CHAPTER 6

RESULTS AND DISCUSSION

6.1 Introduction

An application, SDSS_IUWM has been developed to integrate all components of urban water system. SDSS_IUWM consists of six modules and their sub-modules (detailed in chapter 5) listed below:

Module	**Sub-modules**
Water Demand (WD)	DWD, INWD, IWD, FFD, OWD
Water Supply (WS)	SWS, GWS, AWS
Wastewater Management (WWM)	WWQ, WWC, RP, EDWW, WWTTS
Storm Water Management (SWM)	ARR, SRS, RTH
Urban Water Balance (UWB)	UWBI
Water for Development Planning (WDP)	PSR, WDPI

The developed application SDSS_IUWM has been tested with data of Varanasi city (India) to study the integrated urban water management. The reliability of the developed application is further validated with the data of three other cities of Uttar Pradesh namely, Allahabad, Lucknow and Kanpur. Analyses have been done and the results for the present and future scenarios are discussed in this chapter.

6.2 Profile of Varanasi City

Varanasi (Fig. 6.1) is the fourth largest city of Uttar Pradesh, situated at 25°14' North latitude and 83°03' East longitude. This city is situated between two tributary rivers viz. "Varuna" and "Assi" and therefore known as Varanasi. The holy river Ganga passes through the east of the city. The city is known for its mystic Ghats and rich architectural heritage. It is believed to be more than 3000 years old by modern scholars and considered one of the oldest living cities in the world. As per 2011 census, Varanasi city has population of 1.44 million with 90 administrative wards (Fig 6.2) and an area of 81 sq. km. Reduce level (RL) of the city is about 78 m. The temperature varies from 5^0 Celsius to 45^0 Celsius over the year. An annual average rainfall observed in Varanasi city is 828 mm. The transmissivity varies from 3884 to 8604 m^2/day and storativity ranges from 4.29×10E-4 to 8.0×10E-2. The average household size is 7 and rated very high as compared to the national average of 5 persons per household and state average of 6.3 persons per household. The average floating population is estimated at 2 lakhs per day (Varanasi Municipal Corporation, 2007). The ward map of Varanasi is shown in Fig. 6.2. Varanasi Nagar Nigam (Municipal Corporation). Water supply service is being provide by Uttar Pradesh Jan Nigam (UP, Jal Nigam).

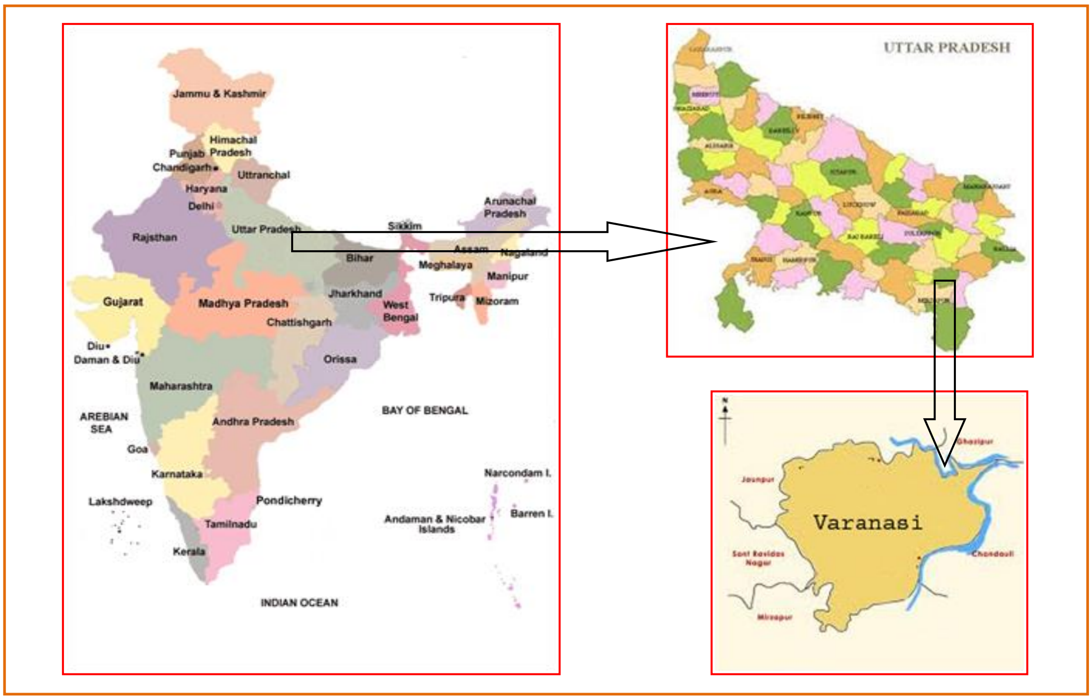


Fig. 6.1: Varanasi district on India map

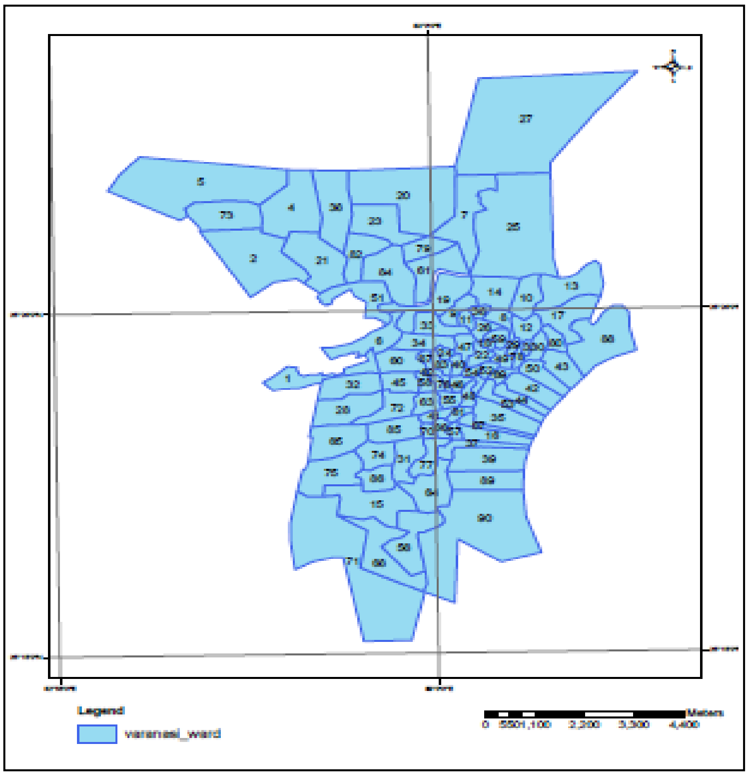


Fig. 6.2: Map of Administrative Ward for Varanasi City

6.2.1 Present Scenario of Water Supply in Varanasi City

At present, average water demand of Varanasi city is 275 MLD and average water supply is 277 MLD (152 MLD from ground water source and 125 MLD from surface water sources) (Source: UP Jal Nigam). The ground water is extracted through 140 Tube-wells and supplied after disinfection. The raw water from river Ganga is taken through intake structure near Bhadaini. and is pumped to 250 MLD capacity water treatment plant at Bhelupur water works.

Considering the topography the whole city is divided in 11 drainage/sewage collection zones which have been adopted for water supply too. Population of individual zone has been prepared using administrative ward map and population data of individual ward (Census 2011). Zone-wise population for the year 2015 has been estimated and is given in Table 6.1.

Table 6.1: Population of Water Supply Zones of Varanasi City

Sr. No.	Name of Zone	Population in 2015
1.	District1	441185
2.	District 2A	486105
3.	District 2B	81858
4.	District 2C	95733
5.	District 2 NSA 2	25950
6.	District 2 NSA 1	43146
7.	District 2 FSA 1	22452
8.	District3	84984
9.	FSA4	52374
10.	District4 FSA 2	90,204
11.	District4 FSA 3	67759
	Total	**1491750**

NSA: Non-Sewerage Area, FSA: Future Sewerage Area

The 11 water supply zones namely, District1, District 2A, District 2B, District 2C, District 2 NSA 1, District 2 NSA 2, District 2 FSA 1, District 3, FSA 4, District 4 FSA 2, District 4 FSA 3 are shown in Fig. 6.3.

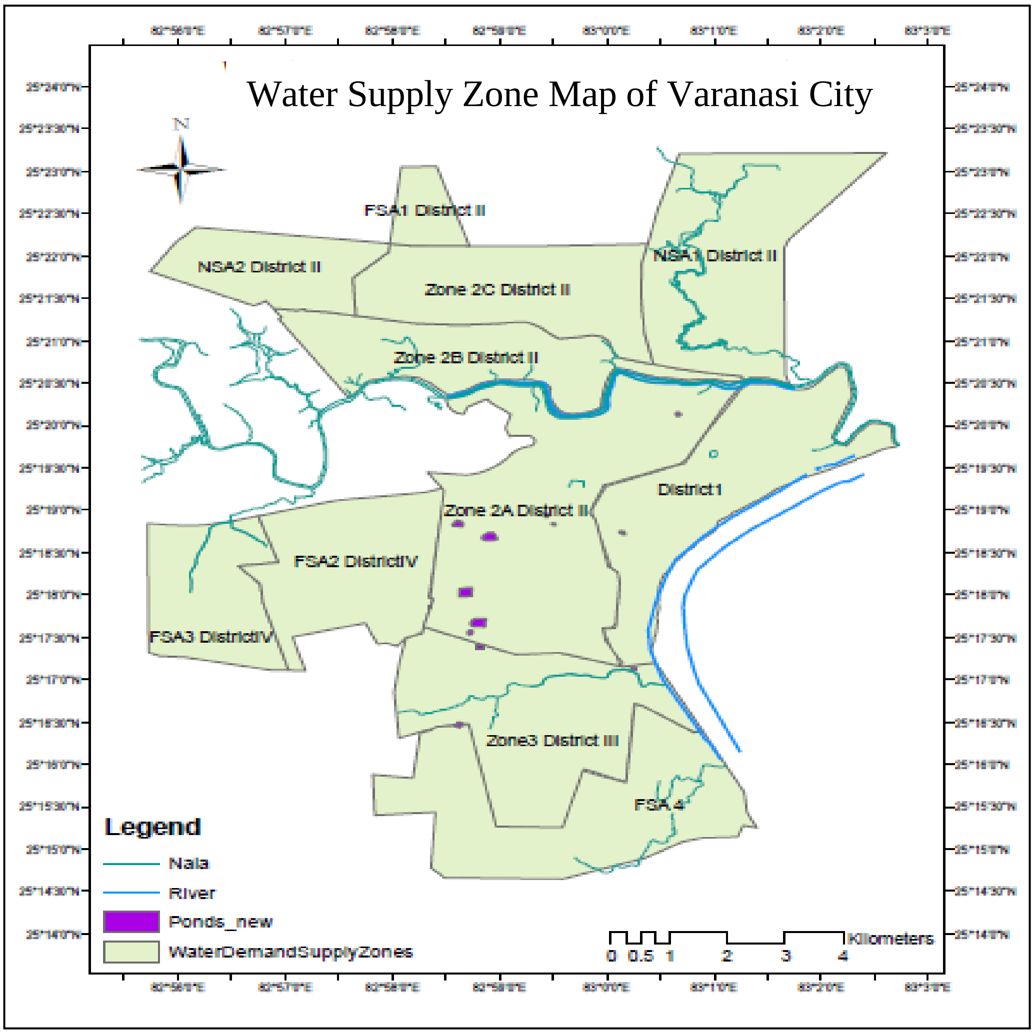


Fig. 6.3: Water Supply Zone Map of Varanasi city (Source: Jalkal, Varanasi, U. P.)

6.2.2 Estimation of Water Quantities for Varanasi City

The water quantity estimation of Varanasi city has been done using SDSS_IUWM. The year of estimation has been taken as year 2015. Water quantity estimation includes water demand, water supply, waste water, and storm water. For this purpose, basic input data is required which can be retrieved from the existing database. Several data are prepared on other software such as ArcGIS, QGIS, ERDAS Imagine to produce input data of the developed application.

6.2.2.1 Basic Data

Name of the state and name of city can be selected from the drop down list. 2011 Census data has been added default with the above selection but it can be changed manually. Design value and the year of projection can be selected. Basic data obtained from the primary and secondary sources have been used as input to the software SDSS_IUWM.

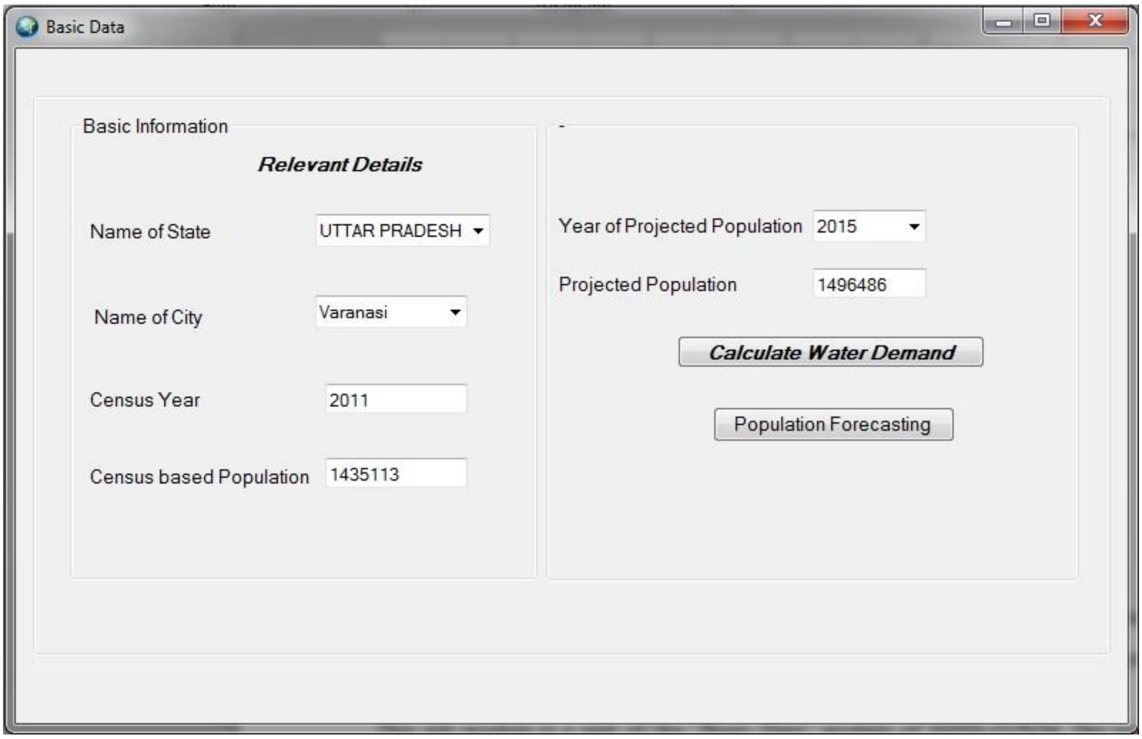


Fig. 6.4: Screenshot of Basic data input for the Varanasi city

6.2.2.2 Population Forecasting

This sub module is a part of the “Basic Data” module of SDSS_IUWM. The screenshot of this sub module is shown in Fig. 6.5. The sub module consists of two parts. In first part, user has to enter the decadal population in the given text boxes. With the help of ‘Population Forecasting’ sub module, the population of the given city is calculated in the desired year by three popular methods: arithmetic progression, geometric progression and incremental increase methods (discussed in section 5.2.4). It also calculates and shows the decadal population growth rates by different methods. In the second part, this sub module calculate the population in any projected year based on yearly population growth rate by arithmetic progression and geometric progression methods.

