CHAPTER 5

DEVELOPMENT OF GRAPHICAL USER INTERFACE AND MODELS

5.1 Introduction

In this chapter the details of models and methods used in development of the graphical user interface (GUI) and database of SDSS_IUWM are discussed. Each model used in present study has been described with their formulae, associated data and the assumptions. The models have been selected keeping in view various needs of SDSS and their input data requirement. The following points have been taken into consideration while opting for a particular model:

1. Development of a generic model in global context
2. Simplicity of the model in terms of easy implementation
3. Primary data requirement and derived data preparation
4. Ability to integrate with all components of urban water systems efficiently

The ideology to integrate components of urban water system is holistic use of water in urban water cycle. However, integration of the components is challenging as they are multitudinous in nature. Water demand, water supply, wastewater, storm water are complex in itself to regulate individually within institutional framework. Each component has a different method of estimation and planning of resource. In order to integrate every component of urban water system there is need to understand interdependence among them. Most of the models have been used in their present available form and are described from the source, but in order to reach to a logical conclusion certain models have also been developed. A data flow diagram of the proposed model is shown in Fig. 5.1.

The database management has been developed so that a tight coupling can be maintained but some external data have also been used with loose-coupling (prepared using other software and taken as an input in the developed application). QGIS and ArcGIS have been used to prepare spatial data.

Detailed program code of each module and sub-module is given in Appendix A. Designing is based on the logical sequence of modules and sub-modules. SDSS_IUWM consists of six main modules. Each module has several sub-modules to estimate the sector specific values.

Basic data has been designed for initial input to start the application. Main modules are as:

1. Water Demand (WD)
2. Water Supply (WS)
3. Waste Water Management (WWM)
4. Storm Water Management (SWM)
5. Urban Water Balance (UWB)
6. Water for Development Planning (WDP)

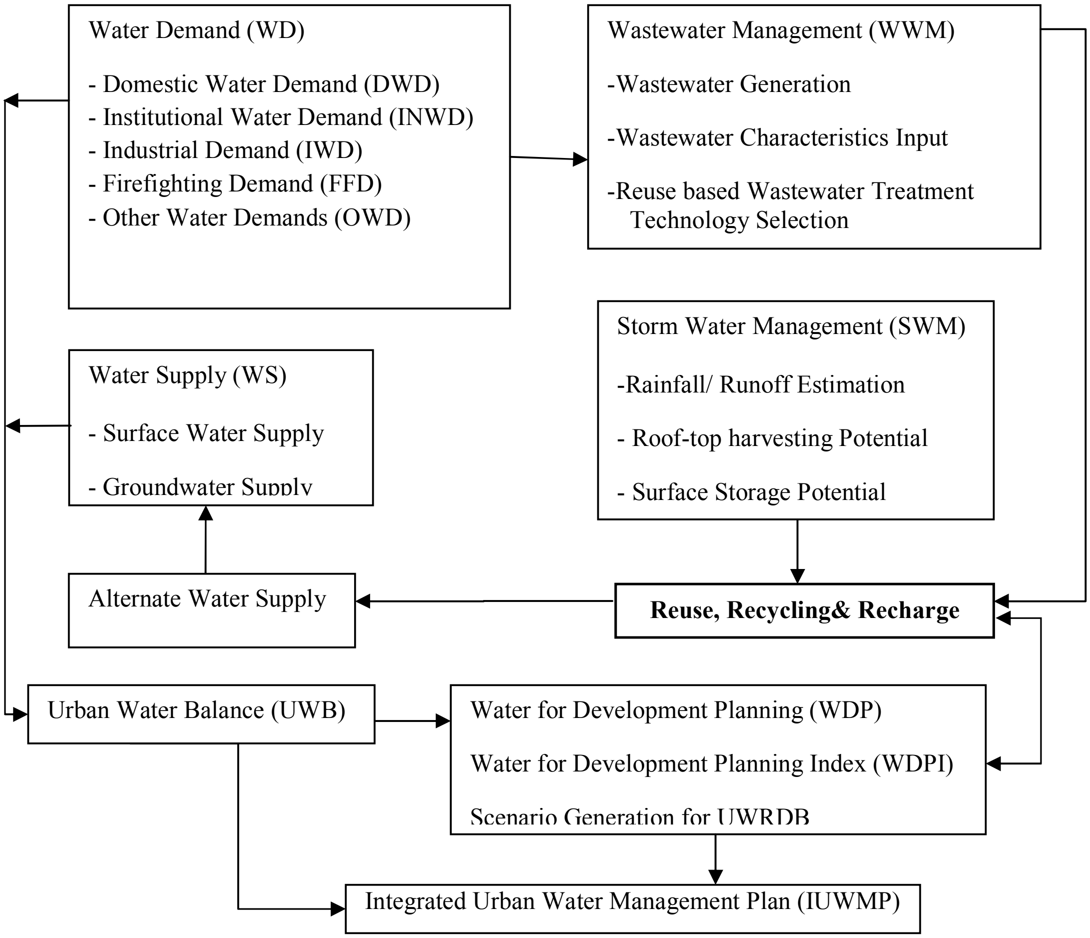

Fig. 5.1 Data flow diagram of SDSS_IUWM

Application SDSS_IUWM has been developed using software Visual Studio 2008, and MySQL 5.6, and SQLyog 5.6.2. An ActiveX control, ESRI ArcGIS Engine 9.3 is used to access and analyze the spatial data. The developed software has been designed to work on the windows operating system. A user friendly graphical user interface (GUI) has been developed using the object oriented programming language, MS Visual Basic (VB.NET). The application development environment has been shown in Fig. 5.2. The main page developed under ADE is shown in Fig. 5.3. This page consist main modules including basic data option.

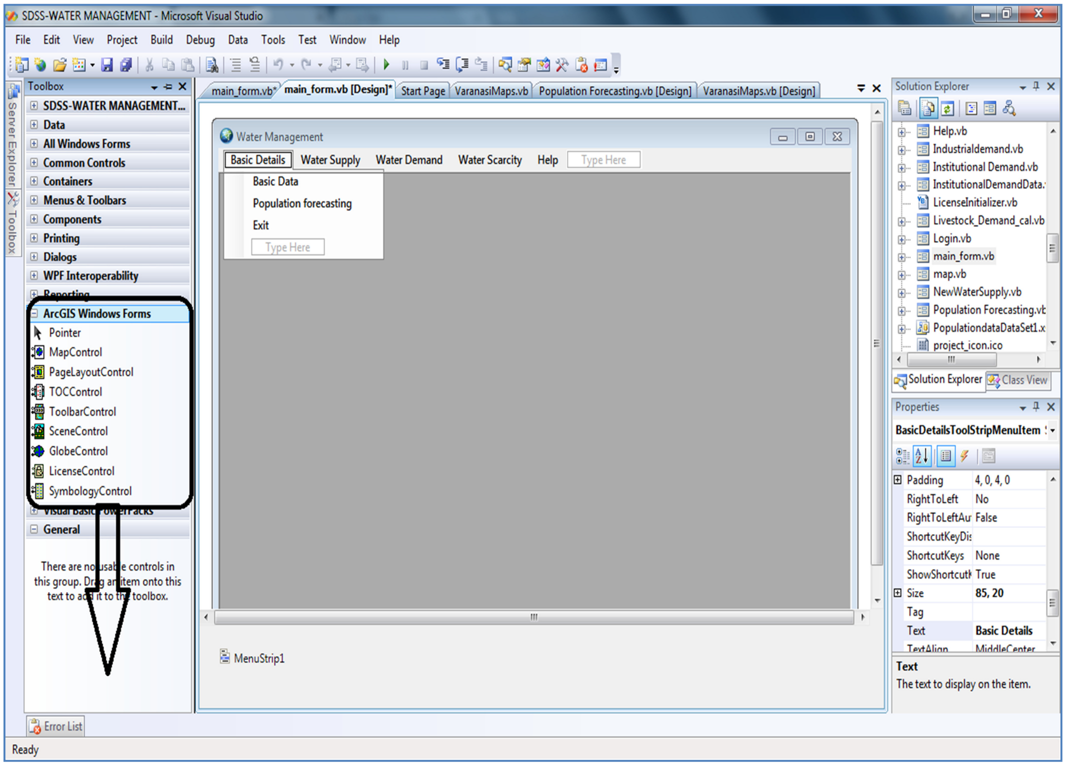

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Fig. 5.2: Screenshot of Application Development Environment for SDSS_IUWM

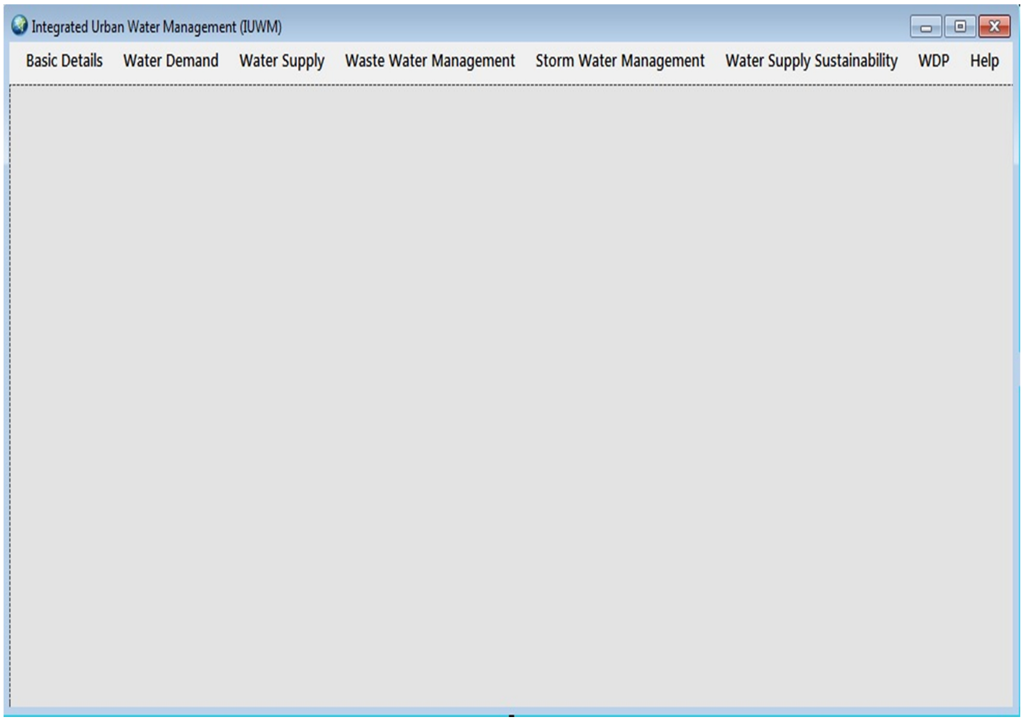
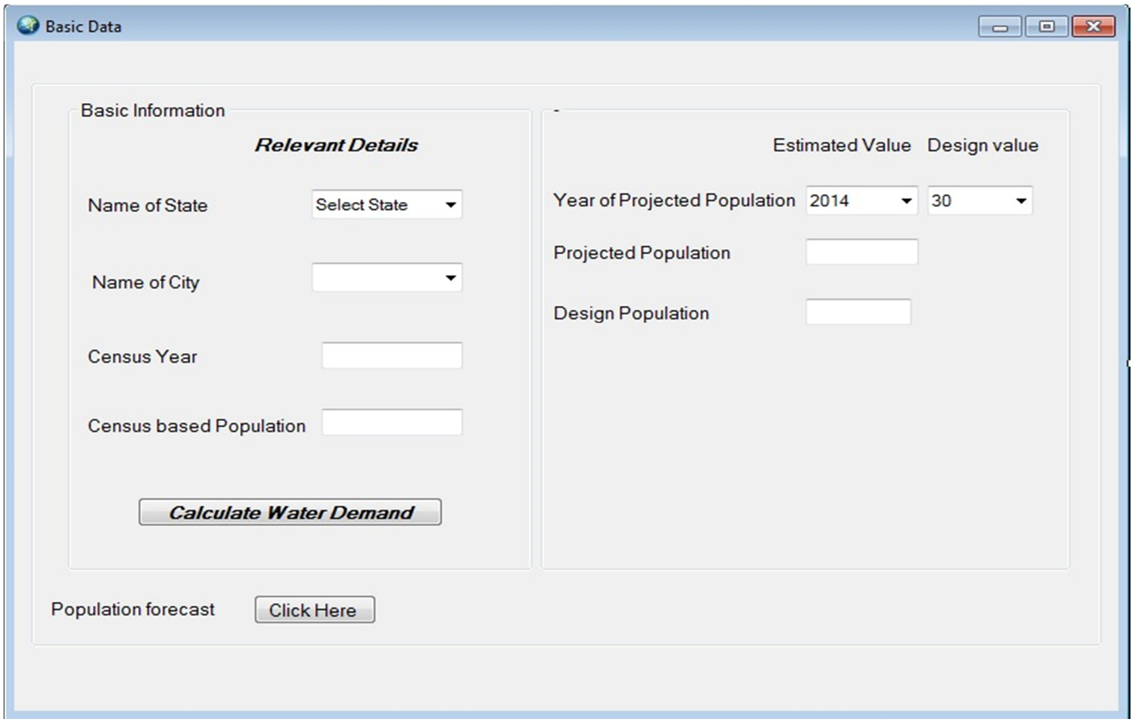


Fig. 5.3: Screenshot of Main Page Designed for SDSS_IUWM

5.3 Basic Data

For better water resource management, lot of data related to population, area, infrastructure fresh water withdrawal, water quality, wastewater reuse, resource recovery, policy management, and public participation etc. are required. Generally municipalities may have most of data with them still there may be some data which may not be readily available. Hence, SDSS_IUWM has been designed and developed with an ability to support the unavailable data with some firsthand approximation value applicable in the region for broad planning.

