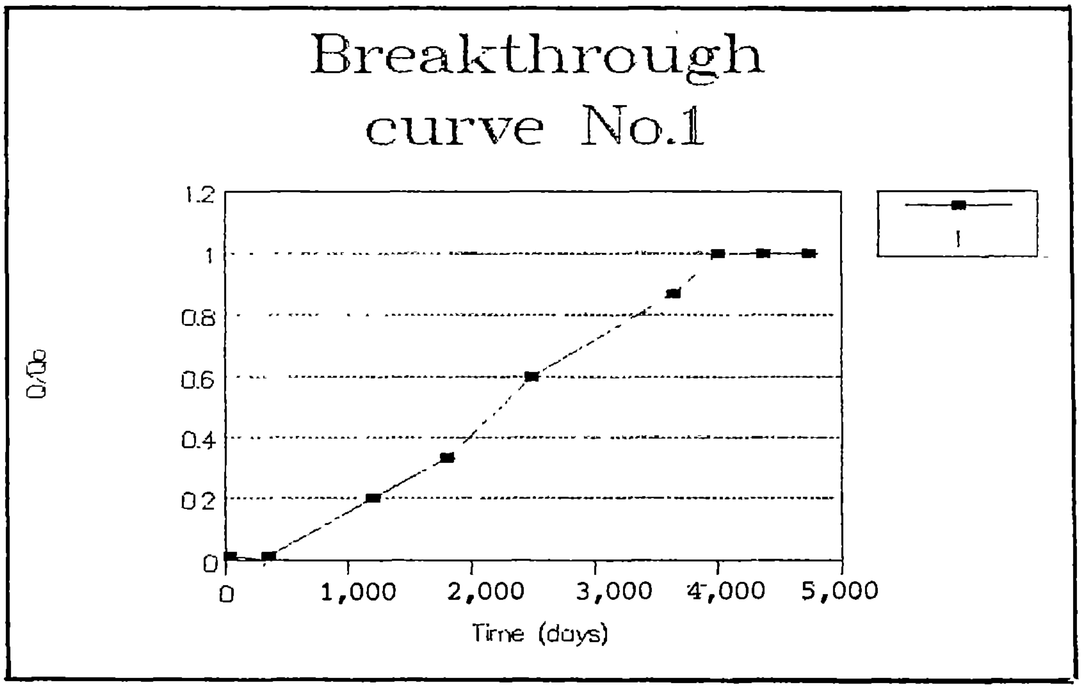


Fig. 6.11 Breakthrough curve for case No. 1

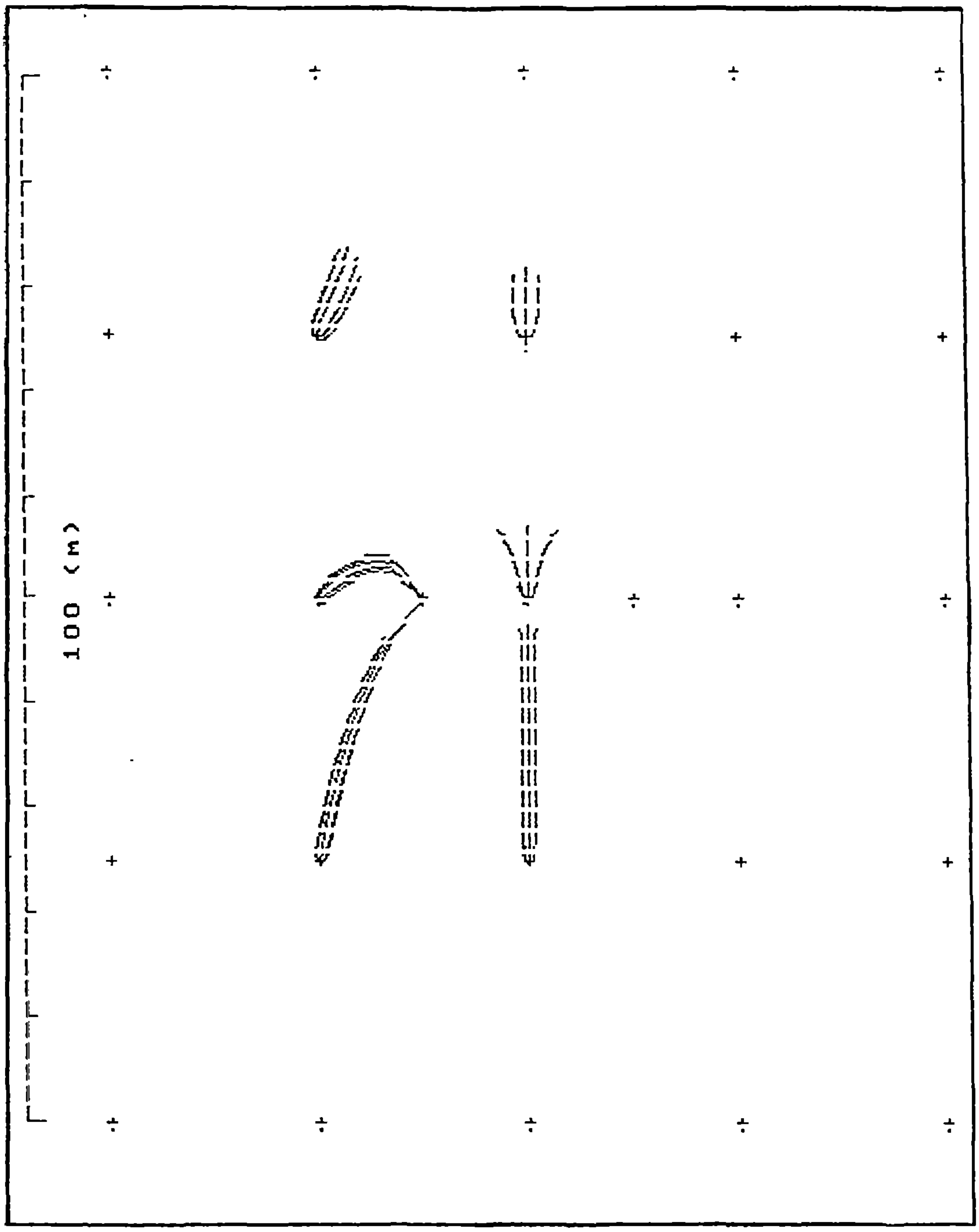


Fig 6.12 Streamlines showing the Manzese model (case No.2)

Fig.6.12 shows that though all wells in the study area can be fed in the model, streamlines can be assigned in areas of particular interest.

