

A Study of Dynamic Interactions between Sanitation and Other Development Sectors

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Abstract:

The sanitation system is a complicated system made up of several interrelated variables, including those related to the people, the environment, the government, and hygiene which causes the system's complexity. With the increasing global focus on sustainable development, ensuring adequate sanitation and its impact on other development sectors has become a critical area of study. System dynamics is an appropriate approach to capture scenarios when different policies are imposed. The research aims to provide a comprehensive analysis of how sanitation policies can influence health outcomes, particularly in terms of resource allocation and infrastructure development. The causal relationships between these factors are interdependent. This research examines how sanitation influences other development sectors such as health, infrastructure, and resource management. This paper examines the linkages between sanitation policy and health sector in a system dynamic modelling approach. A model is created that contains important variables including population growth, sanitation coverage, health infrastructure coverage, infrastructure investment, ADP fraction for both sanitation and health infrastructure and unit maintenance cost to allow simulation of different policy options so that policy makers can visualize the implications of their decisions on sanitation infrastructure and health infrastructure on the long term. The friendly user interface makes it easy to adjust input ranges allowing for flexibility in incorporating extra variables and adjusting to changes in conditions.

Keywords — **System Dynamics, Sanitation Policy, Variables, Sustainable Development, Resource Allocation, Infrastructure Development, Casual Loop.**

I. INTRODUCTION

Sanitation is defined as “access to and use of facilities and services for the safe disposal of human urine and feces” (WHO). Sanitation involves the establishment of facilities and services to manage human excreta safely. This includes the processes of collecting, transporting, treating, and disposing of sewage. It addresses practices such as hygiene, supply of safe drinking water, disposal of solid waste and liquid wastes, and disease prevention. Sanitation is paramount for health – ranging from disease and illness prevention to improving and maintaining mental and social health. It is the lack of hygienic systems which causes infection and diseases

Sanitation has been acknowledged as an essential human right by the United Nations for over a decade. Sanitation means keeping things neat, hygienic, gathering all kinds of solid and liquid, and throwing them away safely for Earth. Despite this, only about half the world's population can access

proper wastewater and sanitation services (WHO and UNICEF, 2020) [1]. Human and human waste need to be distinctly separated to ensure proper sanitation, as recommended by the World Health Organization (WHO). It also treats water waste and encourages clean habits. The policy discusses the management of all types of liquid and solid wastes generated by healthcare facilities, various industries, and local government services. Sanitation is directly linked to the health of humans. More than half of the world's hospital beds are filled by people suffering from illnesses caused by poor cleanliness, according to the United Nations Development Programme (UNDP) [2]. Additionally, a lack of proper sanitation leads to numerous environmental and socioeconomic problems. A number of illnesses, such as polio, diarrheal illnesses, jaundice, typhoid, malaria, dengue virus fever, and cholera, are linked to improper disposal of human waste and poor personal hygiene [3]. Further requirements for accomplishing the objectives of a sustainable

environment include the need for waste reduction, reuse, recycling (3Rs), and changes in attitudes about consumption and production patterns [4]. Two billion people, on average, are thought to lack proper sanitation [5]. As per KP-MICS 2021, most often used facilities are flush toilets linked to septic tanks, flush to pit toilets, and facilities connected to a sewage system, which are utilised by 81 percent of the population of the KP. Over two million individuals, primarily (children) pass away each year from illnesses brought on by poor sanitation and a lack of access to clean water [3]. Access to proper sanitation is essential for maintaining environmental sustainability, preventing the spread of deadly diseases, reducing poverty, and promoting overall psychological health. One of the greatest difficulties of the 21st Century, and one that mankind is still far from conquering, is the everyday fight with sanitation that millions of peri-urban inhabitants face [4]. This problem must be recognized as a socio-technical issue that is deeply ingrained inside a number of complicated and interconnected systems rather than just as a technological obstacle. 6 billion people are projected to reside in cities during the second wave of urbanization [6], which is scheduled to take place between 2005 and 2050, bringing the total world population to 9 billion (United Nations Department of Economic and Social Affairs., 2010, UNEP., 2012).

