CHAPTER 4

RESULTS AND DISCUSSIONS

The strength, weakness and challenges related to the existing Smart Cities framework have been discussed in Literature Review (Chapter 2). The gap demands a holistic framework for Environmentally Sustainable Smart Cities (ESSC). The present study attempts to develop a framework for ESSC which can address the limitations and uncertainties of the existing models. Moreover, the result of the framework developed helps the policymakers in investment and prioritization of domains to take immediate action.

The present Chapter is divided in three parts:

Cluster I: Selection of Indicators, Benchmarking, Weight allocation and Domain Indices (Section 4.1 to Section 4.4)

Cluster II: Validation of data on different cities through DSS-ESSC (Section 4.5 to Section 4.6)

Cluster III: Phased intervention and Sensitivity Analysis (Section 4.7 to Section 4.8)

Cluster I

4.1 Indicators for Environmentally Sustainable Smart Cities (ESSC)

The biggest challenge associated with the development of Environmentally Sustainable Smart Cities (ESSC) is to address the need and futuristic goal of a city by selecting an appropriate set of indicators. There is a great array of available indicator frameworks which varies in their approach to measure smartness and sustainability quotient. Thus, a set of indicators can be selected by understanding the selection methodology and aggregating the information from the available literature on indicators framework. The foremost contribution of the present work is the methodology adopted for selection of indicators which is easy to be implemented and can monitor the success plan of a smart city in line with the vision of environmental sustainability.

4.1.1 Indicators shortlisted from SCM guidelines

To start with, the 14 environmental indicators included in the MoUD (2015) guidelines for Smart Cities Mission of Government of India (Table 4.1) were tested for their appropriateness based on World Bank Environment Development (WBED) 2002 criteria (Segnestam, 2002). Six criteria used to decide the appropriateness of indicators are: (i) Direct relevance to objectives (ii) Direct relevance to the target group (iii) Clarity in design (iv) Realistic collection or development costs (v) High quality and reliability (vi) Appropriate spatial and temporal scale (Segnestam, 2002). Table 4.2 summarises the appropriateness of indicators used in Smart Cities Mission of GoI based on WBED (2002) criteria. It is observed that 11 indicators fully satisfy all the six criteria of WBED (2002). However, three indicators (A.1, A.2 and D.13) do not fully meet the appropriateness criteria fully. It is observed that the indicators A.1: Waste to energy and fuel, and A.2: Waste to compost does not meet the requirements of appropriateness in terms of clarity in design and realistic collections or development costs. The Smart Cities Mission guideline does not have a target-based plan on these areas. However, in Swach Bharat Mission (MoUD, 2017) the degree of waste treatment is measured in terms of decreasing amount of waste going to landfill. If a city manages to dispose less than 20% of its total solid waste generated to landfills, it gets the highest score of 45 and if the waste going to landfill is more than 20%, it gets zero score. From this, it is may be inferred that in Smart Cities, 80% or more of the total organic waste generated should be targeted to be processed for energy conversion or composting. With a clear mention of proportion of waste planned to be converted to energy or fuel (A.1) and waste to fertilizer as compost (A.2), these two environmental indicators included in SCM guidelines may also qualify as appropriate as per WBED (2002) criteria. The indicator D.13: Storm water reuse does not fulfil the criteria in terms of Clarity in design and Realistic collection. In line with Environment guidelines of Mauritius, (MEM, 2015), if achievable targets with probable cost of storm water reuse such as toilet flushing, car washing, garden irrigation etc. are defined in Smart Cities Mission monitoring program, this indicator may also be considered appropriate. In cases where cities report groundwater depletion, Stormwater harvesting can be conservative measure to preserve water. Identification of sites for stormwater harvesting can be done with the help of geospatial knowledge (Pathak et al., 2017). But, till the time these parameters are made objective and target based, in the present form they cannot be considered appropriate indicators for measuring environmental sustainability of the proposal. Hence, these three indicators are not included in the proposed framework for ESSC.

Table 4.1: Environmental indicators in Smart Cities Mission of Government of India (MoUD, 2015)

Environmental Domain	**Indicators (Smart solutions+ Essential features)**
A. Solid Waste Management	1. Waste to energy and fuel
	2. Waste to compost
	3. Recycling and reduction of construction and demolition waste
	4. Solid waste management programs carried in the city during last 3 years

B. Water Supply Management	5. Smart meters and Management
	6. Leakage identification
	7. Water quality monitoring
	8. Adequate water supply
	9. Extent of cost recovery in water supply services
C. Sewerage and Sanitation	10. Coverage of toilets
	11. Waste water recycling
	12. Extent of cost recovery
D. Storm Water Drainage	13. Storm water reuse
E. Pollution	14. Improvement in Air Quality

Table 4.2: Appropriateness of Environmental Indicators used in Smart Cities Mission of GOI based on WBED (2002) Criteria

Environmental Indicators	WBED (2002) Criteria (Segnestam, 2002)						
	(i) Direct relevance to objectives	**(ii) Direct relevance to the target group**	**(iii) Clarity in design**	**(iv) Realistic collection or development costs.**	**(v) High quality and reliability**	**(vi) Appropriate spatial and temporal scale**	**% of compliance out of six criteria**
A. Solid Waste Management							
1.Waste to energy and fuel	✓	✓	×	×	✓	✓	66.6%
2.Waste to compost	✓	✓	×	×	✓	✓	66.6%
3. Recycling and reduction of construction and demolition waste	✓	✓	✓	✓	✓	✓	100%
4. SWMP carried in the city during last 3 years.	✓	✓	✓	✓	✓	✓	100%
B. Water Supply Management							
5. Smart Meters	✓	✓	✓	✓	✓	✓	100%
6. Leakage identification	✓	✓	✓	✓	✓	✓	100%

7.Water quality monitoring	✓	✓	✓	✓	✓	✓	100%
8. Adequate water supply	✓	✓	✓	✓	✓	✓	100%
9. Extent of cost recovery in water supply services	✓	✓	✓	✓	✓	✓	100%
C. Sewerage and Sanitation							
10. Coverage of toilets	✓	✓	✓	✓	✓	✓	100%
11.Waste water recycling	✓	✓	✓	✓	✓	✓	100%
12. Extent of cost recovery	✓	✓	✓	✓	✓	✓	100%
D. Storm Water Drainage							
13.Storm water reuse	✓	✓	✗	✗	✓	✓	66.6%
E. Pollution							
14. Improvement in Air Quality	✓	✓	✓	✓	✓	✓	100%

4.1.2 Additional environmental indicators screened from literature on Sustainable Cities

From the perspectives of environmental sustainability, apart from 14 indicators included in the SCM Guidelines (Table 4.1), 20 additional indicators were screened from available literature on Sustainable Cities (Table 4.3). Significantly, these indicators have largely been considered important and are being used as monitoring parameters in different plans of Government of India. Appropriateness of these additional 20 indicators screened from available literature for Sustainable Cities have been examined similarly based on WBED (2002) criteria, as given in Table 4.4. It is observed that among these 20 indicators, 4 do not fully meet the requirements of criteria for being considered appropriate. In the Smart Cities Mission, frequency of street sweeping per day has not been decided based on total amount of waste generation. Hence the indicator A.1: Street Sweeping may not be considered appropriate at this stage to be included as a measure of Environmentally Sustainable Smart City framework design. A7: Availability of collection bin is considered inappropriate because for a smart city, zero bin concept is desirable objective. A.9: Availability of roadmap does not fulfil the requirements of appropriateness in terms of clarity in design. D.18: Incidence of water logging defined in the terms of number of times water logging reported per year does not give the clear picture in terms of percentage of area flooded with respect to the total area of the city. Hence, this indicator also does not provide clarity in design and hence may not be considered appropriate to be included in the framework. The remaining 16 indicators which fulfil the WBED (2002) criteria for appropriateness were further tested on criteria given by CITYKey Indicators (Bosch et al. 2017). The criteria include (i) Relevance (ii) Completeness (iii) Availability (iv) Measurability (v) Reliability (vi) Familiarity (vii) Non-Redundancy and (viii) Independence (Table 4.5). In the evaluation process of appropriateness, the redundancy of the indicators needs to be examined with due care.

In planning an Environmentally Sustainable Smart City, 100% coverage of collection of the solid waste appears essential. Hence, household coverage in terms of percentage of houses has been taken as redundant. Instead, efficiency of collection which is reflected in the sanitary and aesthetic environment of the city has been considered relevant. For water supply management, 'coverage of the area' is expressed in terms of total number of households with direct water supply connection in reference to the total number of households in the city. 'Adequate water supply' is expressed in the terms of total quantity of water supplied into the distribution system with respect to the total population of the city. Hence the first (coverage of area) is considered redundant. In the sewerage and sanitation sector, 'coverage of sewerage network' denotes the extent to which wastewater management facilities are available to individual properties across the city whereas 'collection efficiency' denotes the actual proportion of waste water generated in the city that is collected by the available sewerage network. Hence, former is taken as redundant for the purpose of preparation of this framework. After such scrutiny, out of the screened 16 indicators, a list of 13 indicators is finalized. Data availability is important criteria for selection of indicators. For the indicators selected, the probable sources for data for different environmental management sectors such as Solid Waste Management, Water Supply Management, Sewerage, and Storm water management and Ambient Environment Conditions have been attempted to be compiled for Indian conditions. City Development Plan (CDP) and Swachcha Sarvechhan Report (SSR) from the Swachcha Bharat Mission program are found prominent sources of these data required for such indicators. Data about groundwater is normally available from reports of Central Groundwater Board (CGWB) of Government of India. Air quality and noise quality data can be obtained through Central Pollution Control Board (CPCB) and ENVIS sources respectively. Thus, the indicators selected are considered well supported with data from available sources for evaluation of ESSC.

Table 4.3: Additional environmental indicators screened through literature

Environmental Indicators	References for relevance
A. Solid Waste Management	
1. Street Sweeping	CPHEEO, 2016; JICA, 2016; MoUD, 2017; Garau et al., 2018
2. Household Coverage	CPHEEO, 2016; MoUD, 2012; MoUD, 2017
3. Degree of Segregation	CPHEEO, 2016; MoUD, 2012; MOUD, 2017
4. Efficiency in collection of MSW	BIS, 2016; MoUD, 2012; MoUD, 2017
5. Extent of solid waste recovered	BIS, 2016; EIU 2012; MoUD, 2012
6. Degree of scientific disposal of MSW	BIS, 2016; EIU 2012; MoUD, 2012
7. Availability of collection bin at appropriate place at commercial and residential areas	Garau et al., 2018; MoUD, 2017
8. Availability of roadmap for waste transportation of MSW as per Swachh city plan	MoUD, 2017
9. Extent of cost recovery in Solid Waste Management services	MoUD, 2012
B. Water Supply Management	
10. Coverage of water supply connections	MoUD, 2012
11. Continuity of water supplied in terms of average number of hours per day	MoUD, 2012
12. Identification of water sources and exploitation of underground water	JICA 2016, Howard et al., 2005
C. Sewerage and Sanitation	
13. Coverage of sewerage	BIS, 2016; Dong et al., 2017
14. Collection efficiency of sewage network	MoUD, 2012
15. Adequacy of sewage treatment capacity	EIU, 2012; MoUD, 2012
16. Quality of treated sewage	MoUD, 2012
D. Storm Water Drainage	
17. Coverage of storm water drainage	MoUD, 2012
18. Incidence of water logging	MoUD, 2012
E. Pollution	
19. Noise pollution	Bosch et al., 2017, BIS,2016
20. Quality of surface water bodies	BIS, 2016

Table 4.4: Appropriateness of 20 Additional Environmental Indicators for Sustainable Cities based on WBED (2002) criteria

	Suitability of Indicator based on World Bank (2002) Criteria (Segnestam, L.,2002)			
Environmental Indicators for Sustainable Cities	**(i)Direct relevance to objectives**	**(ii)Direct relevance to the target group**	**(iii)Clarity in design**	**(iv)Realist… collection… developm…**
A. Solid Waste Management				
1 Street Sweeping	✓	✓	×	×
2 Household Coverage	✓	✓	✓	✓
3 Degree of Segregation	✓	✓	✓	✓
4 Efficiency in collection of MSW	✓	✓	✓	✓
5 Extent of solid waste recovered	✓	✓	✓	✓
6 Degree of scientific disposal of MSW	✓	✓	✓	✓
7 Availability of collection bin at appropriate place at commercial and residential areas	×	✓	✓	✓
8 Extent of cost recovery in	✓	✓	✓	✓
9 Availability of roadmap for waste transportation of MSW as per Swachh city plan	×	×	✓	✓
B. Water Supply Management				
10. Coverage of water supply connections	✓	✓	✓	✓
11. Continuity of water supplied in terms of average number of hours per day	✓	✓	✓	✓
12. Identification of water sources and exploitation of underground water	✓	✓	✓	✓
C. Sewerage and Sanitation				
13. Coverage of sewerage	✓	✓	✓	✓
14. Collection efficiency of sewage network	✓	✓	✓	✓
15.Adequacy of sewage treatment capacity	✓	✓	✓	✓
16 Quality of treated sewage	✓	✓	✓	✓

Table 4.5: Appropriateness of Environmental Indicators for Sustainable Cities based on CITYkeys Indicators criteria (Bosch et al., 2017)

	CITYKeys Indicators criteria (Bosch et al., 2017)				
Sustainable City Environmental Indicators	**(i)Relevance**	**(ii)Completeness**	**(iii)Availability**	**(iv)Measurability**	**(v)Reliability**
A. Solid Waste Management					
1. Household Coverage	✓	✓	✓	✓	✓
2. Degree of Segregation	✓	✓	✓	✓	✓
3. Efficiency in collection of MSW	✓	✓	✓	✓	✓
4. Extent of solid waste recovered	✓	✓	✓	✓	✓
5. Degree of scientific disposal of MSW	✓	✓	✓	✓	✓
6. Extent of cost recovery in SWM	✓	✓	✓	✓	✓
B. Water Supply Management					
7. Coverage of water supply connections	✓	✓	✓	✓	✓
8. Continuity of water supplied in terms of average number of hours per day	✓	✓	✓	✓	✓
9. Identification of water sources and exploitation of underground water	✓	✓	✓	✓	✓
C. Sewerage and Sanitation					
10. Coverage of sewerage	✓	✓	✓	✓	✓
11. Collection efficiency of sewage network	✓	✓	✓	✓	✓
12. Adequacy of sewage treatment	✓	✓	✓	✓	✓

In order to propose and plan Smart Cities as 'Environmentally Sustainable Smart Cities' in India, a set of 20 additional parameters are screened from available literature related with sustainable cities across the world. Out of these 20 additional parameters, only 16 could be found satisfying the requirements of appropriateness as indicator, as per WBED (2002) criteria. When these 16 indicators are further subjected to evaluation on 7 criteria, used by CITYkeys Indicator program (Bosch et al., 2017), only 13 (5 under category A, 2 under category B, 3 under category C, 1 under D and 2 under category E) are found fully satisfying the requirements as environmental indicators and 3 parameters are found to be inadequately defined. Accordingly, a set of 24 indicators are suggested (7 for Solid Waste Management, 7 for Water Supply Management, 6 for Sewerage and Sanitation, 1 for Storm Water Management and 3 under Pollution) which can be used in the scientific framework, named as DSS-ESSC for evaluation and monitoring purposes. The sources of data under Indian administrative set up and programs have also been identified. On the lines of the indices developed for Smart Cities, the selected indicators are envisaged to be used to develop a Smart City Environmental Sustainability Index (SCESI) which may be used to assess the comparative performance of cities on the scale of smartness and sustainability with increasing investment and improving urban infrastructure.

Table 4.6: Environmental indicators suggested for ESSC framework

Indicators included in Smart Cities Mission (MoUD , 2015)	**Additional indicators desirable to be included for 'Sustainable Smart Cities' and their sources in India**
A. Solid Waste Management	
1. Recycling and reduction of construction and demolition waste	1. Degree of segregation (MoUD, 2012, MoUD, 2017)
2. Solid waste management programs carried in the city during last 3 years.	2. Efficiency in collection of MSW (MoUD, 2012, MoUD, 2017)

	3. Extent of solid waste recovered (MoUD, 2012)
	4. Degree of scientific disposal of MSW (MoUD, 2012)
	5. Extent of cost recovery in Solid Waste Management (MoUD, 2012)
B. Water Supply Management	
3. Adequate water supply	6. Continuity of water supplied in terms of average no of hours per day (MoUD, 2012)
4. Smart meters and Management	7. Identification of water sources and Exploitation of underground water (JICA, 2016)
5. Leakage identification	
6. Water quality monitoring	
7. Extent of cost recovery in water supply services	
C. Sewerage And Sanitation	
8. Coverage of toilets	8. Adequacy of sewage treatment capacity (MoUD, 2012)
9. Waste water recycling	9. Collection efficiency of sewage network (MoUD, 2012)
10. Extent of cost recovery	10. Quality of treated sewage (MoUD, 2012)
D. Storm Water Drainage	
	11. Coverage of storm water drainage (MoUD, 2012)
E. Pollution	
11. Improvement in Air Quality	12. Noise Pollution (BIS, 2016)
	13. Quality of surface water bodies (BIS, 2016)

4.1.3 Finalized domains and their corresponding indicators

The screening process of indicators process resulted in selection of 24 environmental indicators divided in five domains: Solid Waste Management, Water Supply Management, Sewerage and Sanitation, Storm water drainage, and Pollution. As the Storm water drainage domain had only one indicator, it may be merged with Sewerage and Sanitation to give Sewerage, Sanitation and Storm water management domain to avoid discrepancy in weight. As SCESI has unilateral behaviour, some of the indicators name is renamed to reflect the coherency with the score obtained. Pollution domain was renamed as Ambient Environment Condition (AEC) to reflect all the three components, i.e. air, noise and surface water bodies. In addition, 'improvement in air quality' is renamed as Ambient Air Quality, noise pollution as Ambient Sound Level and quality of surface water bodies as Ambient Surface water quality. Thus, for the purpose of present study, the environmental sustainability has been analysed under four broad domains: Solid Waste Management (SWM), Water Supply Management (WSM), Sewerage, Sanitation and Storm water management (SSS) and Ambient Environment Condition (AEC). Accordingly, there are 7 indicators under SWM, 7 for WSM, 7 for SSS and 3 for AEC domains (Table 5.7). Corresponding to these four domains of environment considered, the respective domain indices (DIs) have been named as Solid Waste Management Index (SWMI), Water Supply Management Index (WSMI), Sewerage, Sanitation and Storm water Management Index (SSSI) and Ambient Environment Condition Index (AECI) and their combined effect is reflected in Smart City Environmental Sustainability Index (SCESI).

Table 4.7: Finalized domains and their corresponding indicators

Indicators (x_k)	**Abbreviations**
A. Solid Waste Management	**SWM**
1. Efficiency in collection of MSW	EC
2. Degree of Segregation	DS
3. Extent of solid waste recovered	SWR
4. 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. Solid Waste Management 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 hrs	CW

per day	
12. Water Quality Monitoring	WQ
13. Exploitation of underground water	$E_{UG}W$
14. Extent of cost recovery in water supply services	CR_{WS}
C. Sewerage, Sanitation and Storm water Management	**SSS**
15. Collection efficiency of Sewage Network	CE
16. Adequacy of sewage treatment capacity	AS
17. Quality of treated sewage	QTS
18. Waste water recycling	WWR
19. Extent of Cost Recovery	CR_{SSS}
20. Coverage of toilets	CT
21. Coverage of Storm Water Drainage	CSWD
D. Ambient Environment Condition	**AEC**
22. Ambient Air Quality	AAQ
23. Ambient Sound Level	ASL
24. Ambient Surface Water Quality	ASW

4.2 Assigning weights for the indicators

Equal weighting approach is used for the environmental domains and Delphi methodology is carried out for assigning weight to the indicators under the same domain. For allocation of weights a comprehensive questionnaire is prepared and responses from 30 experts including academicians, researchers and policymakers are gathered on a scale of 1 (Least important) to 5 (Most important) (Table 4.8). Thereafter, the collected response is analysed by Delphi Technique. The statistical tool median and mode is used in the Delphi studies to present the collective judgements. The calculated weight based on the significance levels for each of the indicator is given in Table 4.9.

