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Development of a Modelling Approach as a Tool for Effective Decision Making in the Drainage/sewerage Management of the Vavuniya Town

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Abstract

Almost all the urbanized areas in Sri Lanka are observed to have critical environmental problems associated with the lack of management of drainage and sewerage systems. The Vavuniya Town is no exception and, at present it critically suffers from the lack of a comprehensive liquid waste management strategy. As the need to upgrade the present drainage/wastewater management systems is realized, the necessity for investigations on how the present systems can be improved also arises. One possible strategy could be the employment of simulation modelling techniques to evaluate possible management scenarios to arrive at the best set of practices for effective environmental management. This paper provides an insight to how a simulation model can/should be developed to understand the problem of concern in-depth and, how different management strategies can be evaluated so as to aid in decision-making.

[***Key words:*** modelling, system, simulation and hydrology].

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1.0 Introduction:

As urbanization takes place, the need for better and improved waste management systems increases. Of particular concern in these regards is the need for improving drainage and sewerage systems in the urban areas. Almost all the urbanized areas in Sri Lanka are observed to have critical environmental problems associated with the lack of management of drainage and sewerage systems i.e. Colombo city gets flooded and faces severe problems of stagnation of waters from flooded sewers even in the instance of an isolated storm. This paper examines the drainage and sewerage problems in the Vavuniya town and how the wastewater management system could be upgraded to mitigate possible negative environmental consequences.

The Vavuniya town has expanded rapidly and unexpectedly due to the influx of people *as per* the mass displacements from the northern regions in the past decade. This has resulted in rapid urbanization and the production of higher volumes of urban drainage than before. However, the urban drainage (and sewerage) management system has not been updated to cater to these increases.

The outdated drainage (and sewerage) system, where all the drains originating from the Vavuniya town area are collectively joined and emptied into the Vavuniya tank - is the only means for managing urban drainage at present. This system, designed for an area where very minimal polluting activities occurred is **not** suitable for the present volumes of industrial, domestic and other operations that contribute to the urban drainage, as it has no wastewater treatment facilities. Thus, the Vavuniya tank is being drastically polluted, inducing heavy stresses on the ecological balance of the Vavuniya tank and its surroundings.

As such, the critical need for evaluating the negative impacts of the present states of the drainage system on the Vavuniya tank is necessary in-order to revise/update the present wastewater management system. Thus the understanding of the functionality of the system is paramount. System analysis and modelling techniques may be used to approach this problem in order to understand the (functionalities of the) complex system (of concern) in the simplified form.

As a starting point, this present critical situation/dynamics of the tank system can be effectively explained using a modelling approach which can be used as a tool for developing a further research strategy as well as in effective decision making in the drainage/sewerage management of the Vavuniya Town.

The **aim** of this paper is to provide an (methodological/structural) impact assessment of a system that contains a network of urban drainage/sewerage channels and an associated receiving water body using the modelling approach. It is hoped that the modelling methodology developed as such, will provide with a cost effective, easy to comprehend and powerful decision making tool for the betterment of environmental management of the Vavuniya Town. This methodology could be used by the city planners, bureaucrats and decision makers to construct and analyze possible scenarios for different management options they propose.

2.0 Description of the Drainage/sewerage System in the Vavuniya Town:

The Vavuniya town itself has two networks of drainage systems collecting both storm and waste water as shown in Figure: 01. One such drainage system (drawn using yellow lines) was constructed to collect only storm water for the purpose of irrigating the paddy fields. The pollutant load from this drain system is insignificant; as such this network has been ignored in this study. However, the other system (indicated using purple/pink lines) collects both storm and wastewater from the Vavuniya town area and collectively discharges into the Vavuniya tank: a water body located in the Vavuniya town. This has resulted in inducing ecological stress to the environment of the locality. This paper focuses on the analysis of this drainage system and the related dynamics.

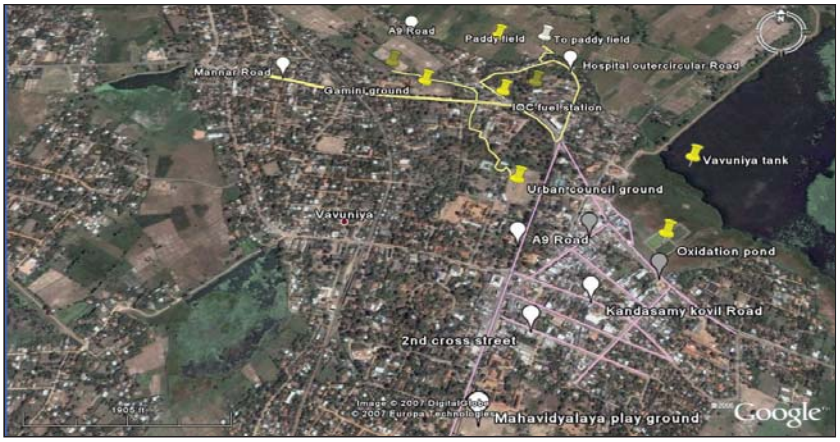

Figure 1: Detailed aerial view of the (two) present drainage network in Vavuniya Urban Council limits

The drainage/sewerage system prone to pollutant load consist of a network of drainage channels (where waste water from the industrial, domestic and other sources is also discharged) and a designated receiving water body (where all the discharges are disposed) – in this case the Vavuniya Tank. As stated earlier, this system was developed for a pre-urbanised condition (around the period of 1948 (*pers. comm*: Mr. Sathasivam, Secretary, Vavuniya Town Council in 1948), prior to the formation of the Vavuniya Urban Council) – for the singular purpose of effective drainage of the town area. The other inherent benefit that was derived from this design was – the effective recharge of the Vavuniya Tank as all the collected storm water from the town area was channelled into it. As such, this design enabled efficient recharge of the tank and the cascade system (consisting of the canals and paddy fields associated to it). The hidden agenda in this design was the conservation of the local unconfined groundwater aquifer (through this system design = as a means efficiently recharging the groundwater aquifer) – which is the only form of quality water resource in the locality.