A data library for SDSS_IUWM has been developed. Data on population of 600 Indian cities of 26 states have been entered into database. A run-time data submission and storing is also implemented during application design. Other urban water systems data have been taken and compiled from city development plan (CDP) and city sanitation plan (CSP) reports in order to give a starting point for planning process. In case the user does not have these basic data, SDSS-IUWM takes the values from such Tables in the knowledge base to support the planner for initial calculations as shown in Fig 5.4.



Name of State: Select State

Year of Projected Population: 2014 (Estimated Value), 30 (Design value)

Fig. 5.4: Screenshot of Basic Data Input Page

5.4 Design Periods and Population Forecasting

The design period and population forecast should be worked out with due provision for the estimated requirements of the future. The future period for which a provision is made in the water supply scheme is known as the design period.

Design period is estimated based on the following:

1. Useful life of the component, considering obsolescence, wear and tear etc.
2. Expandability aspect.
3. Anticipated rate of growth of population, including industrial, commercial developments & migration-immigration.
4. Available resources.
5. Performance of the system during initial period.

5.5 POPULATION FORECASTING

The design population in a future year will have to be estimated taking care of all the factors governing the growth and development of the area in industrial, commercial, educational, social and administrative spheres. Special factors causing sudden emigration or influx of population should also be considered to the extent possible.

There are several methods for forecasting the population of a city. This includes:

- Arithmetic progression method
- Geometric progression method
- Incremental increase method
- Semi-log graphical method
- Area density method

Out of these methods, Arithmetic progression, Geometric progression and Incremental increase methods are common and have been used for estimating the population of a city in the present work.

5.5.1 Arithmetic progression method: This method is based on the assumption that the population increases at a constant rate;

Annual population growth rate= dP/dn=constant=k

The following equations have been used in first hand forecasting of population:

$$P_n = P_0 + kn. \qquad (5.1)$$

Where, P_n = population in desired year, P_o= population in base year, k = Annual population growth rate and n = difference in years of desired and base year.

$$k = dP/dn \qquad (5.2)$$

Using this computed growth rate, desired population for any year may be computed using the equation 5.1.

5.5.2 Incremental increase method: In this method Growth rate is assumed to be progressively increasing or decreasing, depending upon whether the average of the incremental increases in the past is positive or negative. The population for a future decade is worked out by adding the mean arithmetic increase to the last known population as in the arithmetic increase method and to this is added the average of incremental increases, once for first decade, twice for second and so on.

5.5.3 Geometric progression method: The following equations have been used in forecasting of population by Geometric progression method:

$$P = P_o (1 + r)^{n/10} \qquad (5.3)$$

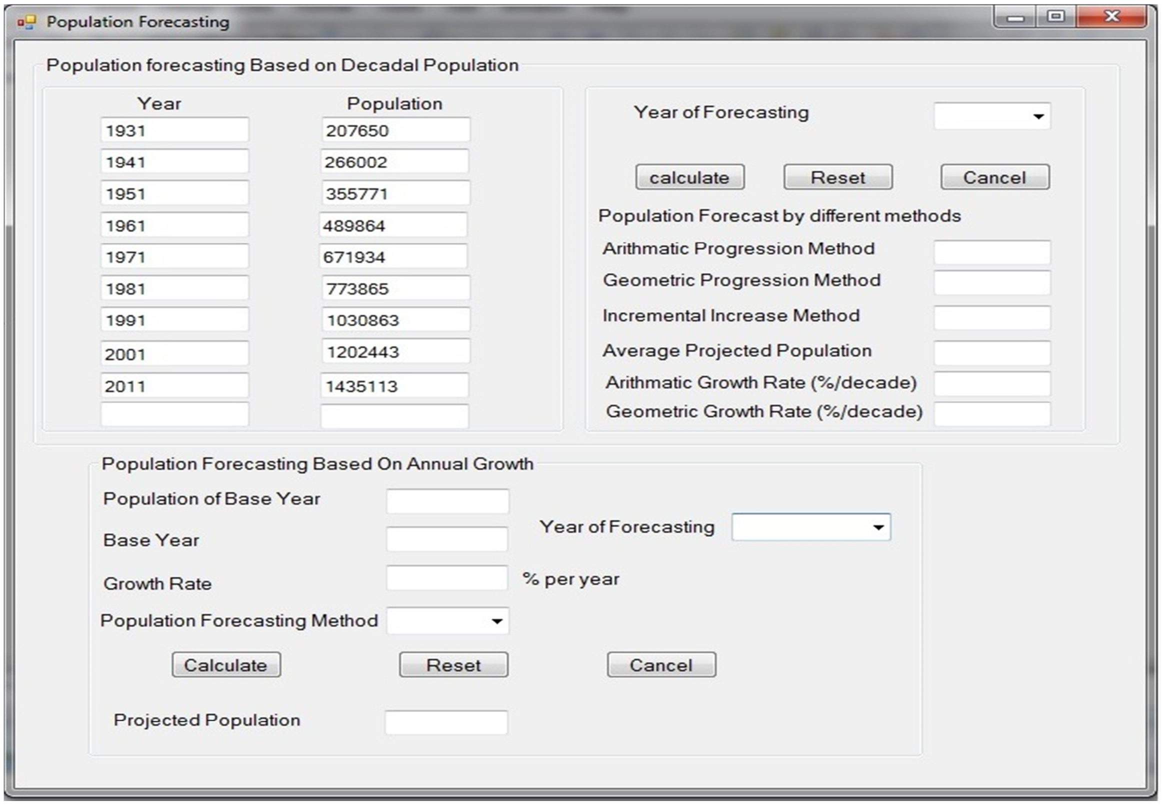
Where, P_n = population in desired year, P_o= population in base year, r = decadal population growth rate and n = difference in years of desired and base year.

The population growth rate and population at the base year can be obtained from census data. In case of unavailability of decadal growth rate data, it can be computed from population data of two consecutive decades for particular duration as follows:

$$r = \left(\frac{P}{P_0} \right) - 1 \qquad (5.4)$$

Using the computed decadal growth rate, desired population for any year can be computed using the Eq. 5.3.

An average of populations projected by all three methods may be taken for planning purpose. Population Forecasting sub-Module have been developed for this purpose as shown in Fig 5.5



Year	Population
1931	207650
1941	266002
1951	355771
1961	489864
1971	671934
1981	773865
1991	1030863
2001	1202443
2011	1435113

Fig. 5.5: Screenshot of Population Forecasting Sub-module

5.6 Water Demand (WD) Estimation:

At ~~a~~ municipality scale, domestic demand is a common term. Besides domestic demand, water is also required for commercial/institutional, industrial, firefighting and other civic or public use. In India, Bureau of Indian Standards (BIS) decides the norms for water management. Indian Standard (IS):1172-1993 specified water demands for different uses. In general, almost every municipal corporation/municipality has defined the requirement of water per capita per day in its own way. One agrees that industrial and commercial development of towns and cities may differ and hence the amount of water required will also vary, but the requirement for domestic use normally does not vary much.

Following Factors affect per capita demand

1. Geographical area and population of the city
2. Rate of Industrialization
3. Water use habits of people and their economic status:
4. Quality of water
5. Efficiency of water governance
6. Reuse of treated wastewater
7. Storm water management

Different water demand has been estimated as given below:

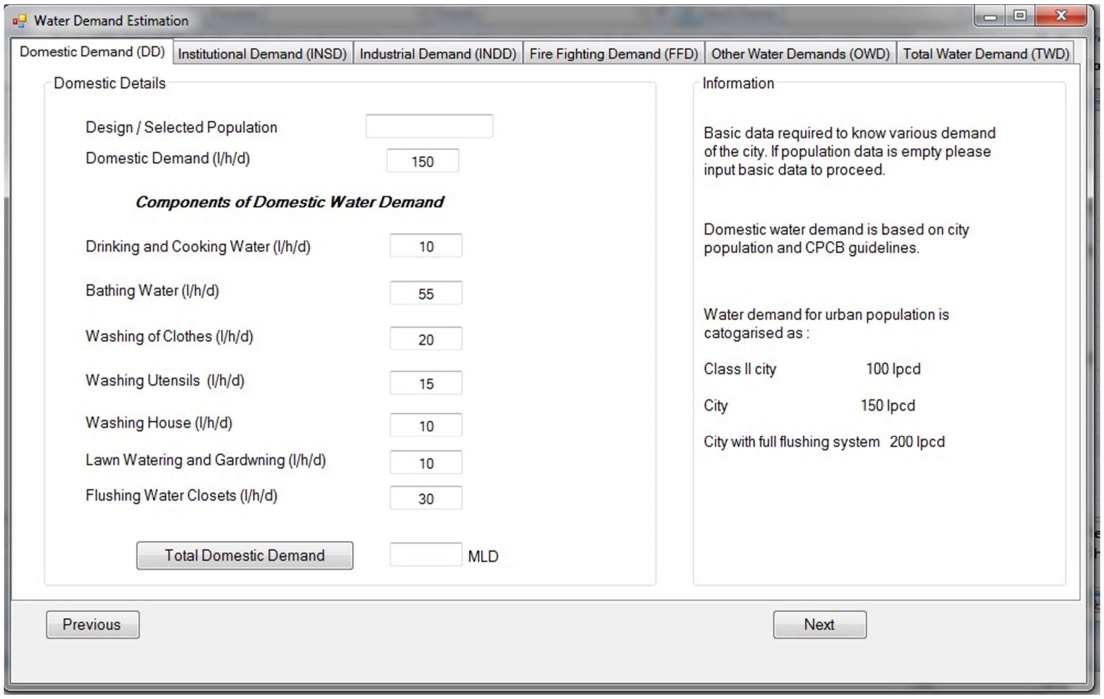
5.6.1 Domestic demand (DD):

This includes the water required in residential buildings for drinking, bathing, gardening, sanitary purpose etc. As per the Bureau of Indian Standards, IS:1172-1993, a minimum water supply of 200 liters per capita per day (lpcd) should be provided for domestic consumption in cities with full flushing systems. The amount of water supply may be reduced to 135 lpcd for the LIG and the Economically Weaker Sections (EWS) of the society and in small towns. The Ninth Plan (1997-2002) had advocated the requirement of water in urban areas as 125 lpcd in cities with planned sewerage systems; 70 lpcd in town without planned sewerage systems; and 40 lpcd for those collecting water from public stand-posts. However, in the Tenth Plan (2002-07), the cities with planned sewerage systems are classified into two groups based on population, i e, metropolitan or megacities and non-metropolitan cities. For metropolitan megacities (with population greater than 10 lakhs), the recommended minimum water supply level is 150 lpcd and for others the rate of water supply may be 135 lpcd(Government of India 1997, 2002).

Domestic water demand (150 lpcd) consists of the following uses (IS 1172:1993):

- Drinking and cooking : 10 lpcd
- Bathing: 55 lpcd
- Washing of clothes : 20 lpcd
- Washing utensils : 20 lpcd
- Washing houses : 10 lpcd
- Lawn water and gardening: 10 lpcd
- Flushing water and closets: 30 lpcd

Fig.5.6 shows the screenshot of domestic demand calculation sub-module based on population of the city.



Domestic Details

Design / Selected Population	
Domestic Demand (l/h/d)	150

Components of Domestic Water Demand

Drinking and Cooking Water (l/h/d)	10
Bathing Water (l/h/d)	55
Washing of Clothes (l/h/d)	20
Washing Utensils (l/h/d)	15
Washing House (l/h/d)	10
Lawn Watering and Gardwning (l/h/d)	10
Flushing Water Closets (l/h/d)	30

Total Domestic Demand ____ MLD

Information

Basic data required to know various demand of the city. If population data is empty please input basic data to proceed.

Domestic water demand is based on city population and CPCB guidelines.