Table 4.8: Expert opinion on the scale of 1(Least Important) to 5 (Most Important)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
A. SOLID WASTE MANAGEMENT (SWM)																															
DS		3	5	5	5	5	5	3	4	5	3	3	5	4	5	5	5	4	3	3	5	4	5	5	4	3	3	4	5	5	5
EC		5	5	5	5	5	3	4	5	4	4	3	5	4	3	5	2	4	3	4	3	5	5	4	4	3	3	3	3	4	5
SWR		4	5	4	5	4	2	4	4	5	3	5	5	5	4	3	3	5	5	5	5	4	4	3	4	5	5	4	4	4	4
SD		5	5	5	4	4	4	5	4	5	5	5	5	5	4	4	4	4	3	5	4	4	4	5	5	5	4	4	4	4	4
SWMP		2	2	1	0	1	3	3	3	4	3	4	3	2	1	3	3	0	2	2	1	3	2	2	1	1	3	3	2	2	2
RCD		3	3	4	3	3	4	4	5	4	4	4	3	4	4	5	3	3	3	3	4	3	5	1	3	4	2	4	3	2	3
CR_{SWM}		4	3	3	2	3	2	3	3	4	3	3	2	4	3	3	3	4	4	4	3	3	3	3	5	4	4	4	5	3	4
B. WATER SUPPLY MANAGEMENT (WSM)																															
AW	4	5	4	5	5	3	3	3	4	4	4	5	5	3	3	3	4	5	5	3	4	5	3	3	4	4	4	4	3	3	5
SMM	3	4	5	4	4	3	4	5	5	3	1	3	4	4	3	3	5	5	4	3	3	4	5	4	4	4	4	3	3	4	4
LI	3	4	5	4	4	2	3	4	3	3	3	4	3	5	5	4	4	4	4	4	3	4	4	3	3	3	3	3	4	3	3
WQ	2	3	3	3	4	4	5	4	3	5	4	3	3	1	2	4	3	4	3	4	4	2	3	3	4	4	3	3	3	3	3
CR_{WS}	5	5	5	5	5	5	4	5	5	4	3	4	4	5	5	5	4	3	3	4	4	5	5	4	3	4	5	3	5	5	4
CW	5	5	3	5	4	3	3	2	4	4	5	4	4	5	5	5	4	4	5	4	5	5	5	4	4	4	3	4	4	5	5
$E_{UG}W$	3	3	3	2	2	2	3	3	4	3	2	4	2	3	3	3	3	4	3	3	1	3	3	2	3	3	3	3	3	3	3
C. SEWERAGE SANITATION AND STORM WATER MANAGEMENT																															
CT	5	5	5	4	5	4	4	5	5	5	3	5	5	4	4	4	3	4	5	5	5	4	4	5	5	5	4	5	3	5	5
WWR	4	5	3	4	5	5	5	5	5	5	5	4	4	3	5	5	5	4	4	4	3	4	5	5	3	3	4	4	5	5	5
CR_{SSS}	4	5	5	3	4	4	5	5	4	4	4	5	5	4	4	3	4	4	5	5	5	4	4	4	4	3	4	3	3	4	5
AS	4	5	5	4	3	4	4	5	5	4	4	5	5	4	4	3	5	5	5	4	3	4	5	4	5	5	4	4	4	4	3
CE	3	4	2	5	5	3	4	3	4	4	4	3	4	5	5	5	4	4	4	5	5	5	5	5	5	4	5	3	3	3	5
QTS	2	3	3	2	2	1	3	2	3	3	4	1	3	3	3	2	2	3	3	3	3	4	4	4	3	3	3	4	4	3	2
CSWD	4	4	2	3	5	3	2	4	3	3	4	4	4	3	4	5	5	4	3	4	3	3	5	5	4	5	3	3	4	5	3
D. AMBIENT ENVIRONMENT CONDITIONS																															
ASL	3	4	4	3	3	4	4	4	3	5	4	5	5	5	4	4	3	5	5	5	3	4	4	5	5	5	4	3	3	4	4
ASW	3	4	3	4	3	4	5	5	5	5	5	5	4	4	4	3	3	3	3	3	4	3	3	3	5	3	3	4	4	3	3
AAQ	5	4	5	5	5	5	5	5	5	5	5	5	4	4	5	5	5	4	5	4	5	4	4	4	5	5	5	5	5	5	4

Table 4.9: Weight of selected indicators

Indicators (x_k)	Weights (w_k)
A. Solid Waste Management (SWM)	
1. Efficiency in collection of MSW (EC)	0.155
2. Degree of Segregation (DS)	0.171
3. Extent of solid waste recovered (SWR)	0.163
4. Degree of scientific disposal of MSW (SD)	0.165
5. Recycling and reduction of construction and demolition waste (RCD)	0.133
6. Extent of cost recovery in Solid Waste Management (CR_{SWM})	0.130
7. Solid Waste Management programs carried in the city during last 3 years (SWMP)	0.083
Total	**1.000**
B. Water Supply Management (WSM)	
8. Adequacy of Water Supply (AW)	0.151
9. Smart meters and Management (SMM)	0.145
10. Leakage identification (LI)	0.138
11. Continuity of water supplied in terms of average no of hrs per day(CW)	0.127
12. Water Quality Monitoring (WQ)	0.167
13. Exploitation of underground water ($E_{UG}W$)	0.163
14. Extent of cost recovery in water supply services (CR_{WS})	0.109
Total	**1.000**
C. Sewerage, Sanitation and Storm water Management (SSS)	
15. Collection efficiency of Sewage Network (CE)	0.156
16. Adequacy of sewage treatment capacity (AS)	0.149
17. Quality of treated sewage (QTS)	0.152
18. Waste water recycling (WWR)	0.148
19. Extent of Cost Recovery (CR_{SSS})	0.101
20. Coverage of toilets (CT)	0.160
21. Coverage of Storm Water Drainage (CSWD)	0.134
Total	**1.000**
D. Ambient Environment Condition (AEC)	
22. Ambient Air Quality (AAQ)	0.376
23. Ambient Sound Level (ASL)	0.325
24. Ambient Surface Water Quality (ASW)	0.299
Total	**1.000**

4.3 Benchmarking of selected indicators

The performance levels of the cities must be monitored against some standards, hence benchmarking is done for each of the finalized indicators. It will help the policymakers to analysis the gap in the performance of the poor categories indicators and introduce the best practices. Benchmarked Indicator value (BIV) of each indicator is obtained on a scale of 0 to 100 and classified into 4 categories: Excellent, Good, Average, and Poor. Benchmarking of all 24 indicators individually on a 0-100 scale, based on standards is done which gives a comparative view of areas of urgent attention, investment and improvement to get better environmental gains.

The indicators based on the logical conditions include Solid Waste Management Programs carried in the city during last 3 years, Recycling and reduction of construction and demolition waste under SWM and Exploitation of underground water in WSM (Table 4.10).

4.4 Grouping of indicators and Domain Indices (DIs)

Based on the data and weights of the selected indicators, indicator score (IS) is calculated. Summation of indicator score of respective domains gives domain indices (DIs). Smart City Environmental Sustainability Index (SCESI) is the summation of Domain Indices which is calculated on a unidirectional scale of 0 to 100.Higher the score of SCESI on the scale of 100 implies that cities are more aligned towards the smartness and sustainability quotient. SCESI will monitor the progress in a specified time frame to assess the performance of the cities. It will serve as a tool to monitor investments under Special Purpose Vehicle and guide the city to make action plans for improvements. Grouping of indicators and calculation of Domain Indices (DIs) is discussed in the next sub-section.

Table 4.10: Benchmarking of indicators (Benchmarking criteria as per MoUD, 2012 guidelines)

Indicator	Method of Benchmarking	Best level of Performance for Benchmarking	Classification based on Benchmarked Indicator Value (BIV) (x_k)			
			A	B	C	D
A. Solid Waste Management (SWM)						
1. Efficiency in collection of MSW	Amount of MSW collected/Total amount of MSW generated	100% of MSW generated should be collected.	> 0.9	0.7-0.9	0.5-0.7	0-0.5
2. Degree of Segregation	Amount of waste segregated/Total solid waste collected	100% of collected solid waste should be segregated.	> 0.5	0.25-0.5	0-0.25	0
3. Extent of Solid Waste recovered	Amount of waste recycled/ Amount of MSW collected	80% of collected solid waste should be recovered.	> 0.5	0.25-0.5	0-0.25	0
4. Degree of Scientific disposal of MSW	Amount of MSW disposed in sanitary landfills/Total MSW disposed	100% MSW disposed should go to sanitary landfills.	> 0.5	0.25-0.5	0-0.25	0
5. Recycling and reduction of construction and demolition waste	Availability of separate system for Construction & Demolition waste (Y or N)	Recycling and reduction of C&D waste should have been started.	1			0
6. Extent of cost recovery in Solid Waste Management	Total revenues earned from MSWM / Total expenses on MSWM	100% of expenses incurred on MSWM should be recovered as revenue.	> 0.6	0.3-0.6	0-0.3	0
7. SWM programs carried in the city during last 3 years	SWM programs carried in the city during 3 years (Y or N)	SWMP should have been started within last three years.	1			0

B. Water Supply Management (WSM)						
8. Adequacy of water supply	Water supplied (lpcd)/ 135	135 lpcd.	> 0.75	0.50-0.75	0.25-0.50	0-0.25
9. Smart meters and Management	Number of metered connections/ Total water supply connections	100% of area covered by water supply connections should be metered.	> 0.75	0.50-0.75	0.25-0.50	0-0.25
10. Leakage Identification	Volume of productive water/ Total volume of water supply	80% volume of water supply should be productive.	0.80	0.70-0.80	0.70-0.50	<0.50
11. Continuity of water supplied in terms of average no of hours per day	Hours of water supply hours/24	24 h * 7days	> 0.80	0.40-0.80	0.20-0.40	0-0.20
12.Water quality monitoring	Area of water supply meeting water quality standards for drinking/ Total area covered with water supply	100% of area under water supply should meet drinking quality standards.	> 0.90	0.70-0.90	0.40-0.70	0-0.40
13. Water sources and extent of exploitation of ground water	Ground Water Table increasing or decreasing	Ground Water Table should be almost constant.	1			0
14. Extent of cost recovery in water supply services	Revenue earned from water bills/ Total Cost in public water supply	100% of cost of public water supply should be recovered through water bills.	> 0.75	0.50-0.75	0.25-0.50	0-0.25
C. **Sewerage, Sanitation and Storm water Management (SSS)**						
15. Collection efficiency of sewage network	Volume of wastewater collected/ Volume of total wastewater generated per day	100% of waste water volume should be collected.	> 0.7	0.4-0.7	0-0.4	0

16. Adequacy of sewage treatment capacity	Wastewater given secondary treatment / Total volume of wastewater generation per day	100% of domestic sewage should be given treatment up to secondary level.	> 0.7	0.4-0.7	0-0.4	0
17. Quality of treated sewage	No of treated wastewater samples which abide by the standards/ Total number of samples collected.	100% of samples should meet secondary treatment effluent standards.	> 0.9	0.8-0.9	0.4-0.8	0-0.4
18. Wastewater recycling	Volume of recycling and reuse of wastewater / Volume of treated waste water recovered per day	More than 20% of total treated waste water should be recycled in the city.	> 0.2	0.1-0.2	0-0.1	0
19. Extent of cost recovery	Cost recovered from sewage management/ Total cost involved.	100% of total cost incurred on sewage management should be targeted to be recovered.	> 0.6	0.3-0.6	0-0.3	0
20. Coverage of toilets	Urban population having access to toilets/ Total urban population	100% of urban population should have access to toilets.	> 0.9	0.7-0.9	0.35-0.7	0-0.35
21. Coverage of storm water drainage	Length covered by the storm water drainage/ Total Road length	100% of roads should be covered with storm water drainage.	> 0.6	0.1-0.6	0.3-0.6	0-0.3
D. **Ambient Environment Condition (AEC)**						
22. Ambient Air Quality	(500-Air Quality Index)/500	Air Quality Index should be less than 50.	> 0.75	0.50-0.75	0.25-0.50	0-0.25
23. Ambient Sound Level	Number of samples abiding the standards of Noise Pollution Regulation Act, 2000 to the total number of samples surveyed.	In industrial areas, the permissible noise limit should be 75 dB for daytime and 70 dB at night. In commercial areas, it should be 65 dB and 55 dB while in residential areas limit should be 55 dB and 45 dB during daytime and night respectively. The noise limit in	> 0.75	0.50-0.75	0.25-0.50	0-0.25

		silence zone should be 50 dB during the day and 40 dB during the night.				
24. Ambient Surface Water Quality	Number of surface water samples abiding the standards of bathing to the total number of samples collected	Surface water bodies should meet following criteria for bathing purpose: 1. Total Coliform Organism MPN/100 ml = 500 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen = 5 mg/l or more 4. Biochemical Oxygen Demand 5 days 20ºC =3 mg/l or less	> 0.75	0.50-0.75	0.25-0.50	0-0.25

4.4.1 Solid Waste Management Index (SWMI)

Solid waste management is one of the most important issues in a Smart City which not only affect the health and hygiene, but also the aesthetics and general appearance of the city. The objective is to reduce and reuse the solid waste generated to minimise the environmental impacts. The effectiveness of solid waste management may be measured through calculating Solid Waste Management Index (SWMI), using seven selected indicator scores (ISs), and may be written as:

$$SWMI = (\Sigma\, IS) = (ECS + DSS + SWRS + SDS + RCDS + CR_{SWM}S + SWMPS) \qquad (4.1)$$

Where ECS, DSS, SWRS, SDS, SWMPS, RCDS and $CR_{SWM}S$ are the indicator scores (ISs) obtained through the respective BIV (x_k) and weight (w_k) using eq. (3.3).

4.4.2 Water Supply Management Index (WSMI)

The rapid increase in population along with urbanization and industrialization has resulted in adverse impact on quality and quantity of water in India. This alarming situation requires immediate redressal through radically improved water resource and water quality management strategies (Babel et.al, 2016).

The Water Supply Management Index (WSMI) may be calculated using its 7 selected indicator scores (ISs):

$$WSMI = \Sigma\, (IS) = (AWS + SMMS + LIS + WQS + CWS + E_{UG}WS + CR_{WS}S) \qquad (4.2)$$

For benchmarking in water supply, adequacy is calculated with reference to 135 lpcd (Benchmark set by MoUD, GoI, 2012). The continuity of water is calculated in terms of average number of hours of water supply, which has a benchmark of 24h. For calculation of exploitation of underground water, the ground water table (GWT) data of 5 years for dug wells in pre-monsoon, monsoon and post–monsoon periods are collected (e.g. from Central Groundwater Board sources). If GWT shows almost a constant level within limits, BIV = 1, and if there is significant declining trend then it is taken as 0.

4.4.3 Sewerage, Sanitation and Storm water Management Index (SSSI)

The geometric population growth had increased the amount of waste discharged in the environment thus developing an increased demand of fresh water. To face the challenging situation of water scarcity, and to reduce the pressure upon the scarcer resources, wastewater recycle and reuse can be an alternative option. Storm water is the major carrier of the contaminants and hence the management strategies should be implemented in a manner that they can reduce sediment load, nutrients and chemical pollutants before reaching natural water sources. The indicators selected for proper management of waste waters, sanitation and storm water drainage in an environmentally sustainable smart city has been enlisted Table 4.7. SSSI is calculated using the 7 selected indicator scores (ISs) as:

$$SSSI = (\Sigma\ IS) = (CES + ASS + QTSS + WWRS + CTS + CR_{SSS}S + CSWDS) \quad (4.3)$$

4.4.4 Ambient Environment Condition Index (AECI)

Under ambient environment, urban inhabitants are exposed to air pollution, noise pollution and are affected by the quality of surface water bodies. The indicators selected for monitoring proper Ambient Environment Condition in an ESSC have been enlisted in Table 4.9. The AECI is calculated using three selected Indicator Scores (ISs) and given by:

$$AECI = \Sigma\ (IS) = (AAQS + ASLS + ASWS) \quad (4.4)$$

Where AAQS, ASLS and ASWS are related indicator scores for air, noise and surface water bodies respectively. The condition of ambient air quality (AAQ) is found using Air Quality Index (AQI), which is tool developed by the Central Pollution Control Board (CPCB) for effective communication of air quality status of the city. It transforms complex air quality data of various pollutants into a single number. Lower is AQI of a city, better is the air environment. Its highest value is 500. AQI is based on sub-index and health breakpoints evolved for eight pollutants (PM10, PM2.5, NO_2, SO_2, CO, O_3, NH_3, and Pb). Based on the measured ambient concentrations of a pollutant, sub-index is calculated, which is a linear function of concentration (e.g. the sub-index for PM2.5 will be 51 at concentration 31 $\mu g/m^3$, 100 at concentration 60 $\mu g/m^3$, and 75 at concentration of 45 $\mu g/m^3$. The worst sub-index determines the overall AQI. AQI is calculated only if data are available for minimum three pollutants out of which one should necessarily be either PM2.5 or PM10 (BIS, 2016).

In order to make it an incremental value index, we calculate the Ambient Air Quality Score (AAQS) given by:

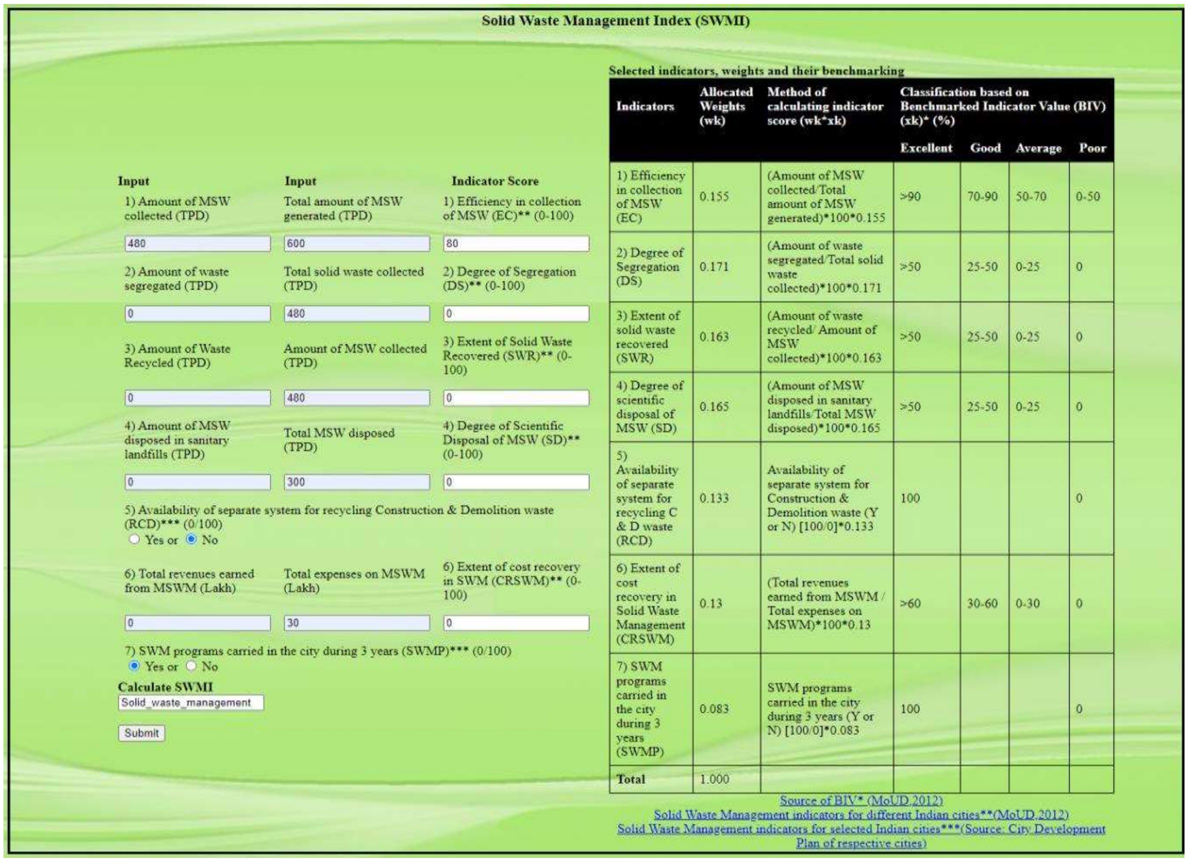
$$AAQS = (500 - \text{Air Quality Index})/500 \quad (4.4)$$

For ambient sound level (ASL), the data is collected from residential, commercial, industrial and silence zones of the city and compared with the standards given by Noise Pollution (Regulation and Control) Rules, 2000. Noise pollution is calculated by mapping the noise level L (day-evening-night) likely to cause annoyance as given in ISO 1996-2:1987 and identifying the areas of the city where L is greater than 55 dB(A) and estimating the population of those areas as a percentage of the total city population. For night L when exceeding 50 dB(A) is likely to cause sleep deprivation. The result shall be expressed as the percentage of the population affected by noise pollution.

For ambient surface water quality (ASWQ), pH, biochemical oxygen demand (BOD), dissolved oxygen (DO) and total coliform (TC) of canals, ponds, and rivers within the city zone are collected and compared with the standards for bathing water quality in India. The number of samples meeting the standards to the total number of samples collected gives the quality of ambient surface water quality. The index developed is modelled to a software tool, DSS-ESSC for hassle free calculations and decision-making, regarding priority domains and indicators in which a city can invest for improving the prevalent scenario. The validation of DSS-ESSC is discussed in the nest section.

4.5 Validation of DSS-ESSC using data of Varanasi (a city under SCM)

The working of DSS-ESSC is validated on the available secondary data for the Varanasi city. User enters the required information and the SCESI along with the domain indices is displayed on the result page. Firstly, the user enters the data of query column field for SWM domain (Fig. 4.1). After submitting the data the user is redirected to the DI page which displays the Poor category of SWMI along with probable improvement measures (Fig. 4.2). Further same process is repeated for other domains which is shown in Fig. 4.3-4.8. On the result page, the domains are displayed in the order of Critically Low to Excellent with three poorly performing indicators for each domain (Fig. 4.9). The order of domain indices in which the improvement is required comes as Ambient Environment Condition Index (Critically low), Solid Waste Management Index (Poor), Water Supply Management Index (Fair) and Sewerage, Sanitation and Storm water Management Index (Fair). The order of priority indicator for the Critically Low domain index AECI, that should be targeted for investing fund is Ambient sound level, Ambient surface water quality followed by Ambient Air Quality. The performance of the Ambient sound level and Ambient surface water quality is equal but the former has higher weight, hence it is on the top of priority indicators list.



