EFFECT OF POPULATION GROWTH ON URBAN WASTE WATER OF NORTH INDIAN CITY, SONIPAT: A SYSTEM DYNAMIC APPROACH

Rajeev Dahiya[1], Nisha Kumari*[2]

[1]Maharaja Surajmal Institute, Janak Puri, New Delhi – 110 058, India
[2]Deenbandhu Chhotu Ram University of Science and Technology, Murthal (Sonepat) - 131039, India

*Corresponding author

Abstract

This paper presents projections for the population expansion and its effects on the generation of waste water in a city in North India. The baseline and modified policy option scenarios were investigated using a system dynamic approach. The major factors considered for regulating the population growth were birth, death and migration rates. Combinations of these factors were used to work out the policy option scenarios and with those scenarios the population growth up to year 2035 was projected. The impact of the increasing population on the waste water generation was studied for as usual baseline scenario and the policy option scenarios. For the proposed policy scenario the waste water discharge will reduce by 32% in 2035 as compared to the baseline scenario. Projections for the reuse of the waste water were made, discharge of waste water will reduce and the same plant can treat all the waste water projected up to the year 2024.

Keywords: Birth rate, death rate, migration rate, policy option scenarios, population, the system dynamic, waste water.

INTRODUCTION

One of the most important needs for sustainable development of fast expanding cities is a sufficient supply of potable water. Water scarcity is a global problem brought on by the rapid urbanization of the planet. To effectively manage the water assets and supply frameworks, this calls for elaborate and intentional efforts. Since water is the second-most essential component for life's sustenance after air, according to human history, towns that do not provide for their water demands will soon become uninhabitable. (Girardet, 2004). A person can live without food even for a month or more, but not without water beyond three to four days. Sometimes it is said that the water scarcity will be a threat to the very survival of the ever growing population. And if there would be third “World War” (God forbid such an occurrence), it would be on the issue of the precious commodity “WATER”.

Most of the cities and towns have a comprehensive water supply system for its inhabitants. The system is built around the sources of water, which may be a river, a lake, water pumped from underground aquifers etc. The raw water received from the source(s) is cleaned in treatment plants and transported to users through the piped network. An equally elaborate system is required for handling and treatment of the waste water generated from domestic, commercial, industrial, institutional and other utilities. Reusing waste water is becoming more important in order to protect water supplies. (Shah, 2016). Additionally, efforts are made to look into potential options to close the growing gap between water supply and demand. As the water supply system is becoming complex, it is becoming difficult to reach agreement on sustainability issues (Chung et al., 2008).

The substantial amount of waste water is generated and discharged in open and covered drains. The waste water is not just sewage. In any case, the water that goes down the channels or into the sewage assortment framework is waste water. This includes water coming out of the households after its use in baths, showers, sinks, dishwashers, washing machines, toilets, etc. Schools, colleges, hostels, hotels, restaurants, hospitals, commercial activities and industrial suppliesprovide large amounts of wastewater to sewage collection systems. Some of them operate their own waste water treatment systems. Most of the waste water flows through the combined municipal sewage drainage systems and taken to the waste water treatment plants, if such plants are installed. Water from storm drains is also added to the municipal waste water streams. Though waste water treatment plants exist in many towns and cities of India, their capacity is not adequate to handle the daily discharge of waste water. Situation becomes acute during the rainy season. Also Changesin water-relatedbehavior affect the availability of water resourcesby creatingsynergy between surface water, groundwater and energy to achieve long-term water efficiency and accessibility (Pani et al., 2021).

The reuse of treated waste water is becoming popular. It is used for horticulture and/or agriculture in the fields or within urban building complexes (Asano, 1998 and 2002). But only a small fraction of the treated waste water is generally reused for horticulture or agriculture. Rest of it is simply discharged and allowed to either evaporate in the natural process or discharged in drains, which may eventually join some rivers. Now it is mandatory to install a captive waste water treatment plant in large housing complexes and to use the treated water. Rain water harvesting is also made compulsory in high rise buildings and big housing complexes.

The topic of research reported in this paper was chosen to study waste water generation and its reuse. Policy scenarios were developed to manage the increasing amount of waste water in Sonipat due to the growth in population. Many researchers (Ahmad and Simonovic, 2000; Sharawat et. al. 2019) have applied system dynamics for application in managing water resources. Observed river run-off datahas also studied renewable water resources (Simonovic, 2004).Oki *et al*. (2001) and Alcamo *et al*. (2003) have made water resource assessments. An effort is made to come out with problem solving scenarios in view of the growing population of the city. The present study of managing waste water in practical context can be useful for medium-sized cities.

The Description of Study Site

The Indian capital, New Delhi, is nearby the medium-sized city of Sonipat. Both the cities fall in the same climatic zone. Sonipat is nearly 50 km north of Delhi and roughly 5 kilometers west of NH No. 1.Geologically it is situated in the range of 76°28'30" and 77°13'40" East and 28°48'30" and 29°17'54" North, respectively. As mentioned earlier, it serves as the administrative centre for one of the state of Haryana's 21 districts. The figure 1shows a map of the Sonipat district. In the distant past, the Yamuna River flowed along the eastern perimeter of the city, yet throughout the long term it has subsided and is currently almost 30 km away. As of now spread over roughly 30 sq. km., Sonipat is a quickly extending city.

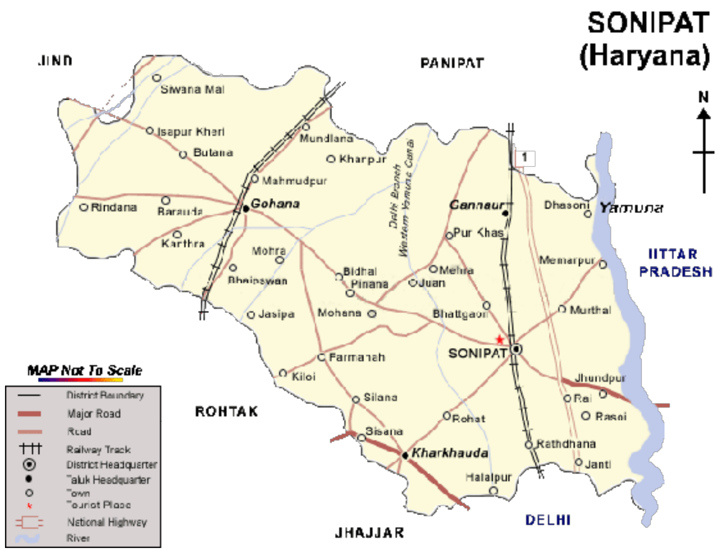

Figure 1: A Sonipat district map indicating Sonipat City location (http://sonipat.nic.in/).

