SUSTAINABLE WATER AND WASTE MANAGEMENT IN URBAN AREAS

A DISSERTATION

Submitted in partial fulfilment of

Requirement for the award of the degree

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By

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CANDIDATE'S DECLARATION

I hereby declare that the work is being presented in the dissertation work, entitled, **"SUSTAINABLE WATER AND WASTE MANAGEMENT IN URBAN AREAS"**, submitted in partial fulfilment of the requirement for the award of the degree of **Master of Technology in Hydrology** in the Department of Hydrology, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from July 2015 to May 2016 under the supervision and guidance of **Dr. Himanshu Joshi**, Professor, Department of Hydrology, Indian Institute of Technology Roorkee (IITR)- 247667 (India).

I also declare that I have not submitted the matter embodied in this dissertation for award of any other degree.

Date: **(NIKI BALA)**

Place: Roorkee

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

The world is witnessed of rapid urbanization in the last few decades. Currently 31 percent of India's population lives in cities and these cities are responsible for driven socio-economic activities. As concern by the statistical data, approximately half of the India population estimates to live in cities by 2030. This unprecedented increasing in urbanization causes significant challenges among which water and sanitation is most important factor. In India water supply and sanitation sector suffers from constantly inefficacy, with limited coverage and poor quality services. So the government main focus on fulfil the needs of society and to provide greater opportunity to improve the quality of life for today and in future. Government of India had launched the JNNURM mission for augmented the existing condition of urban services system. This urban service delivery aspect covered the status of water supply, waste water, solid waste and storm water drainage system.

The main objective of this study is to develop the framework for sustainable water and waste management to investigate whether the present status of water system is sustainable or not. These include evaluation of the existing water system & its solution for improvement by using Multi Criteria Decision Making (MCDM) method. The capability of the MCDM techniques is to provide a hierarchical quantitative framework and a process of comprehensive integration of diverse components. The system to be studied is divided into major interacting components; e.g., water supply, waste water, solid waste & storm water sub- system. These are present as third level indicators. Each third level indicator is determined by a set of second level indicators (For e.g. status of utility, governance & maintenance, Environmental issue & economy) which in turn, depend on basic indicators. The value of all the basic indicators with respect to the present state computed with the help of available information or field monitoring. The extent of contribution of each indicator to overall sustainability is different therefore different weights have been assigned to indicators by using Analytical Hierarchy Process (AHP) method.

The rapid baseline assessment of urban water system by using above method is carried out for five cities (Chandigarh, Allahabad, Visakhapatnam, Solapur and Jabalpur) among which Chandigarh is taken as reference benchmark. This analysis showed that the cities vary considerably with respect to its existing system. The final value of each city is represented in terms of Composite Value Index. This has a minimum score of 0 and maximum score of 1. In this technique, the best solution is the one which minimizes the distance from an ideal point

to an alternative solution. Thus the study demonstrated the evaluation of composite value of sustainability by combining many input indices which measure each single aspect of urban water performances.

As MCDM method used various qualitative and quantatively data for obtained the final score of alternative, while in reality, the decision problem data are changed or unstable. So sensitivity analysis used to effectively resolve this problem. This analysis has done by SAW technique. The main focus is to find most sensitive attribute which lead to higher change. The main focus is to find the most sensitive attribute which lead to change in the final score value by changing the attribute weight.

The SWOT analysis framework is important tool for analysing system strength, weakness, opportunities and threats. It helps to focus on strengths, minimize threats, and takes the greatest possible advantage of available opportunities. In this study SWOT technique is applied to MCDM methods that help to choose appropriate method according to specific objective. Thus it analyze the advantages and disadvantages of MCDM method. It is also used to bring out some of inherent strength and weakness of Chandigarh city.

ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
CBUD	Capacity Building of Urban Development
GoI	Government of India
GSDP	Gross State Domestic Product
Ha	hectare
HH	Household
Hr	Hour
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
MADM	Multi- Attribute Decision Making
MCC	Municipal Corporation Chandigarh
MCDM	Multi Criteria Decision Making
MGD	million Gallons per day
MODM	Multi -Objective Decision Making
MoUD	Ministry of Urban Development
SAW	Simple Additive Weight Analysis
SWITCH	Sustainable Water Management in the City of Future
SWOT	Strength Weaknesses Opportunity Threat
TBL	Triple Bottom Line
TCPO	Town and Country Planning Organization
ULBs	Urban Local Bodies
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
IMD	India Metrological Department
SI	Sustainability Index
LULC	Land Use Land Cover

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CHAPTER 1
INTRODUCTION

1.1 Sustainable Development

Sustainable development has been defined in Brundtland Report, entitled Our Common Future, as "to meet their needs without compromising the ability of future generations to meet the needs of the present generation" (United Nations General Assembly, 1987). "Needs" are the prime basis of the ecosystem, environmental, economic and cultural goals. These goals were further promoted through Agenda 21 by the organization of the UN, governments and major groups in every area in which the human beings influence on the environment. It is a comprehensive plan of action taken care of globally, nationally and locally. It is categorized into four sections: Section I: Social and Economic Dimensions, Section II: Conservation and Management of Resources for Development, Section III: Strengthening the Role of Major Groups, Section IV: Means of Implementation. For further Implementation of Agenda 21, "Millennium Development Goals" (MDGs) were established by the 192 U.N member countries in 2000 to achieve sustainable growth and poverty eradication. Further, United Nations declared during 25-27 September 2015, new global Sustainable Development Goals as "Transforming Our World: The 2030 Agenda for Sustainable Development". This for people, planet and profit is a plan of action (Centre for Environment Education, 2007).

Water is one of the most important parameters of sustainable development because it is the common denominator for all the global challenges of food, health, energy, peace and security and the eradication of poverty. Sustainable water management (SWM) is required to attain the objectives of society and sustaining the ecological, hydrologic and environmental integrity. Defined in terms of sustainability, it emphasizes "human and industrial system design cycle to ensure that the natural resources and economic opportunities do not lead to diminished quality of life due to adverse impacts on social condition, human health and the environment" (Russo et al, 2014). Exploration and incorporation of new technologies rather than the phased improvement of existing technology is preferred as it is better suited for services. Efficient use of resources lead to minimal increase in decline of sustainability and it would require a proactive rather than reactive approach.

1.2 Urbanization and its Impacts on Water Resources

In today's increasingly global and interconnected world, large population (54%) lives in urban areas, although there is significant variability in the level of urbanization across the countries (UN 2014). In India, urbanization has been projected to increase from the current level of 30% to 40% by 2030. The process of urbanization is associated with the transformation in social and economic condition which governs the greater geographic mobility, longer life expectancy, lower fertility, better health and enhanced opportunities. In cities, both urbanized and rural development and poverty alleviation are key factors. Rapid and unplanned urban growth does not allow the sustainable development as the infrastructure does not develop adequately and the environment protection related policies are generally not implemented in proper way. Ideal urban growth integrally linked to the three basic parameters of sustainable development: economic, social and environmental development. The world United Nations Conference on Human Settlements (Habitat III), planned for 2016, is going to bring together world leaders to develop a new model of urban development that integrates all the factors of sustainable development (UN 2015).

With the increase in urban population in India, tremendous pressure has been placed on urban services and service delivery systems at the city and town levels. Water management is one of the most serious problems of urban services. This trend is causing increased per capita consumption and problems with proper sewage disposal. Unplanned urbanization and the tremendous increase in population are always a threat for the water management in the developing countries or emerged urbanized regions. The Water Resources Group estimates that available water supply of the countries will only meet about half the demand within 18 years (GE Power & Water 2010). For the sustainable growth, India needs secure and safe supplies of water. In India, water supply and sanitation sectors suffer from constant inefficacy, with limited coverage and poor quality services. Impact of urbanization on the ground water is one of the most important perspectives of growing cities which is related in terms of land use pattern and quality and quantity of ground water. It leads to a reduction in the infiltration because of an increase in impervious or paved area, which further increases the storm water runoff. The surface water resources, on the other hand, are also adversely affected due to the extensive abstraction on the one hand, and also, due to the discharge of effluents of municipalities and industries, on the other. The quality and quantity scenario of both surface and ground water thus changes drastically. The concept of Integrated Urban water management supports the development and basin management simultaneously to achieve sustainability. However, an important reason for the absence of actions in this regard is also the lack of reliable data or information of the utilities to improve performance. This limits the capability of utilities to understand and assess their performance, and restrain the inter-utility comparison.

1.3 Introducing Sustainability into Existing Utilities: Smart Water Systems

One of a city's most important pieces of critical infrastructure is its water system. With populations in cities growing, it is inevitable that water consumption will grow as well. The term "smart water" points to water and wastewater infrastructure that ensures this precious resource - and the energy used to transport it - is managed effectively. A smart water system should be designed in such a way that a meaningful and actionable data about the flow, pressure and distribution of a city's water is collected or assessed. Further, it is critical that the consumption and forecasting of water use is accurately measured. As supplies are stressed by population growth or water scarcity there is a need to take care of the Non-revenue water or water losses. Smart water system also implies transforming wastewater treatment plants into resource recovery facilities, which include generation of energy. It also implies well planned and designed drainage networks. Drains which receive filtered surface run off should be designed with permeable edges that in turn help grow riparian vegetation that supports aqua flora and fauna. Use of advanced technologies is also implied to convert waste to energy facilities, while also generating renewable energy, reducing greenhouse gas emissions and supporting recycling by recovery of metals. It is reported that at the unit level, a decentralized under-ground waste collection and processing system would reduce the transmission of waste to the landfill to 20% of the total collection (Egis, 2014).

It is imperative that there is an important need of a comprehensive, sustainable and rational model for collection, conveyance and analysis of water supply and sanitation sectors including cost recovery purpose on water utility. Government of India (GoI) launched the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) to strengthen the capacity building of Urban Local Bodies (ULBs) by implementing the projects and rejuvenation across the selected ULBs in India. In order to provide a baseline for implementation of project, the MoUD launched a rapid assessment of the whole process which included two objectives : firstly establish a baseline of the 30 cities and this baseline would be helpful to monitor and evaluation of the progress in the city under the “Capacity Building of Urban Development” (CBUD) programme in mid and long term with the support of World Bank and Secondly implementing the reforms and service delivery benchmarks and identify areas of intervention and support for utilities to be provided to identify the potential gaps. The urban service delivery aspect covered the status of water supply, solid waste management, waste water and storm water drainage (MoUD, 2013). The overall framework adopted to achieve the goal as presented in Figure 1.1.

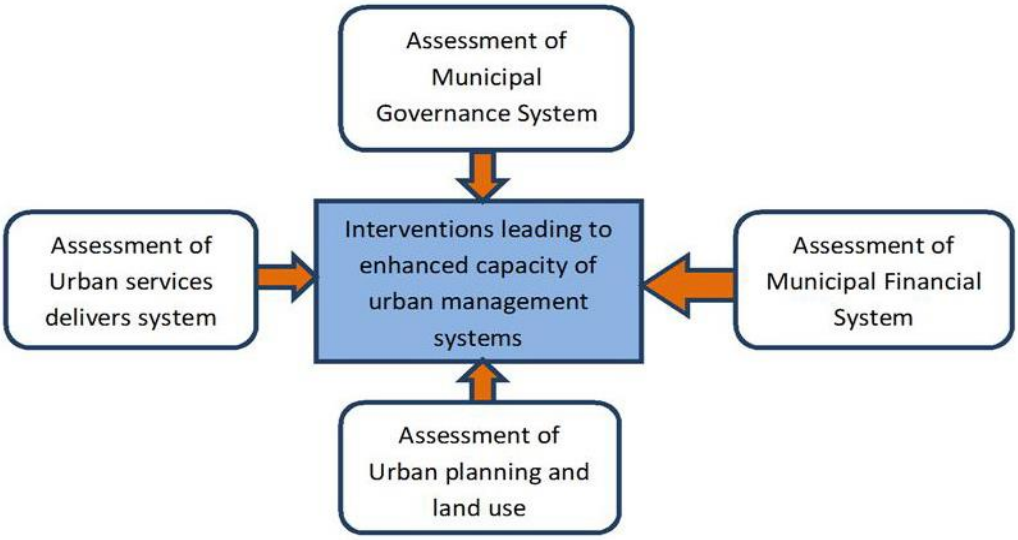

Figure 1.1: Rapid Baseline Study – Process mapping

(Source: MoUD, 2013)

1.4 LITERATURE REVIEW

Sustainable development is the integration of the three essential aspects of development: the economic, environment and ecosystem dimensions, which are commonly referred as the triple bottom line (TBL) sustainability. But it seems to be arguing that TBL approach does not provide a sufficient framework for measuring the overall sustainability (Larsen et al., 1997). Thus it should be the combination of sustaining the natural environment, resources, economy and societal goals.

Water is the one of important criteria for sustainable development as it is the elementary requirement for human life and welfare. With rapid population growth, water withdrawals have tripled over last 50 years and are predicted to increase by 50% by 2025 in developing countries (UNESCO, 2012). The concept of sustainable urban water management involve water supply, waste water treatment, urban drainage and sludge handling. In India, tremendous pressure has been put on key urban services and service delivery mechanism at city/town level because of their growing population. In order to overcome these issues, Ministry of Urban development (GoI) developed a report on "Benchmarking Urban Water Utilities in India" which deals with the existing system of water supply and sanitation sector in India. In this report, design the benchmarking of water and sanitation system to monitor, evaluate and propagate parameters which represent the different aspect of water system management either in social, economic and environmental way (MoUD, 2008).

A research programme, SWITCH (Sustainable Water Management in the City of Future) has been developed to facilitate new solutions to increase the efficiency of urban water systems and switching cities towards sustainability. This research programme was developed by European Union that was implemented and co-funded by a team of 33 partners from across the countries, including 17 from Europe and 12 from Asia, South America and Africa. This overall goal of this approach was to work on sustainable urban water management which combining water supply; waste water and storm water in the 'City of the Future' and integrating these three aspects into city planning (Howe et al. 2012).

In addition to the triple bottom line (TBL) structure of sustainability as indicated earlier. Marques et al. (2015) "developed a framework which includes five dimensions (TBL plus 'assets' and 'governance') corresponding to the basis of "people, profit and planet" criteria for sustainable urban water management. According to him, assets and governance aspects are also crucial dimensions for the success of water utilities with appropriate quality level and also appropriate to consider the impact of its actions on people, resources and places, both in short and long term". To aggregate the numerus aspects which are relevant in this case, a multi-criteria decision analysis approach was proposed. There is also a qualitative technique "MACBETH" method was used to determine the weights by survey stakeholder and decision maker. Furthermore to demonstrate real world application of this method, it was applied for the water utilities in case of Portugal.

Shilling et al. (2013) presented an analytical framework to develop a quantitative water resources sustainability indicator system for California. The framework describes the indicators which show the condition of water system and are correlated with ecosystem, social and economic services. It consists of a hierarchy structure of goals and objective for design the indicator and develops analytical methods for measuring sustainability of existing system. This approach has also been applied in state and regional scale pilot studies for monitoring the natural and human water system of California towards sustainability in the form of Water Footprint.

Multi Criteria Decision Making (MCDM) method is a convenient fast way for users to explore the best management option or alternative based on the most important criteria.

Velasquez et al. (2015) presented a literature review of Multi-Criteria Decision Making methods e.g. Multi- Attribute Utility Theory (MAUT), Analytical Hierarchy Process (AHP), ELECTRE and Fuzzy Set Theory etc. On the basis of survey, he observed the advantages and disadvantages of the identified methods and explained their common applications for each method. This research led to development of a new method which utilized and incorporated the advantages and eliminate disadvantages of the prevalent MCDM methods. Many researchers including (Latif & Joshi, 2003-2004) studied the environmental impact assessment of water resource projects in Bangladesh with; Composite Programming distance based and Multi-Criteria Decision Making Methods.

Hwang & Yoon (1981) "presented a literature on various methods and applications of Multiple Criteria Decision making (MCDM) method. MCDM methods are mainly used to solve complex problems with multiple, conflicting and also subjective criteria. These are classified into multi-objective decision making (MODM) and multi-attribute decision making (MADM) categories. These are based on the mathematical programming and well-formulated theoretical frameworks and can be used for large number of alternative choices, the best of which should satisfy the decision maker's constraints and preferences. MADM methods have been used to solve problems with discrete decision spaces and a limited number of choices. Its solution require inter and intra – attribute comparisons. The technique for order preference by similarity to ideal solution (TOPSIS) is a well-known multi-attribute decision making (MADM) method which is used to identify the best alternative solution among a set of alternatives based on the simulation minimization of the distance from an ideal solution".

Hatami-Marbini et al. (2013) proposed "compromise ratio method (CRM) for solving the group of MADM problems. CRM is similar to TOPSIS method; the chosen alternative should be close to the ideal point. The fuzzy group MADM (FGMADM) method has also been used in this study for improving the usability of the CRM because fuzzy sets are useful to dealing with the ambiguous data".

Shamsudin et al. (2006) worked on "fuzzy composite programming structure for Putrajaya river basin assessment which consists of Sg. Chuau, Sg. Limau Manis and Sg. Bisa. The rivers were ranked using multi-criteria decision making approach. Water quantity and quality are the major criteria to ensure the sustainable use of rivers and wetland systems. The basic indicators selected in this study were flow rate, rainfall, evaporation, DO, BOD and COD which were associated with the sustainability criteria of river systems. The highest ranking was associated with the highest ordered sequence value and shortest distance between the fuzzy box and the ideal point. The analysis showed that Sungai Chuau has the highest ranking with the value of 0.494”.

AHP (Analytical Hierarchical Process) model is used to measure the input factors on the basis of pairwise comparisons and based on the judgements of experts to prioritize the indicators on scale. These scales measure the factors intangibles in relative terms (Satty, 2008). “The comprehension is on the basis of importance of one indicator over another with respect to specific objectives. Then the derived priority scales are normalized by multiplying them to their actual nodes and duly combining all such nodes to get the final results. This AHP model has been applied to the problems based on three factors viz. economics, social sciences and measurement of human life” (Satty et al., 2001). The AHP offers substantial approach to dealing with economic problems through ratio scales whereas the political scientists have used the methodology to quantify the factors. Meanwhile researchers in the physical and engineering sciences can apply the AHP method to solve the conflicts between human values and hard measurement data.

SWOT analysis is basically used for analyzing the Strength, Weaknesses, Opportunity and Threat of various systems. Strengths and Weaknesses are internal factors which can be controlled while Opportunities and threats are the external factors which cannot be controlled & enable the system to achieve its goal (Valentin, 2001). Generally “SWOT analysis presents a list of factors with description of present and future trends of both internal and external environment and provides a good basis for strategic formulation if it is used properly”. But this analysis does not have the capability of comprehensive appraisal of the strategic decision making situation as it is difficult to quantify the factors. It is often left at the level of only identification of the factors (Mcdonald, 1993). Nevertheless, if used with Analytical Hierarchy Process (AHP), SWOT approach can develop a quantitative measure of importance for each factor to aid the decision making (Saaty and Vargas, 2001).

Leeuwen (2015) presented a document “City Blueprints”, which is the baseline assessment of the sustainability of water management for a selected city by European Innovation Partnership (EIP) water action Group. This study was based on the water management and climate change, and was carried out for 45 municipalities and regions in 27 countries. The assessment showed that the cities varied considerably with regard to their water management in the form of Blue City Index (BCI), the arithmetic mean of 24 indicators comprising the City Blueprint. The research concluded that the cities varied considerably with regard to the sustainability of the urban water cycle services. Theoretically BCI varied from a minimum score of 0 to a maximum score of 10. The actual BCI in the selected cities varied from 3.5 (Angola) to 8.5 (Sweden). It was also inferred in the study that cities in transitional and developing countries are particularly at risk but also provide the great opportunities for short term and long term improvements.

1.5 OBJECTIVES

- Development of a framework for Sustainable Water and Waste Management employing the Multi Criteria Decision Making Method to investigate the present status of water and sanitation sector in India.
- Application of the developed framework for a Benchmark town (Chandigarh) and comparison with other selected towns of the country.
- Providing recommendations for improving Sustainability in the Water and Waste management sectors and generation of appropriate information at the level of Indian towns.

1.6 APPROACH

The approach of the study is as follows

a) Development of a hierarchical Indicator framework based on Fuzzy Composite Programming based MCDM methods for water system consisting of four subsystems viz. Water Supply, Waste Water, Solid Waste and Storm Water.
b) Employing AHP model for assignment of Weights in the developed framework.
c) Collection and collation of the information on various aspects of the framework from available primary and secondary sources for all selected towns.
d) Conducting Sensitivity analysis on the results employing SAW method and Evaluation of the results employing SWOT analysis.

CHAPTER 2
METHODOLOGY

INTRODUCTION

The basic aim of this research work is to assess few selected cities in terms of their sustainable urban water supply, sanitation sector and solid waste and storm water management systems. The assessment is proposed to be undertaken through a framework developed employing Fuzzy Composite Programming based - "Multi Criteria Decision Making (MCDM) method. MCDM methods are preferred mainly due to their capability of providing a hierarchical quantitative framework and a process of holistic integration of diverse components. The following components highlight the methodology adopted:

2.1 Multi Criteria Decision Making (MCDM) Approaches

The MCDM approaches are gaining importance as potential tools for analyzing complex real problems due to their inherent ability to judge different alternatives on various criteria. These methods have a unique way of handling multiple incommensurable and conflicting criteria. The three principal types of MCDM techniques internationally employed are; ELECTRE method, Multi Attribute Utility functions method (MAUT), and distance based techniques like Compromise or Composite programming. Out of these, Distance Based Technique method has been used in this work.

