Sanitation technology options in informal settlement: a system dynamics approach

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Abstract

Provision of sanitation services to urban informal settlement is one of the challenges that the urban planners and decision makers are face with in the current era. High population growth and lack of legal status in informal settlements makes it challenging to improve the level of sanitation. The question then is whether there are possible technology options that can be utilized to achieve sanitation crisis in informal settlements. This paper thus delves into the dark and complex world of the sanitation crisis in informal settlements. Using system dynamics approach, it describes the key elements in the sanitation provision in informal settlements, and specifically, in the context of Enkanini, an illegal informal settlement in Stellenbosch. The system dynamics model demonstrates differences between four sanitation technologies, namely: pour flush; ventilated improved pit latrine; compost toilet; and regular toilet. The results show that there is a long-term benefit from waterborne sanitation, as well as rapid improvement in sanitation from cheaper options of a compost toilet and ventilated improved pit latrine. The pour flush toilet and ventilated improved pit latrine occupied the beneficial middle ground of minimal investment for decent output in sanitation improvement as well as improvement of the sanitation experience.

1 Introduction

"Dignity is at the core of all human rights, and lack of sanitation, more than many other issues, threatens that concept. Ensuring that all have access to sanitation is a step towards ensuring a more dignified life for all."

(Catarina de Albuquerque, Independent Expert, Office of the United Nations High Commissioner for Human Rights)

Provision of sanitation technology solutions in urban informal settlements is extremely challenging due to: (i) lack of legal status of the settlement area; (ii) poor accessibility; and (iii) lack of interest by inhabitants to invest in sanitation (Paterson et al., 2007, Katukiza et al., 2010, Katukiza et al., 2012). Sanitation can be regarded as the management of human excreta, solid waste, and grey and storm water (Katukiza et al., 2010).

It is estimated that about two billion people live with inadequate sanitation (Paterson et al., 2007). More than two million people (mostly children) die each year from diseases associated with inadequate sanitation and lack of safe drinking water (Paterson et al., 2007). The battle against inadequate sanitation is not merely about containing the spread of fatal diseases; access to adequate sanitation is vital to human dignity, safety, environmental sustainability, poverty reduction and general psychological well-being (Socio-Economic Rights Institute of South Africa (SERI). 2011). The reality of the daily sanitation struggle for millions of peri-urban residents is a stark reality indeed; it represents one of the major challenges of the 21st Century, one which humanity is still far from overcoming (Paterson et al., 2007). This challenge cannot be seen as being simply a technical foe; instead it must be understood as a socio-technical problem, deeply rooted within multiple complex and intertwined systems, compounded by the complexity of second wave of urbanisation (Tavener-Smith, 2013). In the second wave of urbanisation, the period between 2005 and 2050, global population is expected to reach 9 billion, and out of this, 6 billion people will live in the cities (United Nations Department of Economic and Social Affairs., 2010, UNEP., 2012). For Sub-Saharan Africa, already 62% of urbanites live in slums, and 800,000 new urban dwellers are expected by 2050, which will most likely increase this percentage (Robinson et al., 2013).

In the case of South Africa, vast population growth is being experienced in peri-urban informal settlements (Mels et al., 2009). This implies that providing adequate water and sanitation for the growing population is becoming increasingly difficult, bearing in mind of already existing service delivery woes and the complex environmental, socio-economic and cultural limitations plaguing informal settlements (Mels et al., 2009).

The right to access adequate (standard) sanitation is not specifically catered for in the Constitution of South Africa; however, there are a number of different instances within the constitution which directly or indirectly imply the right (Socio-Economic Rights Institute of South Africa (SERI). 2011). According to World Health Organization (2012), adequate sanitation includes sanitation facilities that hygienically separate human excreta from human contact. Since 2007, the South Africa Department of Water Affairs has made efforts to eradicate the use of the inadequate sanitation systems – commonly known as bucket system. Despite these efforts, there are still millions of people who are forced to use the bucket and other unacceptable systems (Socio-Economic Rights Institute of South Africa (SERI). 2011). The majority of the people existing without adequate sanitation live in already bulging yet continually sprawling, informal settlements. Service infrastructures are strained, without the prospect of more people to support.

This paper delves into the dark and complex world of the sanitation crisis in informal settlements. It describes the key elements in the sanitation provision in informal settlements, and specifically, in the context of Enkanini, an illegal informal settlement in Stellenbosch. The settlement is 40 km west of City of Cape Town and consists of about 8000 people serviced by only 72 toilets (Tavener-Smith, 2013). In light of this predicted predicament, addressing the sanitation issue provides an opportunity to explore the implementation of appropriate technology options which more aptly suit the needs of the residents.

2 Sanitation situation in the City of Cape Town and Enkanini informal settlement

The City of Cape Town is home to more than 220 informal settlements, made up of a population of approximately 900 000 people (Mels et al., 2009). Despite the City of Cape Town Municipality's goal to provide 100% access to basic water supply and at least 70% access to sanitation services to all informal settlements, sanitation coverage is still lagging behind (Mels et al., 2009). Poorly maintained toilets are also evident in the informal settlements (Figure 1)

Figure 1: Poorly maintained toilets in informal settlements in Cape Town

According to official statistics, around 36.5% of the population of informal settlements in Cape Town are serviced with basic sanitation; in reality, this number is considerably lower (Mels et al., 2009). In this case the disparity has two main causes; firstly, the officially accepted number of people living in informal settlements is dramatically lower than the actual number (Mels et al., 2009). Secondly, these statistics also include bucket toilets and eradicate containers as basic sanitation, which the majority of experts agree are not sanitation options at all; taking these details into consideration, the percentage of people in informal settlements provided with basic sanitation is estimated to be around 15% (Mels et al., 2009).

One of the informal settlement struggling from a lack of basic sanitation services is Enkanini, which is an illegal, informal settlement consisting of around 8000 people, which also translates to approximately 2500 households (Tavener-Smith, 2013). According to Shark Dwellers International (2012), the ratio of people to toilets is approximately 72:1 and, of the 80 existing toilet blocks, 9 were in desperate need of maintenance while 9 were vandalised (see Table 1) . It should be noted that the aspiring South African standard ratio for people to toilets is 5 households per toilet (City of Cape Town., 2008). The distribution of these toilets paired with recent violent acts has led to an increase in unequal access, with some 90% of residents expressing fears of using unlit toilets at night (Shack Dwellers International., 2012).

Table 1: Summary of key findings of enumeration in Enkanini

Name of settlement	Enkanini
Age of settlement	7 years (2006)
Type of structures	All shacks
No. of shacks	2494
Land ownership	Municipality
No. of community toilet blocks	80, 9 need maintenance and 9 vandalised
Ratio of toilets/population	1:72
Water taps	32, all functional and well maintained
Ratio of water taps/population	1:139
Disaster experience	Mainly fire (111) and flooding (840)

Source: Adapted from Shack Dwellers International (2012)

The pressures of insufficient sanitation in Enkanini informal settlement are expressed differently depending on whom you ask; but seeing that conventional water supplied sanitation has proved immensely inadequate in a resource and topography constrained Enkanini (see Figure 1), a group of students from the University of Stellenbosch have begun to look at possible alternatives (iShackliving, 2012). This is where the inspiration came from to analyse the effect that different sanitation technologies have on the standard of sanitation.