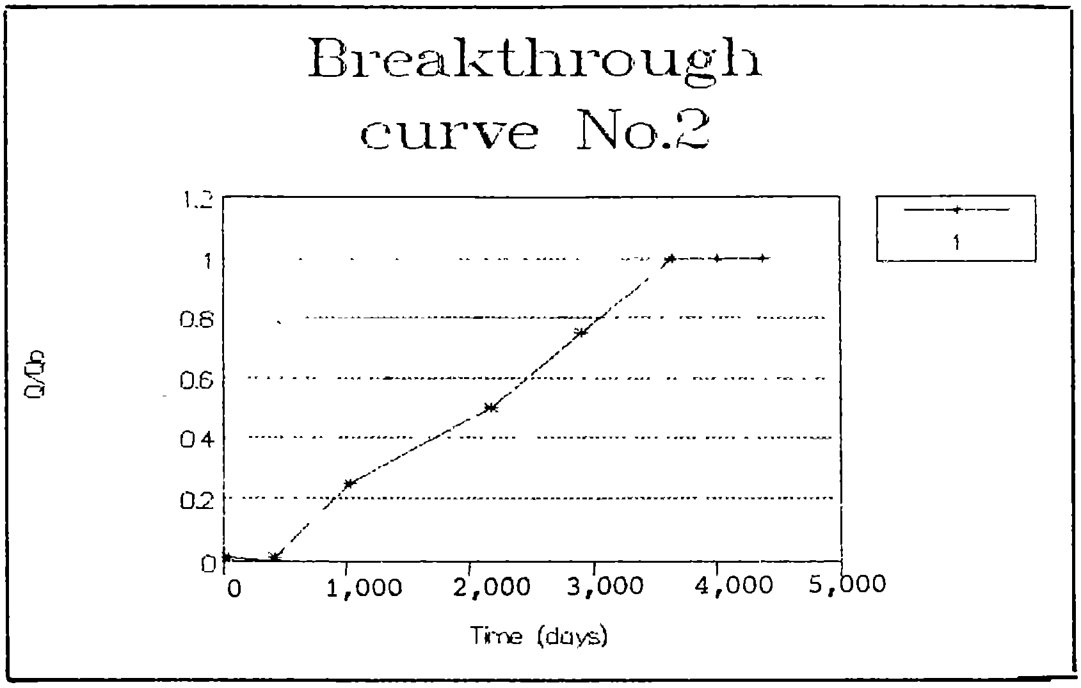


Fig 6.11 Breakthrough curve for case No. 2.

The breakthrough curves (dispersive flow) theoretically are supposed to resemble to a 's' shape. See Fig. 2.8b. The two curves obtained in the Manzese model are not as smooth as they are supposed to be, this can be explained by the difficulty of determining the number of streamlines reaching the well at a particular time. Even though, the shapes so obtained are satisfactory. Breakthrough curves are either a plot of C/C_0 with time or Q/Q_0 with time. When C/C_0 or Q/Q_0 reaches 1 it means a condition of steady state is reached.

Data analysis:

In order to get the picture of the situation, four cases are analyzed. The first two cases with the lowest and highest die-off rates of microorganisms. Then with retardation factors of 1 and 1.5.

As discussed in section 2.2.5, taking retardation factor to be equal to 1 it means that the pollutant is not sorbed and moves at the same speed as the groundwater. While retardation factor of 1.5 has been taken to simulate the situation of clay lenses which will adsorb the pollutants.

From table 3.1, the lowest die-off rate recorded according to Bitton and Gerba, (1984)[19] is that of faecal streptococci, which is equal to 0.03 and Coliphage f2 has the highest die-off rate of 1.42.

In the Manzese model the time taken by the first streamline to travel from the latrine to the well as per the arrangement fed in the model is 360 days. This means for the case of retardation factor of 1.5 it will be 540 days (refer to equation 16)

When the pit latrine is new, for the first 1-3 months it can be taken that the build-up of the clogging mat has not taken place, which means it can as well be assumed that there is no filtration, thus, all what goes in the pit is what goes to the groundwater.

From table 5.3, the amount of faecal coliform produced per capita per day = $2 X 10^{10}$. As 25 people use one latrine, the pit is expected to receive $5 X 10^{11}$ faecal coliform per day.

Four streamlines per latrine has been assigned in the model, if it is assumed that each streamline takes equal share of faecal coliform; $1.25 X 10^{11}$ faecal coliform per streamline.

i) taking the case of faecal streptococci with a retardation factor of 1:

$K = 0.03$; $t = 360$, and $N_0 = 1.25 X 10^{11}$

$N = N_0 e^{-Kt}$

$= 1.25 X 10^{11} e^{-0.03 X 360}$

= 2,549,938 bacteria

ii)taking the case of faecal streptococci with a retardation factor of 1.5

$K = 0.03$; $t=540$ $N_0 = 1.25 X 10^{11}$

$N = N_0 e^{-Kt}$

$= 1.25 X 10^{11} e^{-0.03 X 540}$

= 0.0012 bacteria (say 0)

iii)taking the case of coliphage f2 with a retardation factor 1.

$K = 1.42$; $t= 360$ $N_0 = 1.25 \times 10^{11}$

$N = 1.25 \times 10^{11} \times e^{-1.42 \times 360}$

$= 0$ bacteria

iV) taking the case of coliphage f2 with a retardation factor of 1.5

$K = 1.42$; $t=540$ $N_0 = 1.25 \times 10^{11}$

$N = 1.25 \times 10^{11} e^{-1.42 \times 540}$

$= 0$ bacteria

From the above calculations originating from the MFLOP, it shows that in the Manzese area the groundwater is polluted with microorganisms of low die-off rate and at a retardation factor of one. Coliphage f2 are not likely to be present in the wells.

Nitrate pollution of the groundwater will mainly depend on the depth of the unsaturated zone (aeration zone), whereby nitrification takes place. For the case of Manzese, groundwater level is very high, as anaerobic conditions prevail, thus no nitrification. In case of nitrification taking place, pollution will depend on the denitrification rate. Data on denitrification rate in the case of Manzese model was not enough to come-up with hard conclusions.

7.0 CONCLUSIONS AND RECOMMENDATIONS:

1) Health and water supply problems in developing countries are substantial, it is recommended that there should be more research into the extent of groundwater pollution by pit latrines in these areas. The research carried out should be on factors which will lead to an improvement of guidelines for future pollution risk assessment.

2)The influence of pit latrine use on groundwater pollution is effected by the quantity of the pit latrines, the type of latrines (how much leakage is going into the ground), the hydraulic loading, the retention time of the material before the pit is full and emptied and the way of disposal. Also, effects on groundwater pollution may be due to cleansing methods and solid waste disposal into the pits. Further research for this statement is necessary.

3)"MFLOP" computer programme coupled with a few calculations seems to form a good basis for predicting groundwater contamination by the use of pit latrines. However, validation of the model in the field situation is essential.

4)From the sensitivity test of the model it has been found that distance between wells, extraction capacity, groundwater velocity and permeability of the aquifer are the most sensitive parameters and hence, need more attention in the modelling.

5)From the Manzese model it shows that with an initial value of 1.25 X 10^{11} Faecal streptococci (K= 0.03); 2,549,938 will reach the extraction well after 360 days (assuming no clogging mat and a retardation factor of 1). While the same coliform will hardly reach the well if the retardation factor is 1.5. Coliphage f2 (K = 1.42) will not reach the well as they will die enroute for whatever retardation factor taken.

6)Pit latrines offers the only affordable technical solution for improved waste disposal in many parts of the developing world and it is not the intention of this thesis to discourage the use of pit latrines. The message of this thesis is rather to proceed with caution and continually check that pit latrines are not causing groundwater contamination. Indeed, in some hydrological environments the capacity of the soil to attenuate microbial pollution suggests that much more use might be made of the pits. More research is however needed for the retardation factor and stability of the clogging layer.

7)Groundwater quality monitoring is essential for protection of groundwater and is not beyond the means of the developing countries. Monitoring programmes and networks can be designed within the resource constraints wherever sanitation facilities are introduced or upgraded.

8)The unsaturated zone is the most important line of defence against faecal pollution of aquifers. Maximazation of effluent residence time in the unsaturated zone is, therefore, the key factor affecting removal and elimination of bacteria and viruses. Thus, the use of a shallow twin-pit VIP latrine, rather than a deep single pit latrine, may leave a sufficient depth in the unsaturated zone. Alternatively, a raised VIP latrine, which is provided with an 'artificial' unsaturated zone of fine sand (less than 1mm) to a depth of at least 800mm may alleviate the pollution to acceptable level.

9)The most important faecal pollutants are pathogenic bacteria and viruses, and to a lesser extent nitrates. Bactera can be removed by filtration in soil while adsorption plays an important role in virus retention. Both pathogens are capable of surving for long periods in both soil and groundwater. Because of the relatively large size of protozoa and helminth eggs (> 25 µm), they are effectively removed by physical filtration in soils and are unlikely to pollute groundwater.