Ministry of Environment and Forests (MOEF) of the Indian government, considered advantages of this process and suggested to use anaerobic system, i.e. UASB for all the treatment plants constructed under Yamuna Action Plan in Haryana and U.P. Moreover, encouraged with good performance of UASB technology, the Punjab Water Supply and Sewerage Board decided to adopt this technology under the Satluj Action Plan for construction of waste water treatment plants (Khalil et al., 2008).

Materials and Methods

To calculate population growth and for baseline and modified scenarios, a system dynamic (SD) approach was used. The SD modeling approach is convenient and has been used for many applications in diverse areas. The System Dynamic methodology has been utilized to various studies related to climate change and greenhouse gas emissions (Kumari et al. 2014) and water resource management (Sharawat et al. 2014; Behzadian 2015). The model is run using the Powersim constructor version 2.51 on a PC. Baseline scenario and policy option scenarios were developed to make projections till 2035. A system dynamic approach is used to formulate policies and make predictions for next 25 years for managing the Sonipat city waste water as with the increasing population. In this model, the behavior of the system as a whole is studied by considering the interaction between the elements of the system. Interconnections are taken together to see things as a whole to explain the complexities (Maani and Cavana, 2000). As the name suggests the behavior of the system is monitored over time and is thus dynamic.

The population growth over a time period was evaluated from the given population (P_t) at time t. At time t+1, size of the population (P_{t+1}) would be

$$P_{t+1} = P_t + Pin_t + Pm_t \quad (1)$$

In an equation (1), Pin_t is natural growth from time t to time t + 1 and is given by

$$Pin_t = B_t - D_t \quad (2)$$

and Pm_t is net migration from time t to time t + 1, which can be obtained from

$$Pm_t = Im_t - Em_t \quad (3)$$

where B_t, D_t, Im_t and Em_t are births, deaths, immigrations and emigrations at time t respectively. In the year 2001, Sonipat population (P_t) was 225,000. Projection of population growth was evaluated using equations (1) to (3). A stock flow diagram was used to develop System Dynamic model as shown in Figure 2, for the current inquiries. The diagram demonstrates how the interconnected factors given in equations (1) to (3) affected one another.

Everywhere, there is a need to manage population increase using various birth control methods. For instance, for making it explicit and to plainly mirror the reality of the issue because of spontaneous development of population, we additionally concentrated on the effect of population development on waste water generation. The amount of water usage and the waste water discharged are directly related to the population of the city. The population is evaluated from birth, migration and death rates and it is taken as the stock variable. The other variable is per capita water supply, which has been taken as a constant variable.

The municipal authorities of the city need to meet the water demand of household, schools, colleges, hostels, hospitals, hotels, commercial establishments, restaurants and industrial sectors. Total water demand is the sum of water requirement for all these sectors. Not all the water is completely consumed; rather quite a large volume of waste water is generated and discharged. In the present study, only the waste water discharged from households, hospitals, hotels, schools, colleges and hostels is considered. The Sonipat city, however, has an industrial area, but the industrial waste water is not considered in the present investigations.

In urban areas, like the Sonipat city, with piped water supply system having sewerage system, recommended water supply is approximately 137 lpcd (liter per capita per day) to the household sector (Ministry of Urban Development, New Delhi, 2014). Table 1 gives the breakup of water supplied in Sonipat city, which was taken for baseline scenario.

Table 1: Breakup of Sonipat City's Need for Water Supply. These values are taken as initial parameters[a]

S. No.	Institutions	Litres per head per day
1.	Hospitals	340 (per bed)
2.	Household	137
3.	Hostels	135
4.	Restaurants	70 (per seat)
5.	Schools	45

[a]Source: Ministry of Urban Development, New Delhi (2014).

The per capita household water supply (H_{PC}) is multiplied by the population to get daily requirement of the water supply (H_{WS}) in the city. This is given by

$$H_{WS} = P_t \times H_{PC} \quad (4)$$

In the city hospital water supply (HP_{WS}) is calculated by multiplying the per capita hospital water supply (HP_{PC}) and daily hospital bed rate (HP_{BR}). This is evaluated using the following equation

$$HP_{WS} = P_t \times HP_{PC} \times HP_{BR} \quad (5)$$

Where HP_{BR}= represents the number of beds in the hospitals of the city per total population. Similarly, school water supply (S_{WS}) is calculated by multiplying the per capita school water supply (S_{PC}) and daily school student rate (S_{SR}) in the city. The school waster supply is obtained from the following equation

$$S_{WS} = P_t \times S_{PC} \times S_{SR} \quad (6)$$

where S_{SR} = The number of students in all the schools of the city per total population. Water requirement of the hostels (SH_{WS}) and restaurants (R_{WS}) is obtained from the respective equations given below:

$$SH_{WS} = P_t \times SH_{PC} \times SH_{SR} \quad (7)$$

and

$$R_{WS} = P_t \times R_{PC} \times R_{SR} \quad (8)$$

where SH_{WS} is school hostel water supply and multiplied by the per capita rate school hostel water supply (SH_{PC}) with daily school hostel student rate (SH_{SR}) in the city.

Similarly, restaurant water supply R_{WS} is multiplied by the per capita rate restaurant water supply (R_{PC}) with daily restaurant person rate (R_{PR}).

Obviously, the total annual requirement of the water supply system was evaluated by adding the requirements of all the establishments obtained from equations (4) to (8) and multiplying by 365, the number of days in a year.

The water supplied is not consumed completely and waste water is discharged to flow in sewerage lines. Out of the total water supply in the bathroom, toilet and kitchen for household usage, 90%, 95% and 60% respectively is discharged as waste water from them. The waste water coming out of schools, hostels, restaurants and hospitals is 40%, 80%, 50%, and 80% respectively of the water supplied to these establishments. The amount of waste water discharged from households, hospitals, hotels, schools and restaurants were evaluated considering the above percentages in the respective equations (4) to (8).