Water demand for urban population is catogarised as :

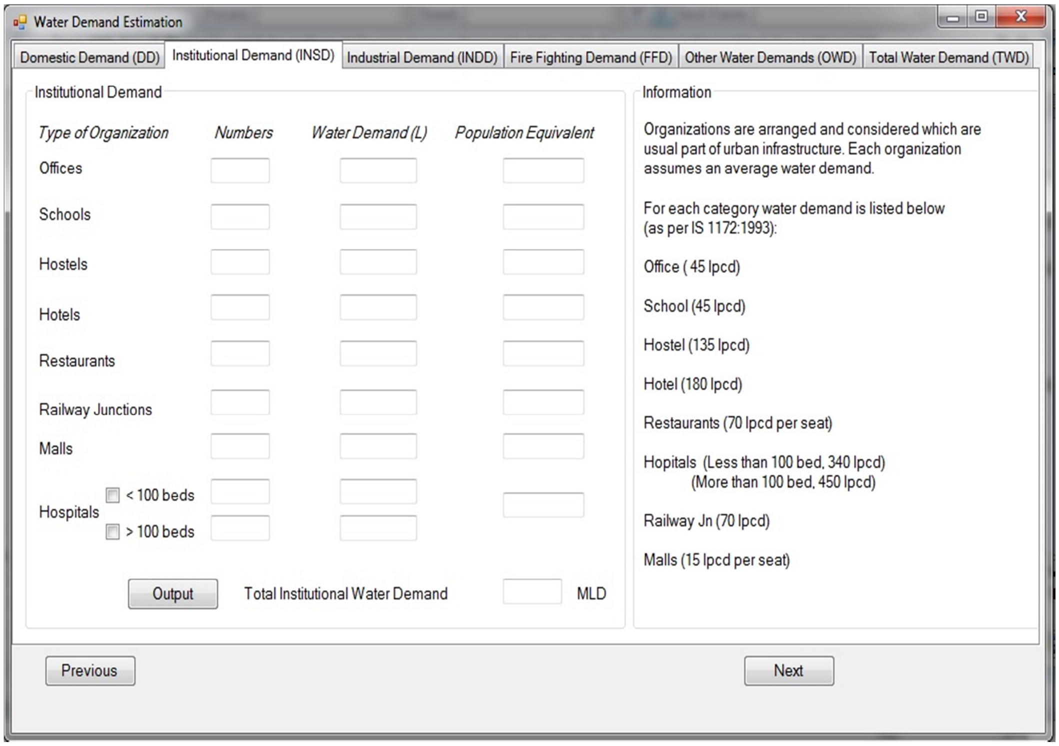
Class II city	100 lpcd
City	150 lpcd
City with full flushing system	200 lpcd

Fig. 5.6: Screenshot of Domestic Demand Calculation Sub-module

5.6.2 Institutional Demand (INSD)

It represents water demand for public utility purposes such as government offices, schools, hospitals, hotels, railway stations, parks, public fountains and road washing etc. If institutional water demand of a city is not known, IS 1172: 1993 suggests20 lpcd for normal commercial area and 50 lpcd for highly commercial area. IS 1172: 1993 provides following water demands (Fig. 5.7):

- Office : 45 lpcd
- School : 45 lpcd
- Hostel : 135 lpcd
- Hotel : 180 lpcd
- Restaurant : 70 lpcd per seat
- Hospital : 340 lpcd (for < 100 beds)
  450 lpcd (for >100 beds)
- Railway Junction : 70 lpcd
- Mall : 15 lpcd per seat



Organizations are arranged and considered which are usual part of urban infrastructure. Each organization assumes an average water demand.

For each category water demand is listed below
(as per IS 1172:1993):

Office (45 lpcd)

School (45 lpcd)

Hostel (135 lpcd)

Hotel (180 lpcd)

Restaurants (70 lpcd per seat)

Hopitals (Less than 100 bed, 340 lpcd)
(More than 100 bed, 450 lpcd)

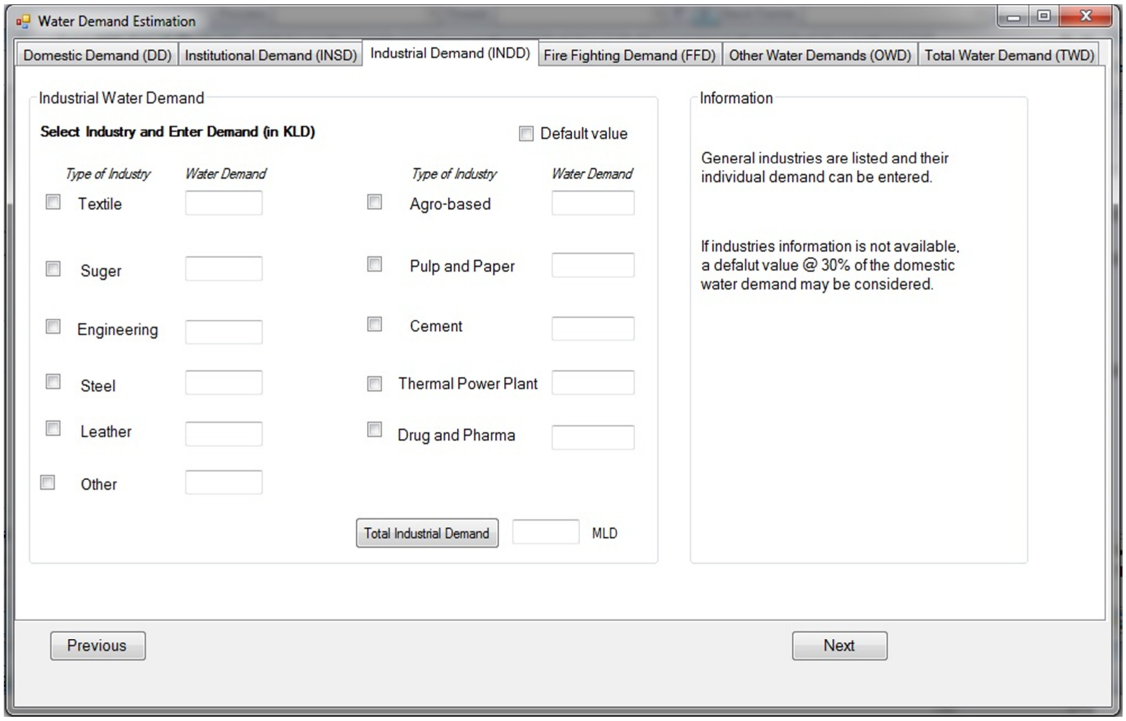
Railway Jn (70 lpcd)

Malls (15 lpcd per seat)

Fig. 5.7: Screenshot of Institutional Water Demand Sub-Module

5.6.3 Industrial demand (INDD)

It represents the water demand of industries which are existing or likely to come within the design period under the urban boundary. The IS: 1172-1993 gives the total requirement of water in industrial and commercial towns with full-flushing system as 280 lpcd. As per IS 1192:1993 normal cities 50 lpcd and industrial cities require 450 lpcd of additional water. So, if industrial demand of a city is not known the above standard can be considered to estimate industrial water demand. Industrial Water Demand Sub-Module is shown in Fig 5.8



General industries are listed and their individual demand can be entered.

If industries information is not available, a defalut value @ 30% of the domestic water demand may be considered.

Fig. 5.8: Screenshot of Industrial Water Demand Sub-Module

5.6.4 Firefighting demand (FFD)

In urban area fire incidences are common. Therefore to control such situations, there is need of water. Per capita fire demand is very less on an average basis but the rate at which the water is required is very high. The rate of fire demand is sometimes treated as a function of population and is worked out from following empirical formula:

Q =Quantity of water in liters per minute,   P = Population in thousands

Kuchling's Formula

Q (L/min) = 3182 x Sqrt (P)

Buston's Formula

Q = 5663 x P

Freeman's Formula

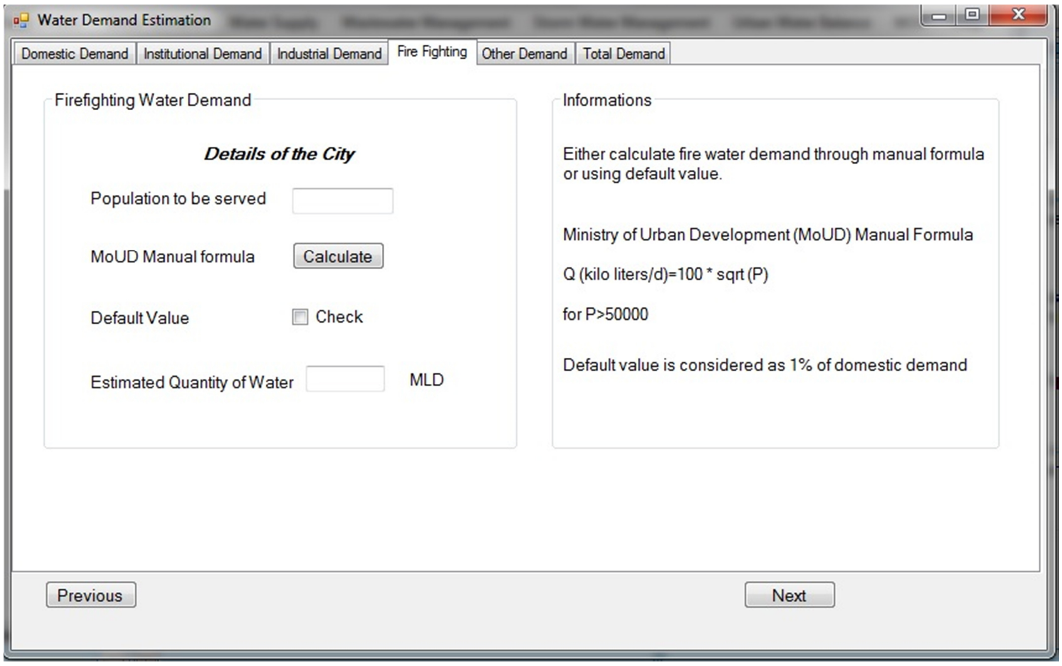
Q (L/min) = 1136.5 (P/5+10)

Ministry of Urban Development (MoUD) manual formula:

Firefighting water demand is estimated from:

Q (kilo liters/d) =100 x Sqrt (P)for P>50,000

Here, in the development of interface MoUD manual formula has been used for firefighting demand. Firefighting Water Demand Sub-Module is shown in Fig 5.9



Either calculate fire water demand through manual formula or using default value.

Ministry of Urban Development (MoUD) Manual Formula

Q (kilo liters/d)=100 * sqrt (P)

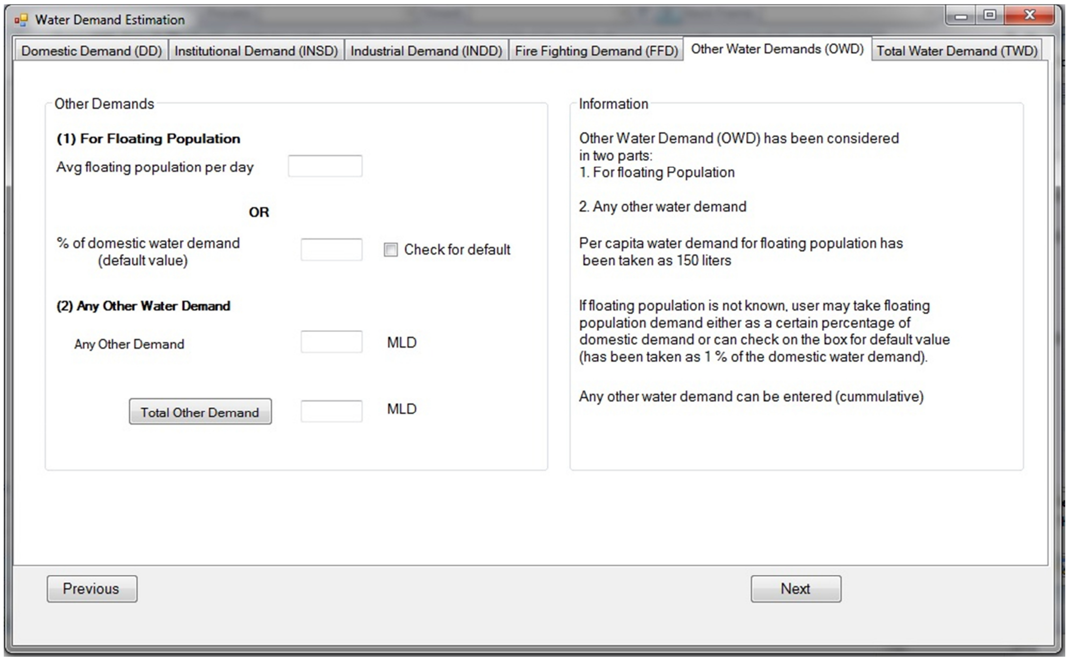
for P>50000

Default value is considered as 1% of domestic demand

Fig. 5.9: Screenshot of Firefighting Water Demand Sub-Module

5.6.5 Other Water Demand (OWD)

Other water demands include floating population water requirement and a few water demands like water required by railway junction due to extra load, sanitation at public places like road washing, drain washing etc. Floating population requires water at the same rate as domestic water requirement per person. If the floating population is not known the other water demand may be estimated as certain percentage of the domestic demand (here it is taken as 1%).Other water demand may vary due to socio-economic, cultural/ religion, and climate situation of the particular region. Other Water Demand Sub-Module is shown in Fig 5.10



Other Water Demand (OWD) has been considered in two parts:
1. For floating Population

2. Any other water demand

Per capita water demand for floating population has been taken as 150 liters

If floating population is not known, user may take floating population demand either as a certain percentage of domestic demand or can check on the box for default value (has been taken as 1 % of the domestic water demand).

Any other water demand can be entered (cummulative)

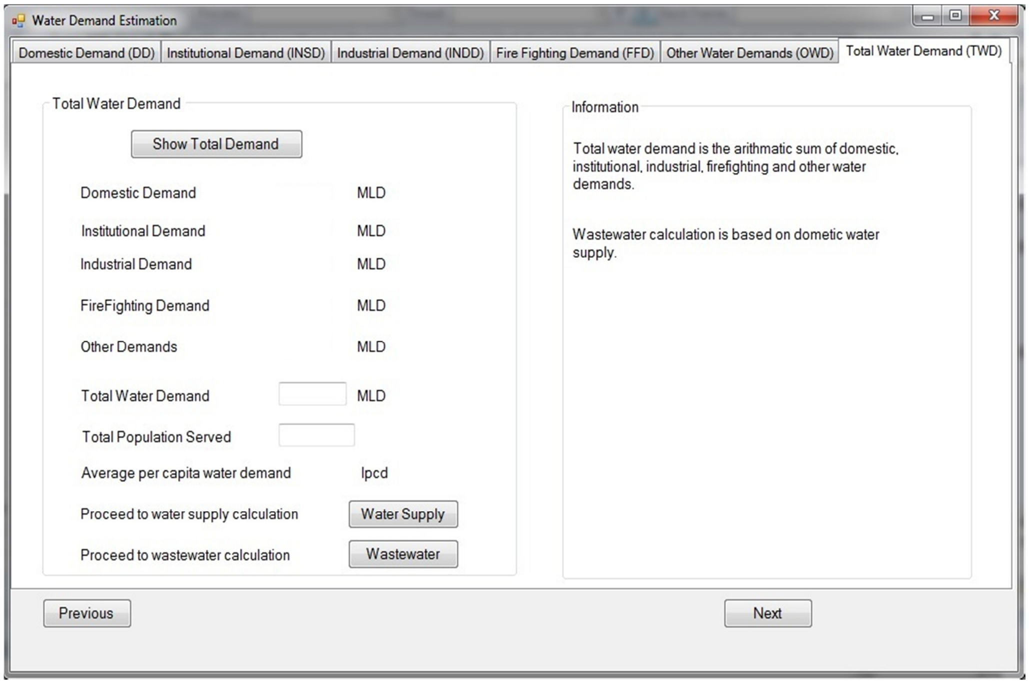
Fig. 5.10: Screenshot of Other Water Demand Sub-Module

5.6.6 Total Water Demand (TWD)

Total water demand of an urban area can be estimated by taking arithmetic sum of all the demand listed above.

