



# Policy options for managing the water resources in rapidly expanding cities: a system dynamics approach

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## Abstract

Sustainable development of water resources and managing the wastewater generated in rapidly expanding cities pose a challenge for working out policy options. System dynamics approach is used to devise policy scenarios for the sustainable development of water resources in conformity with the temporal projections made for population growth. The projections made for water consumption and wastewater generation under the as usual baseline and modified scenarios for a typical district headquarter city in North India have shown that the water demand will enhance by 69% in 25 years if the current water supply practices are continued. Mitigation options proposed for curtailing the water demand and reducing the wastewater generation include progressive approach in succession for population stabilization, grey water reuse after treatment and combined scenario. The proposed modified policies would significantly reduce the water consumption pattern and should cope up with the demand of growing population.

**Keywords** Water supply · Wastewater generation · System dynamics · Population stabilization · Grey water reuse

## Introduction

The urbanization rate in Asia is higher than that in other parts of the world and by the year 2050 nearly 64 % people will live in urban areas. Out of the projected urban population growth of 2.5 billion in next 33 years, India and China will account for 37 percent growth (UN 2014). During this period, the number of urban slum dwellers will reach nearly two billion (GWP 2013). The number of people residing in urban parts of India is predicted to reach 800 million by 2050 (Shah 2016). Population growth will pose challenges for urban water supply and wastewater management. Even now 34% global population is water stressed and nearly one billion people do not have access to safe drinking water (Rohilla et al. 2017).

Indian society is already facing daunting challenges in urban water supply and wastewater management due to increasing population and rapid urbanization (Amerasinghe et al. 2013). According to a survey conducted by Central Pollution Control Board, only 2% cities in India have both sewage treatment plants and sewerage system (CPCB 2011). About 80% of water supplied to households is discharged as wastewater. The data of 2015 show that in India, the urban areas were generating around 62,000 MLD of sewage per day, whereas the wastewater treatment capacity was 23,277 MLD. The actual amount of treated sewage was 18,883 MLD because only 522 out of 816 sewage treatment plants were operational. Thus, around 70% of the sewage generated in urban areas was being dumped into open areas and the rivers. Untreated or partially treated sewage disposal is largely responsible for pollution of water bodies (MoEFCC 2016).

A paradigm shift is required to develop strategies for handling of wastewater. One plausible approach needed to be emphasized is recycle and reuse as it reduces water demand and increases the life of the available water supply (WWAP 2017). In 2015, the Ministry of Environment and forest, Government of India, proposed that the state authorities should restrict the use of groundwater and fresh water for household non-potable purposes such as flushing, cleaning,

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and gardening, instead the treated wastewater should be used (MoEFCC 2016).

A water balance approach is used in this research to devise and study policy scenarios for sustainable development of water resources to address the challenge of growing population. A system dynamics-based simulation model is used for projection of water demand and waste water generation under different scenarios from 2016 to 2041. The policy scenarios proposed will go a long way in decision-making for an effective conservation policy. That policy scenarios proposed will result in sustainable and efficient use of water resources.

## Study area

A typical district headquarter city in North India is considered for developing and testing the policy scenarios to have sustainable growth over next 25 years. The population, water supply and wastewater generation data are collected for district headquarter city Rohtak, which is 75 km northwest of Delhi, the National Capital of India. It is a rapidly expanding city and currently spread over approximately 1745 sq. km. Being among the eight priority centers of National Capital Region (NCR), the city has experienced enormous population growth, urban expansion, land use changes and a substantial increase in economic activities over the last few years (Singh and Kumar 2012). The Rohtak city is being developed for advanced industrial and other economic activities. There will be a concentration of administrative and higher order service functions. All these developmental aspects are expected to exert an increasingly dynamic influence on investment for conducive living and working environment (DDP-2031 2013). The population of the city is also increasing due to the influx of people from the neighboring rural and even far-flung areas. These features are similar to not only of the fast growing cities of India, but also to other developing countries.

In India, the recommended water supply in urban areas, such as Rohtak city, is 135 lpcd (CPHEEO 2013). The sector-wise water supply requirement in the city is given in Table 1. Total water supply in the city is 78 MLD and wastewater treatment capacity is 53MLD. The location and capacity of each water works and sewage treatment plant is shown in Fig. 1. Treated and untreated water is discharged into drain no. 8 which eventually goes to river Yamuna (PHED 2015). The Yamuna river is amongst the most polluted river stretch of India (Singh and Kansal 2016). Despite huge investment in infrastructure, the city still has a large gap between wastewater generated and installed sewage treatment capacity. This gap will further widen in the future. Thus, in the coming years, the city will have the scarcity of fresh water due to increased population, urbanization

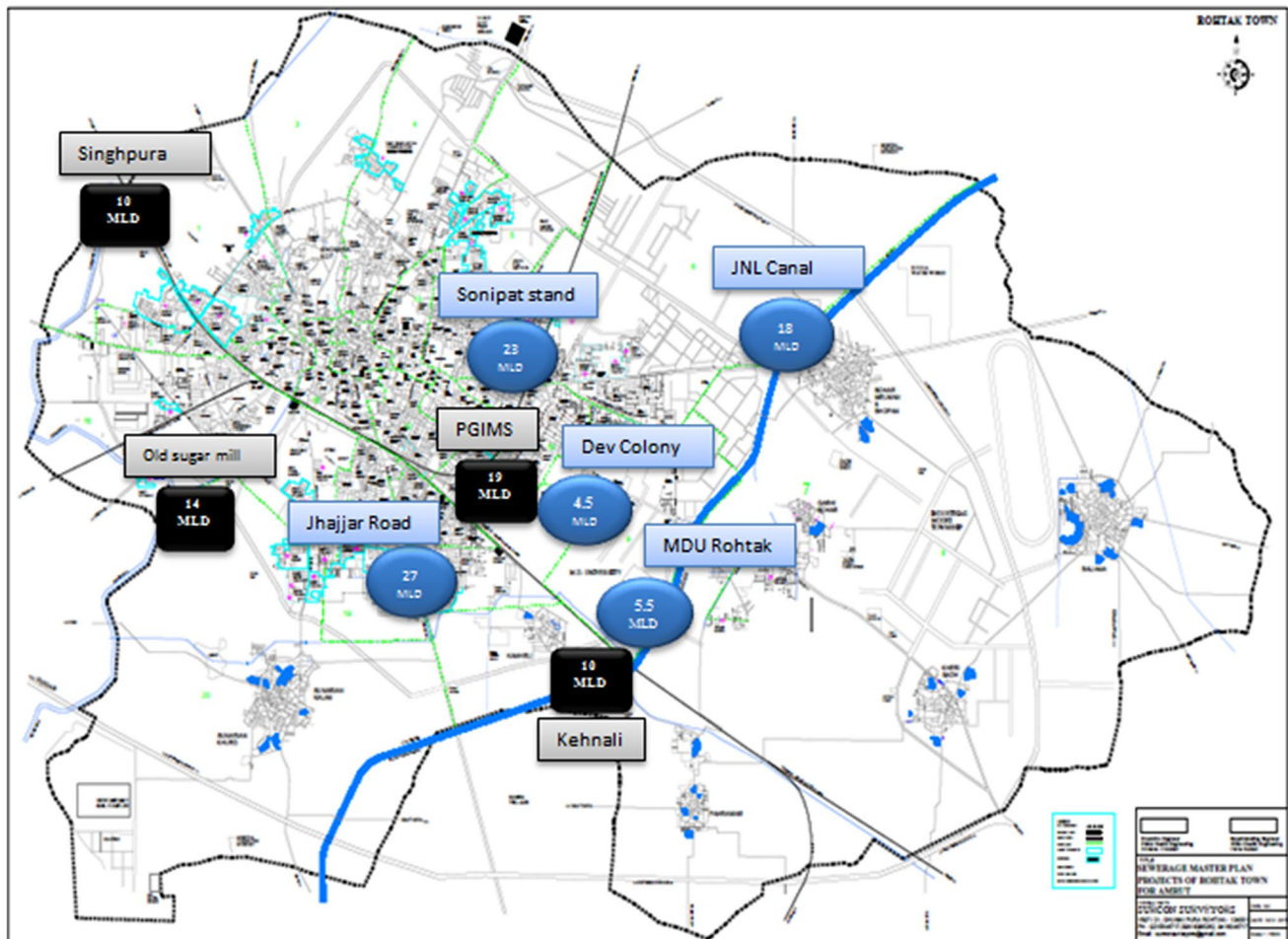
**Table 1** Break-up of water supply requirement in Rohtak city (Source: CPHEEO-Third edition 2013, Manual on Water supply and Treatment)

