Environmental Quality Assessment of a Few Selected Stretches in a River Basin using Multi-Criteria Approaches

THESIS

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By

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CERTIFICATE

This is to certify that the thesis entitled **"Environmental Quality Assessment of a Few Selected Stretches in a River Basin using Multi-Criteria Approaches"** and submitted by **Sumanta Chakrabarti** ID No. **2008PHXF419P** for award of Ph.D. Degree of the Institute, embodies original work done by him under my supervision.

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ABSTRACT

The contemporary problems of population explosion, rapid transformation of the objectives in economic development strategies irrational utilization of finite energy resources and unprecedented instances of rapid urbanization are challenging the very frame work of environmental quality and sustainability. The obvious consequences of such unrestrained and uninhibited exploitation of the environmental resources have reflected in a significant increase in the degradation of our immediate and surrounding environs, as manifested in poverty, environmental pollution, proliferation of slumps and squatters, inadequate waste management and impure water supply, vehicular pollution, increase in traffic jams, road accidents etc. Though, human awareness has been increasing on the pivotal necessities of understanding and undertaking crucial changes in the perspective of environmental exploitation to suit our needs, a considerable effort still remains to be endorsed to identify and establish holistic indices of environmental quality and its immediate future remedial policy appropriate to regional preference and acceptance. To this end, the present study involves a conscious effort to establish the desired indices of environmental quality through a robust analytical and perception study endeavour thus help to establish a pro-active platform of decision making to envision a pragmatic and fruitful recourse to uphold the sanctity of our environment.

This study has made an attempt to identify the major issues of the environmental quality demanding priority in the selected study areas, subsequent to which unique fuzzy multiple-attribute decision support platforms have been proposed for an integrated quality assessment of the environmental attributes under study. The decision support system has been developed by combining the principles of Multi-Attribute Decision Making Analysis and fuzzy set theory in order to reflect the spatial distribution characteristic of the environmental quality and to address the inherent uncertainty associated with various attributes involved in the elements of the environment quality evaluation. The applicability and usefulness of the proposed methodology developed herein has been rationalized through a case study on the evaluation of environmental quality at different sampling stations along Haora River, Tripura, India. It is focused on important

components of environment, dealing primarily with quality aspects of surface water, groundwater and air in the selected region. It incorporates the concept of multiple-attribute decision-making methods, fuzzy rule-based models (fuzzy set theory) and GIS to generate quality maps of environment.

The main purpose of this study has been to develop appropriate models to identify the significant necessity of data accuracy and reliability and to assess the likely consequences of alternate strategies that might be conducive in the effort to improve or maintain the quality of environment in the study areas. The insights gained through the present study is believed to be of pivotal significance in guiding the development and implementation of effective environmental remedial plans and decisions in the areas. In this study, three different models were developed in order to evaluate the pertinent environmental quality indices of surface water, groundwater and air respectively. The results obtained from these models were compared to the indices evaluated through the prevalent methodologies based on weightage principles and field data; and was subsequently observed to provide a more robust and credible platform of environmental quality evaluation and identification in face of the uncertainties that remain eclipsed in the traditional approaches. The analytical recourses to this effect has been complemented by a parallel and independent perception based study to document public awareness and feedback toward environmental issues in Agartala city located along the Haora river.

Once the preliminary environmental quality indices based on conventional methods were generated using the identified parameters of investigation for surface water, groundwater and air resources, the methodology was further refined by developing corresponding indices through fuzzy logic-based models for these components of the environment. The present study was conducted at 10 sampling sites along the Haora river basin. Samples were collected at these sampling sites to evaluate the environmental quality. The quality maps generated through different models have been compared with the field data to verify their effectiveness and suitability. The methodology was further augmented through a comprehensive analysis of public perceptions on overall environmental quality at Agartala city located along the Haora river using a survey questionnaire. The endeavor established clearly as to how perceptions of public can be effectively harnessed to perform analysis of a complex and dynamic environment consisting of physical and social environments in the Haora river basin, especially in Agartala. To illustrate the applicability of the methodology of the proposed models, case studies have been presented. The methodology and accompanying case studies have been explained in Chapters 3, 4, 5 and 6 respectively of this Thesis. Finally, distinct conclusions have been drawn in Chapter 7 based on all the preceding results and their corresponding outlook on the perspectives of the objectives under study.

Comparison of the methodologies has clearly highlighted superiority and robustness of the developed fuzzy platforms in determining the environmental quality indices of each of the parameters under study. It could effectively address the inherent uncertainties involved in the evaluation, modeling and interpretation of sampling data, which was, but beyond the scope of the traditional weighted approaches employed to the same effect. Further, a parallel perception survey was undertaken to complement the analytical recourses in attaining the objectives of establishing a holistic index of environmental quality in the present research. The results of the perception survey, though in majority, indicated a significant agreement to the conclusions obtained from the analytical methodologies that had been perused, did exhibit distinct divergence in the opinion of some of the attributes of water and air quality under study when compared to the corresponding results obtained during the previous evaluation of the objective measures. The observed divergences, established the pivotal necessity to incorporate the salient aspects of a dedicated perception survey as a standalone platform of validation for any intended analytical methodology dedicated in establishing the environmental quality indices at a given location of interest. Though instances of such perception survey in environmental paradigms have been evident in existing literature, there has hardly been any effort to harness the synergistic benefits of a perception survey and analytical effort to design a pragmatic platform of quality index evaluation for effective promulgation and disbursement of environmental remedial policies. It is in this respect that the present study reserves its unique footprint as a proven platform to be perused in future research endeavors in environmental quality assessment.

The ward-wise comprehensive data of air pollution, water pollution, solid waste management, noise pollution, population density, traffic congestion etc. in the case study area will improve the environmental quality evaluation process proposed herein. This was observed to be the ordinary limitations of the present research. In fact, the present study highlights the requirement of applied research and strategy evaluation in the area of environmental quality monitoring, assessment and management. Furthermore, the proposed methods can provide a proven platform for assessment of environmental policies for other study areas of interest in future research endeavours dedicated to the determination of similar environmental quality indices. A number of extensions and applications of the present study has been deemed as possible future courses of perusal in the context of environmental quality assessment, pollution prediction and its remediation.

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LIST OF SYMBOLS

SYMBOL	MEANING
C_i	Concentration of i^{th} normalize parameter
P_i	Relative weight of i^{th} parameter
k	Subjective constant
w_i	Weightage factor of the i^{th} parameter
q_i	Quality rating of i^{th} parameter
$\mu_A(X)$	Characteristic (membership) function of element x in set A
$\in$	Includes
$\notin$	Not includes
a,b,c	Parameters of triangular membership function
σ	The width of Gaussian membership curve
c	Point representing maximum membership value
μ_{wi}	Value of membership function of Fuzzy importance degree/weight
$Q\tilde{I}_n$	Quality index set of n^{th} station as per Yager's max-min model
$\cap$	Intersection operator (minimum operator)
$S_{i,n}$	Score assigned to i^{th} parameter of n^{th} sample
QI_n	Quality index as per Yager's index
$w_{i,n}$	Weightage factor of the i^{th} parameter in n^{th} station
$\mu_{Si,n}$	Membership function of score value s in Fuzzy set S
$\mu_{Qi,n}$	Membership function of quality score value S in Fuzzy set Q
S	Possible water quality score
A	Square matrix expressing all the water quality parameters considered for the study
a_{ij}	Relative weight of i^{th} parameter with respect to j^{th} parameter
ω	Eigenvector
λ	Eigen Value
n	Order of the eigenvector

λ_{max}	Maximum Eigen Value
CI	Calculated Inconsistency index
CR	Consistency Ratio
RI	Saaty's Index of consistency for random judgments derived from a sample of randomly selected reciprocal matrices
$c_{i,actual}$	Actual monitored value of i^{th} water quality parameter
$c_{i,ideal}$	Ideal value of of i^{th} water quality parameter
$c_{i,standard}$	Standard value of i^{th} water quality parameter as per BIS (1991) drinking water quality standard
W	Weight set
$\mu_G(U)$	Membership function representing grade of membership of U in grade G
U	Assessment factor set representing water quality parameters
G	Set of Evaluation class
$\mu_{ij}(x)$	Membership function characterizing fuzzy relation matrix
R	Fuzzy relation matrix
$\mu_{mn}(x)$	Membership value of m^{th} criteria belonging to n^{th} grade class
B	Fuzzy combination matrix
b_j	Elements of fuzzy combination matrix representing integrated assessment value of each sampling station.
α_j	Degree of influence with respect to i^{th} category of grades (also known as defuzzifyng factor)
S_n	Possible fuzzy score at n^{th} station
$\mu_{Gi}(S_n)$	Membership value of i^{th} grade with respect to fuzzy score (S_n)
$\mu_G(U)$	Membership value of grade G with respect to U^{th} criteria
I_P	The index for pollution p
C_P	The rounded concentration of pollutant p
BP_{Hi}	The high breakpoint concentration
BP_{Lo}	The low breakpoint
I_{Hi}	The prescribed AQI value corresponding to BP_{Hi}

I_{Lo}	The prescribed AQI value corresponding to BP_{Lo}
C_i	Value of i^{th} normalize parameter
$\mu_G(S_n)$	Membership value of 'good' grade with respect to fuzzy score (S_n)
$\mu_M(S_n)$	Membership value of 'medium' grade with respect to fuzzy score (S_n)
$\mu_P(S_n)$	Membership value of 'poor' grade with respect to fuzzy score (S_n)
$\mu_{VP}(S_n)$	Membership value of 'very poor' grade with respect to fuzzy score (S_n)
$\mu_S(S_n)$	Membership value of 'severe' grade with respect to fuzzy score (S_n)
F_k	Integrated Assessment score corresponding to k^{th} station
U_i	Membership function of assessment of ith factor/criterion
G_i	Grade/ Evaluation class
r_{ij}	Aggregate rating
A^+	Positive ideal solution (PSI)
A^-	Negative ideal solution (NSI)
$\tilde{v}_j^*$	Maximum value of $\tilde{v}_{ij}$ i.e. $\tilde{v}_j^* = \max\limits_{i=1,2,\ldots,m}\left(\tilde{v}_{ij}\right)$
$\tilde{v}_j^-$	Minimum value of $\tilde{v}_{ij}$ i.e. $\tilde{v}_j^- = \min\limits_{i=1,2,\ldots,m}\left(\tilde{v}_{ij}\right)$
$\tilde{v}_{ij}$	Fuzzy number
d^+	Distance of each ward from NIS
d^-	Distance of each ward from PIS
CC_i	Closeness coefficient

CHAPTER 1

INTRODUCTION

1.1. Introduction

The quality of the environment is deteriorating day by day due to rapid increase in population, economic transformation and development, use of energy, inappropriate development projects such as urbanization. These factors have resulted growing concern about environmental sustainability on earth. For example, the implication of urbanization is manifested in poverty, environmental pollution, impure water supply, vehicular pollution, increase in traffic jams, road accidents and waste handling problems, etc. In today's world, although awareness of environmental protection among the masses has improved, industrial pollution to the air, water and land continue to increase. As a result, environmental problems pertaining to public health, deforestation, soil erosion, climate change are aggravated. These problems have severely threatened the lives and livelihoods of human beings, as well as the global sustainability of resources for future generations.