Figure 1: Photos from the Informal Settlement of Enkanini (taken by J Radmore)

Working side by side with Enkanini residents and the Stellenbosch Municipality in a transdisciplinary co-production process, the group is seeking to conceptualise alternative sanitation solutions (iShackliving, 2012). Many different solutions have been explored, ranging from compost toilets to the use of ventilated improved pit latrines (VIP). The focus has now been placed on the use of pour flush toilets connected to a bio-gas digester, at a ratio of five households per toilet (iShackliving, 2012).

The fact that this is not merely a technical problem has not been forgotten (iShackliving, 2012). Along with the analysis of alternative technologies, the Enkanini Sanitation Cooperative (using the co-production, transdisciplinary process) has begun to explore alternative techniques for governing and maintaining this complex system (iShackliving, 2012). Tracking and developing residents' demand for improved sanitation and building local supply and maintenance capacity are two keystone interventions that the Cooperative are seeking to implement in Enkanini (iShackliving, 2012).

The group has yet to find a 'perfect' solution and is very interested in being able to track the viability of different sanitation technologies as well as the effect it could have on the standard of sanitation, taking into account community demand, community temperament and actions, functionality, dignity, and attached value to name but a few (Tavener-Smith, 2013).

The definition of basic sanitation as described in the City of Cape Town's Water and Sanitation Service Standard is as follows; "The provision of a shared toilet (at a ratio of not more than 5 families per toilet) which is safe, reliable, environmentally sound, easy to keep clean, provides privacy and protection against the weather, well ventilated, keeps smells to a minimum and prevents the entry and exit of flies and other disease-carrying pests; and the provision of appropriate health and hygiene education." (City of Cape Town., 2008).

The standard of sanitation in Enkanini is well below the national average, it is therefore obvious that there is an inadequacy of sewage management and disposal. This inadequacy is made obvious by the gap existent between actual or existing standard of sanitation in informal settlements and the expected standard of sanitation. This gap represents the specific problem being model, using systems dynamics.

3 Model description

System dynamics represents complex systems and analyses their dynamic behaviour over time (Forrester, 1961). According to Coyle (1996): "system dynamics deals with the time dependent behaviour of managed systems with the aim of describing the system, and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control policy through simulation and optimization". Thus, the main objectives of system dynamics approach are (Sterman, 2000, Maani and Cavana, 2007, Ford, 2010): (i) to clarify the endogenous structure of a particular system of interest under study; (ii) to identify the interrelationships of different elements of the system under study; and (iii) to account for different alternatives for simulation and explore the changes in the system under consideration.

Different scholars have organised system dynamic modelling process as following a number of steps, varying from three to seven different stages (Randers, 1980, Richardson and Pugh, 1981, Roberts et al., 1983, Wolstenholme, 1990, Sterman, 2000). Following Sterman (2000), the process of system dynamics modelling begins with problem identification and definition, where the problem and the objective of the analysis are clearly described. This is followed by conceptualisation where the boundaries and identification of causal relations are described. This stage forms the qualitative analysis. The next step is to develop a formal and simulation model utilising system dynamics software packages. Once the model is developed, the modeler is required to test the model reliability and validity before undertaking policy analysis.

For the case of this paper, it was identified that a gap exists between the expected standard of sanitation and the actual standard of sanitation in informal settlements. As the standard of sanitation improves the gap will decrease, this increase in the standard of sanitation will also, with a delay, result in an increase in the sanitation expectation; this follows a simple assumption (mental model) that the more someone has, the more they want. As sanitation expectation grows, the gap between actual and current sanitation also grows (Figure 2).

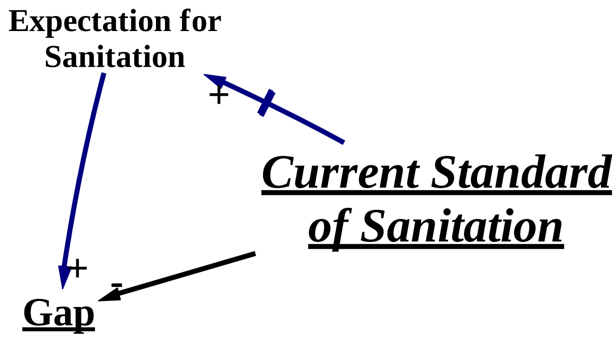

Figure 2: Sanitation problem identification

3.1 Qualitative analysis – causal loop diagram

The first stage of making a causal loop diagram requires identifying the key variables.

Table 2 shows these identified variables and how they were defined for the purpose of the sanitation problem in informal settlement. The sub-sections that follow describe the dynamic hypothesis of the problem.

Table 2: Variables considered in the CLD

Causal Loop Variables	
Current standard of sanitation	The current standard of sanitation within the settlement taking into account the "percentage of the population using improved sanitation facilities (World Health Organisation., 2012)
Expectation for sanitation	The standard of sanitation the individuals within the settlement expect. Using a simple assumption that the more someone has the more they will want
Gap	The difference that exists between the current standard of sanitation and the expected standard of sanitation.
User temperament	The general disposition of the individual user of the sanitation services. How the people within the settlement feel about the sanitation situation. Can be either positive or negative.
User conduct	The actions of residents that result from their temperament, they can care for the existing facilities (or not), engage positively with the service provider, protest or vandalise toilets depending on their current disposition.

Serviced population	The amount of people that have adequate access to the sanitation facilities taking into account the population, the serviceable population and the sanitation experience.
Sanitation experience	The individual's experience when making use of the sanitation facilities taking into account the user's dignity, safety, aesthetics of living space, privacy, and attached value.
Cleanliness of facilities	The general cleanliness of the facilities. The containing unit as well as the toilet itself.
Service provider accountability	The accountability of the service provider, this determines whether or not the facilities are maintained, cleaned and serviced. This declines naturally at a constant rate and is can also be influenced through public action (protest).
Need for additional intervention	If the sanitation problems, vandalism and protest, within the settlement, become too large additional intervention will be needed by either government or private institution.
Emergency budget	The amount of money provided by the intervention team to solve the growing problem
Serviceable population	The number of people, taking into account policy required number of people per toilet and the number of existing number of toilets, that that can be adequately serviced.
Number of functioning facilities	The number of working and clean toilets facilities within the settlement.
Prevalence for disease	The probability or frequency of disease spreading through the settlement
Health	The general health of individuals living in the settlement
Population	The mount of people living in the settlement, taking into account the rate of birth and death.
External defecation	The practice of relieving oneself in open areas, this also takes into account the use of bucket toilets.
Toilet decommissioning rate	The rate at which toilets degrade, to a point where they are no longer usable
Enviro impact	The impact that the external defecation has on the environment.