S. No.	Institutions	Liters per head per day
1	Hospitals	340 (per bed)
2	Household	135
3	Commercial establishments (offices & shops)	45
4	Restaurants	70 (per seat)
5	Educational Institutes	45

and industrialization. Increasing population and development will lead to enhancement in wastewater generation. Hence, there is an urgent need to devise policy scenarios for sustainable development in conformity with the growing population.

## Methodology

System dynamics approach (SDA) is used for analyzing and developing policy scenarios to make projections keeping in view the sustainable development of water resources. The purpose of system dynamics (SD) is to understand the complex and dynamic systems, and suggest the changes in decision-making for improving the performance (Sharawat et al. 2014). It is a computer-aided approach for studying, analyzing and solving complex issues and problems with a focus on policy design (Talyan et al. 2007). A detailed methodology for applying SD approach is given by Sterman in 2002. The SD approach has been used extensively to a number of studies related to environment: solid waste management (Dyson and Chang 2005; Talyan et al. 2007; Kollikkathara et al. 2010), ecological modelling (Bagdon et al. 2016), environment impact assessment (Nouri et al. 2009; Wieland and Gutzler 2014), greenhouse gas emissions and climate change (Anand et al. 2005; Kumari et al. 2014), environmental planning and management (Guo et al. 2001; Guneralp and Barlas 2003) and water resource management (Winz et al. 2009; Mirchi et al. 2012; Dawadi and Ahmad 2012; Sharawat et al. 2014; Zarghami and Akbariyeh 2012; Behzadian 2015). Within water resource management sector, Qaiser et al. (2013) applied SD to assess different conservation policies on indoor and outdoor water uses, along with different population growth scenarios in Las Vegas valley. Simonovic and Rajasekaram (2013) performed model simulations for 12 scenarios to investigate policy options in the area of fresh water availability, wastewater treatment, population growth, economic growth, food production and energy generation. Nasiri et al. (2012) developed a system dynamics approach for urban water reuse planning in Great Lakes region. Xi and Poh (2013) demonstrated the usefulness of



**Fig. 1** Location and capacity of water works and sewage treatment plants. Blue color shows water works and black color shows sewage treatment plants

system dynamics as a decision support tool to help achieve sustainable water management in Singapore. Rathnayaka et al. (2017) used a stochastic approach to predict residential water demand at multiple temporal and spatial scales.

The SD modelling process has two main stages. A causal loop diagram (CLD) is constructed in the first stage in which causal relationships among the system components are identified. Then in the second stage, a stock and flow diagram is formulated based on CLD and the dynamo equations are added to the model (Mandani and Mariño 2009). The simulations in the SD modelling are essentially time-step simulations. The model takes a number of simulation steps along the time axis. The rate equation for the dynamics of the system is represented by

$$dN(t)/dt = kN(t), \quad (1)$$

which has a solution

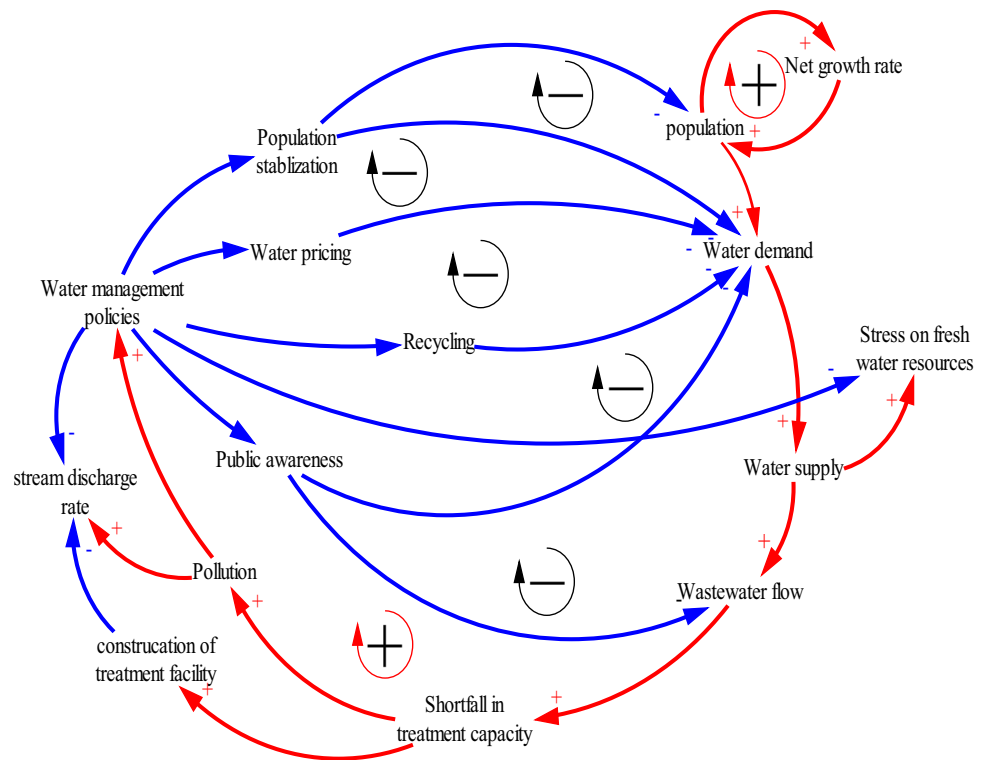
$$N(t) = N_0 \exp(kt), \quad (2)$$

where  $N_0$  is the initial data value of the system,  $t$  is the simulation time and  $k$  is rate constant.

## Water resource management (WRM) model

A holistic mass balance model of the city's water system is developed. The modeling is done using STELLA 9.0.1 software. Figure 2 shows the causal loop diagram (CLD) developed by assimilating the essential components of the water resource management system. The CLD describes the system structure qualitatively and presents how the variables in the system affect each other. The relationships between these variables are shown by arrows with one of the two states of polarity, positive (+) or negative (-). A "+" polarity indicates a reinforcing loop in which both the variables move in the same direction and a "-" polarity indicates a balancing loop where both variables move in

**Fig. 2** Causal loop diagram of water resource management



opposite direction. The polarity of the loop is the product of sums of its links.

