CHAPTER 3

RESEARCH METHODOLOGY

3.1 Evaluating Environmental Sustainability of a Smart City

The entire infrastructure development plan of SCM have been put under four categories: social, physical, institutional and economic (Fig. 3.1). It is clear from literature that while the two major pillars of sustainability, i.e. social and economic are well covered in SCM, the environmental dimension is unfocussed. Some of the environmental elements such as water supply, sewerage, solid waste management etc. have been considered under physical infrastructure category, but many others including ambient air environment, noise pollution level, conditions of surface water bodies etc. do not find any mention. Thus, it becomes imperative to enlist major indicators and broad domains which must be included for monitoring Environmentally Sustainable Smart Cities (ESSC) in order to get long term benefits of the developmental initiatives.

For comparing the environmental status of different cities, a Smart City Environmental Sustainability Index (SCESI) is developed in the present study which is used as a tool to guide the areas of priorities and better environmental productivity. The entire process of SCESI development is done in four steps: i. Selection of Indicators for Environmentally Sustainable Smart Cities, ii. Assigning weights for the indicators, iii. Benchmarking of selected indicators and iv. Calculation of Smart City Environmental Sustainability Index (SCESI). Fig. 3.2 gives a pictorial representation of SCESI development steps.

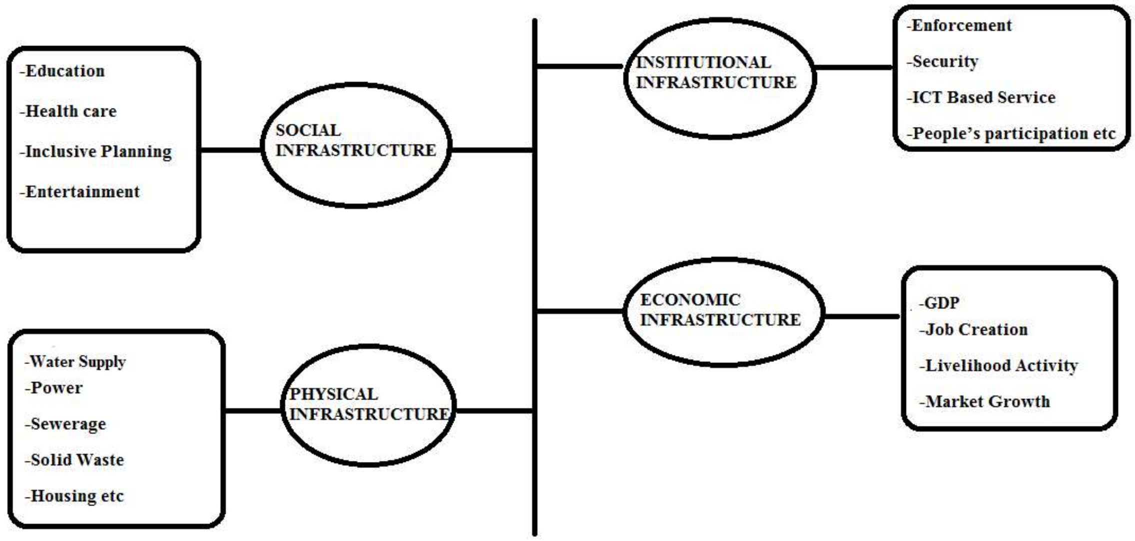

Fig. 3.1: Four Infrastructural Pillars (Social, Physical, Institutional and Economic) of Smart Cities (GOI, 2014).

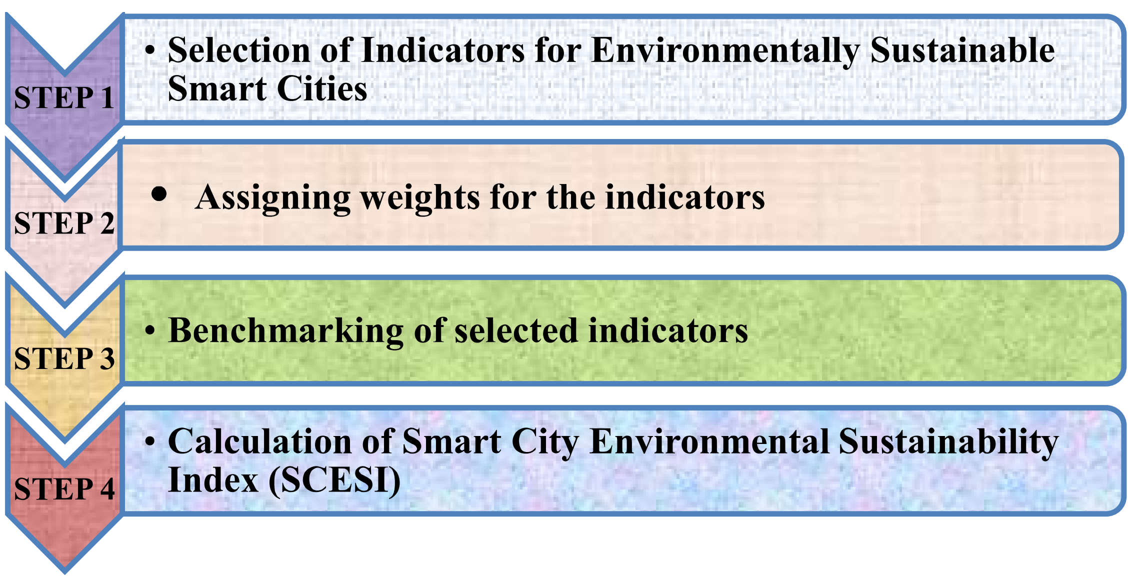

Fig 3.2: Developing Smart City Environmental Sustainability Index (SCESI)

3.1.1 Selection of Indicators for Environmentally Sustainable Smart Cities

The selection of appropriate indicators is the most crucial stage as it will guide the policymakers in performance assessment, monitoring and target-setting (Huovila et al., 2019). The key functional role of the indicator is to reduce the information complexity being conveyed to the decision makers. The indicators should be precise, measurable and independent. It should not be affected by other factors leading to ambiguous results. Data availability is major challenging task while selecting the indicators. The data should be easily gathered from Government reports, public sources, or from observations. Data which are expensive to obtain or needs extensive calculations (such as carbon footprint indicators) should not generally be included. Non-availability of data affects the overall result of index developed. Thus, there is a need to enlist the usable indicators and prepare a framework for evaluating the improvements in quality of life with developing infrastructure. The methodology adopted for the indicator selection is shown in Fig. 3.3.