10)The only permanent nitrate removal mechanism available in soils is bacterial convertion of nitrates to nitrogen gas (denitrification). This means, the groundwater pollution by nitrate from pit latrines could probably be eased-off if methods of artificially inducing increased rates of denitrification can be investigated.

11)As with any modelling study, the reliability of the results is dependent on the input. Although there have been numerous studies in Dar-es-salaam, the collection of hydrological data at Manzese are minimal: therefore, any conclusion must be presented with a note of caution. Reliance on these predictions must be in accordance with the limiting assumptions used in the model. This is not to say that the results and predictions made are meaningless. In addition to providing a means of understanding the pollution situation, the results of modelling can be used to indicate additional data required to improve predictions or strengthen conclusions.

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APPENDIX 1

UNIVERSITY OXIDATION PONDS
UBUNGO OXIDATION PONDS
VINGUNGUTI OXIDATION PONDS
BUGURUNI OXIDATION PONDS
MSASANI OXIDATION PONDS
MBULANI OXIDATION PONDS
UFONGA OXIDATION POND
AIRWING OXIDATION PONDS
TEMEKE
TANDIKA
N
Notes
Area Identification
Population projected for 1996
Principal form of sanitation
PL = Pit latrine
ST = Septic Tank
Rev.
Description
Date
UNITED REPUBLIC OF TANZANIA
MINISTRY OF LANDS HOUSING AND URBAN DEVELOPMENT
DAR-ES-SALAAM SEWERAGE AND SANITATION PROJECT
FOUL SEWERAGE AND STORMWATER REHABILITATION PROGRAMME
ADDITIONAL WORKS
Howard Humphreys (Tanzania) Ltd.
Consulting Engineers
P.O. Box 3850
Dar-es-Salaam
LOW COST SANITATION
AREAS IDENTIFIED IN
MASTER PLAN
Designed by
Drawn by
Checked by
Approved by
Scale
Date FEB 1996
Job No.
Contract
DRAWING No. RHB/DS/2

APPENDIX II

(SOURCE:HASKONING)

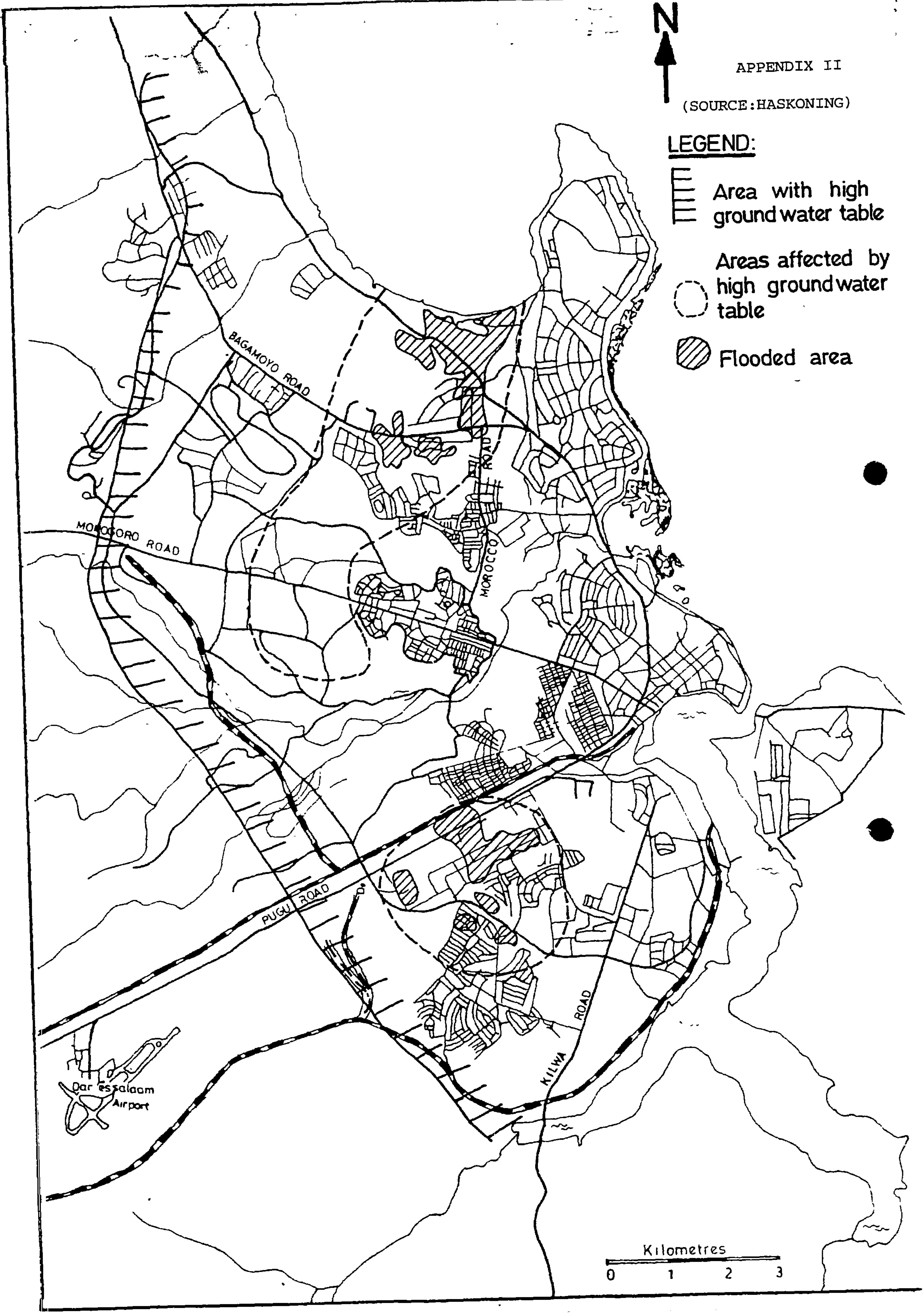

Figure 2.1 CLIMATIC TABLE DAR ES SALAAM WHO NO. 63894

Month	Temperatures		Humidity		Rain		Wind 09.h			Wind 15.h		
	mean daily	mean daily	09.h. %	15.h %	av. mm	days 1 mm No.	main wind direction (50-80% frequency)	days calm No.	speed km	main wind direction (65-80 % frequency)	days calm No.	speed km
January	31	25	80	67	66	7	N - NE	9	2	N - NE	1	2
February	31	25	82	67	66	7	N - NE	14	2	N - NE	3	2
March	31	24	85	69	130	11	SE - SW	17	2	NE - E	5	2
April	30	23	89	75	290	19	S - SW	10	2	E - S	6	2
May	29	22	87	67	188	12	S - SW	6	2	SE - S	2	3
June	29	20	86	60	33	6	S - SW	3	2	SE - S	1	3
July	28	19	87	58	30	6	S - SW	4	2	SE - S	1	3
August	28	19	85	56	25	5	S - SW	7	2	E - SE	1	4
September	28	19	80	57	30	6	SE - SW	15	2	NE - E	1	4
October	29	21	77	60	41	6	SE - SW	20	2	NE - E	0	4
November	30	21	79	65	74	9	SE - SW	20	2	NE - E	1	3
December	31	24	80	67	91	10	N - NE	16	2	NE - E	5	3
means	30	22	83	64				12	2		2	3
TOTALS					1064	104						

APPENDIX IV

Districts and wards in Dar-es-Salaam (Haskoning, 1988).