As the town has expanded, due to the unexpected population boom – the urbanization process has been occurring at a faster pace that is beyond the management capacities of the local authorities i.e. the Vavuniya Urban Council. As the number of industries, businesses and houses have increased in the town area – so has the need for more water. This has resulted in more wells being dug (that tap the unconfined aquifer) – and produces the consequence of more wastewater being channelled into the Vavuniya tank. This system has no treatment system prior to disposal into the tank. It obviously discharges a variety of pollutants into the water body. It causes several impacts such as eutrophication, sedimentation on the receiving water body.

Furthermore, from a system point of view the effect on the water resource potential/s of the locality – (where increased abstraction and increased discharge of pollutive materials is taking place in parallel) is quite obvious. At present, this system is under heavy stress and if the drainage/sewerage system is not upgraded - the threats to the availability of good quality water for human consumption in sufficient amounts will be higher than ever.

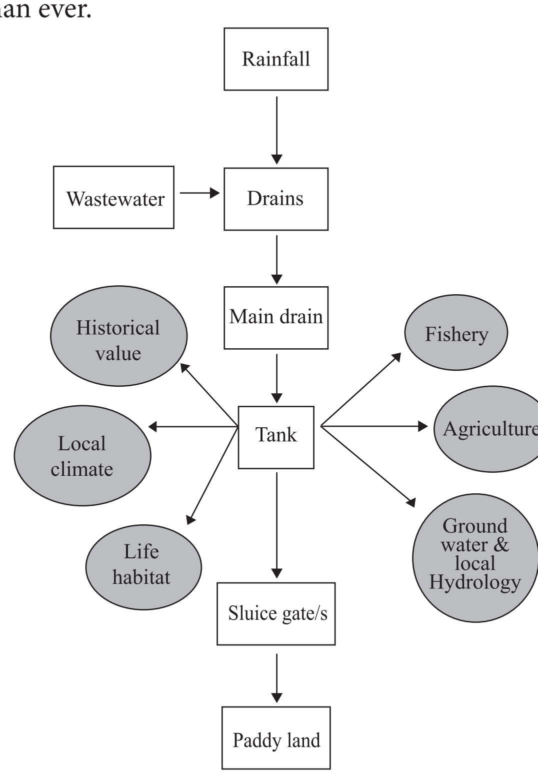

Figure 2: Flowchart of research problem

2.1 Study area:

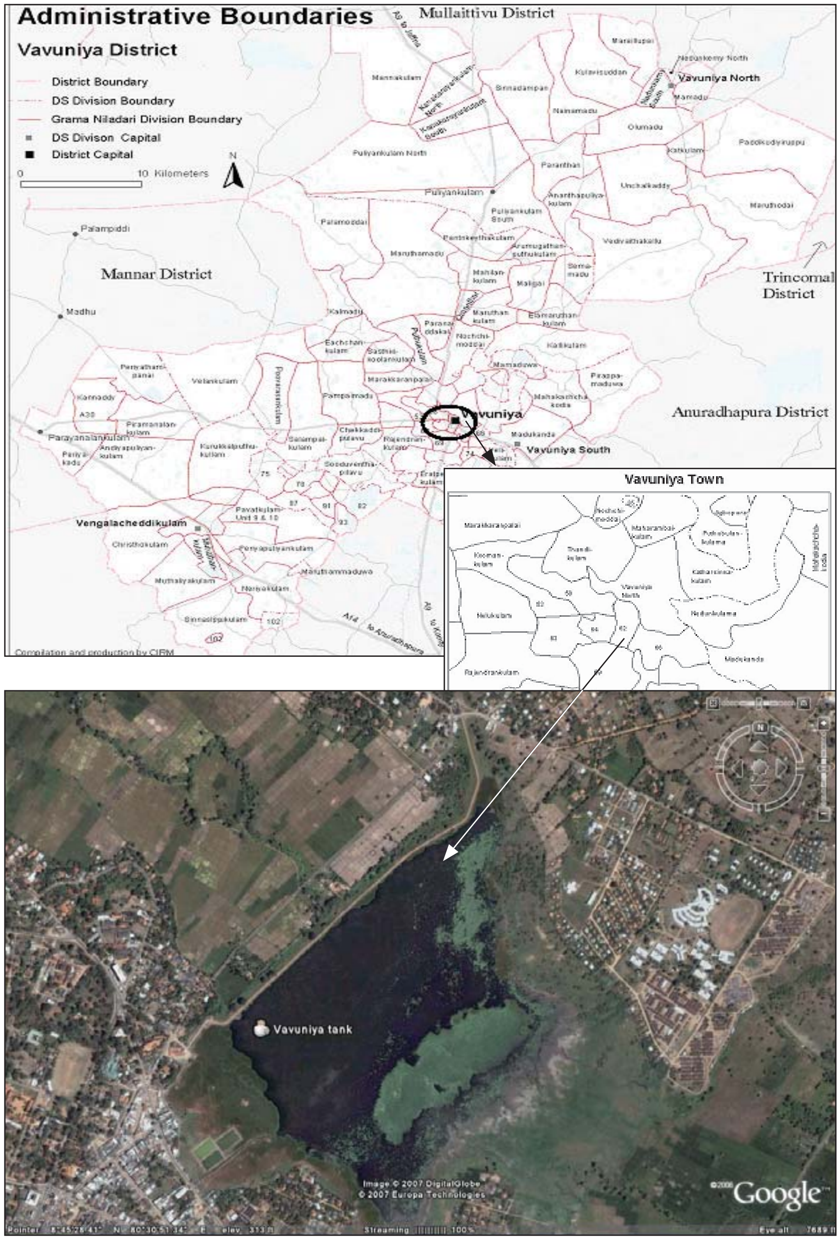

Figure3: Study area (source/s: Survey Dept., Sri Lanka, Google Earth, 2006)