To perform a quantitative analysis, the causal loop diagram is converted to stock and flow diagram, which explains the physical and information flows in the system. The main building blocks for SD model are stocks, flows, converter and connectors. Stock variable, shown as rectangles in Fig. 3, represents accumulations—physical and non-physical. They start with some initial value and thereafter changed only by flows into and out of them. A flow is the rate of change in a stock which is represented by a double-lined arrow with valves. Converters are represented by circles and it serves a utilitarian role in the model. It defines external inputs to the model, holds values for constants and acts as a repository for graphical functions. The job of the connector is to connect model elements.

Mathematically, the relation between stock and flows can be described using the following integral form (Sterman 2000):

$$\text{Stock}(t) = \int_{t_0}^t [\text{Inflow}(s) - \text{Outflow}(s)]ds + \text{Stock}(t_0), \tag{3}$$

where  $t$  is the current time,  $t_0$  is the initial time,  $\text{Stock}(t_0)$  is the initial value of the stock, and  $\text{Inflow}(s)$  and  $\text{Outflow}(s)$  are rate into and out of a stock at any time  $s$  between the current time  $t$  and initial  $t_0$ .  $\text{Inflow}(s)$  and  $\text{outflow}(s)$  have the units of  $\text{Stock}(t)$  divided by time:

$$d(\text{Stock})/dt = \text{Inflow}(t) - \text{Outflow}(t). \tag{4}$$

Equations. 3 and 4 determine the net rate of change of a stock with time (Sterman 2000).

The stock and flow diagram for water supply and wastewater model applicable to Rohtak city, shown in Fig. 3, gives the detailed linkages of the physical and information flows among various elements of the model. The model shows two sectors: one is residential and other is non-residential. Hospitals, offices, restaurants and educational institutes are considered in non-residential sectors. The model used inter-linkages of population growth, overall water requirement and waste water generated from different sectors to give projections up to 2041. The equations and data utilized as input parameters in the model are shown in Table 2.

### Policy option scenarios

The scenarios developed are baseline scenario (BS) and modified scenarios. Three modified policy option scenarios are developed. The first modified policy scenario is population stabilization (PS). This is sub-categorized as PS-I, PS-II, PS-III, PS-IV and PS-V. The second modified scenario is grey water reuse (GR). This scenario is also sub-categorized as GR-I and GR-II. Third modified policy scenario is combined scenario (CS); this scenario is created by combining first (PS) and second modified policy scenario (GR). The data required for analysis were collected from

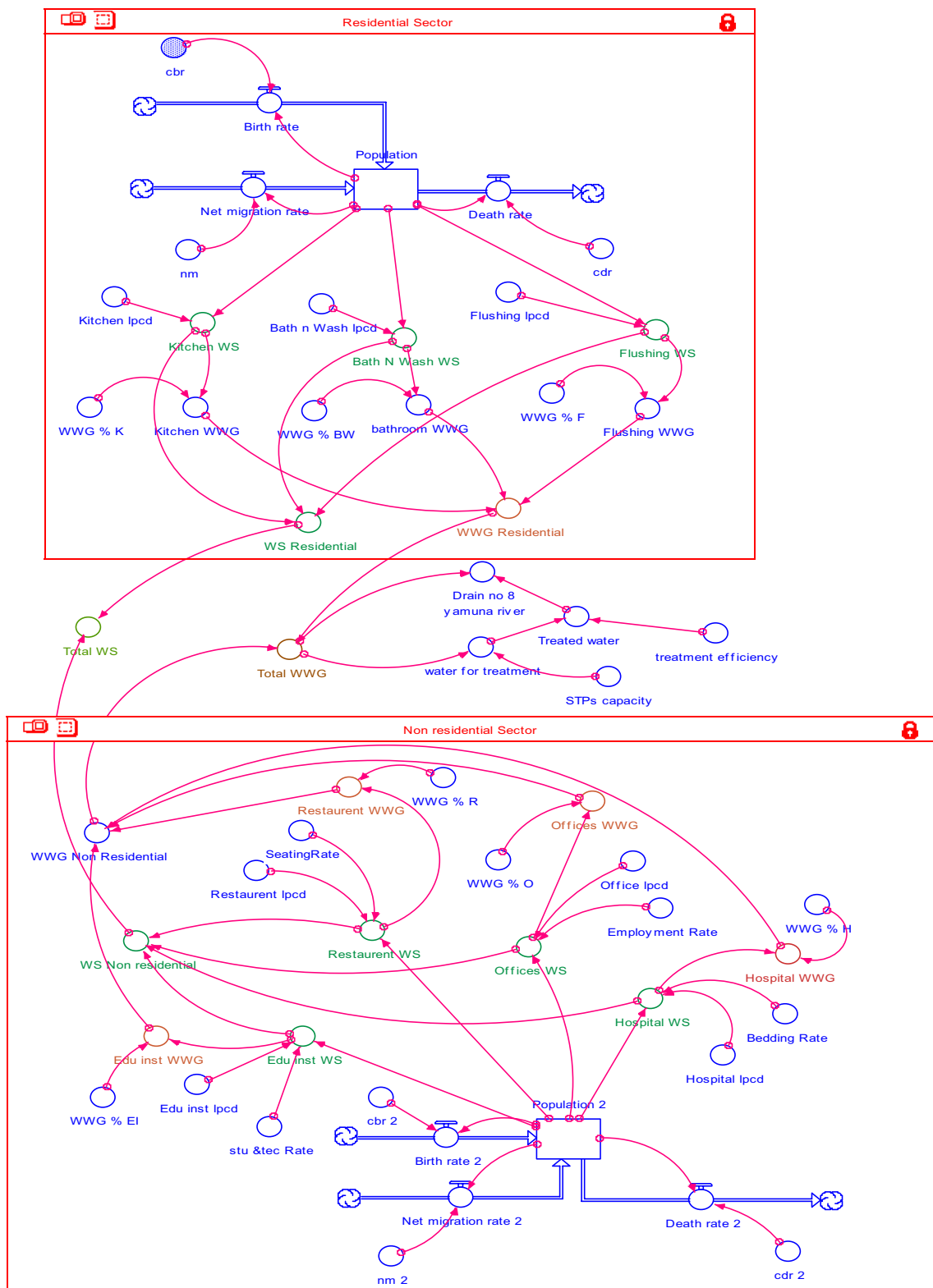


Fig. 3 Stock and flow diagram applicable to Rohtak city

**Table 2** Equations and data used in Stock and flow model (Source: Various departments in Rohtak city such as Public health engineering department (division III), Haryana statistical office, DEO and BEO office, Water works (division III), Kehnali STP, Town and Country planning office, Maharishi Dayanand University through private conversation and also from websites of CPCB, CPHEEO)