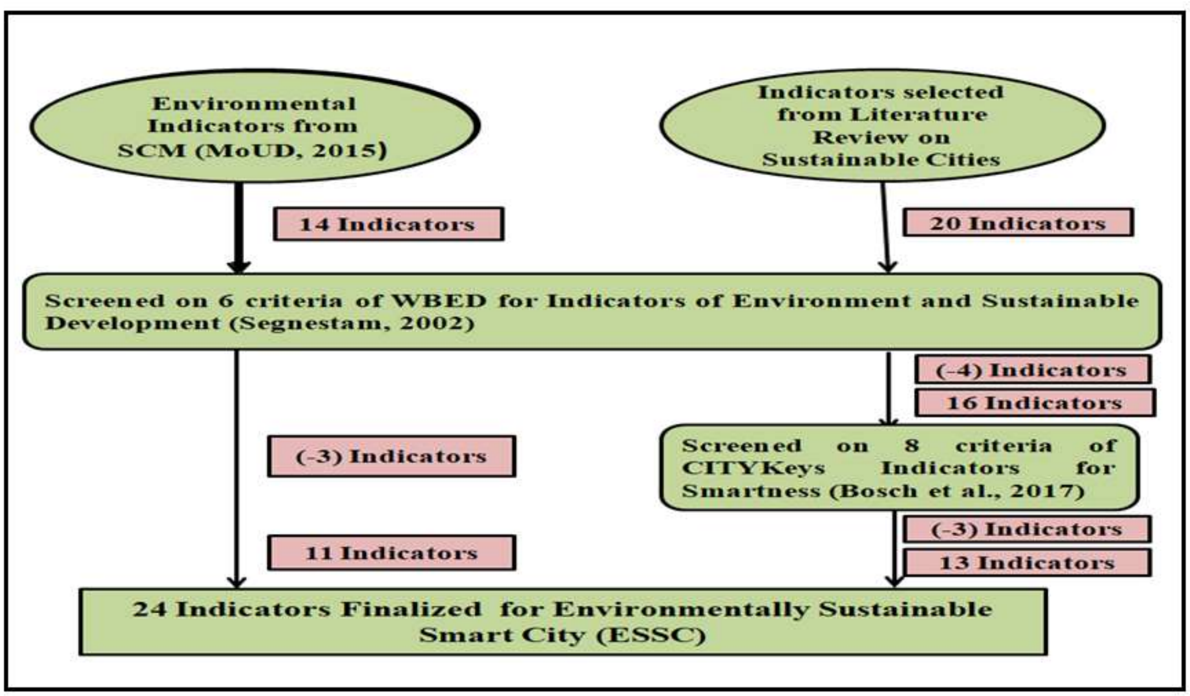

Fig. 3.3: Indicator Selection Process for Environmentally Sustainable Smart Cities (ESSC)

For the aforesaid purpose, 14 indicators from Smart Cities Mission guidelines of GOI and 20 additional indicators through literature related to sustainability frameworks is selected. Further, these two groups of indicators are tested for their appropriateness by a panel of experts on six criteria (Direct relevance to objectives, Direct relevance to the target group, Clarity in design, Realistic collection or development costs, High quality and reliability and Appropriate spatial and temporal scale) as suggested by World Bank Environment Department (WBED) (Segnestam, 2002). The screening results reveals that 11 indicators from SCM guidelines and 16 indicators from another group qualified the criteria. Further, the 16 qualified indicators through the literature are tested on smartness criteria (Relevance, Completeness, Availability, Measurability, Reliability, Familiarity, Non-Redundancy and Independence) given by City Key Indicators (Bosch et al. 2017). Finally, 24 indicators are selected after the screening process, under four broad environmental domains: Solid Waste Management (SWM), Water Supply Management (WSM), Sewerage, Sanitation and Storm Water Drainage (SSS) and Ambient Environment Conditions (AEC) which serve the purpose of ESSC.

3.1.2 Assigning weights for the indicators

Several methods of assigning the weights to the indicators have been reported in the literature. Best Worst Method (BWM) is used when a large number of input variable are present (Rezaei, 2015) and if structural hierarchy is required, Interpretive Structural Modelling (ISM) is used (Kumar et al., 2016, Bansal et al., 2017). AHP involves pairwise comparison which may become a tedious task to handle if large number of input variables are involved (Macharis et al., 2004). Anand et al. (2017), Ameen and Mourshed, (2019) used fuzzy Analytic Hierarchy Process (AHP) and AHP respectively to determine the importance of sustainability factors. Multi-criteria decision making (MCDM) approaches are followed to solve the problems where large number of factors is involved. The output required and nature of the problem decides the selection of appropriate MCDM approach (Yadav and Desai, 2017).

In the present work, weight to each indicator has been allocated using Delphi Methodology. It is a structured communication methodology which involves survey research comprising of expert panel (Awad-Núñez et al., 2014). The Delphi questionnaire was prepared and communicated to a group of 50 environmental panellists comprising of academicians, environmental engineers and policy-makers. The questionnaire was communicated to different regions so that a generic analysis can be achieved. For, the analysis of expert opinion, arithmetic means and median is carried out to exploit the potential of each indicator. Arithmetic mean is intuitive for the expert panel; hence simultaneously median is carried out for rigorous statistical analysis of data.

3.1.3 Benchmarking of selected indictors

Benchmarking is a popular tool to judge the performance of the services provided to the consumers (Unnisa and Hassan, 2013). Most of the indices developed by the agencies such as Green City Index, ISB Index etc. do not provide benchmarking of indicators; hence they judge the performance by simply comparing data of different cities. But a minimum set of standard should be defined for monitoring the service delivery. The urbanization challenge can be addressed by identifying the gaps and introducing the best practices for improving the city's performance. In the present research, benchmarking has been done for each indicator on 0-100 scale based on best suggested condition for different domains applicable under Indian conditions at present based on Handbook of Service Level Benchmark (MoUD, 2012). Here 0 indicates Poor condition and 100 indicate Excellent level. Some of the indicators are scored on the logical basis i.e. if the indicator satisfies the condition then it is allocated 100 representing Excellent category, and if the indicator does not satisfy the condition, it scores 0 signifying Poor category.

3.1.4 Calculation of Smart City Environmental Sustainability Index (SCESI)

In the present study Smart City Environmental Sustainability Index (SCESI) has been developed which is based on four domain indices (DIs): Solid Waste Management Index (SWMI), Water Supply Management Index (WSMI), Sewerage, Sanitation and Storm water Management Index (SSSI) and Ambient Environment Condition Index (AECI).

SCESI and DIs are calculated using indicators selected under each domain. The sustainability of actions, plans or programs in each of these four environmental domains are measured and used as a tool for inter and intra domain comparison.

The general expression for the Smart City Environmental Sustainability Index (SCESI) is given by:

$$SCESI = \left(\sum_{i=1}^{m} vi\ DIi\right)/m, \qquad (3.1)$$

wherei is the serial number of domains considered, m is total number of domains, v_i is weight of i^{th} domain, DI_i is the respective Domain Index.