Solid Waste Management Index (SWMI)

Input	Input	Indicator Score
1) Amount of MSW collected (TPD)	Total amount of MSW generated (TPD)	1) Efficiency in collection of MSW (EC)** (0-100)
480	600	80
2) Amount of waste segregated (TPD)	Total solid waste collected (TPD)	2) Degree of Segregation (DS)** (0-100)
0	480	0
3) Amount of Waste Recycled (TPD)	Amount of MSW collected (TPD)	3) Extent of Solid Waste Recovered (SWR)** (0-100)
0	480	0
4) Amount of MSW disposed in sanitary landfills (TPD)	Total MSW disposed (TPD)	4) Degree of Scientific Disposal of MSW (SD)** (0-100)
0	300	0

5) Availability of separate system for recycling Construction & Demolition waste (RCD)*** (0/100)
Yes or No

6) Total revenues earned from MSWM (Lakh)	Total expenses on MSWM (Lakh)	6) Extent of cost recovery in SWM (CRSWM)** (0-100)
0	30	0

7) SWM programs carried in the city during 3 years (SWMP)*** (0/100)
Yes or No

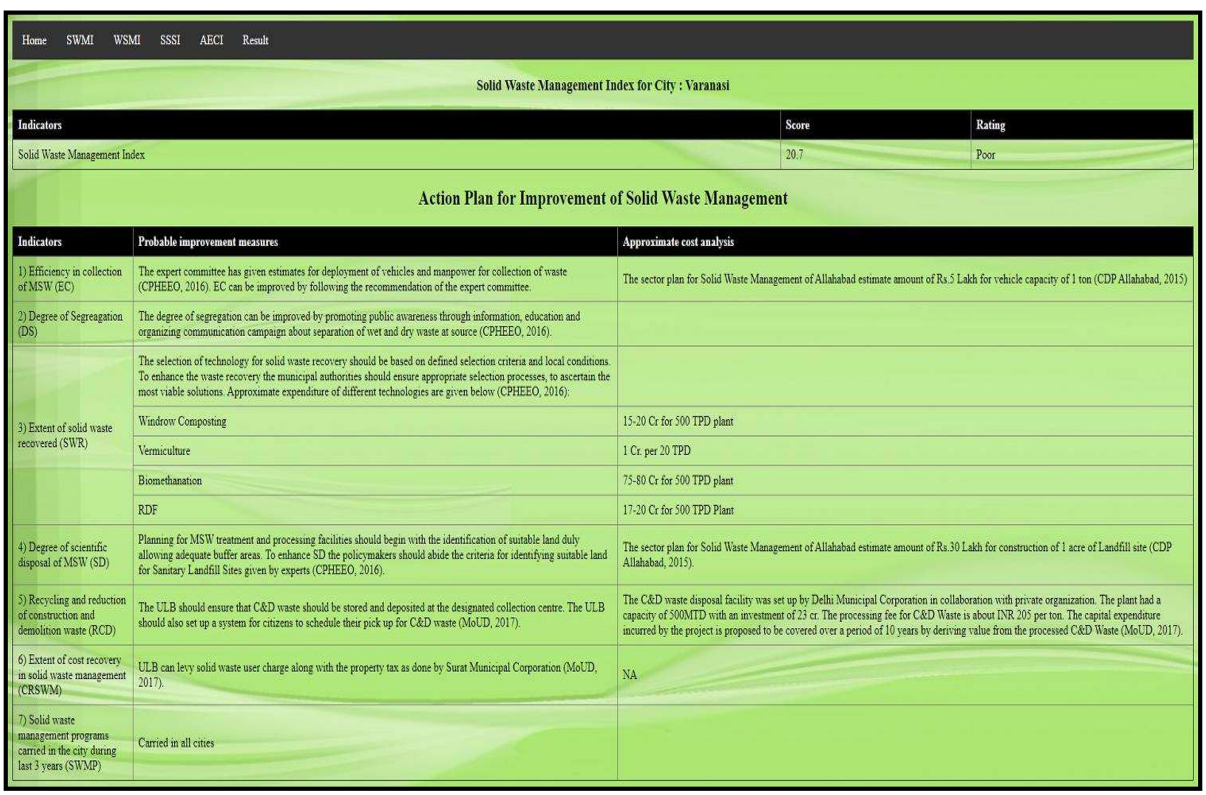
Calculate SWMI
Solid_waste_management
Submit

Selected indicators, weights and their benchmarking

Indicators	Allocated Weights (wk)	Method of calculating indicator score (wk*xk)	Classification based on Benchmarked Indicator Value (BIV) (xk)* (%)			
			Excellent	Good	Average	Poor
1) Efficiency in collection of MSW (EC)	0.155	(Amount of MSW collected/Total amount of MSW generated)*100*0.155	>90	70-90	50-70	0-50
2) Degree of Segregation (DS)	0.171	(Amount of waste segregated/Total solid waste collected)*100*0.171	>50	25-50	0-25	0
3) Extent of solid waste recovered (SWR)	0.163	(Amount of waste recycled/ Amount of MSW collected)*100*0.163	>50	25-50	0-25	0
4) Degree of scientific disposal of MSW (SD)	0.165	(Amount of MSW disposed in sanitary landfills/Total MSW disposed)*100*0.165	>50	25-50	0-25	0
5) Availability of separate system for recycling C & D waste (RCD)	0.133	Availability of separate system for Construction & Demolition waste (Y or N) [100/0]*0.133	100			0
6) Extent of cost recovery in Solid Waste Management (CRSWM)	0.13	(Total revenues earned from MSWM / Total expenses on MSWM)*100*0.13	>60	30-60	0-30	0
7) SWM programs carried in the city during 3 years (SWMP)	0.083	SWM programs carried in the city during 3 years (Y or N) [100/0]*0.083	100			0
Total	1.000					

Source of BIV* (MoUD 2012)
Solid Waste Management indicators for different Indian cities**(MoUD 2012)
Solid Waste Management indicators for selected Indian cities***(Source: City Development Plan of respective cities)

Fig. 4.1: Screenshot of Solid Waste Management Index (SWMI) page



Home SWMI WSMI SSSI AECI Result

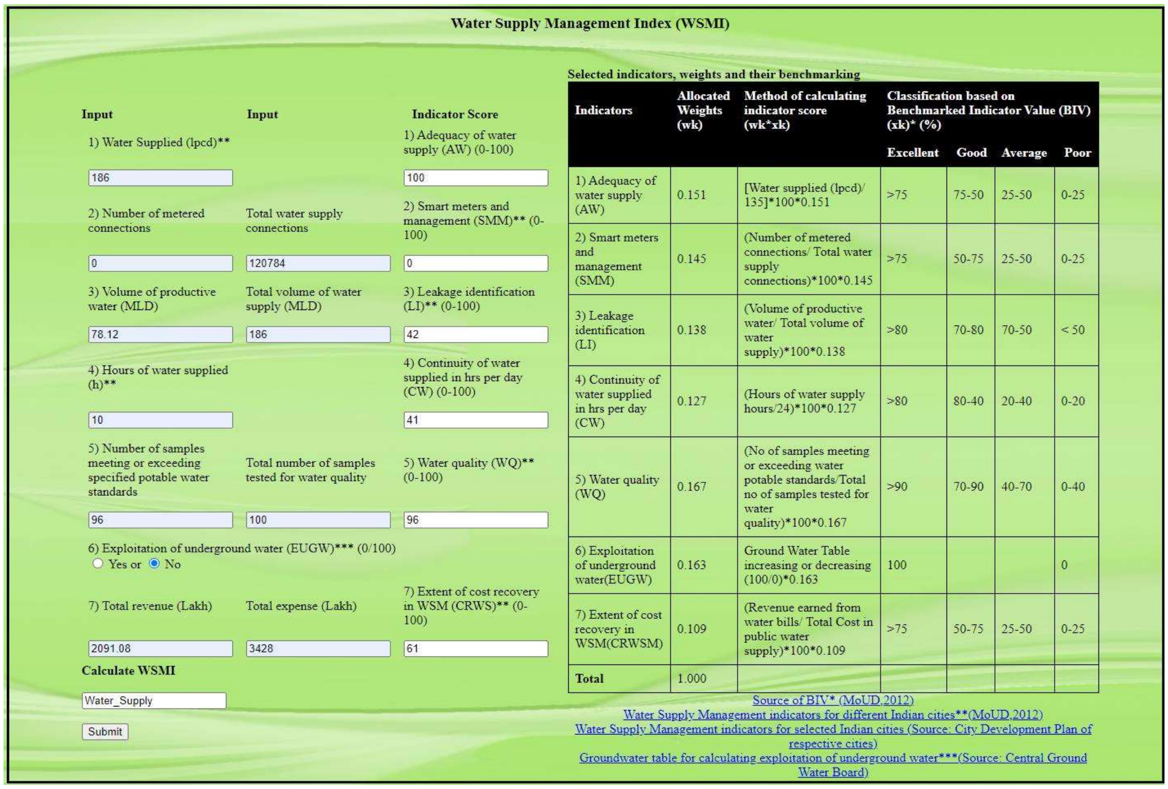
Solid Waste Management Index for City : Varanasi

Indicators	Score	Rating
Solid Waste Management Index	20.7	Poor

Action Plan for Improvement of Solid Waste Management

Indicators	Probable improvement measures	Approximate cost analysis
1) Efficiency in collection of MSW (EC)	The expert committee has given estimates for deployment of vehicles and manpower for collection of waste (CPHEEO, 2016). EC can be improved by following the recommendation of the expert committee.	The sector plan for Solid Waste Management of Allahabad estimate amount of Rs.5 Lakh for vehicle capacity of 1 ton (CDP Allahabad, 2015)
2) Degree of Segreagation (DS)	The degree of segregation can be improved by promoting public awareness through information, education and organizing communication campaign about separation of wet and dry waste at source (CPHEEO, 2016).	
3) Extent of solid waste recovered (SWR)	The selection of technology for solid waste recovery should be based on defined selection criteria and local conditions. To enhance the waste recovery the municipal authorities should ensure appropriate selection processes, to ascertain the most viable solutions. Approximate expenditure of different technologies are given below (CPHEEO, 2016):	
	Windrow Composting	15-20 Cr for 500 TPD plant
	Vermiculture	1 Cr. per 20 TPD
	Biomethanation	75-80 Cr for 500 TPD plant
	RDF	17-20 Cr for 500 TPD Plant
4) Degree of scientific disposal of MSW (SD)	Planning for MSW treatment and processing facilities should begin with the identification of suitable land duly allowing adequate buffer areas. To enhance SD the policymakers should abide the criteria for identifying suitable land for Sanitary Landfill Sites given by experts (CPHEEO, 2016).	The sector plan for Solid Waste Management of Allahabad estimate amount of Rs.30 Lakh for construction of 1 acre of Landfill site (CDP Allahabad, 2015).
5) Recycling and reduction of construction and demolition waste (RCD)	The ULB should ensure that C&D waste should be stored and deposited at the designated collection centre. The ULB should also set up a system for citizens to schedule their pick up for C&D waste (MoUD, 2017).	The C&D waste disposal facility was set up by Delhi Municipal Corporation in collaboration with private organization. The plant had a capacity of 500MTD with an investment of 23 cr. The processing fee for C&D Waste is about INR 205 per ton. The capital expenditure incurred by the project is proposed to be covered over a period of 10 years by deriving value from the processed C&D Waste (MoUD, 2017).
6) Extent of cost recovery in solid waste management (CRSWM)	ULB can levy solid waste user charge along with the property tax as done by Surat Municipal Corporation (MoUD, 2017).	NA
7) Solid waste management programs carried in the city during last 3 years (SWMP)	Carried in all cities	

Fig. 4.2: Screenshot of Solid Waste Management Index (SWMI) page



Water Supply Management Index (WSMI)

Input	Input	Indicator Score
1) Water Supplied (lpcd)**		1) Adequacy of water supply (AW) (0-100)
186		100
2) Number of metered connections	Total water supply connections	2) Smart meters and management (SMM)** (0-100)
0	120784	0
3) Volume of productive water (MLD)	Total volume of water supply (MLD)	3) Leakage identification (LI)** (0-100)
78.12	186	42
4) Hours of water supplied (h)**		4) Continuity of water supplied in hrs per day (CW) (0-100)
10		41
5) Number of samples meeting or exceeding specified potable water standards	Total number of samples tested for water quality	5) Water quality (WQ)** (0-100)
96	100	96

6) Exploitation of underground water (EUGW)*** (0/100)
Yes or No

Input	Input	Indicator Score
7) Total revenue (Lakh)	Total expense (Lakh)	7) Extent of cost recovery in WSM (CRWS)** (0-100)
2091.08	3428	61

Calculate WSMI

Water_Supply

Submit

Selected indicators, weights and their benchmarking

Indicators	Allocated Weights (wk)	Method of calculating indicator score (wk*xk)	Classification based on Benchmarked Indicator Value (BIV) (xk)* (%)			
			Excellent	Good	Average	Poor
1) Adequacy of water supply (AW)	0.151	[Water supplied (lpcd)/ 135]*100*0.151	>75	75-50	25-50	0-25
2) Smart meters and management (SMM)	0.145	(Number of metered connections/ Total water supply connections)*100*0.145	>75	50-75	25-50	0-25
3) Leakage identification (LI)	0.138	(Volume of productive water/ Total volume of water supply)*100*0.138	>80	70-80	70-50	< 50
4) Continuity of water supplied in hrs per day (CW)	0.127	(Hours of water supply hours/24)*100*0.127	>80	80-40	20-40	0-20
5) Water quality (WQ)	0.167	(No of samples meeting or exceeding water potable standards/Total no of samples tested for water quality)*100*0.167	>90	70-90	40-70	0-40
6) Exploitation of underground water(EUGW)	0.163	Ground Water Table increasing or decreasing (100/0)*0.163	100			0
7) Extent of cost recovery in WSM(CRWSM)	0.109	(Revenue earned from water bills/ Total Cost in public water supply)*100*0.109	>75	50-75	25-50	0-25
Total	1.000					

Source of BIV* (MoUD,2012)
Water Supply Management indicators for different Indian cities**(MoUD,2012)
Water Supply Management indicators for selected Indian cities (Source: City Development Plan of respective cities)
Groundwater table for calculating exploitation of underground water***(Source: Central Ground Water Board)

Fig. 4.3: Screenshot of Water Supply Management Index (WSMI) page

Home SWMI WSMI SSSI AECI Result

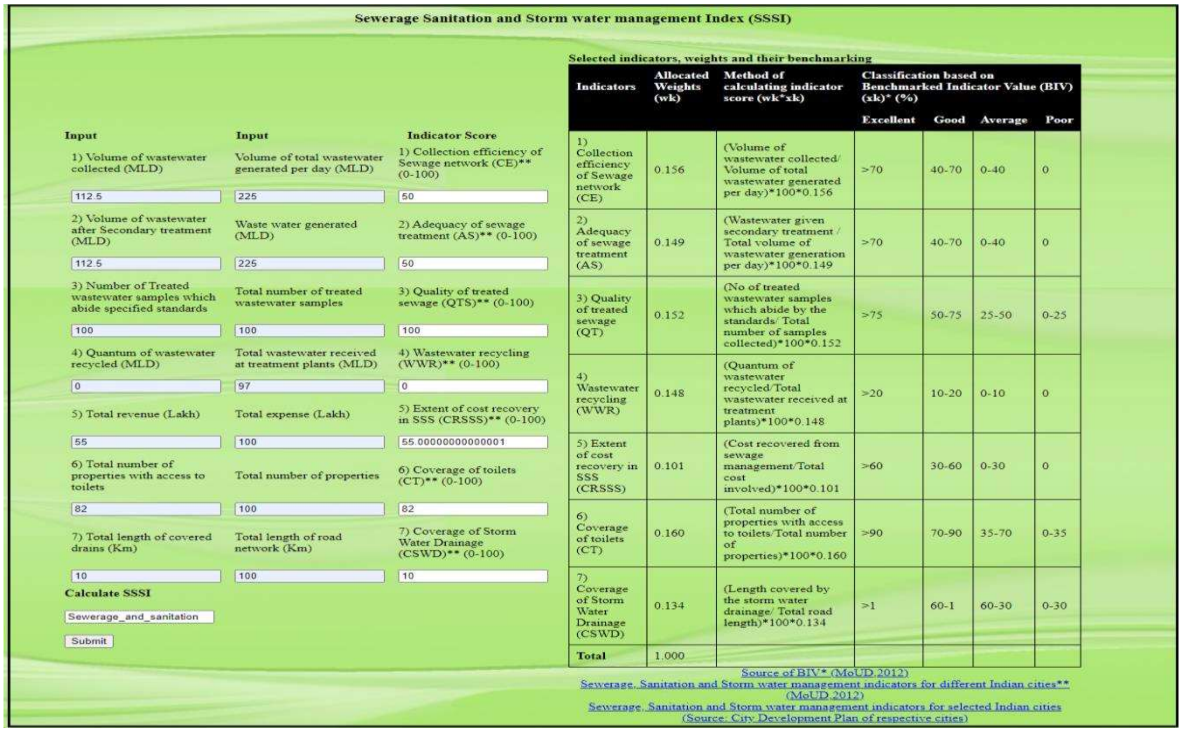
Water Supply Management Index for City : Varanasi

Indicators	Score	Rating
Water Supply Index	48.784	Fair

Action Plan for Improvement of Water Supply Management

Indicators	Probable improvement measures	Approximate cost analysis
1) Adequate water supply (AW)	Development of New Water Sources, strengthening of water treatment plant, replacement of rising and distribution main (JICA, 2016) can enhance per capita water supply.	
2) Smart meters and management (SMM)	Installation of Node MCU System with IoT platform can increase percentage of SMM as it is well-groomed solution for forecasting the usage of water for Smart City. This IoT based concept continuously monitor water usage and if it reaches the minimum amount, it would automatically alert the consumer to recharge (Rasadurai et al, 2017).	
3) Leakage Identification (LI)	Implementation of SCADA with MIS, Survey, 100% metering and Leakage Detection and repair (JICA, 2016)	As per JICA, 2016 estimated amount of 153.33cr is proposed to set up the system which will increase the revenue water of Varanasi from 42% to 70% .
4) Continuity of water supplied in terms of average no of hrs per day (CW)	Installation of pumps of adequate capacity, increased capacity of feeder mains to reservoirs, upgrading of headworks(WSP, 2010)	
5) Water Quality Monitoring (WQ)	Strengthening of lab and online water quality monitoring system (JICA, 2016)	As per JICA, 2016 estimated amount of 0.7cr is proposed to set up the lab which will increase the water quality of Varanasi from 96% to 98% .
6) Exploitation of underground water (EUGW)	Rainwater Harvesting, Groundwater Recharge (Wankhade & Balakrishnan,2014)	
7) Extent of cost recovery in Water Supply Services (CRWS)	Implementing online billing system, spot Billing (Amrut Lucknow, 2015)	An estimated cost of 10 cr is proposed for the implementation of the projects which will increase cost recovery from 60% to 75% in Lucknow.
	Rehabilitate and expansion of payment Collection (Amrut Lucknow, 2015)	An estimated cost of 8 cr is proposed for the implementation of the projects which will increase cost recovery from 60% to 90% in Lucknow.