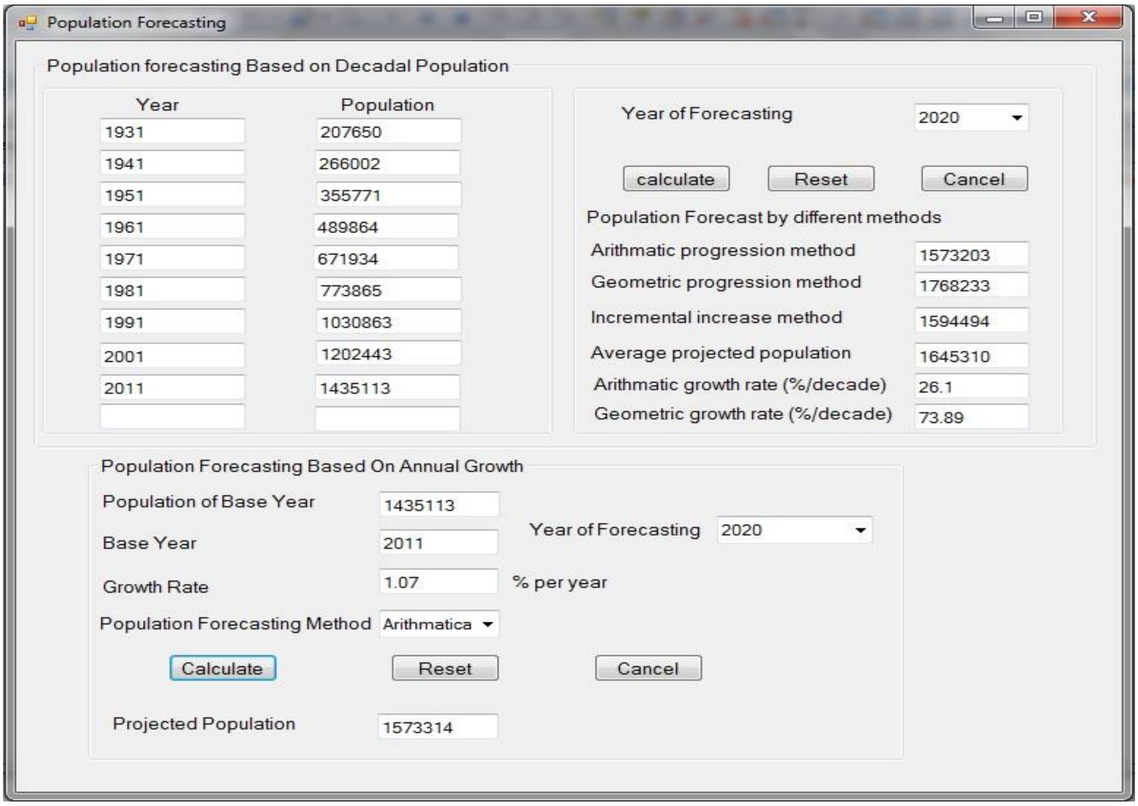


Fig. 6.5: Screenshot of Population Forecasting Interface

The command button ‘Calculate’ executes the codes required to estimate the population. ‘Reset’ cancels all the entries in textboxes and ‘Cancel’ terminates the sub module.

6.2.2.3 Water Demand (WD) Estimation

Domestic water demand (Fig. 6.6) has been calculated based on population and standard water supply (150 lpcd). Institutional water demand (Fig. 6.7) has been calculated based on secondary data prepared by satellite image and municipal statistical data. Location of offices, school/college, hostels, hotels, restaurants, railway junction, malls, and hospitals are retrieved from Google map and their relevant statistical data are collected from Varanasi Nagar Nigam. Based on IS code 1172:1993 per capita/ per seat water demand institutional demand has been calculated. Considering 150 lpcd water demand, the equivalent population being served can be estimated. Industrial water demand has been calculated on the basis of data available for Varanasi city. Firefighting water demand has been calculated based on Ministry of Urban Development (MoUD) manual formula. Total water demand (Fig. 6.9) has been calculated taking the arithmetic summation of all the above demands estimated.

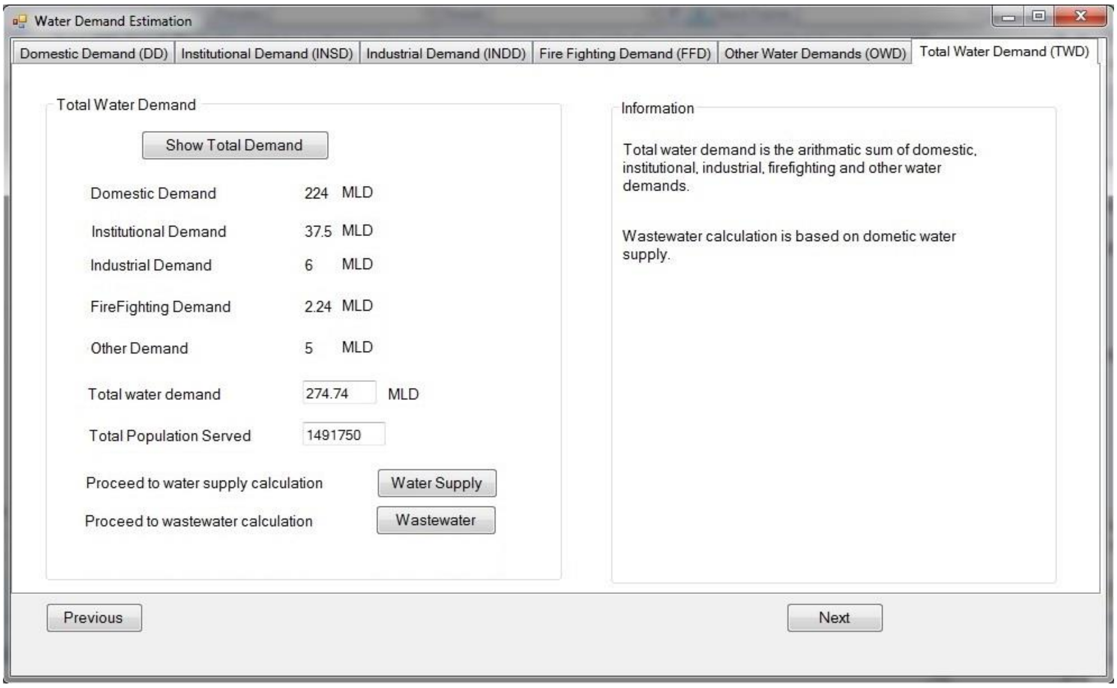


Fig. 6.6: Screenshot of Total Water Demand (TWD) Calculation for Varanasi city

6.2.2.4 Water Supply Status

Based on the actual pumping hours of tube-wells, the present water supply status has been estimated. A ground based survey for the existing water sources are conducted and the GPS locations are plotted on map. Currently, there is no alternate water source (AWS) supply. Other details have also been displayed for the information and assessment. Surface water supply is found 125 MLD from river Ganges. For ground water supply assessment, locations of tube-well and their working condition (data provided by Jal Sansthan, Varanasi) have been checked. Fig. 6.7 shows the zones covered by surface water supply and groundwater supply. Eight zones (District1, District 2A, District 2B, District 2C, District 2 NSA1, District 2 NSA2, District 2 FSA1, District 3) are covered by regulated water supply. Other three zones (FSA3 District IV, FSA2 District IV, and FSA 4) have no public water supply system and hence is covered through private tube-wells.

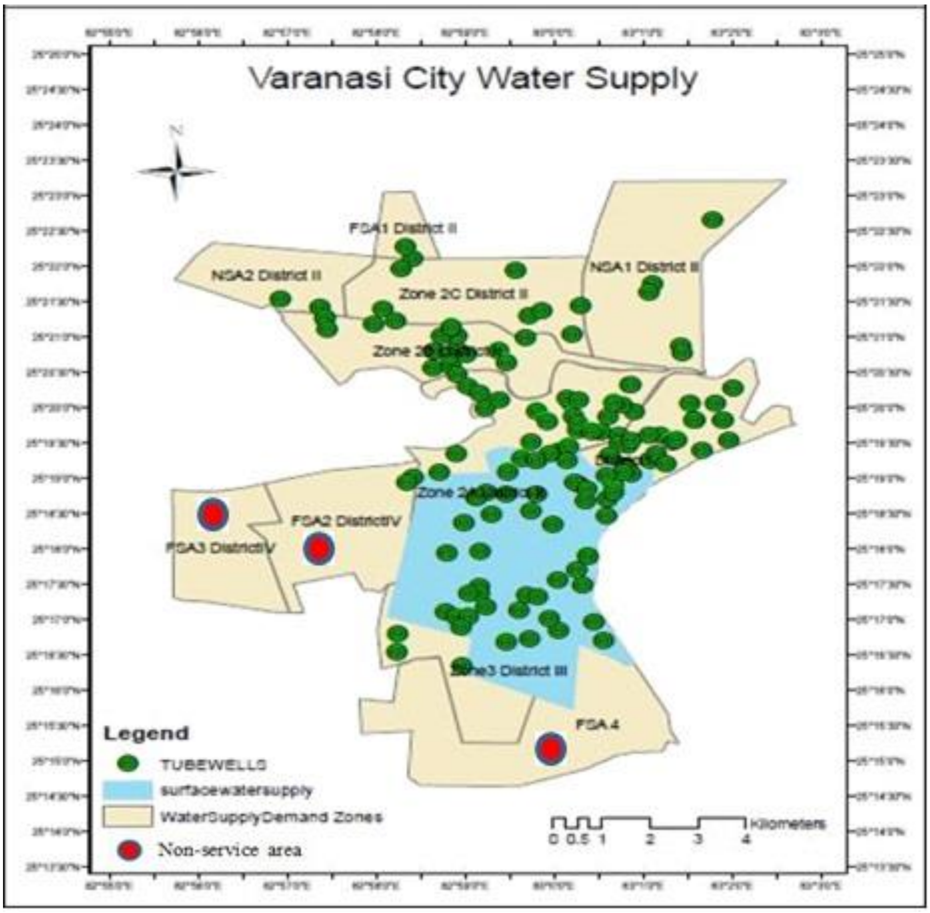


Fig. 6.7: Water Supply Zone Map (service and non-service zones) of Varanasi city

6.2.2.5 Wastewater Estimation

Considering total water supply of 277 MLD and an intercepting factor as 0.8, the waste water generation of the city works out to be 222 MLD. However, the dry weather flow for discharge in Varanasi has been found around 300 MLD out of which waste treatment system for 102 MLD capacity exists and rest around 198 MLD of waste water is discharged untreated to natural drainage system.

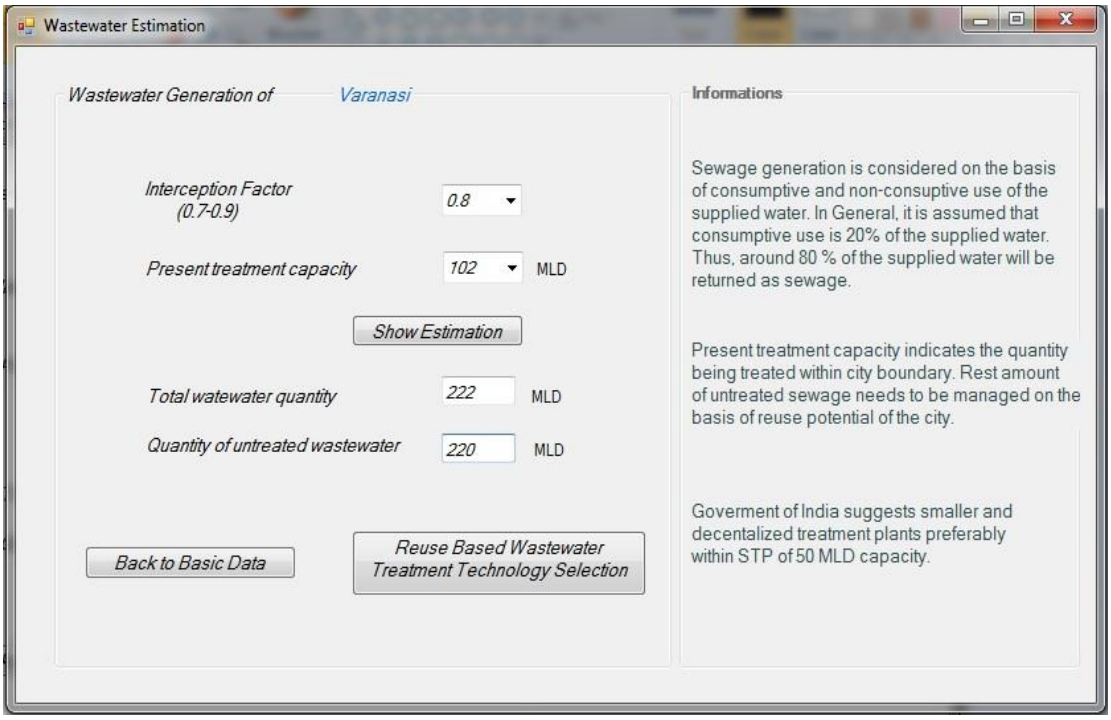


Fig. 6.8: Screenshot of Wastewater Generation Sub-module for Varanasi City.