Districts:

ILALA

Urban wards:

1. Kariakoo
2. Mchafukoge
3. Gerezani
4. Kisutu
5. Kivukoni
6. Jangwani
7. Upanga East
8. Upanga West
9. Ilala
10. Mchikichini

Rural wards:

11. Buguruni
12. Vingunguti
13. Kipawa
14. Tabata
15. Ukonga
16. Kinyerezi
17. Pugu
18. Msongola

KINONDONI

Urban wards:

19. Mzimuni
20. Magomeni
21. Ndugumbi
22. Makurumla
23. Manzese
24. Kigogo
25. Mabibo
26. Ubungo
27. Kinondoni
28. Mwananyamala
29. Msasani
30. Tandale
31. Kawe

Rural wards:

32. Kunduchi
33. Kibamba
34. Goba
35. Bunju
36. Mbweni

TEMEKE

Urban wards:

37. Mbagala
38. Miburani
39. Mtoni
40. Temeke
41. Kurasini
42. Keko

Rural wards:

43. Yombo Vituka
44. Charambe
45. Kigamboni
46. Kimbiji
47. Somangila
48. Vijibweni
49. Kisarawe
50. Tua Ngoma
51. Chamazi
52. Kibada

APPENDIX V

WARD POPULATION GROWTH RATE FOR ILALA DISTRICT 1978- 1988

ILALA DISTRICT	AREA	POPULATION 1978	POPULATION 1988	GROWTH RATE	HOUSEHOLD 1988		POPULATION DENSITY'88
WARDS	HA	CAP	CAP	%p.a	Number	Av.Size	CAP/HA
0-10Km.							
Ilala	460	30,818	35,048	1.3	8,241	4.2	76
M/chini	120	14,319	15,040	0.5	3,372	4.4	125
Vingunguti	530	18,462	33,690	6.2	8,731	3.8	64
Kipawa	1,030	16,277	36,910	8.5	9,282	3.9	36
Buguruni	560	23,936	48,247	7.3	13,198	3.6	86
Kariakoo	60	11,606	12,569	0.8	2,499	5.0	209
Jangwani	220	13,502	15,320	1.2	2,908	5.2	70
Gerezani	85	7,611	7,487	-0.2	1,557	4.8	88
Kisutu	50	7,939	8,358	0.5	1,699	4.9	167
Mchafukoge	120	10,555	8,547	-2.1	1,604	5.3	71
UpangaEast	240	8,391	9,807	1.6	752	13.0	41
UpangaWest	385	10,772	11,020	0.2	1,633	6.7	29
Kivukoni	820	5,121	5,372	0.5	781	6.8	6.6
Tabata	1,640	2,070	18,465	24.5	3,780	4.8	11.3
10-15Km.							
Ukonga	5,130	25,232	45,203	6.0	10,127	4.4	8.8
Kinyerezi	1,950	2,861	3,048	0.6	730	4.1	1.6
15-20Km.							
Pugu	5,600	6,435	6,226	-0.3	1,178	5.2	1.1
Msongola	2,000	2,459	13,351	18.4	3,058	4.3	6.7

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APPENDIX VI

WARD POPULATION GROWTH RATE FOR KINONDONI DISTRICT 1978-1988

KINONDONI DISTRICT	AREA	POPULATION 1978	POPULATION 1988	GROWTH RATE	HOUSEHOLD 1988		POPULATION DENSITY 1988
WARDS	HA	CAP	CAP	%p.a	number	AV.Size	CAP/HA
0-10 Km							
Msasani	1,700	26,065	51,293	7	10,839	4.7	30
M/nyamala	460	44,616	72,508	5	16,943	4.2	158
Tandale	375	25,473	58,413	8.7	13,380	4.3	156
Kinondoni	415	27,859	42,387	4.3	9,526	4.4	102
Mzimuni	170	20,144	23,985	1.8	5,807	4.1	141
Magomeni	165	14,256	16,944	1.7	4,361	3.8	103
Ndugumbi	190	24,156	32,736	3.1	7,933	4.1	172
Makurumla	180	29,408	53,991	6.3	12,987	4.1	300
Manzese	535	28,532	54,499	6.7	12,834	4.2	102
Kigogo	170	16,360	21,222	2.6	4,693	4.5	125
10-15Km.							
Kawe	3,680	27,767	44,085	4.7	10,527	4.1	12
Mabibo	2,600	28,188	45,963	5	10,761	4.2	18
Ubungo	2,300	23,796	46,980	7	9,521	4,9	20
15-20Km.							
Kunduchi	8,250	11,761	22,743	6.8	5,452	4.1	3
Goba	4,380	2,700	4,753	5.8	1,186	4.0	1.1
+20Km.							
Bunju	9,300	5,030	9,977	7.1	2,493	4.0	1.1
Mbweni	2,500	1,317	2,159	5.1	551	3.9	0.9
Kibamba	15,330	8,731	16,751	6.7	3,875	4.3	1.1