3.1.1 Main sanitation loop

The dynamics within the informal settlement sanitation problem is mainly dependent on the sanitation gap (Figure 3). As the gap increases, it in-turn decreases user temperament. As user temperament develops a negative trend, user conduct (actions) begins to deteriorate, resulting in protests, decreased care of the toilets and vandalism. As this worsens, conduct begins to influence the functionality of the facilities negatively (reduced care, vandalism), thus the number of people who have access to functioning facilities decreases. As the serviced population decreases, the sanitation experience (users' dignity, safety, aesthetics and privacy etc.) decreases, further decreasing the standard of sanitation, creating a reinforcing causal loop as seen in Figure 3

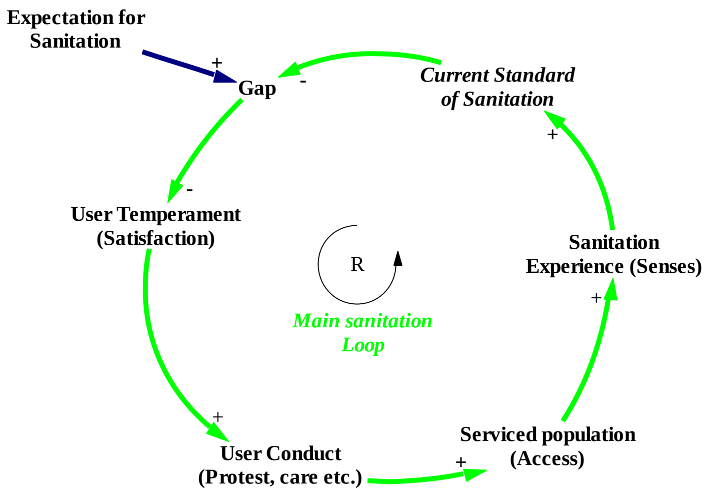

Figure 3: Main causal loop for sanitation

3.1.2 Health, the environment and toilet decommissioning loop

As more people begin to practice bucket or external defecation there is an increase in environmental impact, decreasing the sanitation experience. The better the experiences, the better the current standard of sanitation. This increases the gap, which in-turn decreases user temperament. As user temperament develops a negative trend, user conduct (actions) begins to deteriorate, resulting in protests, decreased care of the toilets and vandalism. This is shown in environment loop in Figure 4.

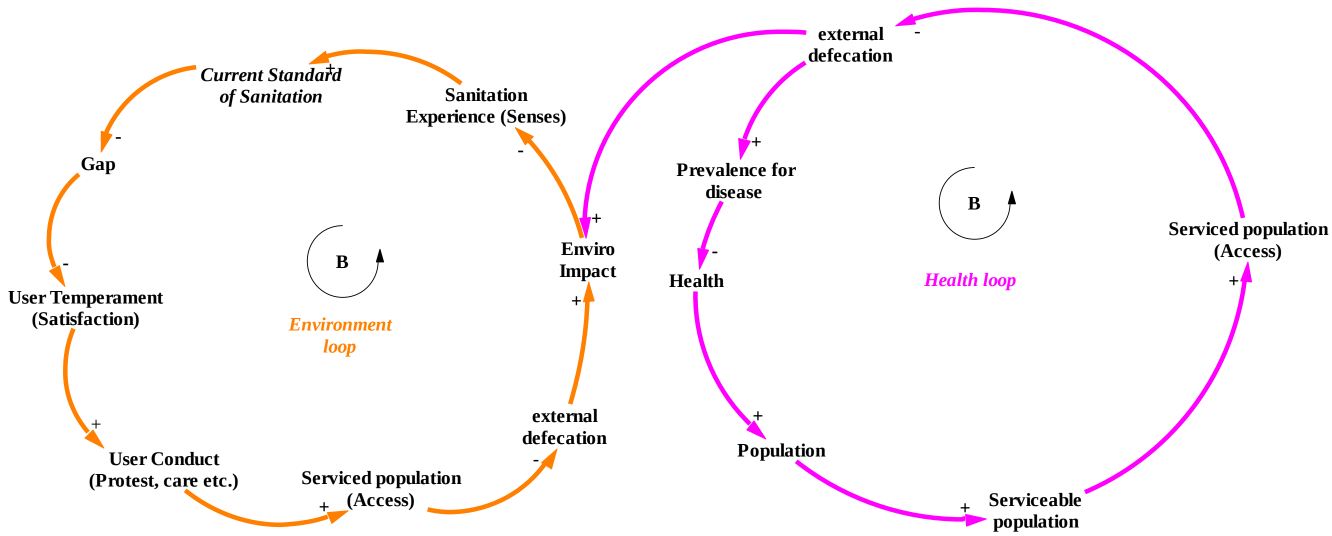

Figure 4: Health loop and environment loop

As fewer people have access to adequate facilities (serviced population) more people begin to practice bucket or external defecation, resulting in an increase in the prevalence of disease, decreasing the general health of the settlement and ultimately the population. As the population decreases the serviceable population (number of people that can be furnished with an adequate facility given the number of toilets) increases, as shown in health loop, which is a balancing one.

3.2 The model

Developing stock-and-flow model required classifying and identifying which are the endogenous variables, exogenous and excluded one. Table 3 presents the boundary map for the sanitation model. Vensim DSS was utilized to develop the model. The time-step for the model was in months and was simulated for 240 months. The model sub-models are discussed in the subsequent section.

Table 3: Variables considered in the formal model; key variables are in bold.

Endogenous			Exogenous	Excluded
Stocks	Flows	Auxiliaries	Parameters	Excluded
Population	Births Deaths	Death-rate	Initial Population Birthrate Base Death-rate	Migration

Endogenous			Exogenous	Excluded
# of Toilets	New Toilets Decommissioned Toilets Destroyed Toilets	New toilets needed Potential toilets to install Monthly Budget Emergency Budget Cost of Toilets Building Delay Vandalism Rate Decommissioning Rate	Initial # of Toilets Initial service provider budget	Who service provider is
Accountability	More / Less		Loss of motivation	Profit Governmental attention
External Waste	External defecation Biodegradation	Total human waste per month Likelihood of external defecation	Average waste per person per month Half-life of Human Waste Area Impacted per Kilogram Initial prevalence for disease Size of Settlement	Effect of Runoff Water
		Standard of Sanitation Serviced Population Serviceable Population	Choice of Technology Policy-Req people per toilet Importance of senses to sanitation	Effect of external defecation on senses (their dignity etc)
		Senses Fulfilled Safety Dignity Privacy Attached value Aesthetic value Current privacy level Current Toilet Distribution Hygiene education	Optimum privacy level Optimum toilet distribution Rate of learning Initial hygiene education level	
		Cleanliness of Facilities Needed servicing Actual servicing Proportion of serviced facilities		
		Expectation of Sanitation Gap Between Expected and Actual Sanitation User Temperament Care Positive Engagement Protest Violence & Vandalism	Emotional Volatility Expectation Creation date Minimum Expectation	Effect of senses on expectation
		Prevalence for Disease	Initial prevalence for disease	

3.2.1 Sub-Models

(i) Population sub-model

The population was determined using one stock, demonstrating growth through births and reduction with deaths (Appendix 1). The prevalence for disease, an auxiliary determined by sanitation's impact on health, is a factor multiplied to the death-rate as it has influence on the death rate.

(ii) Sanitation Experience (Senses Fulfilled) sub-model

The senses of dignity, privacy, aesthetic value and attached value are each given an intrinsic value by the choice of technology, following the notion that each technology will affect these senses differently (Appendix 2). Dignity is further affected by the users' engagement with the service provider; positive engagement shows more dignity and protest shows decreased dignity. This can be interpreted as the engagements directly changing a person's dignity or as a reflection of the dignity required to take these actions.

Privacy is further affected by the number of people having to use each toilet. This is demonstrated using an optimum privacy level (set at 5 people per toilet - one household). The current privacy level uses the current number of toilets to show how many people are receiving optimum privacy out of our total population. Aesthetic value is further affected by the environmental impact. As the impact increases, aesthetic appreciation for the living area will decrease to a point at which it becomes an accepted norm (stable).