Fig. 4.4: Screenshot of Water Supply Management Index (WSMI) page



Sewerage Sanitation and Storm water management Index (SSSI)

Input	Input	Indicator Score
1) Volume of wastewater collected (MLD)	Volume of total wastewater generated per day (MLD)	1) Collection efficiency of Sewage network (CE)** (0-100)
112.5	225	50
2) Volume of wastewater after Secondary treatment (MLD)	Waste water generated (MLD)	2) Adequacy of sewage treatment (AS)** (0-100)
112.5	225	50
3) Number of Treated wastewater samples which abide specified standards	Total number of treated wastewater samples	3) Quality of treated sewage (QTS)** (0-100)
100	100	100
4) Quantum of wastewater recycled (MLD)	Total wastewater received at treatment plants (MLD)	4) Wastewater recycling (WWR)** (0-100)
0	97	0
5) Total revenue (Lakh)	Total expense (Lakh)	5) Extent of cost recovery in SSS (CRSSS)** (0-100)
55	100	55.00000000000001
6) Total number of properties with access to toilets	Total number of properties	6) Coverage of toilets (CT)** (0-100)
82	100	82
7) Total length of covered drains (Km)	Total length of road network (Km)	7) Coverage of Storm Water Drainage (CSWD)** (0-100)
10	100	10

Calculate SSSI

Sewerage_and_sanitation

Submit

Selected indicators, weights and their benchmarking

Indicators	Allocated Weights (wk)	Method of calculating indicator score (wk*xk)	Classification based on Benchmarked Indicator Value (BIV) (xk)* (%)			
			Excellent	Good	Average	Poor
1) Collection efficiency of Sewage network (CE)	0.156	(Volume of wastewater collected/ Volume of total wastewater generated per day)*100*0.156	>70	40-70	0-40	0
2) Adequacy of sewage treatment (AS)	0.149	(Wastewater given secondary treatment / Total volume of wastewater generation per day)*100*0.149	>70	40-70	0-40	0
3) Quality of treated sewage (QT)	0.152	(No of treated wastewater samples which abide by the standards/ Total number of samples collected)*100*0.152	>75	50-75	25-50	0-25
4) Wastewater recycling (WWR)	0.148	(Quantum of wastewater recycled/Total wastewater received at treatment plants)*100*0.148	>20	10-20	0-10	0
5) Extent of cost recovery in SSS (CRSSS)	0.101	(Cost recovered from sewage management/Total cost involved)*100*0.101	>60	30-60	0-30	0
6) Coverage of toilets (CT)	0.160	(Total number of properties with access to toilets/Total number of properties)*100*0.160	>90	70-90	35-70	0-35
7) Coverage of Storm Water Drainage (CSWD)	0.134	(Length covered by the storm water drainage/ Total road length)*100*0.134	>1	60-1	60-30	0-30
Total	1.000					

Source of BIV* (MoUD 2012)

Sewerage, Sanitation and Storm water management indicators for different Indian cities** (MoUD 2012)

Sewerage, Sanitation and Storm water management indicators for selected Indian cities (Source: City Development Plan of respective cities)

Fig. 4.5: Screenshot of Sewerage Sanitation and Storm water management Index (SSSI) page

Home SWMI WSMI SSSI AECI Result

Sewerage Sanitation and Storm water management Index for City : Varanasi

Indicators	Score	Rating
Sewerage Sanitation and Storm Water Drainage Index	50.465	Fair

Action Plan for Improvement of Sewerage, Sanitation and Storm water Management

Indicators	Probable improvement measures	Approximate cost analysis
1) Collection efficiency of sewage network (CE)	Decentralized Wastewater Management (MoUD, 2012)	
2) Adequacy of sewage treatment capacity (AS)	Tare & Bose, 2009 categorized treatment technologies based on comprehensive analysis of performance and cost analysing data from a large number of STPs. Most appropriate technology can be selected by comparative cost analysis and land requirements. Approximate expenditure of different technologies is given below (Tare & Bose, 2009).	
	Waste Stabilisation Pond System	Rs 1.5-4.5 million per MLD capacity
	Activated Sludge Process	Rs 2-4 million per MLD capacity
3) Quality of treated sewage (QTS)	Decentralized Wastewater Management (MoUD, 2012)	
4) Waste water recycling (WWR)	Separate pipelines should be laid for treated waste water. After treatment wastewater can be used for Irrigation, Power Plants, and Coal Washeries (OMC-KORBA, 2017)	As, per Korba city plan 0.4 cr is proposed for laying 1Km pipeline
5) Coverage of toilets (CT)	Portable toilets can be installed to increase the coverage (MoUD, 2017, CDP Allahabad, 2015)	As per CDP Allahabad, 2015, 0.1 cr is estimated for 1 Mobile toilet.
6) Extent of cost recovery (CRSSS)	By selling treated water to power plants. O&M charges can be incurred by selling sludge/manure (OMC-KORBA, 2017).	
7) Coverage of Storm Water Drainage (CSWD)	Rehabilitation of pucca open drains (CDP,Allahabad, 2015)	20 Lakh/Km
	Construction of Pucca closed drains (CDP,Allahabad, 2015)	50 Lakh/Km
	Desilting of drains (CDP,Allahabad, 2015)	10 Lakh/Km

Fig. 4.6: Screenshot of Sewerage Sanitation and Storm water management Index (SSSI) page

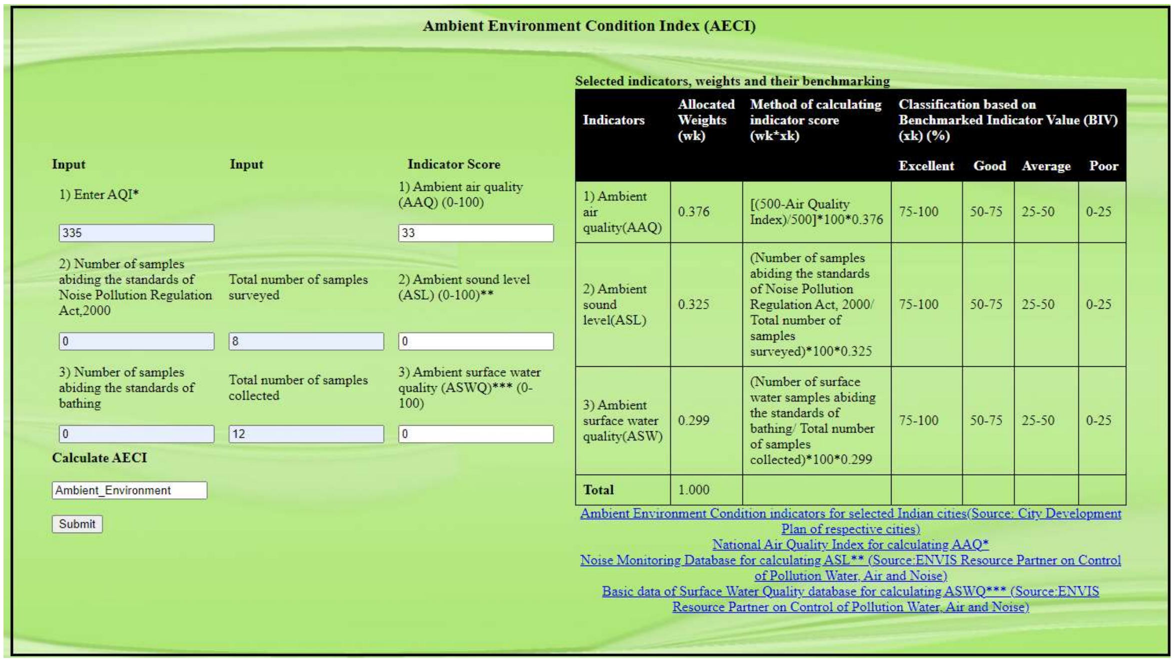


Fig. 4.7: Screenshot of Ambient Environment Condition Index (AECI) page

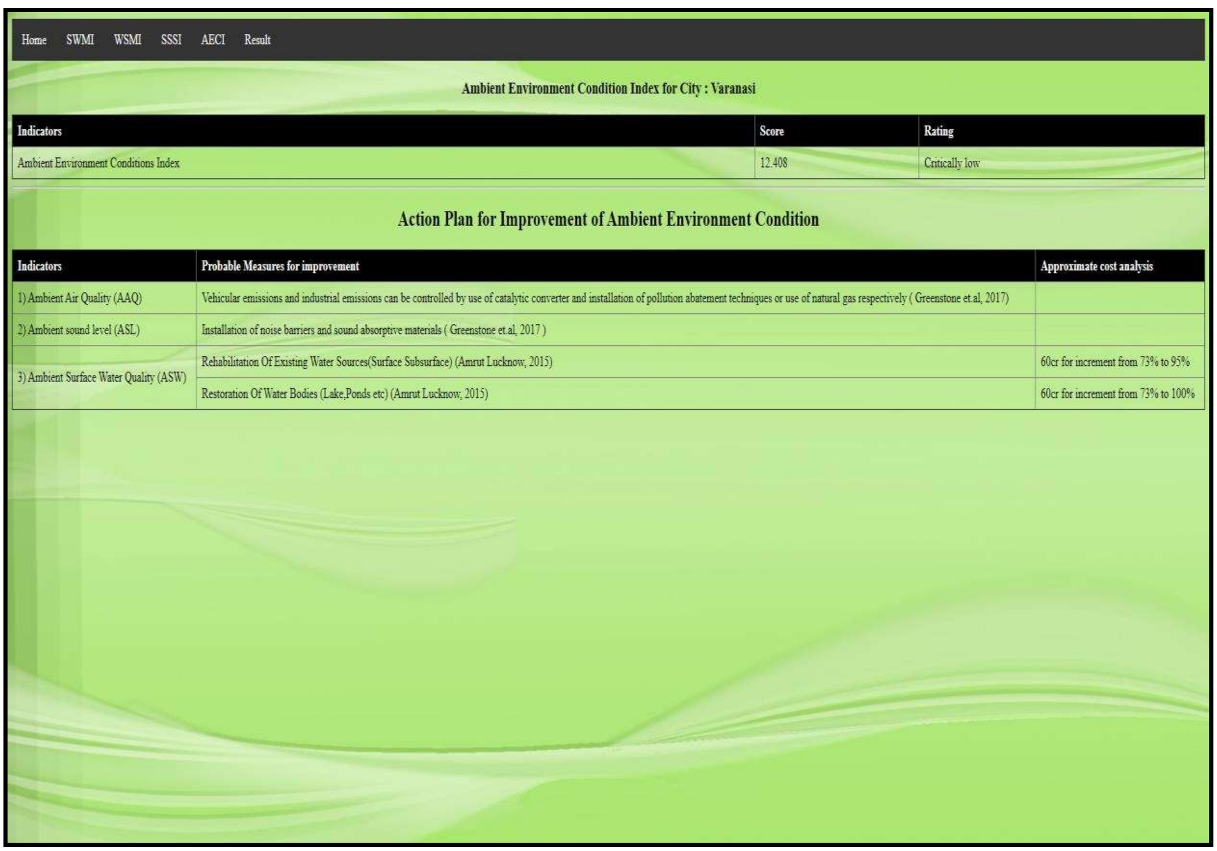


Fig. 4.8: Screenshot of Ambient Environment Condition Index (AECI) page

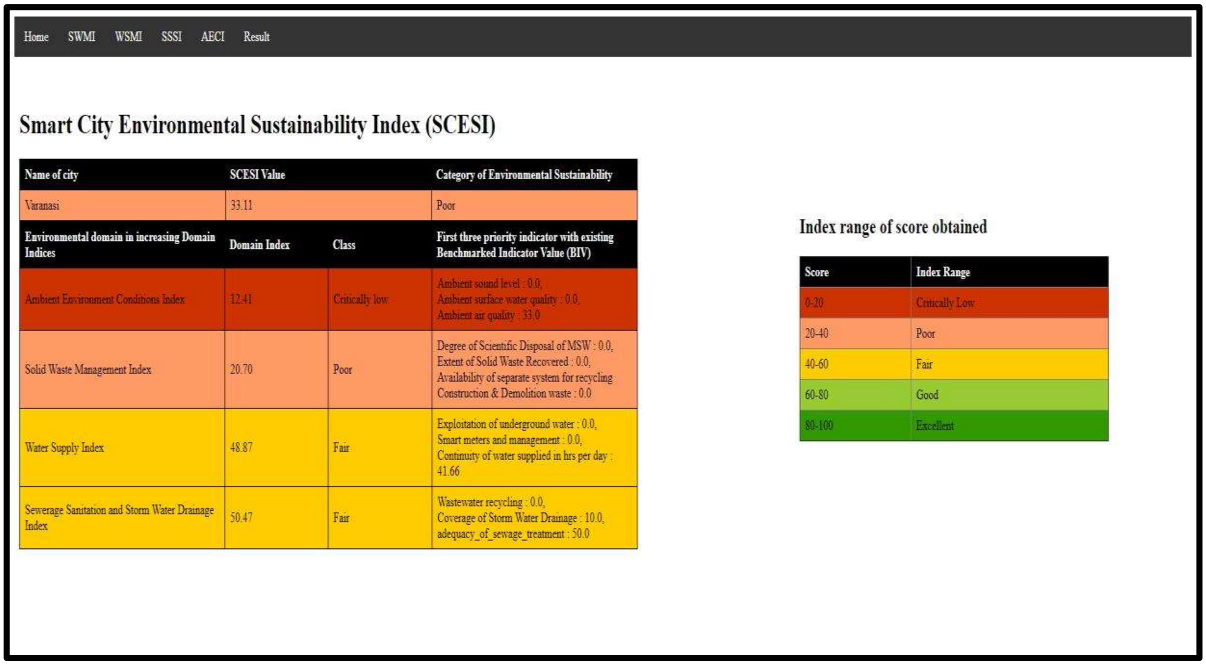


Fig. 4.9: Screenshot of Result Page of Varanasi City

4.5.1 Probable Measures of Improvement

DSS-ESSC, the decision-making tool identifies the priority domains and their corresponding indicators for the improvement of prevalent scenario. For this purpose, probable measures for improvement of each indicator are given in the respective domain pages (Table 4.11-4.14). As cost is the most critical and basic element for planning a smart city, hence approximate cost analysis is also provided along with probable improvement measures. In considering decisions related to developing or investing in new projects, it is often helpful to compare to costs incurred by other cities of similar size, situation, and region. Hence, the input provided will be beneficial for the decision-makers for planning an Environmentally Sustainable Smart City.

Table 4.11: Probable improvement measures for SWM indicators

Indicators	Probable improvement measures	Approximate cost analysis
1. Efficiency in collection of MSW (EC)	The expert committee has given estimates for deployment of vehicles and manpower for collection of waste (CPHEEO, 2016). EC can be improved by following the recommendation of the expert committee.	The sector plan for Solid Waste Management of Allahabad estimates an amount of Rs.5 Lakh for vehicle capacity of 1 ton (CBUD, 2015a)
2. Degree of segregation (DS)	The degree of segregation can be improved by promoting public awareness through information, education and organizing communication campaigns about the separation of wet and dry waste at source (CPHEEO, 2016).	
3. Extent of solid waste recovered (SWR)	The selection of technology for solid waste recovery should be based on defined selection criteria and local conditions. To enhance waste recovery, the municipal authorities should ensure appropriate selection processes to ascertain the most viable solutions (CPHEEO, 2016).	
	Approximate expenditure of different technologies is given below (CPHEEO, 2016): 1) Windrow Composting	Rs.150-200 million for 500 TPD plant
	2) Vermiculture	Rs.10 million for 20 TPD
	3) Biomethanation	Rs.750-800 million for 500 TPD plant
	4) RDF	Rs.170-200 million for 500 TPD Plant
4. Degree of scientific disposal of MSW (SD)	Planning for MSW treatment and processing facilities should begin with the identification of suitable land duly allowing adequate buffer areas. To enhance SD the policymakers should abide the criteria for identifying suitable land for Sanitary Landfill Sites given by experts (CPHEEO, 2016).	The sector plan for Solid Waste Management of Allahabad estimates an amount of Rs.3 million for the construction of 1 acre of Landfill site (CBUD, 2015a).

5. Recycling and reduction of construction and demolition waste (RCD)	The ULB should ensure that C&D waste should be stored and deposited at the designated collection centre. The ULB should also set up a system for citizens to schedule their pick up for C&D waste (MoUD, 2017).	The C&D waste disposal facility was set up by Delhi Municipal Corporation in collaboration with a private organization. The plant had a capacity of 500MTD with an investment of Rs.230 million. The processing fee for C&D Waste is about INR 205 per ton. The capital expenditure incurred by the project is proposed to be covered over a period of 10 years by deriving value from the processed C&D Waste (MoUD, 2017).
6. Extent of cost recovery in solid waste management (CR_{SWM})	ULB can levy solid waste user charges along with the property tax as done by Surat Municipal Corporation (MoUD, 2017).	
7. Solid waste management programs carried in the city during last 3 years (SWMP)	Carried in all cities.	

Table 4.12: Probable improvement measures for WSM indicators

Indicators	Probable Measures for improvement	Approximate cost analysis
1. Adequate water supply (AW)	Development of New Water Sources, strengthening of water treatment plant, replacement of rising and distribution main (JICA, 2016) can enhance per capita water supply.	NA
2. Smart meters and Management (SMM)	Installation of Node MCU System with IoT platform can increase percentage of SMM as it is a well-groomed solution for forecasting the usage of water for Smart City. This IoT based concept continuously monitor water usage, and if it reaches the minimum amount, it would automatically alert the consumer to recharge (Rasadurai et al, 2017).	NA
3. Leakage identification (LI)	Implementation of SCADA with MIS, Survey, 100% metering and Leakage detection and repair (JICA, 2016), Public participation in water supply projects (Das et al., 2019)	As per JICA, 2016 estimated amount of Rs.1530.33million is proposed to set up the system which will increase the revenue water of Varanasi from 42% to 70%
4. Continuity of water supplied in terms of average no of hrs per day (CW)	Installation of pumps of adequate capacity, increased capacity of feeder mains to reservoirs, upgrading of headworks (WSP, 2010)	
5. Water quality monitoring (WQ)	Strengthening of lab and online water quality monitoring system (JICA, 2016)	As per JICA, 2016 estimated amount of Rs.1530.33million is proposed to set up the system which will increase the revenue water of Varanasi from 42% to 70%
6. Identification of water sources and	Rainwater Harvesting, Groundwater Recharge	

Exploitation of underground water ($E_{UG}W$)		
7. Extent of cost recovery in water supply services (CR_{WS})	Implementing online billing system, spot billing (Amrut Lucknow, 2015)	An estimated cost of Rs.100 million is proposed for the implementation of the projects, which will increase cost recovery from 60% to 75% in Lucknow.
	Rehabilitate and expansion of payment collection (Amrut Lucknow, 2015)	An estimated cost of Rs.80 million is proposed for the implementation of the projects, which will increase cost recovery from 60% to 90% in Lucknow.

Table 4.13: Probable improvement measures for SSS indicators

Indicators	**Probable Measures for improvement**	**Approximate cost analysis**
1. Collection efficiency of sewage network (CE)	Decentralized Wastewater Management	
2. Adequacy of sewage treatment capacity (AS)	Most appropriate technology can be selected by comparative cost analysis and requirements (Tare and Bose, 2009)	
	Waste Stabilisation Pond System	Rs 1.5-4.5 million per MLD capacity
	Activated Sludge Process	Rs 2-4 million per MLD capacity
3. Quality of treated sewage (QTS)	Decentralized Wastewater Management	

4. Waste water recycling (WWR)	Laying of pipelines for reuse of treated wastewater Treated wastewater can be used for Irrigation, Power Plants, and Coal Washeries.(OMC-KORBA, 2017)	As per Korba city plan, Rs. 4 million is proposed for laying 1Km pipeline
5. Coverage of toilets (CT)	Portable toilets can be installed to increase the coverage. (MoUD, 2017, CBUD, 2015a)	As per CDP Allahabad, 2015, Rs. 1 million is estimated for 1 Mobile toilet.
6. Extent of cost recovery (CR_{SSS})	By selling treated water to power plants. O&M charges can also be incurred by selling sludge/manure (OMC-KORBA, 2017)	
7. Coverage of Storm Water Drainage (CSWD)	Rehabilitation of pucca open drains (CBUD, 2015a)	Rs. 2 million / Km
	Construction of Pucca closed drains (CBUD, 2015a)	Rs. 5 million/Km
	Desilting of drains (CBUD, 2015a)	Rs.1 million/Km

Table 4.14: Probable improvement measures for AEC indicators

Indicators	**Probable Measures for improvement**	**Approximate cost analysis**
1. Ambient Air Quality (AAQ)	Vehicular emissions and industrial emissions can be controlled by use of catalytic converter and installation of pollution abatement techniques or use of natural gas, respectively (Greenstone et.al, 2017)	NA
2. Ambient Sound Level (ASL)	Installation of noise barriers and sound absorptive materials (Greenstone et.al, 2017)	NA
3. Ambient Surface Water Quality (ASW)	Rehabilitation Of Existing Water Sources (Surface Subsurface) (AMRUT, Lucknow, 2015)	600 million for increment from 73% to 95%
	Restoration Of Water Bodies (Lake, Ponds) (AMRUTLucknow, 2015)	600 million for increment from 73% to 100%

4.6 Application of the DSS-ESSC on representative 5 cities of India under SCM

SCESI is the arithmetic mean of four DIs: SWMI, WSMI, SSSI, and AECI. In order to check the applicability of SCESI, five cities, namely Delhi, Patna, Varanasi, Allahabad, and Bhubaneswar, which are enlisted for development under Smart Cities Mission in India, have been selected. Delhi has been selected as it is the capital city of India and grapples with numerous challenges like rapid population growth, urbanization, environmental degradation due to heavy pollution, and offering a poor quality of life to many of the populace. Patna, Varanasi, and Allahabad are situated on the bank of river Ganga, the longest river of India that is significantly important for its economic, environmental, and cultural values. Rapid population growth, industrialization, haphazard urbanization, and discharge of untreated sewage in the river have degraded the quality of river Ganga. Hence, the framework is applied to these cities to understand the prevailing situation and challenges lying in the water environment and sanitation facility management. Bhubaneswar is selected because it has been shortlisted at the top rank in the first round of Smart Cities Mission among 100 cities (SESEI). Hence, these cities are the perfect epitome for the study and validation of the framework.