2.1.1 Multi-Attribute Utility Functions (MAUT)

MAUT is an expected utility (or disutility) that can decide the best possible alternative by the decision maker from the achievement of the stated objectives (Duckstein and Gerson, 1984). This is accomplished by eliciting the decision maker's utility for each indicator and then combining these single utilities into one overall utility function. The system, which provides the highest degree of utility with respect to all the indicators, is defined as preferred alternative (Mcdonald, 1993.). The preferences of the decision makers requires stronger assumption at each level and also need to be precise to giving specific weights to each of the consequences. MAUT can be used in economic, energy management, financial, water management and agricultural problems which have significant amounts of uncertainty and enough data to make it proper method of decision making.

2.1.2 ELECTRE Method

ELECTRE is an outranking method because of involvement of iteration based on concordance analysis. This methodology was developed by Benayoun et al. (1966) as derived from three concepts, concordance, disconcordance and threshold values and was first used for water resources development by David and Duckstein (1976). Its major advantage is that it takes into account uncertainty. It is based on the concepts of pairwise comparison between alternatives and ranking them on the appropriate criteria. This method is used for Multi-Attribute Decision Making, where attribute value is in the form of interval number and is solved by ranking the alternatives. It chooses those systems which are preferred for most of the indicators and yet do not cause an unacceptable level of disturbance for any one indicator. There are two type of ELECTRE i.e. ELECTRE I and ELECTRE II.

Concordance can be used as the weighted percentage of the criteria for which one action is preferred to another and where the decision makers assign the weights. While, for the evaluation of discordance matrix, an interval scale is first defined, which is common to each criterion .The scale is used to compare the discomfort caused between the worst and best of each criteria. Thus, the discord index can be defined as:

$$D\ (i,j) = (Max.interval\ where\ i > j/(Max.range\ of\ scale)$$

Concordance and discordance matrices are both synthesized after employing additional threshold values suggested by decision makers. The result of ELECTRE I is represented by a graph which shows a partial ordering of the alternative systems. ELECTRE II uses complete ordering for obtaining results (Duckstein et al., 1984).

2.1.3 Distance-Based Technique: Fuzzy Composite Programming (FCP)

Fuzzy MCDM model

Fuzzy logic is a form of many valued logic, it deals with reasoning that is approximate rather than fixed or exact. It is an extension of compromise programming (Zeleny, 1982), which was developed by Bardossy and Duckstein (1982). FCP organizes a problem into the following steps:

- **i.** Define alternatives
- **ii.** Selection of basic indicators
- **iii.** Integrated basic indicators into further smaller and more generalized groups.
- **iv.** Evaluation of the worst and best values for basic indicators
- **v.** Define weights and balancing factors.
- **vi.** Evaluate with FCP method and rank alternatives.

“In this technique, the best solution is that which minimizes the distance from an ideal point to the set of non-dominated solutions. This distance based method incorporates uncertainty and group indicators into multi-level composite structures. The composite distances are calculated as function of the various options and plotted. An option is considered best when its results are the closest to the ideal state highlighting maximum benefit and no negative impact (Figure 2.1). Since the system composite index L measures the distances from the ideal state, the best options should correspond to minimum L (X) with respect to 1 or maximum L(X) with respect to origin (0, 0)".

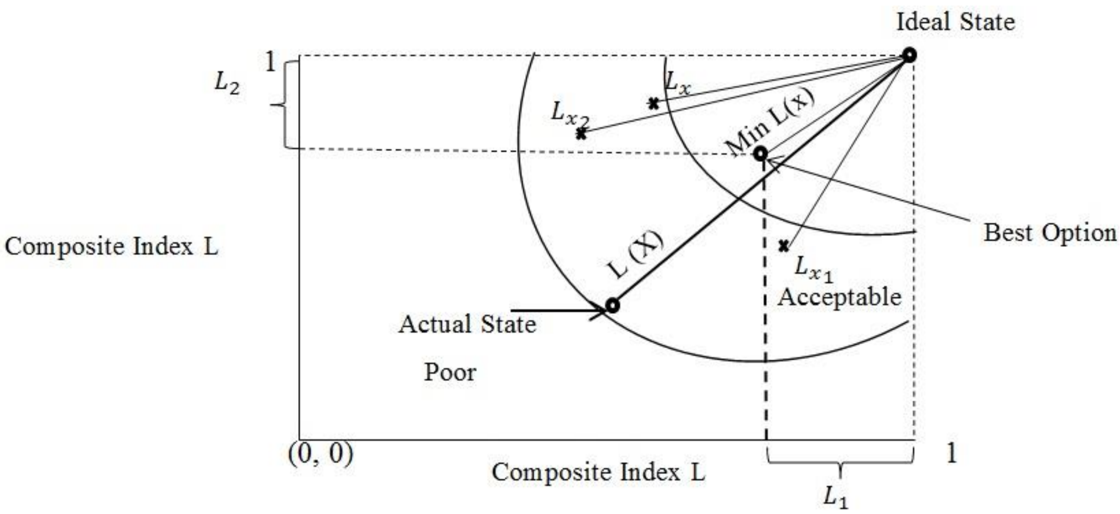

Figure 2.1 Comparison of options (Composite Programming Method)

In this method, composite distances are calculated as functions of various option x. Firstly, to transform the different basic indicators (Z_i) to a common scale, all are normalized in order to produce index functions $S_i(x)$.

$$S_i(x) = \frac{maxZ_i - Z_i(x)}{maxZ_i - minZ_i}$$

Next, they are aggregated into second level indicators (composite distance functions) and lastly into overall composite system indicators as per equations (1), (2) and (3).

$$L_j(x) = \left[\sum_{j=1}^{n_j} a_{ij} S_{ij}(x)^{P_j}\right]^{1/P_j} \quad (1)$$

$$L_k(x) = \left[\sum_{j=1}^{n_j} a_{jk} L_{jk}(x)^{P_k}\right]^{1/P_k} \quad (2)$$

$$L(x) = [\alpha_1 L_1(x)^2 + \alpha_2 L_2(x)^2]^{1/2} \quad (3)$$

where,

$L_j, L_k, L =$ composite distance functions for second level group j of basic indicators, third level group k, and final overall system respectively.

a_{ij}, a_{jk} = weights of second level group j and third level group k.

S_{ij}= actual value of basic index I in second level group j and third level group k.

L_{jk} = Second level composite distance for e.g. water supply, waste water

a_1 & a_2= weight indicating the relative between conservation and development

n_j = number of basic indicator in group k.

P_j & P_k= balancing factor among indicators for group j and k.

The balancing factor basically defines the maximum deviations between the indicators of the same set of group. The values generally used for balancing factor are 1 and 2. With the increasing in the balancing factor, lead to the increase in the deviations on the final value of L_j and L_k from the ideal point, that means the alternatives which have lower performance will be penalized severely. The option (among various options x i.e. alternatives), which results in the shortest distance to the ideal state, is considered the best. Since the best option corresponding to the Min L(x) with respect to (1, 1) or maximum with respect to the origin (0, 0) therefore the best alternative can be chosen from a set of alternatives.

2.2 Analytical Heirarchy Model (AHP)

One of the most popular technique for complex decision-making problems is the analytical hierarchy process (AHP) developed by Saaty (2008), - which divides a decision making problem into a system of hierarchies of objectives, attributes and alternatives. It is used for pairwise comparisons which allow the decision makers to assign weight to each indicator and compare alternatives with relative ease. Scaling ratio is in the range from 1 to 9 which is assigned to subjective judgements on the basis of relative importance of each criterion based on the characteristics. In this case the aim is not the selection of the best alternative, but to obtain the weight of an indicator which represents the relative importance of an indicator within the framework structure by using pairwise comparison technique. In this way all the indicators are assessed in correlation with each other. Four major steps are followed in the AHP technique as follows:

- Develop a hierarchy of input factors impacting on the final decision. This is known as AHP decision model. .
- Extract pair-wise comparison between the input factors.
- Evaluate relative importance of factors by assigning the weight at each level of hierarchy.
- Combine relative importance weights to obtain an overall ranking of the alternatives.

While, comparing two criteria, Satty Ratio scale is used (Table 2.1). Thus for comparing two criteria i and j weights are assigned on the basis of relative preferences of the decision maker.

Table 2.1 Satty Ratio scale for pairwise comparison

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4.6,8	Intermediate values between the two adjacent judgement	When compromise is needed
Reciprocal of above non zero	If the activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

(Source: Satty, 2008)

Mathematical Procedure of AHP method :

Matrix for pair-wise comparison: $\begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix}$

a) Sumation of each coloum of the matrix

$$c_{ij} = \sum_{i=1}^{n} C_{ij}$$

b) Divide each element bt its coloumn summation to evaluate a normalized pair-wise matrix

$$X_{ij} = \frac{c_{ij}}{\sum_{i=1}^{n} C_{ij}} \begin{bmatrix} n_{11} & n_{12} & n_{13} \\ n_{21} & n_{22} & n_{23} \\ n_{31} & n_{32} & n_{33} \end{bmatrix}$$

c) Then for calculation of weighted matrix, divide the summation of normalized coloumn matrix by the number of criteria included (N)

$$W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n} \begin{bmatrix} w_{11} \\ w_{21} \\ w_{31} \end{bmatrix}$$

Table 2.2 summarizes the strengths and weaknesses of various MCDM methods: MAUT, ELECTRE, AHP method and Fuzzy composite programming.

Table 2.2: Comparison of MCDM methods

Methods	Important criteria	Strength	Weaknesses
MAUT (Multi-attribute utility theory)	The whole performance of an alternative is expressed in a single quantified way. Weight is obtained by surveying stakeholders	Easy to compare those alternatives, having overall score values are expressed as single numbers Carried uncertainty and can be incorporate the preferences	Weights are not obtained through accurate method so that it can be provided false results. Not good with respect to group decision making and extensive interaction is required.
ELECTRE Method	Pairwise comparison between alternatives and ranking them on the appropriate criteria. One option is outranks if another is sufficient important or assigned by the weight (Concordance model).	It can handle quantitative and qualitative data. Easy in computation and carry discrete sets of alternative. Does not need to convert all the criteria into single unit.	Does not always take into account whether over performance of one criterion can compensate for underperformance of other criteria. Its process of outranking and outcomes are relatively complex
Fuzzy Composite Programming	Needed hierarchical structure for computation. Weight is assigned by appropriate method on the basis of relative importance of Indicator. Ideal, worst value assigned by users or stakeholders	It converts qualitative into quantitative data by using scaling technique. Can be improve over the time and adapt to changes with respect to specific problem.	This method is often used in a highly quantatively manner to arrive at a false result that does not satisfy stakeholder. Sensitive to inconsistent data.
AHP method	Pairwise comparisons of criteria and alternative is used for evaluate weights and score respectively	Easy to implement Hierarch structure easy to solve diverse components.	Problems because of Interdependence between criteria. Ranking developed by AHP are sometimes not transitive.

(Source: Velasquez et al., 2013

2.3 Simple Additive Weight (SAW) Analysis

SAW method is most commonly used in MADM technique because of its simple analysis and is based on various methods of multi-criteria decision making approach such as AHP and PROMETHEE that help to calculate the final score of alternatives (Memariani et. al., 2009). In SAW method, final score value of alternative is calculated by following equation:

$$P_i = \sum_{j=1}^{k} w_j r_{ij} \quad ; \quad i = 1,2 \ldots\ldots, m \ \ldots\ldots\ldots\ldots \ (1)$$

Where, r_{ij} are normalized values of attributes and w_j is assigned weight

"As MCDM method uses various qualitative and quantatively data for obtaining the final score of alternatives, while in reality, the decision problem data are changed or unstable. So after solving the decision making problems, usually a sensitivity analysis should be used to assess their role in influencing the results. SAW technique is one of the preferred sensitivity analysis methods". The main focus is to find the most sensitive attribute which leads to change in the final score value by changing in the attribute weight. In SAW technique, final score is calculated as follows. :-

2.3.1 The effect of change in weight of one attribute on the weight of other attributes -:

Assume that the weight of attributes is $W^t = (w_1 \, w_2 \ldots\ldots w_k)$ whereas the summation of weight after normalisation is 1.

With these assumptions, if an attribute weight changes, then the weight of the other attributes changes accordingly and gets translated into a new vector i.e.

$$W'^t = (w'_1 \, w'_2 \ldots\ldots w'_k)$$

As the weight of attribute P^{th}, changes as $\Delta_{\boldsymbol{p}}$ then the weight of other attribute changes as

$\Delta_{\boldsymbol{j}}$; $j = 1, 2, \ldots\ldots, k$.

$$\Delta_j = \frac{\Delta_p \, w_j}{w_p - 1} \ ; \ j = 1,2, \ldots\ldots, k, \ j \neq p \ldots\ldots (2)$$

2.3.2 The effect on the final score value by change in the weight of one attribute in SAW technique

In the multi-attribute decision making model of SAW, if the weight of attribute P^{th} changes as Δ_p , then the final score of alternative i^{th} $i =$ 1, 2,...... m would changes as δ_i

$$\delta_i = \Delta_p r_{ip} + \sum_{\substack{j=1 \\ j \neq p}}^{k} \frac{\Delta_p w_j}{w_p - 1} r_{ij} \qquad i = 1, 2, \ldots m \ldots..(3)$$

Then new final score of alternative i^{th}, with respect to its old score and value of change in the attribute weight P^{th} would be

$$P_i{}' = (1 - \frac{\Delta_p}{1 - w_p}) P_i + \frac{\Delta_p}{1 - w_p} r_{ip} \qquad i = 1, 2, \ldots m \ldots (4)$$

This analysis involves the change of one attribute weight while keeping the rest of attributes at their default value, and then calculates the final score. The procedure is repeated for each attribute so that the approach can investigate the importance of individual attributes and relative degree of influence in the final score value. This property can be used in computer programming for calculating new score of each indicator (eq. 4) by considering the old value and changing the value of attribute weight.

2.4 SWOT Analysis:

The SWOT analysis framework is an important tool for analysing system strengths, weaknesses, opportunities and threats. It has originated from SOFT (Satisfactory, Opportunity, Fault and Threat) and came from the research conducted during 1960- 1970. The term Fault is changed to Weaknesses (W) by Urick and Orr (1964) and thus the abbreviation named SOWT. SWOT has been modified into matrix by Weihrich (1991) to match the internal factor to external factor (Table 2.3). It can be used to develop a plan that takes into consideration many different internal and external factors. This method maximizes the potential of the strengths and opportunities of system while minimizing the impact of the weaknesses and threats present in the system that it operates in order to make further steps towards achieving sustainability. Furthermore, “SWOT method does not include the analytical determination of the importance of the factors whereas it is based on the capabilities of the experts participating in the process for qualitative analysis” (Mcdonald et al., 1993). This method facilitates to gain insight into the past and think of possible solutions of problems either for an existing system or new intervention.

Table 2.3: SWOT matrix

	Helpful To achieving the objective	**Harmful** To achieving the objective
Internal (attributes of the System)	Strength	Weakness
External (attributes of the environment)	Opportunity	Threat

(Source: Valentin, 2001)

It is important to use this tool correctly. SWOT analysis involves the following steps:

Step 1 of SWOT analysis involves the collection and evaluation of key data depending on the system, e.g. population, water supply, sanitation, health status and cost recovery etc. Once the data have been collected and analyzed, then the system capabilities in these areas are assessed.

In **step 2** of SWOT analysis, data on the system are collected and sorted into four categories: strengths, weaknesses, opportunities and threats.

- **Strength**: SWOT analysis views strength as current factors that have prompted outstanding contribution in system performances. It is basically a set of internal attributes and resources that either exploit potentials and opportunities or they may be an asset to avoid threats and potential difficulties.
- **Weaknesses:** An internal condition which support the factors or services which are unfavorable to the growth of the system or the areas which might the capable of improvement.
- **Opportunity:** Traditional SWOT analysis views opportunity as significant new interventions available for the sustainable growth of system.
- **Threat:** Threat is the final part of SWOT analysis involving the assessment of the external risk having little or no control of system. These factors need not necessarily be

seen only from the negative side, a threat can also be a challenge which may be posed by an unfavorable situation in the system.

Step 3 involves the development of SWOT matrix for each alternative under consideration, measure the performance of system on the basis of external and internal factors and take correct action.

The advantage of SWOT analysis comes from the fact that it can be applied for any type of problems and conditions with a clear thinking and good judgement to obtain real good results. It is basically based on the capabilities of experts participating in the process. Its limitation is that it is however, able to indicate the direction only but not support to reach final decision by comprehensively assessing the strategic decision support setup.

CHAPTER 3

DEVELOPMENT OF SUSTAINABILITY FRAMEWORK FOR AN URBAN SYSTEM

3.1 INDICATOR STRUCTURE

The indicator structure consists of several features e.g. dimension, attribute and criteria etc. The first step in this approach is to identify the relevant indicators on the basis of specific objectives. These must be independent of each other to eliminate the issues of overlap. The indicators have been selected on one hand from comprehensive lists of sustainability indicators duly promoted by national & regional organizations as well as innovatively developed also on the other. The above indicators are characterised for the four major components of the water system i.e. water supply, waste water and solid waste and storm water systems.

3.1.1 Tree- Hierarchy Method

The Tree hierarchy method represents the overall logical structure of the database. In this case, the tree hierarchy method is associated with fuzzy multi-criteria decision making method to obtain the best alternative. The system to be studied is discretized into major interacting components, e.g. water supply, waste water, solid waste and storm water sub systems. The basic, independent and quantifiable indicators representing the above stated water sub systems are presented as "third level" indicators. These indicators are important water system parameters or components that can be directly observed, measured or computed such as, water supply coverage, quality, metering, non-revenue water, cost recovery, toilet coverage and reuse/recycle waste water more on. The third level indicators aggregate as a set of "second level" indicators classified as Categories (e.g. Status of utility, governance and maintenance, environmental issues, and economy) which, in turn aggregate to form the "Level 1 Indicators" classified as Dimensions representing Sub-components of water system. After identifying the system structure, "ideal and worst values" for each basic indicator are defined. The fuzzy composite structure developed for system contained 28 basic level third indicators, 16 level second indicators, 4 level first indicators (Table 3.1). Justification and explanation of the identified indicators at various levels is provided in the following sections.

Table 3.1 Structure of Water System Indicator

Level 1	Level 2	Level 3
Dimensions	**Categories**	**Basic Indicators**
Water Supply	Status of Service Utility	Coverage of water supply connections
		Per capita supply of water
		Continuity of water supply
		Water Exploitation Index
	Governance & Maintenance	Extent of metering of water connections
		Efficiency in redressal of customer complaints
	Quality	Quality of water supply
	Economy	Extent of non- revenue water
		Cost recovery in water supply services
Waste Water	Status of Service Utility	Toilet Coverage
		Coverage of sewage network services
		Collection efficiency of sewage network
	Governance & Maintenance	Adequacy of sewage treatment capacity
		Efficiency in redressal of customer complaints
	Quality	Extent of reuse & recycling of sewage
		Quality of sewage treatment
	Economy	Extent of cost recovery in sewerage management
	Status of Service Utility	Efficiency of collection of municipal solid waste
		Extent of segregation of municipal solid waste
	Governance & Maintenance	Extent of recovery of waste collected
		Efficiency in redressal of customer complaints

Solid Waste	Quality	Extent of scientific disposal of solid waste recovered
	Economy	Extent of cost recovery in SWM service
Storm Water	Status of Service Utility	Coverage of storm water drainage network
		Permeability Index
	Governance & Maintenance	% of Rainwater Quantity Harvested
		Depression storage Index
	Economy	Extent of cost recovery in storm water management services

3.1.2 Selection of indicators for Levels 1 and 2

The Hierarchy structure consists of four major components on the sustainability of water system and each component is broken down into four sub-criteria. First levels of structure are consists of four subsystems viz. Water Supply, Waste Water, Solid Waste and Storm Water.

Water Supply: Indian cities and town are continuously facing potable water crisis due to increasing demand and inadequate measures to meet that demand. This is because of increasing urban population, inefficient use of water, water pollution and improper management of water supply systems. For adequate availability of piped water supply that also meets benchmarks of water quality, pressure, etc. across the city, it is important to monitor the existing water supply system.

Waste Water: In many Indian cities, only a small percentage of urban areas in the country have an adequate sewage system and even where the system exists, the coverage of population by sewerage system is partial. The system should be adequate for collection and treatment of waste water; otherwise it creates insanitary conditions and results in serious health problems. For sustainable water management it is not just enough to collect and convey the sewage or installed capacity to treat it. It is important that the treated water which is discharged back into the water bodies or use for other purpose, meet the standards. Thus, the whole system needs to be regularly measured and monitored.

Solid Waste: Most urban local bodies of India are unable to deal effectively with the challenging task of collection, transportation and disposal of solid waste not only because of rapid urbanization but also because of non-availability of required open area for landfilling.