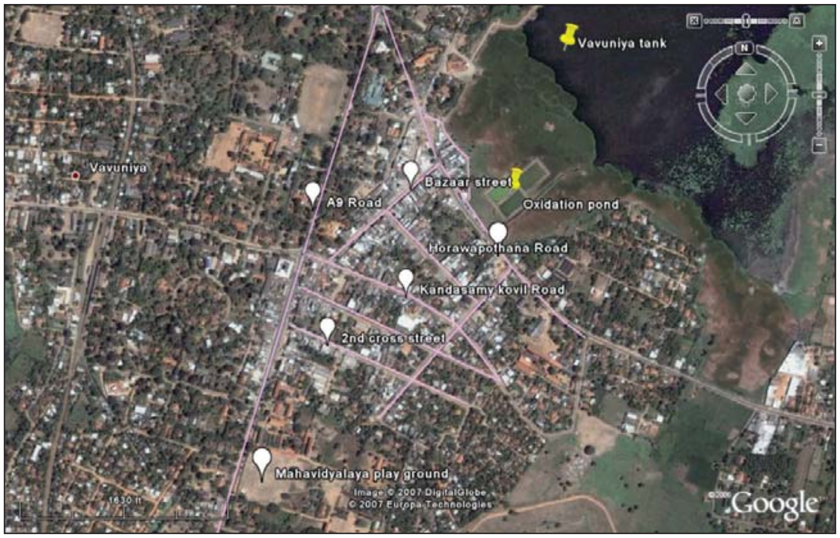

Figure 4: Detailed aerial view of the drainage network considered for this study in the Vavuniya Urban Council limits

3.0 The Modelling Approach Chosen:

The system modelling approach was chosen for assessing the stress on the above mentioned urban drainage/sewerage system of the present times. This is a complex environmental system and can be easily understood by the modelling approach using basic building blocks.

Models usually represent a simplification of reality and hence a means of getting to grips with systems (or phenomena) whose spatial scale or complexity might otherwise put them beyond our physical or mental grasp. Models in science are used to describe, explore and analyze how a system works. (Manobavan, Water Resource Management presentation, FAS, Vavuniya Campus, 2007) Modelling refers to the process of generating a *model* as a conceptual representation of some phenomenon.

Before getting into the modelling approach it is necessary to develop the understandings of the concerned a systems' dynamics*, its

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* **System dynamics** is an approach to understanding the behaviour of complex systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system. (source: wikepedia 2007)

basic elements and the inter-linkages clearly through systems theory perspectives.

System theory/analysis offers a method of reducing the complexity of ecosystems to manageable proportions, easy for human comprehension. With an appropriate partitioning of a system, a model is used to generate predictions that can be tested against further observations, or experimental data. The fundamental tenet of the system approach is that an extremely complex process can be most easily dissected into a large number of very simple unit components (Mukeherjee, 2000).

Our understanding of the real world is based on the accuracy with which we can predict its future behaviour. The principles of modelling involve defining the problem, setting boundaries around the system and analyzing the relationship between its components (Mukeherjee, 2000).

The purpose of system analysis and modelling are threefold (adapted from: Mukeherjee, 2000).

- To understand better how each of the components of an ecosystem contribute to its overall functioning that is to generate hypothesis for understanding the structure and behaviours of the system.
- To predict future events, useful in environmental decisions making and
- To manipulate the system for maximization of some quantity.

Modelling has become an inherent part of the planning and decision-making process in natural resource management, as it provides with the facility (a tool for…) of exploring plausible (possible) future conditions. This '*what if*' analysis using models is called scenario testing. Hence scenario is used to assess the plausible future condition. This however is not a prediction. Testing a scenario is normally referred to as a simulation (Hardisty *et al.*, 1993).

The real power of system dynamics is utilised through simulation. Although it is possible to perform the modeling in a spreadsheet, there is a variety of software (eg: the Stella Platform developed by HPS Inc., USA) packages that have been optimised for this (Sterman, 2001).

Computer software is used to simulate a system dynamics model of the situation being studied. Running ***what if*** simulations to test certain policies on such a model can greatly aid in understanding how the system changes over time (Sterman, 2001).

For modelling to begin at all, it is necessary to state the objective of the study to define what the model is meant to achieve (Mukeherjee, 2000). With regards to this paper, the objective of the modelling exercise is to provide a tool for effective environmental decision making for the system described above.

The quantification of the items of inflow to and outflow from a water reservoir (tank), as well as of changes in storage is represented in the model creation. A few of these were gathered from the secondary data available, some were determined by differences between measured volumes or rates of flow of surface water and some require indirect methods of estimation accordance with hydrological (systemic) concepts. These items are elaborated as below as formulae (or algorithms). We used the capacities provided by the MS Excel software (spread sheet) platform in the development of this model. The capacities of Excel (even though regarded as unconventional) for developing relatively comprehensive complex models of systems have been well documented (Manobavan, 2007).