The total amount of waste water is then given by the following equation:

$$T_{WW} = H_{WW} + HP_{WW} + R_{WW} + S_{WW} + SH_{WW} \tag{9}$$

where T_{WW}, H_{WW} , HP_{WW} , R_{WW} , S_{WW} and SH_{WW} represent the total volume of waste water, household waste water, hospital waste water, restaurant waste water, school waste water and school hostel waste water respectively.

System Dynamic Model for Waste Water

As mentioned earlier, SD model was developed to study policy option scenarios for managing Sonipat waste water. A causal loop diagram (CLD) shown in Figure 2 was formulated. In the SD approach the causal loop diagram shows what interrelated factors mean for each other. The diagram consists of a set of nodes representing the variables associated together. Positive or negative links between these variables are shown by arrows based on the inflow into or outflow from the system.

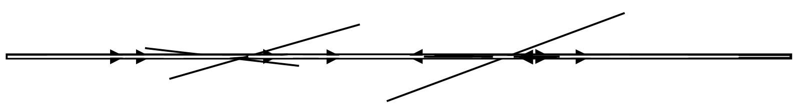

Figure 2: Causal loop diagram for the waste water management model.

A stock flow diagram was made using the causal loop diagram in order to generate a quantitative model. The Sonipat-specific stock flow diagram for the waste water model as shown in Figure 3, describes the definite linkages of the physical and data streams among different components of the model. In this there are three different sorts of variables that serve as the stock flow diagram's fundamental building elements – stock: accumulation of something in the framework, flow: is an intermediary variable used for the many estimations that addresses exercises responsible for the rate change in physical and information flows to and from the stocks, as well as auxiliary: for the change of data from stock variable to stream variable to flow variable.

The symbols in Figure 3 are as follows: rectangles represent the stock variable, a double-lined arrow with valves represents the flow variable, and a circle represents the auxiliary variable. The constants in the diamonds are defined with an initial value and do not change during the run duration. To choose between alternative techniques, the switch control is used to modify the underlying values of constants, auxiliaries, and stock factors. The single arrow refers to the model's cause and effect relationships.

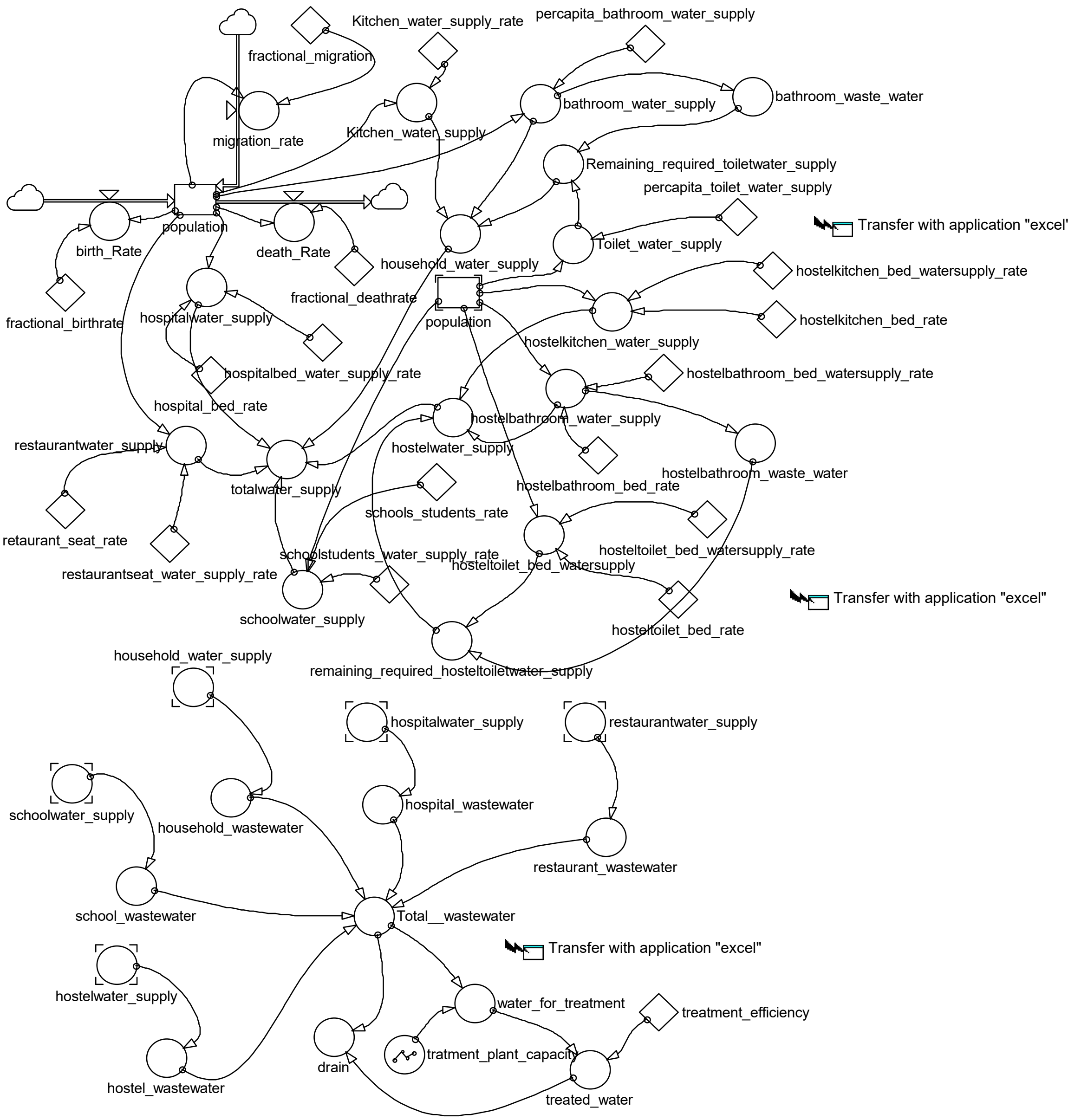

Figure 3: Stock flow diagram of the waste water model applicable to Sonipat.

RESULTS AND DISCUSSION

Model Validation

The system dynamics model for working out policy option scenarios is first validated. The Model behaviour sensitivity was investigated assuming the genuine framework is delicate to the decided arrangement of boundaries. The increasing population is one of the crucial parameters and this was used for the model validation. A comparison of the model-estimated Sonepat population growth with the actual data available has already been provided in Figure 4. A very excellent agreement between model computations and assessed population growth values established the behaviour validity of the model.