Accumulation of uncollected solid waste causes environmental problems, pollutes ground water and surface water. With rapid urbanization, generation of solid waste continues to increase, changing consumption pattern and a shift from recycling to a throwaway society. Therefore it is important to monitor the system with respect of coverage, generation, collection, transportation, disposal and revenue receipts and expenditure.

Storm Water: Lack of storm water drainage system causes the sanitation problem in many cities, especially during monsoon month. Provisions for storm water to feed lakes, maintaining ground water recharge and natural drainage system that would enable recycling of the storm water. It will help in conserving potable water and at the same time prevent water pollution. In most of the cases storm water drains are connected to sewerage network which makes system ineffective. Therefore it is important to measure and monitor the system.

Further each component is divided into sub criteria (Level 2): Status of Utility, Governance & Maintenance, Environmental issues and Economy.

Status of utility: It is important to evaluate the present scenario of the systems for further sustainable development.

Governance & Maintenance: Governance and Maintenance refers the range of social and administrative systems which develop and manage water systems and delivery of water services. For sustainable development, effective management of urban services are essential. “Good governance is an important aspect for good water management”.

Environmental Issues: This indicator is used to find out the impact of system on the environment at any stage including the end life of treatment options (reuse, recycling, quality, disposal to landfill and so on). These impacts may be short term and long term or may be occur at local, regional and global level.

Economy: Financial sustainability is crucial for all basic urban services. For analysing the cost benefit ratio from different components of water system, it is important to measure this indicator. All expenditure may be recovered in the form of user charges, taxes and fees.

3.1.3 Selection Basic Indicator for Water Supply System

- Coverage of direct piped water connection: This Indicator denotes the extent to which the water supply networking has reached out to individual properties (residential, commercial, industry & institutional) of selected area, i.e. a direct piped connection for water supply within the household.

$$= \frac{Total\ no.of\ households\ with\ direct\ service\ connection}{Total\ households\ in\ service\ area}$$

- Per Capita Supply of Water: Measures the total availability/supply of water for a city in proportion to the estimated demand thereby indicating efficiency in meeting the demand.

$$= \frac{Total\ water\ supply}{Total\ design\ demand\ of\ water}$$

- Continuity of Water Supply: Measures of level of continuity in water supply by considering the number of hours of supply in the selected area as a fraction of the total hours in the day i.e. 24hrs.

$$= \frac{No.\ of\ hrs\ of\ water\ supply}{Total\ no.\ of\ hrs\ in\ a\ day}$$

- Water Exploitation Index: Measures the amount of water extracted from the sources i.e. both surface water and ground water as a fraction of the overall availability highlighting status of sustainability.

$$= \frac{Amount\ of\ water\ Extracted}{Total\ \ avaliable\ water\ \ Resources}$$

- Extent of metering of water connections: These measures the extent of accountability in the quantity of water supplied by way of installing water meters for the legalized connections.

$$= \frac{Total\ no.of\ meterd\ water\ connections}{Total\ no.of\ water\ connections}$$

- Efficiency in redressal of customer complaints: This measures the level of satisfaction with respect to redressal of consumer complaints by estimating the number of complaints resolved within 24 hrs. out of total complaints received in the given time period.

$$= \frac{Total\ no.of\ water\ supply\ related\ complaints\ redressed\ within\ 24hrs}{Total\ no.of\ complaints\ recieved\ per\ day.}$$

- Water Quality Compliance: This is the measure of the compliance of the established water quality standards by estimating the fraction of randomly collected samples which meet or exceed the specified potable water standard (safety & health concern).

$$= \frac{Number\ of\ samples\ that\ complied\ the\ specified\ potable\ water\ standards}{Total\ number\ of\ samples\ that\ are\ taken\ for\ testing}$$

- Extent of Non-Revenue Water: This indicator provides information about status of losses of water (thefts, unauthorized connections, leakage) in the water supply system.

$$= \frac{Total\ water\ supply - Net\ water\ consumption}{Total\ \ water\ supply}$$

- Extent of Cost Recovery in Water Supply System: This indicator measures the financial sustainability of water supply services in terms of dues recovered from the consumers towards user service charges, fees and taxes etc.

$$= \frac{Total\ annual\ operating\ revenues}{Total\ annual\ operating\ \ expenses}$$

3.1.4 Basic Indicator Selection for Waste Water System

- Toilet Coverage: This indicator measures the extent to which citizens have access to a toilet, whether on an individual or community basis in the service area. This is an important consideration for India, considering the lack of basic sanitation facilities and the resolve of the government to improve this situation.

$$= \frac{Total\ no.of\ properties\ having\ individual\ or\ community\ toilets}{Total\ no.of\ properties\ in\ the\ service\ area}$$

- Coverage of sewage network services: A Sewerage network is an important service in any town for the collection and transmission of sewage for further treatment and disposal. This indicator measures the extent to which the sewerage network has reached out to individual properties of selected area.

$$= \frac{\begin{matrix} Total\ no.of\ properties\ connected \\ to\ sewerage\ network \end{matrix}}{Total\ no.of\ properties\ in\ the\ service\ area}$$

- Collection efficiency of sewage network: This indicator measures the evaluation of efficiency of the network system to capture and carry the waste water to the treatment system. It measures the amount of wastewater collected as a percentage of sewage generated in the service area.

$$= \frac{Total\ waste\ water\ collected}{Total\ waste\ water\ generated}$$

- Adequacy of Sewage Treatment Capacity: This indicator measures the adequacy of available and operational sewerage treatment plant by-:

$$= \frac{Treatment\ plant\ capacity}{Total\ waste\ water\ generated}$$

- Efficiency in redressal of customer complaints: this indicator has been selected to represent level of customer satisfaction as in the water supply system. It is measured as the total number of sewage related complaints redressed as a percentage of total received complaints in a given period-:

$$= \frac{Total\ no.of\ complaints\ redressed\ within\ month}{Total\ no.of\ sewage\ related\ complaints\ per\ month}$$

- Extent of Reuse & Recycling of Sewage: This indicator reflects the status of resource recovery and reuse options undertaken at the Sewage Treatment Plant (STP) scale. It measures amount of water which is reused and recycled after appropriate treatment for various purposes.

$$= \frac{Total\ amount\ of\ waterExtent\ of\ Reuse\ \&\ Recycling\ of\ Sewage\ after\ treatment}{total\ wastewater\ recieved\ at\ STPs}$$

- Compliance of Sewage Treatment standards: This indicator reflects the level of operational compliance of sewage treatment standards by the STP, thereby indicating its efficiency. It measures the percentage of wastewater samples that pass the specified secondary treatment standards set by the Government. The parameters analyzed to find treated waste water quality are BOD, Suspended Solids, Coliforms, Nitrogen and Phosphorous etc.

$$= \frac{Number\ of\ samples\ that\ complied\ the\ specified\ secondary\ teatment\ standards}{Total\ number\ of\ wastewater\ samples\ tested\ in\ a\ month}$$

- Extent of Cost recovery in Sewage management: This indicator reflects the recovery of operational costs and thus the financial soundness of the system. It is expressed as the operating revenue collected as a percentage of operating expenditure.

$$= \frac{Total\ annual\ operating\ revenues}{Total\ annual\ operating\ \ expenses}$$

3.1.5 Basic Indicator Selection for Solid Water System

- Efficiency of Collection of Municipal Solid Waste: This indicator reflects the efficiency of collection of solid waste measured by estimating the ratio of waste collected to the total waste generated that would depend on the population of city and the general activities pertaining to commercial and industrial sectors-:

$$= \frac{Total\ amount\ of\ waste\ collected\ by\ ULB}{Toal\ waste\ generated}$$

- Extent of Segregation: Segregation facilitates recycle, reuse and treatment of the different components of waste, so important for sustainable solid waste management systems. It is measured by the estimate of waste from households and establishment that is segregated as a fraction of the total solid waste collected.

$$= \frac{Total\ segregated\ solid\ waste}{Total\ solid\ waste\ collected\ by\ ulb}$$

- Extent of Recovery of Waste Collected: This indicator measures the amount of waste recycled or processed with respect to the collected amount, which reflects better management of health & environmental risk, leading to environmental sustainability.

$$= \frac{Total\ solid\ waste\ recycled\ or\ processed}{Total\ solid\ waste\ collected\ by\ ulb}$$

- Efficiency in redressal of customer complaints: Similar to the discussions presented earlier on providing satisfactory services to the clients for different areas, it is measures as a ratio of complaint resolved to the total complaints received in a given time period.

$$= \frac{Total\ no.of\ complaints\ redressed\ within\ a\ month}{Total\ no.of\ sewage\ related\ complaints\ per\ month}$$

- Scientific disposal of Solid waste: This indicator reflects the extent of desired management action taken for solid waste treatment/disposal at the level of the town authorities. It is measured as a ratio of the total amount of waste that is disposed in landfills as per standards for design, construction, operation and maintenance.

$$\frac{Total\ \ waste\ disposed\ in\ compliant\ landfill}{Total\ solid\ waste\ disposed\ in\ all\ landfill}$$

- Extent of Cost recovery: Considering that there is a potential to supplement user charges with revenues that can be gained from recycling, reuse and conversion of waste to either fuel or directly to energy, it is critical for measuring overall cost recovery.

$$= \frac{Total\ annual\ operating\ revenues}{Total\ annual\ operating\ \ expenses}$$

3.1.6 Basic Indicator Selection for Storm Water System

- Coverage of Storm Water Drainage Network: This indicator provides an estimation of the extent of coverage of the storm water drainage in the city.

$$= \frac{Total\ Length\ of\ Drains}{Total\ Length\ of\ Road\ Network}$$

- % of Rainwater Quantity harvested: This indicator is meant to measure the extent of rainwater harvesting undertaken in the urban area.

$$= \frac{Rainwater\ volume\ harvested}{Total\ measured\ rainfall}$$

- Depression storage Index: Rapid disappearance of natural waterbodies from the urban landscape has resulted in shortfall of available water storage areas and has put a considerable strain on the water and land resources. This index is hence meant to define the sustainability of the water bodies (past and present).

$$= \frac{Total\ \ area\ under\ water\ bodies\ encroached}{Total\ \ area\ under\ water\ bodies(datum)}$$

- Permeability Index: This indicator has been used to quantify the paved area with respect to the total area which effects the drainage system. Assessment of the area has been done from the unsupervised classification of LULC map of study area. Permeable area was estimated by adding areas of Agricultural land and vegetation and forestry area.

$$= \frac{Total\ Permeable\ area}{Total\ city\ area}$$

- Water logging & area vulnerability Index: It indicates the determination of the sustainability of an area to flooding. Continuity equation and Rational method used to determine the rainfall intensity causes.

$$= \frac{Total\ flood\ prone\ area}{Total\ city\ area}$$

3.2 Ideal and Worst Values

For the normalization process, maximum (ideal) and minimum (worst) threshold values have been selected for the basic third level indicators. The normalization process has been basically carried out for each basic indicator considering their different measurement units, so that all of them may be maintained on a common scale. The best and worst values may be fuzzy. The equation used for the normalization is given below:

$$S_i(x) = \frac{maxZ_i - Z_i(x)}{maxZ_i - minZ_i}$$

Where, max Z_i is best value & min Z_i is worst value

Brief justification for each indicator follows:

1. Coverage of water supply connections: The water supply services within the household should be through direct piped connection. Various techniques have been adopted by the government for providing piped connection to the properties as in many urban slums. Therefore the benchmark value should be 100% while the worst value is 0% as the public standpost cannot be considered a long term service provision.

2. Per capita supply of water: Presently, the standard mention in BIS 1172:1993 (reaffirmed, 2007) for value of water supply is 135 lpcd whereas to fulfil the minimum requirement for urban communities 70-100 lpcd is considered. Therefore the ideal value used for this indicator is 135lpcd and the worst value is used 70lpcd.

3. Continuity of water supply: In most of the Indian cities, intermittent water supply service is being operated reflecting an inadequate water supply system. A substantial investment is proposed to be taken by ministry of urban development to improve this level towards the target of 24hrs X 7 days (Best Value). 1-2hrs is considered as worst condition.

4. Water Exploitation Index: Over abstraction of water for different purposes causes significant pressure on the quantity of freshwater resources**.** The benchmark value for this indicator is 80% while the worst is considered 100% abstraction.

5. Extent of metering of water connections: All the connection should be metered for the efficient use of water, to detect the leakages and properly charging to the consumer according to its consumption. So the benchmark value for this is 100% while 0% is considered as worst condition.

6. Efficiency in redressal of customer complaints: The best value for this indicator is considered 80% as achieving even this target is considered laudable as it depends on various factor such as nature or medium of complaint, size of the area and network system. The worst condition is when no complaint redressal occurs i.e. 0%.

7. Quality of water supply: The benchmark value of 100% is proposed by W.H.O. The quality of water supply is very important indicator as its poor quality can cause serious public health hazards therefore the indicator should be monitored regularly. The worst value is envisaged as 20%.

8. Extent of non- revenue water: The target value for NRW is considered at 20% which is achieved by well performing system of developing countries. The present situation in various cities is considered extremely poor and considered worst.

9. Cost recovery in water supply services: National target of 100% cost recovery from the water supply services is considered as proposed under the JNNURM schemes in terms of taxes, user charges and fee. 0% recovery from the services is considered as worst value.

10. Toilet Coverage: From the ministry of urban development under the JNNURM scheme and Integrated Low Cost Sanitation plan, the benchmark value is proposed 100% for this indicator. Absence of toilet facilities (scenario in many cities of India) is the worst scenario.

11. Coverage of sewage network services: The coverage of sewage network system of various Indian cities is very low therefore substantial investment has been provided for this area under JNNURM schemes. Its target value is 100% which is also considered the best value in this case. Worst value is considered 0%.

12. Collection efficiency of sewage network: The performance of this indicator basically defines the effectiveness of the network system in collection and conveying the waste into treatment plants. Therefore 50% value of this indicator is considered as worst or inadequate system. The best value is 100% collection of waste water.

13. Adequacy of sewage treatment capacity: The capacity of sewage treatment should be adequate to treat the sewage generated in their cities. The ideal value for this indicator should be 100%. Present condition of sewage treatment plant was extremely poor i.e. 0% adequacy and considered worst.

14. Extent of reuse & recycling of sewage: It is important for sustainable water management that sewage is reused or recycled. Under the Water and Sanitation Program–South Asia (Benchmarking Urban Water Utilities in India - Phase II) the benchmark value for this indicator is considered 20%. While the worst condition is when waste water is not recycled or not reuse for any purpose.

15. Quality of sewage treatment: The current condition of quality of treated sewage is already very low and to improvise upon that, various schemes have been implemented. Thus the quality of treated sewage is expected to reach 80%. Worst value is the present condition of various cities i.e. 0%.

16. Efficiency in redressal of customer complaints: In this service it is important to register the customer complaints for remedial action and resolve them. The best value for this indicator is considered 80% as it is depends on various factor such as nature or medium of complaint, size of the area and network system. The worst condition is when no complaints is solved i.e. 0%.

17. Extent of cost recovery in sewerage management: : The target of 100% cost recovery from the water supply services proposed under the JNNURM schemes in terms of taxes, user charges and fee. 0% recovery from the services is considered as worst value.

18. Efficiency of collection of municipal solid waste: The various methods are available to measure the amount of waste collected. The unaccounted waste tends to gradually find its own way to recycling, degrades if it is biodegradable and moving along the roads. Many projects have been initiated for collection of waste such as Swachh Bharat Abhiyan or Clean India. The target value for this indicator is 100% while the worst value is 0%.

19. Extent of segregation of municipal solid waste: Presently the segregation of waste is absent in the collection of solid waste in various cities which is the worst condition. To improvise this indicator various techniques and procedures need to be implemented and increase its sustainability. The benchmark value is considered 80% for this indicator.

20. **Extent of recovery of waste collected:** The ideal value of this indicator depends on the inert matter available in the waste collected so that waste components are different for each city. The benchmark value is assumed to be 80% while the 0% waste recovery is considered worst condition.

21. Efficiency in redressal of customer complaints: The best value for this indicator is considered 80% as it is depends on various factor such as nature or medium of complaint, size of the area and network system. The worst condition is when no complaints is solved i.e. 0%.

22. Extent of scientific disposal of solid waste recovered: The waste should be disposed finally at the landfill sites which are designed on the basis of standard conditions for avoiding harmful gases or collection and treatment of leachate. It is an important indicator for an environmental sustainability management therefore its benchmark value is assumed to be 100% and worst value is the present condition (0%).

23. Extent of cost recovery in Solid Waste Management service: In case of solid waste management, there is a potential to recover the charges that can be collected from reuse, recycled and conversion of waste to fuel or energy. Thus the ideal value for this indicator is considered 100% which is achievable. The worst condition is when the cost recovery from solid waste is 0%.

24. Coverage of storm water drainage network: The ideal value for coverage of drainage network system should be 100% and the worst value is 0%.

25. Permeability index: The benchmark value of permeable area is considered as 50% while 0% is considered worst scenario.

26. Water logging & area vulnerability Index: The ideal value of this indicator should be 0% for avoiding water logging and flooding in the area. Maximum % is the worst value and in this case it is considered 30%.

27. % of Rainwater Quantity Harvested: There are various techniques to collect the rainwater such as paved area, roundabouts, rooftops and parks. The ideal value for this indicator should be 80%. It is difficult to stored total amount of rainwater whereas absence of any provision for storage of water is considered as Worst.

28. Depression storage Index: Because of increasing rapid urbanization it may be possibility of disappearance of waterbodies from the urban landscape. Thus the ideal value is considered as 60% while the Worst value is considered as complete disappearance of water bodies.

3.3 Weights and Balancing factors

The extent of contribution of each indicator to overall sustainability is different therefore different weights have been assigned to indicators by using Analytical Hierarchy Process (AHP) method. Each indicator is transformed into a common scale so that comparison of different indicators can be possible. Preliminary results indicate that the application of AHP method is effective in decision making. The summation of the weight should be equal to 1 of the same group. The evaluation of the weights by AHP method for water system is presented in ANNEXURE-A.

Balancing factors indicate the possibility of maximum deviation between same set of indicators. It determines the interdependence of the indicator. If the allowable level of interdependence is high between the indicators then low balancing factor is used i.e. 1. For moderate and high level of substitution, a balancing factor 2 and 3 is used respectively. In this system medium dependency between indicators is considered therefore balancing factor 2 is used.

CHAPTER 4
SUSTAINABLITY EVALUATION FOR CHANDIGARH CITY AS A BANCHMARK REFERENCE

4.1 CHANDIGARH: AN INTRODUCTION

General

Chandigarh is one of the few planned Indian cities and is characterized by well-maintained streets, well laid out residential areas and functional amenities like water supply, proper drainage system and sewerage systems. Located in the foothills of the Shivalik range of Himalayas of North West India, Chandigarh spans over an area of about 114 km^2 .Its neighboring states comprise of Haryana and Punjab. The exact cartographic co-ordinates and the average elevation are 30.74°N &76.79°E and 365 meters above MSL respectively. Situated in the northern plains, the city has huge swathes of fertile and flat land. It is bordered by portions of bhabhar in the north east and terai covers the rest of the area (Chandigarh Administration, 2015). (Figure 4.1).

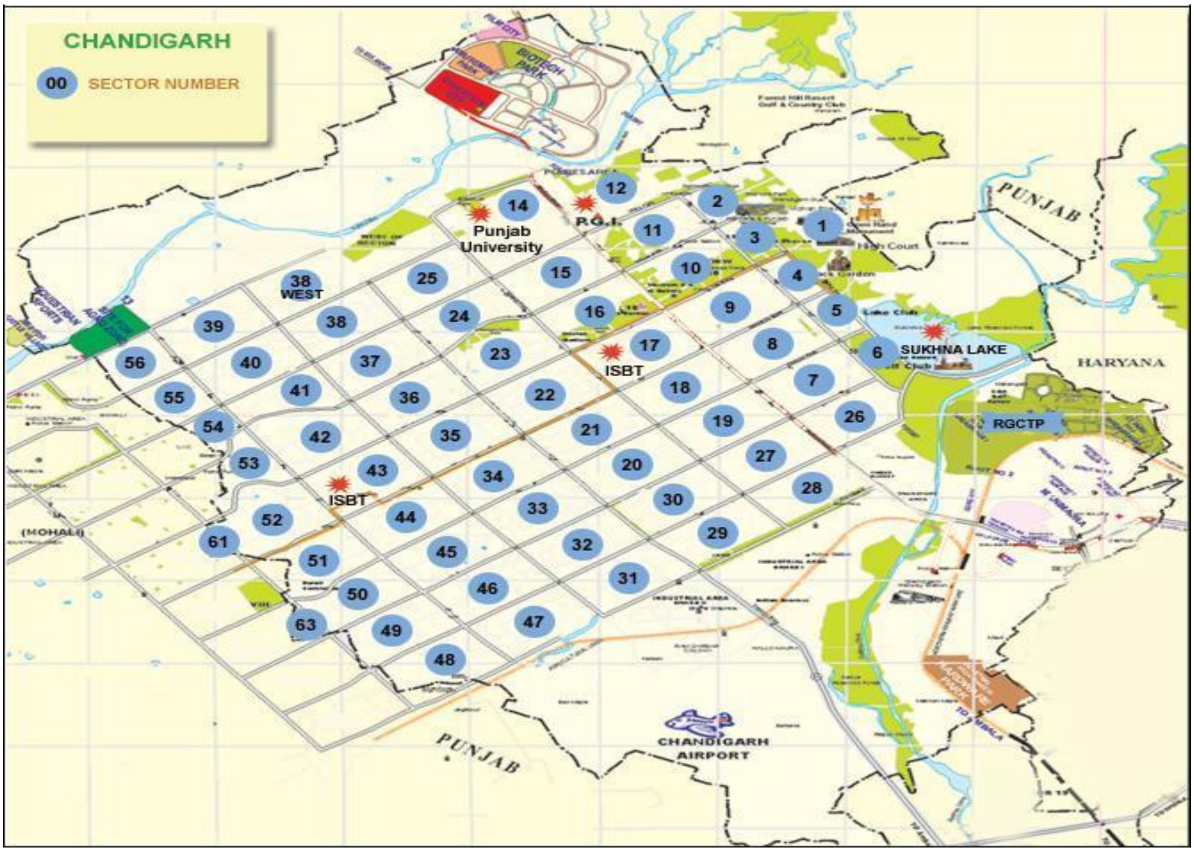

Figure 4.1 Location Map of Study Area
(Source: Chandigarh Administration, 2015)

4.1.1 Demographic Profile

Chandigarh is a union territory that came into existence on 1st of November, 1966 with an area of 114sq.km.The last six decades (1951-2011) have witnessed a forty-fold increase in Chandigarh's population. The population in absolute terms has grown from 2461 in 1991 to 10, 54,686 in 2011. The plan for developing Chandigarh had two phases for half a million population. The first phase included acquisition of 36 sq. km land by city administration for developing 30 sectors while the second phase included development of the remaining 17 sectors (31 to 47). However Chandigarh has exceeded its planned capacity and has grown almost double to the planned capacity. The third phase of development started in sector 48 and beyond to accommodate the rising population (TCPO, 2009). In accordance with the 2011 census, Chandigarh has a population of 10, 54,686 and the population density stand at about 9252 (7900 in 2001) persons per square kilometer.