4.0 Model Development:

4.1 Description of the System Considered in the Investigation

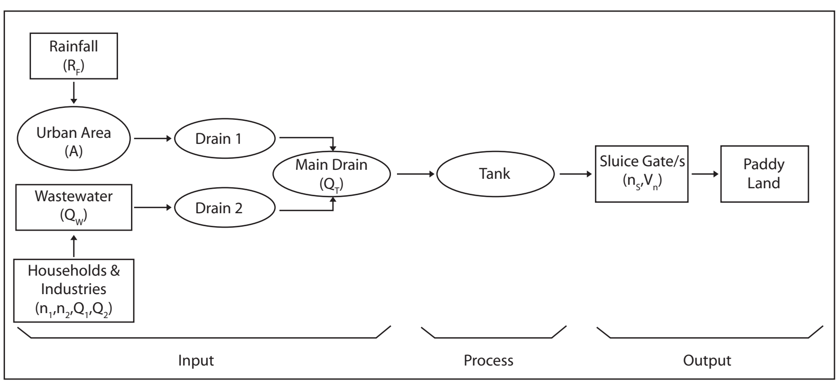


Figure 5*:* Conceptual diagram of system of concern.

The system components considered are:

1. Rainfall
2. Urban catchment areas,
3. Number of households/industries
4. Amount of wastewater generated per household/ industries
5. Number of sluice gates (two sluices were considered in this case)
6. Flow rate via sluice gate

Rainfall and **wastewater** are the system **inputs** and sluice gates are the system output considered for this model.

Parameters that considered are:

R_F Rainfall

A Urban area

n_1 number of households

n_2 number of industries

Q_1 amount of wastewater discharged into drain *per* household

Q_2 amount of wastewater discharged into drain *per* industry

T_w Total amount of wastewater discharged by both households and industries into drain

Q_T Total amount of water both storm water and wastewater discharged into drain

n_s number of sluice gates

V_n flow rate

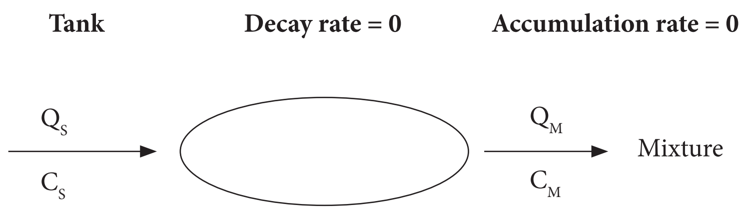
Q_O amount of water that released via sluice gates into agricultural fields.

P Pollutant concentration

It should be noted that this modelling approach has been developed considering the system as a *steady state conservative system.* As such, the substance (pollutant) in questions is conservative. In these cases, the following equation simplifies to the following:

Input rate = Output rate

Where, the steady state conservative system contained within the boundaries might be a water-body, lake or a section of a free-flowing stream. But in this context, it is considered as the Vavuniya tank.



One input of the system is a urban drain water with a flow rate Q_S and the associated pollutant concentration C_S. The other input is assumed to be a waste stream with flow rate Q_W and pollutant concentration C_W. the output is a mixture with flow rate Q_M and pollutant concentration C_M.

$$\mathbf{C_S Q_S + C_W Q_W = C_M Q_M}$$

May environmental pollutants undergo chemical, biological or nuclear reactions and undergo pollutant accumulation. But here, it is assumed to be steady stated conservative systems. As such the rate of accumulation is zero. Thus, here the tank decomposition and accumulation rates are not considered in the model development.

4.2 Algorithms and the model:

Here the rainfall and wastewater discharged from both households and industries are considered as inputs of Vavuniya tank.

Thereby the input of storm water is represented by S_W and can be calculated by

$$S_W = R_F * A \qquad (4.2.1)$$

Where A is the urban area that has low infiltration rate, thereby it assumed all the rainwater strikes on this area is washed into Vavuniya tank.

W_H denotes input of wastewater per household and total amount of water discharged by households are calculated by multiplying the total number of houses with W_H

$$W_H = n_1 * Q_1 \qquad (4.2.2)$$

Total amount of wastewater by industries can be represented by as same in the equation 4.2.2,

$$W_I = n_2 * Q_2 \qquad (4.2.3)$$

Total input of wastewater (T_W) into drain will be equal to the amount of wastewater discharged by both households and industries. Here it is assumed that no loss of water in the drain.

$$T_W = (n_1 * Q_1) + (n_2 * Q_2) \quad (4.2.4)$$

But the total amount of water Q_T discharged into drain will be the sum of both storm water and wastewater. It can be calculated by inserting equations 4.2.1 and 4.2.4.

$$Q_I = [R_F * A] + [(n_1 * Q_1) + (n_2 * Q_2)] \qquad (4.2.5)$$

The water discharged from sluice gates is considered as the only means of output from tank. The water discharged via sluice for a month can be calculated by,

$$Q_O = n_s * v_n * 60 * 60 * 24 * 30 \qquad (4.2.6)$$

Where n_s is the number of sluice gates; v_n is the flow rate of water from sluice gate.

The water remaining in the tank can be obtained by subtracting total input (equation 4.2.5) from total output (equation 4.2.6).

$$Q_I - Q_O = ([R_F * A] + [(n_1 * Q_1) + (n_2 * Q_2)]) - (n_s * v_n * 60 * 60 * 24 * 30) \qquad (4.2.7)$$

Pollutant concentration (P) is inversely proportional to the volume of water, thereby pollutant concentration will lowered with higher thunder storm and can be obtained by diving total amount of wastewater (eq. 4.2.4) by storm water (eq. 4.2.1).