Equations	Description	Data used
$H_{WS} = P_t \times H_{PC}$	$H_{WS}$ = household water supply, $H_{PC}$ = per capita water demand and $P_t$ = population	Per capita water demand is 135 lpcd; waste water generation from household is 80% of the supply
$HP_{WS} = P_t \times HP_{PC} \times HP_{BR}$	$HP_{WS}$ = hospital water supply, $HP_{PC}$ = per capita hospital water demand, $P_t$ = population, $HP_{BR}$ = hospital bed rate, where $HP_{BR}$ = number of beds in all hospitals of the city/ total population	Per capita water demand is 340 lpb, waste water generation from hospital is 80% of the supply and no. of beds available in Hospitals is 2085
$EI_{WS} = P_t \times EI_{PC} \times EI_{S\&TR}$	$EI_{WS}$ = educational institute's water supply, $EI_{PC}$ = per capita demand in educational institute, $P_t$ = population and $EI_{S\&TR}$ = students/teachers rate in the city, where $E_{S\&TR}$ = number of students /teachers in all educational institutes/ population	Per capita water demand is 45 lpcd, waste water generation is 70% of the supply, no. of students in educational institutes are 175,053 and no. of employees in educational institutes are 32,759
$SO_{WS} = P_t \times SO_{PC} \times SO_{ER}$	$SO_{WS}$ = shops and offices water supply, $SO_{PC}$ = per capita water demand, $P_t$ = population and $SO_{ER}$ = employment rate, where $SO_{ER}$ = Number of employees in shops and offices in the city/population	Per capita water demand is 45 lpcd, Waste water generation is 70% of supply and no. of employees in offices are 51,546
$R_{WS} = P_t \times R_{PC} \times R_{SR}$	$R_{WS}$ = restaurant water supply, $R_{PC}$ = per capita water demand in restaurants, $P_t$ = population and $R_{SR}$ = restaurant seating rate	Per capita water demand is 70 lpcd, waste water generation is 50% of supply and total no. of restaurants are 51 (approx..70 seats)
$T_{WS} = H_{WS} + HP_{WS} + EI_{WS} + SO_{WS} + R_{WS}$	$T_{WS}$ = household water supply, $HP_{WS}$ = hospital water supply, $EI_{WS}$ = educational institute's water supply, $SO_{WS}$ = shops and offices water supply and $R_{WS}$ = restaurant water supply	



various published articles and official reports of Government of Haryana, from personal conversation with various government officials and also from websites of CPCB and CPHEEO.

### Baseline scenario (BS)

The business as usual scenario is simulated to understand the existing situation prevailing in the city. It is taken as reference scenario, to which all the other modified policy scenarios can be compared to judge their impact as a policy measure. The baseline population in Rohtak city for the year 2011 was 446164 (Census 2011). The crude birth rate (CBR): births per 1000 persons in a population over a given period of time, crude death rate (CDR): deaths per 1000 persons in a population over a given period of time and net migration rate in the city were 19.5, 5.3 and 7, respectively, (Census 2011; HSO 2015). The per capita water demand in the Rohtak city is 135 lpcd (CPHEEO 2013) and 80% of the water supply is discharged as wastewater (CPCB 2009–2010). Total water supply in the city is 78 MLD and 53 MLD is the treatment capacity. Other existing conditions required for developing the baseline scenario are given in Tables 1 and 2.

### Modified scenario: population stabilization (PS)

On May 11, 2000, Indian population reached 1 billion. It was 16 % of world's population. Global population increased by threefold during this century (1900–2000). The Indian population increased by nearly five times, i.e. from 238 million to 1 billion, during the same period. If the same trend of population increase continues, India will become the most populous country in the world by 2045. For promoting sustainable development with more equitable distribution, stabilizing population is an essential requirement. Multipronged efforts are, therefore, being made in India to control the population growth. The government of India had launched the National Population Policy (NPP) 2000 with the long-term objective of achieving a stable population by the year 2045 at a level consistent with the requirements of sustainable economic growth, social development, and environment protection. A National Commission on population (NCP) presided over by the Prime Minister, Chief Ministers of all states and others as the members have also been constituted in 2000 to oversee and review the policy. The medium-term objective of NPP was set to reduce the total fertility rate (TFR) to 2.1 by 2010. Though the trend of TFR is declining in India, India failed to achieve the target by the stipulated time. The latest report on TFR is awaited but in the last report, i.e. in 2014, the TFR of India is 2.3 as shown in Table 3. On the other hand, the TFR of Rohtak city which is an urban part of Haryana State reached to 2.2

in 2010 which is close to national target as it is located in developed part of the country. The TFR in most of the other cities in India have also reached in the range between 2.1 and 2.3 in 2010. But rural part of India, that constitutes 69% of the population of India (Census 2011), failed to achieve the medium-term objective of NPP.

Migration rate also plays an important role in projecting the population of the region. With the aim of reducing migration and bridging rural–urban divide, the Government of India launched a National rural mission (NRuM) named Shyama Prasad Mukherji Rurban Mission (SPMRM) on 21 February 2016 with an outlay of almost \$ 580 million for first 5 years. SPMRM is an attempt to strengthen the rural areas by providing social, economic and infrastructure amenities. This scheme will lead to a balanced regional development by achieving twin objective of reducing stress in urban areas and strengthening rural areas.

To tackle the healthcare needs of people, the government has launched programmes such as Janani Suraksha Yojana, National Rural Health Mission and ICDS (Integrated Child Development Services). It is expected that these kinds of programmes also contribute to population stabilization.

As the cities are located in the developed region of the country and have high literacy rate. Hence, here the national policy measures are implemented at accelerated pace in comparison with under-developed regions. Therefore, in the present study, we set a target to achieve population stabilization in Rohtak city by 2041 which is little ahead of the national target of 2045. The crude birth rate (CBR), crude death rate (CDR) and net migration rate are altered within the range of national parameters to develop modified policy scenarios and to study the trend of population growth. As stated earlier, the population of Rohtak city in 2011 was 446164 (Census 2011). The CBR, CDR and net migration rates per thousand were 19.5, 5.3 and 7, respectively. Six scenarios are considered. One is baseline scenario (BS) and five are modified scenarios denoted as PS-I, PS-II, PS-III, PS-IV and PS-V. Details of the scenarios are presented in Table 4. These scenarios showed the impact of parametric variations on the population growth.

**Table 3** Values of TFR in India, Haryana and Rohtak city (Source: SRS 2010, SRS 2014, ESH 2015–2016)

Year	India	Haryana state	Rohtak city (Urban part of Haryana)
2010	2.5	2.4	2.2
2014	2.3	2.2	2.1

**Table 4** Scenario description for projection of population

Scenario	Description
BS	For BS, the CBR, CDR and net migration rates are kept as 19.5, 5.3 and 7, respectively, for the entire period
PS-I	In PS-I, the CBR, CDR and migration rates are kept as 19.5, 4.3 and 7, respectively, for the entire period. The nullifying effect of deaths on population growth will come down in coming years because of improvement in health care and infrastructure facilities in the city
PS-II	In PS-II, the CBR of 19.5 is kept constant from 2011 to 2016. After 2016, the CBR is decreased by 0.2 every year. Values of CDR as 4.3 and net migration as 7 are kept constant for the entire period. These values are not changed because we wanted to show the effect of CBR as a single parameter to emphasis the need for birth control
PS-III	In this scenario, the net migration and CBR are kept as 7 and 19.5, respectively, for the year 2011–2016. After 2016, net migration and CBR are decreased by 0.2 every year. CDR is kept 4.3 for the entire period. This scenario is created to show the effect of migration on population of city
PS-IV	This scenario is developed by taking the CBR, CDR and net migration as 19.5, 4.3 and 7, respectively, from 2011 to 2016. Thereafter, the annual decrease in CBR, CDR and net migration of 0.5, 0.1 and 0.2, respectively, are considered
PS-V	In scenario PS-V, the CBR, CDR and net migration are taken as 19.5, 4.3 and 7, respectively, from 2011 to 2016. After 2016, annual decrease in the deaths and migrations of 0.1 and 0.25 per thousand are considered. From 2017 to 2031, the CBR is reduced by 0.5 every year and from 2032 to 2041 it is annually decreased by 1. The annual decrease is considered to reach a policy of the steady state of population growth. It is achievable in Rohtak city as the city has high literacy rate and located in the developed region of India