An interesting fact is that there has been observed a considerable decline in the population growth rate in Chandigarh. The growth rate has been just 17.10% between 2001-2011 and has decreased from 394.13% to 17.10% (Table 4.1) since, 1951-2011(Census 2011). Besides education the main reasons attributed to population decline are rapid urbanization and development in neighboring cities. Chandigarh has evolved as a highly urbanized city with the urban population constituting 97.25% of the total and the rural population comprising just 2.75% (Census 2011). The rural population of Chandigarh is limited to a few villages within Chandigarh on its Western and South-Eastern border while majority of the people live in the heart of Chandigarh (Table 4.2).

Table 4.1 Population Growths in Chandigarh (1951-2011)

Year	Total population	Decadal Growth	Growth Rate (%)
1951	24261		
1961	119881	95620	394.13
1971	257251	137370	114.59
1981	451610	194359	75.55
1991	642015	190405	42.16
2001	900635	258620	40.28
2011	1054686	154051	17.10

(Source: Provisional Population Totals, Paper 1 of 2011, Census of India, 2011, Chandigarh Series 5)

Table 4.2 Demographic Data for Chandigarh

S.No.	Demographic Indicator	Description
1	Population Density	9252 persons/ sq.km in the UT of Chandigarh = 12109.7 persons / sq.km. in the Municipal area (population= 960,787 persons/ area =79.34 sq.km
2	Decadal Population Growth rate	17.10% (2001-2011)
3	Literacy Rate	86.43 for the UT and 86.74 for the Municipal area of Chandigarh
4	Sex Ratio (no. of female per 1000 male)	= 818 for the UT = 829 for the Municipal area
5	Household information	1. Total household : 298367 2. Occupied houses under residential: 247047
6	% of Slum population	12.5%
7	% Houses in Slums (7.6%)	7.62%

(Source: MoUD, 2013)

4.1.2 Rural and Urban Composition

The urban settlements of Chandigarh and Manimajra comprise a major part of its 114 sq.km area of Chandigarh. In 1961 the urban and rural breakup of the Chandigarh population was 82.80% and 17.20% respectively. However As per census 2011 the urban population of Chandigarh was 10, 25,682 (97.25%) and 29,004 (2.75%) was rural (Census, 2011)

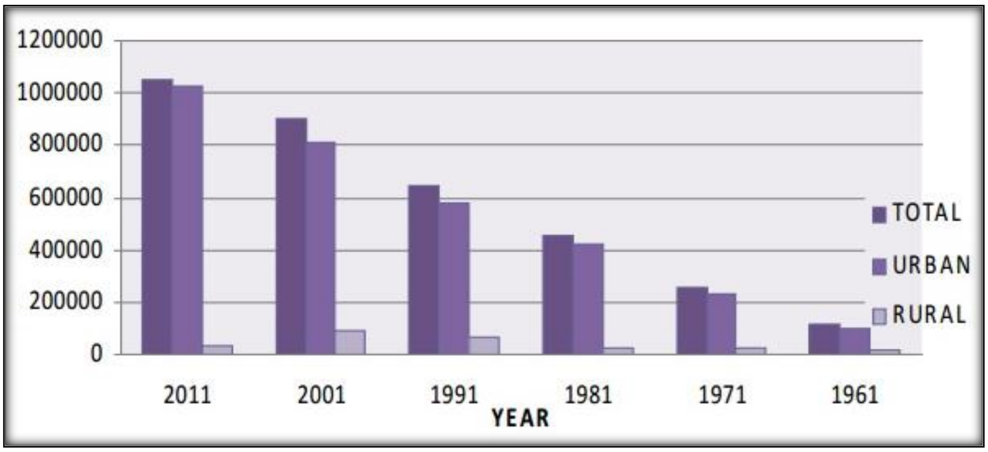

Figure.4.2: Rural – Urban Composition

(Source: Census of India, 2011)

4.1.3 Land Use

The area under study covers a span of 28170 acres and the land uses are categorized into residential, industrial, commercial, open spaces, drainage & waterbodies agricultural land, forest land, and roads etc. (Figure 4.3). The residential area covers 76.3% of the total area that is 20717 acres. Vertical expansion is the only viable solution to meet the residential demand of the city as limited area hinders horizontal expansion. Drainage & water bodies class cover 565 acres (2%). All the water bodies (lakes, ponds and water tanks natural and manmade) sewerage and river channels all are included in this category. An increase in the residential area clearly depicts that residential or commercial construction is the primary factor that would determine the planning resources of a city (Table 4.3).

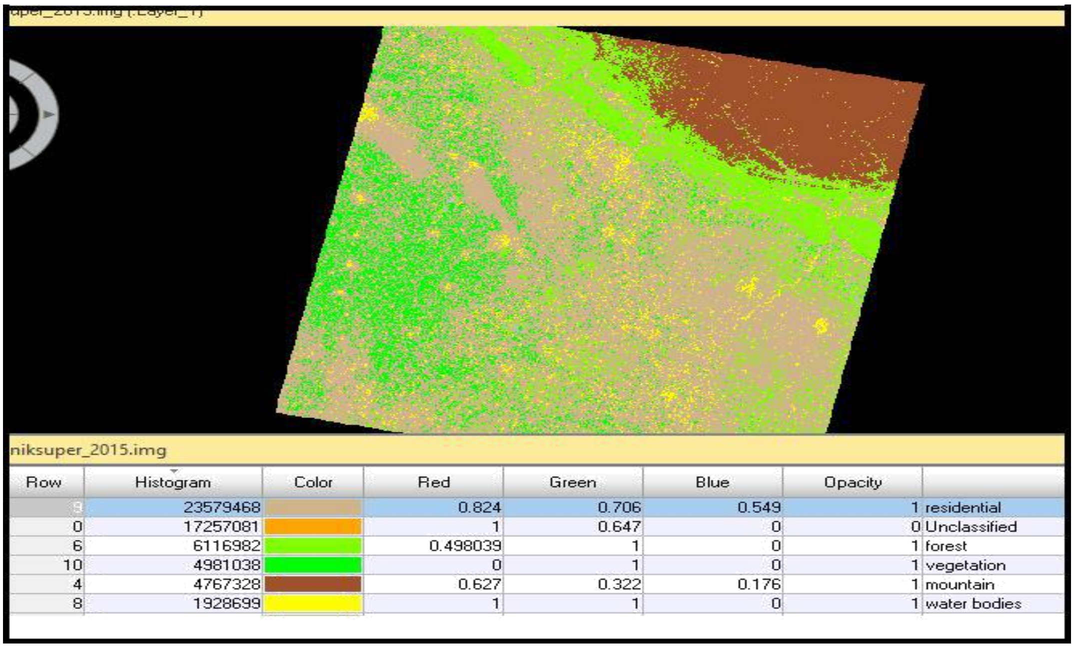

Figure 4.3Classified Image of year 2011

Table4.3 Existing Land Use of the Study Area

S.No.	Land Use	Area In Acres	Percentage (%)
1.	Residential	20717	73.5
2.	Agricultural, plantation & Cropland	3694	13.11
3.	Forest	2122	7.5
4.	Waterbodies/wetlands/lakes	380	1.35
5.	River/stream/canal	185	0.65

4.1.4 Surface Drainage

Chandigarh falls in the Ghaggar Basin. The natural drainage of the city is formed by two major streams, Sukhna Cho and Patiali ki Rao that have their source in the Shiwalik Hills. The Sukhna Choe flows north to south across the eastern part and joins the Ghaggar River while the northern part is drained by the other stream Patiali ki Rao, which flows northeast to southwest. Both these streams are seasonal and witness heavy flows during the monsoon seasons. The N- Choe flows through the leisure valley and covers a major part of the city. The direction of flow is from northeast to southwest direction and the area covered is the north central part of city.

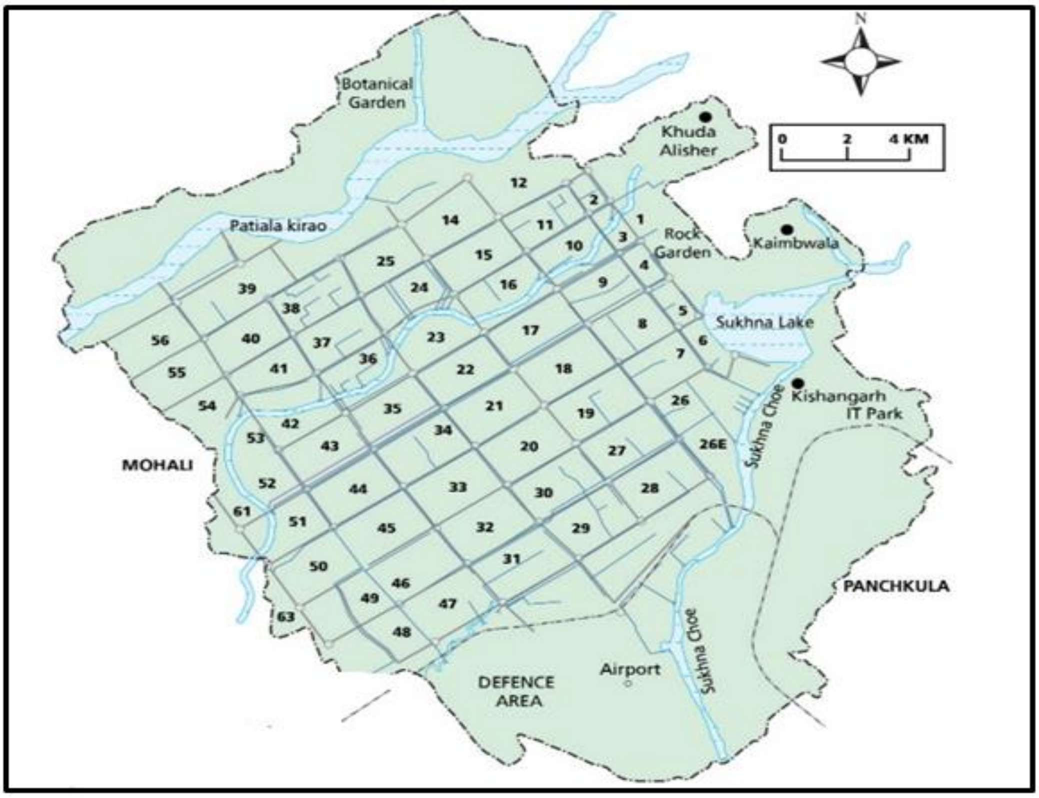

Figure 4.4: Storm Water Drainage System

(Source: Chandigarh Administration, 2010)

4.1.5 Rainfall and Climate

Chandigarh witnesses subtropical climate characterized by hot summer and cold winter. During monsoon season, moisture of oceanic origin reaches the area. Chandigarh receives an average annual rainfall of 106.1 cm, with unequal distribution over the area in 49 days.

The southwest monsoon which starts from the last week of June and continues till

September end makes up 80% of the annual rainfall. The area receives maximum rainfall in July and August and remaining 20% rainfall is received during non- monsoon period due to the western disturbances. The variation in the annual rainfall in Chandigarh is appreciable i.e. 700mm to 1200mm year to year. The average rainfall is 1100.7mm for 20years. The excess, normal and deficient has occurred in 11, 22 and 10 years, respectively out of 43 years of recorded rainfall (IMD, Chandigarh).

The mean maximum temperature recorded has been 39.1 ˚C (May and June) and the mean minimum temperatures recorded has been 6.1 ˚C (January). During May the wind velocity stands at 8.4 km/hr. while in September it remains at 3.2 km/hr. The average annual evaporation for Chandigarh is 211cm. The lowest monthly evaporation is 7.2mm which was recorded during January and the highest takes place in May and stands at 36.3mm (MCC, 2015).

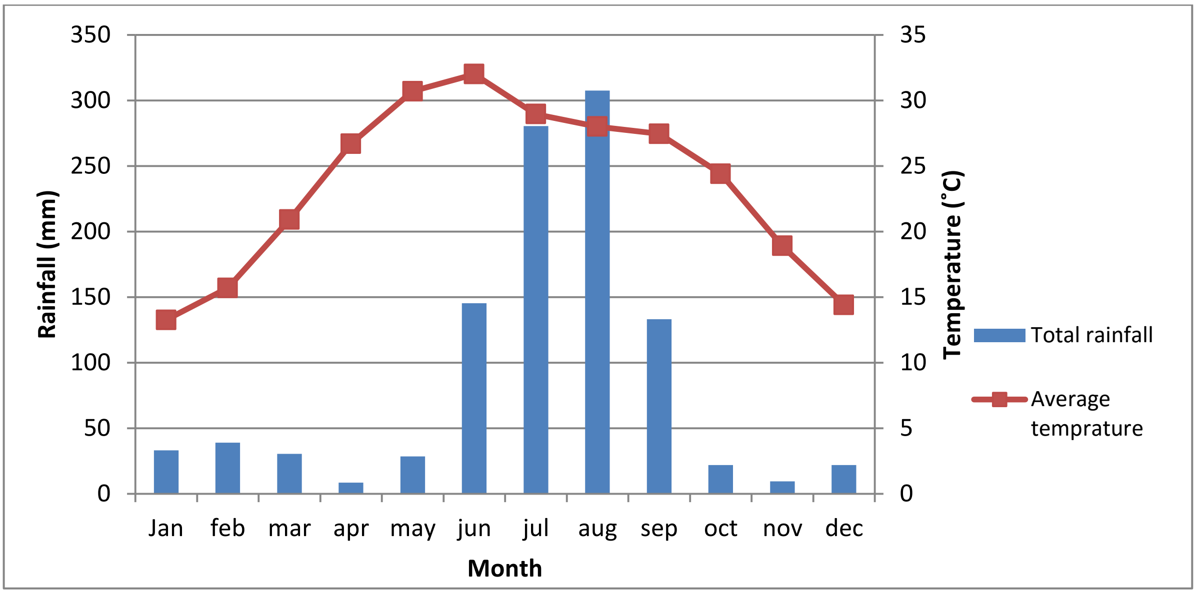

Figure4.5: Rainfall and Temperature in Chandigarh

(Source: http://www.imd.gov.in/section/climate/chandigarh2.htm)

4.1.6 Water Supply and Sanitation

Surface water from Bhakra Main Canal and underground deep Tube wells are the two primary sources of water supply in Chandigarh. The city is water deficient as the water requirement of the city for drinking and domestic purposes stands at 116 MGD (Million Gallon per day) water, while the available supply is only 87 MGD. Thus there is a shortage of about 30MGD. Canal water supply which is approximately 67 MGD forms a major part of the water supply of the city. The number of deep tube-wells in the city is 170, which make a total of 20 MGD of water from ground water sources. In addition to this there are 32 tube-wells. These supply water at the rate of 182 liters per capita per day to rural area also. Chandigarh administration has installed about 35 deep tube-wells for fulfilling the purpose of irrigation. They form a major source of water supply for irrigation (ENVIS Centre, 2016).

The main sewage line runs from west to east. Branches connected to the main line run from south to north. The sewage coverage of the city is 95% with no pumping involvement. The size of the main trunk line varies from 64 inches to 6 inches size in the city. Stoneware sewage pipe network is about 742 km long and serves 95% of population in area. Currently Chandigarh generates 70 MGD sewage per day out of which 56.25MGD is treated at sewage treatment plant (Public Health Department, MCC 2016).

A hierarchy of natural and man-made drains and water bodies characterize the drainage system in Chandigarh and eventually discharge surface runoff into N choe. Presently storm water drains which receive the maximum priority are constructed and maintained by the Municipal Corporation.

4.1.7 Solid Waste

Since Chandigarh is the first planned Indian city in India, the development of a good solid waste management system has been easier as compared to the other cities. The MCC handles solid waste in 56 sectors, 41 urban slums, and 9 villages besides the Notified Area Committee of Manimajra. The salaries of sweepers & rag pickers comprise 80% of total SWM budget allocation while only about 8% is allocated for collection purposes; registered households have 70% collection efficiency while slums & villages have 20%. The Corporation is making a conscious effort for promotion of public private partnership in order to provide sustainable waste management system in the city. Approximately 370 metric tonnes per day of waste is generated in Chandigarh. An attempt is being made to make the sectors free from garbage bins and to achieve this Sehaj Safai Kendras have been constructed at 35 locations out of 125 proposed. Under this concept, garbage is collected from each house and is then taken to Sehaj Safai Kendras and finally to the dumping ground. The allocated dumping site spans over an area of 45 acres out of which 25 acres have been reclaimed scientifically as per the Municipal Solid Waste. Chandigarh faces some challenges in the existing SWM system. These are no segregation of waste at source, less land for sanitary land fill, shortage of garbage bins and unavailability of collection vehicles and suitable manpower (MoUD, 2013).

4.1.8 Storm Water

Chandigarh has a well-planned, covered and maintained network of storm water drains. Thus, there is very little pollution in comparison to other cities. More than 70% of the rain that falls on Chandigarh flows into the storm water drains.

- Residential areas – 38%
- Roads – 20%
- Public & institutional buildings – 10%
- Commercial area – 5%

(Source: Centre of Science and Environment, 2010)
Storm water drains are utilized to drain out a major portion of the rain that falls on the city. This not only helps to address the problem of groundwater shortage but also solves the flooding issues of the area.

4.1.9 Socio-Economy

The growth rate of Chandigarh is around 17.5%. Chandigarh has seen a changes from a traditional manufacturing economy towards knowledge based economy. Knowledge sector, especially Information technology and IT enabled services (ITES) along with the Biotechnology is growing at a fast pace in Chandigarh. The knowledge sector consists of:

- IT & IT enabled services
- Biotechnology and medical sciences
- Industrial technologies

"The primary industries are food products, metal products, machine tools, electrical goods, transport equipment, pharmaceuticals, leather goods and plastic goods. Tourism is a growing sector and the Chandigarh administration is promoting Chandigarh as a major tourist destination. Recently, a new information technology park has been set up for the establishment of modern information technology based companies. Several initiatives have been taken such as setting up of Rajiv Gandhi I.T. Park, development of a hi-tech city, e-governance initiatives, and encouraging private sector presence in Chandigarh's Software Technology Park for the promotion of Information Technology" (Chandigarh Administration, 2011).

Primary Sector: The various crops are grown in Chandigarh such as wheat, paddy and maize which are around 2800 tonnes, 250 tonnes and 40 tonnes respectively. The area covered by cereals has significantly increased from 740 acres in 2004-2005 to 3090 acres in 2006-2007. The field is irrigated from the wells and tube-wells (Department of Agriculture, Chandigarh).

The growth trends in **Secondary sector** are mainly contributed by unregistered manufacturing industries. It is 6.21% of the GSDP. Construction industry of Chandigarh is major contributor on an average of 13% of GSDP. Power supply, Gas and Electricity is only 1.18 percent of the growth rate (http://statisticstimes.com/economy/gdp-of-indian-states.php)

Tertiary Sector: Trading, banking and real estate sectors are fastest growing industries which have contributed 27.85% to 21.1% of GSDP. Public administration is also an important sector which has contributed 6.16%.

Industry in Chandigarh: There are almost 15 large and medium scale industries with 2 public sector enterprises (PSEs) being currently operated**.** Some of the important products are engineering items, auto parts, electronic units, defence items, hardware and house fitting items. Metal products (rods of steel, rolled products and metal alloy) related Industries is one of the most leading industries of the Chandigarh (Statistical Abstract, Chandigarh Administration, 2011).