Wastewater characteristics (Fig. 6.9) data has been taken as input to the application. Wastewater characteristic data have been prepared by collecting samples from different wastewater discharge points (Samneghat Nala, Assi Nala, Khrki Nala, Bhagwa Nala, Dinapur STP) at Varanasi city. In the present study, twelve parameters of waste water characteristics have been measured from the collected samples in the Environmental Laboratory of Department of Civil Engineering, IIT (BHU), Varanasi. Wastewater characteristics (Fig. 6.10) data has been input to the application. On the submission of entered data the information will be stored to the database. Based on reuse requirements of the city Wastewater Treatment Technology Selection (WWTTS) can be done. On the click of Technology Selection button a window for wastewater treatment technology selection (Fig. 6.11) will appear.

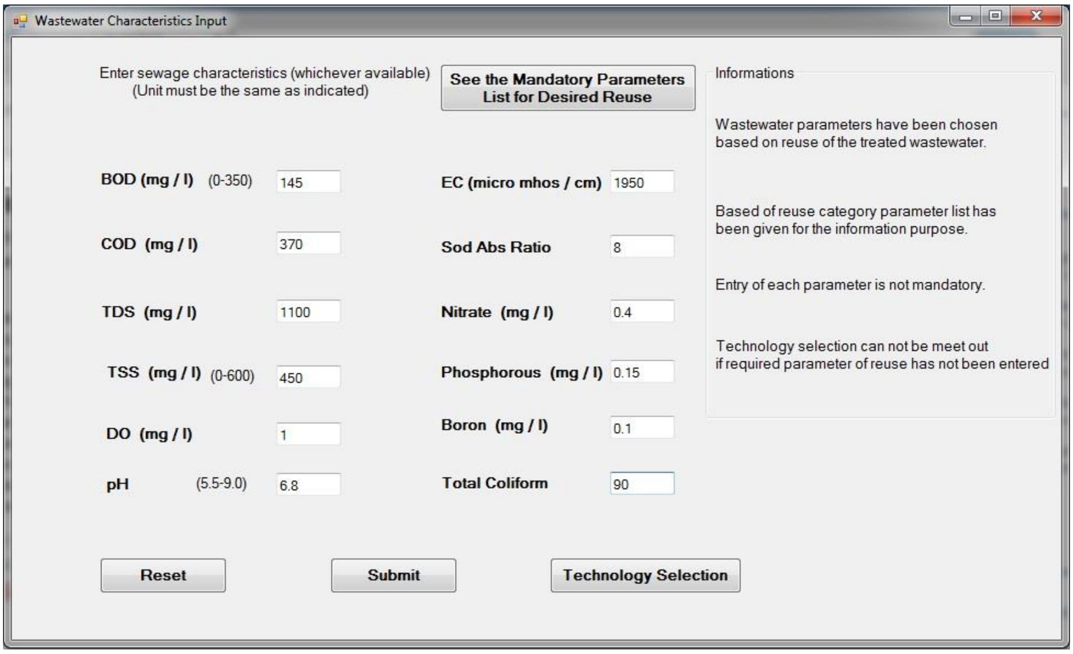


Fig. 6.9: Screenshot of Wastewater Characteristics Input Sub-module for Varanasi City.

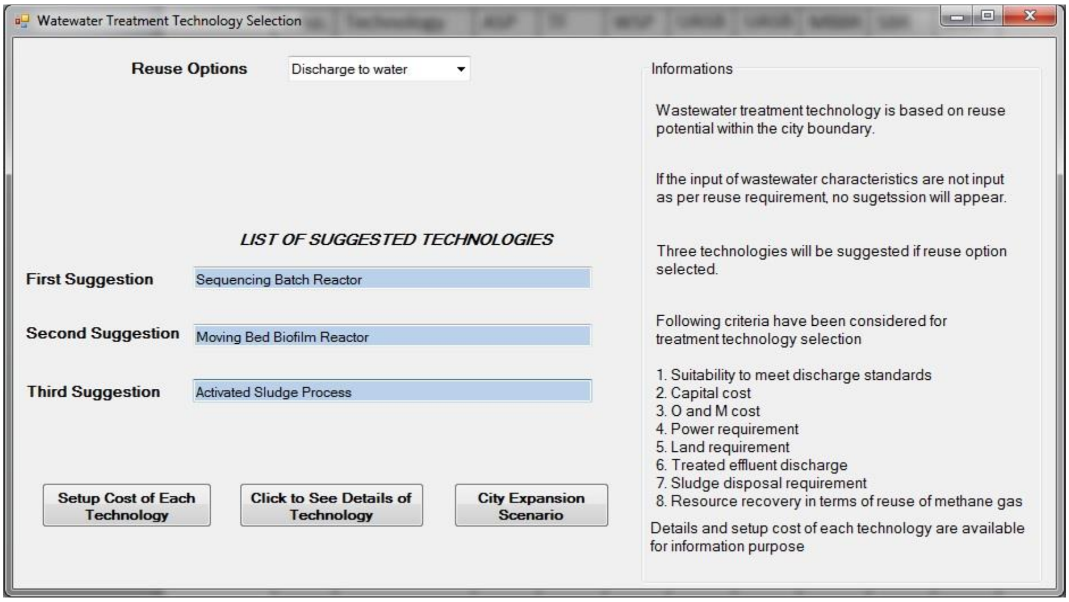


Fig. 6.10: Screenshot of Suggested Wastewater Treatment Technology for Specific Reuse for Varanasi City.

For Varanasi city, different reuse options are worked out with the developed module WWTTS (Table 6.2). Total nine reuse categories have been considered out of which seven categories qualified as per reuse standards. Suggestion of treatment technologies are based on cost comparison. The result shows that there is common suggestion for discharge to water bodies, toilet & car washing, recreational, and firefighting.

Table 6.2: Suggested Wastewater Treatment Technologies for Varanasi City for Different Reuse Categories

Sr. No.	**Reuse Category**	**Suggested Wastewater Treatment Technologies**		
		First Suggestion	Second Suggestion	Third Suggestion
1.	Irrigation	TF	UASB	WSP
2.	Toilet & Car washing	SBR	MBBR	ASP
3.	Recreational	SBR	MBBR	ASP
4.	Industrial	TF	UASB	WSP
5.	Firefighting	SBR	MBBR	ASP

Table 6.3: Costs Comparison of Various Wastewater Treatment Technologies (WWTT)

Wastewater Treatment Technology	**Cost (Rs. Lac/ MLD)**			
	Capital	O & M	Land*	Total
Activated Sludge Process (ASP)	108	629	273	1010
Sequence Batch Reactor (SBR)	115	457	82.5	654.5
Moving Bed Biofilm Reactor (MBBR)	108	638	67.5	813.5
Up-flow Anaerobic Sludge Blanket (UASB)	108	618	217.5	943.5
Trickling Filter (TF)	108	590	243	941
Waste Stabilization Pond (WSP)	63	505	1200	1768

*Average land cost @ Rs. 15000 per sqm (Source: UP Housing & Development Broad, 2017).

Table 6.3 shows the cost comparison among wastewater treatment technologies. Capital cost, O & M cost and land cost have been considered for total cost estimation (Details given in Appendix B). The comparison of total cost indicates that Sequencing Batch Reactor (SBR) is the first option among the considered treatment technologies followed by MBBR and ASP for Varanasi city. This technology selection meets the water quality requirements for toilet & car washing, recreational, and firefighting reuse options. While TF is the first suggestion for irrigation reuse and industrial reuse purpose, UASB is second suggestion. Cost of TF and UASB is approximately same but UASB requires less area in comparison to TF. So, UASB can be a better option as land availability is an issue for Varanasi city.

6.2.2.6 Storm Water Estimation

Storm water estimation requires annual rainfall data, LULC classified map and the area under each class. Annual rainfall data has been retrieved through available online links (www.worldweatheronline.com). LULC map has been prepared on ERDAS Imagine 14.0 academic version using satellite imagery of Varanasi city. After classification the calculated area of each class has been entered into module of Storm Water Management (SWM) to estimate annual runoff of the city. For Varanasi city, Annual runoff is found as 51 MCM.

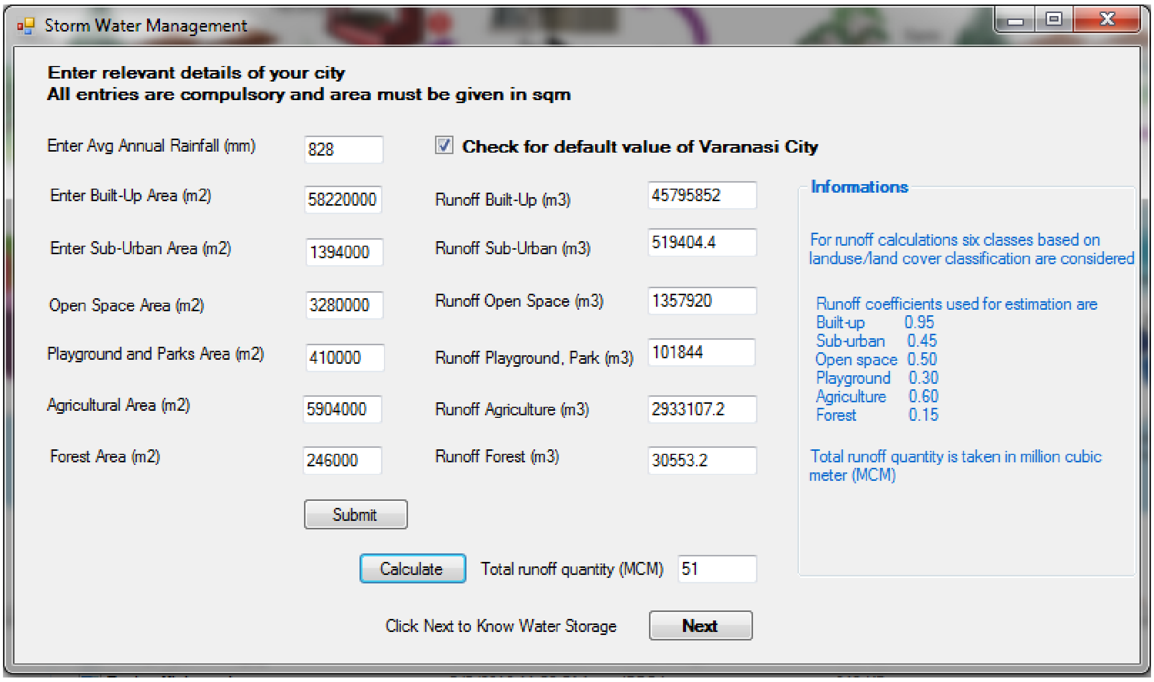


Fig. 6.11: Screenshot of Storm Water Runoff Estimation for Varanasi city.

6.2.2.6.1 Annual Surface Runoff Storage (SRS) Estimation

To estimate surface water storing capacity, digital image of ponds and other water bodies excluding rivers (Fig. 6.13) have been prepared using satellite imagery and ArcGIS 10.2. Average depths have been obtained through actual survey. Based on total surface area and average storage depth for water, the estimated total surface storage capacity for Varanasi city is found as 3500 ML (3.5 MCM).

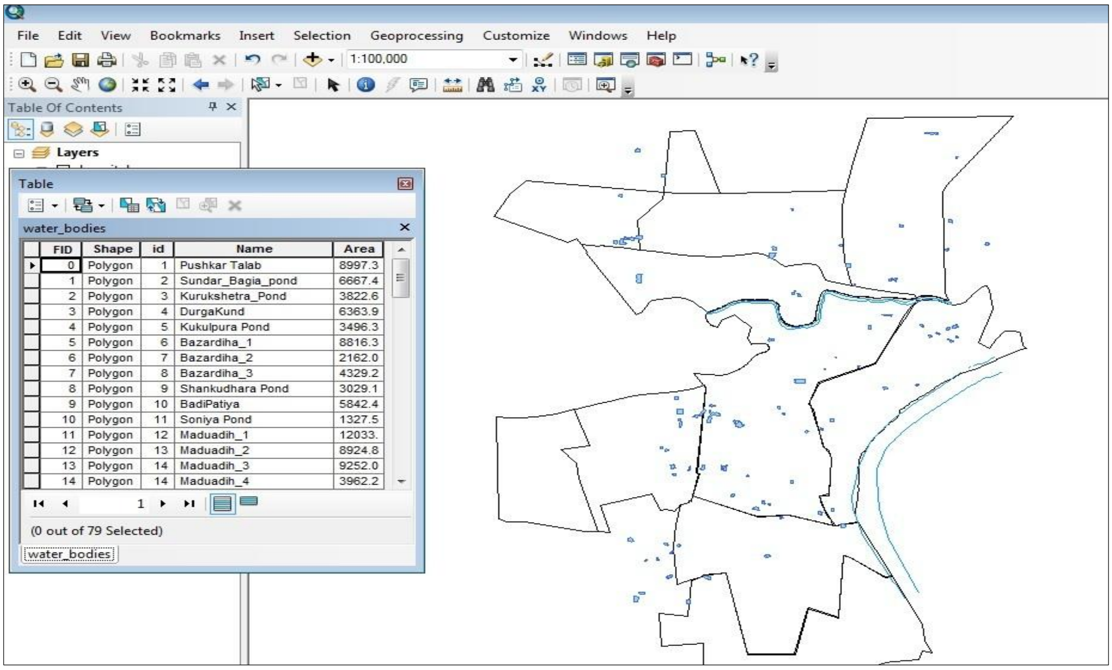


Fig. 6.12: Screenshot of Area Calculation of Ponds in Varanasi city using ArcGIS.

6.2.2.6.2 Roof-top Harvesting (RTH) Potential Estimation

As per Government of India policy, a number of state governments have made rainwater harvesting compulsory for new buildings according to their plot sizes in various cities. At present, Varanasi city has no legislation on rainwater harvesting. However, it is presumed for this study that soon the city will come up with an appropriate legislation for roof top harvesting. To estimate roof-top area of buildings in Varanasi city, a digital map has been prepared using satellite imagery (Fig. 6.11). The available roof top areas have been classified under three categories: i. Roof-top area >1000 sqm, ii. Roof-top area >500 sqm, and, iii. Roof -top area >300 sqm. Initially, all buildings having a roof-top area greater than 1000 sqm will be suggested to have roof-top harvesting facilities. Subsequently, all buildings having roof top area greater than 500 sqm will also be advised to take up roof top harvesting. In the final phase, all buildings with roof top area greater than 300 sqm have to develop roof top harvesting, if required. Accordingly, the roof top harvesting potential for Varanasi city is observed as summarized in Table 6.4.