Domain Indices (DIs) are the summation of individual Indicator Scores (ISs), given by:

$$DI = \sum_{j=1}^{n} ISj \times 100, \qquad (3.2)$$

where j is the serial number of Indicator, n is number of indicators in the chosen domain and IS_j is Indicator Score of j^{th} indicator

Indicator Score (IS) is obtained using the weight of the indicator (w_k) and the benchmarked indicator value (x_k), given by:

$$IS_k = (w_k . x_k) \times 100, \qquad (3.3)$$

Where, k is the identification number of chosen indicator.

Fig. 3.4 presents the skeletal structure for calculating SCESI.

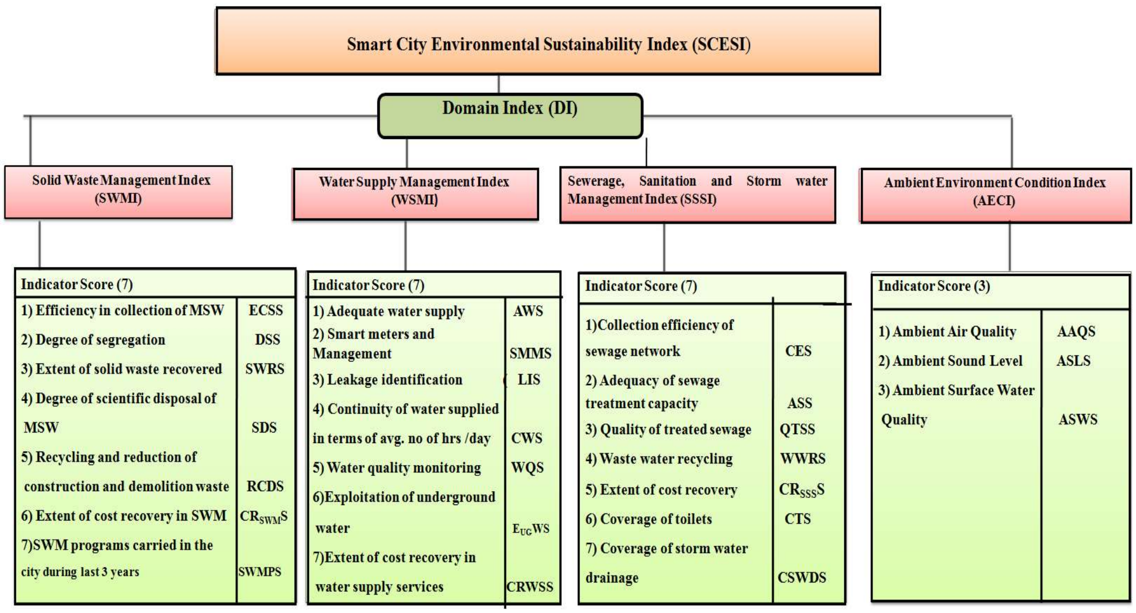

Fig 3.4: Skeletal structure for Smart Cities Environmental Sustainability Index (SCESI)

SCESI, DIs and ISs are numbers on 0-100 scale and the environmental sustainability of a smart city has been categorised as follows (Table 3.1):

Table 3.1: Indicator Score/Domain Index/ SCESI and Environmental Sustainability Condition

SCESI/ DI/IS (0-100)	Environmental Sustainability Category
>80	Excellent
60-80	Good
40-60	Fair
20-40	Poor
<20	Critically low

For demonstration purpose in the present study, all the four environmental domains: Solid Waste Management (SWM), Water Supply Management (WSM), Sewerage, Sanitation and Storm water Management (SSS), and Ambient Environment Condition (AEC) have been given equal weightage (i.e., $v_1=v_2=v_3=v_4=1$).

As m=4 in this case, equation (3.1) simplifies to:

$$SCESI = (SWMI + WSMI + SSSI + AECI)/4 \quad (3.4)$$

DIs: SWMI, WSMI, SSSI and AECI are calculated by summing the indicator scores (ISs) under the respective domain. The IS is a reflection of the performance of the city for a given indicator with respect to a standard benchmark value decided for the purpose and relative weight assigned to it. The indicators have been benchmarked as fractions on 0-100 scale with respect to the intended standard values, and the summation of weight of indicators in a given domain is 1.

3.2 Framework of Decision Support System (DSS) for evaluating the Environmental Sustainability of a Smart City

The present study is carried out to develop a **D**ecision **S**upport **S**ystem for **E**nvironmentally **S**ustainable **S**mart **C**ities in India, henceforth abbreviated and called as **DSS-ESSC**. The application is developed using Django which is an open-source web application framework written in Python. The proposed DSS-ESSC is hosted on PythonAnywhere which is a web hosting service based on the Python programming language. The proposed DSS-ESSC is user-friendly which is easily accessible on urlsmartcitydss.pythonanywhere.com.The development of DSS-ESSC is based on a combination of modules and sub-modules to make decisions over further development planning which incorporates all the environmental aspects of sustainability and smartness. The purpose of the developed tool is to address the paradoxes, constraints, and uncertainties of the existing framework of smart and sustainable cities.

The index developed, SCESI, is modelled to a software tool, DSS-ESSC. It combines all four environmental domains, namely Solid Waste Management, Water Supply Management, Sewerage Sanitation and Storm water Management and Ambient Environment Conditions. The application developed will serve as a tool that will help the policymakers to benchmark the performance of the cities on the scale range of critically low, poor, fair, good, and excellent. In this chapter, the details of models and methods used in development of the DSS-ESSC are discussed. Each model used in the present study has been described with its formulae, associated data, and assumptions. The models have been selected, keeping in view various need of DSS-ESSC and their input data requirement. The output of the user-friendly decision support system will be used by policymakers for the planning and development of smart cities.

Fig. 3.5 presents the structure of DSS-ESSC in terms of various modules and sub modules designed for the purpose.

3.2.1 Theoretical concept of DSS-ESSC and its benefits

One major contribution of this research is the development of the DSS-ESSC.The framework of DSS-ESSC encompasses modules and sub modules for all major activities involved in proper management of environmental dimensions of Sustainable Smart Cities in India. A web based graphical user interface (GUI) has been developed for calculation of SCESI using python django programming language. SCESI is calculated on a unidirectional scale of 0 to 100, which is based on the data and weights of the finalized indicators. The modules and sub-modules is given in Table 3.2.