II. LITERATURE REVIEW

Non-developed nations most especially those located within the regions of Asia are undergoing rapid urbanization due to industrialization and development of the economy. It is forecasted that urban populations will constitute 60% of the global population by the year 2030 in which majority of this urban growth will take place in countries that are still developing. In developing countries, diseases associated with poor hygiene, poor sanitation, and low-quality drinking water are the main causes of illness and mortality, particularly for children under five. To enhance the health of the population, countries must have in place functional sanitation technologies as well as health education to facilitate safe collection and disposal of feces. [28]

When compared to other sectors in Pakistan, the sanitation industry has always received less funding and has not received as much attention when it comes to developing and implementing strategies for sustainable sanitation [29]. Even after the development of the Pakistan National Sanitation Policy in 2006, unfavourable conditions persist. Surface and groundwater pollution as well as cross-contamination of water systems are frequently caused by old, inadequate, leaking, and poorly managed sewage systems with insufficient coverage. Most of the time, the collected home and industrial wastewater is dumped untreated into rivers, streams, and occasionally irrigation canals. Sanitation improves hygiene standards, such as hand washing, and creates a barrier against fecal diseases by collecting and disposing of human waste properly. Additionally, a well-designed sewage collection system lessens the chance of contaminating distribution systems and groundwater which, through water consumption, may have an impact on human health. Furthermore, impacts on the receiving water bodies can be minimized through the treatment and reuse of wastewater. It is estimated that only about 10 percent of collected sewage is effectively treated, resulting in an annual discharge of 2,000 million gallons of sewage into surface water bodies. Untreated domestic and industrial wastewater is being discharged on land and into receiving water bodies in Pakistan, causing significant harm to both surface and groundwater resources. [28]– [30]

As according to government of Pakistan Economic survey (2008) only 42% of people, 65% of whom live in urban areas and 30% in rural ones, have access to sanitation services. Roughly thirty percent of urban dwellers reside in slums. About 30% of people live in slums in urban areas, which lack proper sewage disposal and sanitation systems. The majority of those who live close to open drains or sewers are especially vulnerable to serious health problems. Furthermore, 14% of all deaths in children under five were related to diarrheal illnesses. 670,000 children in Pakistan miss school every day as a result of illnesses and inadequate water sanitation systems. [31]

Pakistan achieved the sanitation Millennium Development Goal for 2015 by cutting the

proportion of the population without sustainable access to basic sanitation in half. Access to rural sanitation increased to 67% in 1991 from 23% in 1991, among other things. [32]

For Pakistan's overall development and well-being, there is a critical relationship between environmental sustainability and economic growth, public health, education, and sanitation. The preservation of natural resources, reduction of pollution, and conservation efforts directly influence the economic productivity, public health outcomes, educational opportunities, and access to proper sanitation services for the population.[35]

To stop the spread of infections in hospital environments, adequate sanitation facilities such as clean water, appropriate sewage disposal, and hygiene services are essential. Many hospitals in Pakistan struggle to provide adequate WASH services, which greatly increases the risk of disease transmission between patients and healthcare personnel. [32]

Attendance rates are significantly impacted by schools' availability of sufficient sanitary facilities, especially for female students. Regular attendance can be discouraged by poor sanitation, particularly for girls who are menstruating. A key component of health education programs in schools is sanitation education, which aims to teach students about good hygiene habits and create long-lasting behavioral changes. [32]

The correlation between sanitation and public health is widely recognised in Pakistan. The nation's high rate of waterborne illness is largely caused by inadequate sanitation infrastructure. In Pakistan, diarrhoeal illnesses are particularly notable as the leading cause of death for children under five. More significantly, this problem is made worse by inadequate sanitary facilities[36]. Empirical studies have yielded convincing proof that improving and allocating resources towards sanitation infrastructure can result in a notable decrease in the prevalence of waterborne infections, ultimately leading to better public health outcomes [37]. Case studies from areas like Sindh and Punjab demonstrate the effectiveness of focused sanitation interventions [38]. For example, there has been a discernible decline in waterborne illnesses as a result of the Punjab Saaf Pani project, which aims

to provide clean drinking water and improved sanitation in rural areas. Similarly, community-led sanitation programs in Sindh have been effective in lowering the prevalence of diarrhoeal illnesses, highlighting the significance of regional efforts in addressing sanitation issues. [39]

In Pakistan, inadequate sanitary facilities in schools pose a serious obstacle to students' educational success, especially for female students. Basic sanitary facilities are lacking in many rural schools, which deters students from attending and raises the dropout rate, particularly for teenage girls who are menstruating. Studies indicate that the availability of hygienic, private, and easily accessible restrooms can greatly enhance student attendance and academic performance. [40]

Initiatives like Pakistan's WASH in Schools program have made improvements to school sanitation a priority in an effort to address these problems. Schools have reported lower absenteeism and higher attendance as a result of these initiatives, especially among girls. [41]