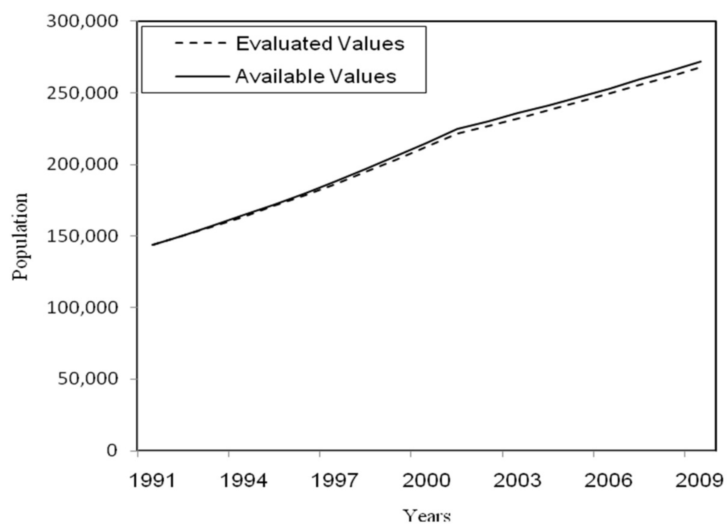

Figure 4: Model predictions for Sonipat's population growth and actual data comparison.

Scenarios to Manage Waste Water

The model utilized between linkages of population growth, by and large water necessity and waste water produced from various areas to give projections up to the year 2035 for different policy scenarios. Baseline (BS) and modified scenarios were considered. Existing conditions given in Table 1 were utilized as input parameters for the baseline scenario. The modified policy scenario was named as a policy scenario (PS). The bathroom waste water from homes and schools was used in this scenario to flush the toilets.

Baseline scenario

Sonipat's current water supply capacity is 23.16 MLD, while residential needs are 137 lpcd (CDPR, 2005). Kitchen water supply, Bathroom water supply and toilet water supply are all included in the household water supply. Breakup of the water supply required for household activities for cooking, drinking, washing, toilet flushing and bathing is: kitchen 27 lpcd, bathroom 50 lpcd and toilet 60 lpcd. The model was used to give temporal projections of the water requirement. Figure 5 shows the temporal projection of the increase in the water supply required for the household usage in the Sonipat city. The water requirement for kitchen, bathroom and toilet is shown separately. In general, an increase in water use corresponds to population growth. The amount of water needed by schools is 45 lpcd, hostels at schools are 135 lpcd, restaurants are 70 lpcd, and hospitals are 340 lpcd. The model was run using these data as input for the base year 2001 to provide forecasts of the water requirements up to 2035. Figure 6 depicts the increase in water usage for various industries.

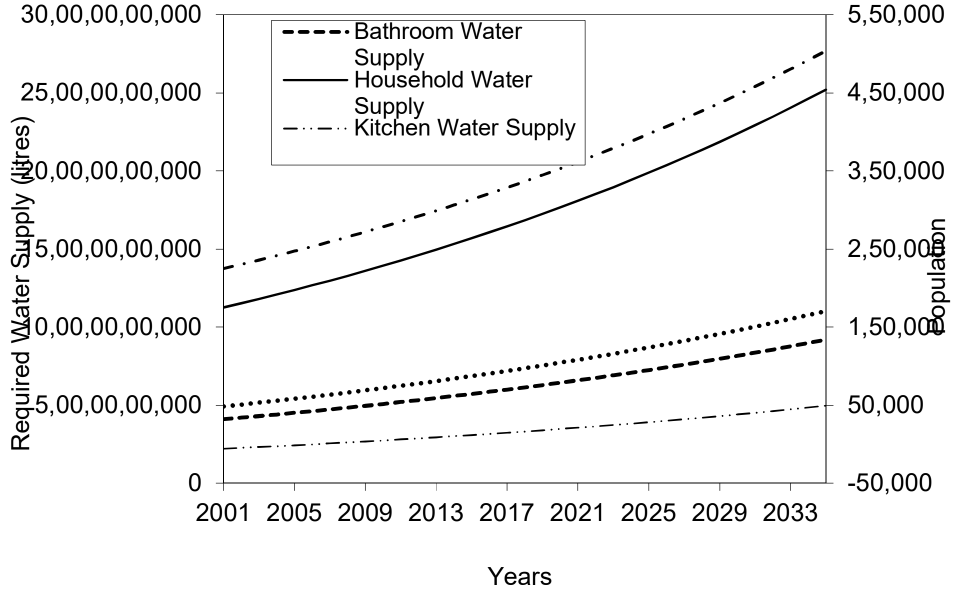

Figure 5: Baseline scenario projections of Sonipat water supply required for household purpose, which includes bathroom, toilet and kitchen supply. Population growth projection is also shown.

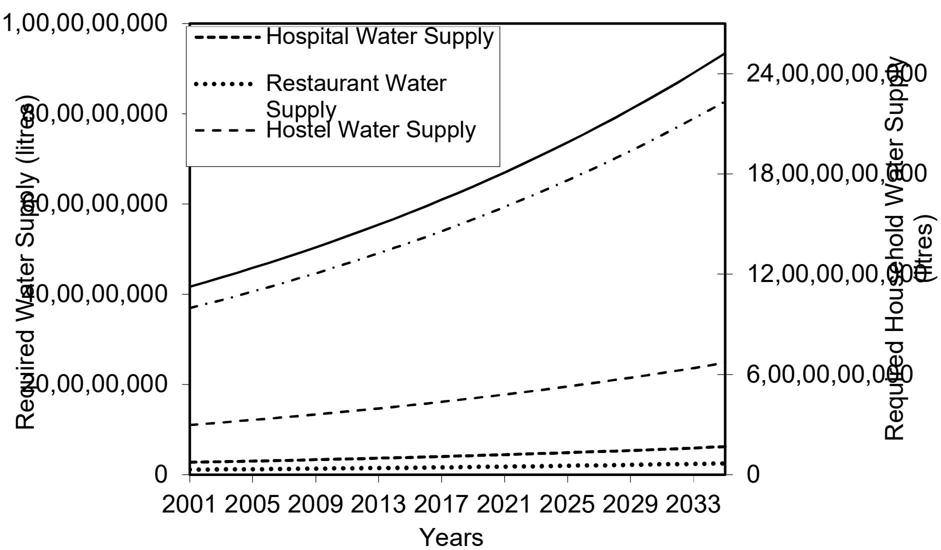

Figure 6: **T**he baseline scenario projections of water supply required in households, schools, hostels, restaurants, and hospitals of Sonipat.