### Modified scenario: grey water reuse (GR)

It has been predicted that by the year 2025, one person in three will live in conditions of absolute water scarcity. It is, therefore, essential to substitute fresh water with alternate water resources and to optimize water use efficiency through reuse options (Amerasinghe et al. 2013). In India, the urban areas are generating around 62,000 MLD of sewage per day and having a treatment capacity of 23,277 MLD as of Dec 2015. But the actual amount of treated sewage is 18,883 MLD because only 522 out of 816 sewage treatment plants are operational. Thus, around 70% of sewage generated in urban areas is being dumped into the rivers and polluting fresh water resources. Untreated or partially treated sewage is responsible for large part of pollution in water bodies. In 2015, the environment ministry proposed that state authorities should restrict the use of groundwater and fresh water for non-potable purposes such as flushing, cleaning, and gardening. Treated wastewater should be used instead (MoEFCC, 2015–2016). According to Waggett and Arotzky, (2006) grey water reuse is one of the feasible options in developing countries like India to overcome the problem of water scarcity. Toilet flushing is one of the most frequent cited applications of grey water. It accounts for approximately 20–30% of the household water use and can reach up to 60% in commercial buildings. In the present study, two modified scenarios, i.e. GR-I and GR-II, are outlined. Details of scenarios are presented in Table 5. Diagrammatic representation of BS, GR-I and GR-II is shown in Fig. 4. The baseline scenario is also plotted along with modified scenarios for the sake of comparison.

**Table 5** Scenario description for grey water reuse

Scenario	Description
BS	No grey water reuse in city
GR-I	<i>Separate grey water recycling system</i> It is assumed that the grey water is collected from bathrooms of households and reused for flushing of toilets, and the same scenario is also applied separately to non-residential sector in which educational institutes and office buildings are included where greywater is collected from hand basins and reused for toilet flushing
GR-II	<i>Combined grey water recycling system</i> Grey water is collected from bathrooms in residential and from the hand basin's in non-residential buildings and treated at one combined treatment system and then recycled back to residential and non-residential

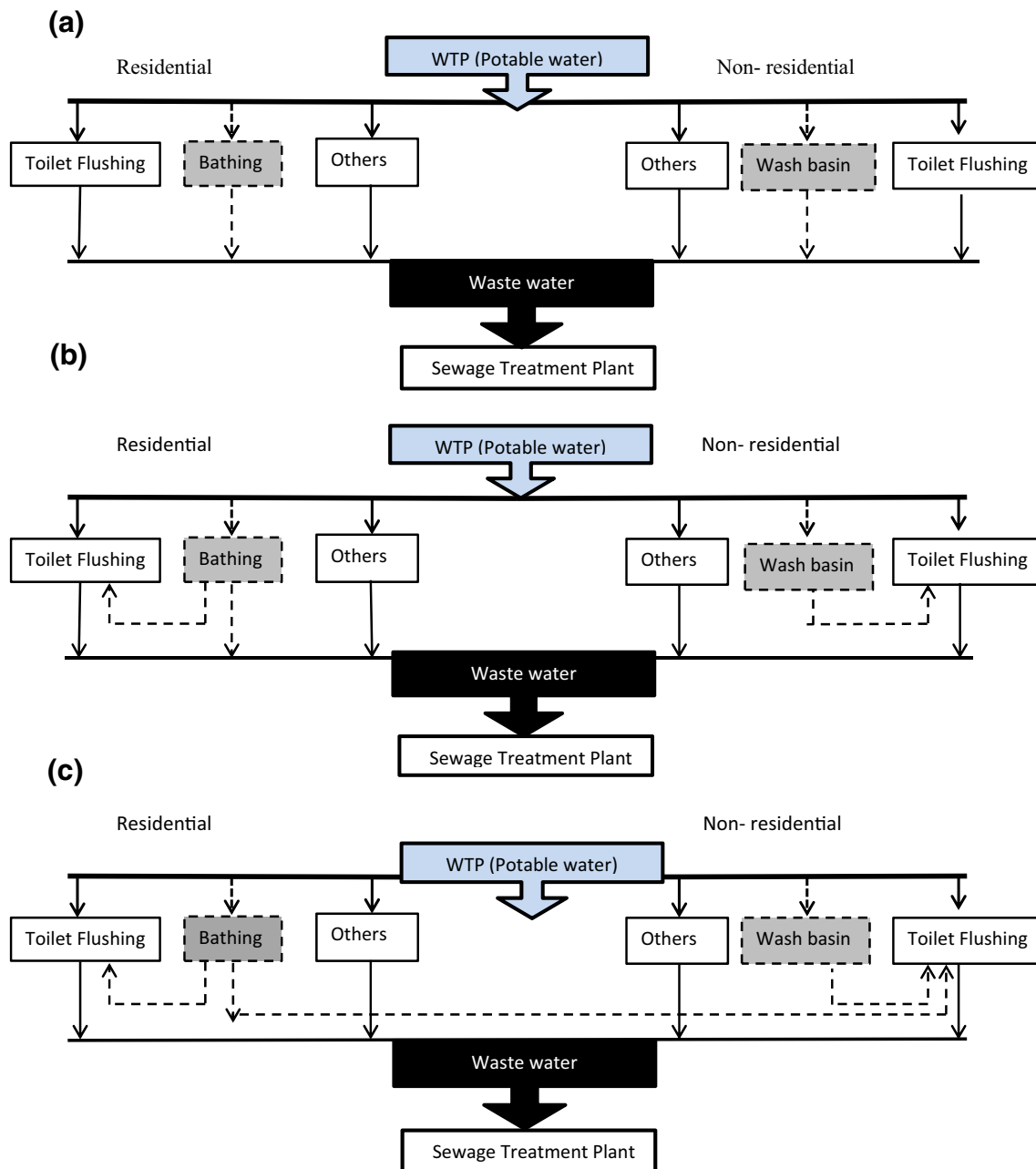
### Modified scenario: combined scenario (CS)

The modified scenario CS is developed by combining the best results of PS and GR to obtain their combined effects as a policy measure.

### Model validation

Validation of SD models is essentially a process of building confidence in soundness and usefulness of the model as a policy tool. The model is validated for its structure and behavior (Sushil 1993). Tests performed for structural and





**Fig. 4** Diagrammatic representation of different scenarios: **a** BS, **b** GR-I, **c** GR-II

behavior validation are extreme condition test, dimensional consistency and historic data validation.

In extreme condition tests, the expected behavior of the real system is compared with the model generated behavior under extreme conditions. The population growth rate is one of the crucial parameters to influence the domestic water supply. For the extreme positive condition (run-I), the population growth rate is doubled and for the extreme negative condition (run-II), the growth rate is stabilized to zero, from the baseline year 2016. Figure 5a shows the results of simulation runs for the water supply with extreme input

conditions. Water supply would be 209 MLD and 60 MLD in run-I and run-II, respectively, in 2041 from the baseline supply 113 MLD in the same year.

Historical validation is done to check the behavior validity. For present model, historical validation of the data is carried out for population variable of Haryana state. Data of 1991–2011 are incorporated into the model to make the projections. The model projection shows very good agreement with the available actual population census data of the same period with a difference of only 0.01%, as is shown in Fig. 5b.