Environmental planning and management is the way to regulate activities so that pollution could be minimized by taking appropriate measures to improve environmental quality. Efficient planning requires an understanding of the quality condition of environment so that suitable management policies can not only be formulated to prevent pollution problems of the environment but also appropriate treatment options and control mechanisms can efficiently be adopted. Due to the complexities involved in the evaluation, there is a need to adopt a systematic methodology which can integrate all attributes pertaining to relevant information for arriving final decisions on environmental quality management and its protection. The integration of these attributes can be performed very well using multiple-attribute decision support system. Since it is difficult to quantify all the attributes, some of them may be assessed qualitatively or linguistically using concept fuzzy set theory. It is also very important to note that the information available on environmental quality evaluation is spatial in character and therefore spatial distribution characteristics of the environmental factors should also be considered. Geographical Information System (GIS) is an efficient tool to study and analyze such problems.

The decision-making process of the environmental quality management and environmental planning consists of conflict analysis characterized by socio-political, environmental, and economic value judgments. The solution alternatives have been evaluated under a given set of criteria which may either be available precisely and accurately or they may be expressed imprecisely and with uncertainty. The process becomes complicated further when opinion of decision-makers (DMs) and other stakeholders conflict while sharing their expert knowledge. Therefore, best solution with a single objective does not usually exist in real life problems and planners search for acceptable compromise solutions. To deal with real-life situations in environmental planning and decision processes, Multi-Criteria Decision Approach (MCDA) methods has been used which provide a framework for processing, analyzing and storing all information so that decision processes become more traceable, clear, easy to use and accurate.

This research has made an attempt to identify the major issues and priority areas of the environmental quality in selected area and therefore proposes a fuzzy multiple-attribute decision support system for integrated environmental quality assessment. The decision support system would be a combination of fuzzy set theory, GIS and Multi-Criteria Decision approach which reflects the spatial distribution characteristic of the environmental quality and incorporate the uncertainty associated with specifying various attributes involved in the elements of the environment quality evaluation. The study will help to quantify the impact of different alternatives of improvement plans and prioritize them.

1.2 Objectives of the Research

The purpose of this research is to perform an important study and to show its applications to environmental quality assessment along Haora river.

The main objectives set for this research study are to:

a) study the status of the environmental quality with respect to surface water, groundwater and air at various sampling sites along a river through quantitative and qualitative analysis.

b) identify principal pollutants in the study area.

c) study the spatial variation of environmental quality in the study area using fuzzy multiple-attribute decision making techniques and investigate strengths and weaknesses of various types of models used in the study.

d) provide useful analysis to undertake remediation of contaminated surface water, groundwater and air resources along a river basin.

e) assess public perceptions on quality of environment in Agartala, the capital city of Tripura state, India using Fuzzy Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) under physical and social environments.

f) compare the results of modified fuzzy rule-based models with the conventional quality indices formulations and field data.

g) suggest an environmental management plan to enhance the overall environmental quality.

The study has made an attempt to determine status of quality parameters of surface water (river), groundwater and air along Haora river basin using fuzzy decision analysis. A perception based study has also been performed to document public awareness and feedback toward environmental issues in Agartala city located along Haora river. The methods presented in this study have integrated the concepts of fuzzy set theory and multi-criteria approach to analyze quality of different components of the environment. Appropriate models have been applied to determine the significance or importance of having more accurate or more detailed data, and to access the likely consequences of alternate strategies that might be considered in an effort to improve or maintain quality of environment. The insights obtained from this study will be useful to develop effective plans and decisions.

1.3 Scope of the Research

Environmental quality has become a major concern in recent years. Since testing of important quality parameters of environment at various sampling locations within a river basin is not economically feasible, one frequently used monitoring strategy is to develop quality maps for different components of environment (viz. surface water, groundwater and air resources etc.), and then prioritize those stations located in the potentially highly contaminated areas for testing of contaminants.

This study deals with assessment of environmental quality along Haora river. It is focused on important components of environment, dealing primarily with quality aspects of surface water, groundwater and air resources. It incorporates the concept of multiple-attribute decision-making methods, fuzzy rule-based models (fuzzy set theory) and GIS to generate quality maps of environment. Three different models were developed to evaluate environmental quality indices for surface water, groundwater and air respectively. The results obtained from these models were compared to the indices evaluated through conventional way.

Once the preliminary environmental quality indices were generated using selected parameters for surface water, groundwater and air resources, the methodology was further refined by developing corresponding indices through fuzzy logic-based models for these components of the environment respectively. This study was conducted at 10 sampling sites along the Haora river basin. Samples were collected at these sampling sites to evaluate the environmental quality. The quality maps generated through different models have been compared with the field data to verify their effectiveness and suitability. The methodology was further refined through analysis of public perceptions about overall environmental quality at Agartala city located along Haora river which have been analyzed using a survey questionnaire. It demonstrates how perceptions of public be used to perform analysis of complex and dynamic environment consisting of physical, social environments in the Haora river basin, especially in Agartala. It incorporates a number of parameters/attributes. To illustrate the applicability of the methodology of suggested models, a case study has been presented.

1.4 Organization of the Research

Chapter-1 gives an introduction to environmental quality evaluation and thereby the various aspects used in the analysis. The objective and scope of the present investigation have also been emphasized along with the organization of the work.

Chapter-2 deals with the comprehensive literature review of the earlier methods used in the analysis along with theoretical considerations especially corresponding to fuzzy-based multiple-attribute decision analysis techniques. The investigations of various authors or researchers and their limitations regarding environmental quality determination are also examined. The nature of the problem is further outlined. The quality characteristics and their estimation are also discussed. The chapter concludes with further investigations required for integration of various components of environment (e.g. water, air, socio-economic etc.) consideration for effective implementation of a remedial action plan so that environmental quality can be enhanced. The literature review presented in this chapter mainly covers three main topics: studies related to the evaluation of environmental quality, introduction of fuzzy set theory and multi-criteria analysis, and studies applying different tools in various areas.

Chapter-3 presents the water quality management of a river by developing a comprehensive technique of fuzzy based water quality index evaluation system and sensitivity analysis. The tremendous increase in population, rapid urbanization, change in irrigation patterns and unplanned growth of industries without proper enforcement of environmental standards are some of the major reasons for poor quality of water in river basins. The situations are getting further aggravated because of unpredictable and scanty rainfalls which are ultimately resulting in uncertain natural stream flows. It also leads to uncertainty in assessing and predicting quality of water. Moreover, the quality of water needed for different beneficial usages depends on the concentration of varying parameters which makes water quality management problem complex and fuzzy. Thus the quality attributes of the parameters can be described by the linguistic variables which have been dealt by conducting expert’s opinion survey in this report. The water quality index of each specific site is calculated by integrating effects of each attribute in proportion to their degree of importance. Finally, a case study of river Haora has been carried out to evaluate the Fuzzy Comprehensive Water Quality Index (FCWQI) with respect to drinking purpose only. The water quality parameters considered in this study are: Dissolved oxygen (DO), Total Coliform, 5-day Biochemical Oxygen Demand (BOD_5), pH, Temperature, Nitrates, Phosphates, Total Dissolved Solids (TDS) and they were collected at ten selected stations along the river. The FCWQI for a particular usage developed herein is based on a holistic, integrated, systems-oriented approach, which clearly describes the overall state of the water quality by a single rational number. Sensitivity analysis has been carried out to demonstrate the cause-effect relationships for various attributes and their inter-relationships which will ultimately help in arriving at the appropriate management options to improve the overall water quality of the river.

In this chapter two methods have been applied to assess status of water quality at different sampling stations of river Haora, viz. (i) Simple Additive Weighting (SAW) and (ii) Fuzzy Comprehensive Method. The methodology presented herein clearly demonstrates the credibility and superiority of the Fuzzy Comprehensive Method as compared to the Simple Additive Weighting (SAW) method to obtain the water quality index by incorporating indicators' uncertainties arising during the quality evaluation process which are not addressed in the traditional methods of indexing such as SAW.

Chapter-4 deals with groundwater quality assessment wherein Groundwater Water Quality Index (GWQI) has been developed to determine suitability of groundwater for different beneficial uses. GWQI has been derived initially using Simple Additive Weighting (SAW) method which has later been compared with another method based on fuzzy set theory. In addition, the polluting parameters at each selected station have also been analyzed using Geographical Information System (GIS). The GWQI has been developed at each of the ten selected sampling stations located in the Haora River basin. The groundwater samples at these 10 sampling stations have been collected to perform physicochemical analysis of 10 important water quality parameters. These are Total Dissolved Solid (TDS), pH, Total Hardness, Ca, Mg, Total Alkalinity, Nitrate Nitrogen, Chloride, Iron and Electrical Conductivity. The study demonstrates that the groundwater of the study area requires certain degree of treatment before consumption, especially at those sampling stations which are affected by Iron.

Chapter-5 deals with the evaluation of air quality index at 10-sampling air sampling sites. Samples are collected from the air after pollutants from the various sources have been thoroughly dispersed and mixed together under natural meteorological conditions. The study will serve as a basis for assessing which precautionary steps require to be addressed if air pollution levels rise beyond the prescribed standards. Policy makers can evaluate health effects, determine the compliance with air quality standards prescribed by CPCB, and predict the effects of proposed new sources of air pollution so that air pollution control strategies can be formulated in an effective manner, if required. In this chapter, an attempt has been made to calculate Air Quality Index (AQI) at 10 sampling stations using two methods, namely modified EPA method and the Fuzzy Comprehensive Assessment Method. The details of methodology, results and discussion, and conclusions are given in the subsequent sections.

In **Chapter-6**, the public perceptions on the overall environmental quality of the Haora river basin have been analyzed using a survey questionnaire which demonstrates how perceptions of public be used to perform analysis of complex and dynamic environment consisting of physical, social environments in the Haora river basin, especially in Agartala, the capital city of Tripura state, India. The city is governed by the Municipal Corporation (AMC) with an initial overall area as 58.184 square Km which has extended up to 76.504 square km after the completion of the restructuring of Agartala Municipal Corporation (AMC). The "perceptions survey" included questions which allowed respondents to rate the importance of forty seven attributes on assessment of environmental quality; score the performance on mainly 3-4 rating scales on each of these attributes; satisfy or not satisfy with a number of parameters on attitudes toward each attribute and provide information on constraints on quality impact (e.g. physical environment, neighborhood and social). Respondents were also asked questions about their usual perceptions on overall quality of environment. In general people of AMC are concerned on environmental issues and vocal about gradual deterioration of quality of life of the city. However, politicians and policy-makers are not confidant about the commitment of the public to protect and conserve the environment. Chapter-6 covers an interactive fuzzy multi-criteria approach for evaluation of environmental quality in a river basin developed in this research. It deals with the study related to the evaluation of environmental quality based on people/expert perception with respect to various attributes. The chapter describes the methodology of the research; where a revealed-preference approach is taken. It describes about research techniques, criteria and methods of data collection and analysis. For this study a fieldwork was carried out between the month of February- March 2012. Primary survey was conducted with regard to various wards of Agartala city. Various secondary data sources were also referred in the process of complete analysis.