Severe problems with gender-specific sanitation exist in Pakistan, particularly in rural areas and informal settlements. For women and girls, access to private, secure restrooms is often severely restricted, endangering their health, safety, and dignity. Inadequate sanitation increases the risk of harassment and violence in places without public restrooms or where they are dangerous. [42]

Gender equality can be advanced and women and girls can be empowered through programs that support improved hygiene practices. For instance, the Orangi Pilot Project in Karachi, which focusses on community-managed sanitation, has improved women's participation in social and economic activities. These programs demonstrate how important it is to include gender perspectives in sanitation laws in order to facilitate more widespread social and economic development. [43]

Pakistan's economy will be significantly impacted by improved sanitation. Due to inadequate sanitation, the nation suffers large financial losses from lost productivity, medical expenses, and environmental damage [44]. According to a World Bank analysis, Pakistan loses billions of dollars in economic value due to poor sanitation, or about 3.9% of its GDP, every year.

It is not only necessary for public health but also economically to invest in sanitation. For example, every dollar invested in enhancing sanitation in Pakistan yields significant economic returns, such as increased productivity and lower healthcare costs, according to a cost-benefit analysis of sanitation interventions [45]. Better waste management systems in urban areas have increased tourism and business opportunities, making the economic benefits of improved sanitation especially apparent there.

In Pakistan, environmental sustainability has a direct link with improvement in sanitation issues if the management of waste and water pollution are taken under consideration. The poor sanitation techniques that have brought raw sewage to be dropped into rivers and other bodies of water have seriously affected public health and the environment [47]. Among the two examples of sustainable sanitation techniques essential to reduce the adverse environmental effects of human waste and push forward Pakistan's sustainable development, there are ecological sanitation systems and wastewater recycling.[48]

Enhancing sanitation is to be one of the priorities for Pakistan under its broader environmental and development agenda; that is why Pakistan is committed to the SDGs. SDG 6, which has placed a strong emphasis on access to clean water and sanitation, holds very special importance in the Pakistani context; and these resources are still severely limited in Pakistan. Coordinated efforts at the local and national levels to incorporate sanitation into more comprehensive environmental and development policies are needed to achieve this goal [49].

Thus, sanitation is a system with multiple interrelated variables, namely, environmental, social, infrastructure, population, governmental, and economic factors. Interfacing the multiple variables in nonlinear feedback loops makes this system complicated.

System dynamics is a method of understanding complex structures. System dynamics is more or less like a driving school in the sense that it teaches its students how complex the driving process is by using automobile-driving simulators. System dynamics often relies on nonlinear dynamics and

counterinitiative response concepts developed either in mathematics or engineering. The system dynamics models are designed in such a way that they can solve any problem in real time. In order to build an adequate model, the following preliminary steps must be carried out.

System dynamics is a top-down approach to modeling with an emphasis on dynamic complexity generated by the very structure of the system, its feedback loops, and also temporal delays. The system dynamic helps policymakers design optimal policies and evaluation studies. SD, originally referred to as industrial dynamics, was developed at the Massachusetts Institute of Technology.

The effective technique is based on system theory, computing information science, organizational theory, feedback control theory, tactical simulations, and tactical decision-making. The primary goal of SD is to create complex issue models that can be used in computer experiments. It uses a traditional causal loop methodology to create qualitative models of a system, which can then be used to generate dynamic hypotheses before developing a quantitative stock flow model. It was initially used in business management, but it has since spread to government policy, healthcare, the auto industry, and urban studies

III. PROBLEM STATEMENT

From the previous research it is found that limited research has been available on dynamics of sanitation system. The sanitation system has many interacting variables i.e., economy, population, investment and environmental factors, making the system complex. While creating sectoral policy, this complexity in the systems is frequently neglected. Conversely, using a linear approach and failing to account for how the system variables are interrelated results in unforeseen outcomes.

IV. OBJECTIVE

Identification of the variables of the sanitation system and other development sectors. Development of casual relationship among the complex variables and identify the Reinforcing Loops and Balancing Loops.

V. SCOPE OF WORK

The study aims to explore dynamic connections between the sanitation sector and other key areas of development, like health, education, water supply and tourism. Exploring this relationship determines how positive changes in sanitation create ripple effects that influence the performance and output of other sectors. For instance, better sanitation leads to healthier lives, reductions in diseases, and thus higher productivity that may contribute both to increased outcomes in education and also towards economic stability. The study will map through system dynamics model such feedback loops, identity mechanisms through which sanitation improvements can affect broader developmental progress, and shed light for integrated policy-making and resource allocation. Such relations need to be understood well in devising overall strategies for maintaining sustainable development.