TWD = DD + INSD + INDD + FFD + OWD

Total Water Demand Sub-Module is shown in Fig 5.11



Total water demand is the arithmatic sum of domestic, institutional, industrial, firefighting and other water demands.

Wastewater calculation is based on dometic water supply.

Fig. 5.11: Screenshot of Total Water Demand Sub-Module

5.7 Water Supply (WS)

Water supply estimation (Fig. 5.12) is based on data provided by municipal authorities. There are two traditional sources of water: (i) Surface water (ii) Groundwater. Surface water and groundwater supply are regulated by local government authorities. Tube-well locations and daily discharge rates have been considered for ground water extraction estimation, whereas quantity of surface water use has been taken as per available facilities for treatment and supply in the area. In addition, private pumping of water is a common practice in developing counties which can be estimated by reverse calculation using actual wastewater produced. Non-traditional source of water termed as Alternate Water Supply (AWS) like reuse of treated wastewater, rooftop harvesting (storage in rain-tanks and aquifer recharge), and surface runoff storage and reuse of treated wastewater. For the purpose, roof-top area, surface storage area, and wastewater treatment technology selection and its efficiency need to be evaluated. This gives the total alternate water supply potential of the area.

Total Water Supply (TWS) = Surface Water Supply (SWS) + Groundwater Supply (GWS) + Alternate Water Supply (AWS)

Groundwater Supply (GWS) = (Number of Tub-wells) x (Discharge Rate) x (Operating Hours)

Alternate Water Supply (SWS) = Roof-top Harvesting (Rain-tank Storage)+ Roof-top Harvesting (Aquifer Recharge) + Surface Runoff Storage + Reuse Potential of Treated Wastewater

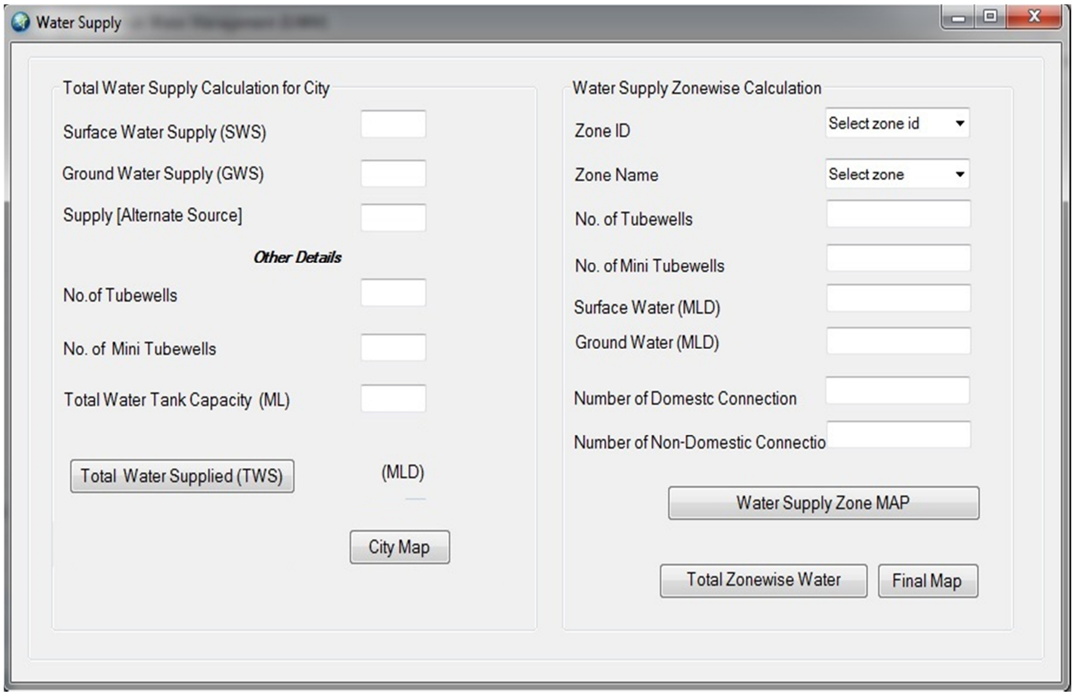


Fig. 5.12: Water Supply (WS) Module Snapshot

5.8 Drinking Water Quality Index (DWQI)

Drinking Water Quality Index (DWQI) is a measure which ensures quality of the supplied water. This sub-module is designed as an optional tool so that one may ensure the quality of drinking water being supplied in a given area. There are several drinking water quality parameters. These parameters have values between a range of desirable and permissible limits. However, the priority should be given to those substances which are known to be important for health and potable use (WHO, 2006). In this module 22 parameters are categorized into five groups on the basis of expert's opinion and having their importance with respect to drinking water quality assessment(Ramesh et al., 2010). A user may evaluate the present status of the drinking water quality in a given area using this sub-module. Drinking Water Quality Index (DWQI) is shown in Fig 5.13.

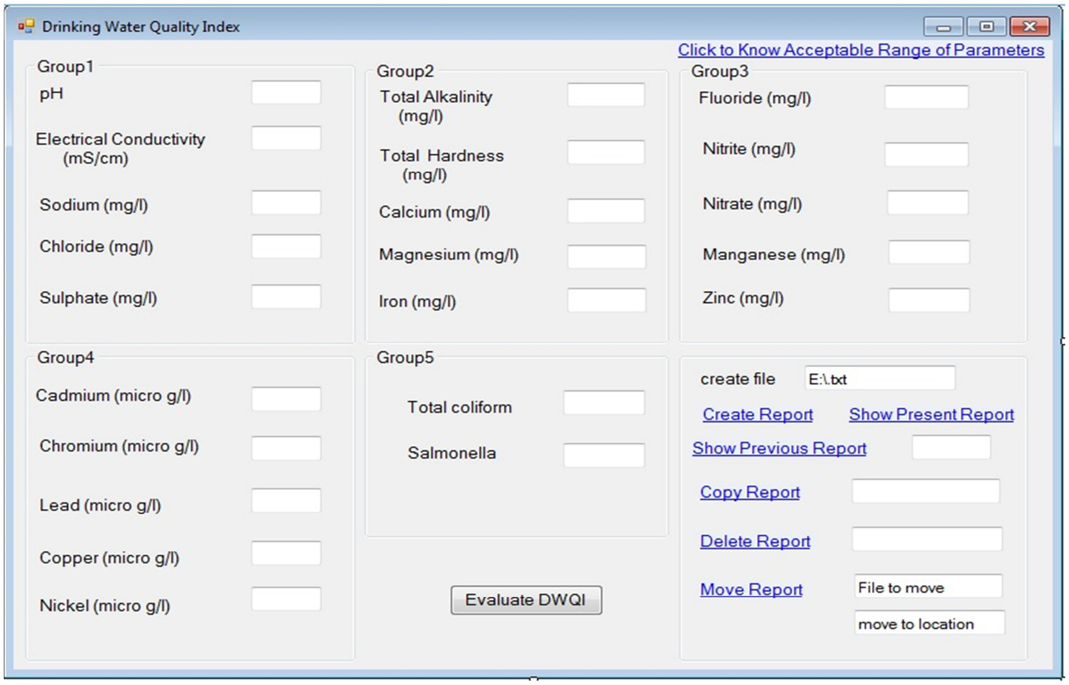


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Fig. 5.13: Screenshot of Drinking Water Quality Index (DWQI) Sub-module

5.9 Wastewater Management (WWM)

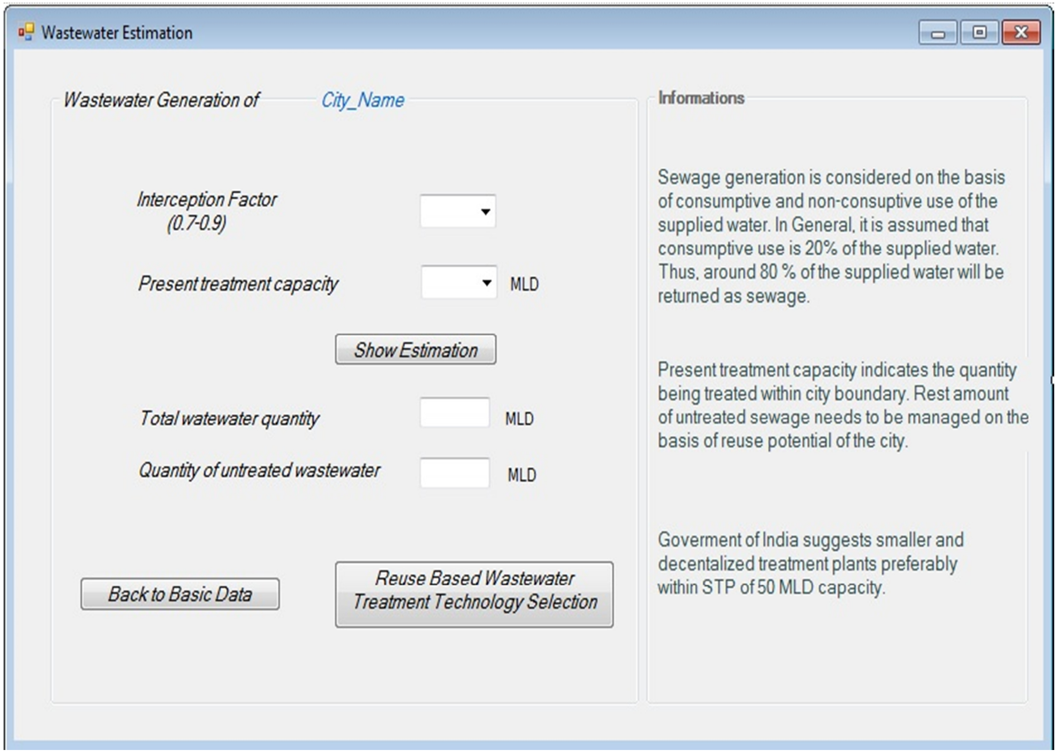
Wastewater management is an important part of the urban water management. It has been seen as a problem as well as a renewable resource. Sources of wastewater are domestic effluent consisting of black-water (excreta, urine and faecal sludge) and grey-water (kitchen and bathing wastewater), water from commercial establishments and institutions including school, hospitals, railways junction etc. The mix and composition will depend on the water supply and sanitation facilities available, water use practices and social norms (UN Water, 2015).

5.9.1Wastewater Quantity (WWQ) Estimation

Estimation of wastewater quantity is an essential process in urban water system. In general, wastewater is estimated with interception factor of 0.7 to 0.9 of the total water supplied but it may vary depending on city. Actual wastewater quantity may differ from estimated quantity due to unauthorized water extraction.

Wastewater Quantity Produced = (Interception Factor) x (Total Water Supplied)

Wastewater Estimation Sub-module is shown in Fig 5.14.



Sewage generation is considered on the basis of consumptive and non-consuptive use of the supplied water. In General, it is assumed that consumptive use is 20% of the supplied water. Thus, around 80 % of the supplied water will be returned as sewage.

Present treatment capacity indicates the quantity being treated within city boundary. Rest amount of untreated sewage needs to be managed on the basis of reuse potential of the city.

Goverment of India suggests smaller and decentalized treatment plants preferably within STP of 50 MLD capacity.

Fig. 5.14: Screenshot of Wastewater Estimation Sub-module

5.9.2 Reused Based Wastewater Treatment Technology Selection

Wastewater Treatment Technology Selection is based on different reuse potentials and requirement of quantity around the city area. For wastewater treatment, reuse potential of city is needed and on the basis of reuse water quality requirements, the technology will be suggested with its respective costs and treatment efficiency. Here data of reuse classes from A to E of Central Pollution Control Board, India (CPCB, 2008) is considered for system validation and technologies list is considered on the basis of treatment technologies used recently in Indian scenario provided by the government reports (Appendix B).

Dataflow diagram of WWTTS has been given in Fig 5.15. It requires number of data i.e. (i) wastewater characteristics input, (ii) wastewater treatment technology removal efficiency (iii) reuse categories and their standards (iv) Techno-economic criteria of treatment technology. Wastewater characteristic data from user input will be stored in the existing database. Apart from the user input a database of treatment technology removal efficiency of each parameters, cost of treatment technologies and reuse standards are saved at the database side. If user selects a reuse option the system will suggest the wastewater treatment technology based on reuse standards of the particular option, wastewater characteristics and removal efficiency of treatment technology. A temporary table has been created during treatment technology selection for comparison between standards of reuse option and effluents standard after applying treatment technology. If the effluent standard is under reuse standards then the technology will be selected else it will not be selected. Wastewater Characteristics Data Input is shown in Fig 5.16.