Conclusions are drawn in **Chapter 7** after all the results and their in-depth analysis.

The limitations of the research and the assumptions made in the study could have been listed here; however, it is thought that they could be appreciated better as their need arises and thus are mentioned in the text as and when they appear.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Environmental quality assessments have been performed using various indicators depending on usage and suitability of environment for living beings. Environmental quality evaluation not only deals with temporal and spatial measurement of such indicators but also their interpretation and prediction in a scientific manner which can precisely describe the quality of each component of environment. The evaluations can be analyzed both qualitatively and quantitatively and can be classified into three categories (i) retrospective evaluation (ii) contemporary evaluation and, (iii) prospective evaluation (Sokhi, 2008).

The retrospective evaluation describes quality of environment of the past certain phase on the basis of historical data. In contemporary evaluation, environmental quality is evaluated using data pertaining to latest 2-3 years. The prospective evaluation deals with the assessment of impacts of the proposed projects on environmental quality in future. This is also called as the environment impact evaluation.

Analysis and prediction of environmental condition and vulnerability have been considered as one of the challenging steps of environmental management systems analysis (Boughton et al., 1999; Cohan et al., 2007; Cormier and Suter, 2008; Kimball, 1972; Suter and Cormier, 2008). The issues, priorities and preferences corresponding to environmental management and its protection changes from one region to another and from one country to another. For example, a poor country which struggles to provide the basic needs of life to its citizens is not likely to be concerned about effects of environmental quality on conservation in comparison to a wealthier country. Moreover, policies dealing with environmental quality management are broad and dealt with complicated issues, which not only involve technical expertise, but also non-technical issues such as socio-political, environmental, and economic value judgments (Nasiri et al., 2007). Thus, assessment of environmental quality is a multidimensional concept which can be analyzed using wide-ranging techniques under multi-criteria framework.

Therefore, the main aim of this study is to identify the elements of environmental quality evaluation and develop environmental quality map by integrating fuzzy set theory and multi-criteria approaches to evaluate overall environmental quality. This chapter deals with the literature review to provide a general overview of assessment studies on various components of environment viz. surface water, groundwater, air and public perception. This chapter gives initially a brief description of past and present studies pertaining to various indicators in these components. The study reviews briefly the existing studies, which have been developed and applied corresponding to different components of environment. It also outlines the scope and theoretical approaches of the studies. Finally, the chapter is concluded by identifying the research gap. Accordingly, the literature review for above have been presented in three major headings:

- water quality assessment studies which are further classified into surface water and groundwater quality assessment
- air quality assessment, and
- public perceptions on quality of environment.

2.2 Water Quality Assessment Models

The overall quality of water for different beneficial usages have been assessed on the basis of magnitude of various parameters which vary with type of water resources, viz. surface water and groundwater. There are a number of studies which evaluate status of water quality under both surface water and groundwater environments. Some of these studies have been reviewed in following sub-sections:

2.2.1 Surface Water Quality Assessment Models

Water quality of a river has been influenced by various factors such as water and wastewater characteristics, climatic conditions, land use patterns etc. (Fulazzaky et al., 2010; Mandal et al., 2009; Singh et al., 2007; Singh et al., 2015). The tremendous increase in population, rapid urbanization, change in irrigation patterns and unplanned growth of industries without proper enforcement of environmental standards are some of the major reasons for poor quality of water in the river. The situations are getting further aggravated because of uneven, unpredictable and scanty rainfalls, which result in uncertain natural stream flows. Thus there is a lot of uncertainty in prediction of quality of the river water.

In the recent years the increase in the level of water pollution has necessitated some quantitative measures to evaluate water quality. Several techniques have been developed by the researchers to deal with the evaluation of status of water quality by incorporating its physical, chemical, hydrological and biological characteristics (Lee & An, 2014). The concept of Water Quality Index (WQI) has also been introduced for sharing information of water quality status conveniently to all stakeholders (Bhargava, 1983; House and Ellis, 1987; Liou et al., 2004; Singh and Ghosh, 1999; Mourhir et al., 2014; Giri and Singh, 2014). The indices developed by integrating important water quality indicators represent status of water quality in the form of a single score which can easily be communicated to the policy makers and planners. Multivariate statistical techniques have also been used to aggregate quality parameters into an index which allows examination of the effects of municipal and industrial activities, along with various other water pollution precursors (Marchini et al., 2009). The multivariate statistical analysis has also been implemented to identify status of water quality in the Nile river at several locations (Awadallah and Yousry, 2012).

As requirement of standards of water quality depends upon its usage, there would be different acceptable levels and importance weights for each indicator parameter corresponding to a given beneficial use. Several researchers have proposed weighting system for assigning importance weights for each indicator parameter/criteria. Horton (1965) has developed an index number system for assessing water quality status which was later refined by various investigators (Nasiri et al. 2007; Simsek and Gunduz, 2007; Singh et al., 2015). In many traditional methods of indexing of water quality status, the weighted average of all the normalized parameters have been determined which were then multiplied with their respective weights. For example, Avvannavar and Shrihari (2008) have considered important water quality parameters, namely

Coliform, Biochemical Oxygen Demand (BOD), Turbidity, pH, Total Dissolved Solids (TDS), and Dissolved oxygen (DO) at different sampling sites along Netravathi river in South India to develop water quality index (WQI) for drinking purposes. They developed rating curves by taking into consideration of permissible limits of inland waters and its impact on health. Each of these parameters was assigned a weight varying from 0 to 1 such that their total sum becomes 1. They applied WQI method suggested by Bhargava and compared the results using Harmonic Mean WQI method. The results were expressed in a scale of 0 to100 by classifying them into five point rating scale: (i) excellent quality: 91-100 (ii) good quality: 71-90: (iii) fair quality: 51-70 (iv) marginal quality: 41-50 and (v) poor quality: 0-40. Conesa Fernandes–Vitora (1997) have proposed subjective water quality index (WQI_{sub}) which can be expressed by equation (2.1):

$$WQI_{sub} = k\frac{\sum_i C_i P_i}{\sum_i P_i} \tag{2.1}$$

where k is a constant which can be used with increment of 0.25 between the limits of 0.25 to 1.00. The lowest value (0.25) represents highly polluted water whereas 1.0 represents pure water, C_i and P_i are the normalized concentration of i^{th} water quality parameter and its relative weight respectively. The parameters are normalized using curves as suggested in the works of Conesa Fernandes–Vitora (1997). Another indexing system was derived on the basis of representative values of 3 water quality parameters: DO, total phosphorus (TP) and turbidity (T). The normalized values of these parameters were obtained from the curve as suggested by Conesa Fernandes–Vitora (1997) and finally WQI was expressed as the arithmetic mean of normalized values of these three parameters i.e. WQI = (DO+T+TP)/3 (Pesce and Wunderlin, 2000).

Fulazzaky et al. (2010) have applied Water Quality Evaluation System (WQES) to determine the status of water quality and pollutants at some selected sampling sites of river Selangor. They also identified sources of pollution and their remedial measures that should be adopted by the local authority. Although, for the last four decades, water quality has been widely assessed under different climatic conditions and locations, some of the primary drawbacks of these studies are non-availability and reliability of field data pertaining to quality status, standard, usage, and its impact on public health. The importance weights assigned to different water quality parameters are also selected arbitrarily (House and Ellis, 1987; Singh et al., 2012). Traditionally, a number of uncertainties have also not been incorporated in WQI system. It is therefore needed to seek a comprehensive approach to incorporate uncertainty aspects of water quality measurement, modeling, prediction, simulation, optimization and imprecise knowledge of interrelationships between pollutant dischargers and river bodies (Canelas et al., 2005; Cibin et al., 2014; Dojlido et al., 1994; House and Ellis, 1987; Karr, 1991; Singh and Ghosh, 2003; Suvarna and Somashekar, 1997; Tappeiner et al., 2007). Also, uncertainty associated with personal preferences and linguistic judgments of subject experts and decision makers lead to impreciseness of the evaluation process.

Thus the information collected from different sources with respect to these aspects is required to be combined to derive an overall integrated value so that quality attributes can be expressed effectively under multiple-usage framework which is missing in fixed crisp weighing system. The growth in technology has aided to understand the importance of integrating water quality variables for developing a comprehensive water quality index. Artificial intelligence techniques have been applied as a tool to develop water quality index by several researchers (Chau, 2006; Green et al., 2014; Mostafaei, 2014). Application of fuzzy logic concepts is one such example of use of artificial intelligence which can be used to incorporate certain features of classification and quantification on indexing system of water quality so that uncertainty associated with impreciseness can be treated (Klir and Yuan, 1995; Ross, 2008; Sakawa, 1993; Zadeh, 1965; Zadeh, 1978).

The qualitative measure of water quality parameters/indicators can be represented by fuzzy sets to incorporate uncertainty associated with impreciseness. These fuzzy sets can be expressed mathematically using several techniques. They are fuzzy arithmetical analysis (Kaufman and Gupta 1991; Singh et al., 2015), fuzzy rule-based mathematical modeling (Ba´rdossy and Duckstein 1995), or fuzzy multi-criteria approaches for preferences and ranking orders (Chen and Chang 2000; Singh and Vidyarthi 2008; Singh, 2008; Singh and Dubey 2012; Singh et al., 2015; Wang, 2002). For example, Singh (2008) has clearly demonstrated the application of fuzzy set theory for assessing potential for water resource development and its impact in Chittorgarh district of Rajasthan, India. The advantages of using fuzzy methods have also been described by other researchers (Lermontov et al. 2009; Nasiri et al. 2007; Singh et al. 2007; Urbanski 1999; Zou et al. 2006).

Tzeng and Tsaur (2002) have analyzed environmental quality of Taipei city using a two-stage model with the application of multi-criteria techniques. The first stage deals with the evaluation of indices for environmental quality on the basis of perception of residents whereas second stage uses the indices derived from the first stage to formulate the suitable criteria and improved strategy for environmental quality for the city. Singh et al. (2015) have developed a fuzzy multi-criteria framework for evaluating status of water quality. They have introduced a mechanism for prioritizing sampling stations corresponding to five important uses of water, namely, domestic, irrigation, industrial, aquatic life, and recreational activities.

Silvert (2000) has applied concepts of fuzzy logic to derive environmental indices for classifying ecological conditions and impacts of pollutants. Wenger and Rong (1987) has developed fuzzy based model suggesting alternative solutions to environmental problems. Smith (1992) presented a discrete transportation model for recognizing uncertainty. Oh and Jeong (2002) have evaluated urban resident environmental quality using fuzzy set approach. Other researchers have also applied fuzzy methods (Burrough and Macmillan, 1992; Baja and Chapman, 2002; Ceballos-Silva and Lopez-Blanco, 2003). However, the fuzzy approach in environmental quality assessment is still having a lot of potential to apply.