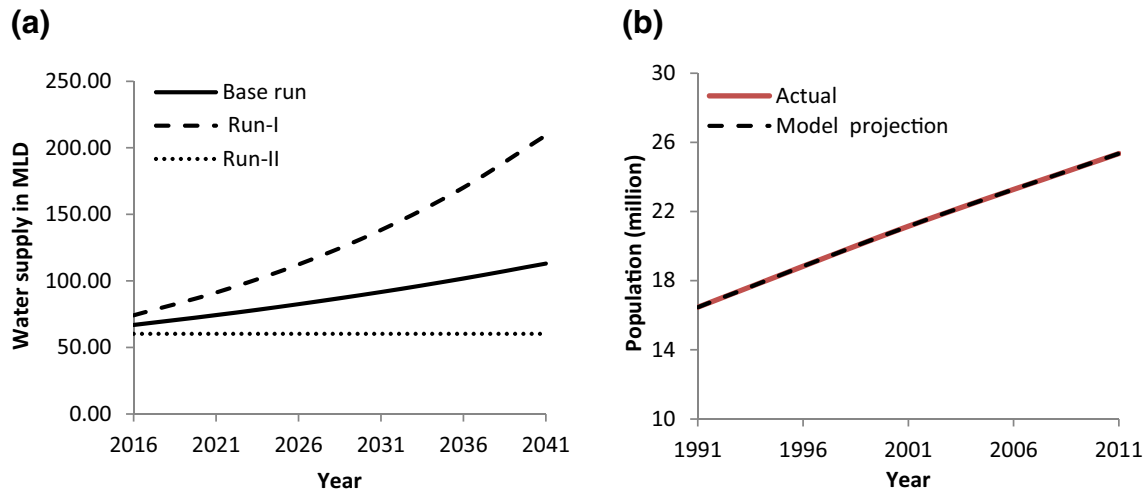


Fig. 5 Model validation **a** extreme test condition, **b** historical data validation

Dimensional consistency is also ensured in all the steps during model development and projection.

### Sensitivity analysis

In SD approach, sensitivity analysis is done to check the robustness of the model. Certain modifications are made in the model parameters to check whether or not minor changes in the model parameters can lead to a change in the model simulation results. Once the robustness of the model is ensured, the model can be used for decision-making process.

For the present work, sensitivity analysis test is done to understand the dynamics of the system as well as to assure the robustness of the model as shown in Fig. 7. The water supply (WS) is directly influenced by increase in population. If the annual births per thousand are increased from 19.5 to 20 from 2016 to 2041, the population of Rohtak city increases to 0.849 million from the projected figures of 0.837 million by the year 2041 as well as the water supply increases to 115 MLD from projected quantity of 113MLD by the year 2041. Results shown in Fig. 6 prove that the system variables of the model respond to minor changes in values. Thus, the model has shown high-degree sensitivity.

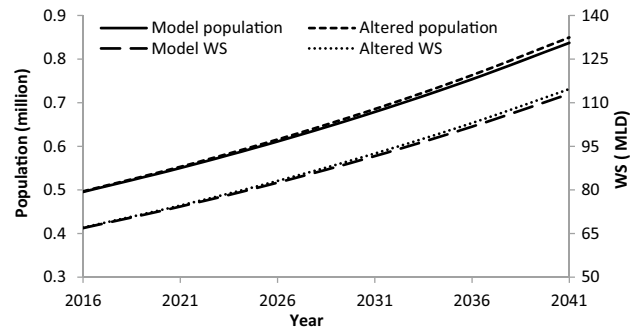


Fig. 6 Variation in water supply with population change

## Results and discussion

### Baseline scenario

The data for a typical city like Rohtak expanding rapidly is considered to study the trend of water resources using system dynamics model. Similar trend would be reflected in other rapidly growing urban areas. At present, total

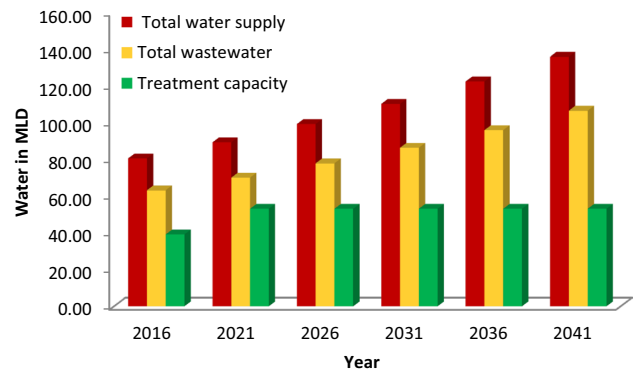


Fig. 7 Growth projected for water supply and wastewater generation for baseline scenario

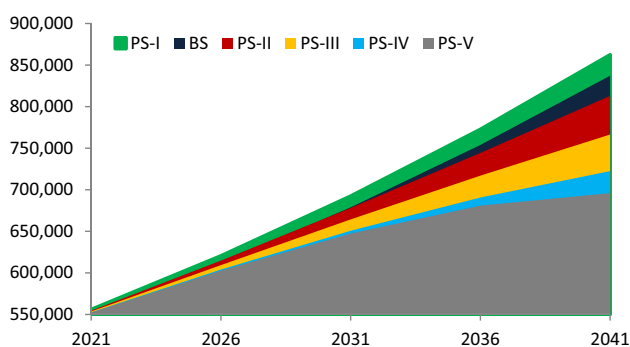
water supply in the Rohtak city is 78 MLD which is less than the required water demand of 80.43 MLD in 2016. The wastewater generation is 63.01 MLD, while the installed sewage treatment capacity is 39 MLD, leaving a gap of 24

MLD. This will widen in future. This means 24 MLD is just flowing in an open drain, which ultimately discharged into Yamuna river and pollute it. The temporal projection for total water supply (TWS) and total wastewater generation (TWWG) in the city for the baseline (BS) scenario is shown in Fig. 7. The TWS includes water supply from residential and non-residential sectors. In the non-residential sector, water supplies of restaurants, hospitals, shops/offices and educational institute are included. The population of Rohtak city is projected to increase by 69% (taking 2016 as baseline year) by 2041, which will result in an increase of water consumption from 80.43 MLD in 2016 to 135.89 MLD in 2041. The wastewater discharge in the city is projected to reach 106.5 MLD in 2041. This will need substantial increase in the wastewater treatment plants. Therefore, the city urgently needs to develop strategies related to water resource management. We have proposed and analyzed policy measures under modified scenarios in next section.

### Modified scenario: population stabilization

The increase in population has a direct impact on water consumption and wastewater discharge. If population stabilization measures can be taken, it will help in achieving sustainable water resource management. Some of the policy scenarios related to population stabilization in Rohtak city are discussed in this section.

Population projection under baseline scenario (BS) and five modified scenarios (PS-I, PS-II, PS-III, PS-IV, and PS-V) are presented in Fig. 8, and birth rate, death rate and migration rate are shown in Fig. 9. A temporal increase in the overall population, births, deaths and migrations computed from the model for BS is shown in Fig. 9a. For the BS keeping the annual birth, death and migration rates per thousand at 19.5, 5.3 and 7, respectively, for the entire period, the total population would reach 837,180 in 2041. In the modified scenario, PS-I, CBR and net migration rate are kept same as of BS and death rate is decreased to 4.3 from 5.3 for the entire period. As shown in Fig. 9b, the



**Fig. 8** Population projection under different scenarios

population is expected to reach 862,126 by the year 2041. This rapid growth of population is due to the low mortality, high fertility, and increasing rural–urban migration. In the coming years, the nullifying effect of deaths on population growth will come down because of improvement in health care and infrastructure facilities in the city.