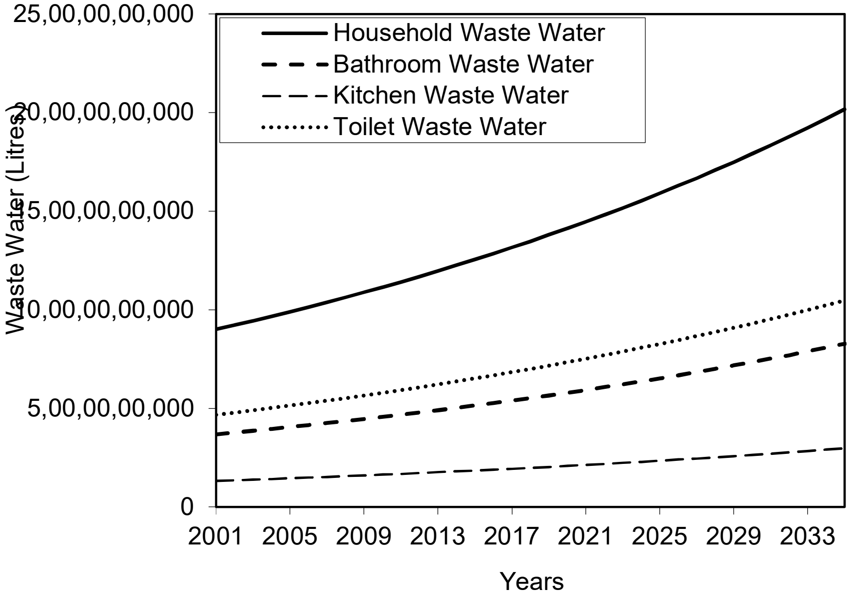

Figure 7: Projections of total waste water generated from households for the baseline scenario. Curves for the amount of waste water discharged from bathrooms, toilets and kitchens for the baseline scenario are also shown.

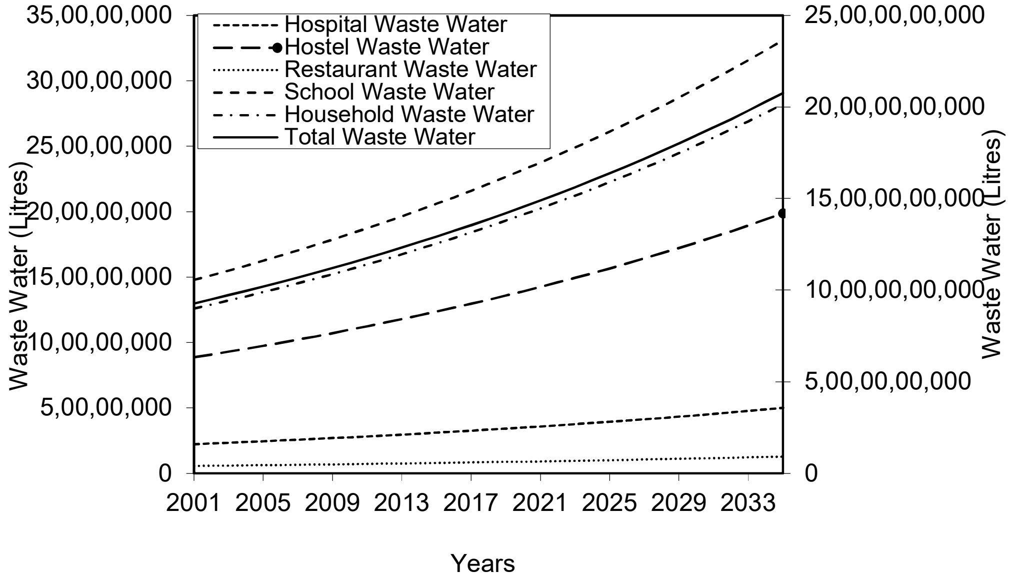

Figure 8: Projections of total waste water including school waste water, hostel waste water, restaurant waste water, hospital waste water, household waste water where household and total waste water lies on secondary axis.

As the water consumption will increase with population growth, the waste water generation will also increase. The model was run to make projections for the waste water generated from different establishments. Temporally projected model values of household waste water and its breakup discharged from bathroom, toilet and kitchen are shown in Figure 7. This figure shows that in the year 2035 household waste water will increase to nearly 55 MLD from 30 MLD in the year 2010.The yearly growth in waste water discharged from household, hospitals, hostels, schools, restaurants and the total amount of waste water is shown in Figure 8. Household waste water graph is plotted on this figure for the sake of comparison.

Sewage lines carry the waste water that is discharged from various industries and establishments to a waste water treatment facility. As was previously mentioned, Sonipat City uses the up flow anaerobic sludge blanket (UASB) technology to remediate waste water. The plant's treatment efficiency is 95%, and its treatment capacity is 30 MLD (http://nbccindia.gov.in). With this capacity, only 30 MLD of the 31.4 MLD of waste water produced in 2010 could be treated; the other 1.4 MLD simply flowed into open drains.Figure 9 depicts the temporal forecasts for the baseline scenario's amounts of total waste water, treated water, and waste water discharged in drains. In 2008, Sonipat City's total waste water surged and exceeded the treatment facility's capacity. Since the facility could treat practically all of it before 2008, very little untreated waste water was dumped in the drain.