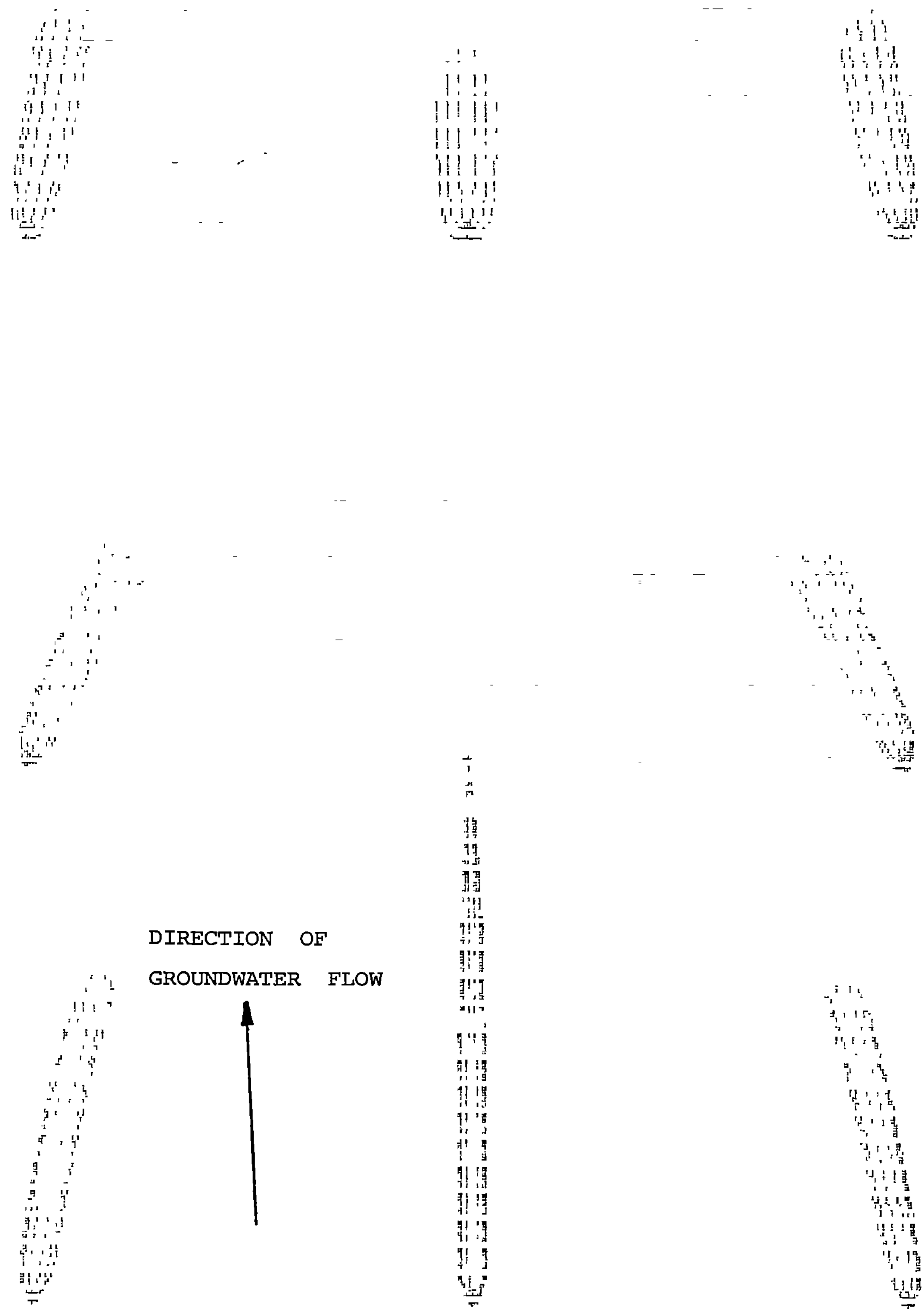
APPENDIX VII

WARD POPULATION GROWTH RATE FOR TEMEKE DISTRICT 1978-1988

TEMEKE DISTRICT	AREA	POPULATION 1978	1988	GROWTH RATE	HOUSEHOLD 1988		POPULATION DENSITY'88
WARD	HA	CAP	CAP	%p.a	Number	Av.size	CAP/HA
0-10Km.							
Kigamboni	3,650	17,324	26,078	4.2	6,197	4.2	7
Vijibweni	1,300	1,948	2,557	2.8	520	4.9	2
Mbagala	2,705	11,129	40,866	13.9	9,539	4.2	15
Yombo	1,430	2,477	5,452	8.2	2,876	4.6	4
Miburani	80	68,479	72,892	0.6	16,793	4.3	911
Temeke	545	72,844	91,144	2.3	22,271	4.0	167
Mtoni	285	13,124	39,417	11.6	9,745	4.0	138
Keko	365	34,762	42,868	2.1	10,493	4.0	117
Kurasini	1,250	16,375	26,776	5.0	5,781	4.6	21
10-15Km.							
Kibada	1,510	2,540	3,003	1.7	752	3.9	2
Chalambe	650	2,719	18,624	21.2	3,974	4.6	29
Tua Ngoma	3,950	4,110	6,652	4.9	1,553	4.2	1.7
15-20Km.							
Kisarawe	5,375	1,276	2,821	8.3	697	4.0	0.5
Somangira	10,718	2,999	6,730	8.4	1,596	4.2	0.6
Chamazi	7,520	3,072	5,452	5.9	1,261	4.3	0.7
+20Km.							
Kimbiji	24,285	3,327	6,465	6.9	1,457	4.4	0.3

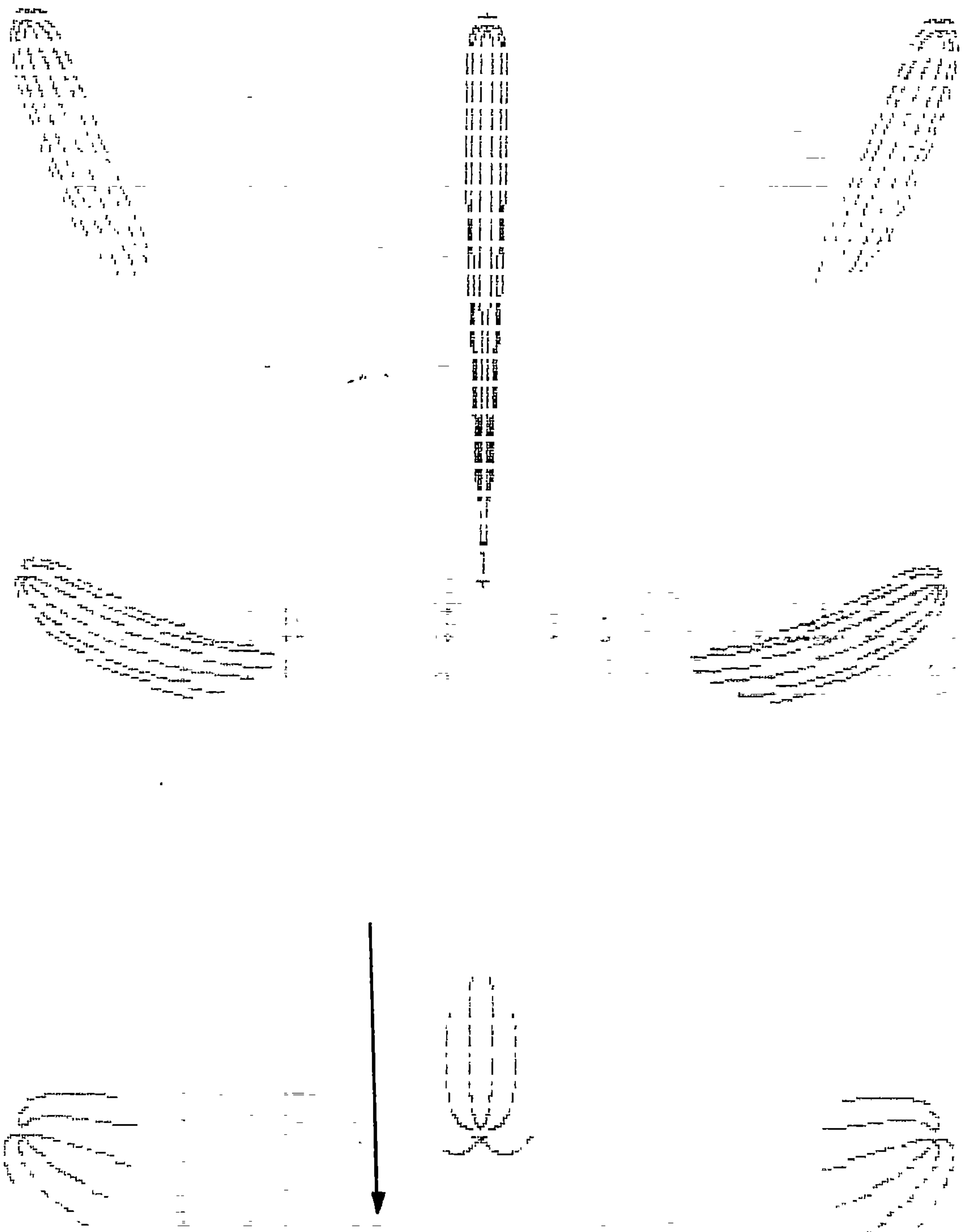
APPENDIX VIII

(POROSITY TEST)