The 24 selected indicators are used to calculate 'Smart City Environmental Sustainability Index (SCESI)' with secondary data for selected cities: Delhi, Patna, Allahabad, Varanasi, and Bhubaneswar. Based on the SCESI score on a scale of 0-100, the environmental status of smart cities may be classified in 5 categories, as given in Table 4.15. The results are obtained from the framework using available data in the public domain, which reveals that the environmental sustainability of Delhi, Allahabad, and Bhubaneswar fall in the Fair category (SCESI= 40-60), while Varanasi and Patna are in the Poor category (SCESI< 40) (Table 4.16). With the present set of data, the environmental sustainability level of Allahabad appears the best, followed by Bhubaneswar and Delhi. The Indicator Score, DI and SCESI of the selected cities are shown in Fig. 4.10-4.15.

Table 4.15: Classification of Environmental Sustainability status of smart cities based on SCESI

SCESI score	Environmental Sustainability Category of the City
>80	Excellent
60-80	Good
40-60	Fair
20-40	Poor
<20	Critically Low

While SWM is the most critical environmental domain to be attended and addressed on a priority basis for Allahabad, it is SSS for Bhubaneswar and AEC for Delhi. Similarly, Varanasi needs to focus on improving its AEC, and SWM appears the most critical for Patna. The domains under Critically Low (SCESI<20) and Poor (SCESI= 20-40) need to be prioritized, and those in the Fair category (SCESI>40) also need to be worked for achieving good status (SCESI> 60). Thus, comparing 4 DIs (SWMI, WSMI, SSSI, AECI) for each of the 5 cities (Total 20), 2 are found in Good (SSSI and AECI for Allahabad), 11 in Fair (SWMI for Delhi and Bhubaneswar; WSMI for all the selected cities; SSSI for Delhi and Varanasi), 5 in Poor (SWMI for Patna, Varanasi, Allahabad; SSSI for Patna and Bhubaneswar) and 2 in Critically Low (AECI for Delhi and Varanasi) categories of environmental sustainability (Fig. 4.15).

Table 4.16: DIs, SCESI and Environmental Sustainability Category of five selected cities

	Delhi	Patna	Varanasi	Allahabad	Bhubaneswar
SWMI	44.83 (Fair)	25.80 (Poor)	20.70 (Poor)	20.70 (Poor)	48.28 (Fair)
WSMI	52.20 (Fair)	40.56 (Fair)	48.76 (Fair)	52.28 (Fair)	41.56 (Fair)
SSSI	58.72 (Fair)	39.52 (Poor)	50.44 (Fair)	60.04 (Good)	35.00 (Poor)
AECI	11.40 (Critically Low)	47.48 (Fair)	12.40 (Critically Low)	63.88 (Good)	56.68 (Fair)
SCESI	**41.80 (Fair)**	**38.36 (Poor)**	**33.08 (Poor)**	**49.24 (Fair)**	**45.39 (Fair)**

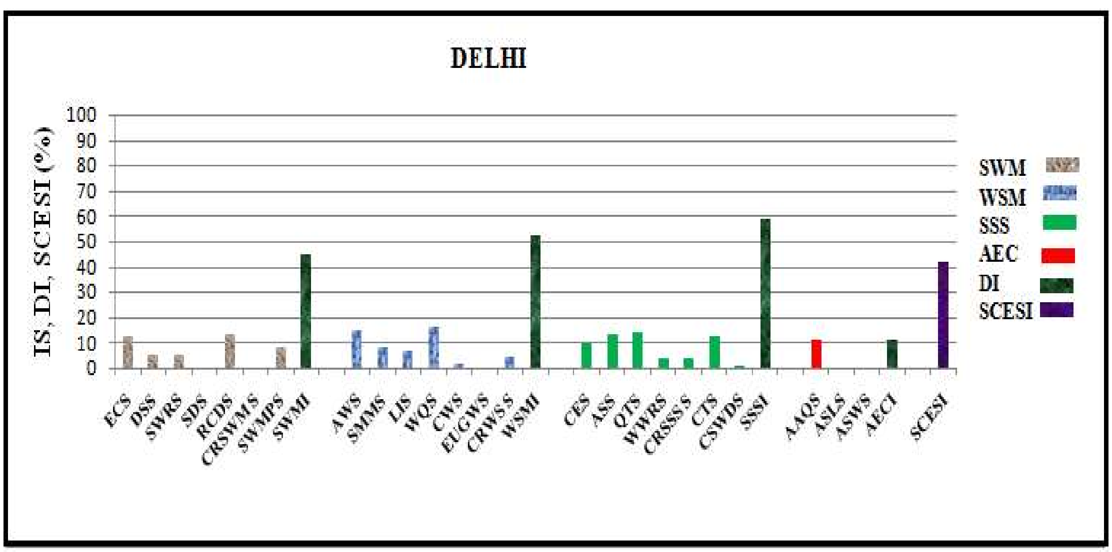


Fig 4.10: Indicator Scores, Domain Indices and SCESI of Delhi

(SWM, WSM, SSS: MoHUA, 2012; AEC: MoEF, 2017)

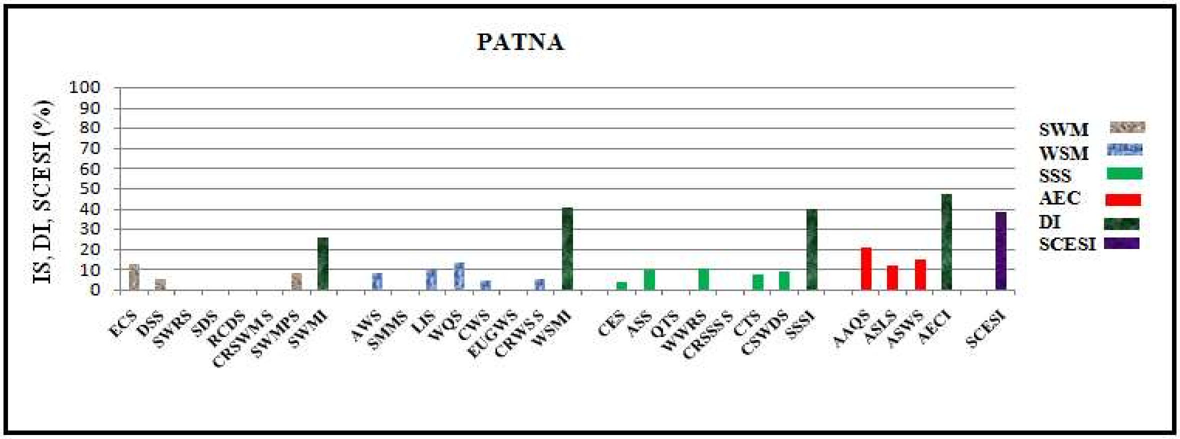


Fig 4.11: Indicator Scores, Domain Indices and SCESI of Patna (SWM, WSM, SSS: AMRUT, 2015; AEC: BSPCB, 2017)

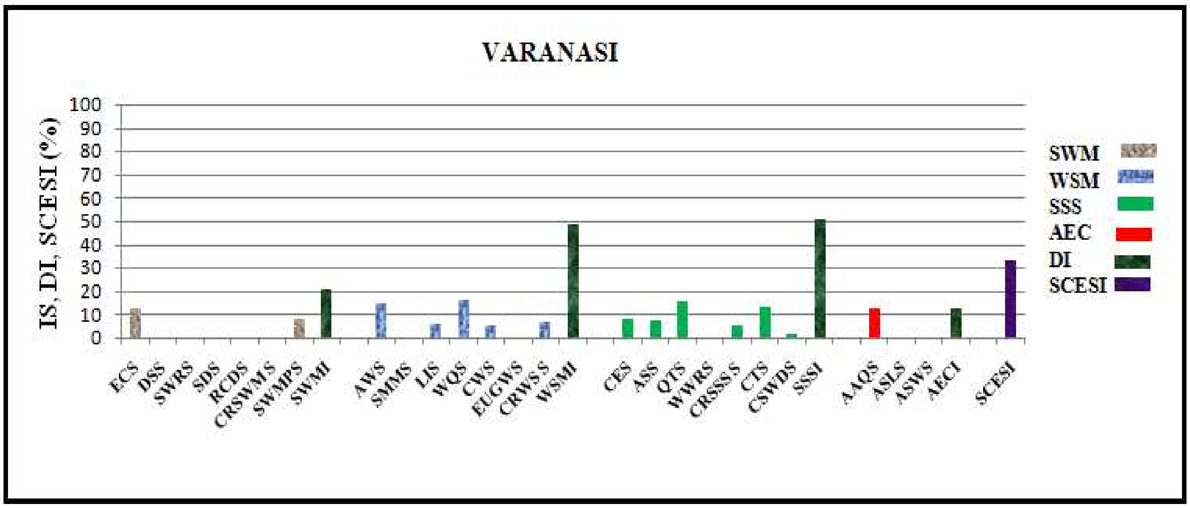


Fig 4.12: Indicator Scores, Domain Indices and SCESI of Varanasi (SWM, WSM, SSS: CBUD, 2015b; AEC: UPPCB, 2017a, b)

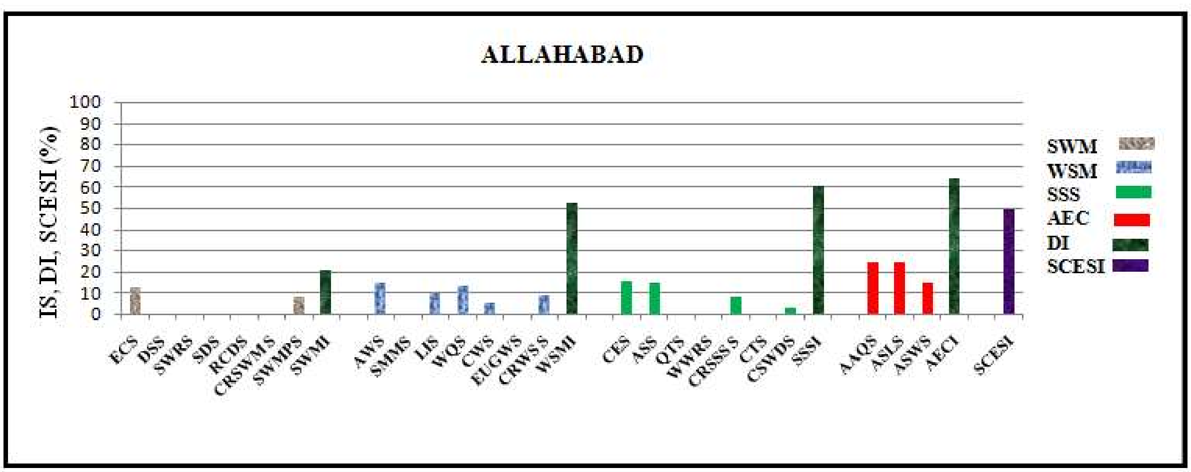


Fig 4.13: Indicator Scores, Domain Indices and SCESI of Allahabad (SWM, WSM, SSS: CBUD, 2015a; AEC: UPPCB, 2017a, b)

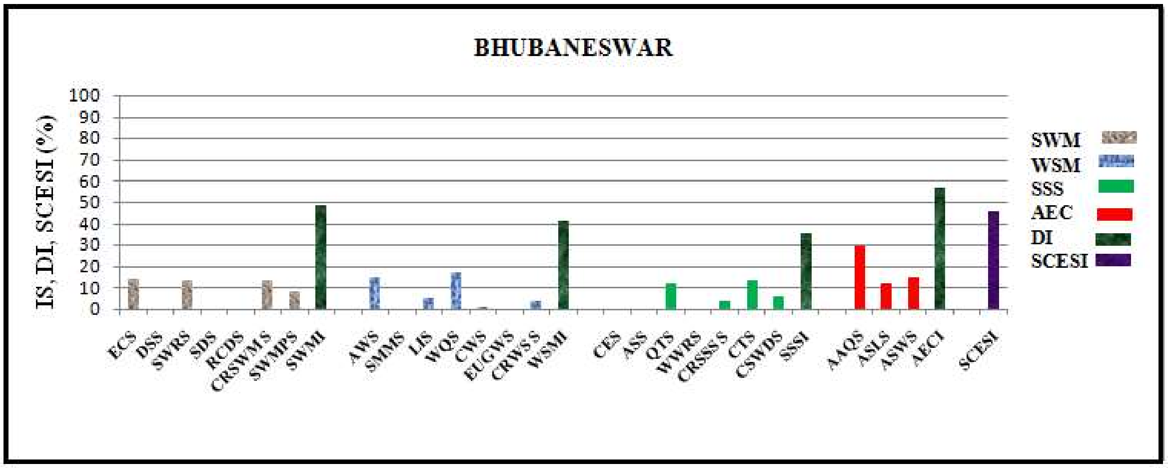


Fig 4.14: Indicator Scores, Domain Indices and SCESI of Bhubaneswar (SWM, WSM, SSS: HoUD, 2015; AEC: OSPCB, 2017a, b)

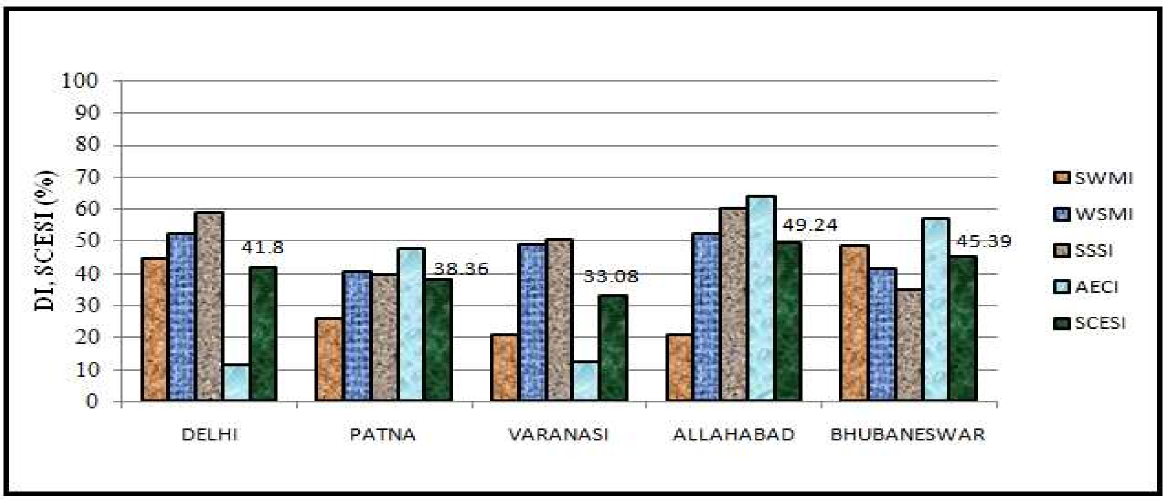


Fig 4.15: Domain Indices and SCESI of selected cities

4.6.1 Application of the DSS-ESSC on additional 10 cities of India under SCM

The approach has been tested using the available secondary data in public domain for five cities of India, namely, Delhi, Patna, Allahabad, Varanasi and Bhubaneswar, which are currently being developed as smart cities under SCM. Overall the framework developed for evaluating environmental sustainability of a smart city through Smart Cities Environmental Sustainability Index (SCESI) appears giving justifiable results and hence may be used as a scientific diagnostic tool to identify critical areas of intervention, investment and improvement for other cities. Hence, 10 more Indian cities are taken up from SCM list: Vishakhapatnam, Muzaffarpur, Surat, Bangalore, Indore, Jaipur, Agartala, Agra, Kanpur and Lucknow. The cities have been selected from all zones with climatic variations to show the effect on SCESI. Vishakhapatnam is the largest and most populated city of Andhra Pradesh which is located in South-Eastern part of India, and has tropical wet and dry climate. Bangalore, the IT capital of India is selected from South western part which enjoys a moderate climate. Surat the commercial and economic centre of Gujarat which is the western part of India has a tropical savanna climate. From the central part of India, Indore is chosen which has a humid subtropical climate. Muzaffarpur is selected in 4^{th} round of SCM and lies in the east India with humid subtropical climate. Agartala is chosen from north east part and has monsoon influenced humid subtropical climate. Jaipur, in Northern India has extremely hot and long summers. KAVAL (Kanpur, Agra, Varanasi, Allahabad and Lucknow) towns from northern India is also selected which mostly have humid subtropical climate. Table 4.17 represents the comparative analysis of DIs and SCESI of the selected cities on a scale range of 0 to 100.

The sample analyses indicates that SCESI of Vishakhapatnam, Bangalore, Surat and Kanpur falls in Fair category while Muzaffarpur, Agartala, Jaipur, Agra and Lucknow lie in Poor category. The only city that manages to secure good category is Indore. According to the Swach Bharat Mission, Indore grabbed the first position for being the cleanest city. As SBM is related to Solid Waste Management and Coverage of toilets, it can be seen from the results that Indore has secured excellent category in Solid Waste Management Domain. The respective Domain Indices and SCESI of the 10 cities are shown in Fig 4.16-4.25.

Table 4.17: DIs, SCESI and Environmental Sustainability Category of ten selected cities

Cities	Zone	SCM round in which cities are selected	SWMI	WSMI	SSSI	AECI	SCESI
1.Vishakhapatnam	S.E.	1st Round	**29.25** (Poor)	**56.26** (Fair)	**65.03** (Good)	**38.88** (Poor)	**47.35** (Fair)
2. Bangalore	S.W.	4th Round	**32.36** (Poor)	**58.12** (Fair)	**75.46** (Good)	**36.70** (Poor)	**50.83** (Fair)
3. Surat	West	1st Round	**47.35** (Fair)	**57.25** (Fair)	**72.50** (Good)	**47.55** (Fair)	**56.23** (Fair)
4. Indore	Central	1st Round	**93.34** (Excellent)	**33.99** (Poor)	**51.36** (Fair)	**62.87** (Good)	**60.39** (Good)
5. Muzaffarpur	East	4th Round	**23.34** (Poor)	**38.79** (Poor)	**13.94** (Critically Low)	**42.27** (Fair)	**29.58** (Poor)
6. Agartala	N.E.	2nd Round	**28.08** (Poor)	**26.01** (Poor)	**10.18** (Critically Low)	**44.99** (Fair)	**28.57** (Poor)
7. Jaipur	North	1st Round	**22.14** (Poor)	**44.00** (Fair)	**44.91** (Fair)	**27.44** (Poor)	**34.62** (Poor)
8. Agra	North	3rd Round	**30.46** (Poor)	**49.34** (Fair)	**46.52** (Fair)	**32.94** (Poor)	**39.81** (Poor)
9. Kanpur	North	3rd Round	**47.61** (Fair)	**45.53** (Fair)	**51.27** (Fair)	**15.93** (Critically Low)	**40.08** (Fair)
10. Lucknow	North	2nd Round	**32.96** (Poor)	**50.06** (Fair)	**56.74** (Fair)	**11.28** (Critically Low)	**37.76** (Poor)