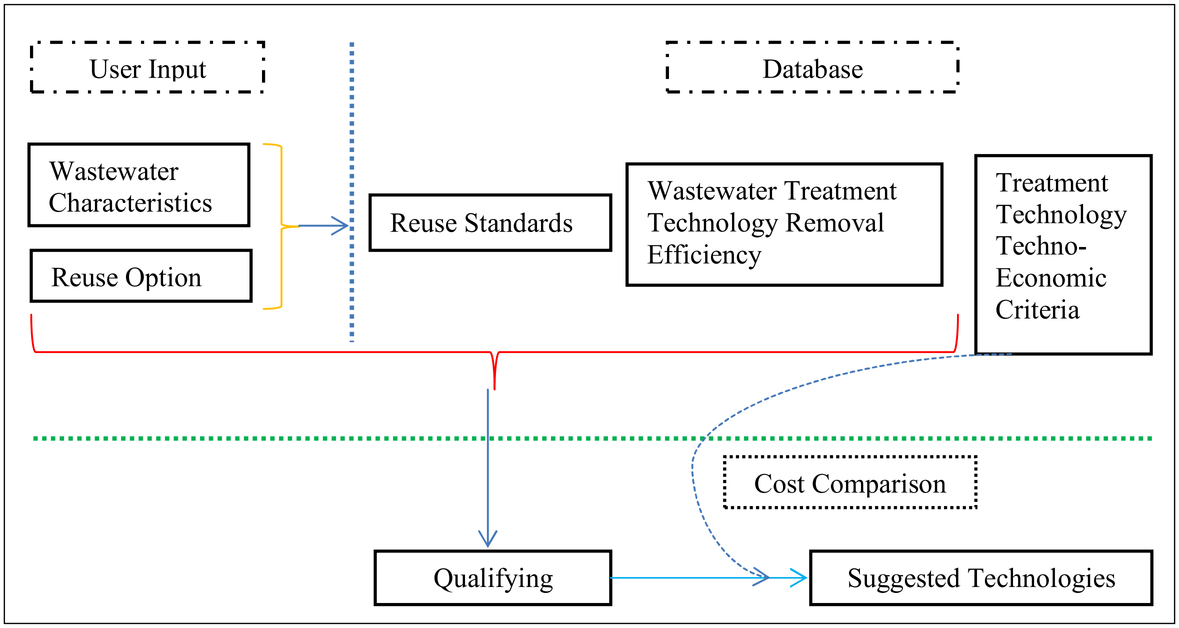


Fig. 5.15: Dataflow Diagram for Wastewater Treatment Technology Selection

Techno-economic criteria have been considered as “JICA (2005) Final report, Vol. I summary. The cost which includes Capital Expenditure (CAPEX), Operation & Maintenance Expenditure (OPEX), and Land Cost (LC) [Appendix C] has been adopted from “Compendium of Sewage Treatment Technologies” (2009)published by National River Conservation Directorate (NRCD), Ministry of Environment& Forest (MoEF, India) for the selection of the treatment technology in this application.

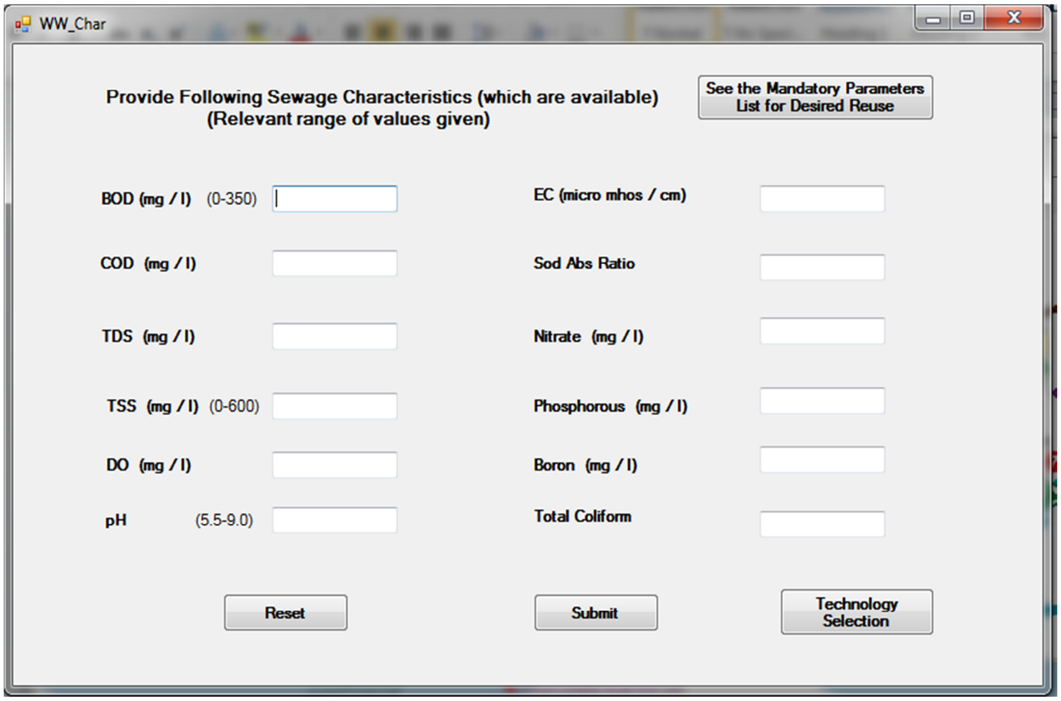


Fig 5.16: Screenshot of Wastewater Characteristics Data Input Sub-Module

5.9.3 Database Preparation for Reuse Options

The various reuse option have been identified based on social practices and guidelines/standards given by different government agencies. During designing of the application eight major reuse options have been considered i.e. Drinking Water, Irrigation, Industrial, Recreational, Firefighting, Discharge to Water Bodies, Toilet and Car Washing, and Outdoor Bathing. Various parameters standards of reuse (Table 5.1) and wastewater treatment technology removal efficiency (Table 5.2) have been given. Database Stored for Wastewater Characteristics Entered by the User is shown in Fig 5.17, Database Management of Different Reuse Options and its Reuse Standards is shown in Fig 5.18, Database Management of Wastewater Treatment Technology Efficiency is shown in Fig 5.19, Reuse Based Wastewater Treatment Technology Selection Sub-Module is shown in Fig 5.20.

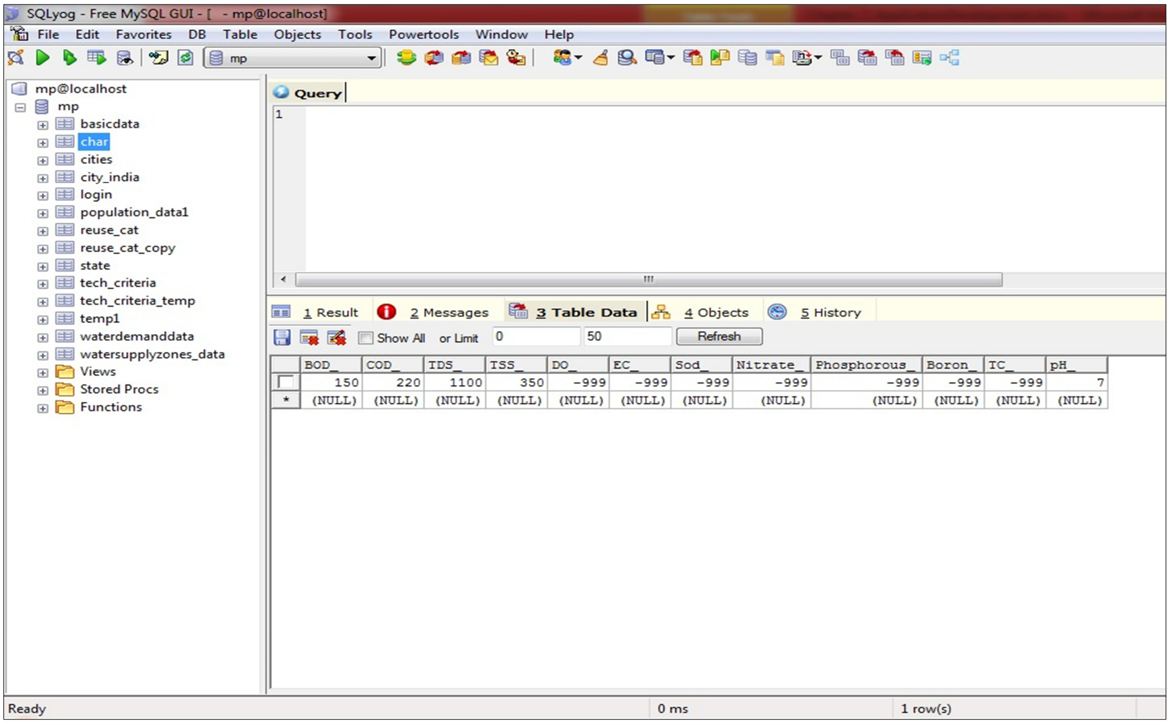
Table 5.1: Reuse Standards of Various Treated Wastewater Reuse option (Source: CPCB, 2008)

Reuse Option	**Reuse Standard Parameter**											
	pH	**BOD**	**COD**	**TDS**	**TSS**	**DO**	**N**	**P**	**EC**	**B**	**SAR**	**TC**
Drinking Water	6.5-8.5	2				6						50
Irrigation	6-8.5								2250	2	26	
Industrial	6-8.5								2250	2	26	
Recreational	6-8.5	10		2100			10	2				
Firefighting	6.5- 8.3	10		2100			10	1				
Discharge to Water Bodies	5.5-9	30	250		50	4						
Toilet and Car Washing	6.5- 8.3	10		2100			10	1				
Outdoor Bathing	6.5- 8.3	10		2100			5	1				

Table 5.2 Removal Efficiency (in Percentage) of Wastewater Treatment Technology (WWTT)

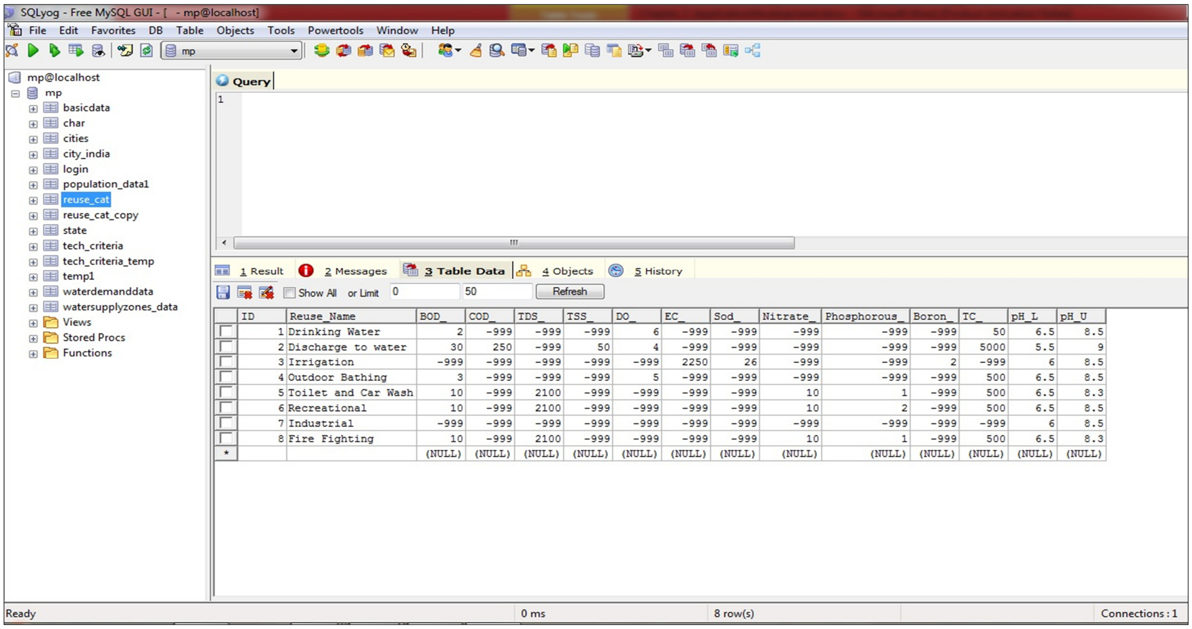
WWTT	**Removal Efficiency (%) of Parameter**											
	pH	**BOD**	**COD**	**TDS**	**TSS**	**DO**	**N**	**P**	**EC**	**B**	**SAR**	**TC**
Activated Sludge Process	7.5	95	90		90		53	18			50	50
Up-flow Anaerobic Sludge Blanket	7.5	70	80		80							50
Trickling Filter	6.7	90	90		85		25	15				25
Moving Bed Bio-film Reactor	7.6	95	90		95							
Sequencing Batch Reactor	7.5	95	96	50	96						63	56
Reverse Osmosis	6.5	50	50		50			50				
Waste Stabilization Pond	7.0	90					20	30				90

Sources: Metcalf and Eddy (1991), MoEF (2004), Khalil et al. 2006, EPA USA 2000.