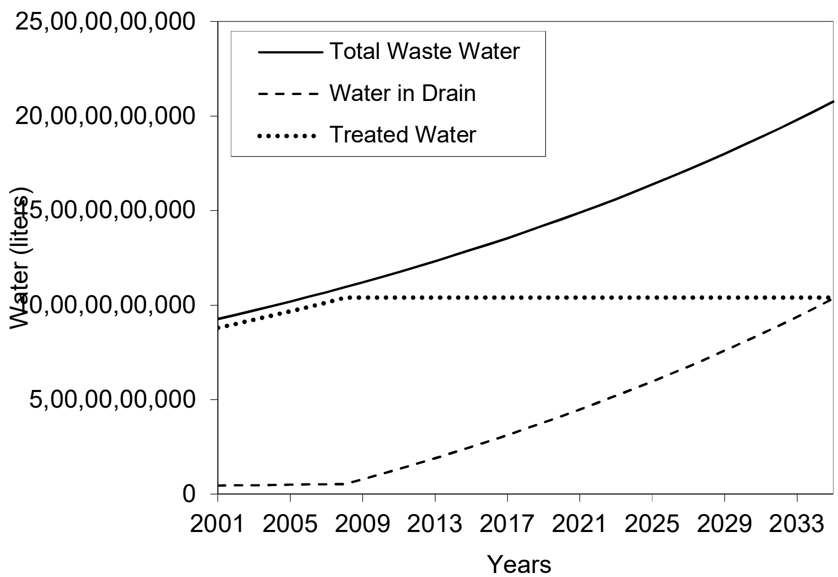

Figure 9: Estimates of the total amount of waste water, water in the drain and treated water for the baseline scenario.

Modified policy scenario

The model was run with modified policy scenario in two segments. In segment I of the policy scenario, the waste water discharged from the bath rooms of households was collected and reused for flushing of toilets. This reduced the potable water intake requirement and accordingly the amount of the waste water eventually discharged from the household decreases. Such a practice is gaining popularity in well organized housing societies. The amount of total water supply, toilet water supply and the waste water discharged from household is shown in the figure 10. The baseline scenario for fresh water required to flush toilets is also plotted for the sake of comparison. The BS projections showed that the water supply requirement in toilets will reach 30 MLD in 2035. But, if the bath room waste water will be used for toilet flushing, the fresh water intake in toilets will come down to merely 8 MLD. Overall discharge of the waste water from household usage would be 55 MLD.

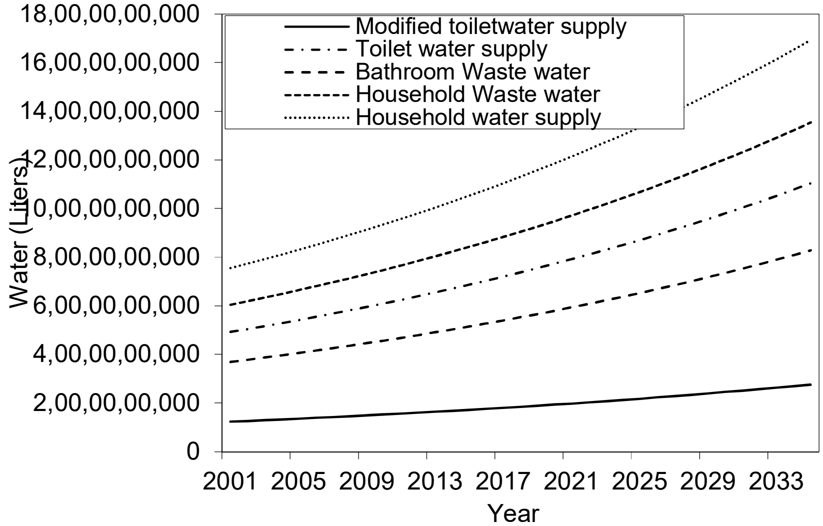

Figure 10: Temporal projections of the household waste water for modified scenario segment I.

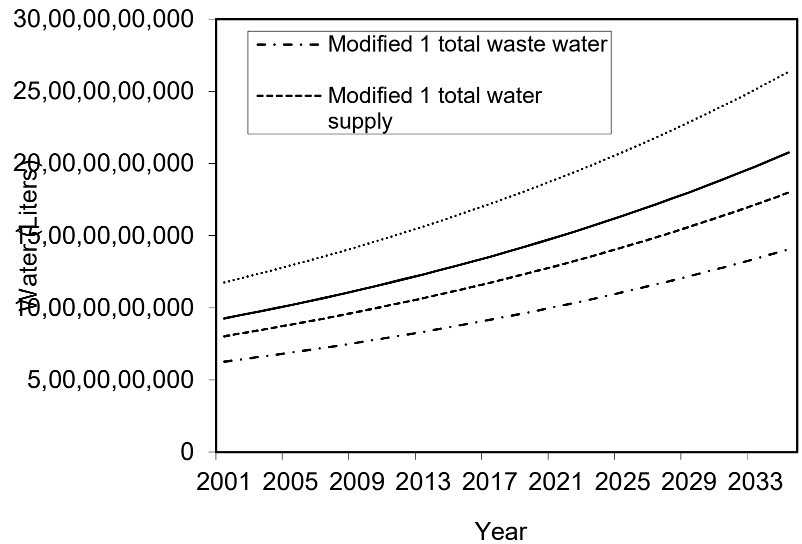

Figure 11: Temporal projections of the total water supply and waste water for BS and modified policy option scenario segment I.

Figure 11compares the total water consumption and waste water production for the BS and the modified policy scenarios. As per the BS projection, in 2035 Sonipat will need 72 MLD of water supply. This would, however, come down to 49 MLD for the proposed modified policy scenario. Modified policy scenario of using bath room waste water to flush toilets was also applied for schools and designated as segment II of the scenario. Figures 12 and 13 shows a comparison of the total water supply and waste water generation in the BS and segment II of the modified scenario respectively.

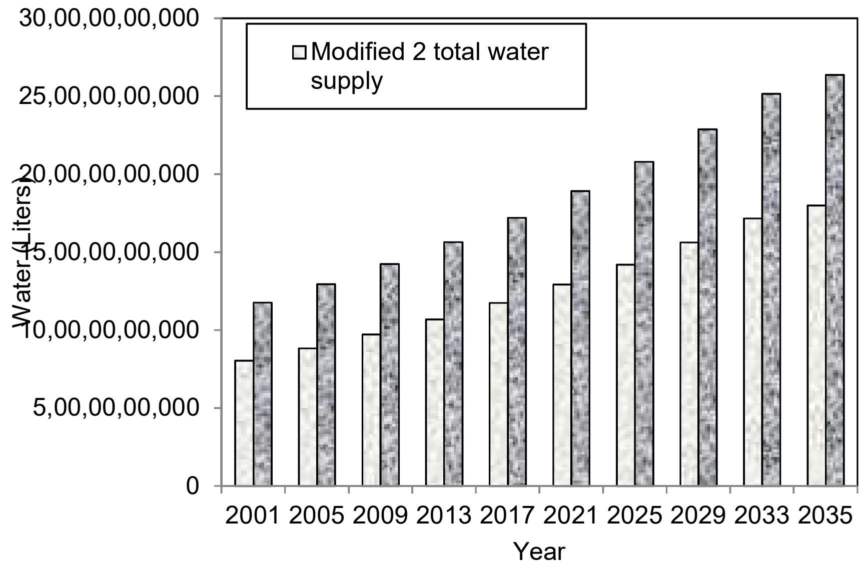

Figure 12: A comparison of the total water supply required for BS and modified policy option segment II.