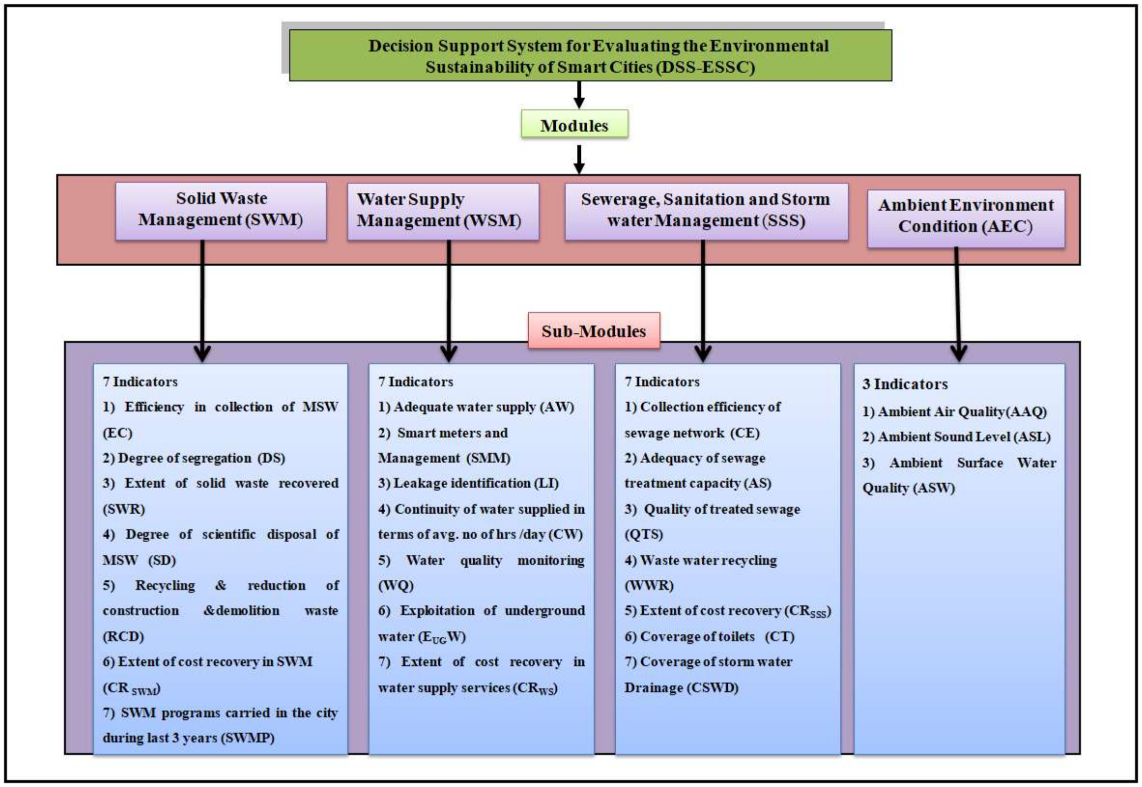

Fig. 3.5: Structure of DSS-ESSC

Table 3.2: Modules and sub-modules of DSS-ESSC

MODULES	SUB-MODULES
(A) Solid Waste Management (SWM)	1. Efficiency in collection of MSW (EC)
	2. Degree of Segregation (DS)
	3. Extent of Solid Waste recovered (SWR)
	3. Degree of Scientific disposal of MSW (SD)
	5. Recycling and reduction of construction and demolition waste (RCD)
	6. Extent of cost recovery in Solid Waste Management (CR_{SWM})
	7. SWM programs carried in the city during last 3 years (SWMP)
(B) Water Supply Management (WSM)	8.Adequacy of water supply (AW)
	9.Smart meters and Management (SMM)
	10. Leakage Identification (LI)
	11.Continuity of water supplied in terms of average no of hours per day (CW)
	12.Water quality monitoring (WQ)
	13.Water sources and extent of exploitation of ground water ($E_{UG}W$)
	13.Extent of cost recovery in water supply services (CR_{WS})

(C) Sewerage, Sanitation and Storm water (SSS) management	15. Collection efficiency of sewage network (CE)
	16. Adequacy of sewage treatment capacity (AS)
	17. Quality of treated sewage (QTS)
	18. Wastewater recycling (WWR)
	19.Extent of cost recovery (CR_{SSS})
	20. Coverage of toilets (CT)
	21.Coverage of storm water drainage (CSWD)
(D) Ambient Environmental Condition (AEC)	22.Ambient Air Quality (AAQ)
	23. Ambient Sound Level (ASL)
	23. Ambient Surface Water Quality (ASW)

The developed software assists in implementation of policies regarding Smart City projects in India by enabling the policymakers to make correct decisions. The achievement of the SCM is demonstrated by the proper management of time and resources, which can be accomplished by the developed software DSS-ESSC. The user enters the current scenario of the city, which is analysed by the software and the priority domain which requires an immediate action for improvement is specified. The developed software attempts to aid decision makers in finding the optimal level of service, while minimizing costs and maximizing the long-term environmental sustainability.

3.3 Working Principle of Application

A web-based Decision Support System for Evaluating the Environmental Sustainability of a Smart City (DSS-ESSC), which aims to sheer and shape existing cities in India, has been presented in this chapter. DSS-ESSC is developed using Python Django and MySQL. The developed application is hosted on PythonAnywhere, which is an online integrated development environment (IDE) and web hosting service based on the Python programming language. Django is a high-level python web development framework that is based on **Model-View-Template** (MVT) architecture (Fig 3.6). When the user, login in a Django based website, the request is processed by the Views and send to the url of the login page. Thereafter server responds to the request and sends it to the browser, and the welcome page is opened. Next, the credentials are entered in the given Template, HTML form. Data is sent to the View and then to the Model. If the user data matches with the database it is send to the Views where it is formatted in the desired response and transmitted to the end-user.