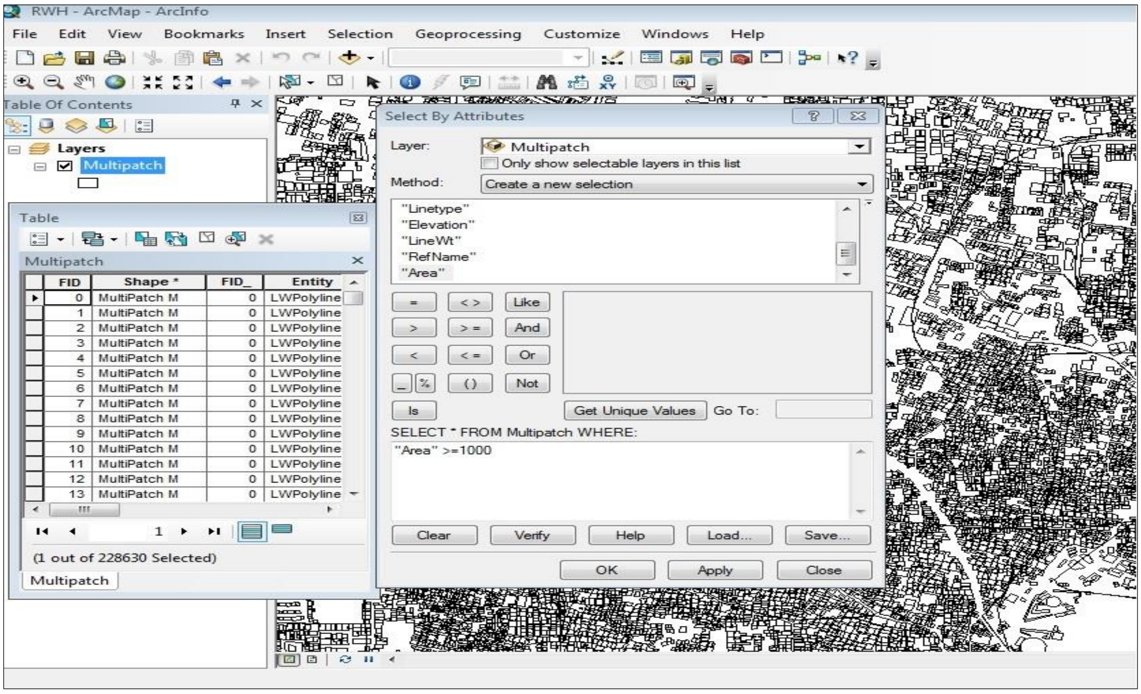


Fig. 6.13: Screenshot of Roof-top Area Estimation for Varanasi city.

Table 6.4: Roof-top Area of Varanasi City Calculated Using Satellite Imagery

Sr. No.	Area Class	Calculated Area (sqm)	Roof-top Harvesting Potential (ML)
1.	>1000 sqm	684416	567
2.	>500 sqm	1244485	1030
3.	>300 sqm	3588869	2080

Thus, the maximum roof-top harvesting potential is estimated to be around 2080 ML (2.08MCM).

6.2.3 Water Supply Sustainability (WSS)

The urban water demand and supply estimated by previous modules serve as the input to the WSS module (Fig 6.14). The water supply adequacy (WSA) for Varanasi city is found to be +2 MLD. A positive value of WSA indicates that the water supply infrastructure is sufficient in the existing condition. The groundwater supply sustainability (GWSS) has been evaluated based on change in water table. For the case of Varanasi city, the analysis of CGWB data for the year 2005-2017 indicates that there is a decrease of approx. 3.5 meter in water table (Fig 6.15). Based on this observation, GWSS sub-module suggests that groundwater supply is not sustainable.

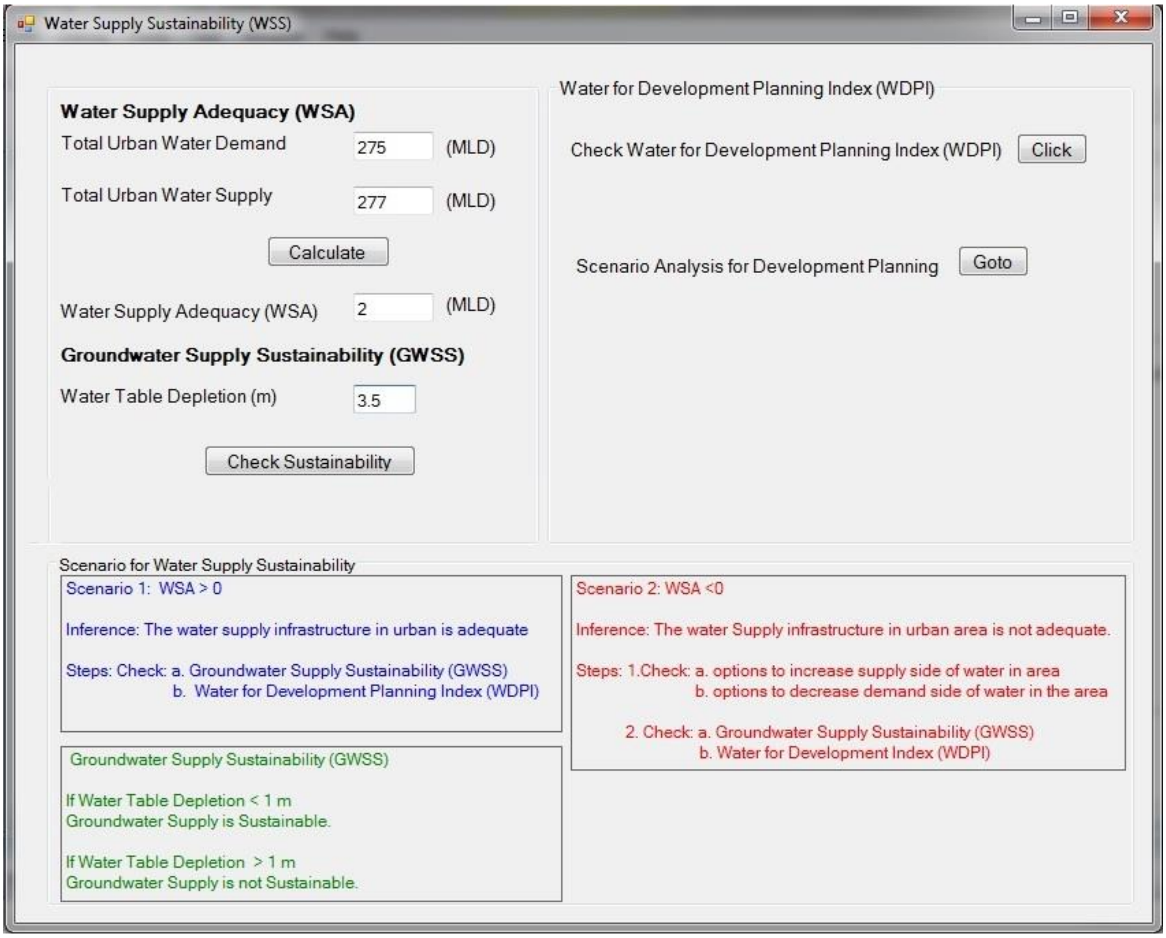


Fig. 6.14: Screenshot of Water Supply Sustainability (WSS) Analyses for Varanasi city.

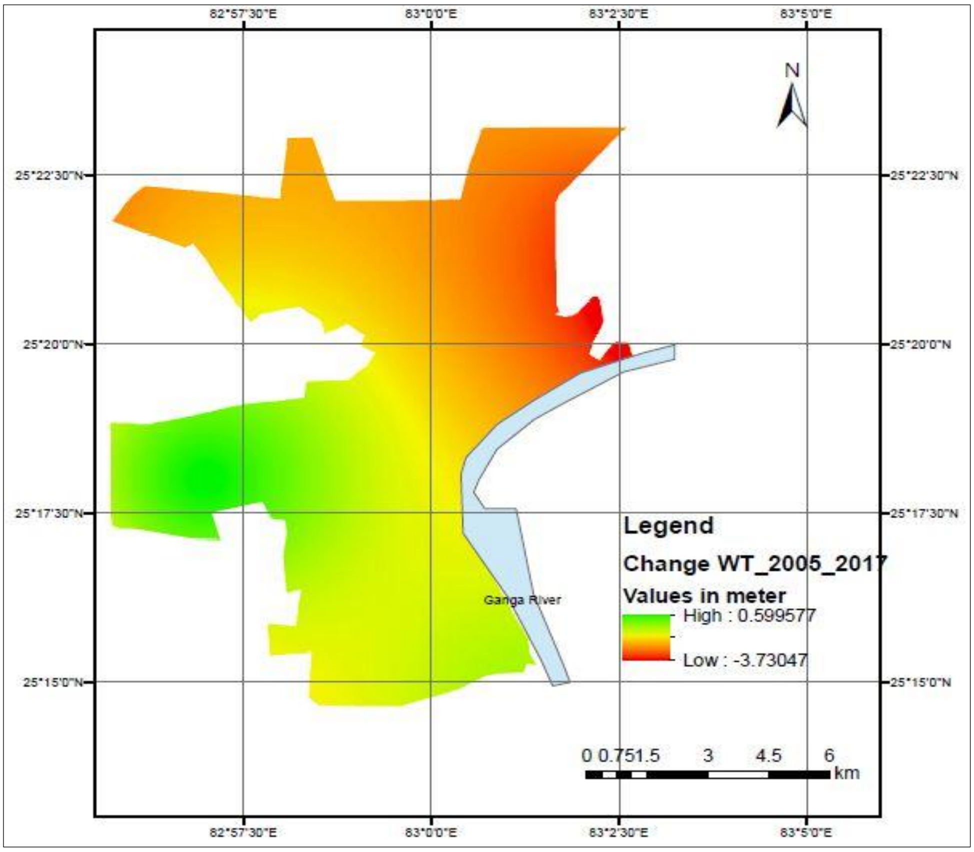


Fig. 6.15: Water Table Depletion of Varanasi city (2005-2017).

6.2.4 Water for Development Planning (WDP)

Condition of water for development planning has been evaluated through the use of two sub-modules i). Pressure-State-Response (PSR) Calculation and ii). Water for Development Planning Index (WDPI) Calculation. The results for Varanasi city are discussed below.

6.2.4.1 Pressure-State-Response Calculation

The Pressure-State-Response sub-module gives values of these objective functions as 4.57, 6.78, and 1.60 respectively on a 0-10 scale (Fig. 6.16). This indicates that whereas the pressure is critical condition, state is in fair condition and response is in poor condition. Sub-indicators which need to be improved for Varanasi city under different objective functions are given below:

Objective Function	Sub-indicators
Pressure	Water Withdrawal (SI-2), Fresh Water Scarcity (SI-3), Pollution Risk Vulnerability (SI-4)
State	Surface Water Quality (SI-6), Consumption (SI-10), Water Supply Coverage Area (SI-11), Wastewater Collection Coverage Area (SI-12), Separation of Storm water and Wastewater (SI-13)
Response	% Availability of Treated Wastewater (SI-14), Reuse Potential of City (SI-16), Economic Efficiency (SI-17), Resource Recovery (SI-18), Groundwater Recharge Potential (SI-19), Management and Action plan (SI-20), Public Acceptability (SI-21), Public Participation (SI-22)

6.2.4.2 Water for Development Planning Index (WDPI)

The pressure, state and response have a weightage of 0.23, 0.37 and 040 respectively. The values of pressure, state and response for Varanasi city have been calculated to be 4.57, 6.78 and 1.60 respectively. Accordingly, the WDPI for Varanasi city is found to be 4.3 on 0-10 scale (Fig 6.16). WDPI less than 5 indicates that the Varanasi city urban water management is under critical condition.

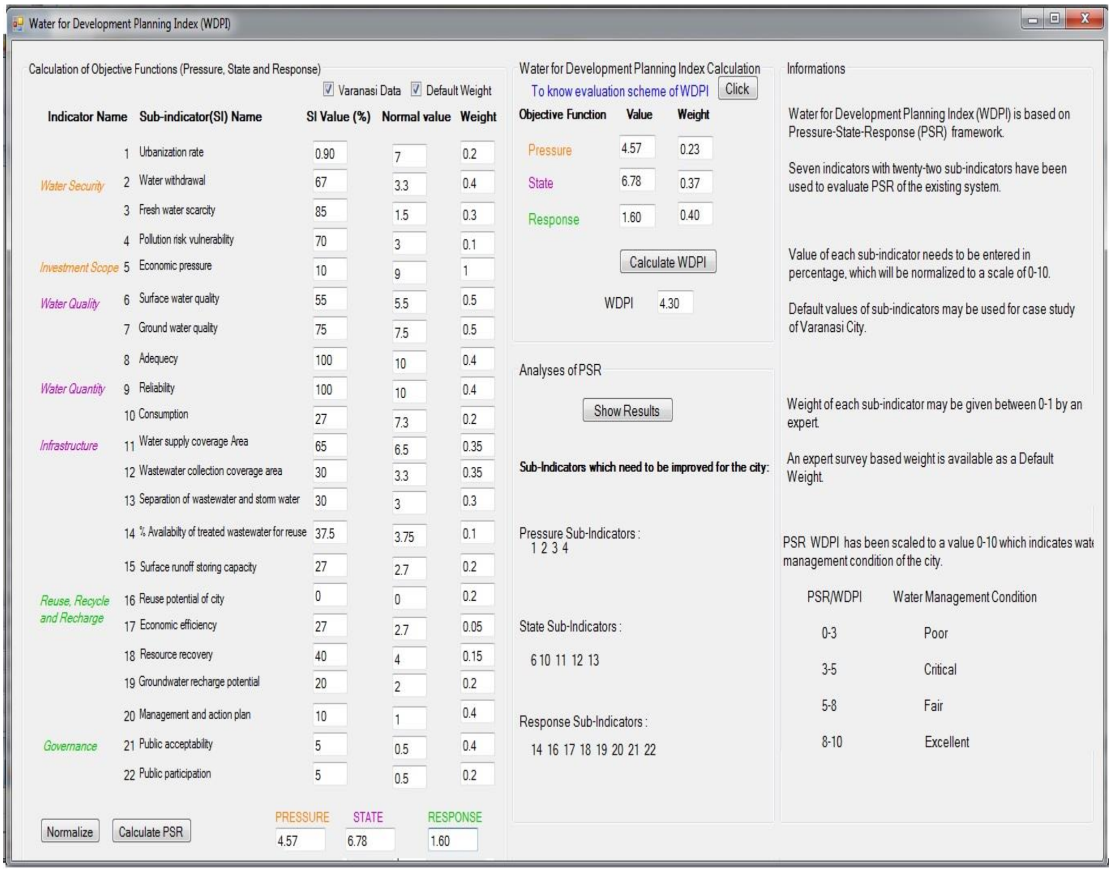


Fig. 6.16: Screenshot of Calculation of PSR and WDPI for Varanasi city for year 2015.