Attached Value of the Technology is further affected by hygiene education, particularly relating to how people value their toilets. This is presented as a potential policy intervention which can be switched on or off, and is determined by an initial education level of the settlement and a rate of learning. Improvements to this could involve a way to change the rate of learning over time, to change hygiene education into a stock, and include a trigger mechanism (if for example the sanitation level drops below a certain point). The baseline sets the initial level at 0.3 and the rate of learning at a static 0.005/month.

Finally, safety is determined by proximity of the user's home to a toilet. In an unstable settlement, the farther the toilet is from the home, the less safe it is to go and use it, particularly after dark. The model assumes an even distribution of toilets, which is not necessarily realistic. It compares the optimum distribution of toilets to the current distribution; current distribution is the current number of toilets divided by the area of the settlement. This sense could be improved with development of a base danger level inherent in the settlement and a more realistic way to show toilet distribution, perhaps with an average distance to household. The baseline has the optimum distribution at 1 toilet per 20 square meters (a maximum 10 meters from the household), and the size of the settlement is 50,000 square meters. Safety is also diminished by the occurrence of protest and violence in the area.

It should be noted that senses can be influenced by a number of external factors, but for the sake of the model, they express only how sanitation influences them. The senses are informed by the technology type, but much isn't shown about the sanitation experience for those who aren't using a toilet. Privacy somewhat includes this by making a ratio of those 'with privacy' and those without.

(iii) Health and Environmental Impact

If a person does not have access to a toilet, then they will find somewhere to do their business; this is called external defecation and has huge impacts on the environmental and human health of the area (Appendix 3). The likelihood of external defecation is the proportion of unserviced people out of the total population.

Health impact is expressed as the prevalence for disease, which may have an initial rating for the area and increases: to a maximum of 60% as external defecation increases (this is based on the likelihood of getting cholera from contaminated water); to a maximum of 30% as the cleanliness of the facilities decrease.

For the model, environmental impact is simplified to the area affected by improper feces disposal out of the total area of the settlement. The waste is presented as a stock which is increased over time by external defecation (percentage of people doing so multiplied by the total waste generated in the settlement), and decreased as the waste biodegrades. These both are served by two parameters, the average amount of waste generated per person (~300g per day or 10kg a month for the baseline) and the half-life of human waste (1kg per year or 1/12kg per month for baseline). This remains logical; however the model then determines the area impacted by this waste in a way that assumes waste can only be deposited on fresh ground (land affected per kg of waste - .25m2 per kg for baseline), therefore assuming an even distribution of impact throughout the settlement.

(iv) *Number of Toilets*

Number of toilets is represented by one stock, which is increased by a flow of new toilets and decreased by flows of decommissioned toilets and toilets destroyed through vandalism (Appendix 4). The model assumes that toilets will only be built if they are needed, needed toilets being determined by the national policy-required number of people per toilet. They can only be built if there are funds available to do so; such funding can come from a monthly service provider budget, or from emergency funding (perhaps from the government or private institution) when the sanitation level is observed to go below 0.2; the emergency funding is enough money to pay for all the needed toilets. The number of toilets which can be built from this budget is determined by the cost of the toilets (dependent on the choice of technology). The length of time it takes to build the toilets is dependent on how accountable the service provider is, taking anywhere from a month to six.

Toilets are destroyed if instances of vandalism and violence occur; the vandalism rate rises slowly to 3% from no vandalism before rising rapidly to a maximum of 30% as people get much angrier. Toilets are decommissioned according to the life expectancy of the technology (choice of technology) and how well maintained they are (cleanliness of facility). If maintenance is high, the decommissioning rate can be reduced by up to 20%, and alternately, if maintenance is low, the decommissioning rate can increase by up to 20%.

The only two parameters for toilets are the initial quantity, set at 66 toilets (the population divided by the policy-required 15 toilets) for the baseline, and the initial budget, set at 0 to show an expected decline in sanitation.

(v) *Cleanliness of the Facility*

The cleanliness of the facility is determined by the proportion of facilities which are serviced, which is in-turn determined by how often it needs to be serviced and how often it is actually being serviced (Appendix 5). The choice of technology informs how often it must be serviced, and the accountability of the service provider determines how often this is actually being done.

Whether or not users care for the facilities also affects the level of cleanliness; as care increases, cleanliness can maximally double, and if it decreases, cleanliness can maximally halve. Should one wish to remove functionality or cleanliness from their definition of sanitation, the switch would allow this.

(vi) Accountability of the Service Provider

Accountability is represented as a stock for this model for simplicity of use (see Appendix 6). The assumption is that without positive engagement, protest or profit, service provider accountability will naturally decline (numerically shown in the loss of motivation variable). As profit has been excluded, positive engagement and protest are the variables which increase accountability (to larger degrees as they increase). It is further assumed that protest increases accountability much faster than positive engagement. As an index, accountability ranges from 1 to 0.2 (assuming, optimistically, that accountability cannot drop below this), so the initial accountability must be between this; baseline starts at 1. For the baseline, our accountability loss is 0.01 per month. Should one wish to see the model without the effects of diminished accountability, it can be turned off with the switch.

(vii) *User Temperament and User Expectations*

User temperament is what determines the user behaviors of care, positive engagement, protest, and vandalism and violence (Appendix 7). With 0.6 as the neutral point, care is at 1 (neutral), positive engagement, protest and violence are at 0 (not occurring). As user temperament gets higher, care gets better and positive engagement begins and increases. As user temperament decreases, care gets worse, and both protest and violence begin and increase. Care is further influenced by hygiene education; as education increases, so does care (ranging from 80% when education is below 1, to 120% when it's above).

To represent a feeling of humanity (and demonstrate the fluctuations feelings), a variable called emotional volatility, which randomly increases or decreases user temperament by 1% each month, is included.

The gap between expected and actual sanitation determines the user temperament. This was difficult aspect to explore, simply because expectations are built from so many things which are not easily explainable, let alone capable of being quantified. Expectations are based on past experiences, what others have (the green-grass syndrome), altered by changes in other aspects of one's life, and e influenced by the hypothetical (dreams). This brings to questions such as: Should expectations continue to grow? Should they be static? Are they always higher than what one actually has? Can one remain happy with what one is receiving?

This warrants a model all on its own. Wishing to keep the influences endogenous, and retain our feedback loops, we simplified expectations into what one had experienced before. The earlier standard of sanitation is determined by the expectation creation date (how long ago one looks back); for the baseline we used 12 months.

A difficulty with only using this is that if the gap between actual and expected is too small, no action will be taken by the users; this is the case regardless of what their standard of sanitation is. While one can logically understand that users will get comfortable receiving what they expect, it doesn't allow any endogenous improvement of sanitation. For this reason, a minimum expectation was added to account for seeing the green grass over the fence. For the baseline, it's at 0.4, meaning that if sanitation dips far below that, users will do something about it. A better improvement to this could be an outsider intervention, similar to the emergency funding for toilets. Connecting the senses of sanitation (or perhaps the expectation inherent to each sense) directly to the expectation of sanitation may also be a way to add dynamic to the expectations

(viii) Choice of Technology

The Choice of Technology has implications for each of our key variables, setting initial or constant values for many parameters in the model using the function of a lookup table. The variables it directly affects are the cost of, and decommissioning rate of toilets, base value for some of the senses, and the need for servicing the toilets. The technologies are each designated a number, with Pour Flush Toilet at 0, Vent Pit Toilet at 1, Compost Toilet at 2, Traditional Flush at 3, and a 'neutral toilet' at 4. The neutral toilet serves as the baseline, having no positive or negative effects on the senses and taking the average of the selected technologies for the other parameters. An example of how a lookup table is used to determine the users' attached value of the toilet is shown in Figure 5.