VI. MATERIALS AND METHODS

The design of the research work consists of an evaluation of the present status of the sanitation system. This encompasses not only the existing literature but also the sanitation policies, laws, and regulations for the sanitation system of the study area for the purpose of recognizing the variables. A causal loop diagram for the thesis's problem area was created, which included all of the variables and demonstrated balancing and reinforcing loops due to their interconnectedness.

These factors identified are listed as below.

1. Population	2. Sanitation	3. Water Supply
4. Ponding of polluted water	5. Diarrheal Incidence	6. Nutritional Status
7. Health Outcome	8. Stunting	9. Health care cost
10. Financial resources	11. Increasing demand for sanitation	12. Hygiene awareness
13. Education	14. Roads	15. Tourism

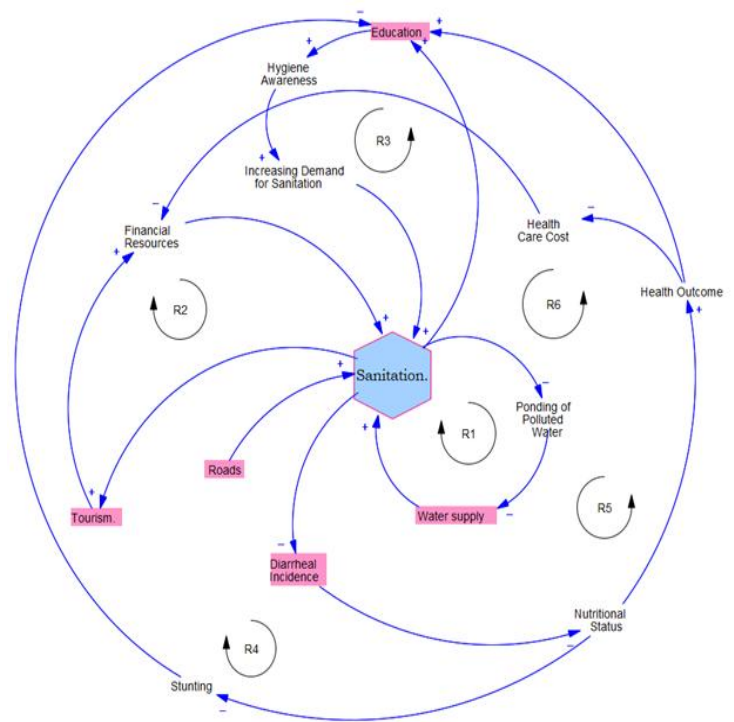


Figure 1 Causal Loop Diagram for Sanitation and other Development Sectors SD Modelling

Figure 1 illustrates the Casual Loop Diagram (CLD) used in this study to demonstrate the complex and interconnected relationships between various developmental sectors and sanitation. This diagram is a useful tool for understanding how changes in one area can have a positive effect on other sides of society, especially in a developing nation like Pakistan where sanitation is a major concern.

Sanitation stands at the heart of the diagram as one of the influential factors that affect as well as get affected by a number of other factors such as infrastructure, health, education, economic resources, and environmental factors. Sanitation affects a nation's outcomes about public health directly. Poor sanitation will lead to the collection of contaminated water, which increases the chances of suffering from diarrhea diseases. More prevalence of disease would lead to a poor nutritional status and general conditions, and therefore higher healthcare costs add up. There are fewer funds available for supplementary investments in sanitation when the healthcare costs

increase, thereby creating a vicious cycle of sustained bad health and bad sanitation conditions.

The better sanitation can have good effects on other sectors, as well as has shown above. The improved sanitation results in more heightened hygiene awareness that increase the need for better sanitation infrastructure. Increased demand maintains this cycle of continuous improvement through additional investments in sanitation infrastructure. Furthermore, improved sanitation results to accumulated financial resources that can be used to improve sanitation and other cognate fields. The resources could probably gain through reduced healthcare cost and greater economic productivity.

Another area strongly impacted by sanitation is education. The more improved sanitary facilities available, the better the education outcomes, as depicted in the diagram. Poor sanitation within schools is a significant barrier to education in the first place and for girls in particular, as they can have to miss school due to a lack of private, sanitary facilities when menstruating. The above diagram demonstrates the association between sanitation and educational outcomes and people's awareness of hygiene. The demand for better sanitation facilities increases with levels of education that propel additional improvements in sanitation infrastructure.