Table 2: Projection of water supply requirement in Sonipat for BS

Water Supply (MLD)					
Years	**Household**	**Restaurants**	**Schools including hostels**	**Hospitals**	**Total**
2005	34.0	0.034	1.4	0.084	35.4
2010	38.1	0.039	1.6	0.094	39.9
2015	42.9	0.044	1.8	0.10	45.0
2020	48.3	0.049	2.0	0.12	50.6
2025	54.4	0.056	2.3	0.13	57.0
2030	61.3	0.063	2.6	0.15	64.1
2035	69.0	0.70	2.9	0.17	72.2

Projection made for the amount of water supply needs and the waste water discharge from various sections of establishments is given in Tables 2 and 3 respectively for BS. Outcome of the proposed policy scenario is given in Table 4. Impact of the growing population of Sonipat on the water supply requirement and the discharge waste water can be curtailed with the proposed policy option.

It is obvious that the modified scenario basically gives policy options to move toward a path of satisfying the demand of water. In addition to the water conservation and reuse of waste water, other measures, like rainwater harvesting, should also be adopted. These actions should be broadly announced to create awareness among the majority.

Therefore, the educational institutions settings were chosen for segment II of the proposed scenario so the arrangement measures could be made well known among the young students with prolific personalities.

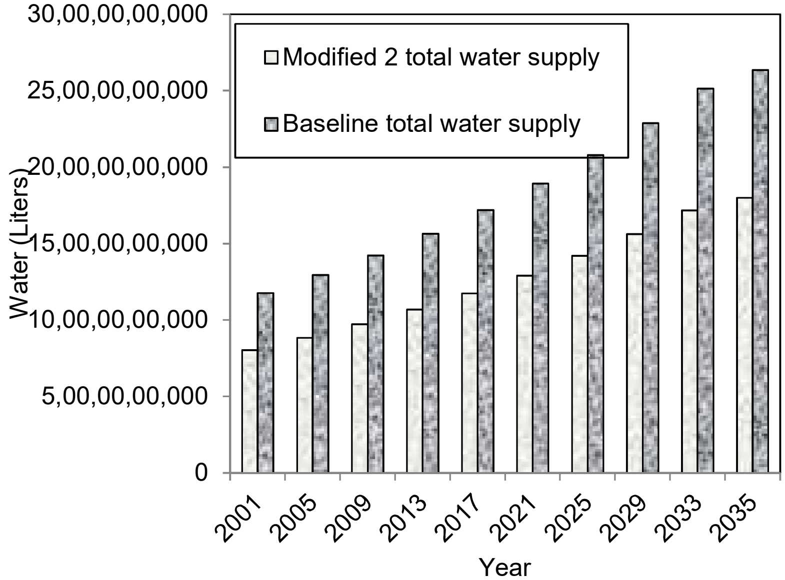

Figure 13: A comparison of the amount of waste water generation for BS and modified policy option segment II.

Table 3: Projection of waste water generated in Sonipat for BS

Waste Water (MLD)					
Years	**Household**	**Restaurants**	**Schools including hostels**	**Hospitals**	**Total**
2005	27.12	0.017	0.71	0.06	27.9
2010	30.5	0.019	0.80	0.07	31.4
2015	34.3	0.021	0.90	0.08	35.3
2020	38.7	0.024	1.0	0.09	39.8
2025	43.5	0.027	1.1	0.10	44.8
2030	49.0	0.031	1.2	0.12	50.5
2035	55.2	0.035	1.4	0.13	56.8

The amount of waste water generated has already exceeded the capacity of the presently available waste water treatment plant of 30 MLD in 2008 itself. However, the projections show that if the proposed policy scenario is implemented in the household and school toilets, the existing plant will be sufficient to treat all the waste water of Sonipat up to the year 2024. After that waste water treatment plant with additional capacity will be required, otherwise the untreated waste water will have to be discharged in the open drain. In case of Sonipat the open drain takes the polluted waste water to the river Yamuna.

Table 4: Projection of water supply requirement and waste water generation in Sonipat for the proposed policy option scenario

Years	Water Supply (MLD)		Waste Water (MLD)	
	Household	Schools including hostels	Household	Schools including hostels
2005	22.7	1.3	18.2	0.62
2010	25.6	1.5	20.5	0.70
2015	28.8	1.6	23.0	0.79
2020	32.4	1.9	25.9	0.89
2025	36.5	2.1	29.2	1.0
2030	41.1	2.4	32.9	1.1
2035	46.3	2.7	37.1	1.2

At present Sonipat has 30 MLD capacity waste water treatment plant. This cannot cope up with the growth in the waste water arising from the population increase. Therefore, excess amount of untreated waste water has to be discharged in open drain. Figure 14shows the forecasts for the proposed policy scenario's open drain discharge of the total amount of waste water, treated waste water, and untreated waste water. The projections go as far as 2035.

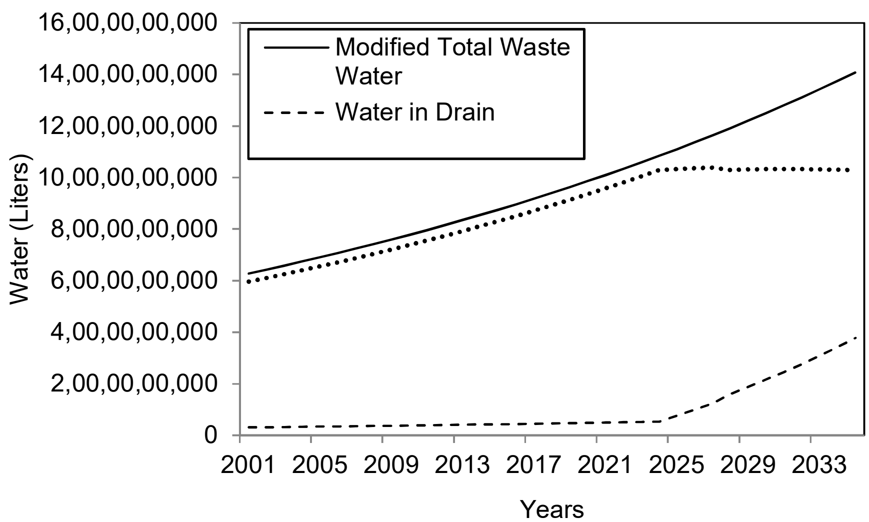

Figure 14: Temporal projections of the amount of total waste water generation in Sonipat, treated waste water and untreated waste water discharged in a drain for modified policy option scenario.