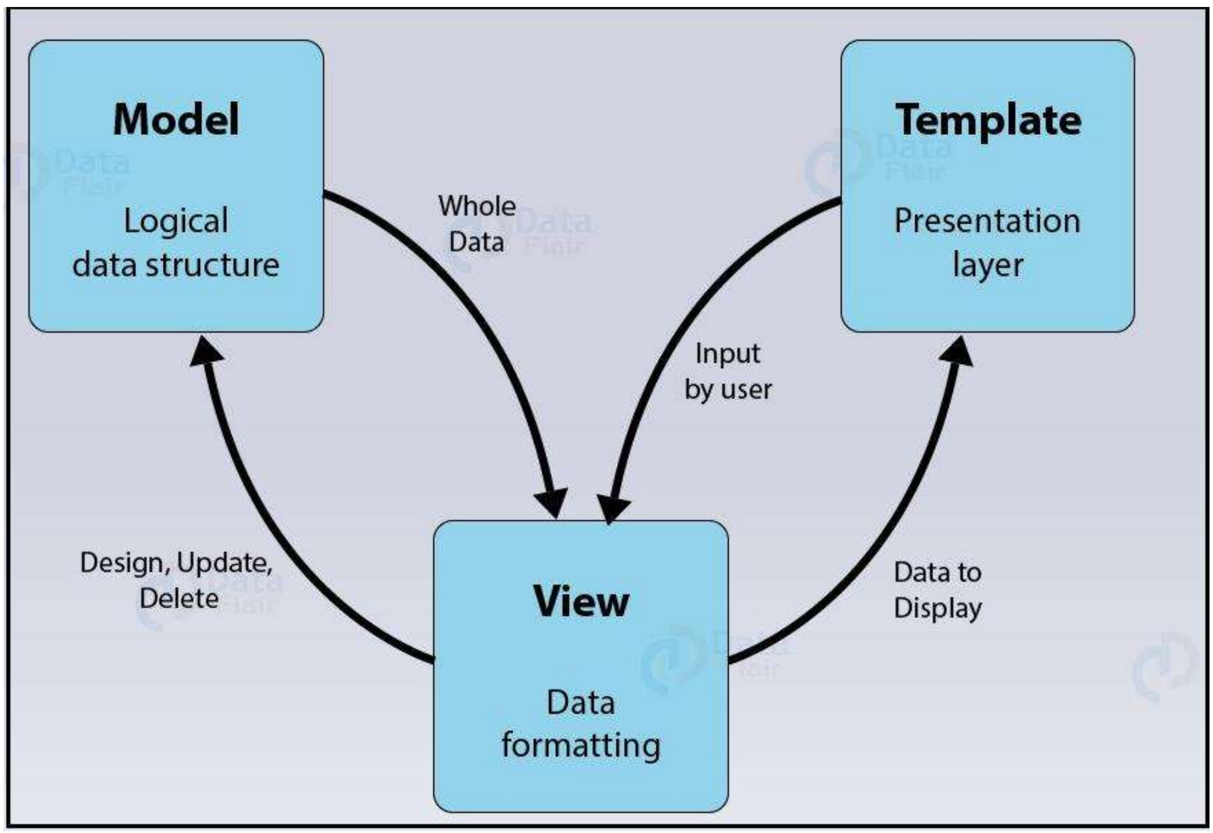

Fig. 3.6: Model-View-Template (MVT) Architecture

The welcome page of the developed application is shown in Fig 3.7. After clicking on hyperlink, the user is redirected to the descriptive page of DSS-ESSC (Fig 3.8). This page contains all the essential information about the methodology adopted for development of Smart City Environmental Sustainability Index (SCESI). Next user has to enter the name of the city (Fig 3.9), which gets saved in the database. Broad environmental domain indices Solid Waste Management Index (SWMI), Water Supply Management Index

(WSMI), Sewerage, Sanitation and Storm water Management Index (SSSI), and Ambient Environment Condition Index (AECI) are displayed as individual pages and functions like separate module (Fig 3.10-3.13). Firstly, the user enters the data of query column field for each domain. Thereafter, the indicator score is calculated as per Equation 3.3.

The benchmarked indicator value and weight allocated is displayed on the respective user domain pages. Domain index (DI) is calculated as per Equation 3.2 and displayed on the next page along with the probable improvement measures and approximate cost estimation for improving the prevalent scenario.

DI value is stored in the database as well as displayed on the next page so that the user can instantly know the city performance in the respective domain index. The working of a database is to store the information about the entity and support the process of decision making. Smart City Environmental Sustainability Index (SCESI) of the city is displayed on the result page which is obtained as per Equation 3.1.

The summation of all the four domain indices is 400; hence to bring the SCESI on a uniform scale of 100, the cumulative value is divided by 3. On the result page, along with SCESI, the calculated domain indices are also shown in the order from critically low to excellent. Respective color-coding is done for each scale range to make it more interactive and user-friendly. Further, three priority environmental indicators is also shown for each domain which is decided by the critical performance followed by weights i.e., if more than one indicator has scored equal, then the priority area is decided by the higher weight. The developed tool can be used for monitoring the improvements and guiding the investments in environmental infrastructure development programs of Smart Cities Mission (SCM) in India.

3.3.1 Basic Data

For better management, a lot of data related to environmental domains are required. Generally, municipalities may have many data with them; still, there may be many which are not readily available. Hence, DSS-ESSC must have the ability to support the unavailable data by some firsthand approximation value applicable in the given area for basic planning and design purposes. The data source hyperlink present in the Solid Waste Management, Water Supply Management, Sewerage, Sanitation and Storm water Management and Ambient Environment Condition domains pages automatically take the user to the government sites for data in order to give a starting point for planning process (Fig 3.6-3.9). In case the user is unable to open the government site, updated data of selected cities is also prepared in a tabular form and can be obtained by clicking on the respective hyperlink. DSS-ESSC takes the values from such tables in the knowledge base to support the planner for initial calculations.