APPENDIX IX

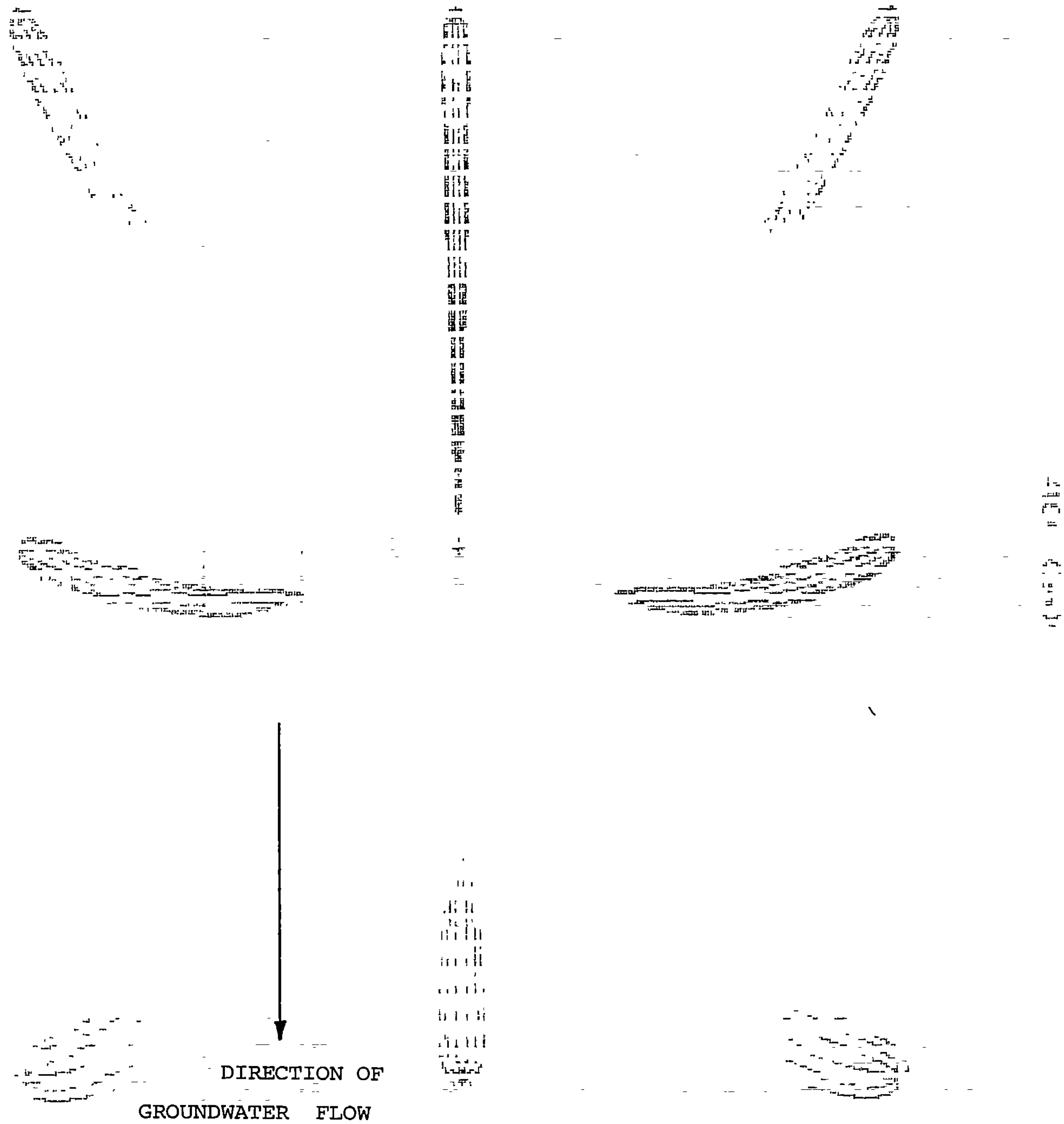
(AQUIFER THICKNESS TEST)



DIRECTION OF
GROUNDWATER FLOW

APPENDIX X

(DISTANCE TEST)



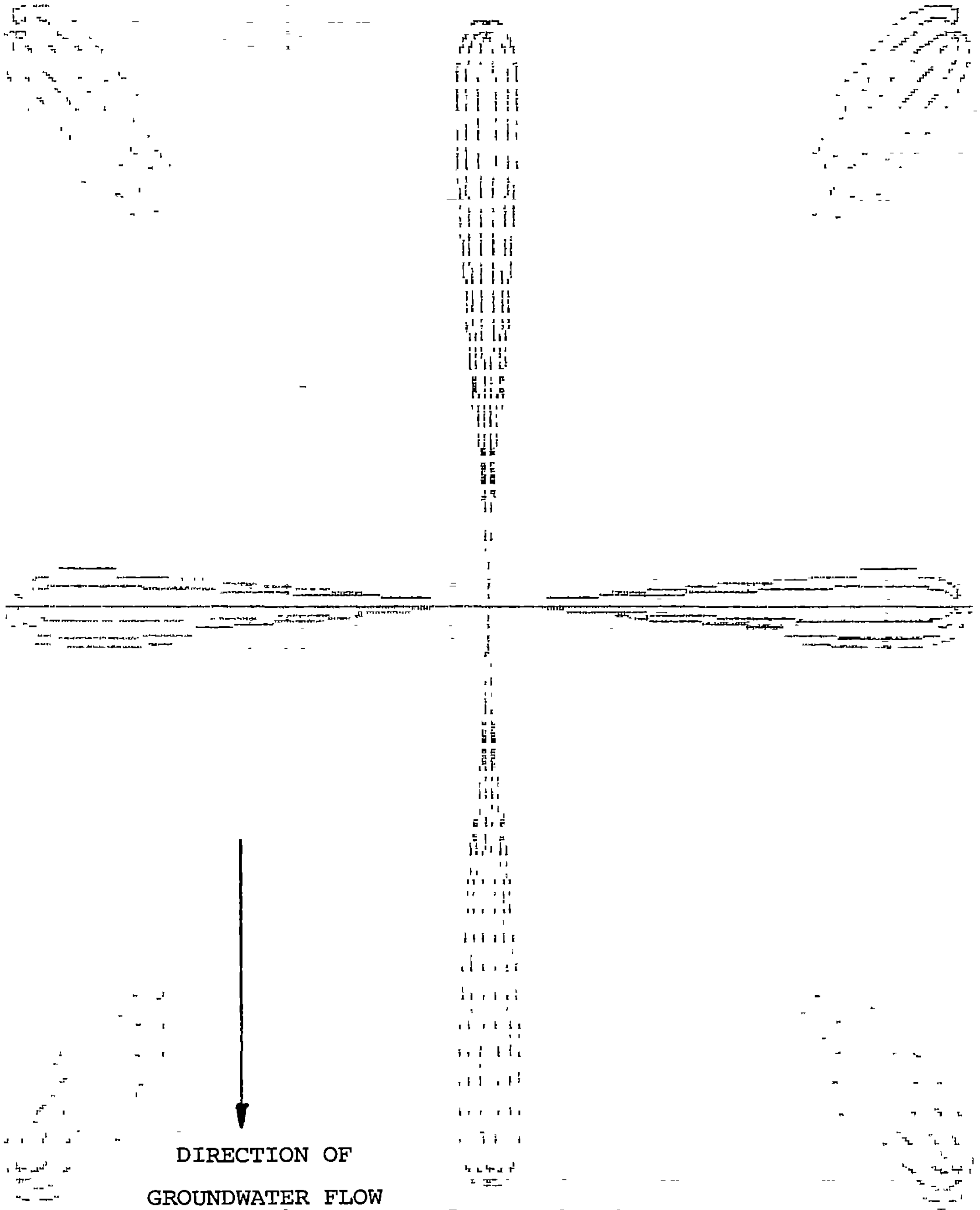
APPENDIX XI

(DISCHARGE TEST)