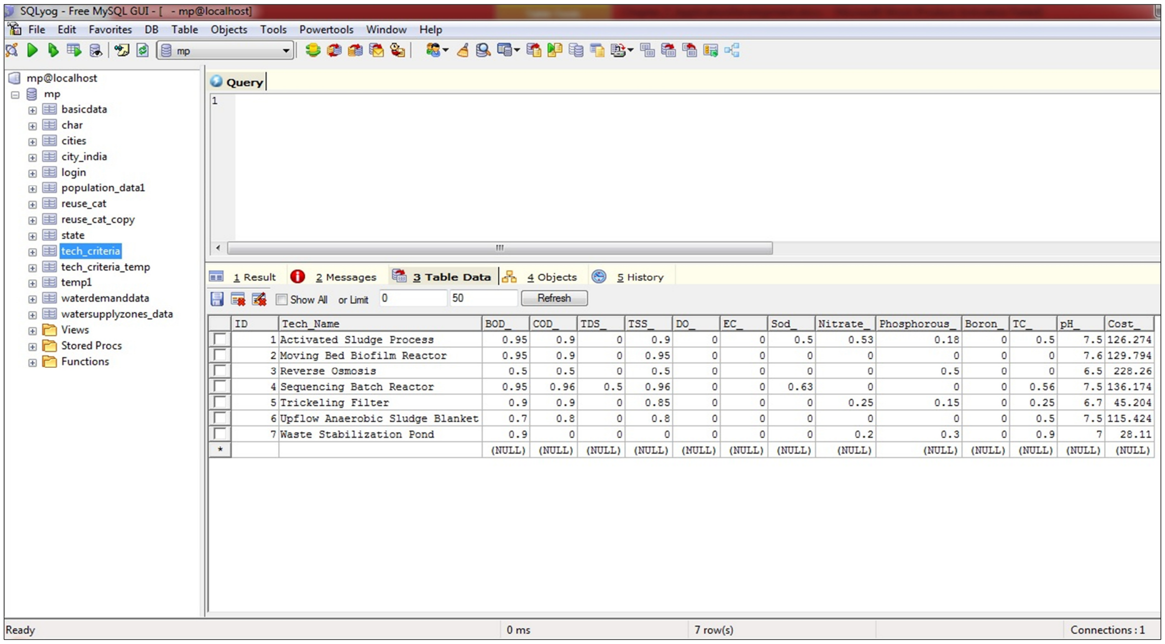
BOD_	COD_	TDS_	TSS_	DO_	EC_	Sod_	Nitrate_	Phosphorous_	Boron_	TC_	pH_
150	220	1100	350	-999	-999	-999	-999	-999	-999	-999	7
(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)

Fig 5.17: Database Stored for Wastewater Characteristics Entered by the User.



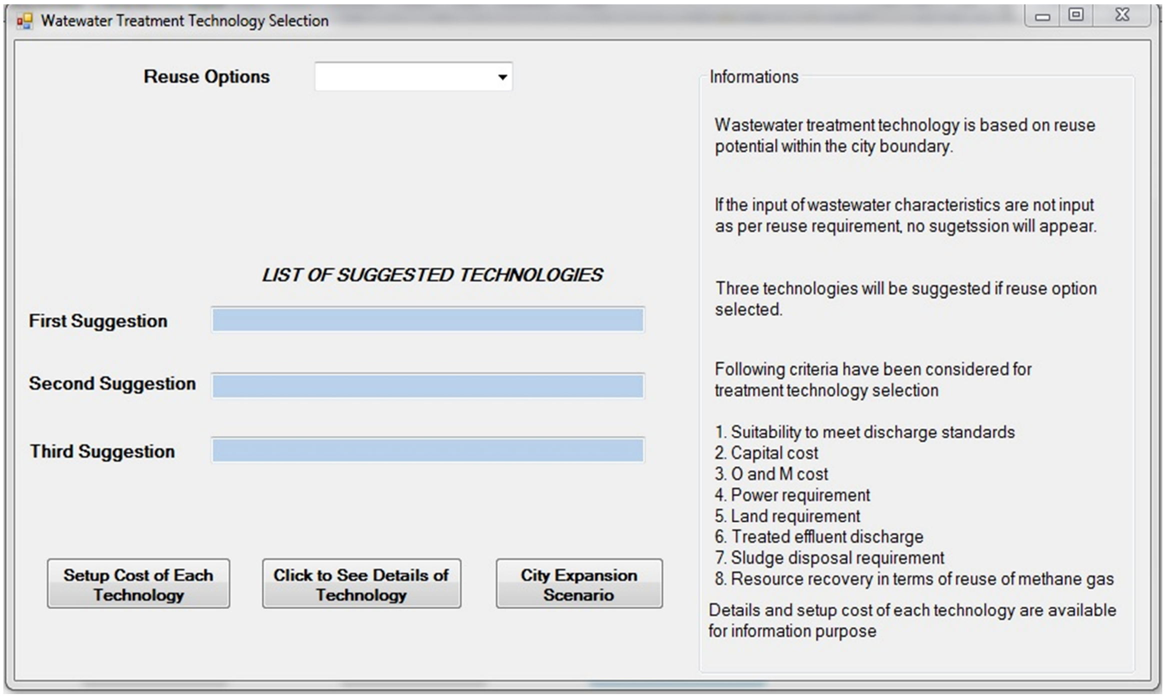
ID	Reuse_Name	BOD_	COD_	TDS_	TSS_	DO_	EC_	Sod_	Nitrate_	Phosphorous_	Boron_	TC_	pH_L	pH_U
1	Drinking Water	2	-999	-999	-999	6	-999	-999	-999	-999	-999	50	6.5	8.5
2	Discharge to water	30	250	-999	50	4	-999	-999	-999	-999	-999	5000	5.5	9
3	Irrigation	-999	-999	-999	-999	-999	2250	26	-999	-999	2	-999	6	8.5
4	Outdoor Bathing	3	-999	-999	-999	5	-999	-999	-999	-999	-999	500	6.5	8.5
5	Toilet and Car Wash	10	-999	2100	-999	-999	-999	-999	10	1	-999	500	6.5	8.3
6	Recreational	10	-999	2100	-999	-999	-999	-999	10	2	-999	500	6.5	8.5
7	Industrial	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	6	8.5
8	Fire Fighting	10	-999	2100	-999	-999	-999	-999	10	1	-999	500	6.5	8.3
		(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)

Fig. 5.18: Database Management of Different Reuse Options and its Reuse Standards



	ID	Tech_Name	BOD_	COD_	TDS_	TSS_	DO_	EC_	Sod_	Nitrate_	Phosphorous_	Boron_	TC_	pH_	Cost_
☐	1	Activated Sludge Process	0.95	0.9	0	0.9	0	0	0.5	0.53	0.18	0	0.5	7.5	126.274
☐	2	Moving Bed Biofilm Reactor	0.95	0.9	0	0.95	0	0	0	0	0	0	0	7.6	129.794
☐	3	Reverse Osmosis	0.5	0.5	0	0.5	0	0	0	0	0.5	0	0	6.5	228.26
☐	4	Sequencing Batch Reactor	0.95	0.96	0.5	0.96	0	0	0.63	0	0	0	0.56	7.5	136.174
☐	5	Trickeling Filter	0.9	0.9	0	0.85	0	0	0	0.25	0.15	0	0.25	6.7	45.204
☐	6	Upflow Anaerobic Sludge Blanket	0.7	0.8	0	0.8	0	0	0	0	0	0	0.5	7.5	115.424
☐	7	Waste Stabilization Pond	0.9	0	0	0	0	0	0	0.2	0.3	0	0.9	7	28.11
*			(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)	(NULL)

Fig.5.19 Database Management of Wastewater Treatment Technology Efficiency



Wastewater treatment technology is based on reuse potential within the city boundary.

If the input of wastewater characteristics are not input as per reuse requirement, no sugetssion will appear.

Three technologies will be suggested if reuse option selected.

Following criteria have been considered for treatment technology selection

1. Suitability to meet discharge standards
2. Capital cost
3. O and M cost
4. Power requirement
5. Land requirement
6. Treated effluent discharge
7. Sludge disposal requirement
8. Resource recovery in terms of reuse of methane gas

Details and setup cost of each technology are available for information purpose

Fig. 5.20: Screenshot of Reuse Based Wastewater Treatment Technology Selection Sub-Module

5.10 Storm Water Management (SWM)

United States Environmental Protection Agency (US-EPA) defined Storm Water Management (SWM) as an effort to reduce runoff of rainwater or melted snow into streets, lawns and other sites and the improvement of water quality. At urban scale, storm water can be seen as a resource in the water supply either using storage of runoff (rainwater tanks, surface storage) or direct aquifer recharge.

In the present application development, two options have been considered: 1. Roof-top Harvesting (RTH) (rainwater tanks, aquifer recharge) and 2. Surface Storage (natural or constructed ponds).Rain water stored in tanks water may be utilized for non-potable purposes which will directly reduce the water demand. Storage through aquifer storage will be direct augment the local groundwater resources.

There is need to estimate the rainfall runoff quantity to know the maximum potential of resource through rain in the urban setup.

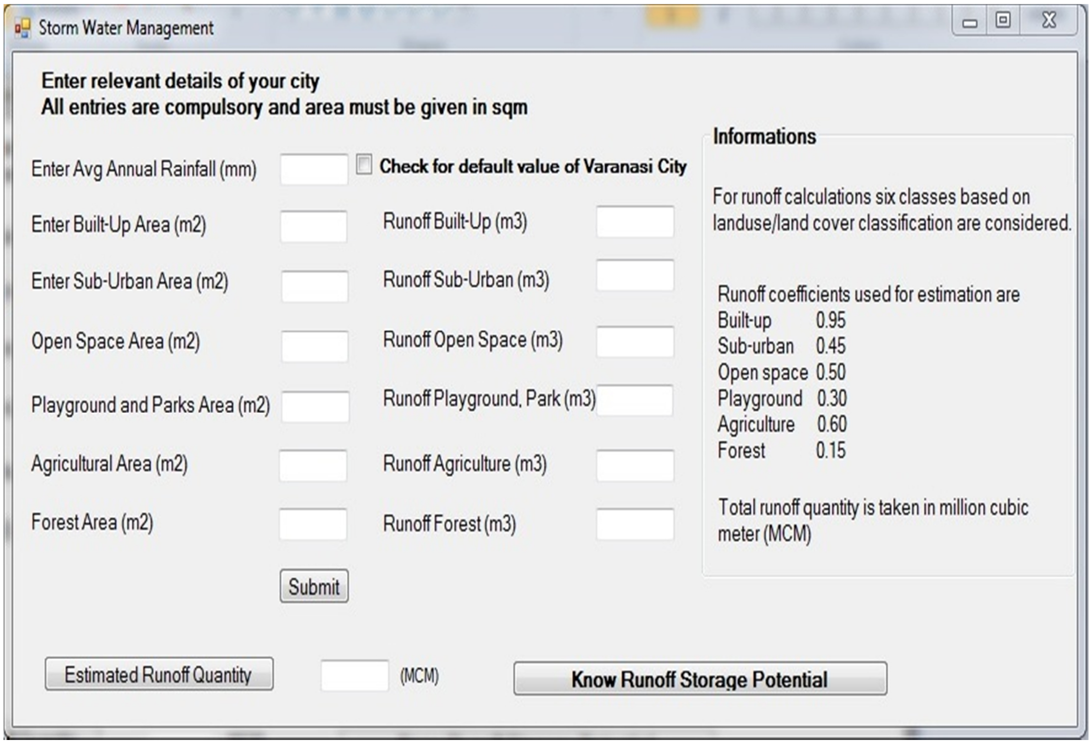
5.10.1 Rainfall/Runoff Estimation

There are several methods for rainfall/runoff estimation. However, view of the generic implementation of this application GIS and remote sensing has been used to estimate rainfall/runoff. Total six classes have been chosen for runoff estimation based on available literature and data. Rainfall/Runoff calculation has been done using six different classes viz. (i) built-up, (ii) sub-urban, (iii) open space, (iv) park and playgrounds, (v) agriculture, (vi) forest. The given area has been classified based on above classes using ERDAS IMAGINE 14.0 academic version. Using boundary map of the city area the classified area have been calculated individually. Further, with the help of runoff co-efficient and the area of individual class runoff has been calculated (eqn. 5.5). The developed sub-module is shown in Fig. 5.21.

Rainfall runoff estimation is based on rainfall data, area of land-use/land-cover classes and their corresponding runoff coefficients (Shakya et al., 2016).

Class	***Run-off Coefficient****
Built-up	0.95
Sub-urban	0.45
Open space	0.50
Parks and Playgrounds	0.30
Agriculture	0.60
Forest	0.15

$$\text{Annual rainfall runoff (m}^3\text{)} = \Sigma \text{ Annual rainfall (mm) x (area of individual class in sqm) x (runoff coefficient of individual class) x}10^{-6} \quad \text{(eqn.5.5)}$$



Enter relevant details of your city
All entries are compulsory and area must be given in sqm

Informations

For runoff calculations six classes based on landuse/land cover classification are considered.