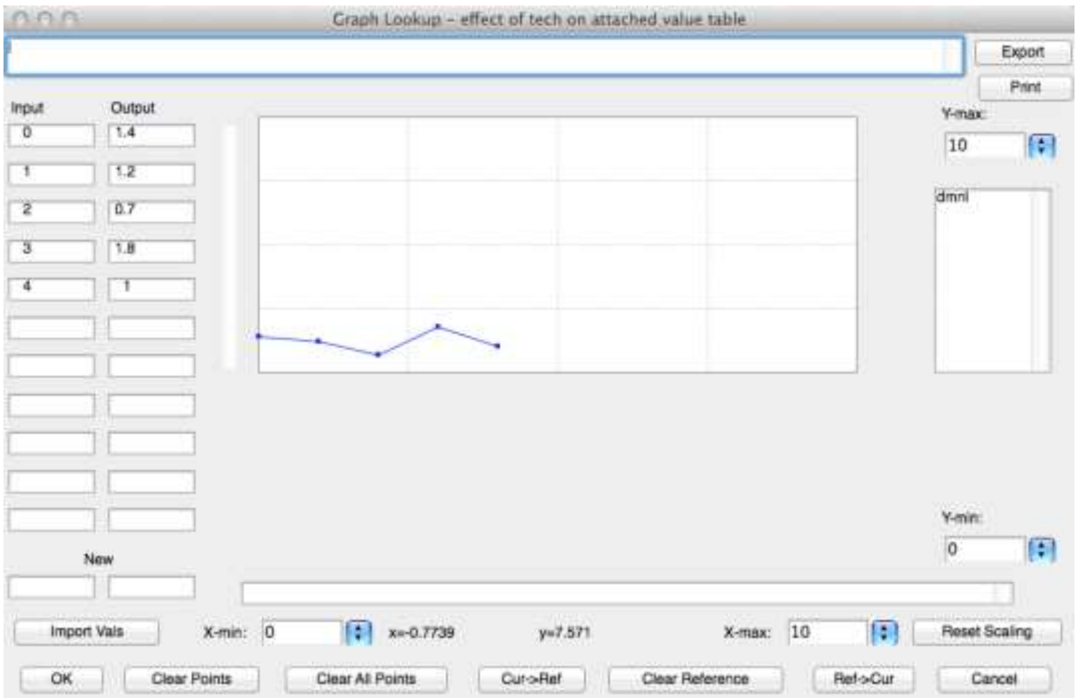

Figure 5: Users attached values to different technologies

Values assigned to each technology are demonstrated in Table 4 and Figure 6. Included in this is the bucket technology, which was originally considered. This is essentially external defecation, as the contents of the bucket are typically deposited in the same area. The model was altered to include the effect of external defecation on environmental impact, and so we no longer include bucket technology in the lookup tables. Environmental impact of technology is excluded from the model, but this refers to any leakage of waste into the environment.

Table 4: Characteristics of different sanitation technologies

Choice of technology / Parameters	Base (4)	Pour Flush (0)	Ventilated Improved Pit (VIP) (1)	Compost toilet (2)	Regular toilet (3)	Bucket
Life span (years)	32	35	35	10	50	5
Decommissioning Rate (1/month)	0.0026	0.00238	0.00238	0.00833	0.0017	0.00017
Cost per unit (R)	5800	7000	4500	1700	10000	100
Frequency of cleaning/servicing	Daily /4years	Daily/month	Daily/2years	Daily /8years	Daily/month	Never
Needs Servicing (1/month)	0.625	15	1.25	0.313	15	0.001
Aesthetic value	1	1.2	1	0.8	1.5	0
Privacy	1	1.6	1.6	1.2	1.6	0.5
Dignity	1	1.2	0.9	1	1.5	0.2
Attached value	1	1.4	1.2	0.7	1.8	0

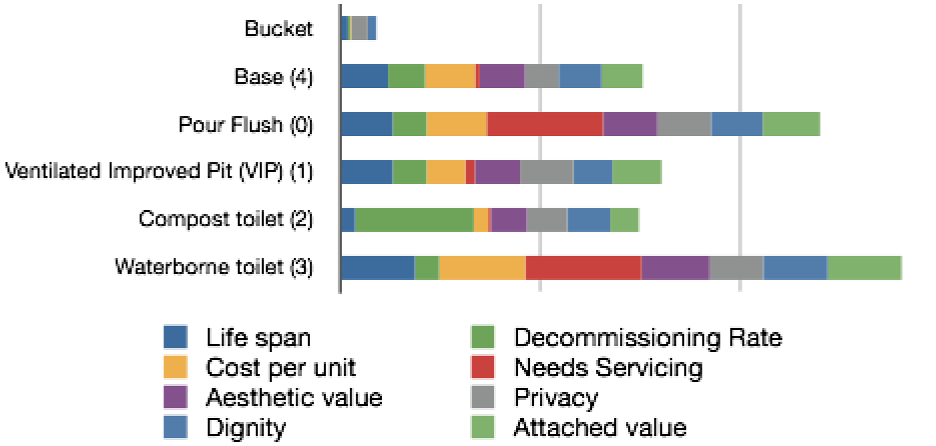

Figure 6: Attributes attached to different sanitation technologies.

3.2.2 Baseline parameters

The baseline parameters and assumptions selected as inputs for Enkanini informal settlement was established through an interview with Tavener-Smith (2013), who is a PhD student working in Enkanini focusing on the sanitation problem, as well as the first two authors personal experience as they are part of the Enkanini research team. The baseline parameters are presented in Table 5.

Table 5: Baseline parameters for Enkanini informal settlement

Name of settlement	Enkanini
Age of settlement	7 years
Choice of Technology	4 (neutral tech for baseline) 0, 1, 2, 3, 4 (Technologies)
Policy-Required people per toilet	15 people/toilet
Population	8000
Birth Rate (SA average)	19.32 births/1,000 population – 0.01932
Death Rate (SA average)	17.23 deaths/1,000 population – 0.01723
No. of community toilet blocks	80, 9 need maintenance and 9 vandalised
Optimum privacy level	5 people/toilet
Initial Service Provider	
Accountability	1
Loss of motivation	0.01
Initial Budget	R230000 per year; R19166 per month
Acceptable number of people/ toilet	5 households per toilet (City of Cape Town, 2008: 11-12)
Optimum toilet distribution	1/20m2
Emergency funding	Twice the initial budget
Importance of sense to sanitation	40%
Emotional volatility	0.99-1.01

Expectation Creation time	12 months
Minimum Expectation	0.4
Average waste per person/month	10kg
Half-life of Human Waste	1/12 kg / month
Area Impacted/Kilogram of waste	0.25m2 / kg
Size of Settlement	254000m2
Initial prevalence for disease	1
Rate of learning	0.005
Initial hygiene education level	0.03

Scenarios for different sanitation technology options were simulated in order to assess their influence on the following variables; the (i) standard of sanitation, (ii) population, (iii) user temperament (related to sanitation), (iv) number of toilets, (v) the sanitation experience (dignity, safety, privacy etc.), (vi) the cleanliness and functionality of the facilities, (vii) service provider accountability and (viii) the health and environmental impact related to sanitation.