4.2 Computation of Sustainability Index (SI) for Chandigarh:

The data used for computation of the index for Chandigarh has been collected from the report "Water and Sanitation programme" (2006) and "Benchmarking and data book of water utilities in India" together these sources helps to complete comprehensive database for Chandigarh.

4.2.1 Quantification of basic Indicator

The indicators selected along with desired targets are presented in Table4.4.

1. Coverage of water supply connections

It consist of the extent of networking system connected to the individual properties (residential, commercial, industry and institutional) of the selected area i.e. direct piped connection for water supply within household. Total number of household is 241,173 out of which 143766 domestic connections and 13141 commercial connections in the city (Census, 2011). This is also including the households which receive municipal water supply at one common point from where it is stored and distributed for all household. About 1million out of

1.15 million populations are served by direct service connections. Chandigarh has reported 89% coverage of water supply connections (MoUD, 2013).

2. Per capita supply of water

The main source of water in Chandigarh is surface water source i.e. Bhakra main Canal which is located 26km from the city. In addition, there are nearly 200 tube-wells are located throughout the city for underground water .The water production in liters per capita per day is 190 lpcd which is higher than the benchmark level (135lpcd). While per capita availability is 290-295 lpcd including irrigation and institutional requirement. This shows the 100% per capita supply of water in Chandigarh (ENVIS Centre, 2016).

3. Continuity of water supply

The average availability of water supply is 12hr to 13hr which represent the intermittent water supply system of Chandigarh (MoUD, 2013).

4. Water Exploitation Index

The present average withdrawal from the Bhakra main canal is 290.56 MLD and from the ground water sources it is 90.80 MLD with maximum withdrawal of 290 MLD in summer and minimum of 263 to 273 MLD in winter (ENVIS Centre, 2016). The requirement of water for drinking and domestic purposes is 500MLD, whereas available supply is only 381.36 MLD as per census 2011. Thus there is a shortage of about 118.64 MLD. It is observed that 76% of water is used from canal and only approx. 24% of water is used form the ground water resources (PH Department, MCC). Though Municipal Corporation installed almost 38 new tube wells, to fulfil the increasing demand of water. This will provide an additional 7.5 MGD of water, to compensate the shortage of 6MGD water to Panchkula. The unbalance usage of water is the major challenge faced by Municipal Corporation.

5. Extent of metering of water connections

Total number of metered connection is 127103no while the unmetered connection is 18212no, thus the extent of metering of water connection for the selected properties is 87%. The per capita daily production is in the range of 290-295 lpcd which is measured by flow meters. Whereas the per capita daily consumption levels have been is measured 239-256 lpcd. Thus the unaccounted water is about 13%, but in this case the reliability of the data is low as not all the connections provided by authority are metered (ENVIS Centre, 2016).

6. Efficiency in redressal of customer complaints

Consumer can register their complaints in their respective ward offices in writing and can also send through email and telephone. MCC website of Chandigarh provides the detailed information about the procedure of registering complaints and the expected redress time on the basis of nature of complaints. The efficiency of complaints redressal in Chandigarh is very high almost 98% according to the JNNURM scheme of Capacity Building of Urban Development (MoUD, 2013).

7. Quality of water supply

On an average, the MCC supply the water for 12hrs daily. With respect to the quality of water supplied to the Chandigarh is reported that 100% of the samples passed the test for quality standard (MCC, 2016).

8. Extent of non- revenue water

Chandigarh has low level of metered connections which has further contributed to increase in the unaccounted water levels. Although the MCC of Chandigarh has established SCADA system to minimize the water loses during supply, still about 27% of non -revenue water has been reported (MCC, 2016).

9. Cost recovery in water supply services

Presently, Municipal Corporation of Chandigarh recovers approximately 68% of the operating cost of water supply services from revenue but the aim is to increase it to 100%. Out of 210,000 consumers, only 130,000 consumers are paying water charges.

10. Toilet Coverage

In Chandigarh only 11% households are lacking in having direct connection to sewerage services and only 3% households lack in having access to toilets either on an individual or community basis. 89% of coverage of toilets within household with further additive 9.1% coverage is through the public conveniences (MoUD, 2013).

11. Coverage of sewage network services

Chandigarh has separate sewerage and storm water drainage systems. The sewage is discharged from the east to south slope by gravity flow because of its good natural slope. The length of sewerage pipe network pipe system is 742 km and it is covered almost 98% of population of area. 1 million customers are approximately serviced through direct sewer connection and the remaining 0.15 million customers use community toilets (MoUD, 2013).

The reliability of sewerage coverage data is low as the estimation is based on the MCC staff and not by documentation or on basis of measurement.

12. Collection efficiency of sewage network

There is a well-organized system of main and branch sewerage drains. The egg shaped brick trunk sewers is connected to 18 inches diameter stoneware pipe branch sewer of each sector. The length of sewage pipe network is 742 km which is running from west to east. There is no pumping involved due to its topography. The waste water collection efficiency of network system is 100% (MCC, 2015).

13. Adequacy of sewage treatment capacity

Chandigarh Pollution Control Committee monitors all the 4 STPs and drains on the monthly basis and transfer all the required information to the MCC and Chandigarh administration to take necessary action. The city generates around 70 MGD of waste water daily whereas the capacity of treatment plant of 56.25 MGD. Thus the adequacy of sewage treatment in Chandigarh is 84 % (Pollution Control Committee, Chandigarh 2015).

14. Efficiency in redressal of customer complaints

The complaints of sewerage services are increases constantly. The efficiency of redressal complaints is very high almost 98% according to the statistics data shared by MCC.

15. Extent of reuse & recycling of sewage

10 MGD waste water after treatment upto tertiary level is used by the city for irrigation purposes and the balance after the secondary treatment level is discharged into natural streams. Reuse water is approx. 15% of the sewage in Chandigarh through tertiary level which is very low (MCC, 2015).

16 Quality of sewage treatment

As per the data prepared for Chandigarh by Capacity Building of Urban Development under JNNURM scheme, the quality of sewage treatment is 100%.

17. Extent of cost recovery in sewerage management

The cost recovery in Chandigarh is very low and only 25% amount of the operational cost is recovered. As the sale of treated water upto tertiary level is not available in the city therefore the cost recovery figure cannot be considered as reliable.

18. Efficiency of collection of municipal solid waste

Overall collection efficiency of Chandigarh is 90% out of which 60-70% is for registered household and only 20% is for slums. As per census 2011, total amount of waste generated is 370 metric tonnes per day (MTD) out of which 360 metric tonnes per day are collected. Solid waste is collected door to door by the cycle rickshaw carts handled by sector welfare association.

Figure 4.6: Handcarts and containers used for solid waste collection in Chandigarh City

(Source: MoUD, 2013)

19. Extent of segregation of municipal solid waste

Currently issue is the absence of segregation of waste at source. In Chandigarh only 18% of solid waste is segregated (MoUD, 2013). The waste is ideally segregated at the Sehaj Safai Kendras and at the time of processing it for refuse the methane gas.

20. Extent of recovery of waste collected

In Chandigarh the extent of recovery of waste collected is high almost 98%. A major municipal solid waste processing plant is the Jaypee Municipal solid waste processing plant having the capacity to process approx. 600tonnes garbage daily (Pollution Control Committee, Chandigarh, 2015).

Figure 4.7: Processing of Solid Waste at refuse derived fuel plant in Chandigarh

(Source: MoUD, 2013)

21. Efficiency in redressal of customer complaints

The efficiency of redressal complaints of solid waste is very high almost 97% according to the statistics data shared by MCC of Chandigarh.

22. Extent of scientific disposal of solid waste

There is only one designated dump yard consisting of 45 acres of land which is situated in Sector 38 near Dadu- Majra labour colony. Almost 300tonnes of solid waste is disposed off at the site. MCC is struggling to find the place for disposal of solid waste because of rising of population and increase the amount of waste by residential and floating population. From the available data, 95% of solid waste is scientifically disposed (MCC, 2016).

23. Extent of cost recovery in SWM service

In Chandigarh, regarding O & M cost and solid waste recovery services, there is no plan of action till now. Proportion of cost recovered from the solid waste is only 0.3%.

24. Coverage of storm water drainage network

Chandigarh is covered by well laid storm water drainage network system. Therefore, there is very little pollution of storm water drains in comparison to other cities. More than 70% of the rains that falls into the storm water drains.

- Residential areas – 38%
- Roads – 20%
- Public & institutional buildings – 10%
- Commercial area – 5%

25. Permeability Index

It has been determined from the unsupervised classification of LULC map of study area. Permeable area was estimated by adding areas of agricultural land and vegetation and forestry area (2122+3694 acres). Total area of Chandigarh city is 114 sq.km out of which 24.97sq.km is permeable which is calculated by Landsat 8 image for the year 2011.

26. Water logging & area vulnerability Index

It indicates the determination of the sustainability of an area to flooding. Continuity equation and Rational method have been used to determine the rainfall intensity caused flooding in storm water drainage system. The data have been taken from the year 2000 to 2012. Observed rainfall intensity is 60.9mm while the rainfall intensity which causes flood is 205.2mm (IMD, Chandigarh).

27. % of Rainwater Quantity Harvested

To ensure long-term sustainability of water source for the city, rainwater harvesting is simple and effective solution. It can be done from the paved area of roads, roundabouts, rooftops and parks. The rainwater harvesting of Chandigarh with an area of 114sq.km (Annual rainfall of 1059.3mm and assuming coefficient of 50%) is 60380.1 million liters. (Statistical abstract, Chandigarh administration, 2011)

28. Depression storage Index

According to the UT forests and wildlife department, about 4.72% of total area of the UT of Chandigarh is under water bodies which include Sukhna wetland (1.6%) and seasonal rivulets (3.12%). The spread area of water in the lake has reduced from 228.64 ha in 1958 to around 148ha

Table 4.4 Quantification of Water System Indicator for Chandigarh

Dimensions	Categories	Basic Indicators	Indicator Value (%)
Water Supply	Status of Service Utility	Coverage of water supply connections	89
		Per capita supply of water	100
		Continuity of water supply	50
		Water Exploitation Index	76
	Governance & Maintenance	Extent of metering of water connections	84
		Efficiency in redressal of customer complaints	98
	Quality	Quality of water supply	100
	Economy	Extent of non- revenue water	27
		Cost recovery in water supply services	64
Waste Water	Status of Service Utility	Toilet Coverage	98.1
		Coverage of sewage network services	89
		Collection efficiency of sewage network	100
	Governance & Maintenance	Adequacy of sewage treatment capacity	84
		Efficiency in redressal of customer complaints	98.2
	Quality	Extent of reuse & recycling of sewage	17.7
		Quality of sewage treatment	100
	Economy	Extent of cost recovery in sewerage management	25
Solid Waste	Status of Service Utility	Efficiency of collection of municipal solid waste	97
		Extent of segregation of municipal solid waste	18
	Governance & Maintenance	Extent of recovery of waste collected	98
		Efficiency in redressal of customer complaints	97

	Quality	Extent of scientific disposal of solid waste	95
	Economy	Extent of cost recovery in SWM service	0.3
Storm Water	Status of Utility	Coverage of storm water drainage network	100
		Permeability Index	21
		Water logging & area vulnerability Index	29.6
	Governance & Maintenance	% of Rainwater Quantity Harvested	50
		Depression storage Index	64

4.2.2 Ideal, Worst values and Normalization of basic Indicators

Ideal and worst values of the indicators are presented in Table 2.0. These values are selected on the basis of available data or desirable targets.

The normalization process is basically carried out for each basic indicator to allow the comparison with each other in the same unit or common scale (ranged between 0 and 1). The estimated normalized indicator values and ideal and worst value for Chandigarh city are given in Table4.6.

4.2.3 Quantification of Weights and Balancing factors

The estimation of weights has been done by using AHP model. In this case, the indicators have been structured in a hierarchical order with assigned "weights" obtain from "pairwise comparison" technique. In this way, all indicators have been assessed in correlated with others. The summation of the weight should be equal to 1 of the same group.

Balancing factor has been assumed as 2 by allowing the medium level of substitution or interdependence between the indicators of the same set. Weights and balancing factor for Chandigarh city are presented in Table 4.5.

Table 4.5: The Weighting and balancing factors

Dimensions	Weight	Balancing factor	Categories	Weight	Basic Indicators	Weight	Balancing factor
Water Supply	0.3	2	Status of Service Utility	0.35	Coverage of water supply connections	0.23	2
					Per capita supply of water	0.54	2
					Continuity of water supply	0.13	2
					Water Exploitation Index	0.1	2
			Governance & Maintenance	0.12	Extent of metering of water connections	0.8	2
					Efficiency in redressal of customer complaints	0.2	2
			Environmental Issues	0.35	Quality of water supply	1	2
			Economy	0.18	Extent of non- revenue water	0.4	2
					Cost recovery in water supply services	0.6	2
Waste Water	0.24	2	Status of Service Utility	0.35	Toilet Coverage	0.49	2
					Coverage of sewage network services	0.26	2
					Collection efficiency of sewage network	0.26	2
			Governance & Maintenance	0.18	Adequacy of sewage treatment capacity	065	2
					Efficiency in redressal of customer complaints	0.35	2
			Environmental Issues	0.22	Extent of reuse & recycling of sewage	0.55	2
					Quality of sewage treatment	0.45	2
			Economy	0.25	Extent of cost recovery in sewerage management	1	2

Solid Waste	0.22	2	Status of Service Utility	0.35	Efficiency of collection of municipal solid waste	0.55	2
					Extent of segregation of municipal solid waste	0.45	2
			Governance & Maintenance	0.25	Extent of recovery of waste collected	0.7	2
					Efficiency in redressal of customer complaints	0.3	2
			Environmental issue	0.15	Extent of scientific disposal of solid waste recovered	1	2
			Economy	0.25	Extent of cost recovery in SWM service	1	2
Storm Water	0.24	2	Status of Service Utility	0.44	Coverage of storm water drainage network	0.55	2
					Permeability index	0.45	2
			Governance & Maintenance	0.28	% of Rainwater Quantity Harvested	0.6	2
					Depression storage Index	0.4	2
			Environmental issue	0.28	Water logging & area vulnerability Index	1	2

Table 4.6 Indicators of Water System Sustainability- Normalized Value

Dimensions	Categories	Basic Indicators	Chandigarh	Ideal	Worst	Normalized
Water Supply	Status of Utility	Coverage of water supply connections	89	100	0	0.89
		Per capita supply of water	100	100	30	1
		Continuity of water supply	50	100	10	0.44
		Water Exploitation Index	76	80	100	1
	Governance & Maintenance	Extent of metering of water connections	84	100	0	0.84
		Efficiency in redressal of customer complaints	98	80	0	1
	Environmental issues	Quality of water supply	100	100	80	1
	Economy	Extent of non- revenue water	27	20	40	0.65
		Cost recovery in water supply services	64	100	0	0.64
Waste Water	Status of Service Utility	Toilet Coverage	98.1	100	0	0.981
		Coverage of sewage network services	89	100	0	0.89
		Collection efficiency of sewage network	100	100	50	1
	Governance & Maintenance	Adequacy of sewage treatment capacity	84	100	0	0.84
		Efficiency in redressal of customer complaints	98.2	80	0	1

	Environmental issues	Extent of reuse & recycling of sewage	17.7	20	0	0.885
		Quality of sewage treatment	100	80	0	1
	Economy	Extent of cost recovery in sewerage management	25	100	0	0.25
Solid Waste	Status of Service Utility	Efficiency of collection of municipal solid waste	97	100	0	0.97
		Extent of segregation of municipal solid waste	18	80	0	0.225
	Governance & Maintenance	Extent of recovery of waste collected	98	80	0	1
		Efficiency in redressal of customer complaints	97	80	0	1
	Environmental issues	Extent of scientific disposal of solid waste recovered	95	100	0	0.95
	Economy	Extent of cost recovery in SWM service	0.3	100	0	0.003
Storm Water	Status of Utility	Coverage of storm water drainage network	100	100	0	1
		Permeability index	21	50	0	0.42
		Water logging & area vulnerability Index	29.6	0	30	0.013
	Governance & Maintenance	% of Rainwater Quantity Harvested	50	80	0	0.625
		Depression storage Index	64	60	0	1

4.2.4 Computation of Index Value for Chandigarh

The Sustainability index (SI) value for water system of Chandigarh is present in Table 4.7.

Table 4.7 Composite Indicator of Water System Sustainability for Chandigarh

Dimensions	Sub Indicator	Categories of Sustainability	SI (Categories)	Sustainability Index
Water Supply	Status of Utility	Coverage of water supply connections	0.92	**0.76**
		Per capita supply of water		
		Continuity of water supply		
		Water Exploitation Index		
	Governance & Maintenance	Extent of metering of water connections	0.89	
		Efficiency in redressal of customer complaints		
	Environmental issues	Quality of water supply	1	
	Economy	Extent of non- revenue water	0.64	
		Cost recovery in water supply services		
Waste Water	Status of Utility	Toilet Coverage	0.96	**0.82**
		Coverage of sewage network services		
		Collection efficiency of sewage network		
	Governance & Maintenance	Adequacy of sewage treatment capacity	0.89	
		Efficiency in redressal of customer complaints		
	Environmental issues	Extent of reuse & recycling of sewage	0.93	
		Quality of sewage treatment		
	Economy	Extent of cost recovery in sewerage management	0.25	

Solid Waste	Status of Utility	Efficiency of collection of municipal solid waste	0.73	**0.75**
		Extent of segregation of municipal solid waste		
	Governance & Maintenance	Extent of recovery of waste collected	1	
		Efficiency in redressal of customer complaints		
	Environmental issues	Extent of scientific disposal of solid waste recovered	0.95	
	Economy	Extent of cost recovery in SWM service	0.003	
Storm Water	Status of Utility	Coverage of storm water drainage network	0.79	**0.77**
		Permeability index		
	Governance & Maintenance	% of Rainwater Quantity Harvested	0.39	
		Depression storage Index		
	Environmental issues	Water logging & area vulnerability index	1	
Water System			**Composite Value**	**0.78**

Benchmarking for Chandigarh

For water supply dimension, Chandigarh has better sustainability index with respect to status of service utility and governance & maintenance with a value of 0.92 and 0.89 respectively. This good performance is mainly because of well-planned system of water supply distribution of Chandigarh which leads to relatively high coverage of networking system, per capita consumption and metering system of water. Even with respect to access to environmental issue with a value of 1 of sustainability benchmark which shows the 100% good quality of water. Chandigarh perform poorly on a sustainability scale with respect to indicator like non-revenue and cost recovery in water supply services which causes relatively lower level of economy with a composite index value of 0.64 (Figure 4.8).

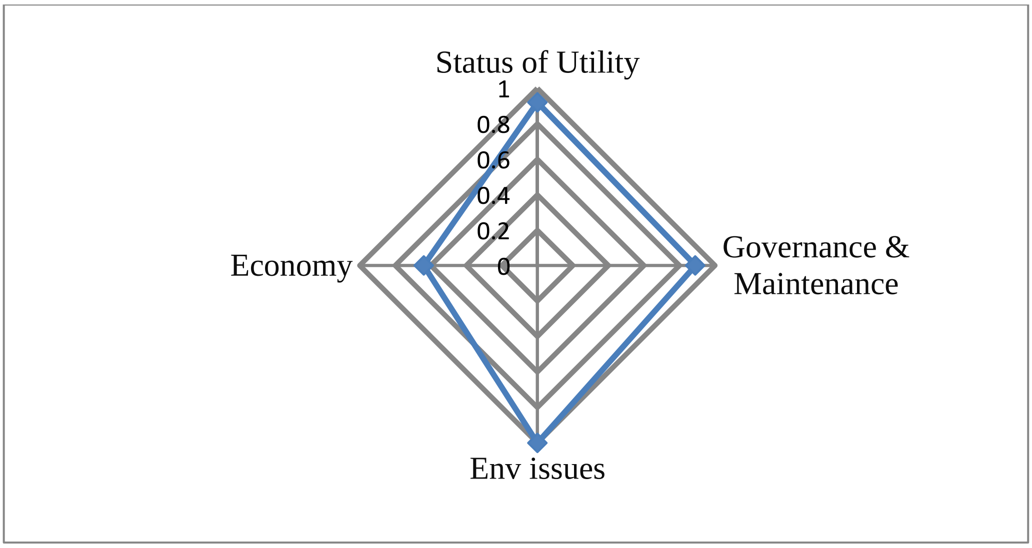

Figure 4.8 Benchmarking Water Supply Sustainability

Fig.4.9 shows the comparison of composite waste water index value for Chandigarh with respect to benchmark value. Chandigarh city performs better with respect to waste water sustainability dimension with respect to other water utilities. Especially, the index value for status of utility, governance & maintenance and environmental sustainability are relatively high with an index value of 0.96, 0.89 and 0.93 respectively. This is because of well-organized network of main and branch sewerage drains which leads to better performance to toilet coverage, conveying, collection and treatment of waste water. With regard to economy indicator Chandigarh has composite index value of 0.25 which is very low. Overall Chandigarh compares favorably for waste water sustainability benchmark.