The rapidly growing population is of concern as it dilutes the impact of growing economy. Investigations are, therefore, made to work out policy scenario for arresting the population growth. In scenario PS-II, CBR is kept constant from 2011 to 2016. After 2016, the CBR is decreased by 0.2 annually. The values of CDR as 4.3 and net migration as 7 are taken constant for the entire period. The values are not changed because we want to show the effect of a single parameter at a time, i.e. CBR, to emphasize the need of birth control. Figure 9c shows the results of this scenario. The population is projected to reach 812,902 by 2041 in comparison with 837,180 for the baseline scenario. In modified scenario PS-IV, the values of CBR and CDR are same as in scenario PS-III. The only difference lies in net migration. The net migration is kept constant, i.e. 7 from 2011 to 2016. Thereafter, the annual decrease of 0.2 per thousand is considered upto 2041. This scenario is developed to show the effect of migration on city's population. The population is expected to reach 766,344 after this scenario as shown in Fig. 9d. Obviously, the result shows that reducing rural–urban migration can play an important role in stabilizing the population.

The scenario PS-IV is developed by taking CBR, CDR and net migration rates as 19.5, 4.3 and 7, respectively from 2011 to 2016 and thereafter, the annual decrease in births, deaths and net migration of 0.5, 0.1 and 0.2 per thousand, respectively, is considered. Projections of births, deaths, net migration and population for this policy are shown in Fig. 9e and the projected population comes out to 722,314 in 2041. In Fig. 9e, a gentle slope is seen in city's population growth, but stabilization effect is not so profound. Further measures need to be taken. Hence another scenario is considered.

In scenario PS-V, the CBR, CDR and net migration are taken as 19.5, 4.3 and 7, respectively, from 2011 to 2016. After 2016, annual decrease in the deaths and migrations of 0.1 and 0.25 per thousand are considered. From 2017 to 2031, the CBR is reduced by 0.5 every year and from 2032 to 2041 it is annually decreased by 1. The decrease in stages is considered annually to reach a policy of the steady state of population growth. It is achievable in Rohtak city as the city has high literacy rate and located in the developed region of India. It is evident from Fig. 9f that the population of Rohtak city can be stabilized around a value of 695,958 if the proposed steps are taken to have a considerable reduction in the birth rate. The reduction can be targeted in stages, as shown in PS-V.

**Fig. 9** Projected population under different scenarios: **a** under BS, **b** under PS-I, **c** under PS-II, **d** under PS-III, **e** under PS-IV, **f** under PS-V

Water supply and wastewater discharge under different modified scenarios of population stabilization are shown in Tables 6 and 7, respectively. The baseline water supply in the city shall reach 135.89 MLD in 2041. For PS-I 3.6% increase is reflected. On the contrary PS-II, PS-III, PS-IV and PS-V scenarios in 2041 are projected to decrease by 2.9%, 8.5%, 13.7%, and 16.9%, respectively. Accordingly, the wastewater discharge will reduce.

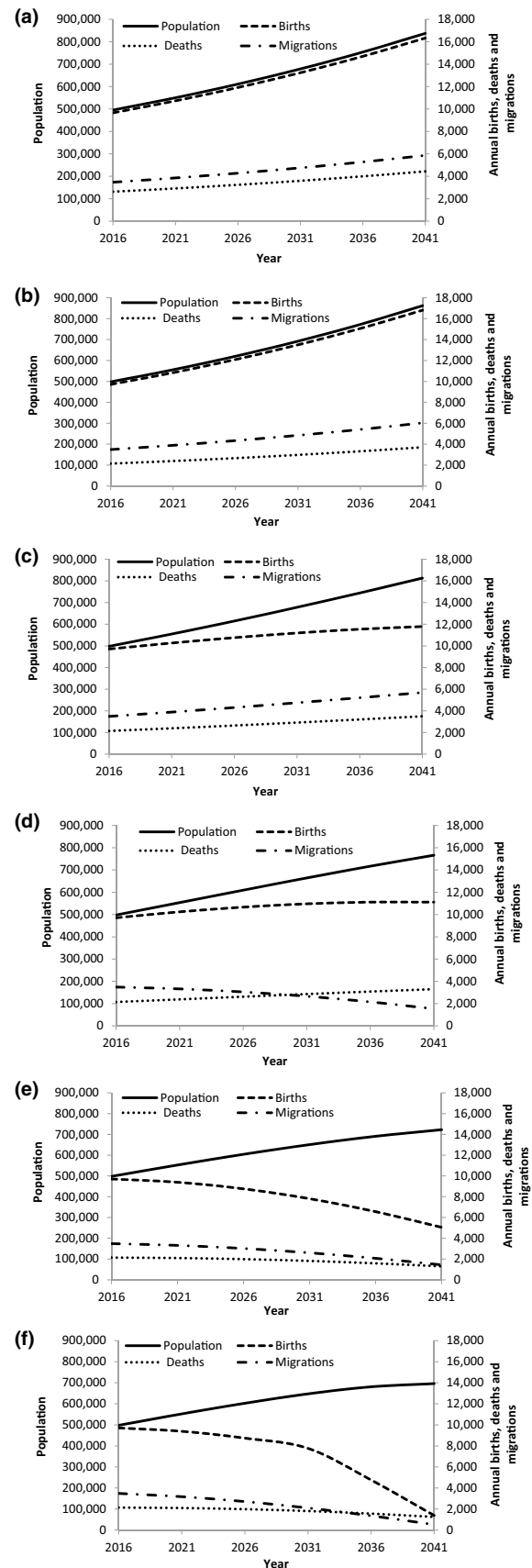
### Modified scenario: grey water reuse

The BS projection shows that the total water supply requirements in the city will reach 135.89 MLD in 2041. But if the bathroom wastewater is used for toilet flushing, the fresh water intake will come down to 106.09 MLD in 2041 for modified scenario GR-I. Then the overall discharge of the wastewater in 2041 for GR-I would be 83.09 MLD compared to the baseline 106.46 MLD.

But a substantial excess of grey water will remain in the residential area once toilet flushing demands are met through grey water supplies. In contrast, the grey water produced in non-residential buildings is substantially less than the requirement of grey water use as shown in Figs. 10 and 11. Therefore, to overcome this deficit in non-residential, modified scenario GR-II is developed in which greywater collected from bathrooms of residential areas and non-residential hand basins are treated at a shared treatment unit, and then recycled back to both residential and non-residential sectors.

A comparison of the total amount of water required in the city for baseline scenario and modified scenarios, GR-I and GR-II, is shown in Fig. 12. As per projections, the water supply in GR-I and GR-II will reduce to 106.09 MLD and 98.13 MLD, respectively, from the baseline water supply projection of 135.89 MLD in 2041. If no conservation measures are adopted, the wastewater discharge in the household will reach 106.46 MLD in 2041 from its usage of 63.01 MLD in 2016. For the policy scenarios, the wastewater discharge will reduce to 83.09 MLD in GR-I and 77.52 MLD in GR-II from the baseline 106.46 MLD in 2041 as shown in Fig. 13.

It is evident from the above results that the modified scenarios for grey water reuse essentially give policy options to move in a direction of fulfilling the growing demand for water. These measures must be widely publicized to create awareness among the masses. The educational institutes were chosen in non-residential sector so that the policy measures could be made popular among the young students with fertile minds.