6.2.4.3 Scenario Analyses of Water for Development Planning (WDP)

It is observed that the WDPI for Varanasi city is 4.3 for the year 2015 which indicates its critical condition. In order to improve the urban water management, a combination of five options: (i) Reduction in Unaccounted Groundwater Withdrawal (UGWW), (ii) Groundwater Recharge (GWR), (iii) Rooftop Rainwater Harvesting (RTH), (iv) Surface Runoff Storage (SRS) and (v) Reclaimed Water (RW) Reuse have been considered. For Varanasi city, the Scenario Analyses of Water for Development Planning (WDP) module suggests following possible line of action:

Option	Extent of Action to be Taken
Reduction in Unaccounted Groundwater Withdrawal	50 % of UGWW
Groundwater Recharge	10% of RTH
Roof-top Harvesting	50 % of RTH
Surface Runoff Storage	10 % of SRS
Reclaimed Water Reuse	10 % of AWP

The above actions are likely to compensate around 85 % of unaccounted groundwater withdrawal.

Fig. 6.17: Screenshot of Scenario Generation to Improve WDP for Varanasi city.

However, an additional data of water supply through reverse calculation of observed wastewater quantity in the city is required. For Varanasi city, return water of 300 MLD indicate that actual water production in the city is 375 MLD against 275 MLD as obtained through primary and secondary data. This indicates that 100 MLD unaccounted extraction of fresh water is excess than of demand. A summary of results found through analysis using SDSS_IUWM for Varanasi city is given in Table 6.5.

Table 6.5: Summary of Results from SDSS_IUWM for Varanasi City (2015)

Sr. No	Parameters	Values
1.	Population (millions)	1.49
2.	Water Demand (ML/Year)	100375
3.	Water Supply (ML/Year)	136875
4.	Unaccounted Groundwater Withdrawal (ML/Year)	36500
5.	Annual RTH Potential (ML/Year)	2080
6.	Surface Runoff Storage Potential (ML/Year)	3500
7.	Wastewater Generation (ML/Year)	109500
8.	Available Treated Wastewater (ML/Year)	36500
9.	Pressure score of the Existing System (0-10)	3.8
10.	State score of the Existing System (0-10)	7.0
11.	Response score of the Existing System (0-10)	1.5
12.	WDPI of the Existing System (0-10)	4.3

Further, analysis of indicators and its measure for Pressure, State and Response give an insight about the possible options need to be considered for a sustainable Urban Water Management Futuristic Plan.

6.2.5 Existing Condition of City (2015)

Pressure, State, Response, and WDPI have been calculated using sub-module Water for Development Planning (WDP) module in SDSS_IUWM which is based on the proposed framework of WDPI (Chapter 4). The existing scenario of Varanasi city shows that the city is under critical condition as WDPI is 4.3 (Fig. 6.18).

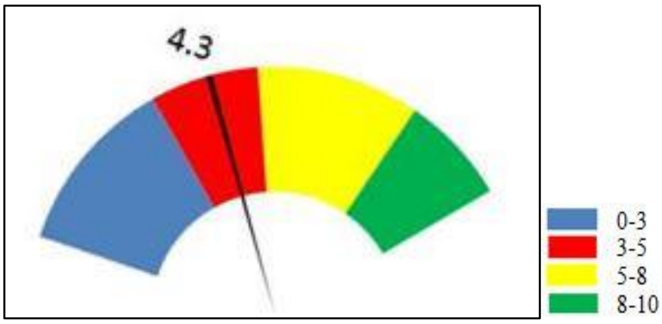


Fig.6.18: Existing condition of WDPI for Varanasi City (2015).

Pressure, state, and response are also calculated for further scope of improvements. The analysis of five individual sub indicators for pressure shows that there is scope of improvement in three of them: water withdrawal, fresh water scarcity, and pollution risk vulnerability. As such, there appears no scope of limiting the rate of urbanization and scope of investment for water development projects have already been found favorable.

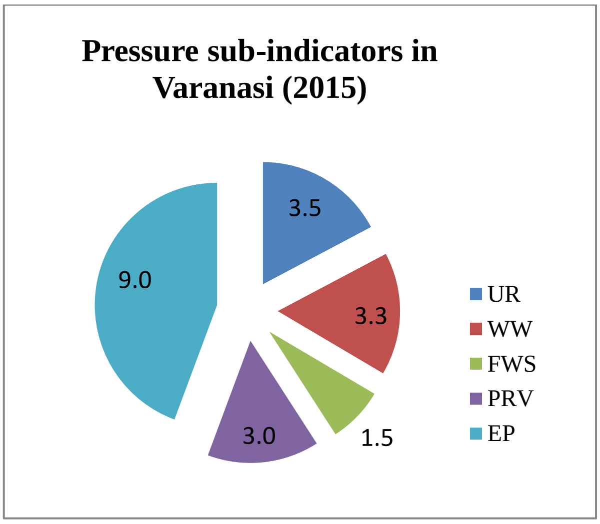


Fig. 6.19: Sub-indicator values of Pressure Objective Function for Varanasi city (2015).

Fig 6.20 shows the score for the second objective function: State. The analyses indicate that out of eight sub indicators involved, three of them-namely, ground water quality, reliability and adequacy are satisfactory, but five may be improved further. These include surface water quality, extra consumption of water, water supply coverage area, waste water collection coverage area and separation of storm water to domestic wastewater. Enhancement of wastewater treatment infrastructure is likely to improve surface water quality. There is scope to reduce extra consumption of water through policy intervention and regulation of ground water withdrawal. Improvement in infrastructure for a target based enhancement in water supply coverage area, wastewater collection coverage area, and separation from wastewater to storm water.

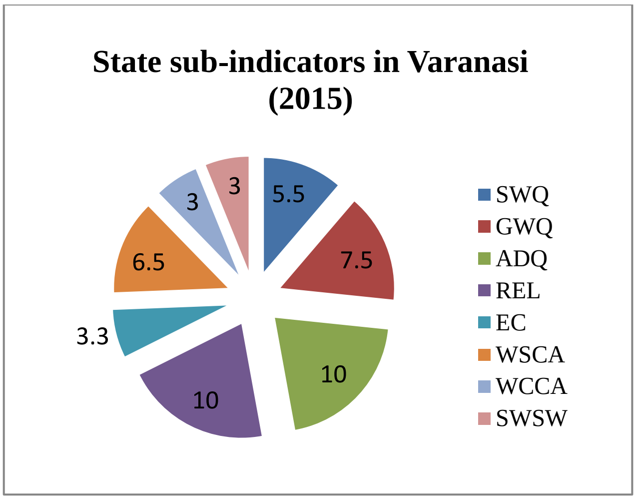


Fig. 6.20: Sub-indicator values of State Objective Function for Varanasi City (2015).

Fig. 6.21 shows the score of third objective function: Response. Overall the response score for Varanasi city for the year 2015 is 1.5, which indicates poor condition. Out of 9 sub indicators, eight of them reflect poor condition, and only one, i.e. surface runoff storage capacity is found satisfactory. Reuse potential, groundwater recharge potential, resource recovery, management and action plan, public acceptance, and public participation are substantially low. Wastewater treatment and economic efficiency are above poor, but still need improvements.

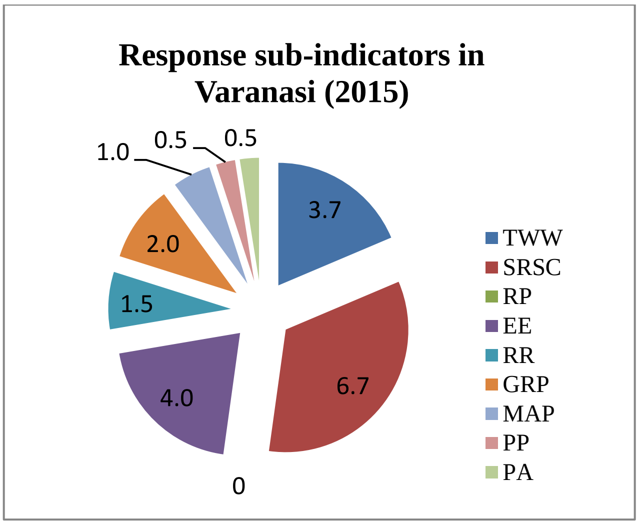


Fig. 6.21: Sub-indicator Values of Response Objective Function for Varanasi City (2015).

Overall, there is scope to improve water security, water quality, infrastructure, water reuse, recycle & recharge, and governance indicators.

The improvement shall be implemented phase wise, so an analysis for WDPI is made.

6.2.6 Analysis of futuristic WDPI for Varanasi city

A target based scenario (Table 6.6) has been considered to calculate the futuristic pressure, state and response. It is planned to use improvement options in defined phase.

Table 6.6: Target based Improvement in Water Supply Sustainability

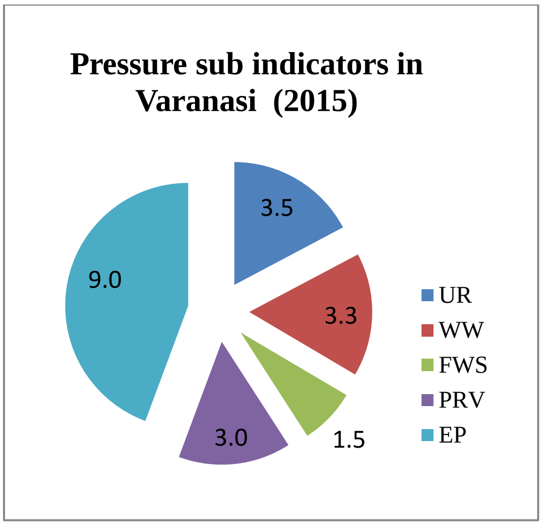
Improvement Option	**Target Year**		
	2020	**2030**	**2040**
Reduction in Unaccounted Groundwater Withdrawal	15 %	25 %	50%
Surface Runoff Storage	10%	20%	30%
Rooftop Harvesting (Rain-tanks)	5%	10%	20%
Rooftop Harvesting (Groundwater Recharge)	5%	10%	20%
Reclaimed Water Reuse	10%	20%	30%

The scenario evaluation for year 2020 has been done based on above target improvement options. The values of parameters for this scenario have been given in Table 6.7.

Table 6.7: Projected Water Situation in Varanasi City for Year 2020

Sr. No.	Parameters	Value
1.	Population (Lac)	1573203
2.	Total Water Supply (ML/ year)	143810
3.	Ground Water Supply (ML/ year)	98185
4.	Surface Water Supply (ML/ year)	45625
5.	Wastewater Produced (ML/ year)	115048
6.	Available Treated Wastewater (ML/ year)	92710
7.	Reuse of Treated Wastewater (ML/ year)	11504
8.	Roof-top Harvesting (ML/ year)	250
9.	Reduction to Extra Water Extraction (ML/ year)	5365
10.	Fresh Water Saving (ML/ year)	11754

The projected condition with suggested options results in improvements in the objective functions of pressure, state, and response for the year 2020. Among the pressure sub indicators, the score of water withdrawal improves from 3.3 to 3.5, fresh water scarcity improves from 1.5 to 1.9 and pollution risk vulnerability score improves from 3.0 to 3.2 (Fig. 6.22). These improvements are being observed due to integration of wastewater and storm water in as Alternate Water Supply (AWS) in the existing system. An improvement in pollution risk vulnerability is due to enhancement of coverage area for wastewater and storm water collections.



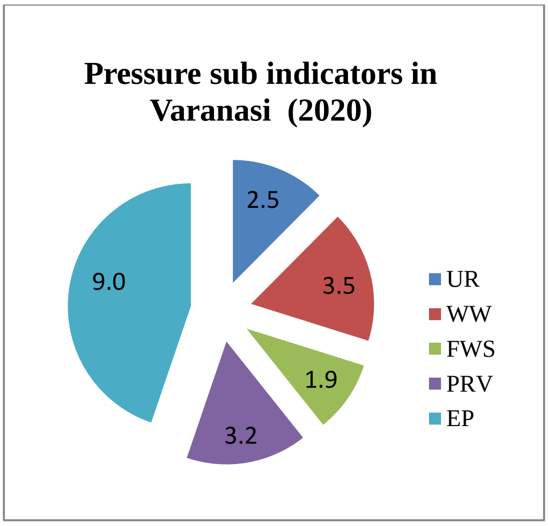


Fig. 6.22: Comparative View of Pressure Sub-indicators for Varanasi City in 2015 and 2020.

Similarly, the improvement analyses of sub-indicators of state and response objective functions have been done for Varanasi city for year 2020 (Fig. 6.23). The improvement in state sub indicators is due to enhancement of infrastructure including water supply coverage area (WSCA), wastewater collection coverage area (WCCA), and separation of wastewater to storm water (SWSW). The values of WSCA, WCCA, and SWSW improve from 6.5 to 6.7, 3.0 to 3.2, and 3.0 to 3.2 respectively.

Score of response sub indicators for year 2020 improve due to enhancement in wastewater treatment, reuse potential, management and action plan, public participation, and public acceptance. Wastewater treatment score increases from 3.75 to 5.5 and reuse potential score advances from 0 to1. The governance measures depend on the awareness of the public and the promotion of programs related to management of resources. It is considered based on the growth of public awareness, improvement in education and practices, and action taken by the authorities.