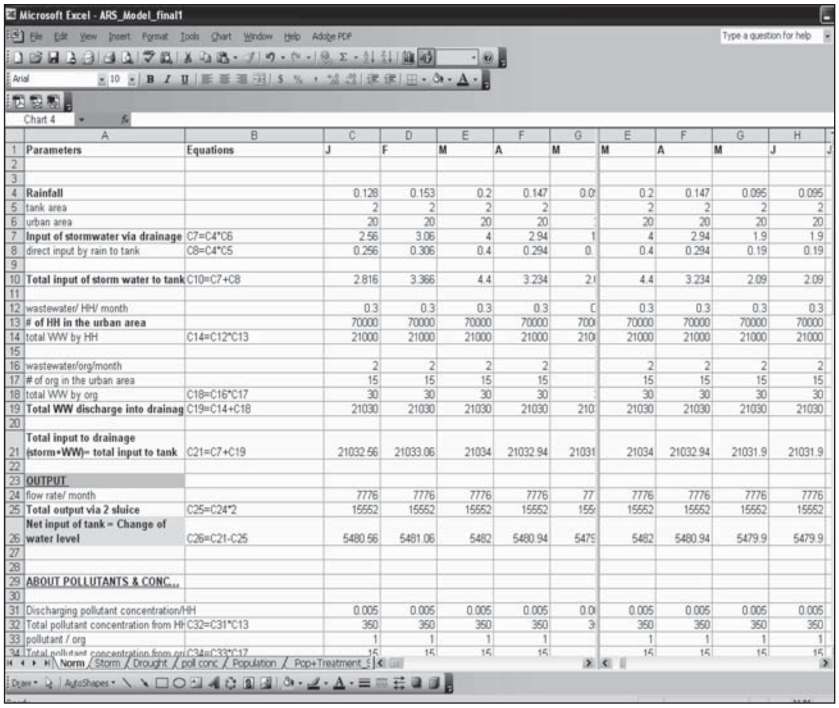
$$P = [(n_1 * Q_1) + (n_2 * Q_2)] / [R_F * A] \qquad (4.2.8)$$

(Please note: The amount of wastewater was assumed as the total amount (or volume) of pollutants for the convenience of modelling).

The following **assumptions** were (also) made **when constructing the model:**

- Rainfall and wastewater are considered as the inputs.
- The urban area has the runoff co-efficient of 1, thereby almost all the rainwater hits on the land will be washed into Vavuniya tank *via* drainage.
- Pollutants are carried by wastewater not by storm water.
- The factors such as evaporation, transpiration, evapotranspiration and, stream flow are negligible.
- The amount of wastewater generated by every household are same.
- No loss of water in the drainage system.
- The water flow from the sluice assumed to be constant month throughout.

The model of the system of concern was developed on the MS Excel platform (figure 06 shows a screen shot of the model being coded on MS Excel). Different simulations were then performed and the graphical outputs were generated banking on the excellent visualization interface of the Excel software.



	A	B	C	D	E	F	G	E	F	G	H
1	**Parameters**	**Equations**	**J**	**F**	**M**	**A**	**M**	**M**	**A**	**M**	**J**
2											
3											
4	**Rainfall**		0.128	0.153	0.2	0.147	0.0	0.2	0.147	0.095	0.095
5	tank area		2	2	2	2		2	2	2	2
6	urban area		20	20	20	20		20	20	20	20
7	**Input of stormwater via drainage**	C7=C4*C6	2.56	3.06	4	2.94	1	4	2.94	1.9	1.9
8	direct input by rain to tank	C8=C4*C5	0.256	0.306	0.4	0.294	0.	0.4	0.294	0.19	0.19
9											
10	**Total input of storm water to tank**	C10=C7+C8	2.816	3.366	4.4	3.234	2	4.4	3.234	2.09	2.09
11											
12	wastewater/ HH/ month		0.3	0.3	0.3	0.3	0	0.3	0.3	0.3	0.3
13	**# of HH in the urban area**		70000	70000	70000	70000	700	70000	70000	70000	70000
14	total WW by HH	C14=C12*C13	21000	21000	21000	21000	210	21000	21000	21000	21000
15											
16	wastewater/org/month		2	2	2	2		2	2	2	2
17	# of org in the urban area		15	15	15	15		15	15	15	15
18	total WW by org	C18=C16*C17	30	30	30	30		30	30	30	30
19	**Total WW discharge into drainag**	C19=C14+C18	21030	21030	21030	21030	210	21030	21030	21030	21030
20											
21	**Total input to drainage (storm+WW)= total input to tank**	C21=C7+C19	21032.56	21033.06	21034	21032.94	21031	21034	21032.94	21031.9	21031.9
22											
23	**OUTPUT**										
24	flow rate/ month		7776	7776	7776	7776	77	7776	7776	7776	7776
25	**Total output via 2 sluice**	C25=C24*2	15552	15552	15552	15552	155	15552	15552	15552	15552
26	**Net input of tank = Change of water level**	C26=C21-C25	5480.56	5481.06	5482	5480.94	5479	5482	5480.94	5479.9	5479.9
27											
28											
29	**ABOUT POLLUTANTS & CONC...**										
30											
31	Discharging pollutant concentration/HH		0.005	0.005	0.005	0.005	0.0	0.005	0.005	0.005	0.005
32	Total pollutant concentration from HH	C32=C31*C13	350	350	350	350	3	350	350	350	350
33	pollutant / org		1	1	1	1		1	1	1	1
34	Total pollutant concentration from or	C34=C33*C17	15	15	15	15		15	15	15	15

Figure 6: Screen shot of Model-work sheet (Spread sheet)

5.0 Some plausible scenarios for explaining the dynamics of the system

The scenarios were developed based on the factors that frequently affect the system dynamics. As such, the factors considered are shown below (Figure. 07):