Wu et al. (2007) developed a fuzzy based model to derive status of water quality in Hunhe river for 9 years starting from 1996 to 2004, which clearly demonstrates how water quality was degraded with increase in organic pollutants, oil and ammonia. Cheng et al (2007) studied the status of heavy metal contamination on agricultural soils in Zhejiang Province, China. They demonstrated how quality of environment in tea soils was better than soils under other cropping environment such as vegetable, fruit and paddy. They have shown that integration of GIS with multivariate statistical techniques can effectively map status of soil contamination at provincial scale.

However, it is felt that still there is a tremendous scope to apply these techniques to develop water quality indices using field data for assessing overall quality of water especially in Indian context.

2.2.2 Groundwater Quality Assessment Models

The measurement of the groundwater quality parameters has always been important in the area of environmental management. There are various methods which can analyze different groundwater quality parameters. The groundwater quality indices are developed to integrate/represent effects of important environmental indicators into a single value which can represent one of the possible grades of quality of water viz., very poor, poor, fair, good or excellent (Fulazzaky 2009; Mitchell and Stapp, 2000; Resource Management Plan, 2002). Researchers have also emphasized application of fundamentals of hydrochemistry in assessing the ground water quality (Brown et al., 1970; Debels et al., 2005; Latha and Rao, 2012; Rosemond et al., 2009; Srinivas et al., 2013; Tiwari and Mishra, 1985). Ramakrishnaiah et al. (2009) used ground water quality index as a tool to assess the suitability of ground water of Tumkur, Karnataka, India for human consumption.

A number of studies related to water quality assessment exist in the literatures which determine the quality of groundwater and its suitability for different beneficial uses such as drinking, irrigation, or industrial needs. Batheja et al. (2007) studied physico-chemical characteristics of groundwater especially TDS, EC and major ions (calcium, magnesium, nitrate, fluoride, sodium and potassium) in Churu district of Rajasthan, India. They revealed that observed value of TDS concentration is 1500 mg/l or so which is beyond the maximum limit as prescribed by Indian Council of Medical Research (ICMR) and therefore most of the water samples were non potable for human consumption in this region.

Muhamed and Mukundan (2007) evaluated status of water quality at four stations located in Ernakulam District of Kerala state in India which falls under Periyar river Basin. They found that calcium and magnesium were present in excess during the summer season though Cu, Fe, Mn, and Zn are found well below the maximum permissible limits and were detected occasionally. Mercury and lead were detected in only in the months of January and March at Kanakkandavu. Authors concluded that the growing demands of drinking water for Cochin city can be fulfilled using groundwater sources available in the region.

Bangar et al. (2008) have carried out studies on assessing suitability of groundwater irrigation in Ujjain District of Madhya Pradesh, India. Out of 712 samples, 105, 144, 150, 84, 68, 111 and 50 samples belong to Ujjain, Mahidpur, Khachrod, Tarana, Barnagar, Nagda and Ghatia tehsils of the district respectively. 80% samples indicated good water quality, whereas 14% samples were found saline (9%: marginally saline (B1), 4%: saline (B2), 1%: high SAR saline (B3)) and 6% samples were alkali (5%: marginally alkali (C1), and 1%: alkali (C2)) categories as a whole in the district. The samples belonging to 'good quality category were mainly Ca-Na-Mg type with the high concentration of chloride followed by HCO_3^- and CO_3^- whereas poor quality waters were either having salts with higher electrical conductivity (EC) or high residual sodium carbonate (RSC) and sodium adsorption ratio (SAR). A high value of negative correlation coefficient was also observed between pH and SO_4^-. The sodium content showed significant positive correlation with EC.

Hakim et al. (2009) studied the suitability of groundwater for drinking, irrigation and industrial purposes in 28 wells located at 28 villages of Chiribandar region in Dinajpur district, Bangladesh during February-April 2006. The groundwater samples were analyzed for several water quality parameters. The results revealed that concentration of cation and anion constituents of groundwater in the study area were suitable for irrigation, drinking and industrial purposes. Saeedi et al. (2010) used the GWQI to identify the places with best drinking water quality in the Qazvin Province, West Central Iran. Sharma and Patel (2010) developed WQI to determine pollution potential of ground water of Surat City, India. Reza and Singh (2010) used the water quality index technique to evaluate the potability of ground water in Angul-Talcher area, Orissa, India. Banerjee and Srivastava (2010; 2011) studied impacts of industrial activities on groundwater quality in Pantnagar using air and water quality indices.

Vyas (2011) has assessed quality of drinking water in Gandhinagar city, Guiarat, India. For the analysis of groundwater, eighty-four samples were taken from taps located in different areas of the town during the period April 2006 to March 2007. Water samples were analyzed for pH, conductivity, Turbidity, Dissolved oxygen, TDS, Calcium, Magnesium, Total alkalinity, Chloride, Sulphate, Total Hardness, Nitrate, Iron, Fluoride and Arsenic. The analyzed data was compared with BIS and WHO standards. From the results, it was found that the physico-chemical parameters were well within the maximum permissible limit of drinking water standards. However, low fluoride content (mean 0.6 mg/l) was observed in all groundwater samples and high iron content (mean 0.45 mg/l) in 13% of the samples. The study also revealed that groundwater of area is very hard and is dominated by carbonate and bicarbonate anion with calcium and magnesium cations.

Ananthakrishnan et al. (2012) studied the groundwater quality in Alathur block-Perambalur district for suitability of drinking water. The study was conducted over ten villages in Perambalur district, Tamilnadu. They analysed water quality parameters such as pH, TDS, EC, TH, Total Alkalinity, Sulphate, Chloride, Nitrate, Calcium and Magnesium during pre monsoon, monsoon and post monsoon. From the results, it was revealed that most of the parameters in all three seasons were in excess of the desirable limit prescribed by WHO and ICMR standards.

The knowledge of hydrochemistry is essential to determine quality of ground water (Srinivas et al., 2013). Shi et al. (2013) analyzed the suitability of groundwater in deep aquifers in Jiaozuo city of north China. They compared the concentration of hydro-chemical parameters with prescribed standard values for various purposes by developing variable fuzzy set (VFS). They have presented a case study wherein the spatial distribution of GQI has been demonstrated in the form of maps for varying purposes.

Some of the authors have analyzed temporal variation of quality of groundwater by combining fundamentals of WQI with the geographical information systems (GIS). These approaches have been used to formulate water quality indices. GIS has been found to be a very useful technique for representing various hydro-chemical parameters spatially. GIS has also been used to represent variation of groundwater quality in industrial and agricultural regions by many other researchers (Anbazhagan and Archana, 2004; Goyal et al., 2010; Hong-Il and Hyo-Taek, 1999; Ketata et al., 2012; Singh and Lawrence, 2007; Singh et al., 2013).

Yidana and Yidana (2010) have developed WQI and applied multivariate analysis technique to assess status of groundwater from the southern Voltaian region for drinking purposes. Adhikari et al. (2013) and Stigter et al. (2006a, 2006b) have also applied concept of groundwater quality indices to evaluate impact of agricultural activities on several key parameters of groundwater. They have also correlated the recharge with discharge zones of groundwater.

There have been various other important attempts to estimate status of groundwater quality for drinking, agriculture and industrial purposes (Jalali and Merrikhpour, 2007; Goyal et al., 2010; Singh et al., 2012). The WQI was established to evaluate groundwater quality using the fuzzy set theory (Muhammetoglu and Yardimci, 2006), the Bhargava method (Avvannavar and Shrihari, 2008), the multivariate analysis (Stigter et al., 2006a, 2006b; Yidana and Yidana, 2010) and the probabilistic neural networks (Nikoo et al., 2011).

Srinivas et al., (2015) have developed a fuzzy inference tool for estimating status of groundwater quality in Bikaner district in Rajasthan. 11 water quality parameters have been analyzed to determine water quality characteristics in 15 groundwater wells. All 15 wells were ranked corresponding to fuzzy inference score obtained for both drinking and irrigation uses.

Although a wide spectrum of literature is available as cited above, it is essential to perform groundwater quality assessment in Indian context especially in north-eastern region of the country. A timely study of groundwater quality assessment will not only essential but instrumental in taking appropriate remedial action plans for improving the quality, especially handling uncertainty components under different circumstances. So, research is still required with an integrated approach of interpreting quality of groundwater especially in context to north-eastern part of India.

Keeping in view of above facts, it is felt to develop a methodology for assessment of status of groundwater quality in the north-eastern region of the country along Haora River. GWQI has been derived initially using Simple Additive Weighting (SAW) method which has later been compared with another method based on fuzzy set theory. In addition, the polluting parameters at each selected station have also been analyzed using GIS.

2.3 Air Quality Assessment Models

Air is very essential for the survival of all forms of life on earth. Everyone of us likes to breathe fresh and clean air. However, the atmosphere is highly susceptible to pollution from human activities. Air quality assessment has been a difficult task for environmental engineers as it requires assessment of several pollutants emerged from different energy and industrial processes. A number of monitoring programs have been undertaken in the past throughout the world to estimate air quality using data on concentration of various air pollutants (Daly and Zannetti, 2007).

Presently air quality is evaluated by comparing monitored values with respect to a prescribed set of standard (CPCB, 2000; Nagendra et al., 2007). Often, it becomes difficult to fit the prescribed set of standards into a reference scale (Banerjee and Srivastava, 2011). Environmental quality has been classified in the form of qualitative terms by comparing actual measured values with upper threshold value of the prescribed standard (Dee et al. 1973; Singh, 2006). The concept of Air Quality Index (AQI) has been introduced by many researchers across the world to evaluate severity of air pollution in terms of a set of certain air quality parameters (Banerjee and Srivastava, 2009; EPA, 1998; Sharma et al., 2003). Ambient air quality has been assessed using a piecewise linear function using maximum operator and AQI can be expressed to demonstrate temporal variations (Banerjee and Srivastava, 2010; Sharma et al., 2003). The piecewise linear functions are essentially based on National Ambient Air Quality Standard (NAAQS) and risks associated with potential health hazards (Balakrishnan, et al., 2014).

Inhaber (1975) had formulated the structure of Canadian air quality assessment by deriving indices under three main categories, namely (i) index due to specific pollutants in large urban areas, (ii) index of inter-urban air quality at certain locations away from center of urban cities but around urban areas (e.g. airports) and (iii) index of industrial emissions for assessing the impact of emissions of specific pollutants on surrounding environment. Environmental Protection Agency of United States (US EPA) has established Pollution Standards Index (PSI) by which air quality is rated in the range from 0 to 500 as per National Ambient Air Quality Standards (NAAQS) (Ott and Hunt, 1976; Khanna, 2000). The daily PSI is determined for each of the five criteria pollutants viz. carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulates (PM_{10}) and sulfur dioxide (SO_2) and by the highest value of one of these five main air pollutants (EPA, 1994).