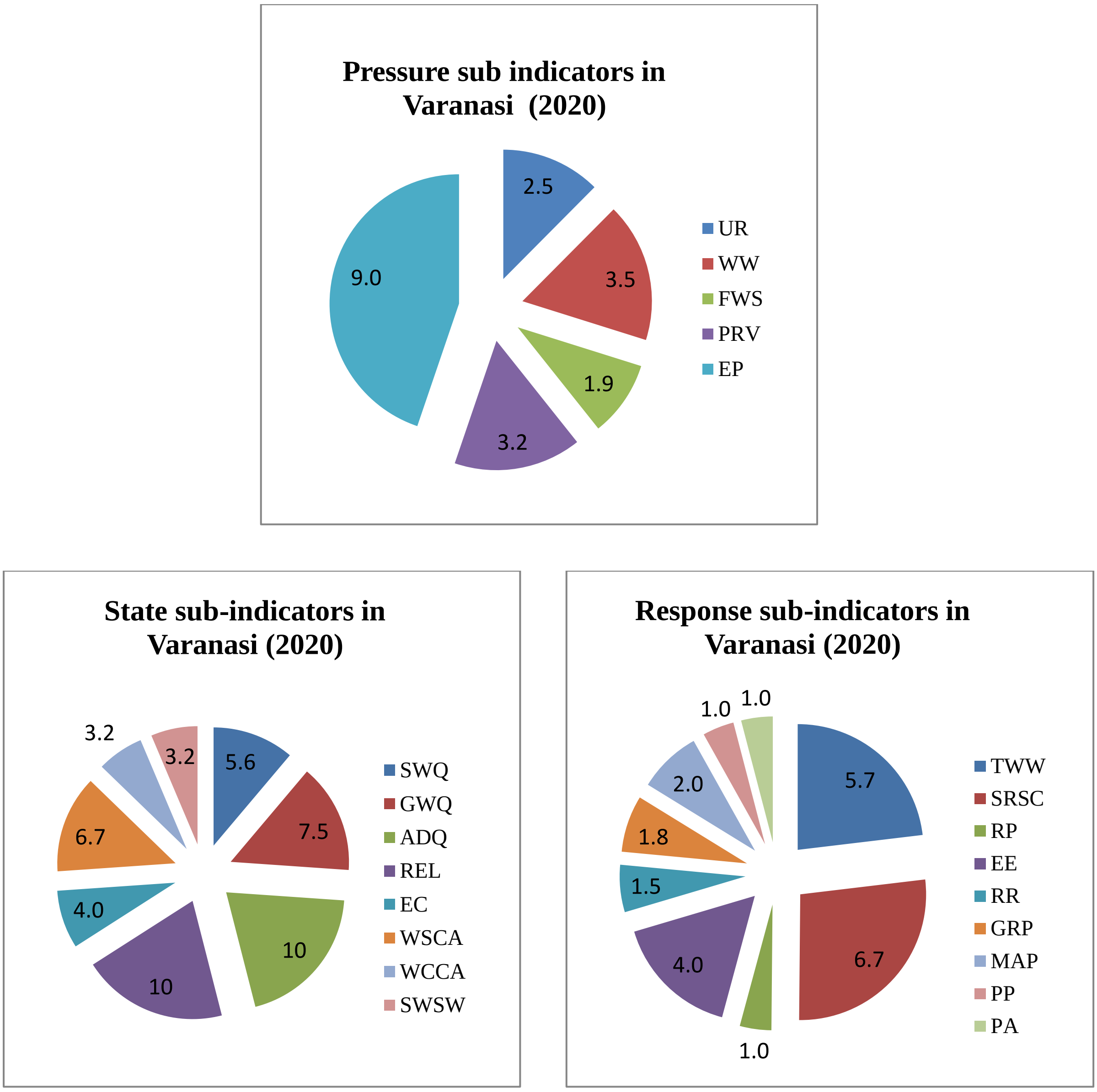


Fig. 6.23: Sub-indicator Values of Pressure, State, Response Objective Functions for Varanasi City (2020).

The scenario evaluation for year 2030 has been done based on targeted improvement options mentioned in Table 6.6. The projected water situation for Varanasi city in the year 2030 is given in Table 6.8.

Table 6.8: Projected Water Situation in Varanasi City for Year 2030

Sr. No.	Details	Value
1.	Population (Lac)	1726635
2.	Total Water Supply (ML/ year)	157315
3.	Ground Water Supply (ML/ year)	111690
4.	Surface Water Supply (ML/ year)	45625
5.	Wastewater Produced (ML/ year)	125852
6.	Available Treated Wastewater (ML/ year)	109500
7.	Reuse of Treated Wastewater (ML/ year)	25170
8.	Roof-top Harvesting (ML/ year)	500
9.	Reduction to Extra Water Extraction (ML/ year)	8942
10.	Fresh Water Saving (ML/ year)	25670

The suggested improvements have reflection on the sub indicators of pressure, state, and response in the year 2030 (Fig. 6.23). It is found that the score of pressure sub indicators such as water withdrawal improves from 3.5 to 3.6 and fresh water scarcity improves from 1.9 to 2.2 due to reduction in extra fresh water withdrawal by 25% and other suggested steps.

Improvement in state sub indicators is due to enhancement of infrastructure including water supply coverage area (WSCA), wastewater collection coverage area (WCCA), separation of wastewater to storm water (SWSW) and extra consumption (EC). The values of WSCA, WCCA, and SWSW improve from 6.7 to 7.5, 3.2 to 6.0, and 3.2 to 6.0 respectively.

Wastewater treatment sub indicator score increases from 5.5 to 8.7 and reuse potential score advances from 1.0 to 2.0. The governance sub indicator scores improves from 2.0 to 3.0, 1.0 to 2.0, and 1.0 to 2.0 for management and action plan, public participation and public acceptance respectively.

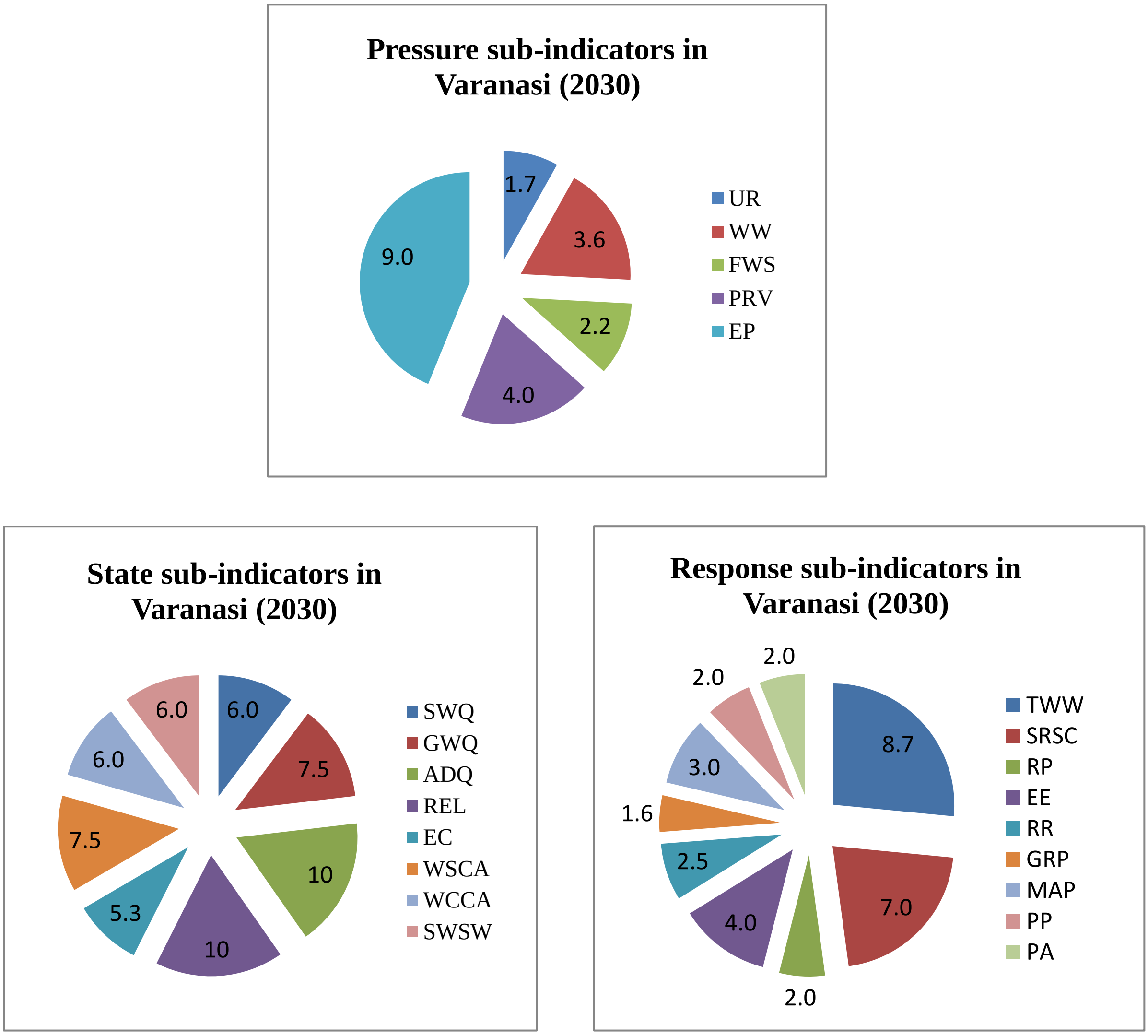


Fig. 6.24: Sub-indicator Values of Pressure, State, Response Objective Functions for Varanasi City (2030).

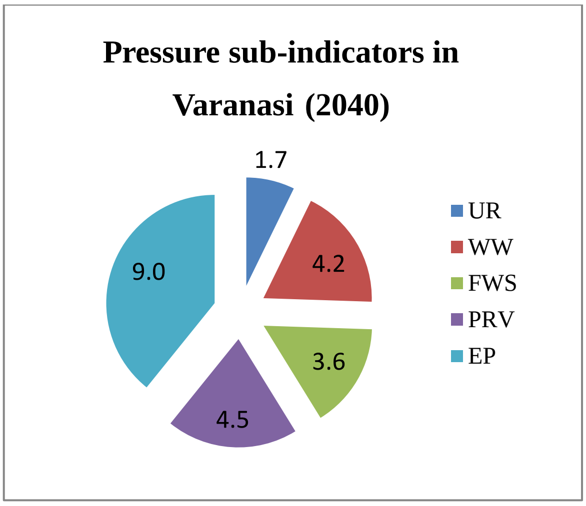
The scenario evaluation for the year 2040 has been done based on targeted improvement options mentioned in Table 6.6. The projected water situation for Varanasi city in the year 2040 is given in Table 6.9.

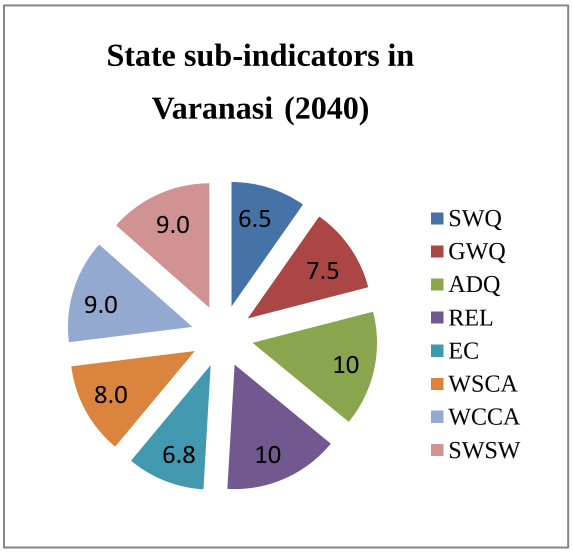
Table 6.9: Projected Water Situation in Varanasi City for Year 2040

Sr. No.	Details	Value
1.	Population (Lac)	1880068
2.	Total Water Supply (ML/ year)	171550
3.	Ground Water Supply (ML/ year)	125925
4.	Surface Water Supply (ML/ year)	45625
5.	Wastewater Produced (ML/ year)	137240
6.	Available Treated Wastewater (ML/ year)	127750
7.	Reuse of Treated Wastewater (ML/ year)	41172
8.	Roof-top Harvesting (ML/ year)	750
9.	Reduction to Extra Water Extraction (ML/ year)	17885
10.	Fresh Water Cut (ML/ year)	59807

The suggested steps have reflections in the form of improvements in the score of the pressure, state, and response objective functions, as shown in Fig. 6.24. For year 2040, the score of pressure sub indicators such as water withdrawal improves from 3.6 to 4.5, fresh water scarcity also improves from 2.2 to 3.6, as a result of reduction in extra fresh water withdrawal by 50% and other suggested steps. Improvement in state sub indicators is due to enhancement of infrastructure including water supply coverage area (WSCA), wastewater collection coverage area (WCCA), and separation of wastewater to storm water (SWSW), extra consumption (EC). The values of WSCA, WCCA, and SWSW improve from 7.5 to 8, 6 to 9.0, and 6.0 to 9.0 respectively.

Score of response sub indicators for the year 2040 improves due to enhancement in wastewater treatment, reuse potential, management and action plan, public participation, and public acceptance. Wastewater treatment score increases from 8.7 to 10 and reuse potential score advances from 2.0 to 3.0. The governance sub indicators improve from 3.0 to 4.0, 2.0 to 3.0, and 2.0 to 3.0 for management and action plan, public participation, and public acceptance respectively.





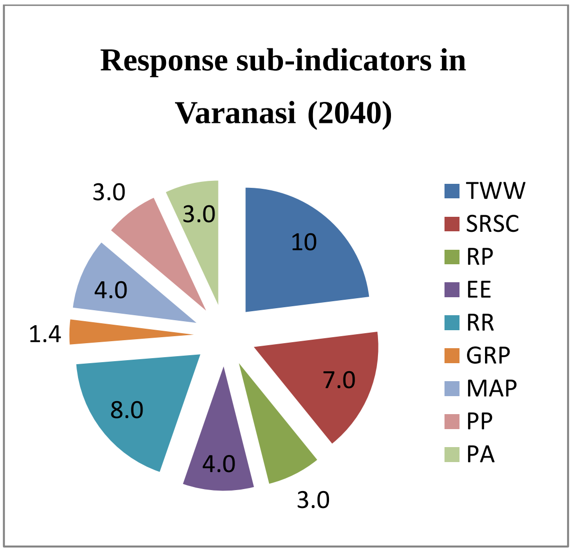


Fig. 6.25: Sub-indicator Values of Pressure, State, Response Objective Functions for Varanasi City (2040).