DIRECTION OF
GROUNDWATER FLOW

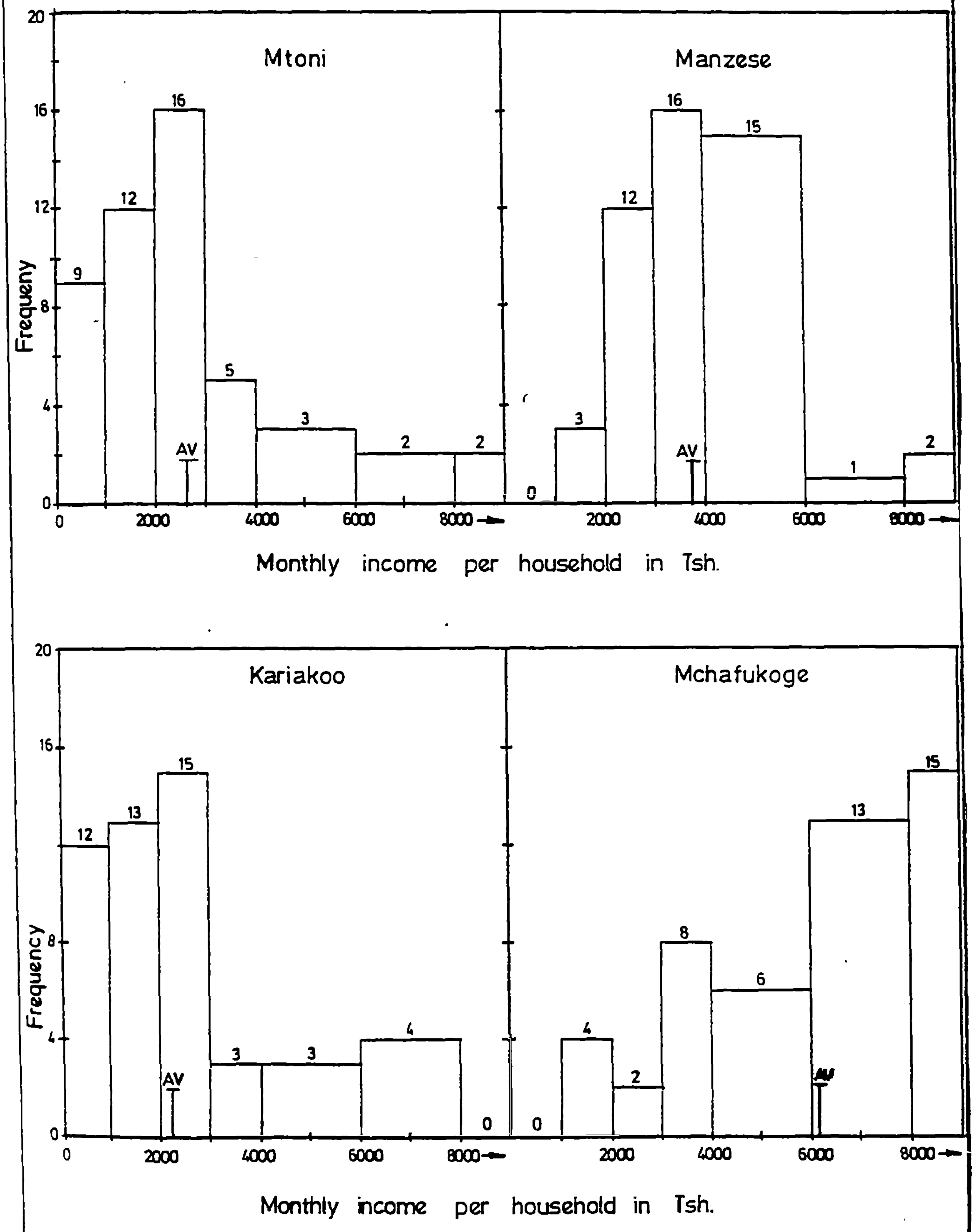
APPENDIX XII

(REGIONAL VELOCITY TEST)



APPENDIX XIII

Income distribution in sample areas



APPENDIX XIV

FACTORS AFFECTING SURVIVAL OF ENTERIC BACTERIA IN SOIL:

FACTORS	COMMENTS
1. Moisture content	Greater survival time in moist soils and during times of high rainfall.
2. Moisture holding capacity	Survival time is less in sandy soils than in soils with greater water-holding capacity.
3. Temperature	Longer survival at low temperature; longer survival in winter than in summer.
4. pH	Shorter survival time in acid soils (pH3-5) than in alkaline soils.
5. Sunlight	Shorter survival time at soil surface (the UV of sunlight and drying are killers).
6. Organic matter	Increased survival and possible regrowth when sufficient amounts of organic matter are present.
7. Antagonism from soil microflora	Increased survival time in sterile soil, soil microflora compete with bacteria for nutrients.

APPENDIX XV

FACTORS THAT MAY INFLUENCE VIRUS MOVEMENT TO GROUNDWATER (Gerba,1975)

FACTORS	COMMENTS
1. Soil type	Fine-textured soil retain viruses more effectively than light-textured soils. Iron oxides increase the adsorptive capacity of soils. Muck soils are generally poor absorbents.
2. pH	The hydrogen ion concentration has a strong influence on virus stability as well as adsorption and elution. Generally, a low pH favours virus adsorption while a high pH results in elution of adsorbed virus.
3. Cations	Adsorption increases in the presence of cations (cations help reduce repulsive forces on both virus and soil particles.) Rainwater may desorb viruses from soil due to its low conductivity.
4. Soluble organics	Soluble organic matter has been shown to compete with viruses for adsorption sites ao the soil particles, resulting in decreased adsorption or elution of an already adsorbed virus.
5. Virus type	Adsorption to soils varies with virus type and strain. Viruses may have different isoelectric points.
6. Flow rate	The higher the flow rate, the lower virus adsorption to soils.
7. Saturated versus unsaturated flow	Virus movement is less under unsaturated flow conditions.

APPENDIX XVI

(41)

FACTORS THAT MAY INFLUENCE VIRUS SURVIVAL IN SOILS (GERBA,1975)

FACTORS	COMMENTS
1. Temperature	One of the most detrimental factors.
2. Desiccation	One of the most detrimental factors. Increased virus reduction in drying soils
3. Sunlight	May be detrimental at the soil surface
4. Soil pH	May indirectly affect virus survival by controlling their adsorption to soils.
5. Cations	Certain cations have a thermal stabilizing effect on viruses. May also indirectly influence virus survival by increasing their adsorption to soil (viruses appear to survive better in the sorbed state).
6. Soil texture	Clay minerals and humic substances increase water retention by soil and thus have an impact on viruses subjected to desiccation.
7. Biological factors	No clear trend regard to the effect of soil microflora on viruses.