Lohani (1984) applied an approach using factor analysis to assess air quality in Taipei city of Taiwan which was compared with Pindex method. Bezuglaya et al. (1993) derived an Integral Air Pollution Index (IAPI) which was evaluated by adding air pollution index (normalized pollution concentrations with maximum permissible concentration) of each parameter. The USEPA, in 1999, has modified earlier method to calculate daily AQI. The concentration values are converted into numerical indexes. The overall AQI at a sampling station is determined by taking the maximum AQI among all monitored criteria pollutants. The overall AQI evaluated in the range from 0 to 500 is classified further into six categories depending upon magnitude of potential health risks due to air pollution.

Cheng et al. (2007) suggested a revised EPA air quality index (RAQI) which includes by introducing an entropy function to incorporate impact of remaining pollutants other than the pollutant with maximum AQI. RAQI has clearly showed that the suspended particulates have significantly greater impact on $PM_{2.5}/PM_{10}$ ratio in southern parts than central and northern area of Taiwan. Kassomenos et al. (1999) have assessed urban pollution scenario using uniform indexing scale for air quality indicators of atmospheric pollution in Athens, Greece. Air quality indexes have also been dealt to represent variation of air quality by many other researchers (Bortnick et al., 2002; Cogliani 2001; Elshout et al., 2008; Elshout et. al., 2014; Murena 2004; Jiang et al., 2004; Khanna 2000; Landulfo et al., 2007; Longhurst 2005; Mayer and Kalberlah, 2008; Swamee and Tyagi, 1990; Xu et al., 2014; Sun 2014).

In Indian context, the AQIs have been developed for Chennai (Ravinder et al., 2014), Delhi (Sengupta et al., 2000), Kanpur (Sharma et al., 2003) and Mumbai (Sharma, 1999). These indexes are derived on the basis of exposure of pollutants and its impact on health as defined by USEPA and Indian air quality standards. In the same study, Sengupta et al. (2000) determined quality of air using additive function of sub-indexes for Delhi. However, the main drawback of this approach was its eclipsing effect on index. It was also revealed that overall air quality falls under acceptable limits in spite of violation of air quality standard of some pollutants. The Maximum Operator Concept (MOC) proposed by USEPA has been applied by considering the maximum value of any of the sub-indexes to define the overall AQI suggested (Bishoi et al., 2009). In this method the values of lower sub-indexes derived from other pollutants are discarded which is one of the limitations (Radojevic and Hassan, 1999). This is mainly due to the fact that additive or synergistic effects of pollutants on the human health are generally excluded while deriving index value. Moreover, the break points used for evaluation of air quality indices are also not defined by USEPA when NO_2 concentrations are less than 0.65 ppm. Another important point is that AQI evaluation system proposed by USEPA is not usable presently in several parts of the world due to non-availability of $PM_{2.5}$ concentration (Cheng et al., 2007). The ordinal scale used to describe the pollution level of the pollutant in the form of sub-index has also been used to define overall aggregate index though the severity of the pollution level described by the aggregate index is not linear with sub-index scores.

Once quality of air is assessed, important management issues can be addressed to combat serious threat occurring to the public health (Dholakia et al., 2014; British Medical Association, 2014). Analysis can also be performed among the tradeoffs in finding alternative solution for air pollution control and formulating appropriate policies or the improving performances of equipment to reduce emission of pollutants (Davies and Mazurek, 2014; Morgenstern, 2014).

In this study, AQI has been estimated along Haora river using two methods, namely modified EPA method and the Fuzzy Comprehensive Assessment Method. Samples are collected from the air after pollutants from the various sources have been thoroughly dispersed and mixed together under natural meteorological conditions. The study will serve as a basis for assessing which precautionary steps require to be addressed if air pollution levels rise beyond the prescribed standards.

2.4 Public Perceptions Models

Public perceptions have also been observed in specifying temporal and spatial variations of the environment, especially in context of physical and social environment in their respective neighborhoods (Grimm et al., 2000; Sampson et al., 2002; Mahler et al., 2005; Tuan, 2013; Boudet et al., 2014; Liang et al., 2014; Chang et al., 2014). Such perception study can provide valuable quantitative information on the changes in the environmental attributes over time. It helps to understand how and why environmental quality is degrading and what are the solutions for enhancing quality of environment, and how and why these solutions are likely to influence/evolve in the future (Viscusi and Huber, 2000; James et al., 2003; Marans, 2003; Flanagan et al., 2007; Dhakal, 2010).

2.5 Existing Research Gap

It is clear from the above literature review that many research studies have been conducted to deal with the data analysis, modeling and prediction of environmental quality. However, very few field studies have been reported wherein fuzzy uncertainty, multidimensional and spatial characteristics of environmental phenomenon have been incorporated to evaluate environmental quality on a regional basis. Moreover, these studies have faced serious problems of aggregating information obtained from various sources.

It is therefore essential to perform assessment of quality of surface water, groundwater and air in Indian context especially in north-eastern region of the country which lacks such information. A timely study of assessment of quality of various components of environment, viz. surface water, groundwater and air will not only essential but instrumental in taking appropriate remedial action plans for improving the quality of environment for sustainable development of the region. New sources of information and new principles developed provide exciting opportunities to work on methodology which can interrelate concepts of fuzzy set theory with available MCDM techniques for environmental quality evaluation so that cumulative impacts on a regional basis can be studied. It should act as a building block for taking decisions on environmental quality management, which is lacking at present in Indian Case studies. By using data on pollution in surface water, groundwater, air, one can be able to identify critical component which may be vulnerable.

As discussed above, several techniques have been proposed over the years, to incorporate complex issues of environmental planning and management. There are various alternative plans and solution techniques available in the literature which can be applied for each environmental category, be it air (Rachdawong and Christensen, 1997; Statherropoulos et al., 1998; Yu and Chang, 2000), water (Dougherty et al., 2006; Topalian et al., 1999; Singh et al., 2015), soil (Jay and Handley, 2001) and revealing the relationships among different indicators, which is closely related to a particular environmental condition (Calais et al., 1996; Chen et al., 2009; Chinag and Lai, 2002; Lehr et al., 2002, Tran et al., 2004). The environmental quality index can be used to analyze various alternative plans available for appropriate solution.

The interpretation of environmental quality has also been made either by objective way (Odemerho and Chokor, 1991) or more on subjective way used in socio-psychological term (Sinclair and Diduck, 2005; Wegner et al., 2005). In objective way of analysis, opinion of professionals/subject experts working on environment field has been taken into consideration whereas in subjective way of analysis perception on environmental quality of the general public/residents who have no clue on complex mathematical model of environmental quality evaluation, have been considered.

The growth in technology has aided to understand the importance of integrating water quality variables for developing a comprehensive indexing system. However, the main challenge is to deal with uncertainty associated with various aspects of water quality measurement, modeling, prediction, simulation, optimization and imprecise knowledge of interrelationships between pollutant dischargers and river bodies.

It is therefore needed to seek a comprehensive approach to incorporate uncertainty aspects of water quality measurement, modeling, prediction, simulation, optimization and imprecise knowledge of interrelationships between pollutant dischargers and river bodies and other environmental components (Baja and Chapman, 2002; Burrough and Macmillan, 1992; Canelas et al., 2005; Cibin et al., 2014; Dojlido et al., 1994; House and Ellis, 1987; Karr, 1991; Leung and Leung, 1993a & 1993b; Singh and Ghosh, 2003; Suvarna and Somashekar, 1997; Tappeiner et al., 2007). Also, uncertainty associated with personal preferences and linguistic judgments of subject experts and decision makers lead to impreciseness of the evaluation process.

Moreover, the requirement of standards of water quality depends upon its usage which requires different acceptable levels and importance weights for each indicator parameter corresponding to a given beneficial use. Therefore the research is still needed to explore an integrated approach for assessing quality of environment by incorporating uncertainty component along with all important information so that uncertainties can be handled effectively, if they can be formulated under multi-criteria framework. The concept of fuzzy sets theory should be applied in this very important area of study in a consistent manner. Thus, there is a plenty of scope to deal environmental quality as a multidimensional, multi-criteria, concept with different kinds of uncertainty for its comprehensive evaluation.

2.6 Summary

Many researchers have shown effectiveness of fuzzy set theory to deal uncertainty in the evaluation of both temporal and spatial distribution of environmental quality. It has become evident to incorporate uncertainty under multidimensional framework of environmental phenomenon in present day context. An application of fuzzy set theory combined with GIS has also become important especially when planning strategies are to be formulated by satisfying requirement of chemical, economical, environmental, physical, social, and technical constraints. At present, the application of fuzzy set theory and GIS under multi-criteria framework has not been explored efficiently especially in context to environmental quality evaluation in north-eastern region of the country. Thus there is a need to perform adequate applied research in this field.

The investigations described in this literature review show that there is accelerated pace of research into environmental quality evaluation methods. The certain key findings of recent research include that (1) there is need to develop a framework of improved problem formulation and solution techniques for assessing quality of different components of environment, (2) methodology should be developed that can link/integrate various parameters in an effective manner.

Therefore, this prompts further investigation of environmental quality assessment along Haora river located in north-eastern part of the country with respect to following aspects:

- To present a systematic framework for environmental quality assessment and compare various assessment models used in this area.
- To know the status of surface water quality along Haora river so that water pollution in the river can be assessed and proper water pollution reduction strategies can be suggested.
- To know the status of groundwater quality at some sampling sites along Haora river so that quality can be assessed to take remedial actions plans for its sustainable management if necessary.
- To know the status of air quality in the selected region along Haora river so that quality status can be assessed to take remedial actions plans.
- To develop a fuzzy comprehensive model to assess the quality of air, surface water and groundwater along Haora river based on the monitoring data and Indian Environmental Quality Standards. This is needed to adopt a scientific approach for evaluating urban environmental quality by incorporating concepts of multi-criteria evaluation method and Fuzzy Set Theory.
- To put more emphasis on the scale of urban neighborhood, the physical or socio-cultural quality of the environment while evaluating overall quality of environment in the region by investigating environmental quality of neighborhood of Agartala city through the interviews of the households.

CHAPTER 3

SURFACE WATER QUALITY ASESSMENT IN HAORA RIVER BASIN

3.1 Introduction

Water is essential for sustaining ecological processes that support human survival, aquatic lives, vegetation, wetlands, wildlife, birdlife and so on. Also it is needed for the development of human beings and is used for agricultural production, domestic and municipal uses, industrial and manufacturing processes, hydroelectric power generation, recreation, navigation, low flow augmentation, enhancement of fish and wildlife, drinking and personal hygiene, and a variety of other purposes. The unplanned and uneconomical utilization of water and non-adherence to basic environmental norms have led to emerging water problems due to depletion in water quantity and deterioration in water quality. While over-exploitation of groundwater has become a serious problem for many Indian states, river waters are also getting increasingly polluted and are being utilized inefficiently.

Water quality of a river has been influenced by various factors such as water and wastewater characteristics, climatic conditions, land use patterns etc as explained in Chapter 2. A large number of researchers have integrated different water quality parameters and successfully developed indices for different beneficial uses. These indices are defined with different weights and rating systems for different types of water uses.

Horton (1965) has developed an index number system for assessing water quality status which was later refined by U.S Sanitation Foundation. In many traditional methods of indexing of water quality status, the weighted average of all the normalized parameters have been determined which were then multiplied with their respective weights (Avvannavar and Shrihari, 2008; Bhargava, 1983; Suvarna and Somashekar, 1997).