The potential for reducing water demand and reusing it is real and expanding. Reuse strategies, conservation and improvement of system efficiency would substantially reduce the water demand. Water can be utilized on numerous occasions, by flowing it from higher to lower-quality needs. Reclaimed water can be used to supplement the supply side of the infrastructure. Effective water demand management and reusing the available water are policy possibilities that might be supported in order to reduce the water stress that population increase is causing.

Studies made for the baseline and proposed policy option scenario showed that the impact of population growth on water requirement can be diluted by conserving the precious commodity 'water'. As a policy the bath room waste water should be reused for toilet flushing in all the establishments.

CONCLUSIONS

Impact of population growth on water requirement and waste water generation up to the year 2035 was investigated for the medium-sized Sonipat city. Scenarios for household, schools, hostels, restaurants and hospitals were considered. Baseline with as usual approach and modified policy option scenarios were analysed using SD approach. In the modified policy scenario, the waste water discharged from bath rooms was proposed for reuse in toiled flushing. If no conservation measures are adopted, the water requirement will reach 72.2 MLD in 2035 from its usage of 39.9 MLD in 2010. For the proposed policy scenario the waste water discharge will reduce by 32% in 2035 as compared to the baseline scenario. Moreover, the existing waste water treatment plant of 30 MLD capacity in Sonipat will be sufficient to treat all the waste water projected for the year 2024 if the proposed policy scenario is fully implemented.

REFERENCES:

Ahmad, S. and Simonovich, S. P. (2000), 'Modeling reservoir operations for flood management using system dynamics', *Journal of Computing in Civil Engineering*, **14**(3), pp. 190–198.

Alcamo, J., Doll, P., Henrichs, T., Kaspar, F., Lehner, B., Rosch, T. and Siebert. S. (2003), 'Global estimates of water withdrawals and availability under current and future "business-as-usual" conditions', *Hydrological Sciences*, **48**(3), pp. 339-349.

Asano, T. (1998), *Wastewater reclamation and reuse*, Water Quality Management Library Vol. (10), Lancaster- Pennsylvania, USA: Technomic Publishing.

Asano, T. (2002), *Recycled water task force second meeting*, Workgroup presentation and discussions, Manhattan, Beach Mariott Hotel.

Behzadian, K. (2015) Modelling metabolism based performance of an urban water system using WaterMet2. Resources Conservation and Recycling 99, 84–99, https://doi.org/10.1016/j.resconrec.2015.3.015.

CDPR (2005), *City Development Plan Report for Sonipat*, Design and Development Forum for the Haryana Urban Infrastructure Development Board, Sonipat, India.

Chung, G., Kim, J.H. and Kim, T. (2008), 'System Dynamics Modeling Approach to Water Supply System', *KSCE Journal of Civil Engineering,* **12**(4), pp. 275-280.

Girardet, H. (2004), *Cities, People, Planet,* Wiley Academic, Chichester, UK.

Khalil, N., Sinha, R., Raghav, A. K. and Mittal, A. K. (2008), *UASB Technology for sewage treatment in India: Experience, Economic Evaluation and its potential in other developing countries,* Twelfth International Water Technology Conference, Alexandria, Egypt.

Kumari, S., Dahiya, R.P., Kumari, N., Sharawat, I. (2014), Estimation of methane emission from livestock through enteric fermentation using system dynamic model in India. Int J Environ Resear Dev 4(4):347–352. https://www.ripublication.com/ijerd_spl/ijerdv4n4s pl_13.pdf

Maani, K. E. and Cavana, R. Y. (2000), *Systems Thinking and Modelling: Understanding Change and Complexity*. Prentice Hall, Auckland, N.Z.

Meenakshi, Kumar, K. E., and Kumari, N. (2021). Forecasting the Electricity Demand with Increasing Population by Using System Dynamic Approach - A Case Study of Karnal City (India). Applied Ecology and Environmental Sciences, vol. 9, no. 7, 707-714. doi: 10.12691/aees-9-7-10.

Ministry of Urban Development, New Delhi, 2014, Urban and Regional Development Plans Formulation and Implementation Guidelines, Vol.1.

NBCC, *National Buildings Construction Corporation Limited*, Ministry of Urban Development, New Delhi, http://nbccindiagov.in.

Oki, T., Agata, Y., Kanae, S., Saruhashi, T., Yang, D. and Musiake, K. (2001), 'Global assessment of current water resources using total runoff integrating pathways', *Hydrological Sciences*, **46**(6), pp. 983-995.

Pani, A., Ghatak, I. & Mishra, P. (2021), Understanding the water conservation and management in India: an integrated study. *Sustain. Water Resour. Manag.* **7,** 77, https://doi.org/10.1007/s40899-021-00556-2.

Sharawat, I., Dahiya, R.P., Dahiya, R., Kumari, S. (2014), System Dynamics approach: a novel water resource management tool. Int J Environ Resear Dev 4(4):347–352. http://www.ripublication.com/ijerd _spl/ijerdv4n4spl_05.pdf.

Sharawat, I., Dahiya, R., Dahiya, R.P. *et al.* (2019), Policy options for managing the water resources in rapidly expanding cities: a system dynamics approach. *Sustain. Water Resour. Manag.* **5,** 1201–1215.https://doi.org/10.1007/s40899-018-0296-7.

Shah, M. (2016), Urban Water Systems in India: A Way Forward. Indian Council for Research on International Economic Relations, Delhi. http://icrier.org/pdf/Working_Paper_323.pdf

Simonovic, S. P. and Rajasekaram, V. (2004), 'Integrated analyses of Canada's water resources: A system dynamics approach', *Canadian Water Resources Journal*, **29**(4), pp. 223–250.