4 Model testing and validation

Validation is an important step for creating a model. Barlas (1996) explains that for a causal-descriptive model (any systems dynamics model), validation must not only look for an accurate output, but at all the relationships which determine this behavior. Because such models are used to test the effectiveness of policy changes or adaptations to the behavior, these relationships must be explicit and simply influenced. Barlas (1996) offers two sequential validation procedures to check the structure-oriented behavior and the behavior patterns, which include theoretical and empirical structure tests, before moving onto structural behavior tests and then behavior pattern tests. At each point, should a test fail, the model must be revised and re-tested. Finally the model must be submitted for expert analysis to confirm the validity of the model (Barlas, 1996).

The model presented in this paper was subjected to structural and behavioral tests, following each of the causal links and looking at overall patterns. The difficulty in engaging with a complex problem is identifying a single behavioral effect from the system’s output. This is addressed through the addition of parameter sensitivity analysis.

Within the bounds of our limitations, the model awaits a final step of expert consultation, which will enable a thorough reworking of any magnitude issues.

5 Results – Enkanini case study

The results for this case study are presented as follows:

- Comparative results for the four technologies
  - Standard of sanitation
  - Sanitation experience
  - Number of toilets
  - User temperament
- Scenario 1 – Causal interactions for the Neutral Technology in Enkanini

Each scenario represents an integrated dynamic analysis of the (i) standard of sanitation in informal settlements, (ii) population, (iii) user temperament (related to sanitation), (iv) number of toilets and (v) the sanitation experience/senses fulfilled (dignity, safety, privacy etc.) for a different technology.

5.1 Comparative results for standard of sanitation

Figure 7 represent comparative results of the four different technology options and the neutral technology for the standard of sanitation, senses fulfilled the number of toilets and the user temperament. Each of these are key indicators within the system that allow for a more effective conceptualisation of the current standard of sanitation in Enkanini as well as an analysis of the possible influences that new technologies could have on the situation.

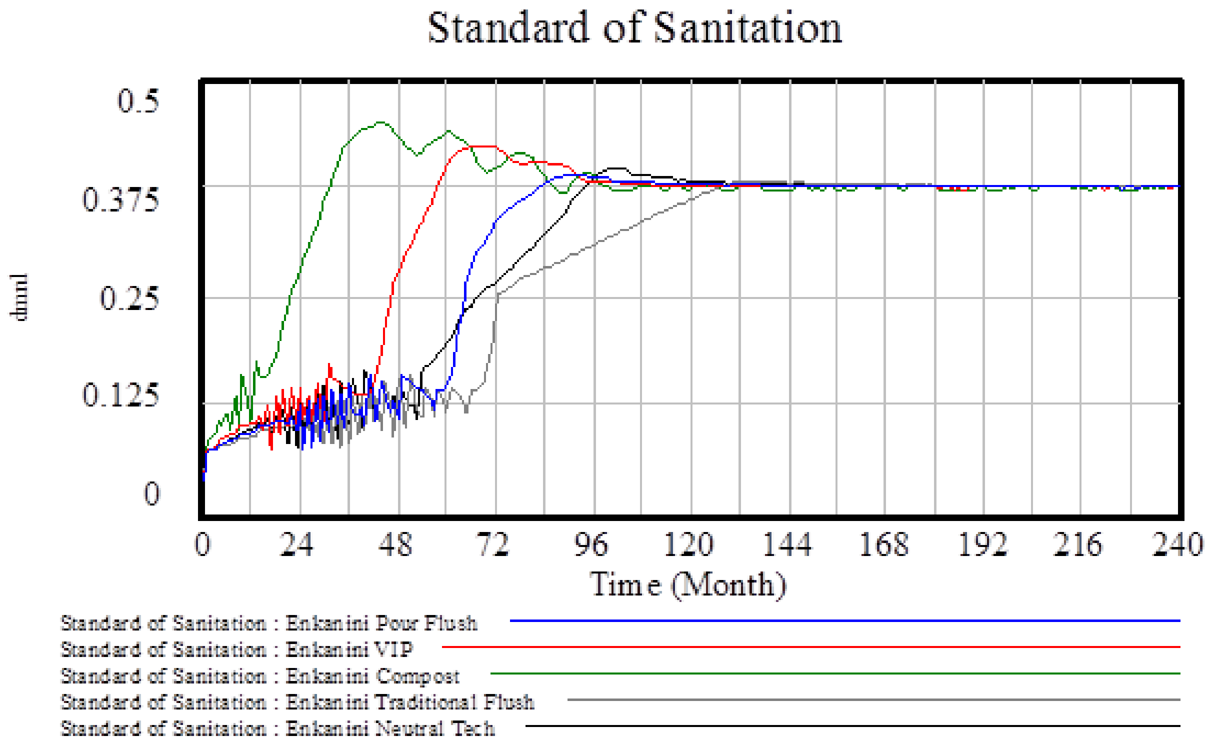

Figure 7: Comparison of Technologies: Standard of sanitation

From Figure 7, it can be seen that with the introduction of compost toilets the standard of sanitation quickly improves within the settlement. On the other end of the scale it is seen that the traditional waterborne technology will take the greatest amount of time to influence the standard. All of the different technologies increase the standard of sanitation at different rates before flattening out at 0.4; this is due to the fact that the model does not allow them to surpass the minimum expectation for sanitation of 0.4. A minimum expectation was added to account for seeing the green grass over the fence. For the baseline, it's at 0.4, meaning that if sanitation dips far below that, users will do something about it.

This is one of the limitations of the model as it proved very difficult to accurately and effectively model expectation. This graph does however illustrate how different technologies will address the sanitation problem at different rates; it also indicates the possible need of another policy intervention should the sanitation level become stagnant at a low level.

5.2 Sanitation Experience/senses fulfilled

Once again it is observed that the different technologies influence the sanitation experience at different rates with the waterborne ending well above the other options and the compost toilet well below. This fulfills the original mental model, staying true to what was expected as shown in Figure 8. It also is something for policy makers to consider when addressing sanitation; these differences in sanitation experience are as important as addressing the physical sanitation needs of a people. Awareness of this may reduce instances of protest or occurrences of 'poo wars.'