Some of the primary drawbacks of these studies are non-availability and reliability of field data pertaining to quality status, standard, vague information on water usage, and pollutants impact on public health. The importance weights assigned to different water quality parameters are also selected arbitrarily. The development of new techniques such as artificial intelligence, in recent years, has aided in improving the quantification of comprehensive water quality index (Chau, 2006; Green et al., 2014; Mostafaei, 2014).

Application of fuzzy logic concepts is one such example of use of artificial intelligence which has been used to incorporate certain features of classification and quantification on indexing system of water quality so that uncertainty associated with impreciseness can be treated. Though the advantages of using fuzzy methods have also been explained by many other researchers as explained in Chapter 2, it is felt that still there is a tremendous scope to apply these techniques to develop water quality indices using field data for assessing overall quality of water especially in Indian context.

In this chapter two methods have been applied to evaluate surface water quality conditions at different sampling sites of river Haora, viz. (i) Simple Additive Weighting (SAW) and (ii) Fuzzy Comprehensive Method. In simple additive weighting method, the decision maker (DM) specify weights of all water quality parameters on the basis of their relative importance's and a new objective function is constructed by deriving weighted average of the evaluation values corresponding to the different water quality parameters. In fuzzy comprehensive method, uncertainty aspects of water quality parameters due to measurement, prediction and management of these parameters are incorporated by combining all the information collected from different sources and can derive an overall integrated value. The uncertainty associated with water quality management due to random nature of hydrologic variables, impreciseness in flow data, climatic conditions, river characteristics, pollution control and error in measurement and/or modeling can also be incorporated. Total eight water quality parameters namely, 5 days Biochemical Oxygen Demand (BOD_5), pH, Dissolved oxygen (DO), Nitrates, Phosphates, Total Coliform (TC), Total Dissolved Solids (TDS), Temperature were measured at chosen sampling sites along Haora river to derive water quality indices in terms of both Surface Water Quality Index (SWQI) based on Simple Additive Weighting (SAW) and Fuzzy Comprehensive Water Quality Index (FCWQI).

Finally, sensitivity analysis has been performed to understand the stability of the indices, which in turn facilitates to identify the parameters, the quality of which is to be changed and by what extent to improve the overall quality of water.

The methodology presented herein clearly demonstrates the credibility and superiority of the fuzzy comprehensive method as compared to the simple additive weighting method to obtain water quality index by incorporating indicators' uncertainties arising during the quality evaluation process which not addressed in the traditional methods of indexing such as SAW.

3.2 Description of Haora River Basin

Haora river is one of the major rivers in North-Eastern region of India. It is fulfilling major requirement of drinking water and other usages for entire population of Agartala, the capital of Tripura besides fulfilling the demand of water of local population residing near both the banks of the river in the state. The river originates from the ranges of Baramura hill in West Tripura district which flows 53 kilometers in the Indian Territory from east to west through alluvial plains along Chandrasadhubari, Champak Nagar, Debendranagar, Jirania, Ranirbazar, and Pratapgarh and enters into Agartala city before finally flowing down into Bangladesh and met river Titas. This has a basin area of 570 km^2 with annual flow as 36,032 m^3. To meet the demand of water for the communities the Drinking Water and Sanitation Department (DWS) and Agartala Municipal Corporation (AMC) draw water from the river by means of intake wells situated near Ranirbazar, Jogendranagar and Bardowali and another intake well is under construction at Jirania. Though the river Haora has been one of the prominent rivers in the state and the water drawn from it, is extensively used for irrigation, domestic and drinking water supply purposes, the quality is highly influenced by the pollution problems imparted by urbanization and the dumping of human excreta, domestic sewage and the disposition of industrial effluent directly into the river. At present, more than 3500 families/inhabitants are residing on both sides of the river bank of Haora and most of them are very poor. These inhabitants have constructed unconventional and cheap latrines where the excreta are simply allowed to flow directly into the river.

The Haora river basin is situated between the latitudes of 23˚37′ N and 23˚53′ N and longitudes of 91˚15′E and 91˚37′ E. It has 1106 first order streams, 176 second order streams, 47 third order streams, 21 fourth order streams with total basin area of about 457.97km^2. The river Haora is a fifth order stream as described in Figure 3.1**.**

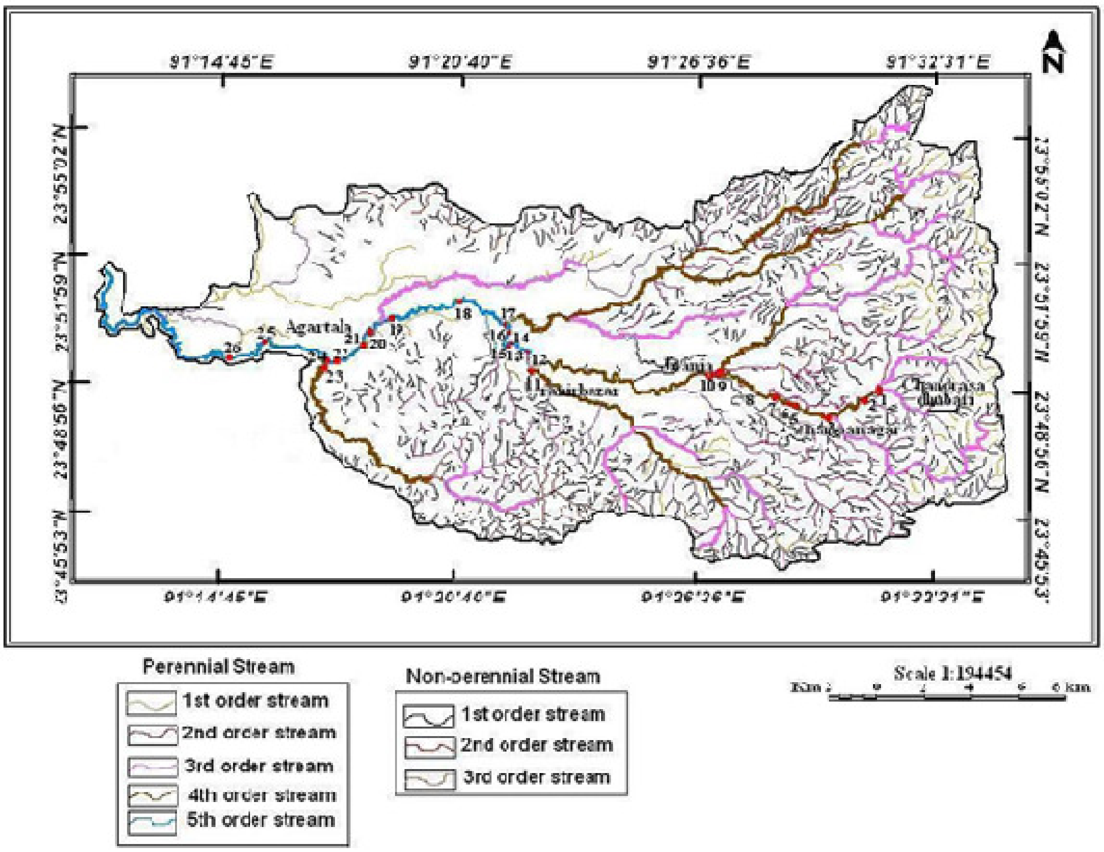

Fig 3.1: Stream order map of Haora River

Out of 1106 first order streams mentioned above, 83 streams are perennial having a total length of about 81.755 km. These 83 perennial first order streams are the main source of water of the whole basin during lean period. Very little amount of water is recharged along its way in the lower course but most of them are dirty and sediment rich. There is no alternate source of water by which the river is being recharged except a few municipal drains in downstream. Some amount of water is also lost through evaporation and human extraction. A brief scenario of perennial and non perennial streams of Haora river basin is given in Table 3.1.

Table 3.1: Number, length and condition of streams of different orders

Stream Order	Non-perennial		Perennial	
	Number of streams	Total length (km)	Number of streams	Total length (km)
1st order	1023	548.836	83	81.755
2nd order	134	195.664	42	77.580
3rd order	18	27.716	29	97.424
4th order	--	--	21	10.847
5th order	--	--	1	33.147
	Total	772.215	Total	300.753

3.3 Methodology

Assessment of water quality in a river basin involves a complicated process dealing with biological, chemical, physical and hydrological characteristics of water and wastewater. The requirement of water quality changes from one particular use to another. For example- water should be free from impurities, wholesome, and potable for drinking purposes. Similarly, dissolved solids and toxicants are important for irrigation purpose. Pathogens are critical in case of outdoor bathing. The linguistic concept or feeling of how pure is pure or how potable is potable or how critical is critical make the problem even more complicated. This is because the quantification of such statements is difficult. There are no clear boundaries to classify these objectives. The uncertainty due to vagueness can be dealt using the concept fuzzy logic for better planning and management of water quality in a river.

Therefore, this study attempts to integrate the effect of a number of important water quality indicators into a single water quality index using two methods namely, Simple Additive Weighting (SAW) and Fuzzy Comprehensive Analysis. These two methods develop a WQI score in terms of SWQI and FCWQI respectively for a particular usage (e.g. public water supply, municipal uses etc). These indices clearly describe the overall state of the water quality by a single rational number. This number would be useful in taking decisions for formulating and implementing policies by the policy makers and planners. These are discussed under following subsections.

3.3.1 Surface Water Quality Index using Simple Additive Weighting Method

3.3.1.1 Surface Water Quality Index formulation

The Simple Additive Weighting (SAW) Method has been applied to calculate SWQI at particular sampling station, which can be defined as the composite index calculated by taking into consideration of various water quality parameters. Mathematically it is given in equation (3.1):

$$\mathrm{SWQI} = \sum_{i=1}^{n} \frac{w_i q_i}{w_i} \qquad (3.1)$$

where, n is number of parameters (attributes) that define the overall SWQI, q_i is the rating score corresponding to i^{th} water quality parameter (attribute) at a given sampling station based on actual measured values and w_i is the importance weight assigned to i^{th} water quality parameter. If the scale for weight assigned to different water quality parameters is such that $\sum_{i=1}^{n} w_i = 1$, the SWQI can be expressed as given in equation (3.2):

$$\mathrm{SWQI} = \sum_{i=1}^{n} w_i q_i \qquad (3.2)$$

In equation (3.2), w_i is the importance weight assigned to any water quality parameter (i) and q_i is the quality rating of the water quality parameter (i). An overall score of SWQI at a given sampling station can be estimated if the rating corresponding to all the parameters can be normalized on the same scale which is explained in subsequent sections. The complete methodology adopted in evaluating SWQI is explained with the flow-chart given in Figure 3.2. All steps proposed in Figure 3.2 are explained under the paragraphs from 3.3.1.2 to 3.3.1.4.