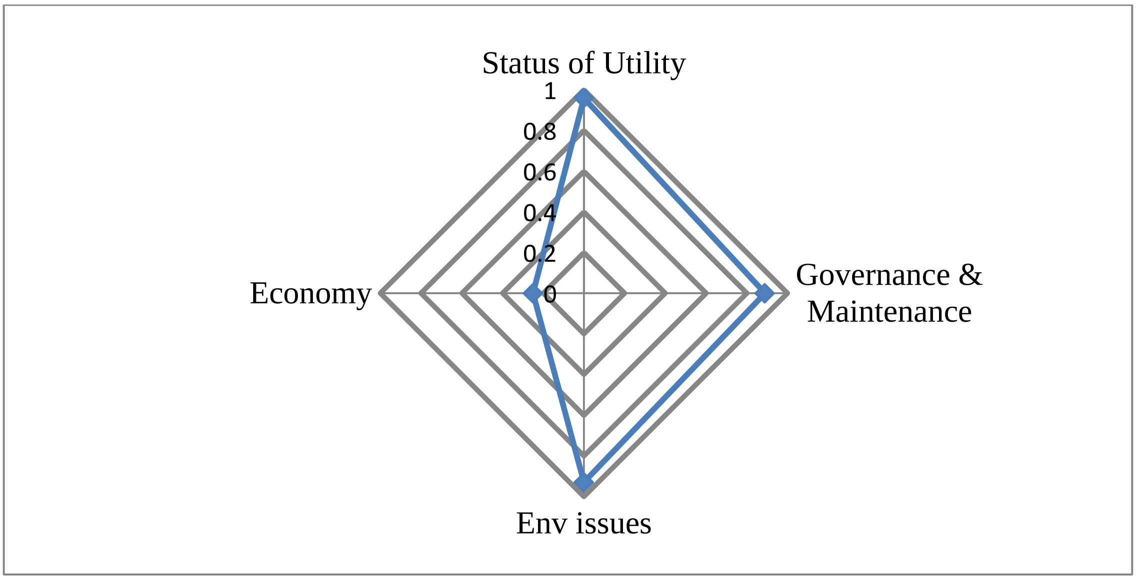

Figure 4.9: Benchmarking Waste Water Sustainability

Chandigarh is the first city in India developed in a planned manner which has helped in developing a comparatively better solid waste management in comparison to other Indian cities. Fig.4.10 shows the solid waste composite indicator with respect to sustainable benchmark. In all four categories under solid waste dimension, Chandigarh has better performance with respect to governance & maintenance and environmental sustainability with a value of 0.97 and 0.95 respectively, which is very close to benchmark. The performance of status of service utility composite indicator of solid waste management is based on collection of solid waste and segregation with the value of 0.97 and 0.18 respectively. But the overall composite value of status of utility is 0.73. Proportion of cost recovered from solid waste is very low therefore the economic composite index value is relatively very low i.e. 0.003.

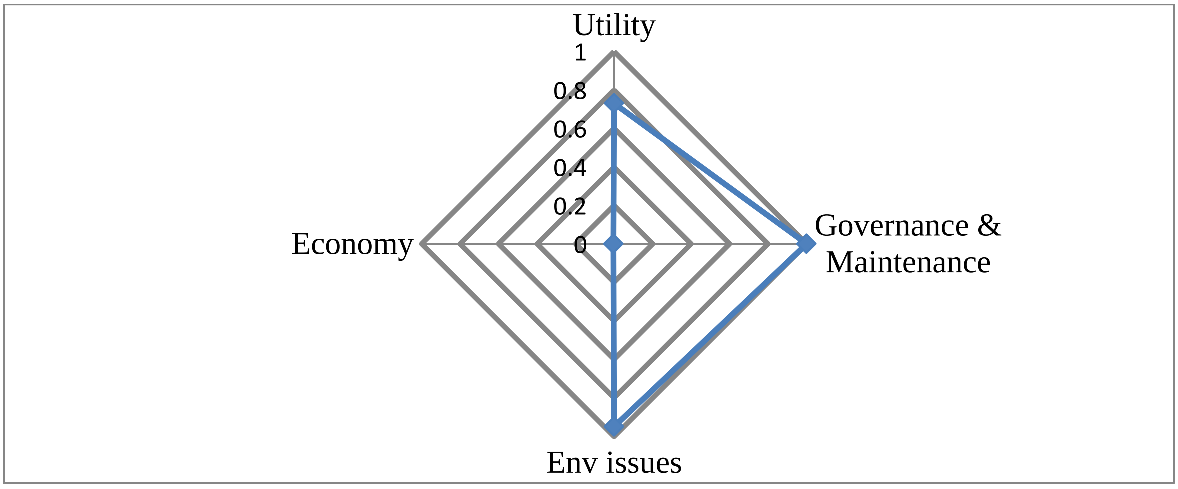

Figure 4.10 Benchmarking Solid Waste Sustainability

The next dimension used for benchmarking is Storm Water (Fig. 4.11). Chandigarh has better sustainability index values with respect to status of utility and environmental sustainability with index values of 0.79 and 0.64 respectively. The main reason of this good performance is the relatively high values obtained from the indicator like coverage of drainage network, depression storage index and permeability index. It may be observed from the figure that governance & maintenance composite index value is quite a distance away from the benchmark value of 1. This is because of increasing urbanized area, which leads to increased run off co-efficient tremendously. This has resulted in the over loading of storm water drainage system and hence flooding of low lying area of city.

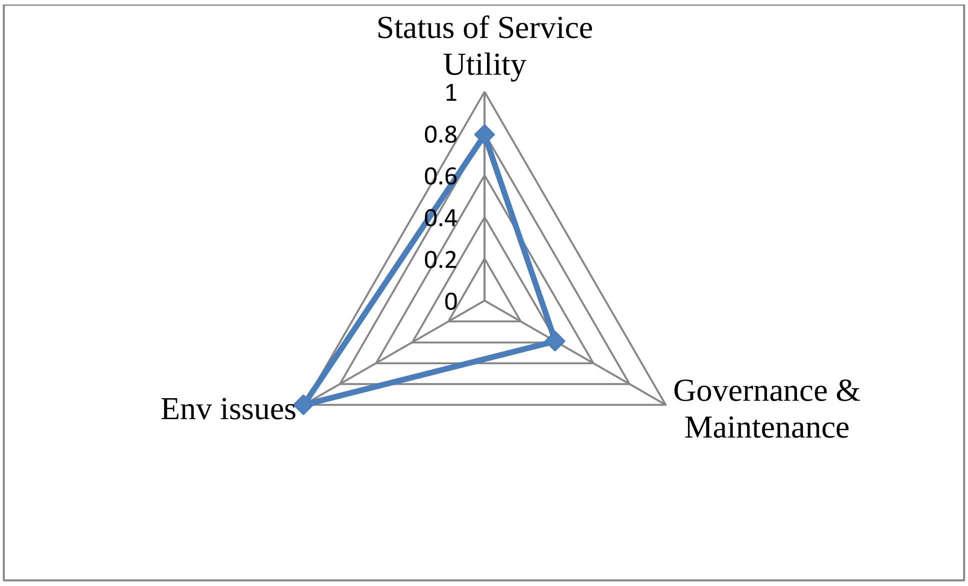

Figure4.11: Benchmarking Storm Water Sustainability

Finally, the composite index values of the dimensions of water supply, waste water, solid waste and storm water sustainability are compared with the benchmark index values (figure 4.12). Among the four dimensions based sustainability index values for Chandigarh, the waste water dimension is closer to benchmark values as compared to other dimensions. Whereas Chandigarh has better scenario for water supply solid waste and storm water with the value of 0.76, 0.75, and 0.77 respectively.

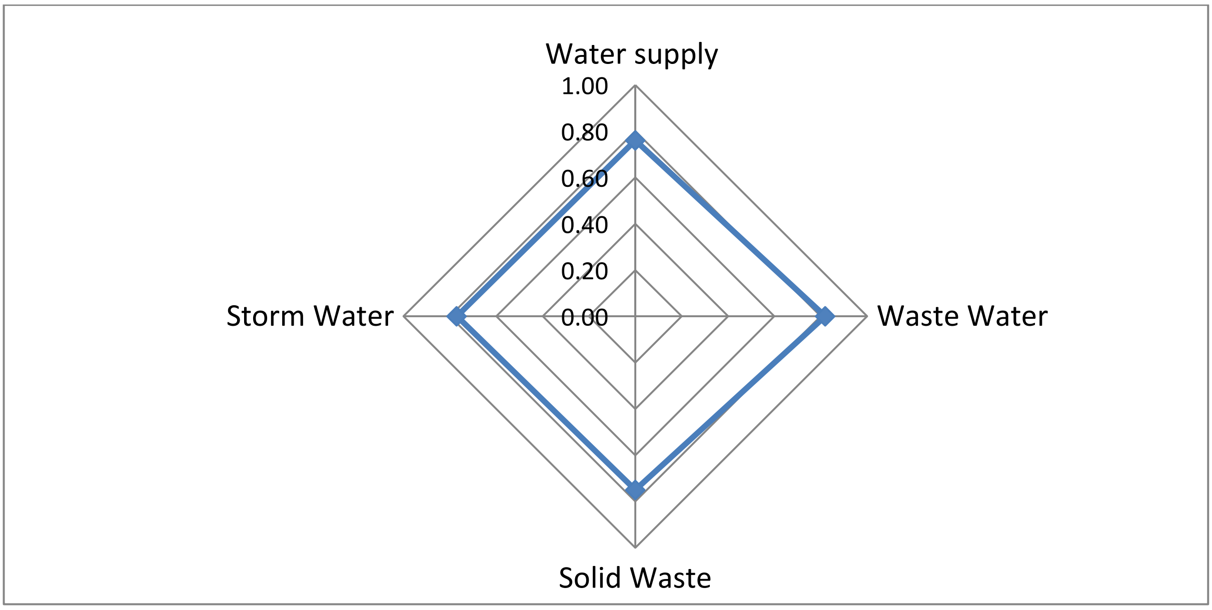

Figure4.12: Benchmarking Water System Sustainability for Chandigarh

4.3 Sensitivity Analysis of the proposed Indicator framework

In the case of Chandigarh, the SAW technique is apply to find out the most sensitive attribute among the set of indicators. In this analysis assumed that the weight of attribute is taken as 0.2, 0.4, 0.6, 0.8 and 1 then analyzed the change in the final score value corresponding to each weight. The most sensitive attribute is one which causes higher change in third level indicators i.e. water supply, waste water, solid waste and storm water by changing its weight. As the methodology of SAW technique is already explained in Chapter 2. The trend occurs by changing the weight of basic indicator of different set of components is shown in below:

Sensitivity Analysis for Water Supply by SAW method

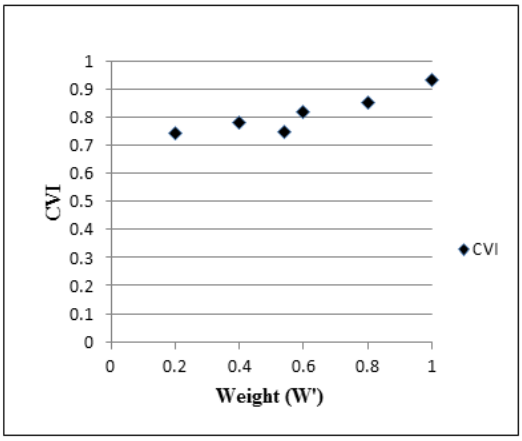

Fig. 4.13 (a)Coverage of water supply connection

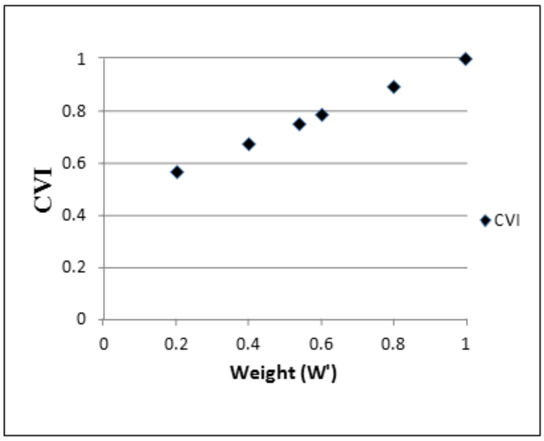

Fig. 4.13 (b) Per Capita water supply

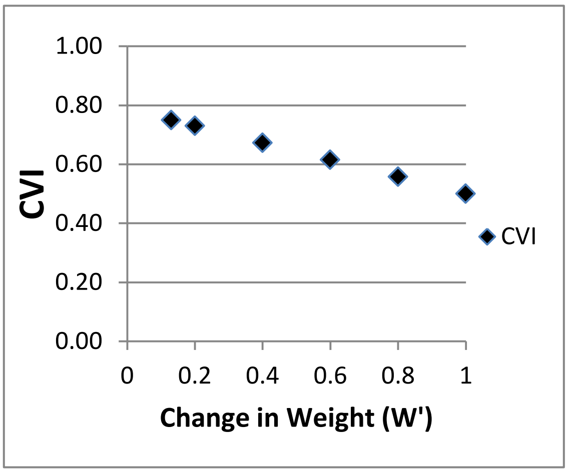

Fig. 4.13 Continuity of Water Supply

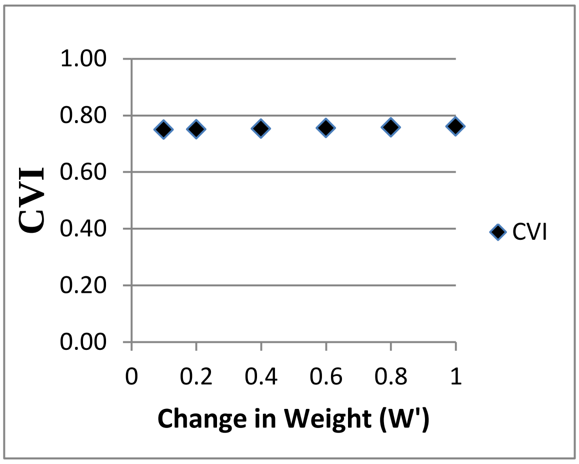

Fig. 4.13 Water exploitation Index

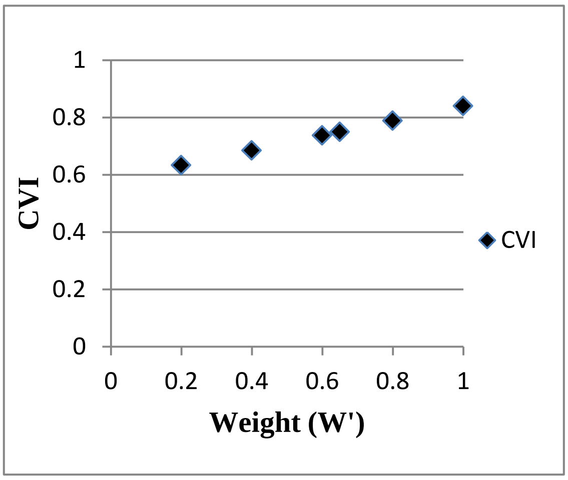

Fig. 4.13 (e) Metering System

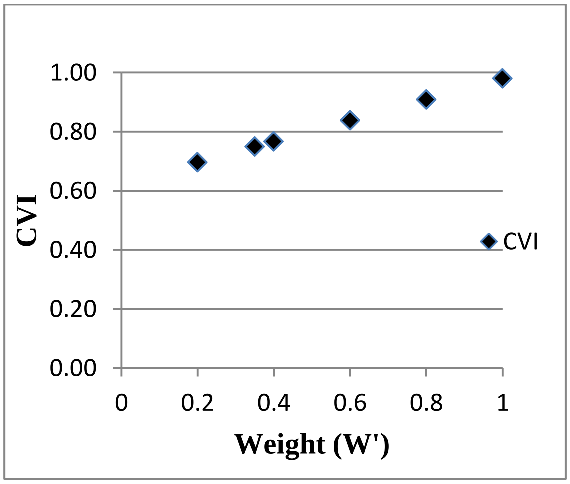

Fig. 4.13 (f) Efficiency in redressal of complaints

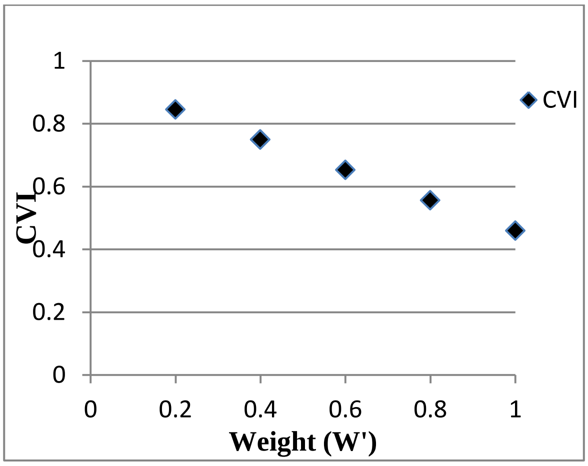

Fig.4.13 (g) Non- Revenue Water

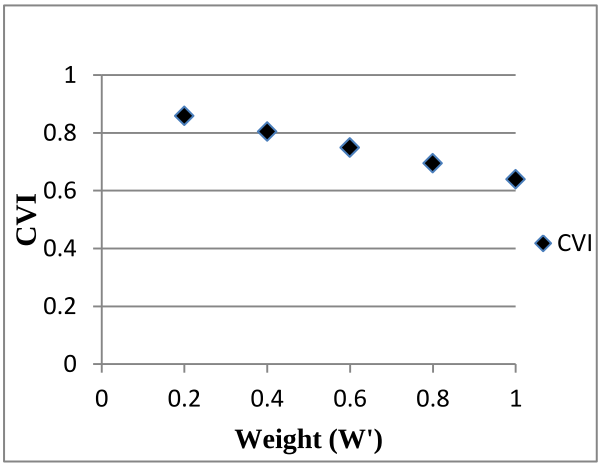

Fig. 4.13 (h) Extent of Cost Recovery in System

Figure 4.13: Sensitivity Analysis for Water Supply

This analysis showed that the most sensitive attribute is per capita water consumption followed by coverage of water supply connection and redressal of customer complaints as by increasing its weight, overall score value of water supply system increases and approaches to 1(ideal value).While least sensitive attribute is continuity of water supply while increasing its assigned weight there is no significantly change in sustainability index value.