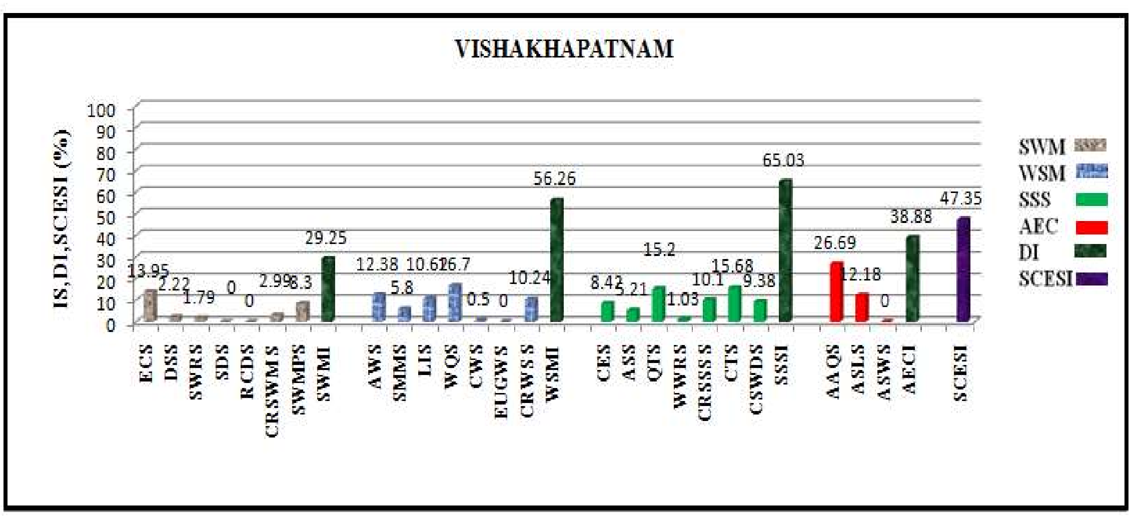


Fig. 4.16: Indicator Scores, Domain Indices and SCESI of Vishakhapatnam

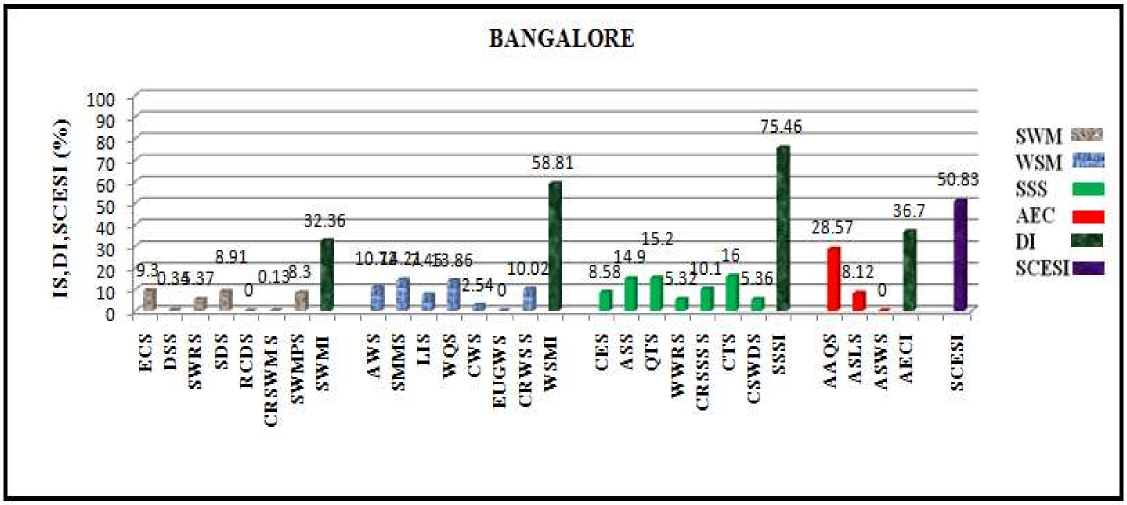


Fig 4.17: Indicator Scores, Domain Indices and SCESI of Bangalore

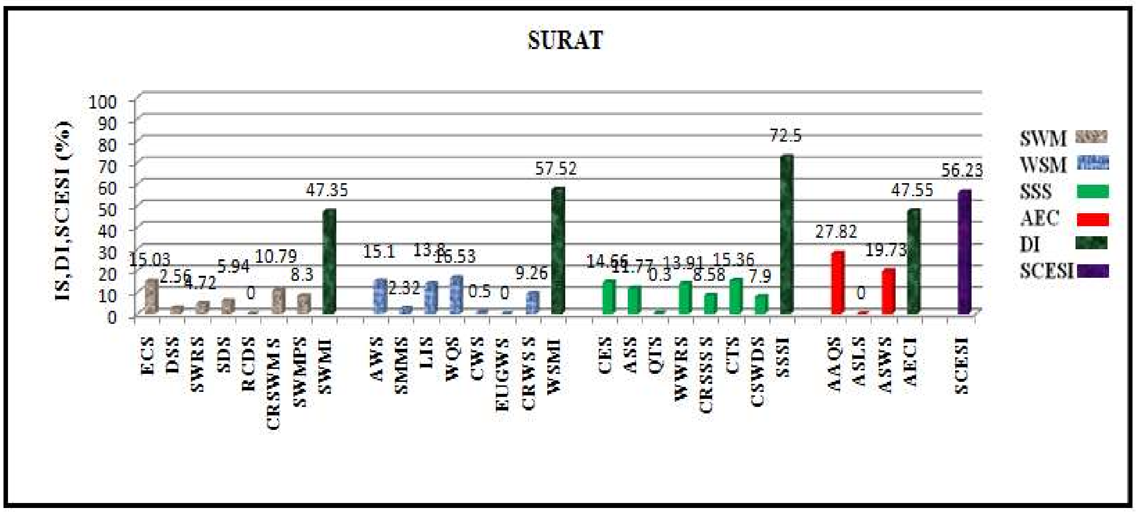


Fig 4.18: Indicator Scores, Domain Indices and SCESI of Surat

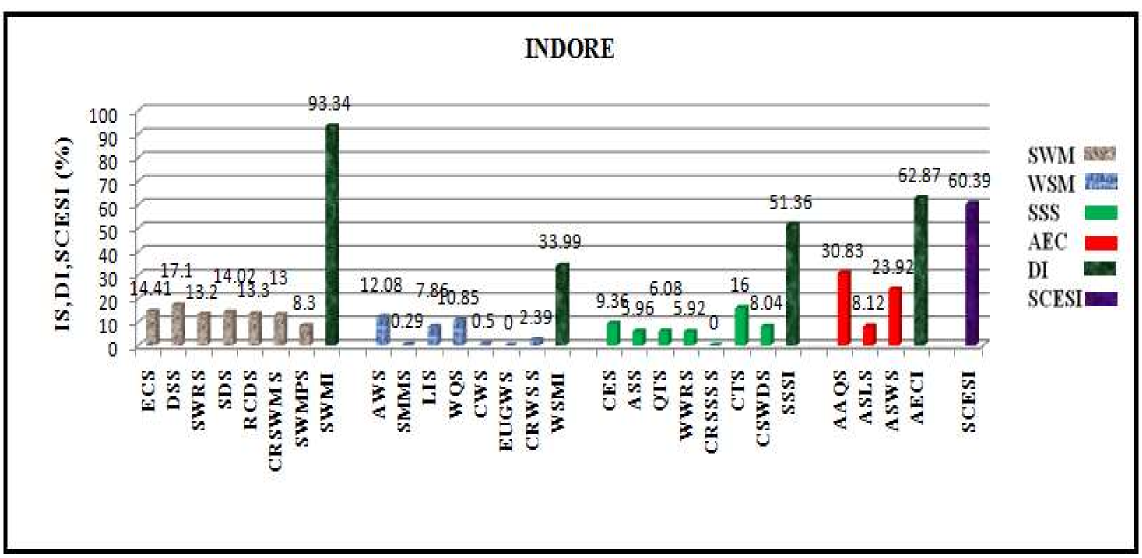


Fig 4.19: Indicator Scores, Domain Indices and SCESI of Indore

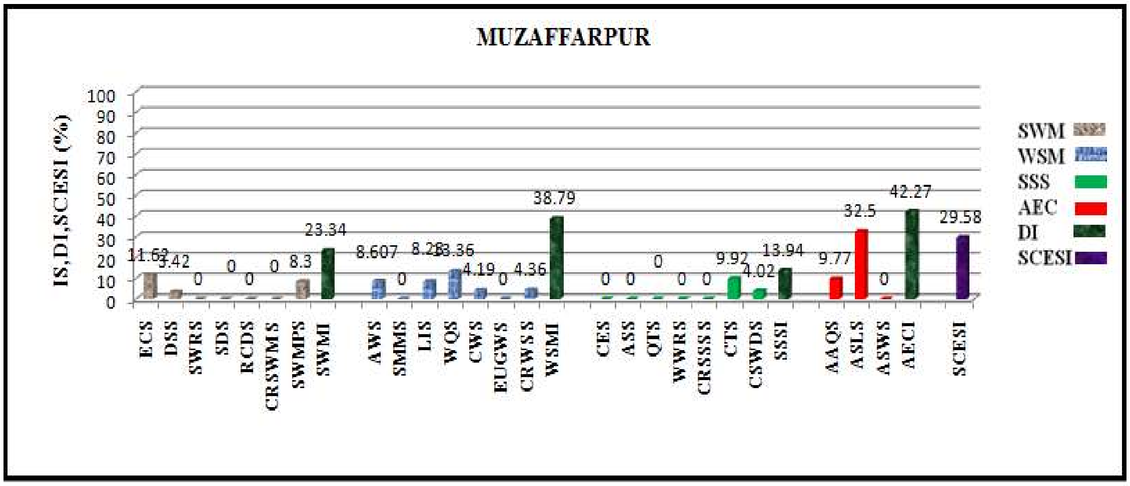


Fig 4.20: Indicator Scores, Domain Indices and SCESI of Muzaffarpur

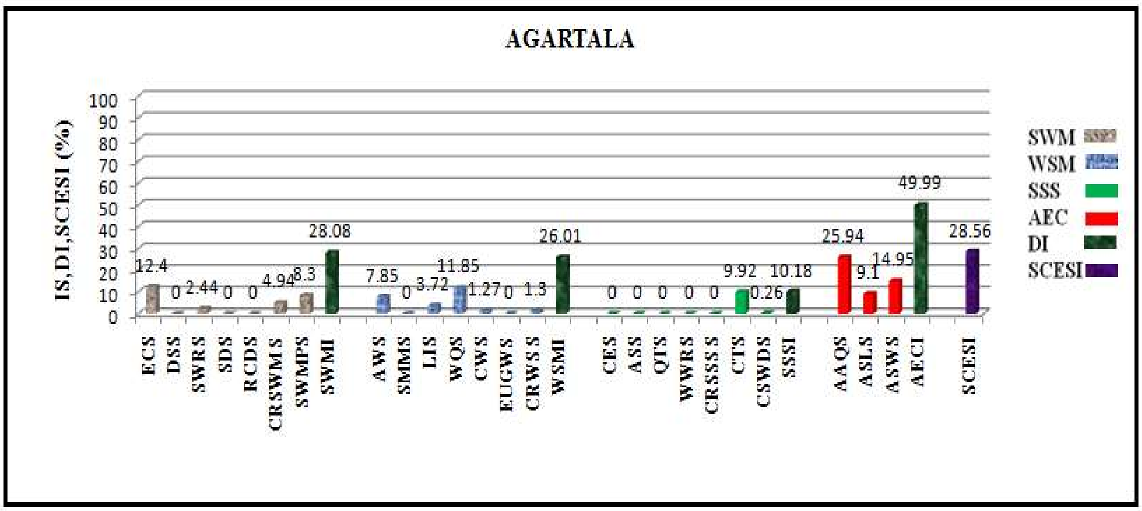


Fig 4.21: Indicator Scores, Domain Indices and SCESI of Agartala

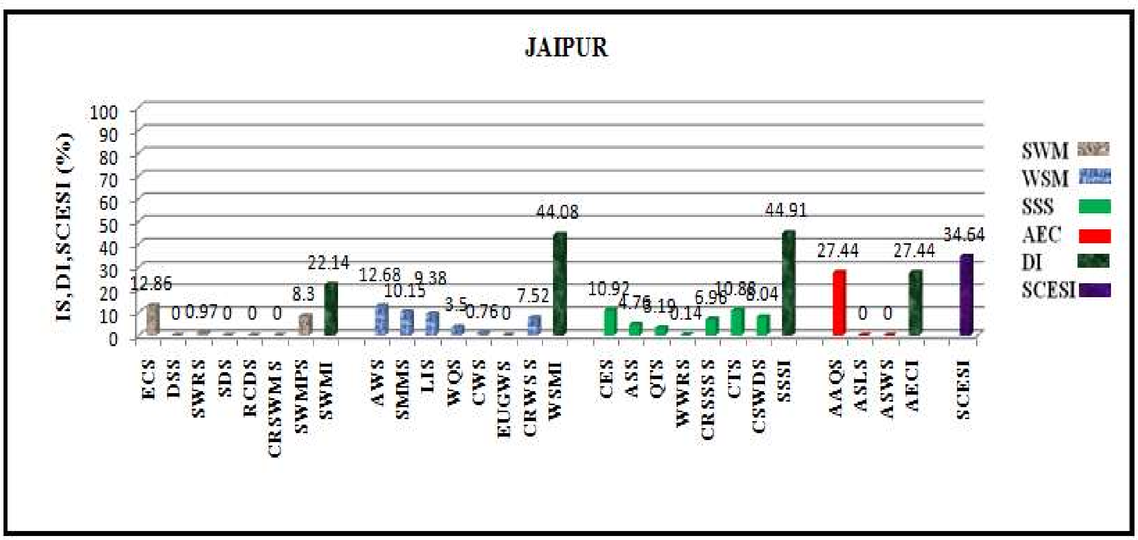


Fig 4.22: Indicator Scores, Domain Indices and SCESI of Jaipur

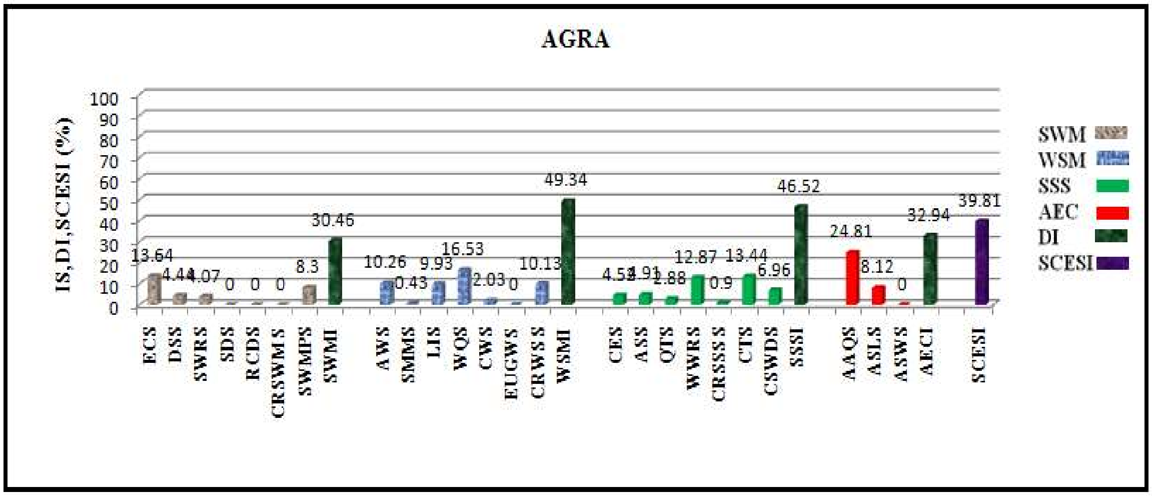


Fig 4.23: Indicator Scores, Domain Indices and SCESI of Agra

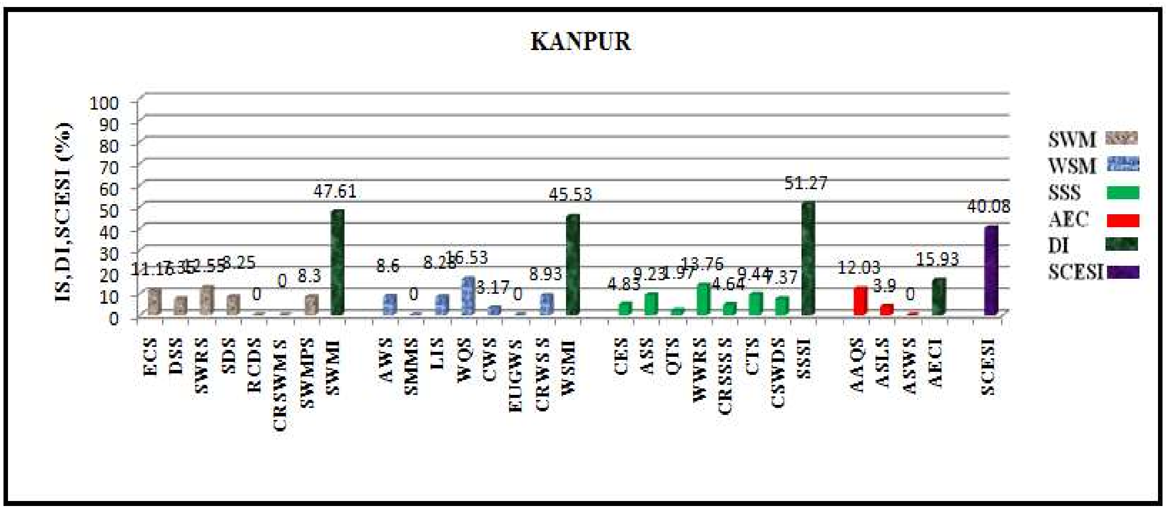


Fig 4.24: Indicator Scores, Domain Indices and SCESI of Kanpur

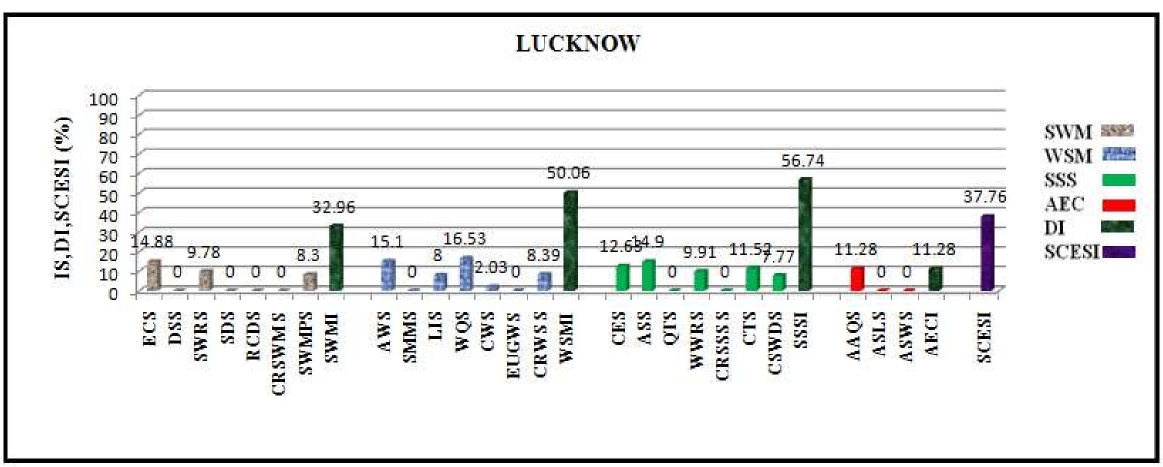


Fig 4.25: Indicator Scores, Domain Indices and SCESI of Lucknow

Cluster III

4.7 Five Year Phased Intervention Plan for developing Smart Cities towards ESSC

The existing condition of the city must be improved and upgraded by implementing remedial measures. A target-based scenario is generated for improving the existing condition and upgrading the SCESI to good category. For this purpose, phased intervention is carried out to achieve the target of Environmentally Sustainable Smart Cities in 5 years. The existing scenario can be improved to good condition by target based improvements, comprising of selection of priority environmental domains and respective indicators based on SCESI score. In the first 3 years, the environmental domain which lies in critically low and poor category is selected. Further the indicators of respective domains are upgraded by one category except the indicators in the excellent category. After the upgradation of indicators if SCESI still do not manage to achieve the target of Good category then, time frame of further 2 years is allotted. During this duration, the domain with least score is selected and its respective indicators are improved. Thus, in the time frame of 5 years it is presumed that cities will manage to upgrade the SCESI score to Good category.

The analytical result of Delhi shows that the most crucial driver for improving the SCESI score is Ambient Environment Condition (AEC) which lies in Critically Low condition. In the Ist Phased Intervention the AEC indicators are upgraded and AAQ is improved from Fair to Good category and ASL and ASWQ is brought to Fair level. After the target based improvements, AEC is improved to Fair category surpassing the Poor condition, but SCESI lies in the higher side of Fair category. Hence, 2nd Phased Intervention is carried out, by selecting Solid Waste Management. Keeping, AECI in Fair condition, the performance of SWM indicators are improved, which results in improvement of SWMI (71.63) and SCESI (60.48) to Good condition (Figure 5.26). In the Ist Phase Intervention, SWMI and SSSI are selected for Patna as both lies in Poor category. The indicators are improved which results in upgradation of SWMI (67.73) and SSSI (69.34) to Good and SCESI (56.27) to Fair condition. SCESI is improved to Good condition (67.21) in the 2nd phase intervention by upgrading WSM indicators (Fig 4.27).