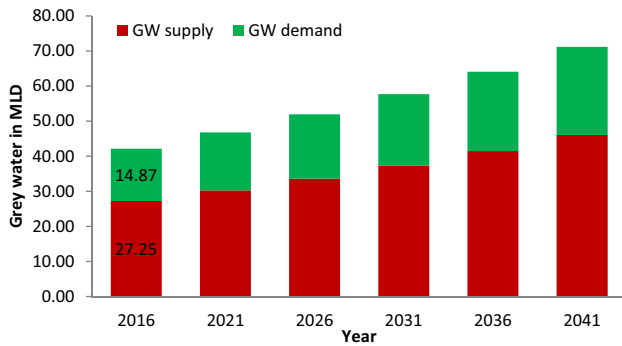


**Table 6** Projections of water supply in Rohtak city under different scenarios

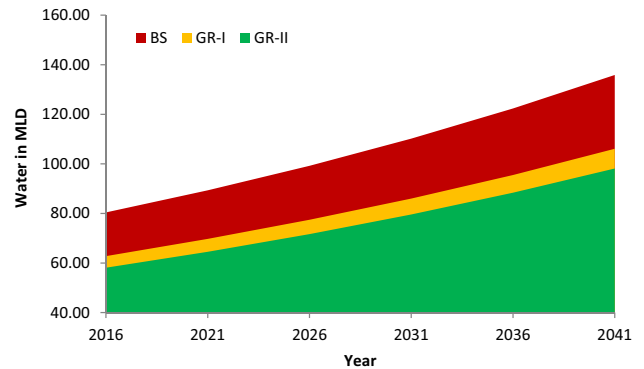
Year	Water supply in MLD								
	Baseline	Population stabilization					Grey water reuse		Combined
	BS	PS-I	PS-II	PS-III	PS-IV	PS-V	GR-I	GR-II	CS
2021	89.32	90.20	90.02	89.85	89.67	89.63	69.74	64.51	64.73
2026	99.2	100.67	99.78	98.91	98.04	97.82	77.45	71.64	70.65
2031	110.17	112.35	110.06	107.82	105.61	105.07	86.01	79.56	75.88
2036	122.35	125.38	120.80	116.38	112.10	110.51	95.53	88.36	79.81
2041	135.89	139.93	131.94	124.39	117.24	112.96	106.09	98.13	81.58

**Table 7** Projections of waste water generation in Rohtak city under different scenarios

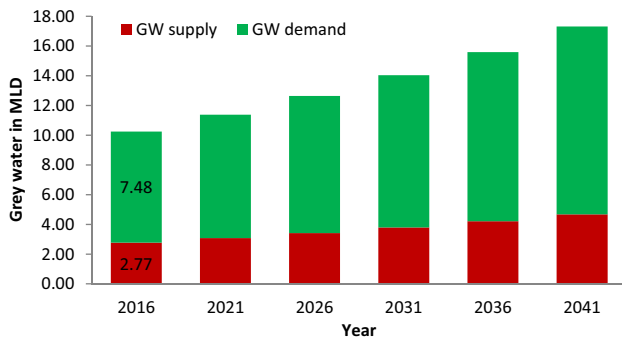
Year	Wastewater generation in MLD								
	Baseline	Population stabilization					Grey water reuse		Combined
	BS	PS-I	PS-II	PS-III	PS-IV	PS-V	GR-I	GR-II	CS
2021	69.98	70.67	70.53	70.39	70.25	70.22	54.62	50.96	51.13
2026	77.72	78.87	78.18	77.49	76.81	76.64	60.66	56.59	55.81
2031	86.31	88.02	86.23	84.47	82.75	82.32	67.37	62.85	59.94
2036	95.86	98.23	94.65	91.18	87.83	86.58	74.82	69.80	63.05
2041	106.46	109.63	103.37	97.45	91.85	88.50	83.09	77.52	64.45



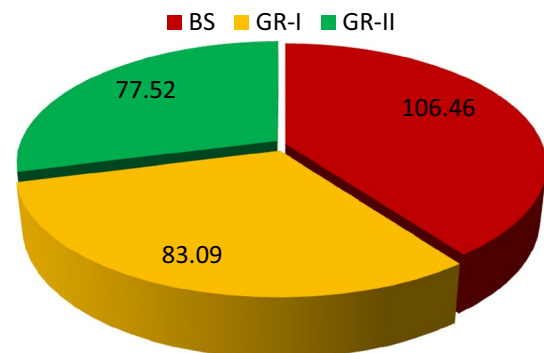
**Fig. 10** Grey water supply and demand in residential area



**Fig. 12** A comparison of the amount of water supply projected for city for BS, GR-I and GR-II

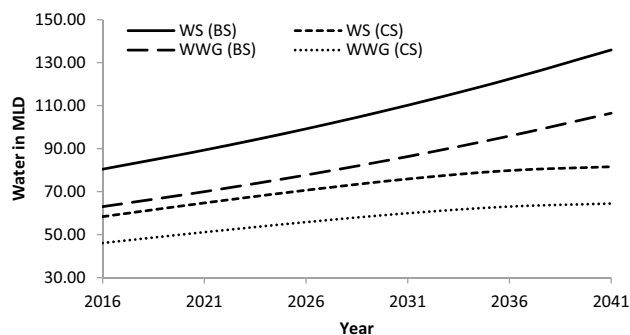


**Fig. 11** Projection of grey water supply and demand in non-residential area



**Fig. 13** A comparison of the amount of wastewater generation in MLD projected for BS, GR-I and GR-II in 2041





**Fig. 14** Temporal projections of total water supply (WS) and wastewater generation (WWG) for baseline scenario, BS and modified scenario, CS

The water demand management and its reuse opportunities are real and increasing. Water can be used multiple times, by cascading it from higher to lower quality needs. Effective water demand management and reuse of the supplied water give option for sustainable policy scenarios to reduce the water stress building up due to population growth.

### Modified scenario: combined scenario

This scenario is developed to show the combined effect of modified scenarios PS-V and GR-II for the plausibility of sustainable development. Figure 14 shows the total amount of water supply and wastewater discharges for CS is shown in Fig. 14. As per projection, in 2041 the city will need 135.89 MLD of water supply. This would, however, come down to 81.58 MLD for the proposed CS and accordingly, the amount of the wastewater discharged decreases to 64.45 MLD from the baseline 106.46 MLD in 2041. Results show that water supply requirements and wastewater generation in modified scenario CS are less than the other proposed scenario as shown in Tables 6 and 7. Therefore, the modified scenario CS essentially gives policy options to move in a direction of sustainability fulfilling the growing demand for water.

### Conclusion

Temporal projection of water requirement and wastewater discharge are made for a typical city of North India for the period of 2016–2041. Business as usual approach and modified policy options proposed for wastewater management of the city are analyzed under various scenarios using a system dynamic approach. The scenarios developed are to stabilize the population and reuse the treated grey water. As per projections, in 2041 the water supply and wastewater generation for the rapidly growing city Rohtak city will increase by 69%

from 2016 onwards. Out of five modified scenarios on population stabilization, scenario PS-V showed better results for curtailing the water demand. For this policy scenario, 17% reduction in water supply is projected compared to 135.89 MLD in BS.

Scenarios related to grey water reuse showed a decrease in water consumption pattern by 22% and 27% in GR-I and GR-II, respectively. A reduction of 40% in water demand is seen for the combined scenario. Results of the policy scenarios show that the combined strategies shall be effective for sustainable management of water resources in conformity with the growing population.

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