Waste Water Sensitivity Analysis

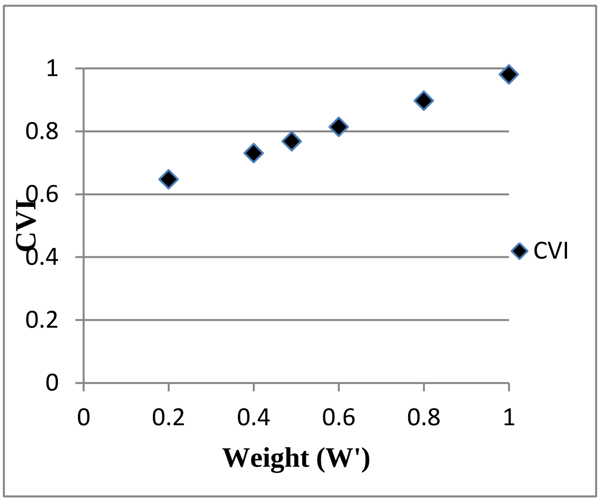

Fig. 4.14 (a) Toilet Coverage

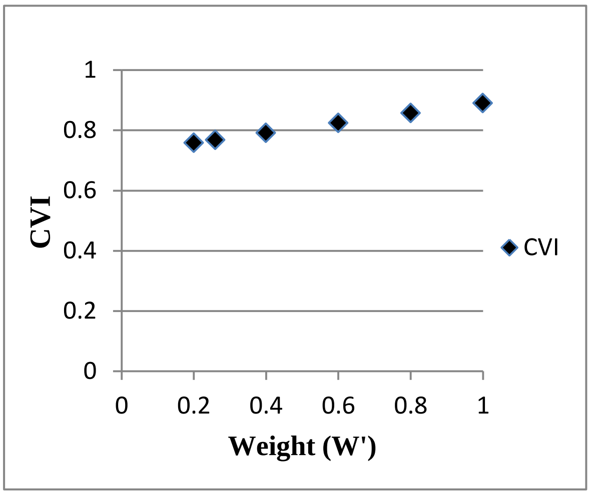

Fig. 4.14 (b) Sewage network services

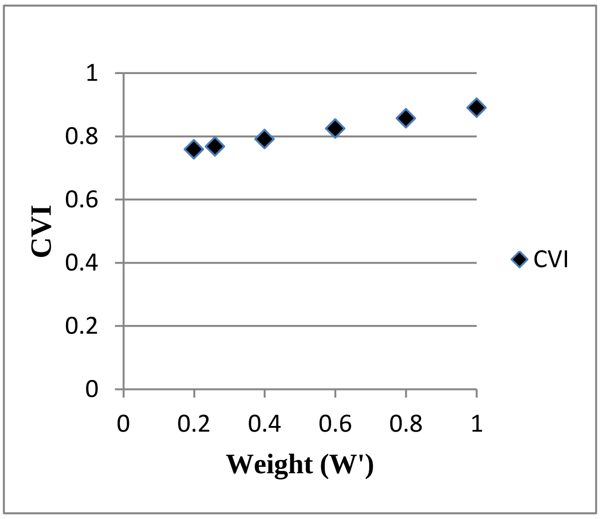

Fig. 4.14 (c) Collection efficiency of sewage network

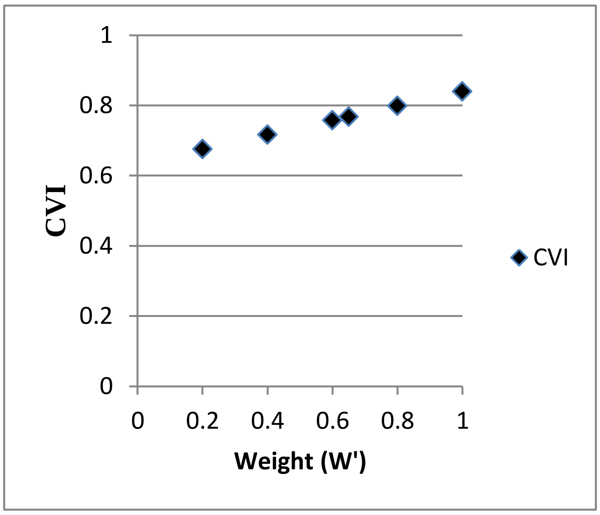

Fig4.14 (d) Adequacy of sewage treatment

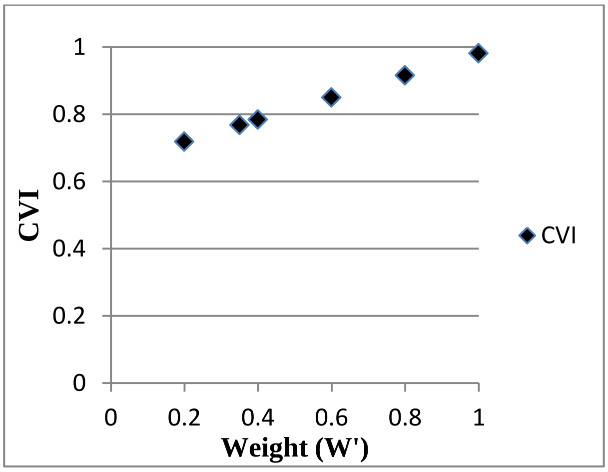

Fig. 4.14 (e) Efficiency in redressal of complaints

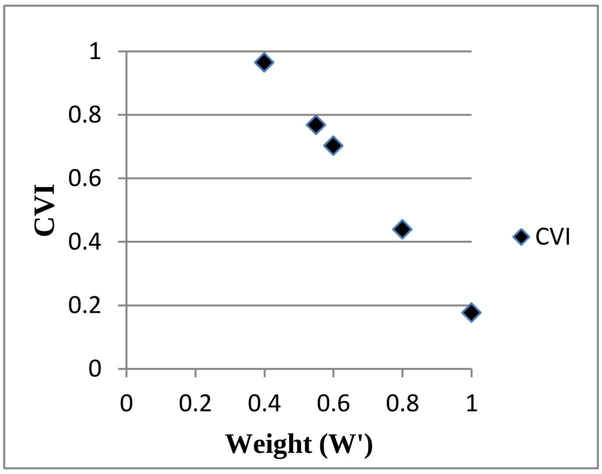

Fig. 4.14 (f) Sewage reuse & recycling

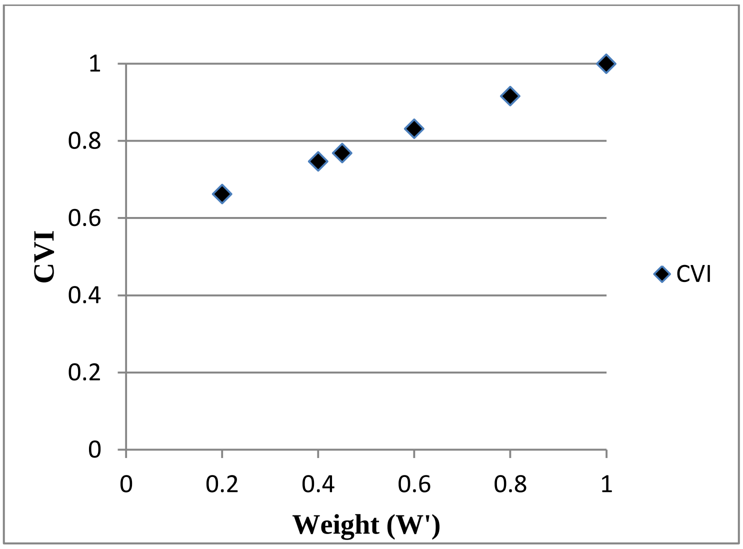

Fig. 4.14 (g) Quality of Sewage Treatment

Figure 4.14: Sensitive Analysis for Waste Water

Compliance quality of sewage treatment is most sensitive attribute as its contribution in the overall score value is increases by change in weight. This is followed by toilet coverage and efficiency of redressal complaints which increases the Sustainability index of waste water system by increase in its weight. So from the above analysis it is observed that Waste water management in Chandigarh is better.

Solid Waste Sensitivity Analysis

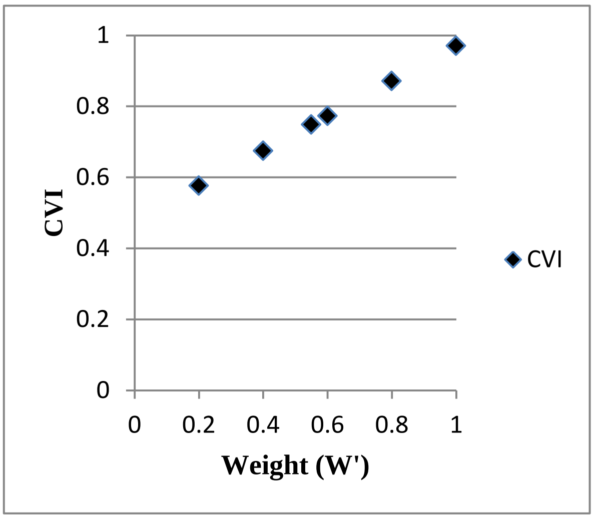

Fig. 4.15 (a) Efficiency of Collection of Solid Waste

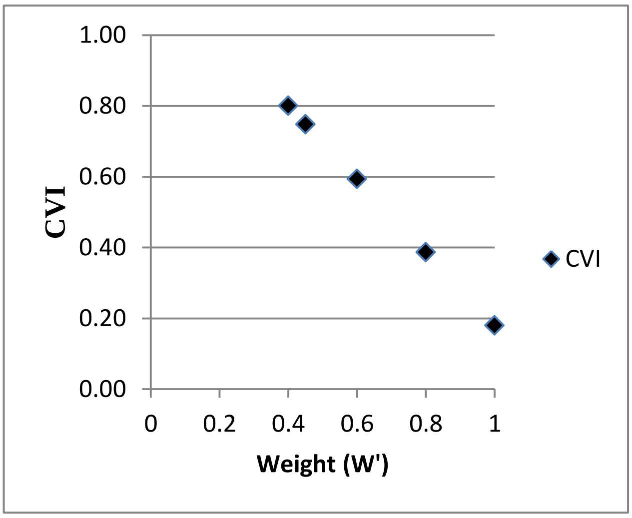

Fig. 4.15 (b) Extent of Segregation

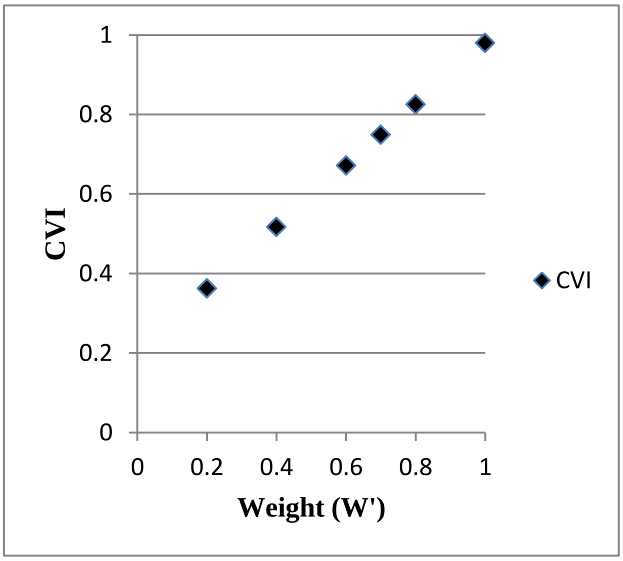

Fig. 4.15 (c) Extent of Recovery of Waste Collected

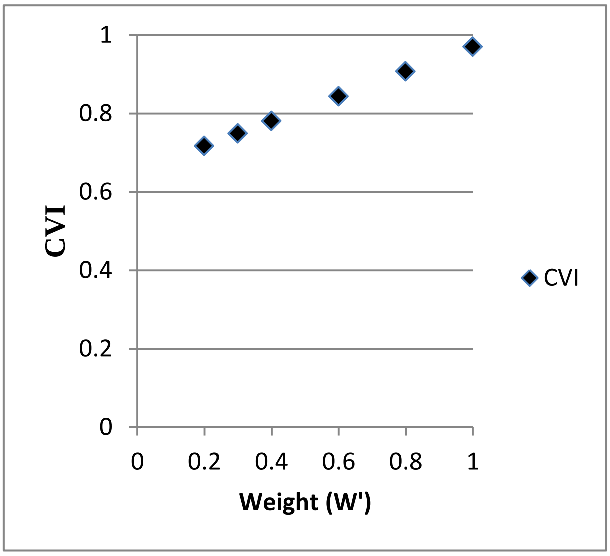

Fig 4.15 (d) Efficiency in complaints redressal

Figure 4.15: Sensitive Analysis for Solid Waste

The most sensitive attribute is recovery of waste collected followed by Collection of solid waste and efficiency of redressal complaints which share relatively same importance. It indicates that Efficiency of collection, convey and treatment of solid waste is in better condition. Currently issue is the segregation of waste and shortage of land for sanitary landfill having shown low contribution in the overall score value by increasing its importance.

Storm Water Sensitive Analysis

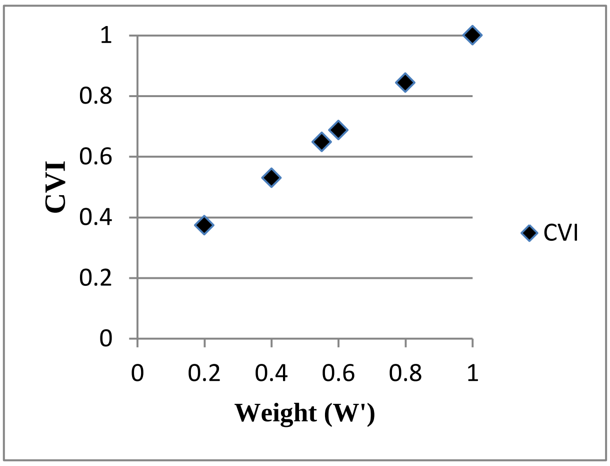

Fig. 4.16(a) Coverage of storm water network

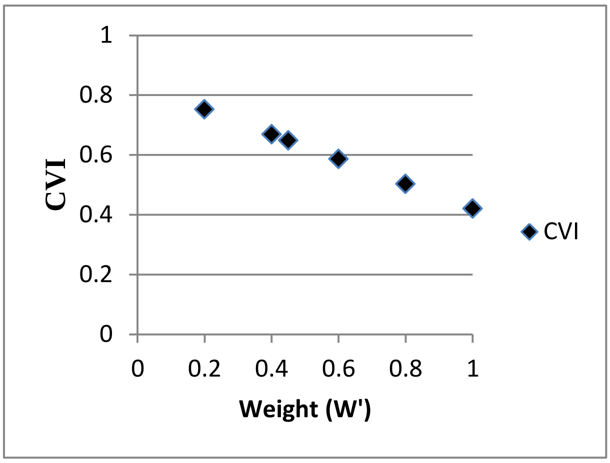

Fig. 4.16 (b) Permeability Index

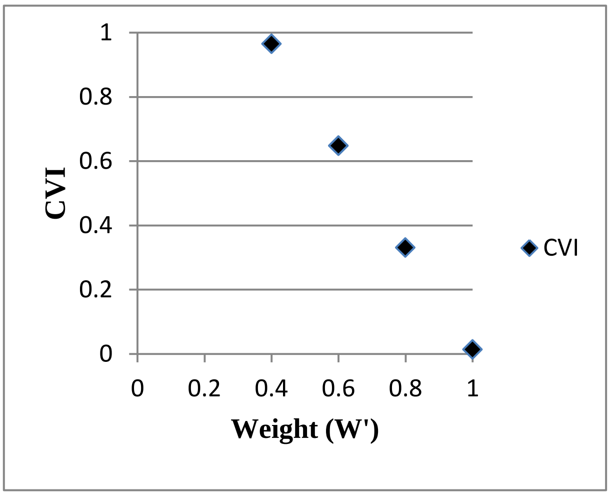

Fig. 4.16 (c) Water logging & area vulnerability Index

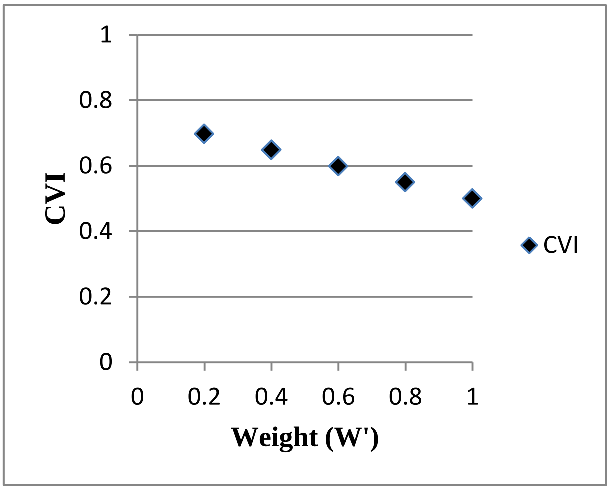

Fig. 4.16 (d) % of Rainwater harvested

Figure 4.16: Storm Water Sensitive Analysis

This analysis shows that the coverage of storm water drainage network is most sensitive in comparison to others attribute as by increasing its assigned weight, it increases the overall score value and approaches the ideal value i.e. 1. While increasing the relative importance of Water logging index, it shows the low overall score value. Permeability index and % of rainwater harvested also decrease the sustainability index value by increasing its weight. From this analysis it is observed that the Chandigarh needs to augment the whole storm water drainage system.

4.4 SWOT Application for Sustainability Assessment of Chandigarh City:

Chandigarh is the first planned city of India, which is known for its architectural and urban planning. It has well laid interconnected roads which are lined with rows of trees and plants. It has a fine balance between the traditional and modern architecture. But with this strength, Chandigarh has also grown much beyond its planned capacity which impacts on the infrastructure facilities. SWOT analysis has been used to perform sustainability assessment of this city. Table 4.8 shows a summarized list of strengths, weaknesses, opportunities and threats related to this city.

Table 4.8 SWOT Analysis for Chandigarh

STRENGTHS	WEAKNESSES
• Well planned with green, open and public spaces • Infrastructure: ➢ 100% of coverage of water supply ➢ 100% coverage of toilet & infrastructure ➢ Topography is conducive for collection of wastewater and conveyance to STP through gravity. ➢ Well laid out system of storm water drains. ➢ Scientific Segregation and solid waste management. ➢ Well planned roads and pavements also connected cycle track.	• Pressure issues in water distribution because of urbanization. • Absence of segregation of solid waste at source. • Limited availability of land for future development. • Low cost recovery from water utility. • Flooding of roads and other critical issues needing urgent augmentation of the Storm water drainage system. • Inadequate public transport facilities

OPPORTUNITY	THREATS
• Effective use of solar energy being India's first model solar city • Formulation and implementation of new policies considering good track record for success in other policies ➢ Waste water recycling	• Increasing traffic congestion and parking issues • Storm water directly falling in Sukhna choe and Patiala ki Rao causing environmental pollution and needing urgent solution. • Population growth especially of

➢ Usage of renewable energy ➢ Green buildings • Develop innovations or knowledge hub for solutions in all domains. • Enhancing IT applications for effective deliver of citizen services.	floatation population. • Lack of STPs with respect to generated sewage. • Cost recovery figures not reliable indirectly effecting revenue system of city

In Chandigarh the 'Strengths' are related to the sectors including its connectivity, tourism, road networks, administration and commerce. The areas of 'Weaknesses' include urban infrastructure facilities, environmental issues and urban growth which needs to be improvised. The 'Threats' are primarily arising from the existing weakness if they are not controlled as they may hamper the development of city. Lastly, 'Opportunities' are derived from the strengths, which may be gainfully utilized for the development of city.

CHAPTER 5

EVALUATION AND COMPARISON OF INDIAN CITIES FOR SUSTAINABILITY

INTRODUCTION

An assessment of water system of Chandigarh with respect to the benchmark indices (ref. Chapter4) has been employed by using MCDM methodology. Now considering the Chandigarh city as a reference benchmark, few other selected cities have been compared with it on the sustainability scale. For this comparison, four cities have been chosen, viz.,- Visakhapatnam, Allahabad, Solapur and Jabalpur. The information has been collected from "City Development Plan" which is prepared under JNNURM scheme for funding the urban services in 65 cities. As the same information is not available for all cities for computation of all the 28 water system indicators, only 23 indicators have been considered for all five cities.

5.2 Quantification of basic Indicators

The first step in the process of comparing cities is to collect required data for quantifying all the selected indicators. The data was mainly collected from secondary sources of information i.e. governmental reports, journal papers and websites of the concerned government departments and ministries and variety of databases from the internet. The data obtained for all the indicators are presented in ANNEXURE –B: Table 2.

5.3 Normalization of basic Indicators

For the evaluation of sustainability index, the basic indicator values were transformed into normalized scores by using ideal and worst values for each. Scaling technique is used in the process of normalization of indicator which is lies in the range of 0 to 1. The equation used for this is same as that given in Chapter 2. The calculated normalized indicator values for five cities are given in Table 5.1. These values are used in the next step of developing composite indicators.

Table 5.1 Indicator of Water System Sustainability- Normalized Value (Comparing Cities)

Dimensions	Sub Indicator	Categories of Sustainability	Chandigarh	Visakhapatnam	Allahabad	Solapur	Jabalpur
Water Supply	Status of Utility	Coverage of water supply connections	0.89	0.85	0.73	0.42	0.43
		Per capita supply of water	1.00	0.63	1.00	0.98	0.80
		Continuity of water supply	0.44	0.00	0.35	0.00	0.03
	Governance & Maintenance	Extent of metering of water connections	0.84	0.23	0.01	0.40	0.67
		Efficiency in redressal of customer complaints	1.00	1.00	0.00	1.00	1.00
	Environmental issues	Quality of water supply	1.00	1	0.00	0.50	0.00
	Economy	Extent of non- revenue water	0.65	0.35	0.00	0.85	0.00
		Cost recovery in water supply services	0.64	1.00	0.81	0.85	0.40
Waste Water	Status of Utility	Toilet Coverage	0.981	0.56	0	0.94	0.6
		Coverage of sewage network services	0.89	0.26	0.2	0.54	0
		Collection efficiency of sewage network	1	0	0.7	0	0.6
	Governance & Maintenance	Adequacy of sewage treatment capacity	0.84	0.48	0.85	0	0
		Efficiency in redressal of customer complaints	1	1	0	0	1
	Environmental issues	Extent of reuse & recycling of sewage	0.885	0.15	0	0	0
		Quality of sewage treatment	1	1	0	0	0
	Economy	Extent of cost recovery in sewerage management	0.25	0.6	0.81	0.961	0

Solid Waste	Status of Utility	Efficiency of collection of municipal solid waste	0.97	0.91	0.8	0.98	0.889
		Extent of segregation of municipal solid waste	0.225	0.0625	0	0.65	0
	Governance & Maintenance	Extent of recovery of waste collected	1	0.1125	1	0.65	0
		Efficiency in redressal of customer complaints	1	1	0	0	1
	Environmental issues	Extent of scientific disposal of solid waste recovered	0.95	0	1	0	0
	Economy	Extent of cost recovery in SWM service	0.003	0.26	0	0.97	0.32
Storm Water	Status of Utility	Coverage of storm water drainage network	1	0.7	0.25	0	0.9

5.4 Computation of Index Values and Benchmarking Water Sustainability

The category-wise calculations of sustainability index value for the different aspects of water system are proposed in Table 5.2. These estimates are derived for all the selected cities. In case of individual criteria index, cities show considerably variation in sustainability index value when compared to each other. Under the water supply sub indicator, Chandigarh has best index value of 0.87 for status of utility because of high value of coverage networking of water system and metering system whereas Visakhapatnam has lowest value (0.62). Allahabad has 0.83 index value for status of utility which is higher than Solapur and Jabalpur having value 0.74 and 0.62 respectively. Under the economy indicator category Solapur city does well with a value of 0.85, while Jabalpur has lowest value of 0.33. For the governance & maintenance criteria, Chandigarh has the index value of 0.89 because of higher percent of metering connection which is close to benchmark and higher than that scored by other cities. Chandigarh and Visakhapatnam have the best index value of 1 for environmental sustainability under the water sub component.

Under waste water sub component, Chandigarh has best index values for categories status of utility and governance & maintenance. Solapur tops in economy category due to higher value of cost recovery from sewage management. Chandigarh and Allahabad obtains relatively high values for environmental sustainability indicator.