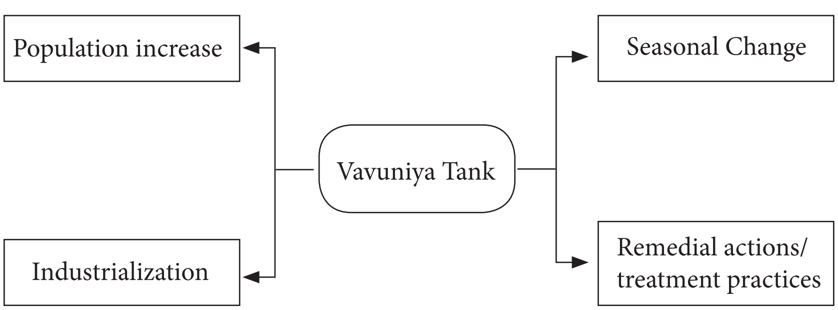


Figure 7: Factors affecting system dynamics

Figure: 08, shows, the scenario 01 for the normal conditions.* Vavuniya receives a bimodal pattern of rainfall annually. As such the change of water levels in tank mimics the rainfall pattern. The pollutant concentration is inversely proportional to the volume of water. Thus, the pollutant concentration will be lowered at the point where it meets a severe thunder storm (Figure 08). In these regards (under normal conditions) this system is under the critical limit, thus there is no need of treatment (except during the month of October).

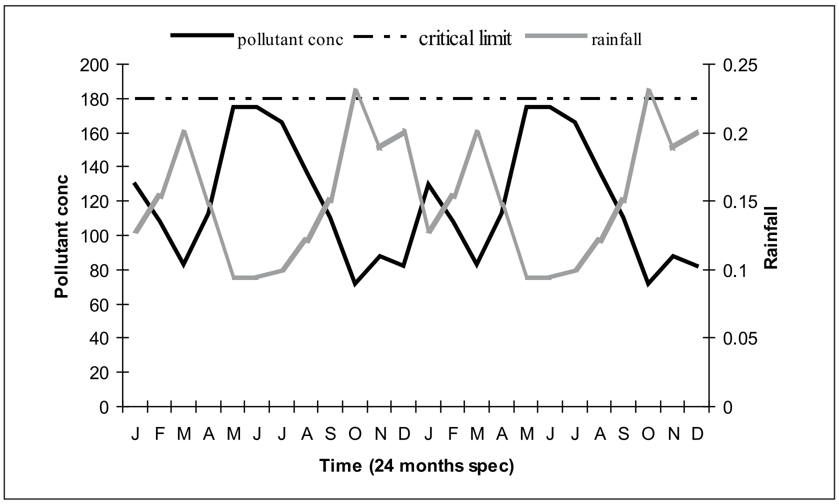


Figure 8: Scenario 01- Pollutant concentration vs. seasonal changes (rainfall)- the normal condition (This simulation considers the time spec of 24 months).

Figure: 09, shows the scenario 02 for an unexpected rainfall. Due to an unexpected event of severe rainfall received in October (during the 1st half of the 24 month time-spec) the pollutant concentration has drastically reduced. In this case, the concentration is far below the critical limit due to the dilution effect thus, the natural assimilation capacity is enough to treat water.

* Conditions in which a system persists in an equilibrium state – hence the term: 'normal conditions'.

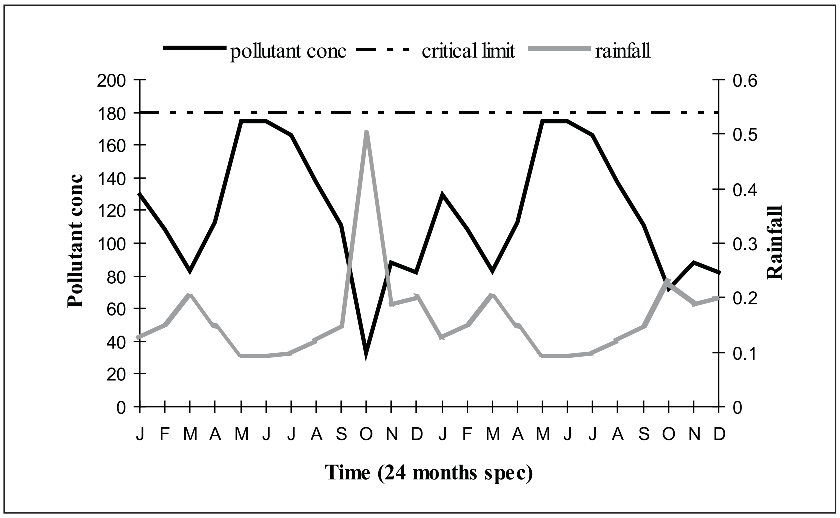


Figure 9: Scenario 02-Pollutant concentration with the severe unexpected thunderstorm (This simulation considers the time spec of 24 months)

Figure 10, shows the scenario 03, for a severe drought occurring in June. In this case the pollutant concentration is rapidly increasing with a severe drought occurring around June. In this case, June onwards the pollutant concentration is above critical limit, thus having a treatment system is mandatory to avoid the stress on tank.

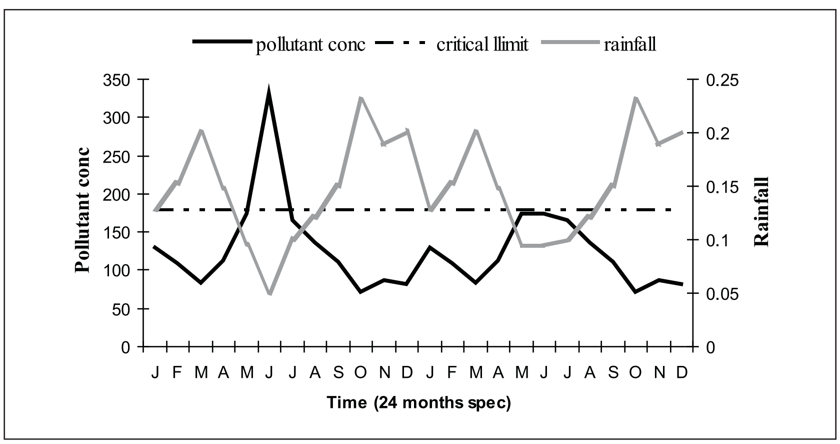


Figure 10: Scenario 03- Pollutant concentration for a severe drought.