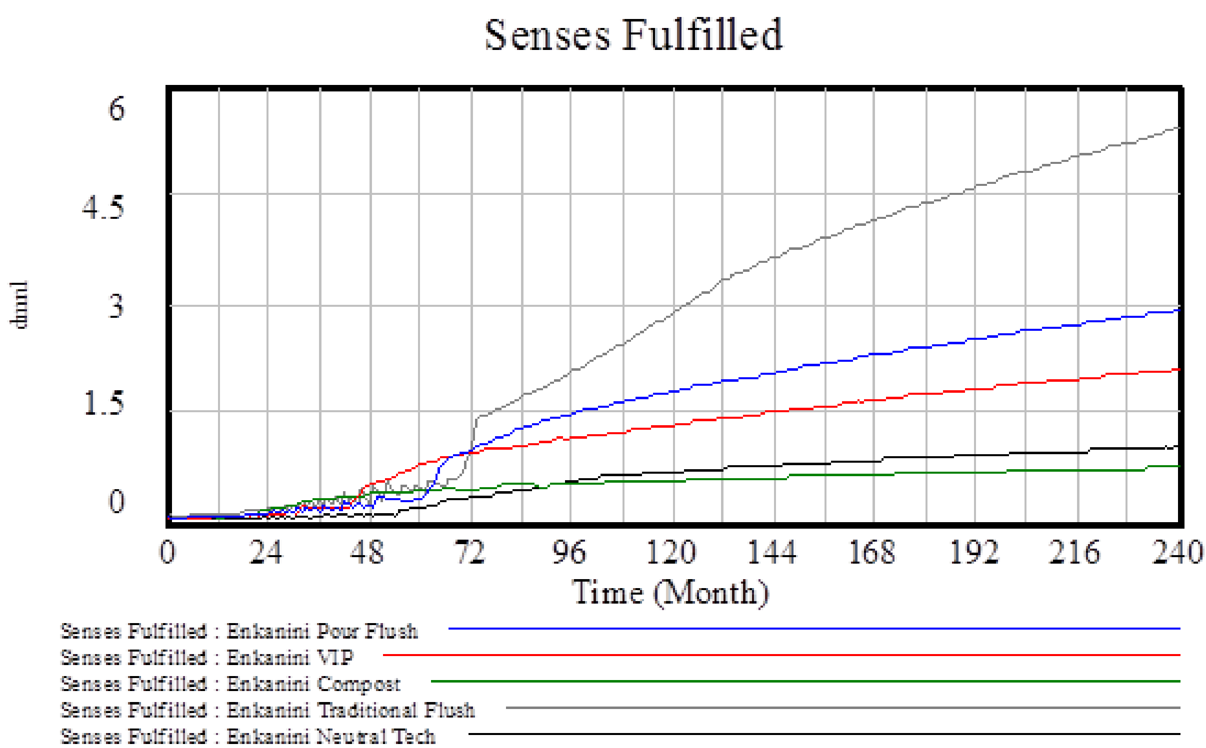

Figure 8: Comparison of Technologies: Sanitation Experience/senses fulfilled

5.3 Number of toilets

Figure 9 represents the stock of toilets for each technology. The stock of toilets increased by a flow of new toilets and decreased by flows of decommissioned toilets and toilets destroyed through vandalism. Each technology has a different cost per unit as well as decommissioning rate hence the difference on the graph. Compost toilets are relatively cheap and have a slow decommissioning rate. Whereas waterborne technology carries a high unit cost and an average decommissioning rate resulting in fewer toilets over time. The rate of toilet growth slows as the sanitation level stabilizes.

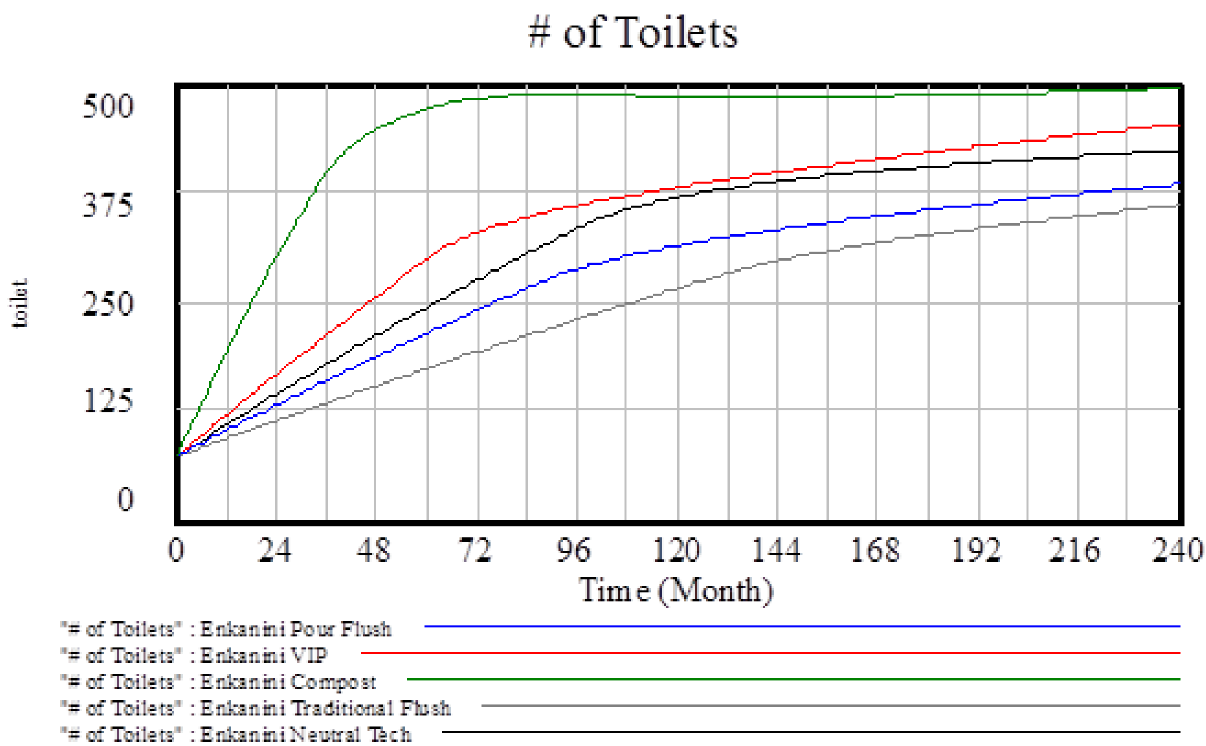

Figure 9: Comparison of Technologies: Number of toilets

5.4 User temperament

The gap between expected and actual sanitation determines the user temperament. Given the rate at which compost toilets can be produced (low cost price) this technology has a quick influence on the standard of sanitation in the informal settlement thus reducing the gap and improving the temperament. Waterborne toilets take long to build therefore influence the standard of sanitation and thus the user temperament at a slower rate. Figure 10 shows that user temperament results in leveling out of the sanitation standards.