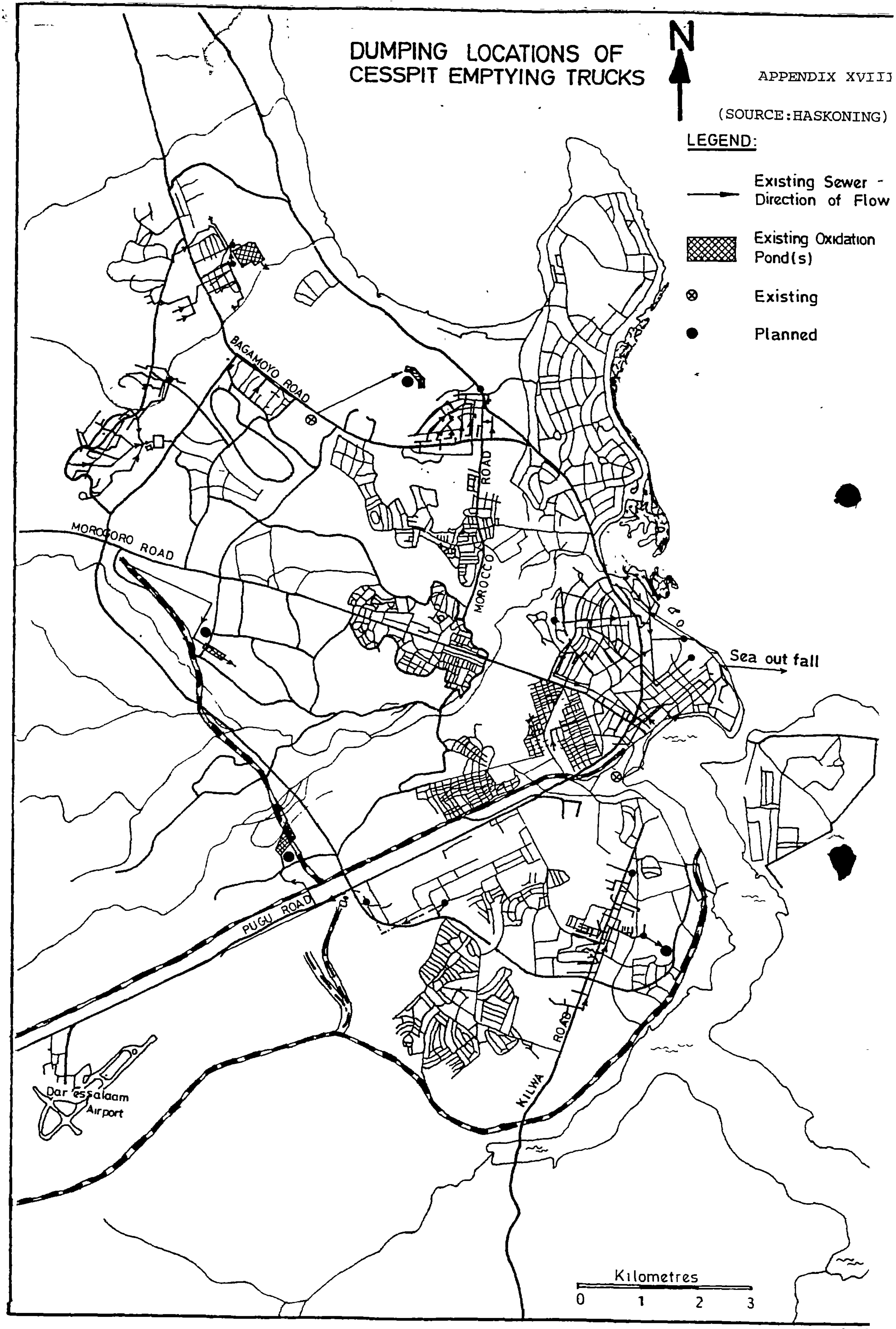
APPENDIX XVII

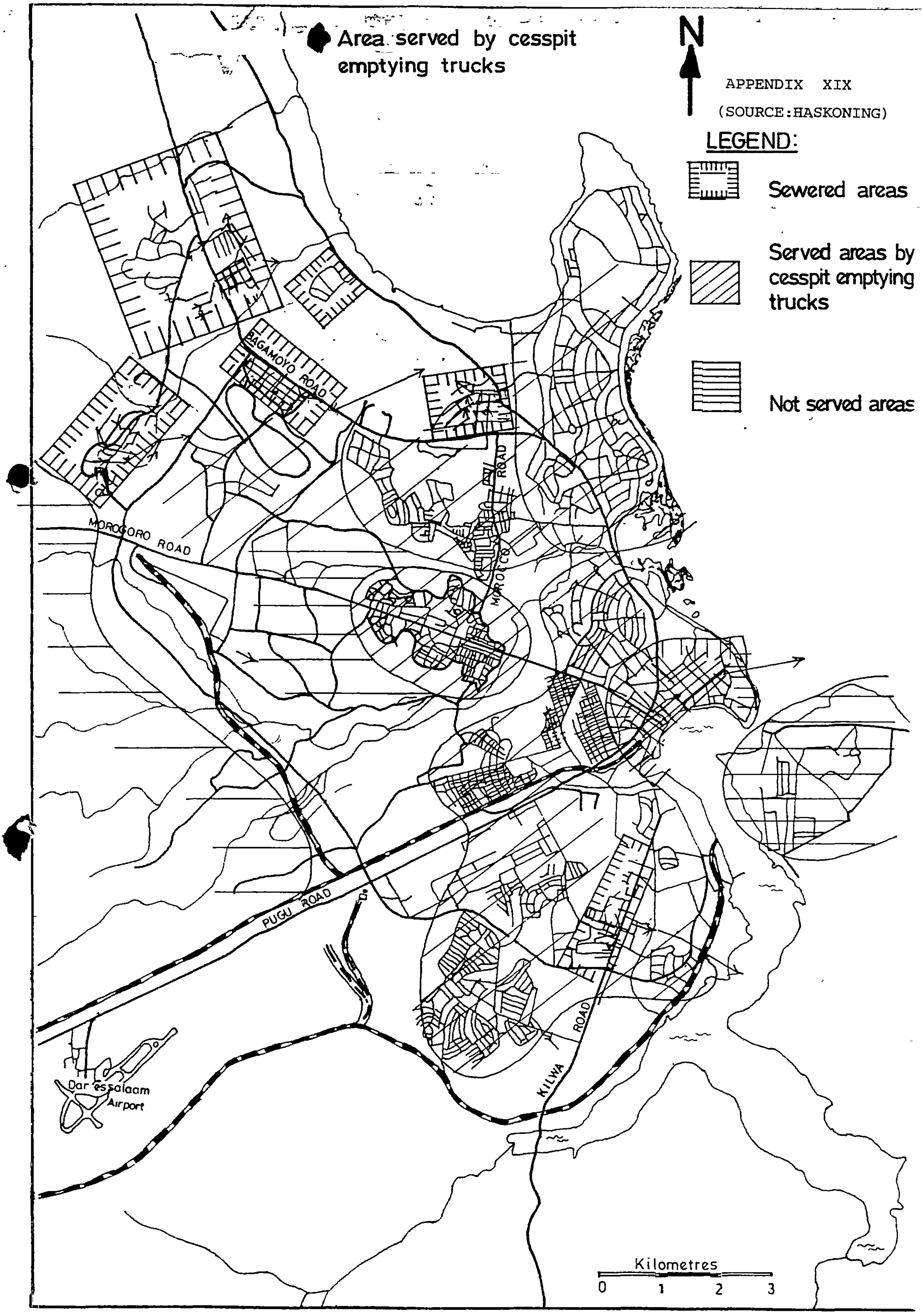
RANGE AND MEAN VALUES OF POROSITY

Material	Range (percent)	Mean (percent)
clay	34.2 - 56.9	42
silt	33.9 - 61.1	46
sand, fine	26.0 - 53.3	43
sand, medium	28.5 - 48.9	39
sand, coarse	30.9 - 46.4	39
gravel, fine	25.1 - 38.5	34
gravel, medium	23.7 - 44.1	32
gravel, coarse	23.8 - 36.5	28
loess	44.0 - 57.2	49
eolian sand (dune sand)	39.9 - 50.7	45
till, predominantly silt	29.5 - 40.6	34
till, predominantly sand	22.1 - 36.7	31
till, predominantly gravel	22.1 - 30.3	26
glacial drift, predominantly silt	38.4 - 59.3	49
glacial drift, predominantly sand	36.2 - 47.6	44
glacial drift, predominantly gravel	34.6 - 41.5	39
sandstone, fine grained	13.7 - 49.3	33
sandstone, medium grained	29.7 - 43.6	37
siltstone	21.2 - 41.0	35
claystone	41.2 - 45.2	43
shale	1.4 - 9.7	6
limestone	6.6 - 55.7	30
dolomite	19.1 - 32.7	26
granite, weathered	34.3 - 56.6	45
gabbro, weathered	41.7 - 45.0	43
basalt	3.0 - 35.0	17
schist	4.4 - 49.3	38

Reference: Morris and Johnson (1967).

APPENDIX XVIII





Area served by cesspit emptying trucks
N
APPENDIX XIX
(SOURCE:HASKONING)
LEGEND:
Sewered areas
Served areas by cesspit emptying trucks
Not served areas
BAGAMOYO ROAD
MOROGORO ROAD
MOROGORO ROAD
PUGU ROAD
KILWA ROAD
Dar es salaam Airport
Kilometres
0 1 2 3

[redacted]

[redacted]

[redacted]