(This simulation considers the time spec of 24 months)

Figure 11, shows the scenario 04 represents the effect of population increase on the Vavuniyatank. This scenario may resemble the past history of Vavuniya, which has experienced a massive population increase due to the mass displacements in the past decade. In this scenario the pollutant concentration is obviously (drastically) increasing above the critical limits. The urban drainage (and sewerage) management system has not been updated to cater to the resulted increasing the production of higher volumes wastewater. This obviously increases accumulation of pollutant and causes sedimentation, Eutrophication thereby reducing the overall benefits gained from this tank system. This ultimately threatens sustainability of the locality (local ecology and environmental stability).

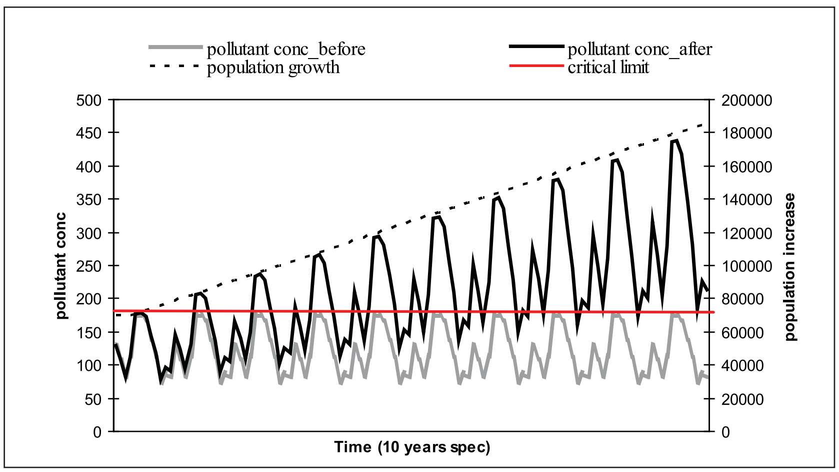


Figure 11: Scenario 04- Pollutant concentration vs. population growth

(This simulation considers a 120 months/10 years time spec)

This is the time of take actions to reduce the further degradation of tank. Since the Vavuniya tank has lack of treatment facility, thus the establishment of a treatment system is necessary. The figure 12, scenario 05 represents that the applying treatment system reduces the pollutant concentration *gradually* to a certain extent, thereby helping in restoring the tank dynamics and (may) lead to sustainability in a certain period of time.

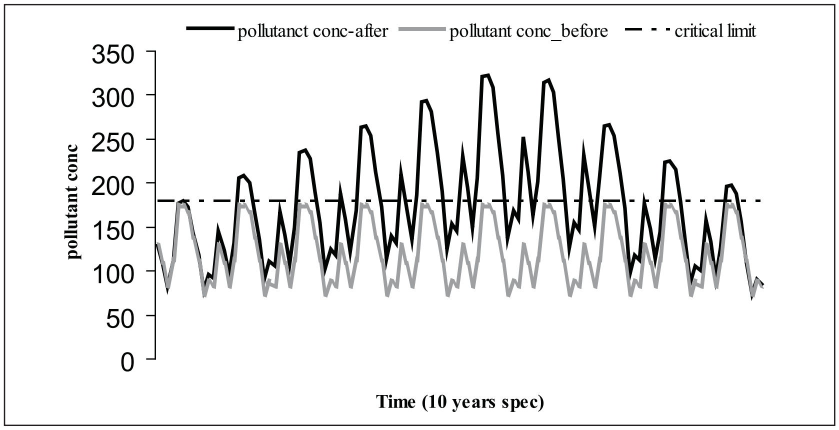


Figure 12: Scenario 05-Pollutant concentration vs treatment applied gradually (This simulation considers a 120 Months/10 year time spec)

The Figure 13, shows the scenario 06, which represents the reduction of pollutant concentration with the application of abrupt treatment.

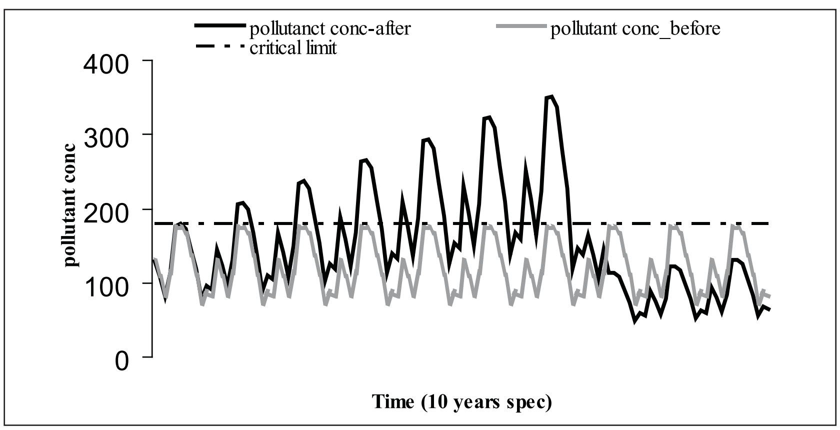


Figure 13: Scenario 06 – Pollutant conc. *vs* the application of abrupt treatment system

However, the application of any abrupt treatment system reduces the pollutant concentration drastically below the original point of concentration. This sudden shock applied to the system may disturb the functioning of the system and, it may eventually impact on its overall functionality. As such, ideally, this system should be recovered with the application of gradual chemical treatment (see figure 14).