The above diagram illustrates the relationship of infrastructure, such as water supplies and roads, to sanitation. Better infrastructure development often is associated with better sanitation because clean water and sanitary facilities become more accessible to the public. This translates into many systemic benefits from investments made into sanitation and leads to further improvements in health and nutritional outcomes.

The diagram also presents other related impacts such as the impact of sanitation on gender equality in other broader societal outcomes. A significant promotion of gender equality is facilitated by improvement in sanitation since women's health, dignity, and ability to work as well as attend school depend on the availability of Privat, safe restroom. Women and girls would be most impacted by inadequate sanitation wherein their ability and opportunities would be limited by such conditions

while deepening gender disparities within various aspects of life.

Another sector that is impacted by sanitation is tourism. From the graph above, improved sanitation is likely to attract more people to some areas for tourism. In Pakistan, hygiene and easily accessed sanitation facilities are of essence since the tourism sector has tremendous potential to boost economic growth in the country. Apart from boosting the general well-being of tourists, improved sanitation enhances the health of the public in general, while the environment in places visited by tourists will become sustainable.

Reinforcing Loops

1. Sanitation → -Ponding of Polluted Water → - Water Supply → + Sanitation
2. Sanitation → + Tourism → + Financial Resources → + Sanitation
3. Sanitation → + Education → + Hygiene Awareness → + Increasing Demand for Sanitation → + Sanitation
4. Sanitation → -Diarrheal Incidence → - Nutritional Status → - Stunting → - Education → + Hygiene Awareness → + Increase Demand for Sanitation → + Sanitation
5. Sanitation → -Diarrheal Incidence → - Nutritional Status → + Health Outcome → -Health Care Cost → - Financial Resources → + Sanitation
6. Sanitation → -Diarrheal Incidence → - Nutritional Status → + Health Outcome → + Education → + Hygiene Awareness → + Increasing Demand for Sanitation → + Sanitation

VII. RESULTS

The results from the causal loop diagram show dynamics between sanitation and several other development sectors by depicting which improvements in sanitation will cause feedback effects across the system.

Sanitation and Health Outcomes: Improved sanitation reduces diarrheal diseases, which subsequently improves nutritional status and lower stunting levels among children. Lower levels of stunting and improved health translate to lower healthcare costs. There is a reinforcing loop that improves health altogether as a result of the improvement observed in these factors. Cleaner water supply and increased reduction in water pollution, therefore, contribute to further reductions in diarrheal incidences.

Sanitation and Education Outcomes: This feedback loop from sanitation to education implies that as sanitation improves, better hygiene awareness rises, which results in a healthier school environment. In this way, there is positive feedback of improved health into improved educational outcomes, with a healthier child attending school more consistently and better doing in class.

Sanitation and Economic Sector: Economic development also relates to improvements in sanitation. A better sanitation system will attract more tourists, for cleaner environments are a greater attraction. Also, good sanitation promotes better road maintenance-most likely as waste management becomes more efficient. Higher incomes and better infrastructure make more finance available, which could be further invested in sanitation improvement, thus creating an upward cycle of economic growth.

Sanitation, Road and Tourism: Improvements in sanitation also mean that roads are kept in better condition, possibly because an effective waste management system does less damage to the underlying infrastructure. Improved roads enhance tourism as places become more accessible and appealing, generating further sources of finance for local government or businesses. These added funds can then be reinvested in sanitation projects as a reinforcing loop involving sanitation, infrastructure, and economic growth.

Sanitation and Ponding of Polluted Water: Poor sanitation leads to water piling up, which intensifies problems like the spread of waterborne diseases including diarrheal cases. Sanitation improvement reduces the ponding of contaminated water hence establishing a healthier setting with fewer outbreaks. This development feeds into the

loop driving sanitation efforts for clean environments to be maintained.

VIII. CONCLUSION

This study thus appears to indicate that sanitation is playing an essential role in driving beneficial outcomes in most sectors of development-including health, education, and economic-by opening up certain causal loops, that otherwise would sound cyclical. For instance, the provision of adequate sanitary conditions improves nutritional status, reduces the incidence of diseases, increases economic activities with tourist arrivals and infrastructure development, and enhances educational outcomes.

These results underlie the imperative that sanitation investments become part of the larger development strategy. The reinforcing loops show that even minor gains in sanitation lead to giant, wide-ranging benefits, thus creating health, social, and economic virtuous circles. In addition, releasing health care and increasing productivity put released resources back into sanitation and other linked sectors, underlining the systemic value of integrating sanitation into development planning.

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