Runoff coefficients used for estimation are

Built-up	0.95
Sub-urban	0.45
Open space	0.50
Playground	0.30
Agriculture	0.60
Forest	0.15

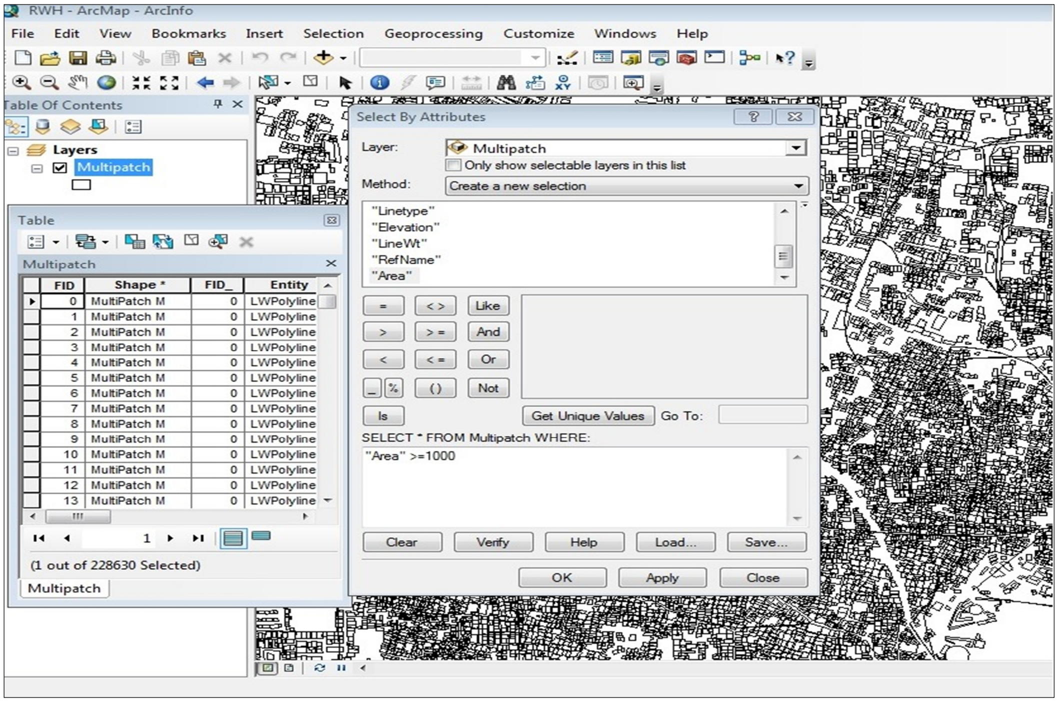
Total runoff quantity is taken in million cubic meter (MCM)

Fig. 5.21: Screenshot of Annual Rainfall Runoff (ARR) Estimation Sub-module

5.10.2 Roof-Top Harvesting (RTH) Potential Estimation

Rooftop rainwater harvesting is the technique through which rain water is captured from the roof catchments and stored. Harvested rainwater can be stored in constructed rainwater tanks to meet the household needs through storage in tanks or in sub-surface ground water reservoir by adopting artificial recharge techniques.

For roof-top harvesting there is need to calculate the roof-top area available for the purpose. Roof-area can be calculated using digitized map (prepared from satellite image) in ArcGIS software version 10.2 (Fig. 5.22). Roof-top area may be categorized in three different classes viz. roof-top area >1000 sqm, roof-top area between 500-1000 sqm, and roof-top area between 300-500sqm, so that roof-top harvesting may be implemented in phases.



Layer: Multipatch

☐ Only show selectable layers in this list

Method: Create a new selection

"Linetype"
"Elevation"
"LineWt"
"RefName"
"Area"

SELECT * FROM Multipatch WHERE:

"Area" >=1000

Multipatch

FID	Shape *	FID_	Entity
0	MultiPatch M	0	LWPolyline
1	MultiPatch M	0	LWPolyline
2	MultiPatch M	0	LWPolyline
3	MultiPatch M	0	LWPolyline
4	MultiPatch M	0	LWPolyline
5	MultiPatch M	0	LWPolyline
6	MultiPatch M	0	LWPolyline
7	MultiPatch M	0	LWPolyline
8	MultiPatch M	0	LWPolyline
9	MultiPatch M	0	LWPolyline
10	MultiPatch M	0	LWPolyline
11	MultiPatch M	0	LWPolyline
12	MultiPatch M	0	LWPolyline
13	MultiPatch M	0	LWPolyline

(1 out of 228630 Selected)

Multipatch

Fig. 5.22 Screenshot of calculation of Roof-top area by using digitized roof-top area map within the city boundary.

Using query option available in ArcGIS software the area with desired constraint (e.g. roof area more than 1000sqm) can be calculated. Further, using total roof top area in the region and annual rainfall the harvesting potential can be calculated.

Roof-top harvesting potential = (Total Roof-top area in sqm) x (Annual rainfall (mm))

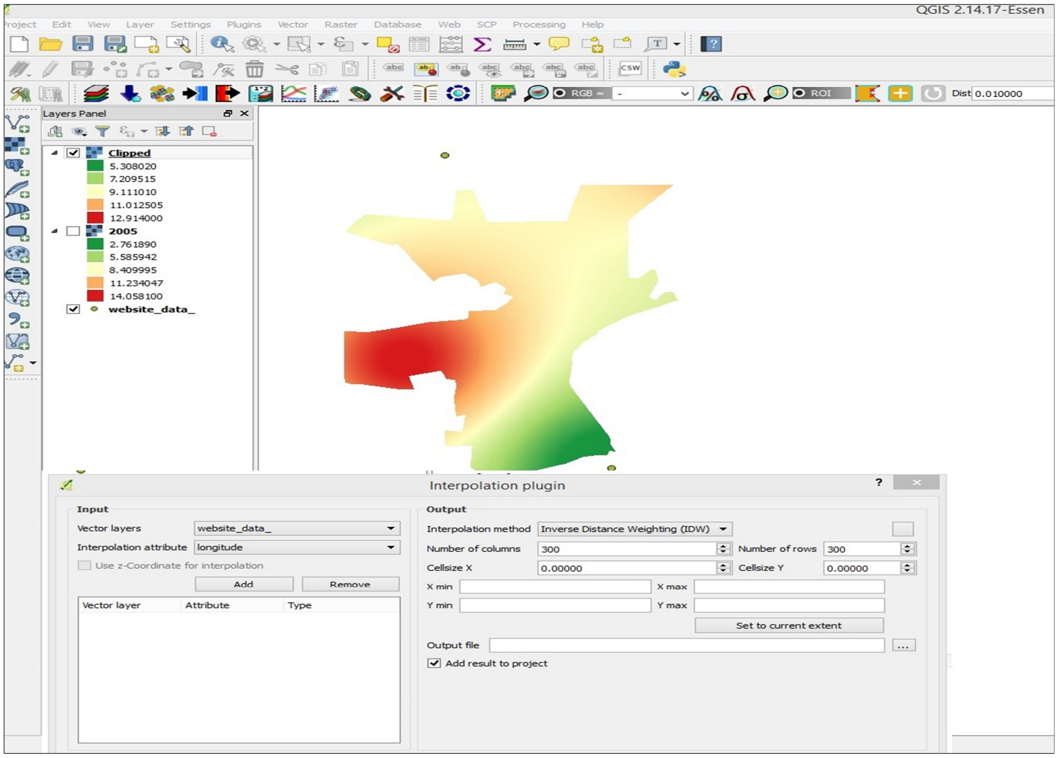
5.10.3 Surface Runoff Storage (SRS) Potential Estimation

Runoff water may be stored in volume available in water city body within the boundary. To estimate the potential of surface water storage, area of water bodies like ponds, natural reservoirs and constructed wetlands may be calculated. Satellite images and QGIS software are used for estimating the area of water bodies. All the water bodies are digitized as polygone feature manually in the QGIS software and their area is calculated in sqm by software.

Surface Storage Potential = Σ (area of water body in sqm) x (average storage depth for the water body in m)

5.11 Water Table Depletion Estimation

Urban water resource exploitation and its reflection must be assessed before permitting any new development around the city area. There is need to estimate the annual variation of water table of the given region. The estimation can be done based on interpolation technique. Interpolation is a commonly used GIS technique to create continuous surface from discrete points. If we want to model these surfaces for analysis, it is impossible to take measurements throughout the surface. Hence, the field measurements are taken at various points along the surface and the intermediate values are inferred by a process called ‘interpolation’. In QGIS, interpolation is achieved using the built-in interpolation plugin. Inverse Distance Weightage (IDW) method has been selected to interpolate and find the range of value for water depleting table. Geographical position and depth of water in open well or hand pump at different years may be taken for the preparation of raster maps of groundwater table of study area using interpolation technique. Well data provided by central ground water board (CGWB) may be used as default data to prepare the maps. Map to show the change in water table between any two years may be prepared in GIS environment by subtracting the raster map of two years. Fig. 5.23 shows the estimation of water table depletion which has been done in QGIS software taking secondary data from. Average annual depletion/increase in water table is calculated by dividing the above map by number of years. Negative values in the map indicates depletion in water table and positive value shows increase in water table level over time Volume of extra water extracted from the ground water is calculated by multiplying change in water level at each cell of raster map by the size of each cell and storativity of aquifer. This is a preliminary step to assess status of water supply sustainability and water for development planning. In fig 5.23 red area shows the area where water is depleting and green area shows the area where water level is rising.



Vector layers: website_data_

Interpolation attribute: longitude

☐ Use z-Coordinate for interpolation

Interpolation method: Inverse Distance Weighting (IDW)

Number of columns: 300

Number of rows: 300

Cellsize X: 0.00000

Cellsize Y: 0.00000

X min

X max

Y min

Y max

Output file

☑ Add result to project

Fig. 5.23: Screenshot of Water Table Depletion Estimation Using QGIS Software

5.12 Water Supply Sustainability (WSS) Estimation:

There are different stakeholders of water in the urban region. Each stakeholder does not need the same quality of water for his use. Hence, there is an opportunity to supply different quality of water to different stakeholders. Water Supply Sustainability (WSS) is the management of water supply from the existing water resources of different quality. Water Supply Adequacy (WSA) can be estimated by taking the difference between annual water supply (W_R) (from aquifer, surface water, and alternate water) and the total water demand (W_D) for various services.

Water Supply Adequacy (WSA) = $(W_R - W_D)$

Where, $W_R = R_{SW} + R_{GW} + R_{AW}$

$W_D = D_{DWD} + D_{INWD} + D_{IDW} + D_{FWD} + D_{OWD}$

$R_{AW} = R_{RW} + F \text{ x } R_{SR}$

Where, SW = surface water, GW = ground water, AW = alternate water, F= factor of recharge, RW = reclaimed water, SR= surface runoff,

DWD = domestic water demand, INWD = institutional water demand

IDWD = industrial water demand, FWD = firefighting water demand

OW = other water demand

Water for Development Planning (WDP) can defined as

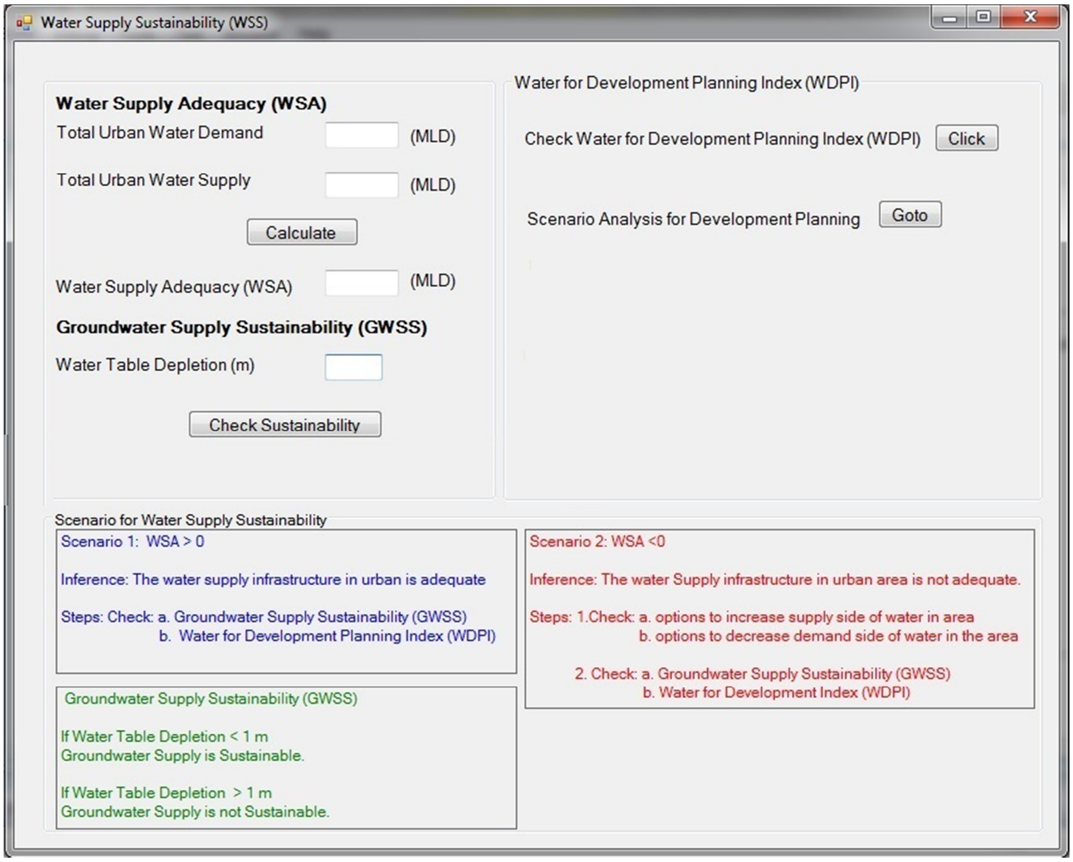
WDP = $(W_R - W_D)$ / FoS; provided: $(W_R - W_D) > 0$ and WDPI > 5

Where FoS = Factor of Safety

There are two conditions of WSS which will trigger the decision of water for development planning. These conditions and there relevant course of actions have been given in Table 5.3 and Fig. 5.24 shows the Water Supply Sustainability (WSS) estimation.

Table 5.3: Urban water balance condition and relevant course of action

WSS Condition	Physical Condition	Course of Action
Condition 1:WSS >0	Water supply infrastructure in urban area is adequate	**Check :** Groundwater Supply Sustainability (GWSS) **Check :** Water for Development Planning Index (WDPI)
Condition 2: WSS<0	Water supply infrastructure in urban area is not adequate	**Check 1:** A: Option to increase supply side of water in area B: Option to decrease demand side of water in the area **Check 2:** A: Groundwater Supply Sustainability (GWSS) B: Water for Development Planning Index (WDPI)



Scenario 1: WSA > 0

Inference: The water supply infrastructure in urban is adequate

Steps: Check: a. Groundwater Supply Sustainability (GWSS)
b. Water for Development Planning Index (WDPI)

Scenario 2: WSA <0

Inference: The water Supply infrastructure in urban area is not adequate.