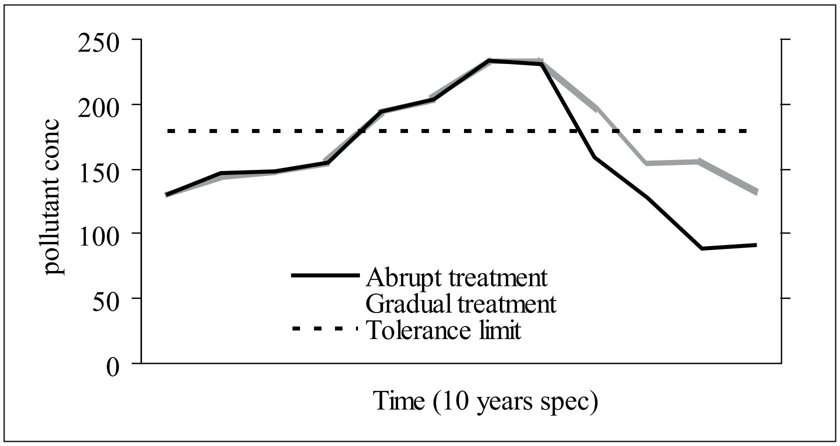


Figure 14: Scenario 06 - Comparison of the reduction of pollutant conc. for the application of the abrupt chemical treatment and the gradual chemical treatment methods. This simulation considers a time spec of 120 months/ 10years)

Therefore, as per the results derived from the scenario development excercise, it can be seen that this modelling approach could be used as a tool in the decision-making process (due to its excellent visualization capacity) and helps by assessing the plausible conditions of this dynamic environmental system. This may be useful in environmental planning and management at the Vavuniya Urban Council levels.

6.0 Further Development of the Model

This model can be further upgraded by incorporating Multi Criteria Evaluation (MCE) and software-interfacing tools those are needed to make comprehensive models user-friendly. Recent developments in environmental information technologies, such as expert systems, geographical information systems (GIS) and visualization software, have great potential to simplify the use of models and make this approach more synergistic. These technologies can help the user manage large amounts of input data and present the output in an easily understandable format. As such, much of the model complexity can be hidden from the user by the application of appropriate interface software. These enable the user to apply complex and comprehensive models as easily as he/she would normally handle standard off-the-shelf word processing software.

Furthermore:

1. There is certain amount of water released into atmosphere via evaporation from this tank's surface area. Especially for Vavuniya district, the evaporation rate is six inches per month (*pers. comm*: Prof. S. Rajadurai, Rector, Vavuniya Campus of the University of Jaffna, 2007) But here this is factor is/was not taken into account. This causes the increase of pollutant concentration in the dry season.
2. Also, the output of water *via* sluice gates will be higher in the dry season for irrigating crops, but the rate of discharge is considered as same for all the months throughout the year. The above arguments might require a system of further higher degree of treatment in the dry season.

As such, for further improvements to the modelling methodology presented here in this paper, the items #1 and #2 should also be considered.

7.0 Conclusion

The mismanagement of water bodies and the environmental consequences of such actions imposed on the society are a critical problem in Sri Lanka. Mismanagement occurs whenever the local environmental management system experiences a change that is beyond its capacity. Within the context of this research paper, due to the rapid and unexpected population increase, the present urban drainage (and sewerage) management system of Vavuniya town is not in a condition to cater to the production of higher volumes of urban drainage than before.

This has been observed to have profound effects on the ecological conditions of the Vavuniya tank and its surroundings. As such, the need to quantify and categorize the pollutants and their pollutive pathways is pre-mandatory – *in-order* to revise/update the present wastewater management system – if the wastewater management system for the Vavuniya town is to be improved.

In this paper, the following options are considered for the effective environmental decision making in the management (or upgrade) of the present urban drainage and the Vavuniya tank's management protocols.

1. Seasonal changes: the pollutant concentration of the Vavuniyatank shows a significant change in the dry wet seasons in a bimodal pattern. There is no need of treatment system in the wet season (due to the excess dilution effect). However designing a treatment process is **essential** in the **dry season.**
2. Population increase resulted to the production of higher volumes of wastewater which increasing the pollutant concentration of Vavuniyatank. In this case, designing and implementing an appropriate treatment system or BMPs* are necessary with the increasing population.
3. Industrialization also has the same the effect of population increase. The pollutant concentration (in the waterbody) drastically increases with the wastewater discharged by the industries. Therefore, the designing a treatment system for treating industrial wastewater is mandatory.
4. Once a system undergoes a stress and changes its composition (as a result), then returning to its absolute/original conditions is very difficult. However, the system can be brought to normal conditions through a gradual series of steps. As such, the Vavuniya tank can be brought to normal conditions *via* series of steps (i.e. gradual decrease of pollutant concentrations) by applying an effective treatment system (e.g.: constructed wetlands, oxidation pond). However, enforcement of policy measures and effective environmental legislations is the better action plan than the application of chemical treatment on the longrun.

In this paper, the above four options are (only) taken into account. At present, the model (developed for this study) is incapable of producing

* Best Management Practices.

scenarios of other possibilities (e.g.: increase of evaporation, infiltration, seepage etc. and, extraction of water [both from the tank and the ground water sources] for other purposes by people); since there are (some) factors that were not considered in the model such as, evaporation, infiltration, seepage, water used by people, livestock, birds etc.

Once the model is upgraded further, in-terms of comprehensively simulating local hydrology, then this model can be further improved by combining MCE, Expert Systems, GIS and, *state of the art* modelling software etc., to make the model more comprehensive and user friendly.

Further, many decisions in environmental management are based on model predictions that are plagued by uncertainty. It is sensible to consider this uncertainty also because it can influence the outcome of the decision-making process.

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