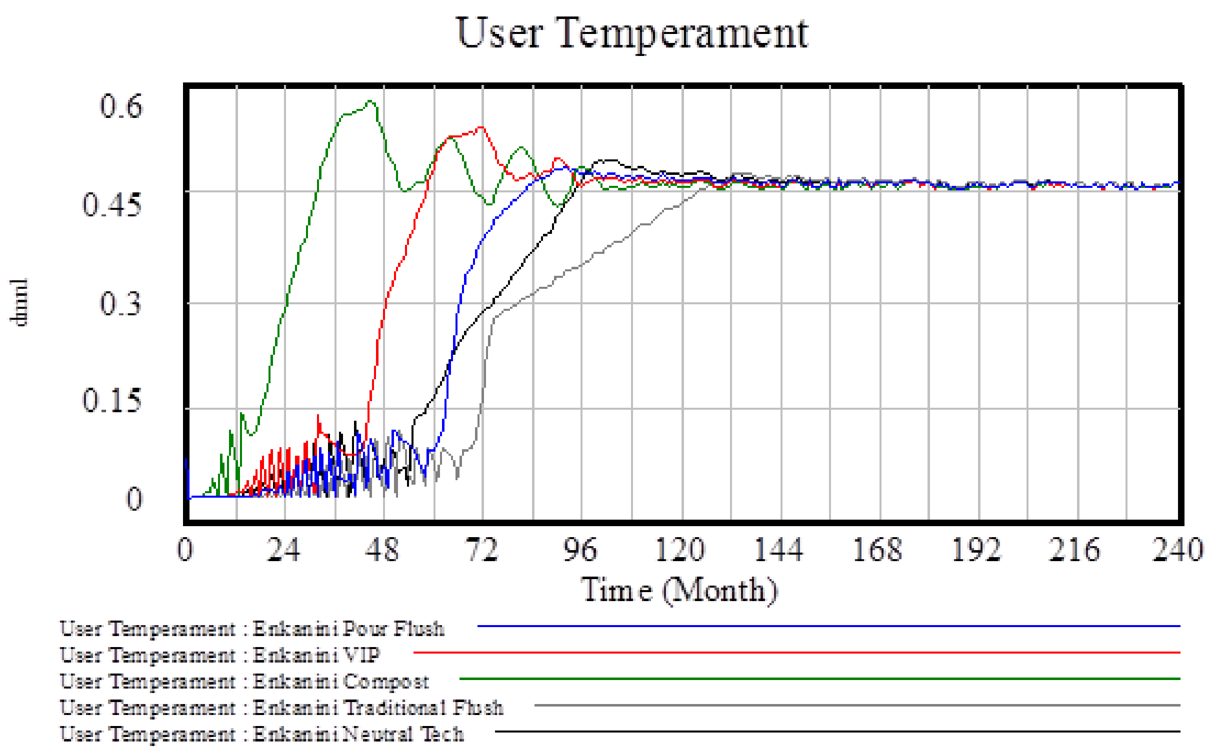

Figure 10: Comparison of Technologies: User Temperament

5.5 Causal interactions for the Neutral Technology in Enkanini

Taking into account the before mentioned parameters of Enkanini and a neutral technology the following results were obtained for the following indicators; number of toilets, population, senses fulfilled, standard of sanitation, user temperament, accountability and cleanliness of facilities.

Figure 11 demonstrates the workings of the model for the Enkanini case study. "The turquoise line shows a steady exponential population growth over time with a monthly budget of R19166, about 3.8 neutral tech toilets can be built a month (blue line). This tapers off as the sanitation level (black line) stagnates, but continues to grow to address population growth. The initial introduction of toilets improves the user temperament (brown line) which improves the standard of sanitation. Poor user temperament ensures high service provider accountability (red line), which keeps cleanliness (green line) high; the fluctuations in cleanliness are caused by the fluctuations in user temperament which determine how users care for the facilities. Finally, sanitation experience (grey) is seen growing then leveling out. This Figure demonstrates the average of all the other technologies combined.

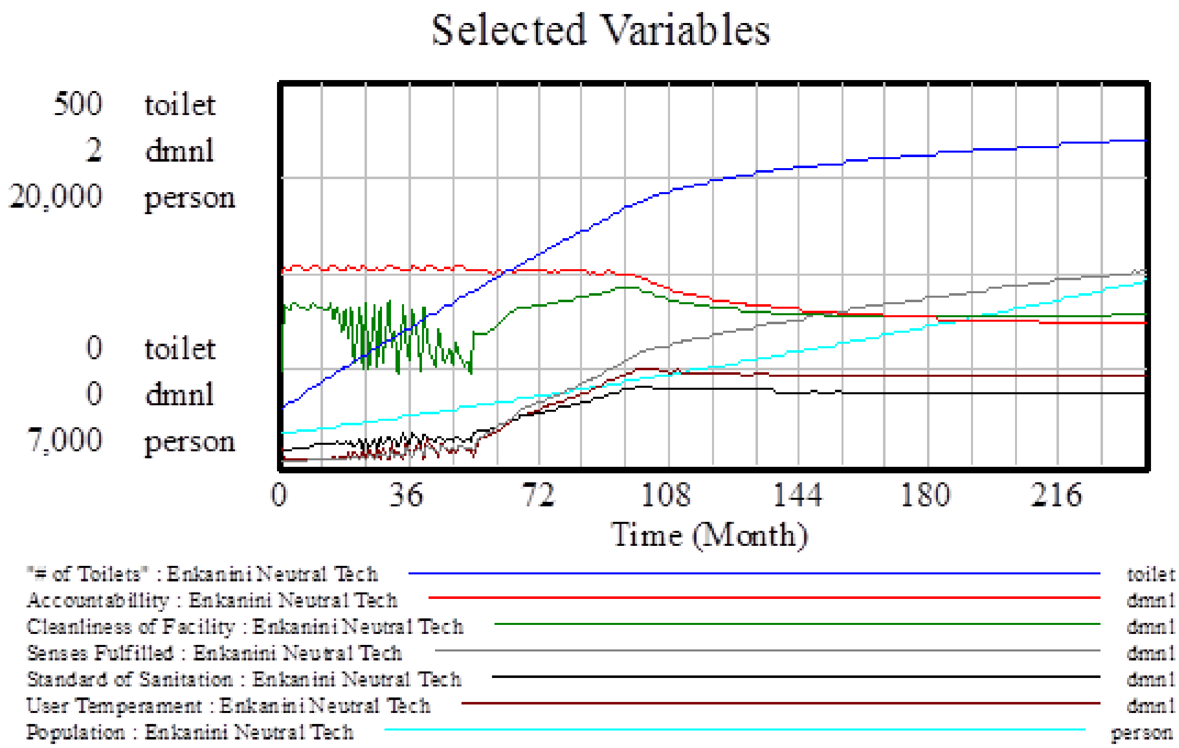

Figure 11: Key Variable Comparison: Enkanini Neutral Technology.

All of the technology scenarios tested showed an obvious positive improvement with regards to sanitation experience, the standard of sanitation and user temperament, albeit at different rates. They show what we would expect: that new facilities will have an impact on health and sanitation of world slums. It further demonstrates that the type of technology is vitally important for achieving sanitation goals, particularly in addressing the sanitation experience and balancing the costs and benefits of each technology.

6 Conclusion

This paper utilised systems dynamics to conceptualise the current standard of sanitation in Enkanini informal settlements as well as analyse possible influences that new technologies could have on the situation. The analysis is based on an understanding of internal and external interactions within the informal settlement, and the induced changes in its properties over time.

The application of the model to Enkanini was a useful demonstration of the model's strengths and limitations. The different scenarios produced unique results yet they all showed a common improvement with regards to the standard of sanitation in informal settlements, confirming to the world understanding that providing functioning facilities will improve sanitation. This however does not take into account the importance of context specific solutions and the sanitation experience which we believe to be a vital element of sanitation solution.

The model successfully demonstrated differences between the various technologies, suggesting a long-term benefit from waterborne sanitation, while showing the rapid improvement in sanitation from cheaper options of a compost toilet and ventilated improved pit latrine. The pour flush toilet and vent pit latrine occupied the beneficial middle ground of minimal investment for decent output in sanitation improvement as well as improvement of the sanitation experience.

Application to the case study also demonstrated the difficulty of modelling expectations as well as drawing out faults in the magnitude of certain variables' feedbacks into the system. Prevalence for disease had a greater impact on death rate than feasible, and will warrant some expert consultation. Within the bounds of the limitations, useful information was gleaned and further learning was afforded to the authors.

Using this model to analyse the major dynamics in informal settlement sanitation demonstrated that seeing the sanitation problem as merely a technical fix will not suffice. True change will require a transformation in how users and service providers approach the problem of sanitation, taking into account community demand, community temperament and actions, functionality, dignity, safety and attached value. This is truly one of the pressing challenges of the 21st Century.

Finally, this is still work in progress and the model is will further be refined through engaging with various stakeholders.

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