Steps: 1.Check: a. options to increase supply side of water in area
b. options to decrease demand side of water in the area

2. Check: a. Groundwater Supply Sustainability (GWSS)
b. Water for Development Index (WDPI)

Groundwater Supply Sustainability (GWSS)

If Water Table Depletion < 1 m
Groundwater Supply is Sustainable.

If Water Table Depletion > 1 m
Groundwater Supply is not Sustainable.

Fig. 5.24: Water Supply Sustainability (WSS) Estimation Module.

5.13 Water for Development Planning Index (WDPI)

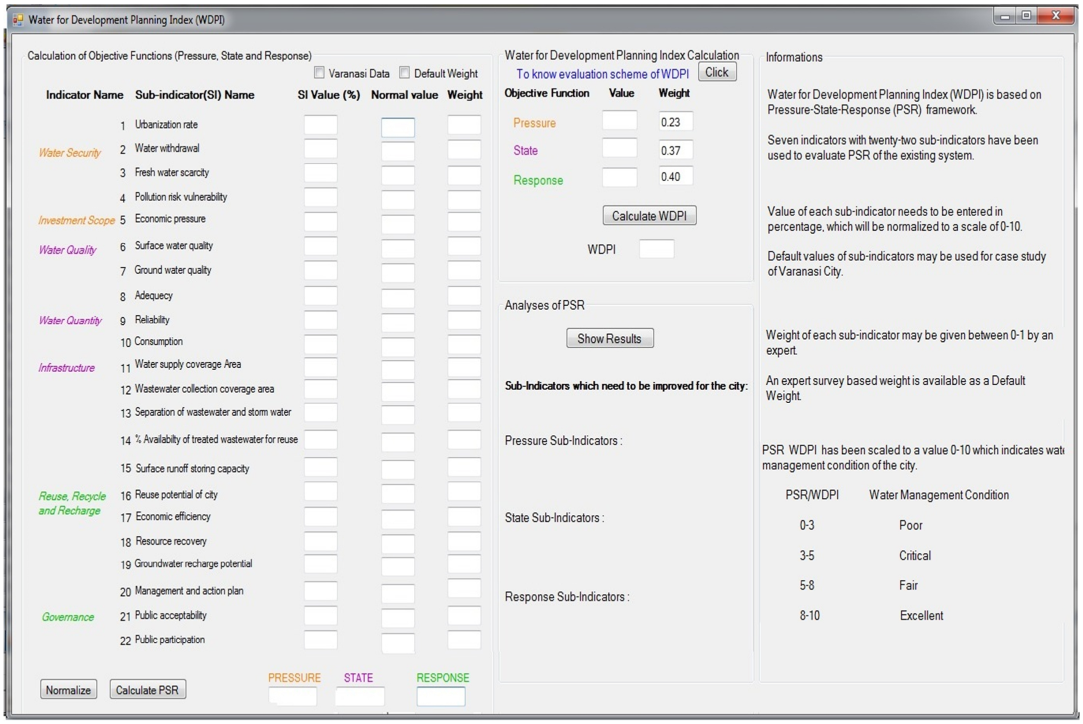
Water for Development Planning Index (WDPI) has been developed as a single index measure to know the status of water sustainability in the given urban region. It includes components of urban water systems which are grouped the measures with their subjectivity. WDPI formulation is based on pressure-state-response (PSR) framework (European Commission, 2003). **Seven indicators,** based on literature are identified for WDPI formulation as shown in Table 5.4

Table 5.4: Indicators and Relevant Sub-Indicators for WDPI

Sr. No.	Indicator Name	Sub-Indicator (s)/ Measure
1.	Water Security	Urbanization rate, Water withdrawal, Fresh water scarcity, Pollution risk vulnerability
2.	Investment Scope	Economic pressure
3.	Water Quality	Surface water quality, Ground water quality
4.	Water Quantity	Adequacy, Reliability, Extra consumption
5.	Infrastructure	Water supply coverage area, Wastewater collection coverage area, Separation of wastewater and storm water
6.	Water Reuse, Recycle & Recharge	Percentage Availability of treated wastewater, Surface runoff storing capacity, Reuse potential of city, Economic efficiency, Resource recovery, Groundwater recharge potential
7.	Governance	Management and action plan, Public participation, People's acceptability

The Water for Development Planning Index (WDPI) has been evaluated through the calculation and aggregation of seven indicators (I). These indicators further consists 22 sub-indicators (SI). Weighting scheme of indicator and sub-indicator is based on Environmental Performance Index (EPI) developed by Yale University and Columbia University. Each indicator combined which fit over three objectives termed as pressure-state-response (PSR). Details of estimation method of water for development planning and water for development planning index has been detailed in chapter 4.

Three objectives have been combined to evaluate WDPI. The interface developed for WDPI has been shown in Fig. 5.25.The value of sub-indicators can be entered in percentage which is further normalized to a common scale of 10. User can input weight of sub-indicator individually or may select the default weight. Normalized value will be multiplied to respective weight of sub-indicator to get a weighted value of sub-indicators. The weighted sub-indicator value in group will be multiplied by the group weight i.e. indicator weight to calculate indicator. The indicator values are further grouped (pressure-state-response) and multiplied by indicator weight to get objective values. The objective value will be multiplied by objective weight to get a final value of WDPI. There is an option to show under which objective category what measures need to be addressed.



Objective Function	Weight
Pressure	0.23
State	0.37
Response	0.40

Water for Development Planning Index (WDPI) is based on Pressure-State-Response (PSR) framework.

Seven indicators with twenty-two sub-indicators have been used to evaluate PSR of the existing system.

Value of each sub-indicator needs to be entered in percentage, which will be normalized to a scale of 0-10.

Default values of sub-indicators may be used for case study of Varanasi City.

Weight of each sub-indicator may be given between 0-1 by an expert.

An expert survey based weight is available as a Default Weight.

PSR WDPI has been scaled to a value 0-10 which indicates wat management condition of the city.

PSR/WDPI	Water Management Condition
0-3	Poor
3-5	Critical
5-8	Fair
8-10	Excellent

Fig. 5.25: Water for Development Planning Index (WDPI) Interface Snapshot

5.14 Scenario Generation to Improve Water Supply Sustainability:

To improve urban water resource-demand balance five options have been identified (i) illegal groundwater pumping, (ii) groundwater recharge, (iii) rooftop rainwater harvesting (iv) surface runoff storage and (v) reclaimed water (treated wastewater). Different cases have been generated with the combination of five cases given below in Table 5.5.

Table 5.5: Basic Cases to Improve Water Supply Sustainability

Case	Description
I	Integration of *Unaccounted Groundwater Withdrawal* with existing scenario
II	Integration of *Groundwater Recharge* with existing scenario
III	Integration of *Rooftop Rainwater Harvesting* with existing scenario
IV	Integration of *Surface Runoff Storage* with existing scenario
V	Integration of *Reclaimed Water* with existing scenario

5.14.1 Technological Intervention Factor:

Water received from the source need technical intervention to make it suitable for domestic use. A technological intervention depends on the quality of the source water received from the source. The technological intervention adds additional cost to the water supply management system. Hence, depending upon the degree of the technological intervention a weight factor has been introduced in this study. By using Analytic Hierarchy Process (AHP) method weight of the different options has been calculated.

Options	**Technical Intervention Factor***
o Reclaimed water use	3 – 5**
o Rainfall Runoff Storage	1.5
o Groundwater Recharge	1.25
o Roof-top Harvesting (Rain-tanks)	1.25
o Controlling unaccounted ground water withdrawal	1.05

* Factors have been considered based on technical field expert's view (considering fresh water as a factor of 1).

** Depends upon the degree of treatment.

All criteria for a purpose of option selection do not carry equal importance. Thus different weights are assigned to these criteria on the bases of their importance in technical intervention factor. In order to find the weights of different options, analytical hierarchy process (AHP) as developed by Saaty (1980) has been used is considered in this study. In AHP, a complex decision problem is decomposed into simpler decision steps to form a decision hierarchy and a rating scale of 1 to 9 (Table 5.6)is generally used to reflect the relative preference of one factor over another in pair wise comparison (Saaty, 2000). Weights of different criteria are assigned by pairwise comparisons (Table 5.3). In the present study, above have been selected on the basis of model proposed and ranking of criteria has been done independently by five experts working in the area of urban water management. Different experts may also be given appropriate weightage (1 to 10) based on their experience. The comparison matrix based on the weight assignment to different criteria by one of the experts is shown in Table 5.7 (a). After developing comparison matrix, the composite weights are calculated by means of a sequence of multiplication. After getting the individual weights by different experts, final weights are obtained by normalizing the weights by different experts (Table 5.7 (b)).

Table 5.6: Analytic Hierarchy Process (AHP) for weight assignment (Saaty, 2000).

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance	Experience and judgment slightly favor one activity over another activity over another
5	Strong importance	Experience and judgment strongly favor one
7	Very strong importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extremely importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, and 8	Intermediate values between adjacent scale values	Compromise is needed between two judgment

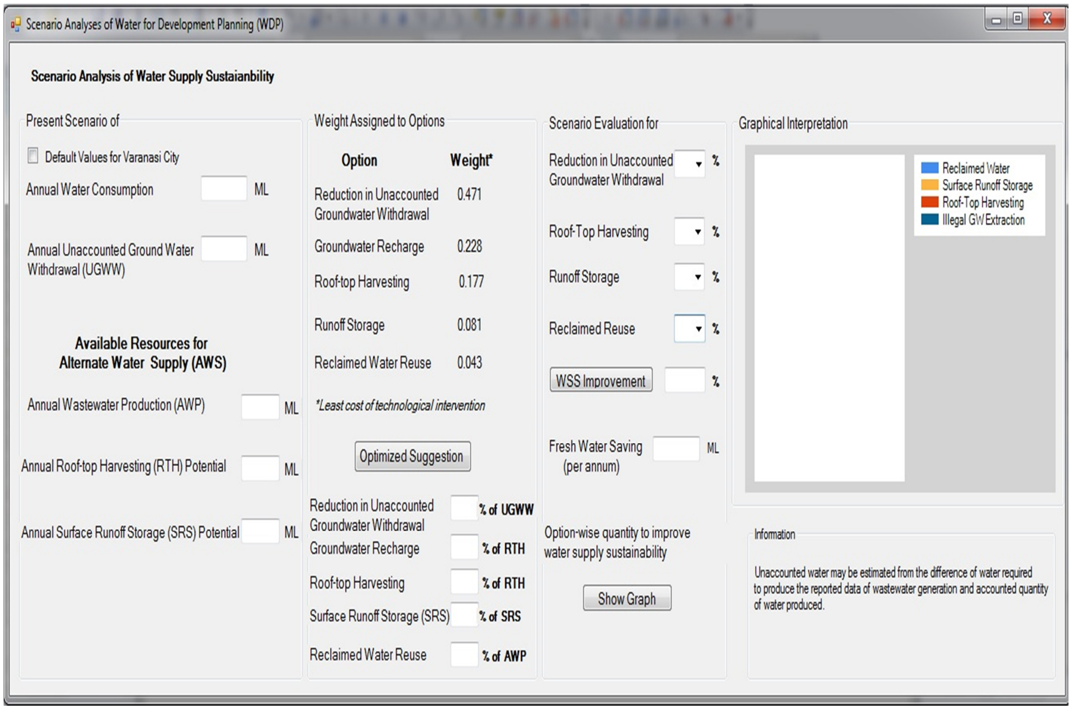
Table 5.7 (a): Weight assignment to options for improved Urban Water Balance (UWB)

Criteria	Unaccounted ground water withdrawal reduction	Ground water recharge	Roof-top RWH	Surface runoff storage	Reclaimed water
Unaccounted ground water withdrawal reduction	**1**	2	2	4	7
Ground water recharge	1/2	**1**	1	3	6
Roof-top RWH	1/2	1	**1**	3	6
Surface runoff storage	1/4	1/3	1/3	**1**	4
Reclaimed water	1/7	1/6	1/6	1/4	**1**

Table 5.7 (b): Calculated weight of options for improved Urban Water Balance (UWB)

Criteria	**Weight**
Unaccounted Groundwater Withdrawal Reduction	0.471
Ground Water Recharge	0.228
Roof-top Rainwater Harvesting (rain-tank)	0.117
Surface Runoff Storage	0.081
Reclaimed Water	0.043

Screenshot of Scenario analysis for Water Supply Sustainability (WSS) using improvement cases is shown in Fig 5.26. There will the data as inputs calculated from the previous modules. Inputs are in two categories (1) Data which existing system is utilizing (2) Data of available water sources which can be used as a resource. Annual water consumption, urban water resource-demand balance, and illegal water pumping have been calculated. On the other hand, wastewater production, roof-top rainwater harvesting potential, and surface runoff storing potential have been estimated on annual basis.



Option	Weight*
Reduction in Unaccounted Groundwater Withdrawal	0.471
Groundwater Recharge	0.228
Roof-top Harvesting	0.177
Runoff Storage	0.081
Reclaimed Water Reuse	0.043

Least cost of technological intervention

Unaccounted water may be estimated from the difference of water required to produce the reported data of wastewater generation and accounted quantity of water produced.

Fig 5.26 Screenshot of Scenario analysis for Urban Water Balance Improvement Cases

Using the improvement options discussed above the water supply sustainability can be improved based on availability of the resources and its applicability to the given region. Since there is limited quantity of each available resource and its ease of implementation different, flexibility to user has been provided to select the different options with number of combinations.