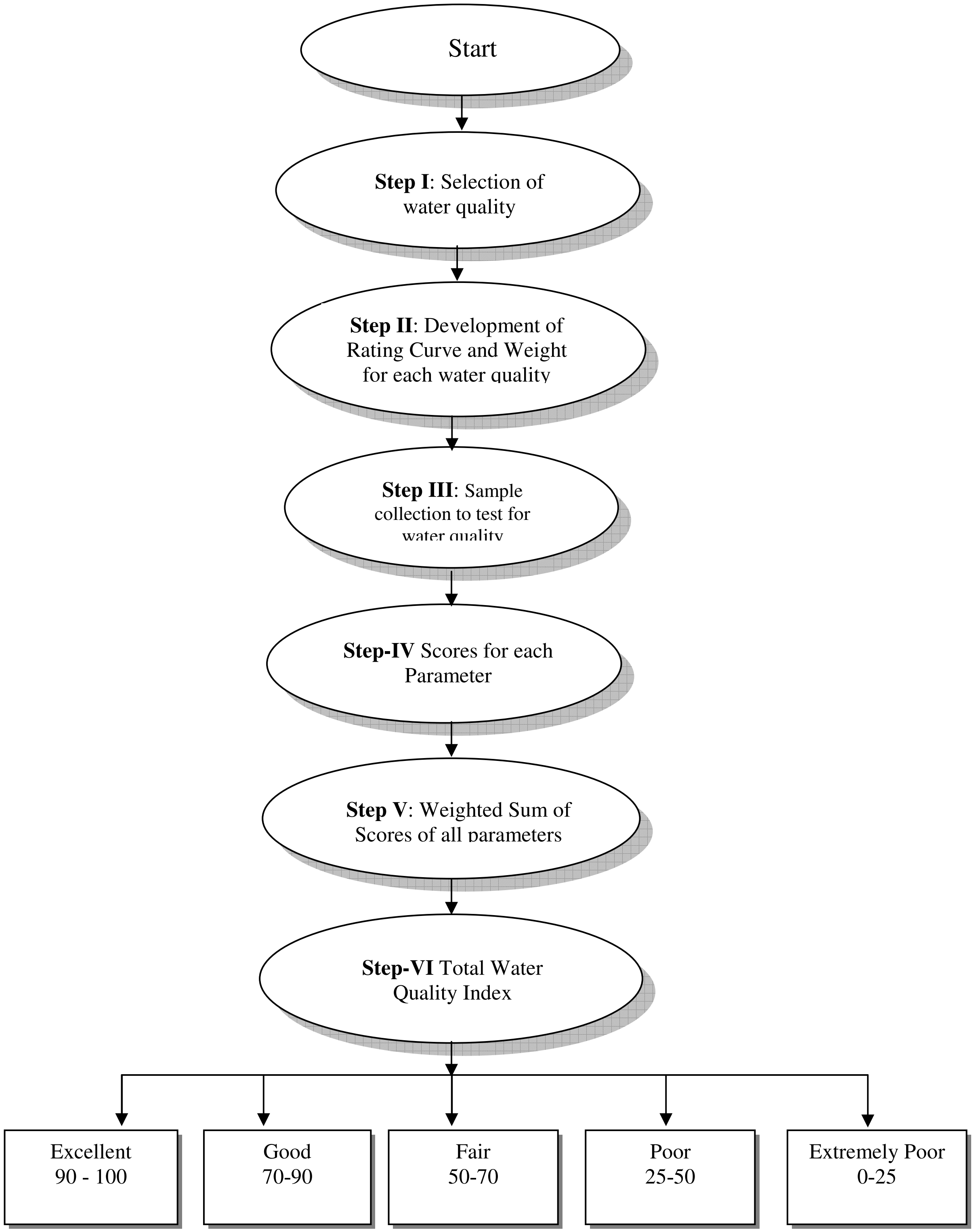

Figure 3.2: Flow chart showing the calculation of Water Quality Index

3.3.1.2 Selection of Water Quality Parameters

Water quality characteristics can be analyzed by measuring physical, chemical and biological parameters and comparing them with their standards as prescribed by the central pollution control board. A set of given parameters may be important for a particular beneficial use whereas it is not necessary that the same sets of parameters are equally important for another beneficial use. The selection of parameters for water quality assessment is an important task which is dependent on water quality characteristics of receiving body and its hydraulic behavior, wastewater characteristics which is discharged into the receiving water body, and best-designated uses of water.

The water samples were collected from ten different locations along river Haora in March–April 2010 and tested for 19 water quality parameters. The important parameters are 5-Days Biochemical Oxygen Demand (BOD_5), pH, Dissolved oxygen (DO), Nitrates, Phosphates Temperature, Total Coliform (TC) and Total Dissolved Solids (TDS). In addition to these parameters, 11 water quality parameters were also measured but were found of very low concentration and of less significance from analysis point of view. These are Total Suspended Solids, Colour, Turbidity, Alkalinity, Calcium, Magnesium, Chemical Oxygen Demand (COD), Hardness, Nitrite and Ammoniacal Nitrogen. All 8 important parameters which have been selected to determine status of water quality are described below:

Dissolved Oxygen (DO)

Aquatic organisms need oxygen for their survival. When water comes in contact with air, oxygen is dissolved in the water due to reaeration process. This is consumed by the aquatic organisms through breathing. If there is deficiency of dissolved oxygen, aquatic organisms will not survive.

In the absence of organic matter, Dissolved Oxygen (DO) concentration is very high. However, when organic matter is disposed into river water, it is decomposed which reduces DO concentration in the water. It has been observed that warmer water holds less oxygen than cold water. In fact dissolved oxygen is the measure of water quality of river which is decreasing due to decomposition of organic wastes present in the river water. It changes with temperature of water. If water is warm, it has less oxygen than if it is cold.

Total Coliform (TC)

Total coliform is a an bacterial indicator of sanitary quality of food and water which are majorly found in the feces of warm-blooded animals, but can also be found in the aquatic environment, in soil and vegetation. Coliforms are responsible to cause many nosocomial illnesses. The prescribed tolerable limit of concentration of Total coliform is 500 MPN/100ml.

Biochemical Oxygen Demand (BOD)

During the process of decomposition of organic matter in water, microorganisms consume oxygen. The consumption of oxygen by the microorganisms is known as Biochemical Oxygen Demand (BOD). More oxygen is used for harder work of microorganisms and as a result BOD increases leaving less oxygen for other aquatic life in the water.

Due to rapid depletion of oxygen in rivers and streams, the value of BOD increases which indicates less oxygen is available for other aquatic life like insects and fish. Both high BOD and low dissolved oxygen harm stream health in the same ways because in such situations aquatic organisms become stressed, suffocate and die, only few organisms like carp and sewage worms which can survive with less oxygen will increase in number.

If more organic mattes like leaves and woody debris; dead plants and animals; animal manure; effluents from pulp and paper mills, wastewater treatment plants, feedlots, and food-processing plants; failing septic systems; and urban storm water runoff enter a stream, the BOD will rise.

pH

The acidity or basic quality of water is measured by pH. The pH value varies from 0 (very acidic) to 14 (very basic) and pH at 7 represents neutral condition. Natural water is usually having pH value between 6.5 and 8.2. Water quality will be unfit for aquatic organisms at extremely high or at low pH levels (for example 9.6 or 4.5) as they are very sensitive with small variations in pH value.

Temperature

Temperature of water is an indicator of heat present in the water. In fact it is one of the important parameter which signifies status of health of a river. The temperature effects can be summarized below:

1) Dissolved oxygen: Higher temperature of water indicates low dissolved oxygen levels and vice versa.
2) Flora and fauna: The rate of photosynthesis and plant growth is directly proportional to the temperature. Drastic change in the temperature of the water body may endanger the aquatics.
3) Toxic wastes: The presence of toxic wastes generated by industries and power plants (Thermal Power Plants) also leads to the rise in temperature. This effect is also a form of Thermal pollution which deteriorates the river health.
4) Deforestation: It is also observed that deforestation along the banks of river leads to the rise in temperature.

Nitrate

Nitrates are essential for aquatic plants, however they are not utilized by fish and aquatic insects. The presence of excess level of nitrates in water causes extreme conditions for survival of aquatics. The excrete wastes produced by humans and aquatic organisms also contain nitrates. Nitrates are also formed by bacterial activities occurring in the water system. Organic matter present in the soil contributes to rise in nitrate level in similar manner. An increase in nitrate level may lead to contamination of both ground and surface water.

In addition to the above, agricultural activities such as use of fertilizers also contain nitrates. These fertilizers enter the river stream in the form of runoff during rainfalls and thus increase the amount of nitrate. Excess levels of nitrate present in the water can adversely affect the health of humans. It interferes with the activity of red blood cells and has poisonous impact on infants which manifests in the form of blue baby syndrome.

Phosphate

Phosphorus is present in water body in the form of phosphates. Industries, human and animal wastes and runoff carrying fertilizers contribute significantly to increasing level of phosphate. This leads to increased growth of plants in the water environment. Excess growth of plants contaminates the water, as the bacteria use most of the oxygen to decompose the dead plants. Thus the dissolved oxygen level depletes in the water with increase in the amount of phosphate.

Total Dissolved Solids

The inorganic salts and small amounts of organic matter present in water refers to Total Dissolved Solids (TDS).Carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium, and magnesium are the principal ions contributing to TDS. Other qualities of water, such as taste, hardness, corrosion, properties, and tendency to incrustation are influenced by TDS and it may originate from natural sources, sewage effluent discharges, urban runoff, or industrial waste discharges. A limit of 500 mg dissolved solids per liter is desirable for drinking waters and mineralized water with high minerals is not suitable for many industrial applications. TDS level over 500 mg/L of water is unsuitable for irrigation of many plants and also tastes become unpleasant to drink.

3.3.1.3 Development of Rating Curve and Weight for each Water Quality Parameter

(a) Rating Curve for each Water Quality Parameter

Rating curve for each water quality parameter have been developed on a scale of zero to 100 based on the opinion of experts so that each attribute can be assigned a value depending on its existing water quality condition. The rating value (Q) equal to 100 signifies the best water quality condition and rating zero shows the worst water quality condition. Figures 3.3 to 3.10 are the rating curves for Dissolved Oxygen (DO), Total Coliform (TC), 5 Days Biochemical Oxygen

Demand (BOD_5), pH, Temperature, Nitrates, Phosphates and Total Dissolved Solid (TDS) respectively.