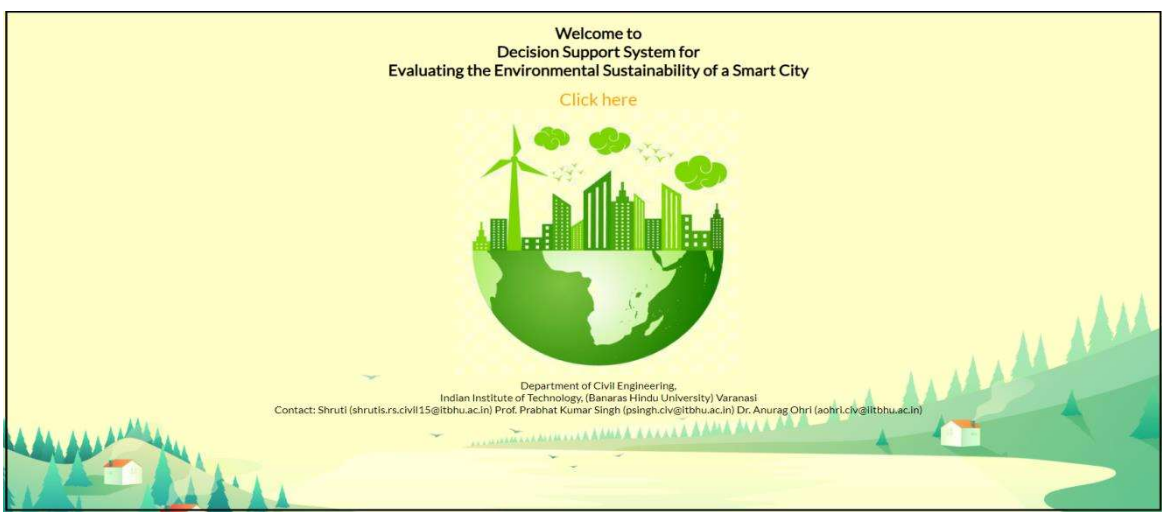

Fig. 3.7: Screenshot of welcome page

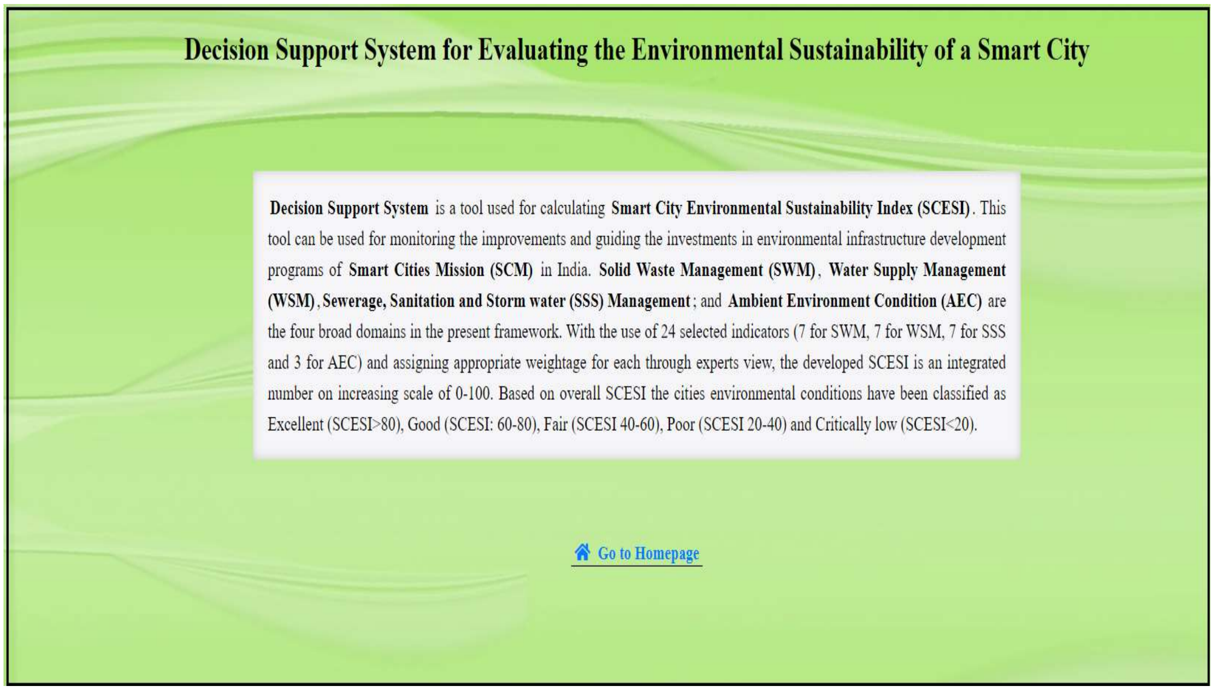

Fig. 3.8: Screenshot of description page

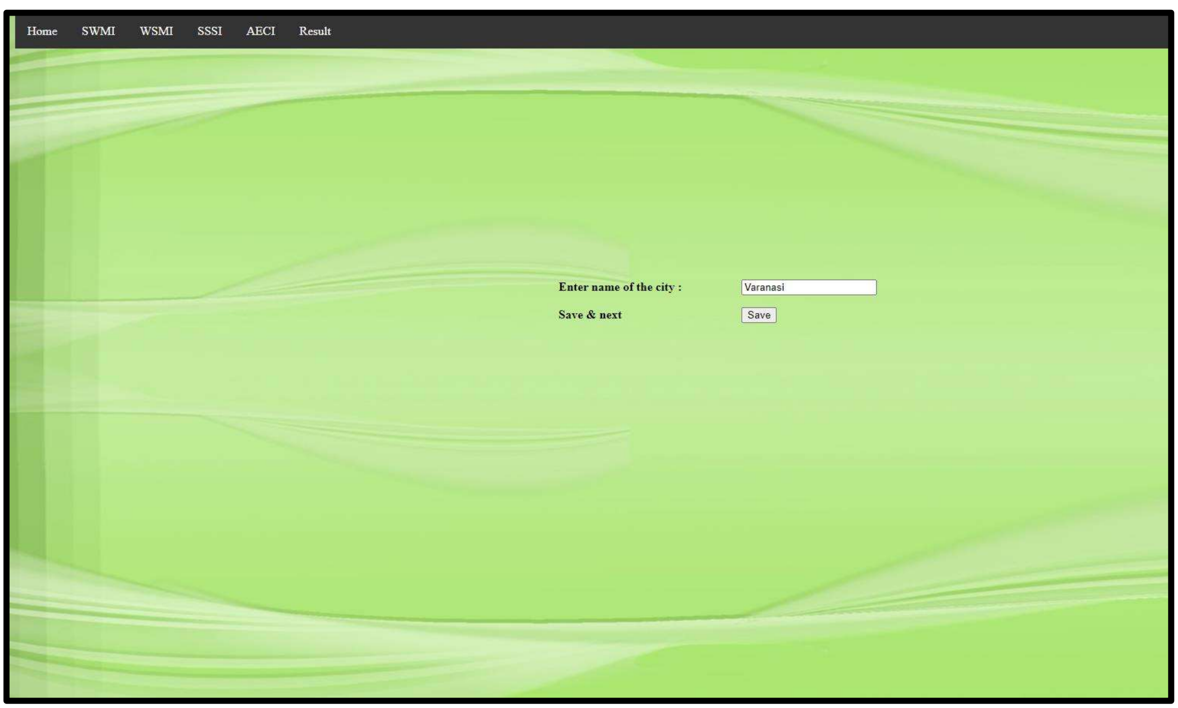

Fig 3.9: Screenshot of query page

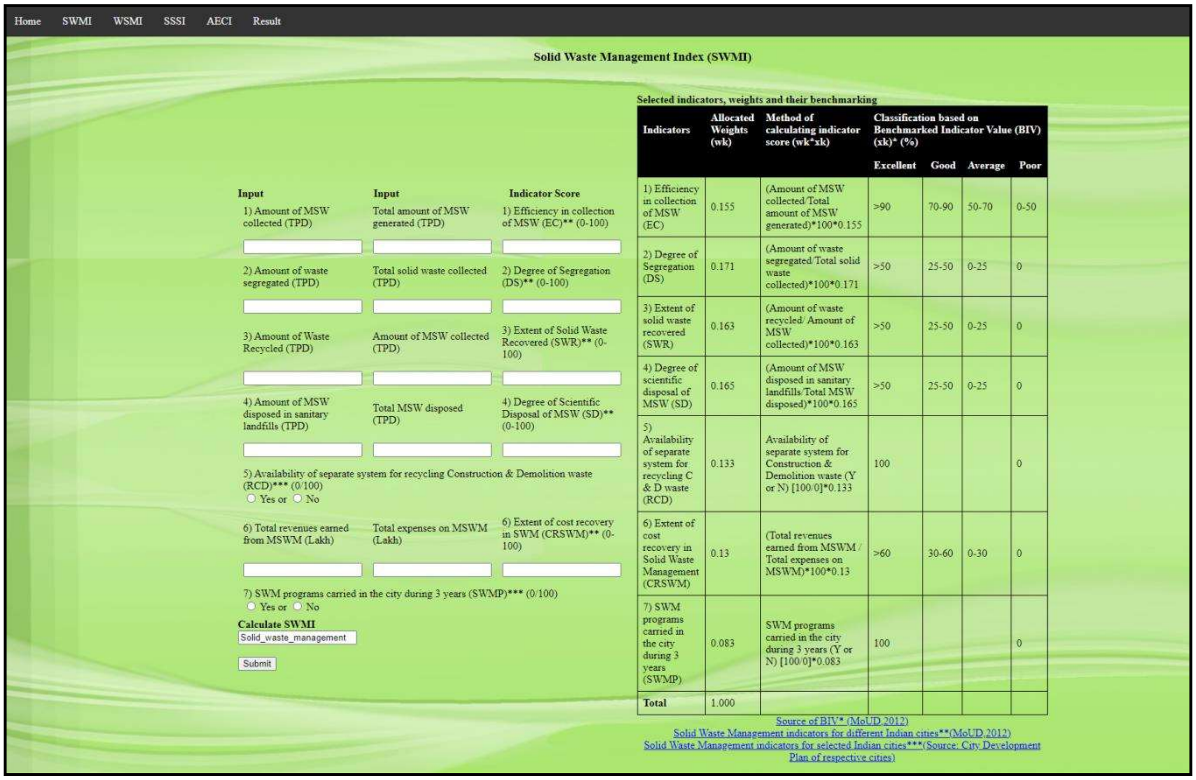

Fig 3.10: Screenshot of Solid Waste Management page

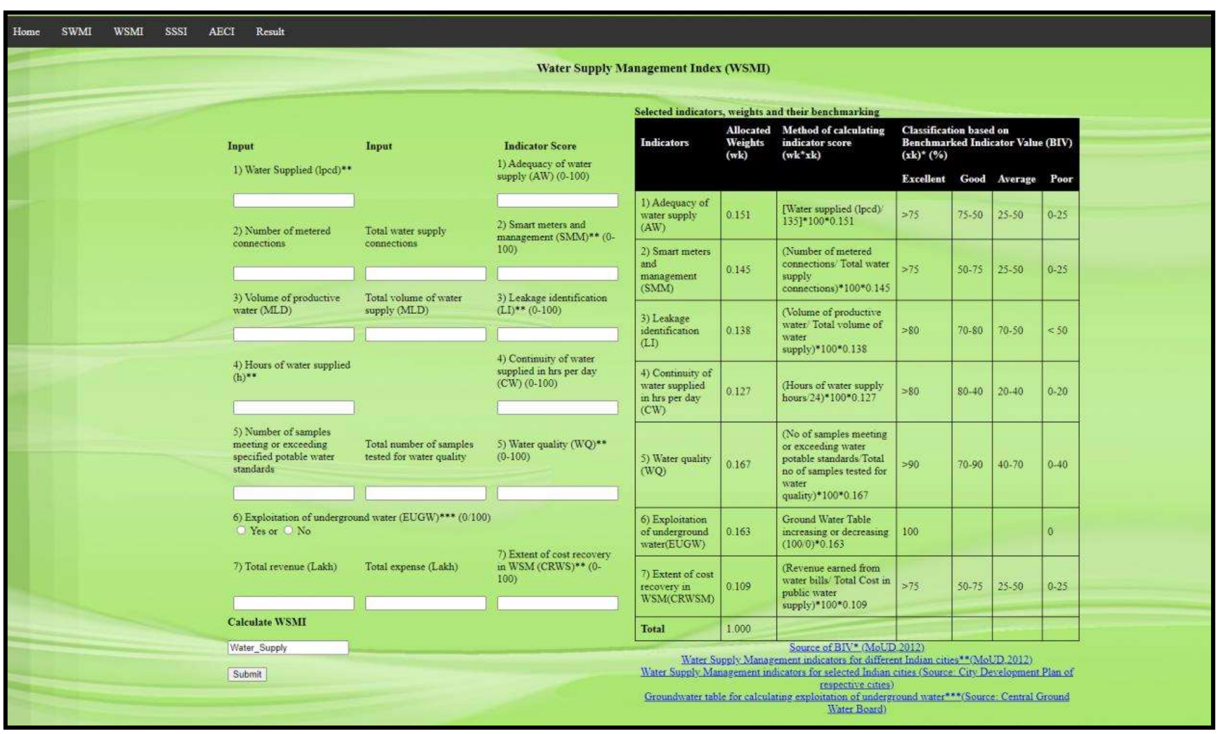

Fig 3.11: Screenshot of Water Supply Management page

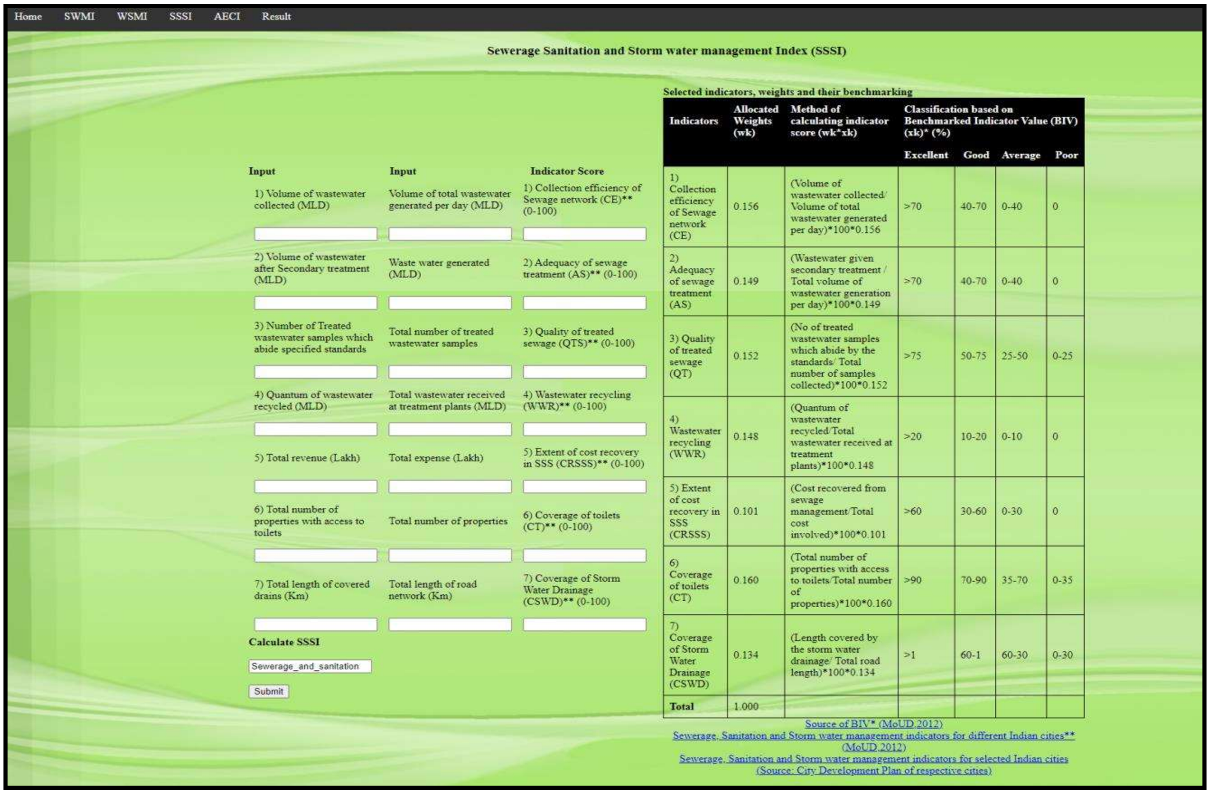

Fig 3.12: Screenshot of Sewerage Sanitation and Storm water management page

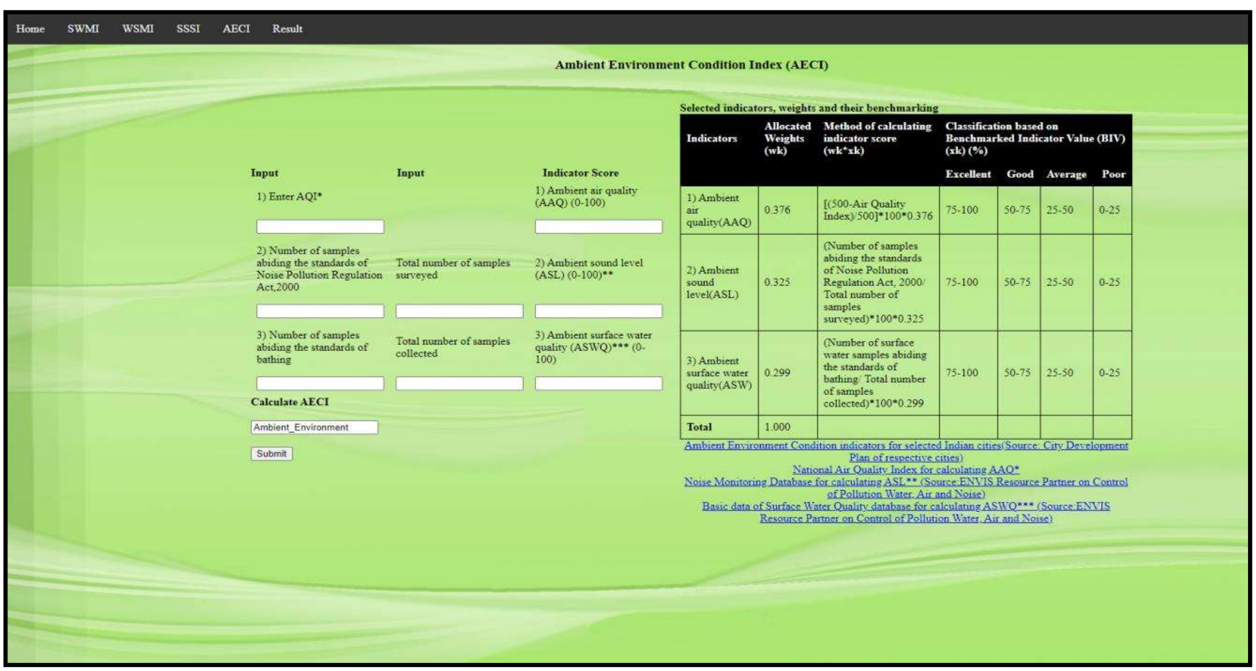

Fig 3.13: Screenshot of Ambient Environment Condition page