Chandigarh obtains the index value of 0.73 for the category status of utility under the solid waste sub component whereas Allahabad tops with a best index value of 1 for the category of environmental sustainability. Chandigarh performs best under the governance & maintenance category by obtaining high value for recovery of waste collected and redressal of customer complaints. This indicates that Chandigarh has better solid waste management as compared to other cities. Under the Storm water sub component, Jabalpur has relatively high value of 0.9 whereas Chandigarh and Visakhapatnam has second and third position with index value of 0.79 and 0.7 respectively. Solapur however has last position among five cities for storm water sub component. Overall, Solapur performance with respect to water supply and solid waste system categories appears to be better compared to waste water and storm water system.

The overall process of Fuzzy composite programming for selected cities is presented in ANNEXURE-B: Table 3- Table 7

Table 5.2 Sustainability Sub Index values

Dimensions	Sub Indicator	Categories of Sustainability	Chandigarh	Visakhapatnam	Allahabad	Solapur	Jabalpur
Water Supply	Status of Utility	Coverage of water supply connections Per capita supply of water Continuity of water supply Water Exploitation Index	0.87	0.62	0.83	0.74	0.62
	Governance & Maintenance	Extent of metering of water connections Efficiency in redressal of customer complaints	0.89	0.62	0.008	0.67	0.80
	Environmental issues	Quality of water supply	1	1	0	0.5	0
	Economy	Extent of non- revenue water Cost recovery in water supply services	0.64	0.80	0.63	0.85	0.31
Waste Water	Status of Utility	Toilet Coverage Coverage of sewage network services Collection efficiency of sewage network	0.96	0.41	0.37	0.71	0.52
	Governance & Maintenance	Adequacy of sewage treatment capacity Efficiency in redressal of customer complaints	0.89	0.70	0.68	0	0.59
	Environmental issues	Extent of reuse & recycling of sewage Quality of sewage treatment	0.93	0.68	0	0	0
	Economy	Extent of cost recovery in sewerage management	0.25	0.6	0.81	0.96	0

Solid Waste	Status of Utility	Efficiency of collection of municipal solid waste Extent of segregation of municipal solid waste	0.73	0.67	0.5933	0.84	0.65
	Governance & Maintenance	Extent of recovery of waste collected Efficiency in redressal of customer complaints	1	0.55	0.83	0.54	0.54
	Environmental issues	Extent of scientific disposal of solid waste recovered	0.95	0	1	0	0
	Economy	Extent of cost recovery in SWM service	0.003	0.26	0	0.97	0.32
Storm Water	Status of Utility	Coverage of storm water drainage network	1	0.7	0.25	0	0.9

These category-wise index values are used to construct dimension sustainability indices. Table 5.3 presents the estimated index values for four dimensions of sustainability for selected cities. It is observe that Chandigarh has the best well planned water system as compared to other cities with a value of 0.88, 0.82, 0.75 and 1 respectively for water supply, waste water, solid waste and storm water management dimensions. Jabalpur obtains relatively high value only in case of storm water management with value of 0.9 as compared to other dimensions where it has lowest position with respect to other cities.

Table 5.3 Sustainability Index of Water System Sustainability for Comparing Cities:

Dimensions of Sustainability	**Composite Indicator Values**				
	Chandigarh	Visakhapatnam	Allahabad	Solapur	Jabalpur
Water Supply	0.88	0.80	0.55	0.68	0.47
Waste Water	0.82	0.58	0.54	0.63	0.39
Solid Waste	0.75	0.50	0.66	0.78	0.50
Storm Water	1	0.7	0.25	0	0.9
Sustainability Index value	**0.87**	**0.60**	**0.52**	**0.60**	**0.59**

Benchmarking System – Comparing five cities

For the comparison of five cities for water system sustainability across categories and dimensions with respect to benchmark, Radar diagrams have been used.

Fig.5.1 shows the benchmarking of Chandigarh for water supply sustainability against four cities with different sustainability index values. In case of Status of utility, all cities perform well; the values have crossed 0.62 approaching 0.87. This is because of the indicators related to high values of coverage of network of water systems, metering system and fulfillment of the water demand. There is a large variation shown in case of governance and maintenance as Chandigarh has index value of 0.89 whereas Allahabad has a very low value of 0.081, primarily due to its inadequate storage capacity and near absence of metering system. For Economy segment, Visakhapatnam and Solapur obtain high index values of 0.80 and 0.85 respectively with respect to benchmark.

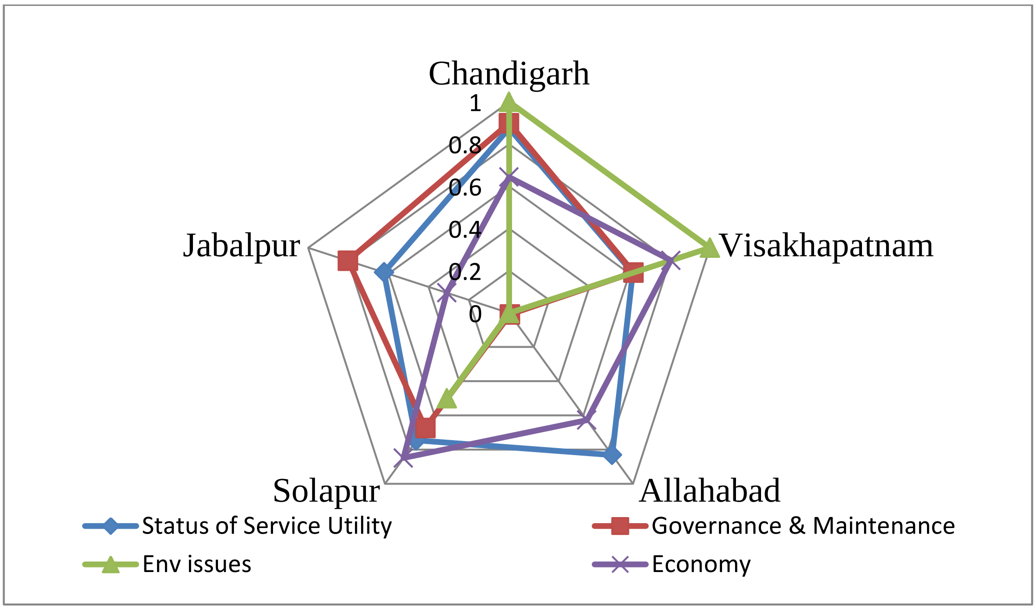

Fig 5.1Benchmarking Water Supply Sustainability- Comparing Cities

In the waste water sub component (Fig.5.2), for the status of utility and governance & maintenance indicator, Chandigarh city performs better with the value of 0.87 and 0.89 respectively as compared to other cities. Only with respect to economy, it has low value of 0.64. Jabalpur city does poorly with respect to environmental and economy sustainability categories resulting in a poor overall performance. Visakhapatnam has relatively high value in case of environmental sustainability, where all other cities have lowest benchmark. Solapur obtains lowest benchmark for environmental sustainability and governance & maintenance, due to the problems related to its quite old and inefficient sewage treatment plant.

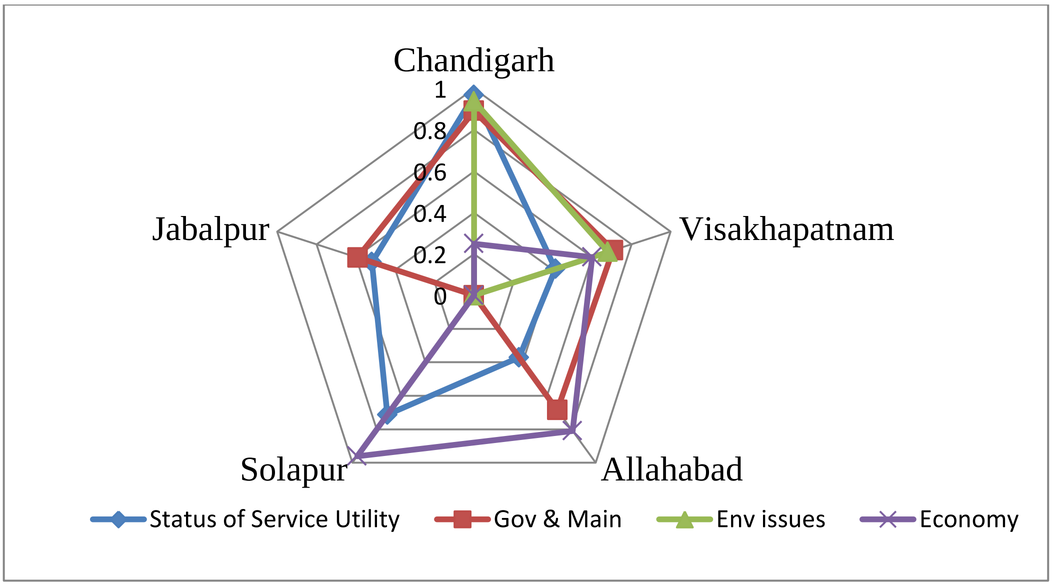

Fig 5.2 Benchmarking Waste Water Sustainability- Comparing Cities

Fig.5.3 shows the comparison of the sustainability index values for the solid waste system for different categories with benchmark sustainability value. In case of status of utility, Solapur has a high index value of 0.84 whereas Allahabad is lowest with the value 0.59. For environmental sustainability segment Solapur, Jabalpur and Visakhapatnam have lowest benchmark value whereas Chandigarh and Allahabad have better index value of 0.95 and 1 respectively. Chandigarh city also does well with respect to three categories under waste water sustainability. Only with respect to economy segment, it has lowest value i.e. 0.003 primarily due to absence of user charges on solid waste management services.

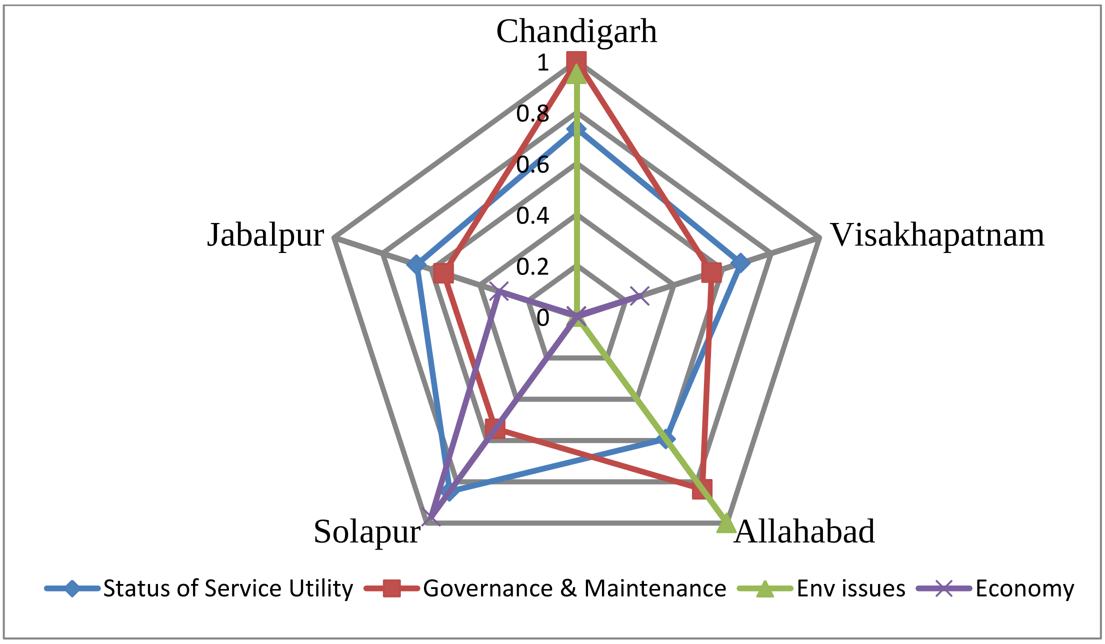

Fig 5.3 Benchmarking Solid Waste Sustainability- Comparing Cities

While comparing cities for storm water system sustainability, Chandigarh, Visakhapatnam and Jabalpur obtain the index value 1, 0.7 and 0.9 respectively this is close to benchmark for the storm water network coverage (Fig.5.4). However Allahabad and Solapur score low due to absence of planned storm water drainage.

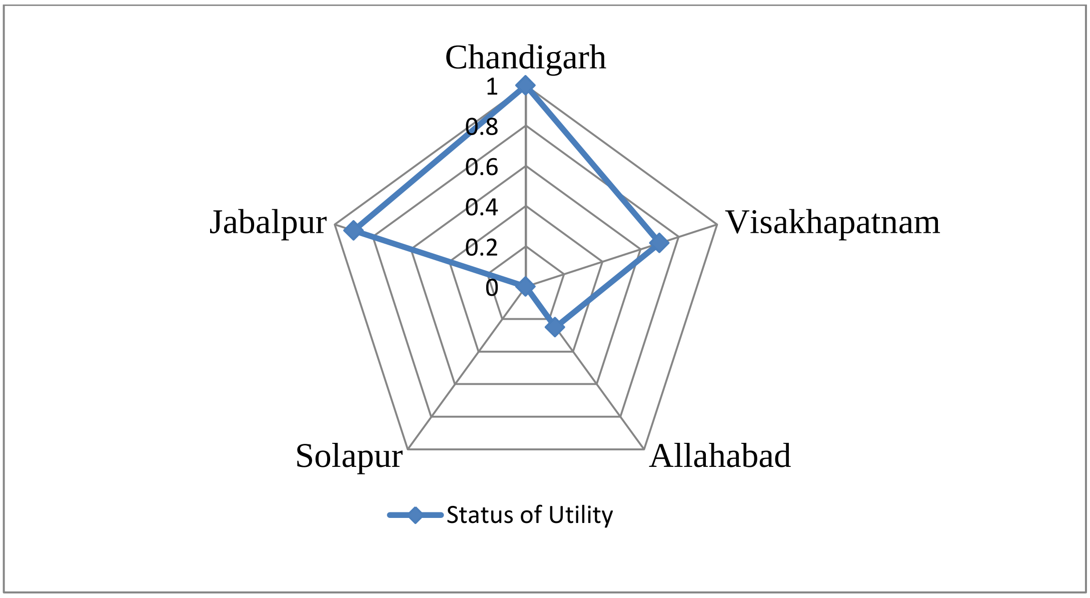

Fig 5.4 Benchmarking Storm Water Sustainability- Comparing Cities

Finally, the composite overall sustainability Index value of water supply, waste water, solid waste and storm water sustainability sub components are compared for all the five cities (Fig 5.5). The best performance showed by these cities is with respect to water supply where the composite index values achieved by the cities are lies in the range of 0.88 to 0.47. Chandigarh performs better with respect to all dimensions. The least achievement is by the Solapur with respect to storm water system having 0 index value. Allahabad and Jabalpur have consistent value for all dimensions except storm water where Jabalpur has highest index value (0.9) and Allahabad has lowest index value (0.25).

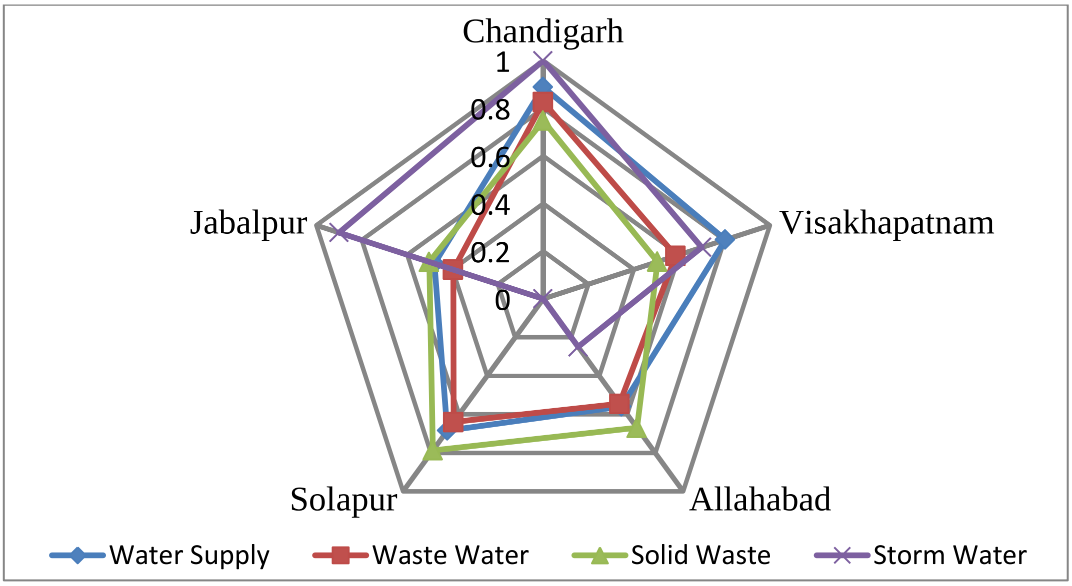

Fig5.5 Benchmarking Water System- Comparing Cities

The overall sustainability index value is compared for five cities are presented in Fig.5.6. As with individual dimension index values, the rank order remain same with Chandigarh emerging as the most sustainable water system.

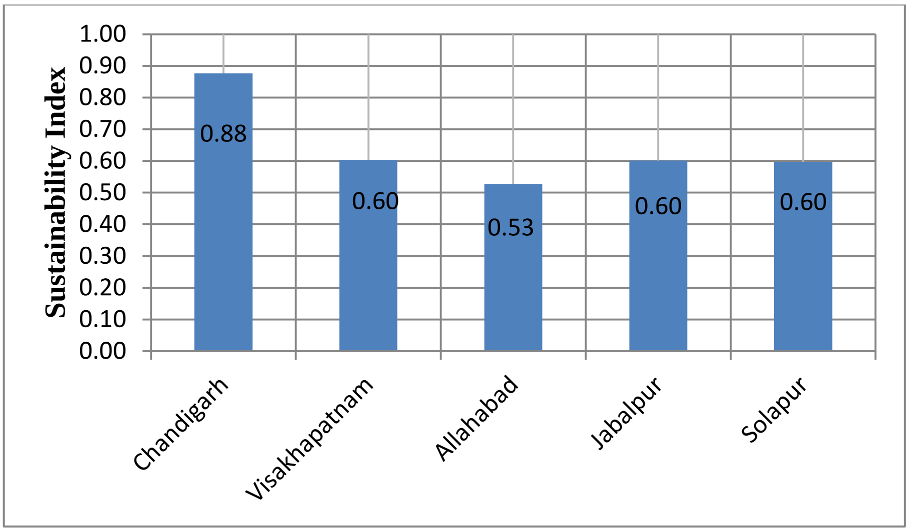

Fig 5.6 Sustainability Index Value for Water System

CHAPTER 6
CONCLUSION AND DISCUSSION

6.1 Conclusions

Fuzzy Composite Programming method of the Multi-criteria decision making (MCDM) approach has successfully been employed to develop the Sustainability Assessment framework. Identification of the hierarchical indicator structure representing the system under study followed by determination of weights and balancing factors employing AHP has led to computation of a single value of Sustainability Index and its components following the aggregation scheme.

The first application of the development framework has been done for the benchmarking of the whole water system of one of the best planned cities of India viz. Chandigarh by estimating its composite index value with lowest and highest sustainability index scores from 0 to 1. Availability of abundant information about the system has led to employing a large number of basic indicators. The performance scores have been observed to be better with respect to water supply, waste water and solid waste systems with the values 0.74, 0.76 and 0.74 respectively. This is apparently because of well-planned water supply and waste water sub systems of Chandigarh and also moderately good solid waste management sub system. However the storm water sub system demonstrates a lower score of 0.64. Individually, Chandigarh city has demonstrated relatively low sustainability scores for economy segment. The observed scores provide useful information so that targeted interventions may be adopted with respect to low scoring indicators for attaining better sustainability.

Further, comparison of sustainability status has been attempted for four other cities of India (viz. Allahabad, Jabalpur, Solapur and Vishakhapatnam) with Chandigarh employing the same framework. However, considering the availability of relatively lesser information for cities other than Chandigarh, less number of basic indicators could be used. Among five cities compared, Chandigarh has again emerges as the most sustainable city with an overall SI score of 0.88 whereas Allahabad got the lowest position with the score of 0.53. Vishakhapatnam, Solapur and Jabalpur are at ranks second, third and fourth respectively with the scores 0.60, 0.60 and 0.59 respectively.

Sensitivity analysis of the MCDM results could highlight the factors considered in the framework, which influenced the sustainability score positively, and thus presented yet another dimension to deciding about the interventions.

SWOT approach was also successfully applied for Sustainability Assessment of Chandigarh, which highlighted the strengths, weaknesses, opportunities and threat to attain sustainability for the city. This information may be employed for devising further interventions.

6.2 Limitations

The biggest limitation in this study is the Subjectivity at the level of the researcher in deciding the indicator structure, weights and the balancing factors. Although due diligence has been followed for taking a rational decision on the above and using established techniques like AHP, MCDM for the above; yet an Opinion Poll based values would still be better which may be attempted later.

Another limitation of this study is the availability of data/ information at the level of all the cities excluding Chandigarh regarding several aspects related to water supply, wastewater, solid waste and storm water management systems. A drastic change in the data consolidation and availability is needed at the nationwide scale.

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