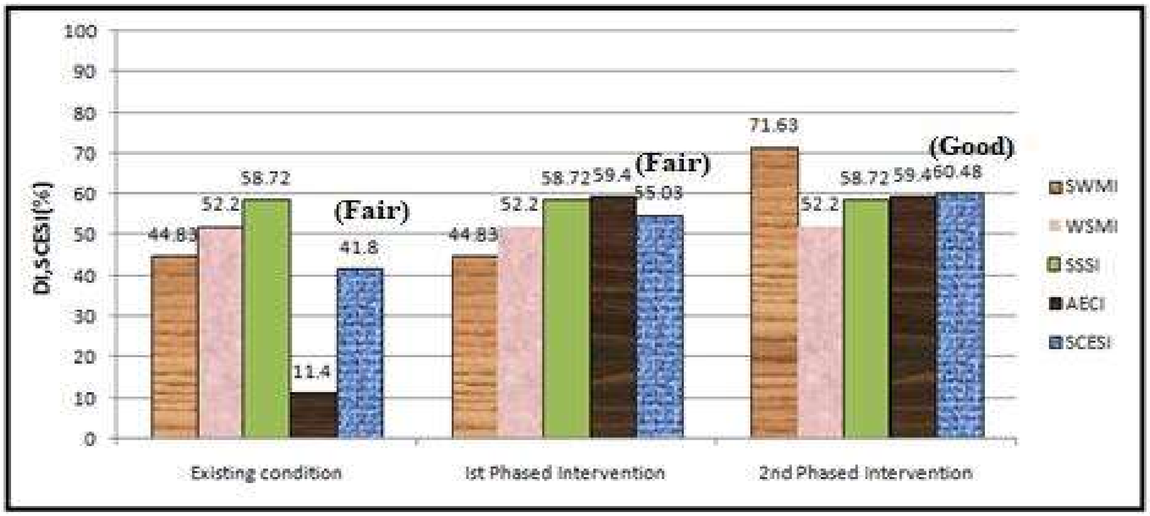


Fig. 4.26: Phased intervention and improvements in DIs and SCESI for Delhi

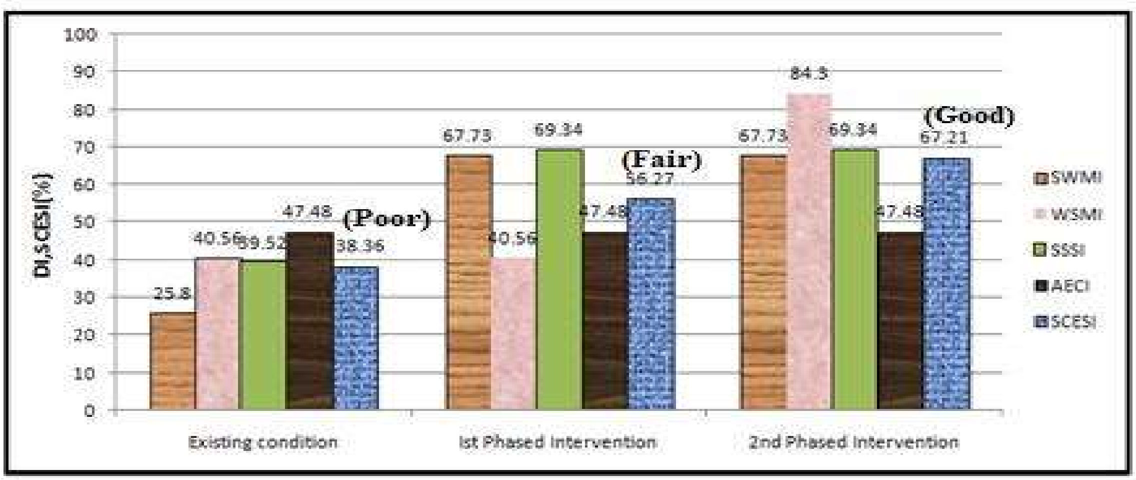


Fig. 4.27: Phased intervention and improvements in DIs and SCESI for Patna

Varanasi has Poor performance in AEC and SWM, which is taken up in the Ist phased intervention. After carrying the improvement plans, AECI (58.4), SWMI (52.7) and SCESI (52.82) is improved to Fair condition. In the 2nd phased intervention, WSMI (84.31) is upgraded to Excellent from Fair category and SCESI (61.7) is improved to

Good condition (Fig. 5.28). SWMI and SSSI are selected and improved to good condition in Ist phased intervention for Allahabad and Bhubaneswar respectively (Fig. 5.29-5.30). As the SCESI still lies in Fair category, WSMI is taken up for 2nd phased intervention, and as a result SCESI is improved to Good condition. Thus, the trend analysis shows that the SCESI can be improved in 5 years by carrying out 2 phased interventions each of 3- and 2-years duration respectively.

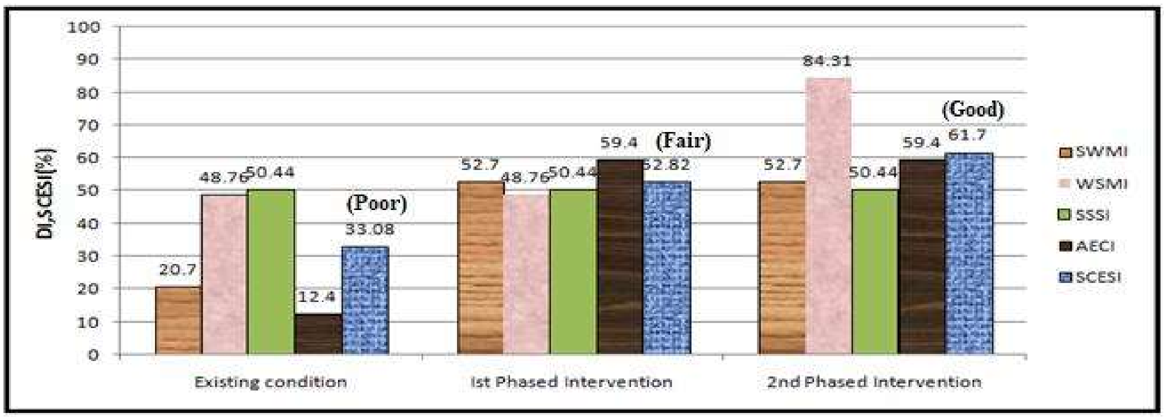


Fig. 4.28: Phased intervention and improvements in DIs and SCESI for Varanasi

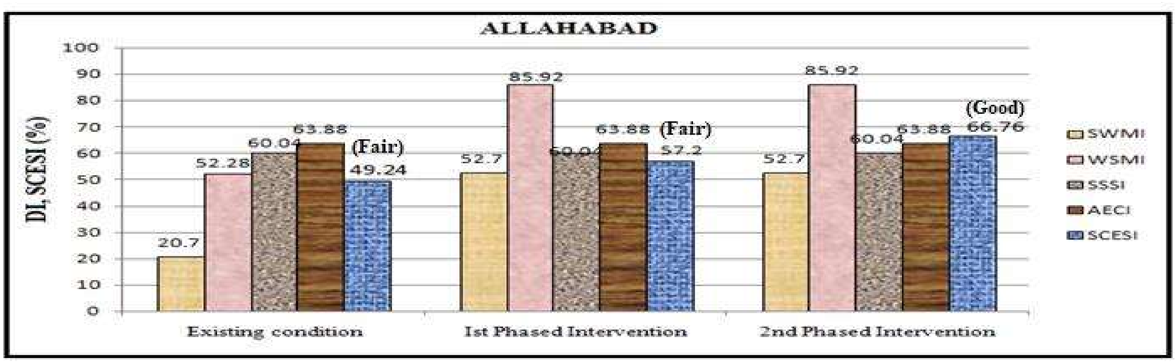


Fig. 4.29: Phased intervention and improvements in DIs and SCESI for Allahabad

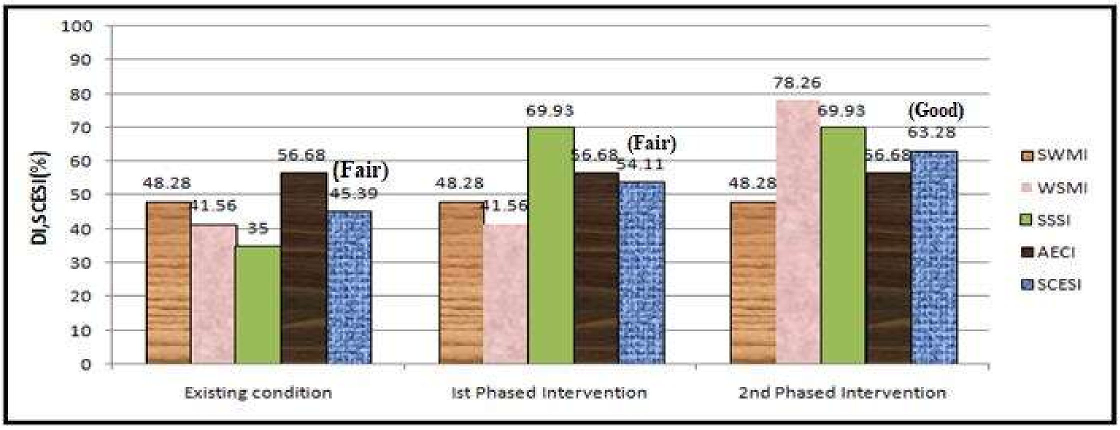


Fig. 4.30: Phased intervention and improvements in DIs and SCESI for Bhubaneswar

4.8 Sensitivity Analysis

The non-availability of data for some of the environmental indicators may be possible, which in turn affects the overall index result. Hence, sensitivity analysis is carried out by generating eight scenarios. When the data is not available for all the 24 environmental indicators included in environmental domains, then domain index is calculated using Eqn 4.5. Summation of normalized domain indices (DI_m) gives normalized Smart City Environmental Sustainability Index ($SCESI_m$).

$$DI = \frac{\sum_{j=1}^{n} ISj}{\sum_{i=1}^{n} Wi} * 100 \qquad (4.5)$$

Where, W_i is the summation of the weights given by experts to the indicators in each domain; $W_i \leq 1$.

Non-availability of data can cause error in the calculation of SCESIwhich can be calculated by using Eqn 4.6.

$$\text{PercentageError} = \frac{\text{SCESIm} - \text{SCESI}}{\text{SCESI}} \qquad (4.6)$$

To assess the uncertainties involved due to non-availability of data case study of five Indian cities: Delhi (D), Patna (P), Varanasi (V), Allahabad (A) and Bhubaneswar (B) is taken up. The sources of data for Solid Waste Management, Water Supply Management and Sewerage, Sanitation and Storm water Management are City Development Plan (CDP) and SwachhSarvechhan Report (SSR) from the Swachh Bharat Mission program. Ambient Environment condition data is obtained through Central Pollution Control Board (CPCB) and ENVIS website of respective cities. To avoid discrepancy in the result a factor of 0.25 is taken for indicator having critically low performance. To estimate the errors involved in calculating the SCESI due to the non-availability of indicator data, an approach of ignoring indicator data based on weight factor is used (Kumar and Alappat 2005, Ohri and Singh 2011). Further, in this approach, two options are explored. In the first option, the data of the environmental indicator having high weight in each of the four domains is ignored and in the second option, the data of the environmental indicator having low weight in all the four-domain data are assumed to be unavailable. The results obtained in the two options are analysed.

4.8.1 Effect of Removing Indicators with high weights

i. In the first step, the DIs are calculated using 7 indicators (7I) for SWMI, 7 indicators (7I) for WSMI, 7 indicators for SSSI (7I) and 3 indicators for AECI (3I). Respective Domain Indices is calculated using Equation 3.2.

ii. In the second step, the indicator having highest weight in each domain is presumed to be unknown. For calculating DIs, 6 indicators (6I) for SWMI, 6 indicators (6I) for WSMI, 6 indicators for SSSI (6I) and 2 indicators for AECI (2I) is involved. Degree of Segregation (w=0.171) in SWM, Water Quality Monitoring (w=0.167) in WSM, Coverage of toilets (w=0.160) in SSS and Ambient Air Quality (w=0.376) in AEC are ignored (Table 4.18). As the data of indicator having highest weight is presumed to be unknown, the DIs are calculated using Equation 4.5.

iii. In the third step, it is presumed that indicators having second highest weight are unavailable along with the indicators involved in step 2. For calculating domain indices 5 indicators (5I) for SWMI, 5 indicators (5I) for WSMI, 5 indicators for SSSI (5I) and 2 indicators for AECI (2I) are taken up. Degree of scientific disposal of MSW (w= 0.165) in SWM, Exploitation of underground water (w=0.163) in WSM and Collection efficiency of Sewage Network (w=0.156) in SSS are ignored (Table 5.18). Respective DIs is calculated using Eqn 4.5.

iv. The percentage error occurred in calculating DI value with respect to the DI value when data for all the indicators are available is also reported in the last row (Table 4.18).

4.8.2 Effect of Removing Indicators with low weights

i. In the first step, the Domain indices is calculated using 7 indicators (7I) for SWMI, 7 indicators (7I) for WSMI, 7 indicators for SSSI (7I) and 3 indicators for AECI (3I). Respective DIs is calculated using Eqn. 3.2.

ii. In the second step, the indicator having lowest weight in each domain is presumed to be unknown. For calculating domain indices 6 indicators (6I) for SWMI, 6 indicators (6I) for WSMI, 6 indicators for SSSI (6I) and 2 indicators for AECI (2I) are involved. Solid Waste Management programs carried in the city during last 3 years (w=0.083) in SWM, Extent of cost recovery in water supply services (w=0.109) in WSM, Extent of Cost Recovery (w=0.101) in SSS and Ambient Surface Water Quality (w=0.299) in AEC is ignored (Table 4.19). As the data of indicator having lowest weight is presumed to be unknown the DIs are calculated using Eqn. 4.5.

iii. In the third step, it is presumed that the second-lowest weight indicators are unavailable along with the indicators involved in step ii. For calculating DIs 5 indicators (5I) for SWMI, 5 indicators (5I) for WSMI, 5 indicators for SSSI (5I) and 2 indicators for AECI (2I) are taken up. Extent of cost recovery in Solid Waste Management (w=0.130) in SWM, Continuity of water supplied in terms of average no of hrs per day (w=0.127) in WSM and Coverage of Storm Water Drainage (w=0.134) in SSS are ignored (Table 4.19). Respective DIs are calculated using Eqn.4.5.

iv. The percentage error due to calculating domain index value with respect to the domain index value when data for all the indicators are available are also reported (Table 4.19).

Table 4.18: Estimating Errors introduced in calculation of domain indices due to non availability of High weight indicators

	Wt.	D	7I	6I	5I	P	7I	6I	5I	V	7I	6I	5I	A	7I	6I	5I	B	7I	6I	5I
Solid Waste Management (SWM)																					
1. DSS	0.171	0.31	5.40	----	------	0.30	5.13	-----	-----	0.25	4.27	----	------	0.25	4.27	-------	-----	0.25	4.27	-----	-----
2. SDS	0.165	0.25	4.12	4.12	------	0.25	4.12	4.12	------	0.25	4.12	4.12	-----	0.25	4.12	4.12	------	0.25	4.12	4.12	------
3. SWRS	0.163	0.31	5.15	5.15	5.15	0.25	4.07	4.07	4.07	0.25	4.07	4.07	4.07	0.25	4.07	4.07	4.07	0.80	13.04	13.04	13.04
4. ECS	0.155	0.80	12.52	12.52	12.52	0.80	12.40	12.40	12.40	0.80	12.40	12.40	12.40	0.80	12.40	12.40	12.40	0.90	13.95	13.95	13.95
5. RCDS	0.133	1.00	13.30	13.30	13.30	0.25	3.32	3.32	3.32	0.25	3.32	3.32	3.32	0.25	3.32	3.32	3.32	0.25	3.32	3.32	3.32
6. $CR_{SWMS}S$	0.130	0.01	0.15	0.15	0.15	0.25	3.25	3.25	3.25	0.25	3.25	3.25	3.25	0.25	3.25	3.25	3.25	1.00	13.00	13.00	13.00
7. SWMPS	0.083	1.00	8.30	8.30	8.30	1.00	8.30	8.30	8.30	1.00	8.30	8.30	8.30	1.00	8.30	8.30	8.30	1.00	8.30	8.30	8.30
Summation	1.000		48.95	43.55	39.43		40.60	35.47	31.35		39.75	35.47	31.35		39.75	35.47	31.35		60.01	55.74	51.61
Total Wt.			1.000	0.829	0.664		1.000	0.829	0.664		1.000	0.829	0.664		1.000	0.829	0.664		1.000	0.829	0.663
Normalized SWM			48.95	52.54	59.38		40.60	42.79	47.21		39.75	42.79	47.21		39.75	42.79	47.21		60.01	67.23	77.73
% Error			0	7.31	21.29		0.00	5.38	16.27		0.00	7.65	18.77		0.00	7.65	18.77		0.00	12.03	29.52
Water Supply Management (WSM)																					
1. WQS	0.167	0.99	16.53	------	------	0.80	13.36	-----	-------	0.96	16.03	------	------	0.80	13.36	-------	------	1.00	16.70	------	------
2. $E_{UG}WS$	0.163	0.25	4.07	4.07	------	0.25	4.07	4.07	-------	0.25	4.07	4.07	-------	0.25	4.07	4.07	------	0.25	4.07	4.07	-------
3. AWS	0.151	1.00	15.10	15.10	15.10	0.52	7.92	7.92	7.92	1.00	15.10	15.19	15.10	1.00	15.10	15.10	15.10	1.00	15.10	15.10	15.10
4. SMMS	0.145	0.55	8.01	8.01	8.01	0.25	3.62	3.62	3.62	0.25	3.62	3.62	3.62	0.01	0.14	0.14	0.14	0.01	0.20	0.20	0.20
5. LIS	0.138	0.47	6.56	6.56	6.56	0.70	9.66	9.66	9.66	0.42	5.79	5.79	5.79	0.70	9.66	9.66	9.66	0.37	5.17	5.17	5.17
6. CWS	0.127	0.12	1.52	1.52	1.52	0.33	4.19	4.19	4.19	0.41	5.20	5.20	5.20	0.41	5.20	5.20	5.20	0.08	1.01	1.01	1.01
7. $CR_{WS}S$	0.109	0.41	4.46	4.46	4.46	0.50	5.45	5.45	5.45	0.61	6.64	6.64	6.64	0.81	8.82	8.82	8.82	0.31	3.38	3.38	3.38
Summation	1.000		56.28	39.75	35.68		48.28	34.92	30.85		56.48	40.45	36.37		56.37	43.01	38.94		45.65	28.95	24.88
Total Wt.			1.000	0.833	0.670		1.000	0.833	0.670		1.000	0.833	0.670		1.000	0.833	0.670		1.000	0.833	0.670
Normalized WSM			56.28	47.72	53.25		48.28	41.93	46.05		56.48	48.56	54.29		56.37	51.63	58.12		45.65	34.76	37.14
% Error			0	15.20	5.39		0	13.16	4.63		0	14.02	3.87		0	8.40	3.09		0	23.86	18.65
Sewerage, Sanitation and Storm water Drainage (SSS)																					
1. CTS	0.160	0.78	12.48	------	------	0.45	7.2	-----	-----	0.82	13.12	------	------	0.25	4.00	------	------	0.81	12.96	------	-----
2. CES	0.156	0.63	9.82	9.82	-------	0.25	3.9	3.9	------	0.5	7.80	7.80	-------	0.99	15.44	15.44	-------	0.01	0.15	0.15	------
3. QTSS	0.152	0.94	14.37	14.37	14.37	0.25	3.8	3.8	3.8	1	15.20	15.20	15.20	0.25	3.80	3.80	3.80	0.80	12.16	12.16	12.16
4. ASS	0.149	0.89	13.26	13.26	13.26	0.63	9.38	9.38	9.38	0.5	7.45	7.45	7.45	0.99	14.75	14.75	14.75	0.01	0.14	0.14	0.14
5. WWRS	0.148	0.27	4.05	4.05	4.05	0.7	10.36	10.36	10.36	0.25	3.70	3.70	3.70	0.25	3.70	3.70	3.70	0.25	3.70	3.70	3.70
6. CSWDS	0.134	0.05	0.72	0.72	0.72	0.65	8.71	8.71	8.71	0.1	1.34	1.34	1.34	0.22	2.94	2.94	2.94	0.45	6.07	6.07	6.07
7. $CR_{SSS}S$	0.101	0.39	4.02	4.02	4.02	0.25	2.52	2.52	2.52	0.55	5.55	5.55	5.55	0.81	8.18	8.18	8.18	0.34	3.52	3.52	3.52

Summation			58.75	42.24	36.44		45.88	38.68	34.78		54.16	41.04	33.24		52.82	40.64	33.38		38.72	25.76	25.60
Total Wt.			1.00	0.840	0.684		1	0.84	0.684		1.000	0.840	0.684		1.000	0.840	0.684		1.00	0.840	0.684
Normalized SSS			58.75	50.29	53.28		45.88	46.05	50.85		54.16	48.86	48.60		52.82	48.38	48.80		38.72	30.66	37.43
% Error			0.00	14.40	9.30		0	0.36	10.82		0.00	9.78	10.26		0.00	8.40	7.61		0.00	20.79	3.32
Ambient Environment Condition (AEC)																					
1. AAQS	0.376	0.30	11.43	------		0.55	20.83	------		0.33	12.40	-------		0.65	24.59	-------		0.78	29.55	------	
2. ASLS	0.325	0.25	8.12	8.12		0.36	11.70	11.7		0.25	8.12	8.12		0.75	24.37	24.37		0.37	12.18	12.18	
3. ASWS	0.299	0.25	7.47	7.47		0.50	14.95	14.95		0.25	7.47	7.47		0.50	14.95	14.95		0.50	14.95	14.95	
Summation			27.03	15.60			47.48	26.65			28.00	15.60			63.91	39.32			56.69	27.13	
Total Wt.			1.000	0.624			1.000	0.624			1.000	0.624			1.000	0.624			1.000	0.624	
Normalized AEC			27.03	25			47.48	42.70			28.00	25.00			63.91	63.02			56.69	43.48	
% Error			0	7.51			0	10.08			0	10.73			0	1.39			0	23.28	

Table 4.19: Estimating Errors introduced in calculation of domain indices due to non-availability of Low weight indicators