Based on the existing conditions in 2015 and the proposed improvements through suggested steps in identified areas, WDPI has been worked out, as shown in Fig 6.24. The WDPI successively improves from 4.3 in 2015 to 4.5 in 2020, 5.1 in 2030 and 5.8 in 2040. This indicates that the urban water management may be improved from critical condition to fair condition by the year 2030 and beyond.

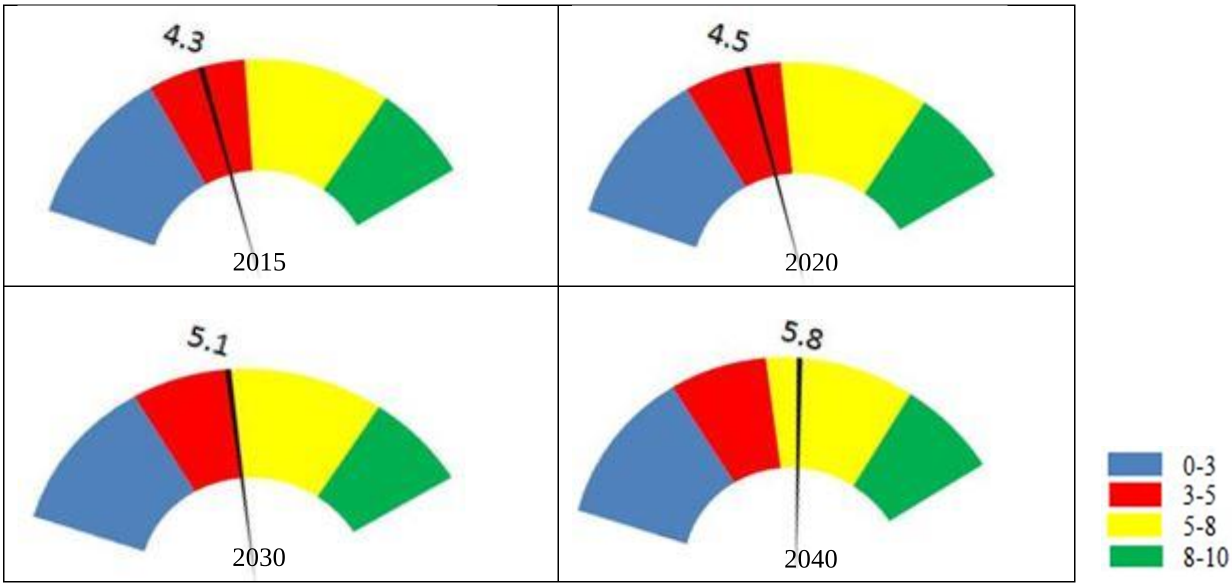


Fig. 6.26: WDPI of Varanasi city for the years 2015, 2020, 2030 and 2040

The critical analysis of Pressure, State, and R indicate that within the given boundary conditions, the suggested improvement options have its own limits. But due to time constrain and lack of data, the extent of possible improvement could not be studied.

6.3 Test Check for Allahabad, Lucknow, Kanpur

The developed application of SDSS_IUWM has also been validated with water utility data of other three cities of Uttar Pradesh, namely- Allahabad, Lucknow, and Kanpur.

6.3.1 City Profile of Allahabad

Allahabad is the seventh most populous city in the state of Uttar Pradesh, with an estimated population of 1.21 million under metropolitan region. The city was earlier known as Prayag. Allahabad city covers an area of 81 sq. km. District lies between 24^0 47' and 25^0 47' north latitude and $81^0$09' and $81^0$21'E. The average annual rainfall in the district is 934 mm. Climate is sub-humid and is characterized by hot summer, pleasant monsoon and cold season. About 90% of rainfall takes place during the months June to September. Temperature of Allahabad city varies from 41.5^{0}C in summer to 4^{0}C in winter.

Based on the existing conditions and the proposed improvements in identified areas, WDPI for Allahabad city has been worked out for the years 2015, 2020, 2030 and 2040 and depicted in the Fig 6.29. As is seen, the WDPI score improves from 4.6 in 2015 to 5.0 in 2030 and 5.6 in 2040, indicating that the urban water management may improve from critical condition to fair by the year 2030 and beyond by incorporating suggested steps.

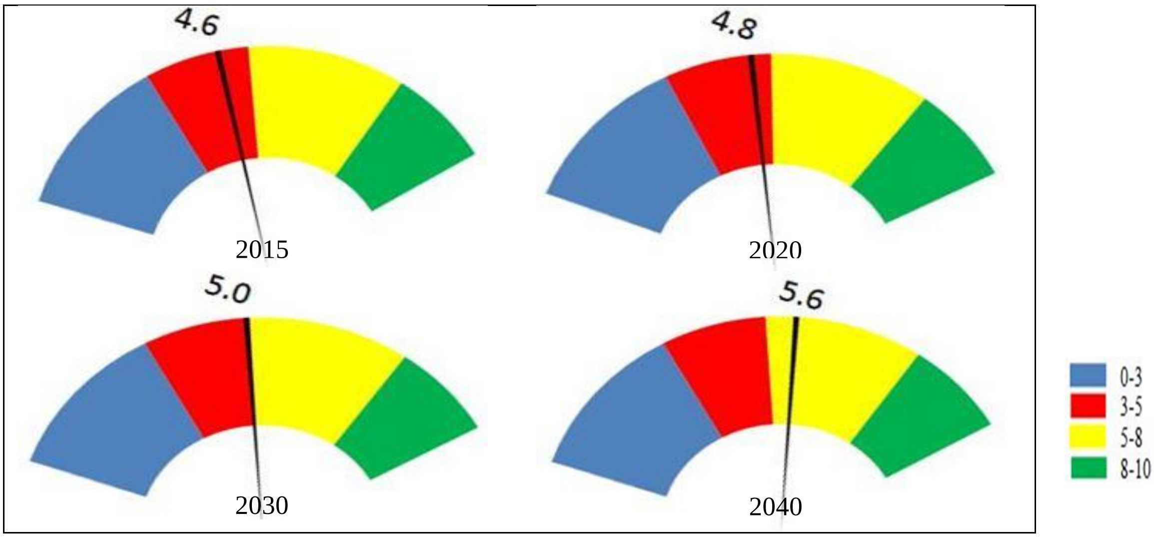


Fig. 6.27: WDPI of Allahabad city for the years 2015, 2020, 2030 and 2040.

6.3.2 City Profile of Lucknow

Lucknow is the capital and largest city of Uttar Pradesh and is also the administrative headquarter of the state. It is the eleventh most populous city and the twelfth most populous urban agglomeration of India. The city stands at an elevation of approximately 123 m above mean sea level. The city of Lucknow is spread over a total area of 333.5 sq. km and has a population close to 2.85 million. There are total 110 administrative wards. The rainy season is from July to September with an annual average rainfall of

896 mm. The temperature throughout year varies from 3^0 C in winter to 45^0 C in summers. The water supply and sanitation is managed by Lucknow Municipal Corporation. Total water supply in Lucknow city is 613 MLD (333 MLD from surface sources and 280 MLD from ground water resources). Total wastewater produced at Lucknow city is 490 MLD [Source: Lucknow Nagar Nigam, 2015]. At present, the city has been operating two STPs of 56 MLD and 345 MLD capacities at Daulataganj and Bharwara respectively. The actual treatment capacity is approximately 280 to 300 MLD of waste water. However, there is no provision for re-use of treated waste water.

WDPI has been worked out based for the existing condition of 2015 and with proposed improvement options in the years 2020, 2030 and 2040 (Fig. 6. 27). It is observed that the urban water management in Lucknow is relatively better with respect to Varanasi and Allahabad.

The WDPI of Lucknow is calculated to be 4.8 in 2015, which improves to 5.0 in 2020 with suggested steps of better urban water management. The WDPI is projected to reach 5.2 in 2030 and 5.7 in the year 2040. Thus, whereas the current situation appears critical, it may be improved to fair condition by 2020.

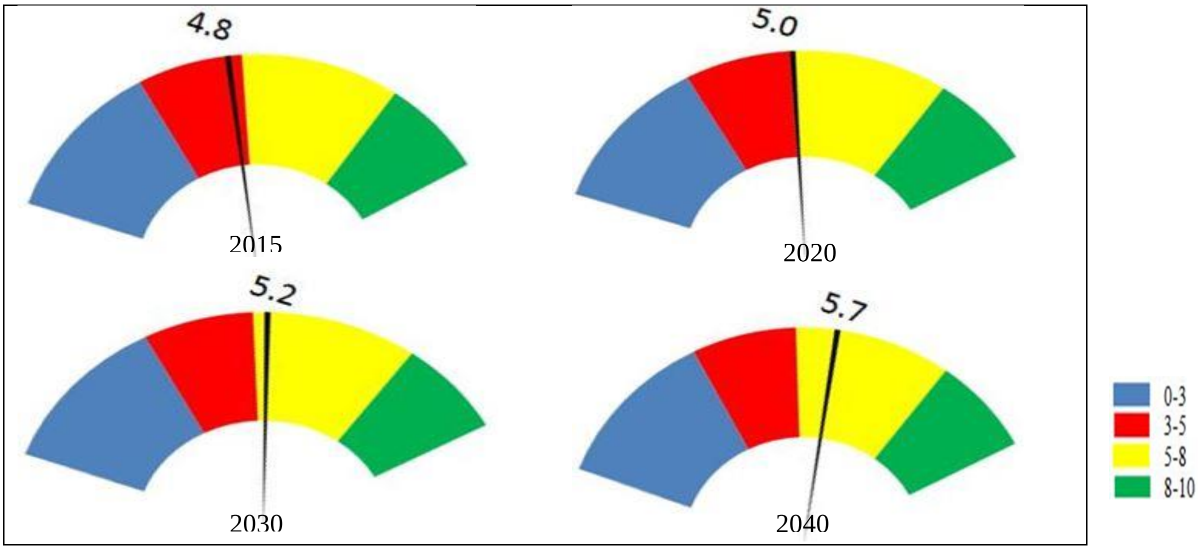


Fig. 6.28: WDPI of Lucknow city for the years 2015, 2020, 2030 and 2040.

6.3.3 City Profile of Kanpur

Kanpur is the biggest city of Uttar Pradesh and known as Manchester of India due to main centre of commercial and industrial activities. It is situated on the most important national highways no. 2 and 25 and state highway, the main Delhi-Howrah railway trunk lines and on the bank of holy river Ganga. The city stands at an elevation of 126 m above mean sea level. Kanpur is a metropolitan city, sprawling over an area of 260 sq. km. According to the census 2011, Kanpur has a population of 2.75 million. It is administratively divided into 6 zones and 110 wards. About 80% is covered by water supply and about 60% is covered by sewerage system. The annual average rainfall is observed as 959 mm. The main source of surface water in the city is from the catchment of Ganga River and Pandu River.

Kanpur City has a total water supply of 385 MLD (255 MLD from surface sources and 130 MLD from ground water sources). The total raw water treatment capacity in Kanpur city is 540 MLD (Benajhaber 310 MLD, Gujaini 30 MLD, and Ganga Barrage 200 MLD). The total raw water supply is about 255 MLD (210 MLD raw water from Bhaironghat pumping station and 45 mld from Lower Ganga Canal) and approximately 130 MLD water is drawn from groundwater comprising of 80 MLD from tube wells (around 135 in number) and 50 MLD from hand pumps (around 9830 in number), thereby making a total water supply of 385 MLD. There are 2.84 lakh assesses and 4.2 lakh properties in Kanpur city. However, the coverage of Kanpur Jal Sansthan (KJS) is only 1.8 lakh connections. This shows inadequacy existing in the system, especially considering that the distribution network covers 80% of the city area. In addition, there are large numbers of private bore wells in residential and industrial areas which are unaccounted.

Kanpur city generates about 450 MLD of wastewater. Apart from three wastewater treatment plants of 5 MLD, 36 MLD and 136 MLD, new STPs such as 43 MLD at Jajmau, 42 MLD at Sajri, Chakeri are under construction. About 50 MLD of waste water is being generated by tanneries, but only 9 MLD is reported to be being treated.

WDPI for Kanpur city has been calculated for the years 2015, 2020, 2030 and 2040. It is observed that the WDPI of Kanpur city is 5.2 in the year 2015 indicating a fair condition of water management. With proposed improvement options, the WDPI may further be improved to 5.4 in 2020, 5.6 in 2030 and 5.7 in 2040 (Fig. 6. 28)

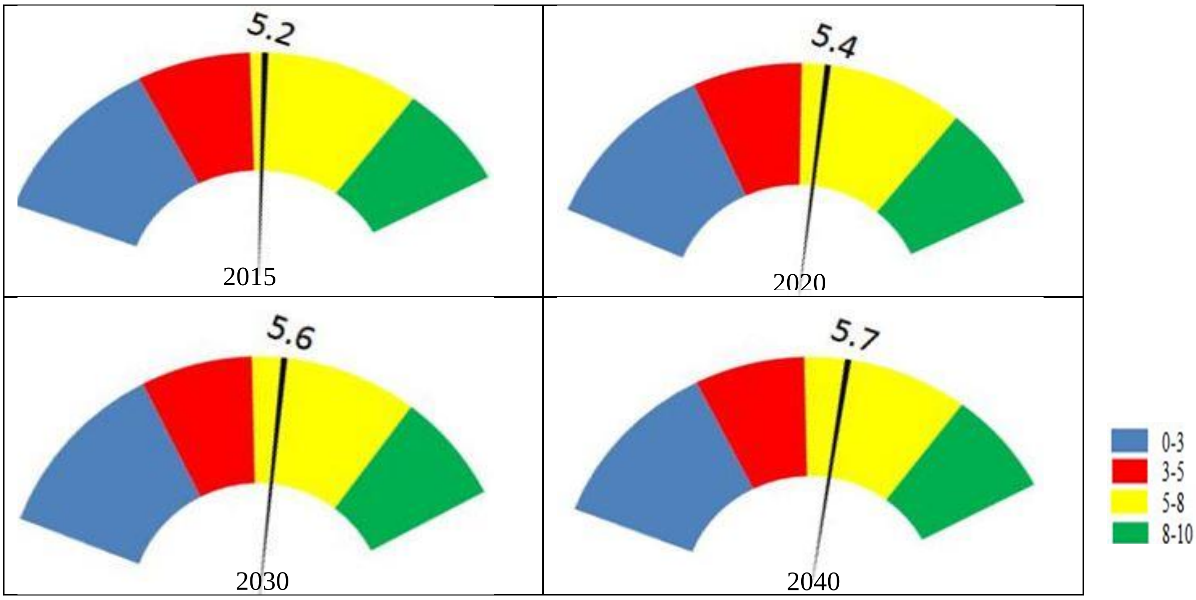


Fig.6.29: WDPI of Kanpur city for year 2015, 2020, 2030, and 2040.