DSS-ESSC provides a framework for planning the existing cities in an effective way to meet future demands. The developed tool must be useable and must be able to communicate the results to the end-users in a comprehensible manner to be accepted by the target audience. For this purpose, it must be validated on real data of cities which is discussed in the next chapter.

3.4 Sensitivity Analysis

The developed SCESI basically depends on the value of indicator and its weight given by experts. It is reasonable to assume that data gathered by municipalities or reliable sources is not flawless, and some percentage of error may be expected (Saisana and Saltelli, 2008). Hence, Sensitivity Analysis which investigates the variation in output factor when there is variation in input factors (Pianosi et al., 2016) is carried out in the present research. The pictorial analysis of sensitivity analysis by generating different scenarios has been depicted in Fig. 3.14.

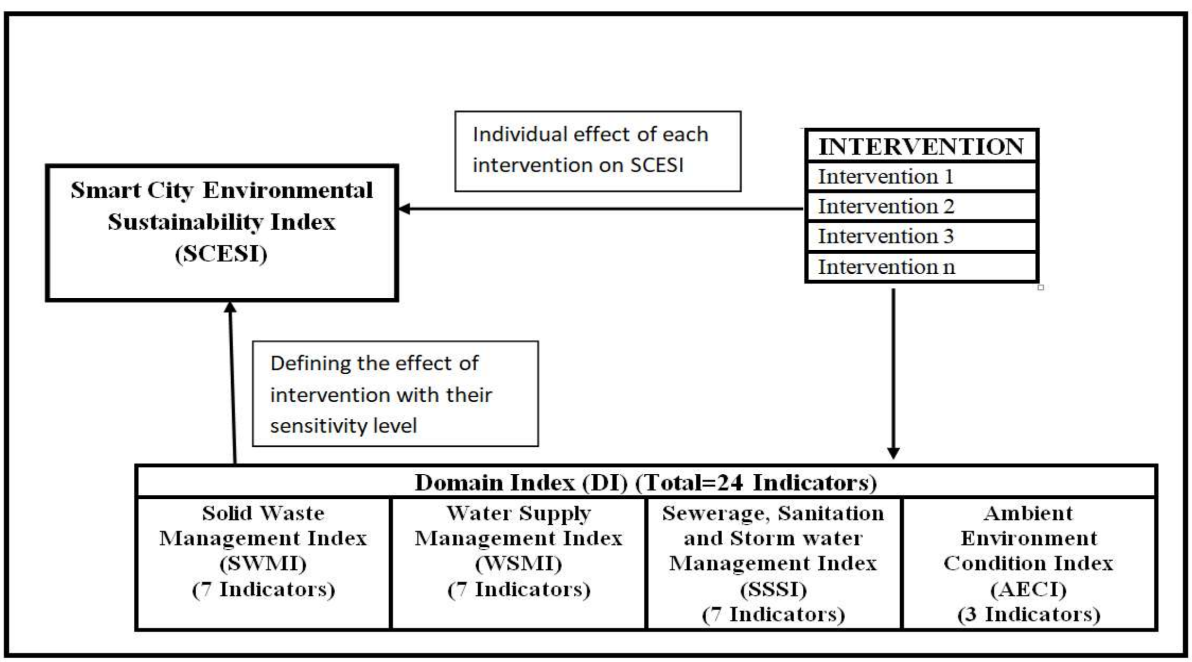

Fig. 3.14: Methodology for Sensitivity Analysis

The result of the analysis can address wide range of questions, such as which indicator has the highest dependency, lowest dependency or negligible effect on the SCESI.

The validation of the results on real data has been discussed in the next chapter.