	Wt.	D	7I	6I	5I	P	7I	6I	5I	V	7I	6I	5I	A	7I	6I	5I	B	7I	6I	5I
Solid Waste Management (SWM)																					
1. DSS	0.171	0.31	5.40	5.40	5.40	0.30	5.13	5.13	5.13	0.25	4.27	4.27	4.27	0.25	4.27	4.27	4.27	0.25	4.27	4.27	4.27
2. SDS	0.165	0.25	4.12	4.12	4.12	0.25	4.12	4.12	4.12	0.25	4.12	4.12	4.12	0.25	4.12	4.12	4.12	0.25	4.12	4.12	4.12
3. SWRS	0.163	0.31	5.15	5.15	5.15	0.25	4.07	4.07	4.07	0.25	4.07	4.07	4.07	0.25	4.07	4.07	4.07	0.80	13.04	13.04	13.04
4. ECS	0.155	0.80	12.52	12.52	12.52	0.80	12.40	12.40	12.40	0.80	12.40	12.40	12.40	0.80	12.40	12.40	12.40	0.90	13.95	13.95	13.95
5. RCDS	0.133	1.00	13.30	13.30	13.30	0.25	3.32	3.32	3.32	0.25	3.32	3.32	3.32	0.25	3.32	3.32	3.32	0.25	3.32	3.32	3.32
6. $CR_{SWMS}S$	0.130	0.01	0.15	0.15	------	0.25	3.25	3.25	-----	0.25	3.25	3.25	------	0.25	3.25	3.25	------	1.00	13.00	13.00	-----
7. SWMPS	0.083	1.00	8.30	------	------	1.00	8.30	------	------	1.00	8.30	-----	------	1.00	8.30	------	------	1.00	8.30	-----	-----
Summation	1.000		48.95	40.65	40.50		40.60	32.30	29.05		39.75	31.45	28.20		39.75	31.45	28.20		60.01	51.71	38.71
Total Weight			1.000	0.917	0.787		1.000	0.917	0.787		1.000	0.917	0.787		1.000	0.917	0.787		1.000	0.917	0.787
Normalized SWM			48.95	44.33	51.46		40.60	35.22	36.91		39.75	34.29	35.83		39.75	34.29	35.83		60.01	56.39	49.19
% Error			0	9.43	5.11		0	13.23	9.07		0.00	13.71	9.85		0.00	13.71	9.85		0.00	6.03	18.03
Water Supply Management (WSM)																					
1. WQS	0.167	0.99	16.53	16.53	16.53	0.80	13.36	13.36	13.36	0.96	16.03	16.03	16.03	0.80	13.36	13.36	13.36	1.00	16.70	16.70	16.70
2. $E_{UG}WS$	0.163	0.25	4.07	4.07	4.07	0.25	4.07	4.07	4.07	0.25	4.07	4.07	4.07	0.25	4.07	4.07	4.07	0.25	4.07	4.07	4.07
3. AWS	0.151	1.00	15.10	15.10	15.10	0.52	7.92	7.92	7.92	1.00	15.10	15.10	15.10	1.00	15.10	15.10	15.10	1.00	15.10	15.10	15.10

	Wt.	D	7I	6I	5I	P	7I	6I	5I	V	7I	6I	5I	A	7I	6I	5I	B	7I	6I	5I
4. SMMS	0.145	0.55	8.01	8.01	8.01	0.25	3.62	3.62	3.62	0.25	3.62	3.62	3.62	0.01	0.14	0.14	0.14	0.01	0.20	0.20	0.20
5. LIS	0.138	0.47	6.56	6.56	6.56	0.70	9.66	9.66	9.66	0.42	5.79	5.79	5.79	0.70	9.66	9.66	9.66	0.37	5.17	5.17	5.17
6. CWS	0.127	0.12	1.52	1.52	------	0.33	4.19	4.19	------	0.41	5.20	5.20	-----	0.41	5.20	5.20	-----	0.08	1.01	1.01	-----
7. $CR_{WS}S$	0.109	0.41	4.46	------	------	0.50	5.45	------	------	0.61	6.64	-----	------	0.81	8.82	-----	------	0.31	3.38	------	-----
Summation	1.000		56.28	51.81	50.29		48.28	42.83	38.64		56.48	49.83	44.62		56.37	47.54	42.34		45.65	42.26	41.25
Total Wt.			1.000	0.891	0.764		1.000	0.891	0.764		1.00	0.891	0.764		1.00	0.891	0.764		1.000	0.891	0.764
Normalized WSM			56.28	58.15	65.83		48.28	48.07	50.58		56.48	55.93	58.41		56.37	53.36	55.41		45.65	47.43	53.99
% Error			0.00	3.32	16.95		0.00	0.43	4.75		0.00	0.97	3.41		0.00	5.34	1.69		0.00	3.90	18.25
Sewerage, Sanitation and Storm water Drainage (SSS)																					
1. CTS	0.160	0.78	12.48	12.48	12.48	0.45	7.20	7.20	7.20	0.82	13.12	13.12	13.12	0.25	4.00	4.00	4.00	0.81	12.96	12.96	12.96
2. CES	0.156	0.63	9.82	9.82	9.82	0.25	3.90	3.90	3.90	0.50	7.80	7.80	7.80	0.99	15.44	15.44	15.44	0.01	0.15	0.156	0.15
3. QTSS	0.152	0.94	14.37	14.37	14.37	0.25	3.80	3.80	3.80	1.00	15.20	15.20	15.20	0.25	3.80	3.80	3.80	0.80	12.16	12.16	12.16
4. ASS	0.149	0.89	13.26	13.26	13.26	0.63	9.38	9.38	9.38	0.50	7.45	7.45	7.45	0.99	14.75	14.75	14.75	0.01	0.14	0.14	0.14
5. WWRS	0.148	0.27	4.05	4.05	4.05	0.70	10.36	10.36	10.36	0.25	3.70	3.70	3.70	0.25	3.70	3.70	3.70	0.25	3.70	3.70	3.70
6. CSWDS	0.134	0.05	0.72	0.72	-------	0.65	8.71	8.71	------	0.10	1.34	1.34	-----	0.22	2.94	2.94	------	0.45	6.07	6.07	------
7. $CR_{SSS}S$	0.101	0.39	4.02	------	-------	0.25	2.52	-------	-------	0.55	5.55	------	------	0.81	8.18	------	------	0.34	3.52	------	------
Summation			58.75	54.72	54.00		45.88	43.30	34.64		54.16	48.61	47.27		52.82	44.64	41.69		38.72	35.19	29.12
Total Wt.			1.000	0.899	0.765		1.000	0.899	0.765		1.000	0.899	0.765		1.000	0.899	0.765		1.000	0.899	0.765
Normalized SSS			58.75	60.87	70.59		45.88	48.22	45.29		54.16	54.07	61.79		52.82	49.65	54.50		38.72	39.14	38.07
% Error			0.00	3.60	20.14		0.00	5.11	1.28		0.00	0.17	14.07		0.00	5.99	3.17		0.00	1.10	1.67
Ambient Environment Condition (AEC)																					
1. AAQS	0.376	0.30	11.43	11.43		0.55	20.83	20.83		0.33	12.40	12.40		0.65	24.59	24.59		0.78	29.55	29.55	
2. ASLS	0.325	0.25	8.12	8.12		0.36	11.70	11.70		0.25	8.12	8.12		0.75	24.37	24.37		0.37	12.18	12.18	
3. ASWS	0.299	0.25	7.47	------		0.50	14.95	-------		0.25	7.47	-----		0.50	14.95	-------		0.50	14.95	------	
Summation			27.03	19.55			47.48	32.53			28.00	20.53			63.91	48.96			56.69	41.74	
Total Wt.			1.000	0.701			1.000	0.701			1.000	0.701			1.000	0.701			1.000	0.701	
Normalized AEC			27.03	27.89			47.48	46.40			28.00	29.29			63.91	69.85			56.69	59.54	
% Error			0.00	3.20			0.00	2.26			0.00	4.58			0.00	9.28			0.00	5.03	

The precision of the outcome is determined by sensitivity analysis when certain interventions are applied (Sözer and Takmaz, 2020). Each intervention has a different impact on the overall index developed. Eight scenarios are generated in total. The different combinations involved in eight scenarios are as follows:

i. 7 indicators of SWM, 7 indicators of WSM, 7 indicators of SSS, 3 indicators of AEC (Total=24);

ii. 6 indicators of SWM, 7 indicators of WSM, 7 indicators of SSS, 3 indicators of AEC (Total 23);

iii. 5 indicators of SWM, 7 indicators of WSM, 7 indicators of SSS, 3 indicators of AEC (Total 22);

iv. 5 indicators of SWM, 6 indicators of WSM, 7 indicators of SSS, 3 indicators of AEC (Total 21);

v. 5 indicators of SWM, 5 indicators of WSM, 7 indicators of SSS, 3 indicators of AEC (Total 20);

vi. 5 indicators of SWM, 5 indicators of WSM, 6 indicators of SSS, 3 indicators of AEC (Total 19);

vii. 5 indicators of SWM, 5 indicators of WSM, 5 indicators of SSS, 3 indicators of AEC (Total 18);

viii. 5 indicators of SWM, 5 indicators of WSM, 5 indicators of SSS, 2 indicators of AEC (Total 17).

Normalized SCESI is calculated by summing up the normalized DIs. Percentage error is calculated using Eqn 5.7. The result of the analysis is shown in Fig. 4.31 and Fig. 4.32. It is observed that the highest error of 8.8% in SCESI is introduced when 2 indicators of high weight are ignored in the city of Bhubaneswar. A marginal error upto 5% is reported in the other cities. The analysis gives an indication that the tentative error involved in the calculation of SCESI ranges from around 5-10%, when some of the indicators are missing. The result indicates that the SCESI is significantly dependent on benchmarked indicator value as well as weight allotted to indicators. Thus, it is realized that included 24 indicators have their own significance and missing of any indicator may incur error in SCESI.

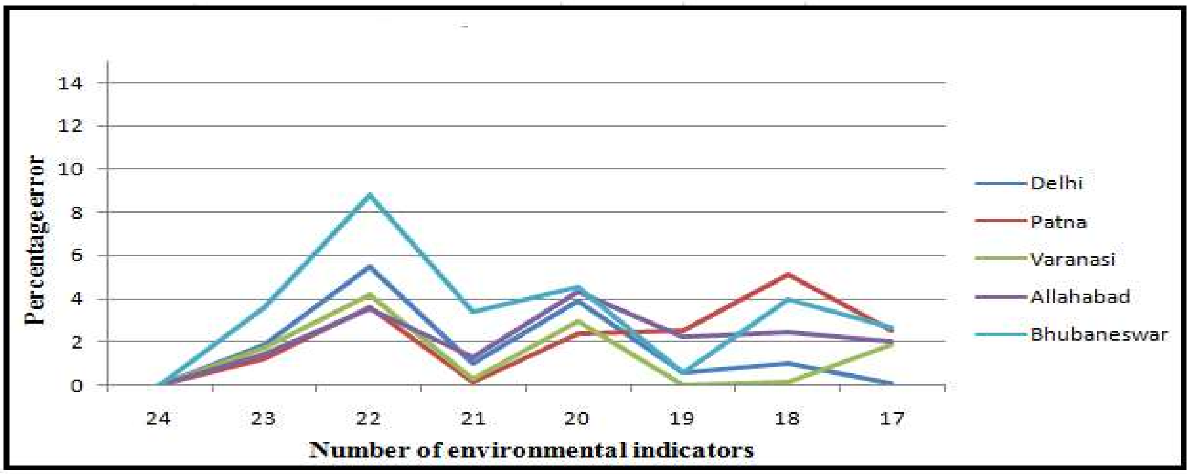


Fig. 4.31: Variation of percentage error in SCESI with decreasing number of indicators due to non availability of high weight parameters

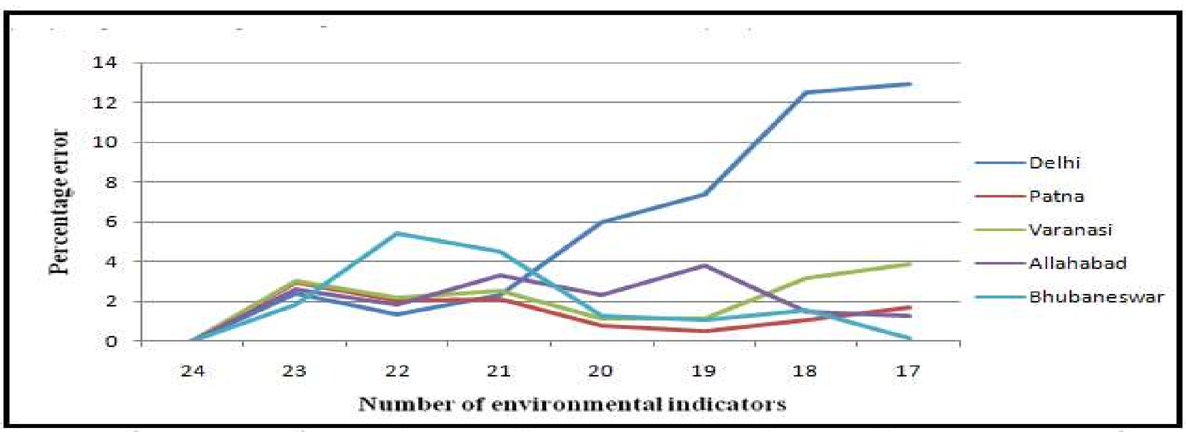


Fig. 4.32: Variation of percentage error in SCESI with decreasing number of indicators due to non availability of low weight parameters

4. 9 Summary of observations

In the present study, a vision of 'Environmentally Sustainable Smart Cities (ESSC) has been proposed, and a framework has been developed to calculate 'Smart City Environmental Sustainability Index (SCESI)' on a 0-100 increasing scale using 24 selected indicators to classify the existing environmental conditions of cities under five broad category: Excellent, Good, Fair, Poor and Critically Low. The SCESI may serve as a tool to measure, monitor, and maneuver the infrastructural initiatives based on environmental indicators. Further, the developed index is modelled to a software tool, DSS-ESSC for hassle free calculations and decision-making, regarding priority domains and indicators in which a city can invest for improving the prevalent scenario. The proposed DSS-ESSC aims to provide a straightforward analytical analysis of the current scenario of cities and recommends an optimal solution for the challenges associated with building ESSC.

The use of DSS-ESSC for validation using data of environmental indicators for Varanasi indicated that the SCESI for the city is 33.11 and falls under Poor category of environmental sustainability. Among 4 domains, 3 (SWM, WSM and SSS) are in Fair category and the fourth (AEC) is under Critically Low condition. Extending the application of DSS-ESSC on other four cities (Delhi, Kanpur, Allahabad, and Bhubaneswar) and comparing with Varanasi, it is observed that while Delhi, Allahabad and Bhubaneswar are in Fair category, Patna and Varanasi are found in Poor category. In order to improve the conditions a sequential prioritization for fund allocation can be done for environmental domains under Critically Low and Poor conditions. Among these five cities (Table 5.20) AEC is found under Critically Low category and indicated as the first priority for Delhi and Varanasi. Similarly, SWM is found under the Poor category for three cities (Allahabad, Varanasi, and Patna). SSS is found under Poor category for two cities (Patna and Bhubaneswar).

Based on individual indicator scores (ISs) obtained using currently available data for Delhi, the first three priority areas of attention and urgent action include (a) management of ambient sound level, (b) improvement in quality of water bodies, and (c) betterment of ambient air quality (all under AEC domain). In Patna, both SWM and SSS domains are under Poor category. For improving SWM, the first three priority areas are (a) Degree of Scientific disposal of MSW (b) Extent of Solid Waste recovered and (c Recycling and reduction of construction and demolition waste. Under SSS domain, (a) improvements in quality of treated sewage, (b) cost recovery from recycling and reuse and (c) enhancing collection efficiency of sewerage network constitute the three priority actions For Varanasi, while the AEC domain improvement requirements are similar to Delhi, under the SWM domain, (a) increasing degree of segregation, (b) scientific disposal of MSW, and (c) recovery of resources from MSW are the top three priority areas. Allahabad needs similar prioritized intervention in SWM as recommended for Varanasi. For improving SSS conditions in Bhubaneswar, (a) wastewater recycling, (b) enhancement of collection efficiency of sewage network, and (c) adequate sewage treatment capacity are found as priority action areas.

Table 4.20: Environmental Domain(s) under 'Poor (P)' and 'Critically Low (CL)' categories of environmental sustainability and Priority Indicators

Name of City	**Sequential priority of environmental domains for fund allocation**	**Environmental Domain(s) under Poor (P) or Critically Low (CL) categories**	**Priority Indicators**		
			First	**Second**	**Third**
i. Delhi	1. AEC 2. SWM 3. WSM 4. SSS	AEC (CL)	Ambient Sound Level	Ambient Surface Water Quality	Ambient Air Quality
ii. Patna	1. SWM 2. SSS 3. WSM 4. AEC	SWM (P)	Degree of scientific disposal of MSW	Extent of solid waste recovered	Recycling and reduction of construction and demolition waste
		SSS (P)	Quality of treated sewage	Extent of cost recovery	Collection efficiency of sewage network
iii. Varanasi	1. AEC 2. SWM	AEC	Ambient	Ambient Surface	Ambient Air

	3. WSM 4. SSS	(CL)	Sound Level	Water Quality	Quality
		SWM (P)	Degree of Segregation	Degree of scientific disposal of MSW	Extent of solid waste recovered
iv. Allahabad	1. SWM 2. WSM 3. SSS 4. AEC	SWM (P)	Degree of Segregation	Degree of scientific disposal of MSW	Extent of solid waste recovered
v. Bhubaneswar	1. SSS 2. WSM 3. SWM 4. AEC	SSS (P)	Waste water recycling	Collection efficiency of sewage network	Adequacy of sewage treatment capacity

After observing results and satisfactory observations for the above five cities, the application of DSS-ESSC was extended to additional 10 cities under SCM of India broadly representing all four parts of the country. Table 5.21 summarises the sequential order of environmental domains and indicators for fund allocation and attention on priority basis.

Table 4.21: Environmental Domain(s) under 'Poor (P)' and 'Critically Low (CL)' categories of environmental sustainability and Priority Indicators

Name of City	**Sequential priority of environmental domains for fund allocation**	**Environmental Domain(s) under Poor (P) or Critically Low (CL) categories**	**Priority Indicators**		
			First	Second	Third
i. Vishakha-patnam	1. SWM 2. AEC 3. WSM 4. SSS	SWM (P)	Degree of Scientific disposal of MSW	Recycling and reduction of construction and demolition waste	Efficiency in collection of MSW
		AEC (P)	Ambient Surface Water Quality	Ambient Sound Level	Ambient Air Quality
ii. Bangalore	1. SWM 2. AEC 3. WSM 4. SSS	SWM (P)	Recycling and reduction of construction and demolition waste	Extent of cost recovery in Solid Waste Management	Degree of Segregation

		AEC (P)	Ambient Surface Water Quality	Ambient Sound Level	Ambient Air Quality
iii. Indore	1. WSM 2. SSS 3. AEC 4. SWM	WSM (P)	Exploitation of underground water	Smart meters and Management	Continuity of water supplied in terms of average no of hours per day
iv. Muzaffar-pur	1. SSS 2. SWM 3. WSM 4. AEC	SSS (CL)	Collection efficiency of sewage network	Quality of treated sewage	Adequacy of sewage treatment capacity
		SWM (P)	Degree of Scientific disposal of MSW	Extent of Solid Waste recovered	Recycling and reduction of construction and demolition waste
		WSM (P)	Exploitation of underground water	Smart meters and Management	Continuity of water supplied in terms of average no of hours per day
v. Agartala	1. SSS 2. WSM 3. SWM 4. AEC	SSS (CL)	Collection efficiency of sewage network	Quality of treated sewage	Adequacy of sewage treatment capacity
		WSM (P)	Exploitation of underground water	Smart meters and Management	Continuity of water supplied in terms of average no of hours per day
		SWM (P*)	Degree of Scientific disposal of MSW	Degree of Segregation	Recycling and reduction of construction and demolition waste
vi. Jaipur	1. SWM 2. AEC 3. WSM 4. SSS	SWM (P)	Degree of Scientific disposal of MSW	Degree of Segregation	Recycling and reduction of construction and demolition waste
		AEC (P)	Ambient Sound Level	Ambient Surface Water Quality	Ambient Air Quality
vii. Agra	1. SWM 2. AEC 3. SSS 4. WSM	SWM (P)	Degree of Scientific disposal of MSW	Extent of cost recovery in Solid Waste Management	Recycling and reduction of construction and demolition waste

		AEC (P)	Ambient Surface Water Quality	Ambient Sound Level	Ambient Air Quality
viii. Kanpur	1. AEC 2. WSM 3. SWM 4. SSS	AEC (CL)	Ambient Surface Water Quality	Ambient Sound Level	Ambient Air Quality
ix. Lucknow	1. AEC 2. WSM 3. SWM 4. SSS	AEC (CL)	Ambient Sound Level	Ambient Surface Water Quality	Ambient Air Quality
		SWM (P)	Degree of Segregation	Degree of Scientific disposal of MSW	Recycling and reduction of construction and demolition waste of solid waste

Surat is the only city where all environmental domains are under Fair or better category and there is no domain either under Poor or Critically Low categories.

On the basis of the results derived from the application of DSS-ESSC, it can be confidently said that the developed DSS-ESSC may serve as an important tool to help the policymakers in understanding and evaluating environmental sustainability status of the cities in more acceptable and precise way and it may provide scientific basis for prioritization of domains as well as activities for urgent action.

The results obtained established and highlighted avenues for research within the domain of the smart cities. The key concepts identified during the research that should be included for framing the policies has been elaborated in the next chapter. The finding, challenges and limitations of the study has also been discussed in the conclusion part.