6.6 Trend Analysis of PSR and WDPI for the selected cities

Using the WDP module of SDSS_IUWM application, the PSR scores and WDPI values on 0-10 scale have been calculated for the existing condition (year 2015) and the projected years of 2020, 2030 and 2040 for four major cities of Uttar Pradesh, namely - Varanasi, Allahabad, Lucknow, and Kanpur. A summary of results is presented in Table 6.10. The conditions of water management in the cities in four broad categories, namely, Poor, Critical, Fair and Excellent have been shown in Table 6.11.

Table 6.10: Pressure, State, Response Scores and WDPI for Varanasi, Allahabad, Lucknow and Kanpur cities without applying improvement options with the existing scenario (base year 2015 and projected years 2020, 2030, 2040)

City	**PSR Scores and WDPI**															
	2015				2020				2030				2040			
	Pressure	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**
Varanasi	4.5	6.8	1.6	4.3	4.3	6.8	1.6	4.2	4.2	6.7	1.6	4.1	3.9	6.8	1.5	4.0
Allahabad	3.7	7.2	2.7	4.6	3.6	7.2	2.6	4.5	3.3	7.3	2.5	4.4	3.1	7.3	2.2	4.2
Lucknow	6.0	7.0	2.0	4.8	5.6	7.0	2.0	4.7	4.7	7.0	1.9	4.5	4.3	7.1	1.9	4.4
Kanpur	7.5	7.3	2.0	5.2	7.2	7.2	2.1	5.2	6.2	7.2	2.0	4.9	4.6	7.3	1.3	4.3

Table 6.11: Pressure, State, Response and WDPI Conditions for Varanasi, Allahabad, Lucknow and Kanpur cities without applying improvement options with the existing scenario (base year 2015 and projected years 2020, 2030, 2040).

City	**PSR and WDPI Conditions**															
	2015				2020				2030				2040			
	Pressure	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**
Varanasi	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Critical
Allahabad	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Critical
Lucknow	Fair	Fair	Poor	Critical	Fair	Fair	Poor	Critical	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Critical
Kanpur	Fair	Fair	Poor	Critical	Fair	Fair	Poor	Fair	Fair	Fair	Poor	Critical	Critical	Fair	Poor	Critical

The observations from Table 6.10 and 6.11 indicate that without proper planning for better management, the water sustainability for Varanasi, Allahabad, and Lucknow are in critical condition and appears to be sliding down towards worse side. The Kanpur city is currently in fair condition, but may move to critical state in years 2020 onwards. A trend analysis of PSR scores and WDPI has been performed for all four cities, as shown in Fig. 6.30. Obviously, the State stands higher in all these cities, indicating that the water supply infrastructure and water quality level is reasonably well. The response scores are lower, indicating unsatisfactory condition of wastewater treatment, poor reuse of reclaimed water, less integrated storm water resources and poor water sector governance.

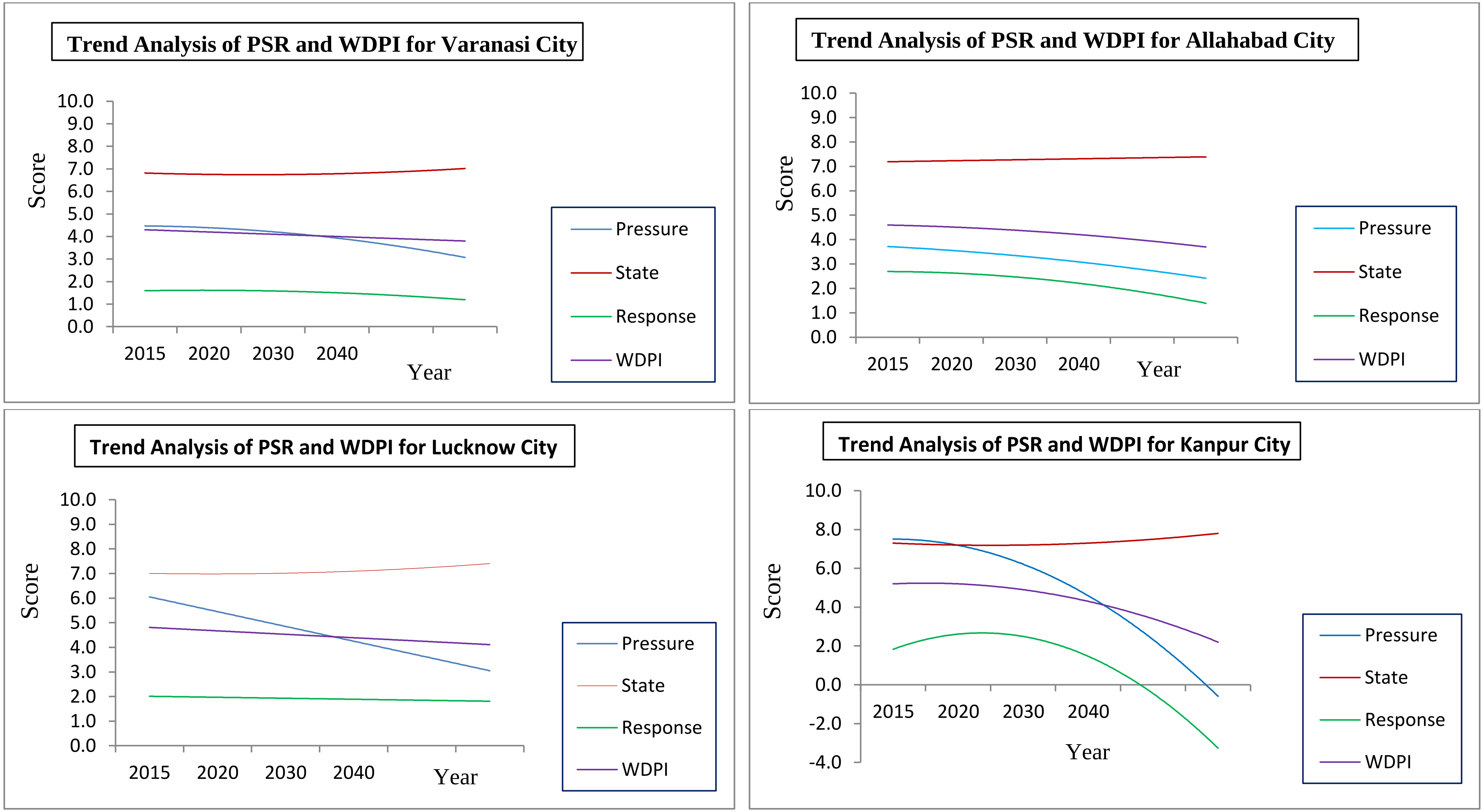


Fig 6.30: Trend Analysis of Pressure, State, Response and WDPI (2020, 2030, and 2040) for Varanasi, Allahabad, Lucknow, and Kanpur city with the existing scenario (2015) without applying improvement options.

Table 6.12 shows Pressure, State, Response Scores and WDPI for Varanasi, Allahabad, Lucknow and Kanpur cities with applying improvement options in the existing scenario (base year 2015 and projected years 2020, 2030, 2040). The values indicate that for Lucknow and Kanpur, the suggested options have the abilities to improve the water condition from critical to fair by 2020, but for Varanasi and Allahabad, the situation may take longer and up to 2030 to move from critical to fair. The implementation of proposed options and steps are likely to bring the water management scenario for all the four cities from critical to fair condition by 2030 and beyond (Table 6.13).

A trend analysis of PSR scores and WDPI with implementation of suggested steps has been performed for all four cities, as shown in Fig. 6.31. It is observed that the Pressure score has increasing trend which reflect that integration of reclaimed water and storm water to the existing system are being effective to improve the water sustainability condition. State score also has a rising trend, indicating improving water infrastructure. Increasing trend in Response score indicates significant improvement in recycling of water and better governance of water sector.

Table 6.12: Pressure, State, Response Scores and WDPI for Varanasi, Allahabad, Lucknow and Kanpur cities after applying improvement options with the existing scenario (base year 2015 and projected years 2020, 2030, 2040)

City	**PSR Scores and WDPI**															
	2015				2020				2030				2040			
	Pressure	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**
Varanasi	4.5	6.8	1.6	4.3	4.8	6.9	2.0	4.5	4.9	7.7	2.8	5.1	5.0	8.7	3.6	5.8
Allahabad	3.7	7.2	2.7	4.6	3.8	7.3	3.0	4.8	3.8	7.5	3.5	5.0	4.2	7.9	4.3	5.6
Lucknow	6.0	7.0	2.0	4.8	6.4	7.0	2.5	5.0	5.5	7.5	3.0	5.2	5.7	8.0	3.6	5.7
Kanpur	7.5	7.3	2.0	5.2	7.0	7.3	2.6	5.4	6.4	7.7	3.0	5.6	5.6	8.3	3.4	5.7

Table 6.13: Pressure, State, Response and WDPI conditions for Varanasi, Allahabad, Lucknow and Kanpur cities with applying improvement options with the existing scenario (base year 2015 and projected years 2020, 2030, 2040)

City	**Year**															
	2015				2020				2030				2040			
	Pressure	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**	**Pressure**	**State**	**Response**	**WDPI**
Varanasi	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Fair	Fair	Excellent	Critical	Fair
Allahabad	Critical	Fair	Poor	Critical	Critical	Fair	Poor	Critical	Critical	Fair	Critical	Fair	Critical	Fair	Critical	Fair
Lucknow	Fair	Fair	Poor	Critical	Fair	Fair	Poor	Fair	Fair	Fair	Poor	Fair	Fair	Excellent	Critical	Fair
Kanpur	Fair	Fair	Poor	Fair	Fair	Fair	Poor	Fair	Fair	Fair	Poor	Fair	Fair	Excellent	Critical	Fair

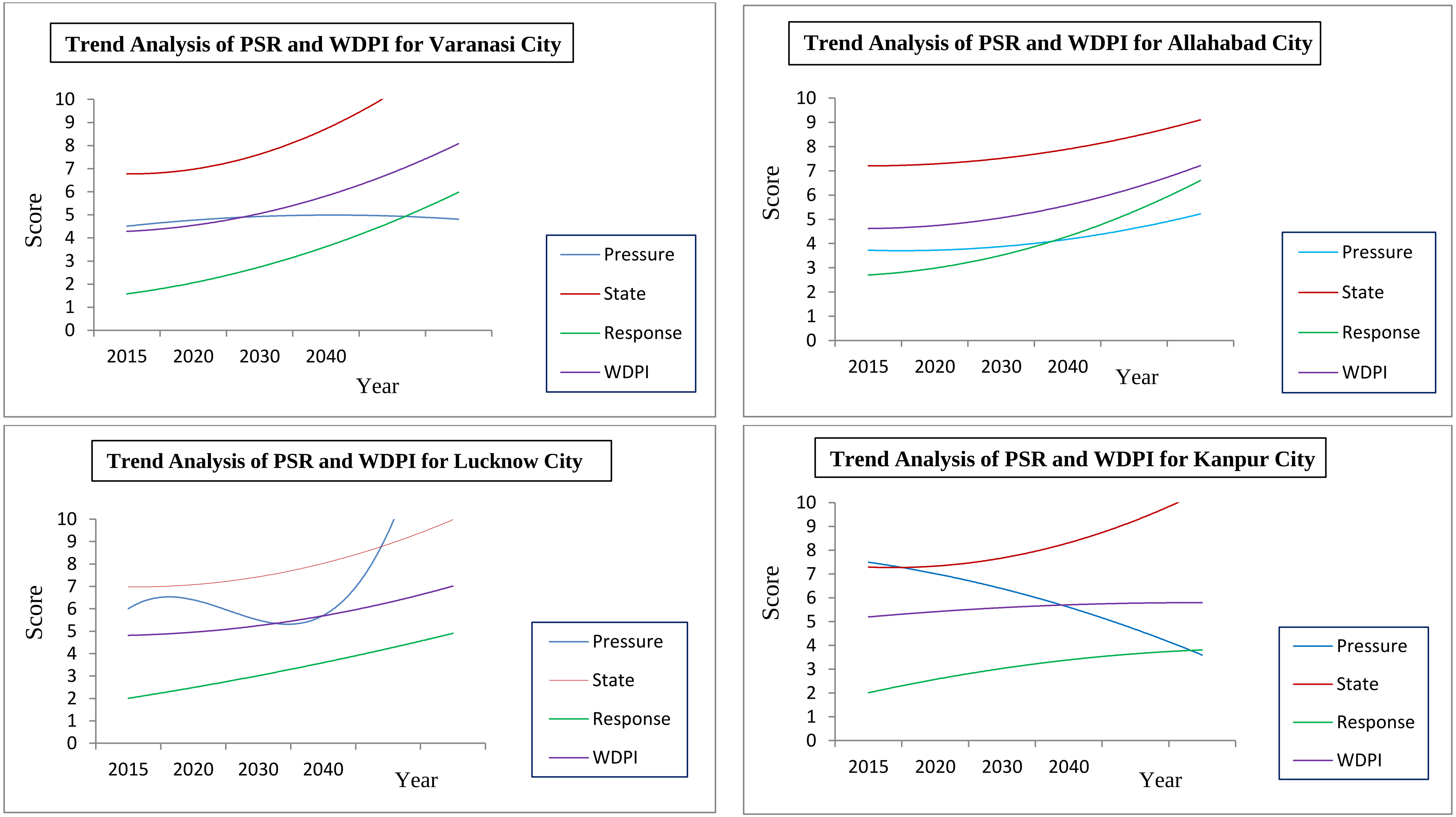


Fig 6.31: Trend Analysis of Pressure, State, Response and WDPI (2020, 2030, and 2040) for Varanasi, Allahabad, Lucknow, and Kanpur city with the existing scenario (2015) with applying improvement options.