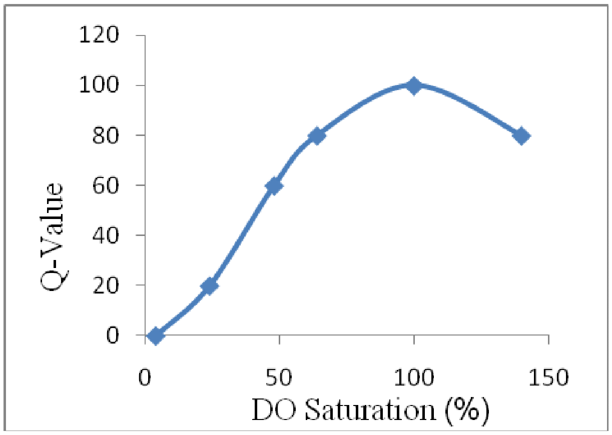

Fig 3.3 : Rating curve for Dissolved Oxygen

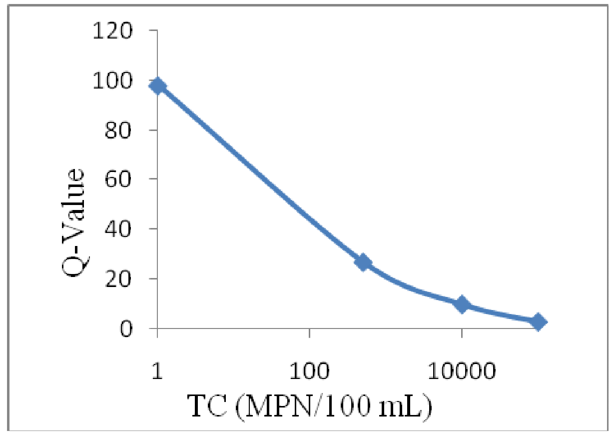

Fig 3.4 : Rating curve for Total Coliform

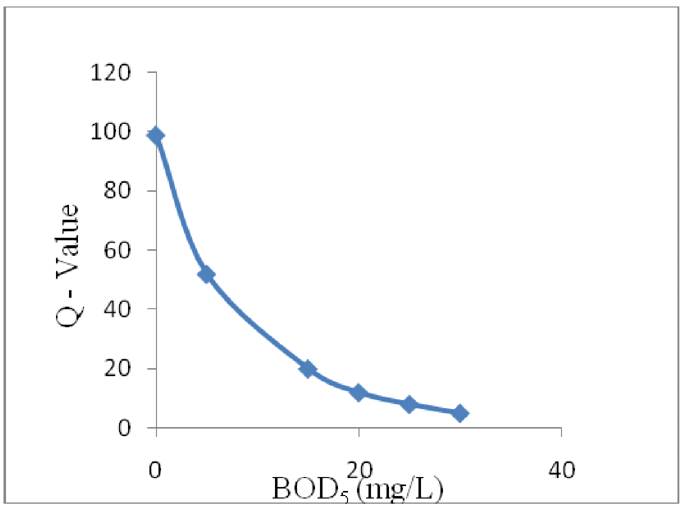

Fig 3.5 : Rating curve for BOD_5

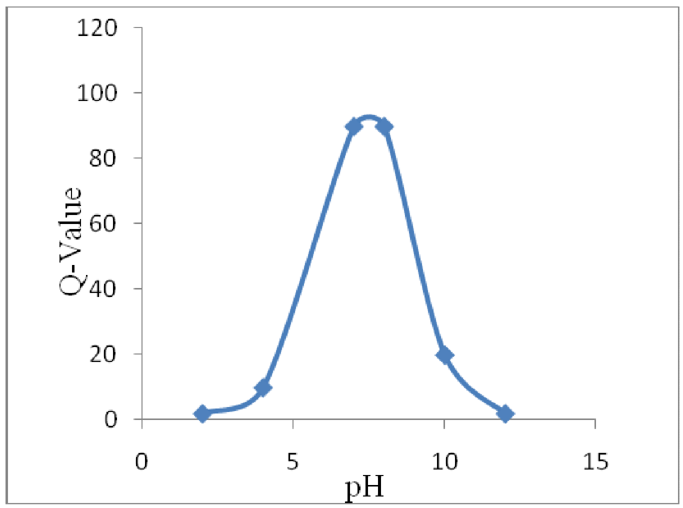

Fig 3.6 : Rating curve for pH

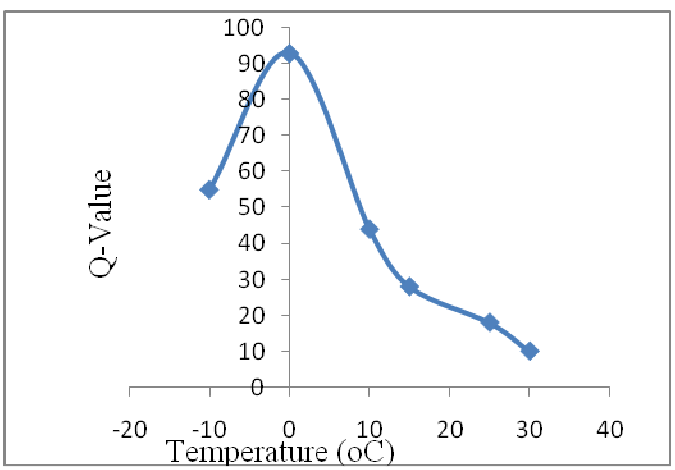

Fig 3.7 : Rating curve for Temperature

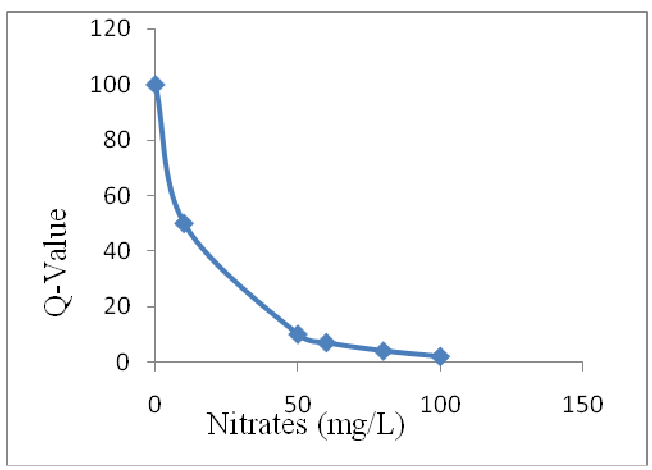

Fig 3.8: Rating curve for Nitrates

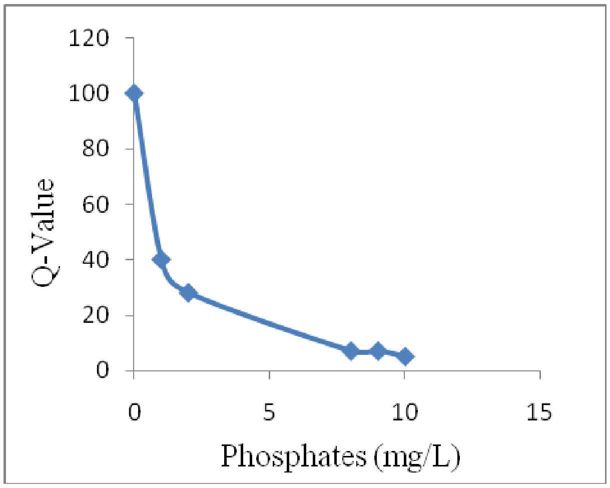

Fig 3.9 : Rating curve for Phosphates

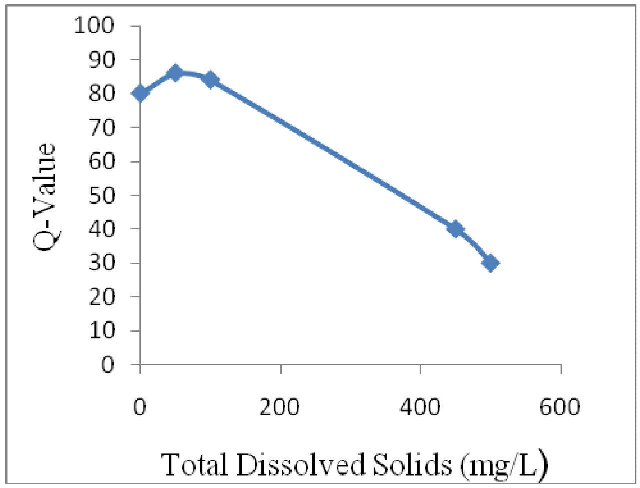

Fig 3.10 : Rating curve for Total Dissolved Solids

(b) Weighting of Water Quality Parameters

The relative importance of each water quality parameters has been derived through a questionnaire which was prepared and sent to the subject experts of water quality management. Each respondent was asked to weigh the parameter by giving a number between 1 and 10; 1 representing the most important parameter and 10 with lowest importance. Finally these weights were converted into a scale of 0 to 1. Table 3.2 gives the opinion about the relative importance of the selected eight parameters. From table, one can infer that DO has been rated as the most important parameter. The weightings of the parameters have been assigned by a numerical value between 0 and 1. The final calculated weightings of the parameters are shown in the Table 3.2.

The data and information relevant to water use and water pollution at ten sampling stations of Haora river basin was collected during March 2010 to April 2010. Eight important parameters have been indentified based on the relative weightings of opinion of experts to formulate the water quality index of the river Haora at selected sampling sites.

Table 3.2: Weights assigned for eight selected Water Quality Parameters

Parameters	Weight
DO	0.18
TC	0.17
BOD_5	0.12
pH	0.12
Temperature	0.11
Nitrates	0.11
Phosphates	0.11
TDS	0.08

3.3.1.4. Measurement of Water Quality Parameters

With rapid increase in population and uncontrolled industrialization, it is felt that quality of environment should be assessed along Haora river especially in and around Agartala, the capital city of Tripura state. Keeping in view of growing awareness of multi-pollutant linkages, it is felt that water quality of Haora river should be measured so that a comprehensive approach can be developed to identify the status of the Haora's water quality. The ten sampling stations have been chosen to determine the water quality index, which are well represented and selected considering different factors like demography, pollution load, industrial activity and opinion of experts working in the field. Eight important water quality parameters out of 19 as explained earlier have been identified to formulate the water quality of river Haora at following selected sampling sites. These sampling stations are given below:

Sampling Site at Confluence Point of two streams (the point of origin) of Haora River, West Tripura (**S1**): This is the place actually from where river Haora was originated after the confluence. This point in the upstream was selected to assess the condition and quality of river without human interference. Only one point S1 was selected from the 10km long hilly stretch of Haora River.

Sampling Site near National Brick Field at Jirania, West Tripura (**S2**): After flowing through the hilly stretch just about 1 km ahead of this point the Haora River falls in the Plain stretch, passing some small villages and entered a small town Jirania. This small agglomeration is having more than 40 Brick Fields in both side of the river. Due to non availability of stone and other type of building materials brick in Tripura is manufactured using top soil. Brick manufacturing is considered to be a major industrial activity in Tripura.

Sampling Site near Ranir Bazar Market, West Tripura **(S3)**: This is the first urban agglomeration Haora River crosses after originating and entering plain stretch. Ranir Bazar is an Urban Local Body (ULB) having a population of around 20,000 (2011 Census). To see the impact of urban activities of a small ULB on the Haora River this point was selected.

Sampling Site near Chaturdash Devata Bari Bathing Ghat, Baldakhal Road, Khayerpur, West Tripura **(S4)**: One of the famous temples having historical significance is located here. Huge numbers of devotees taking holy dip daily at this point on Haora. This point was selected because of this reason.

Sampling Site near the Bridge on Haora River connecting Chandrapur and Baldakhal, Chandrapur, West Tripura (**S5**): Two major tributaries joined few meters in upstream from this location. The boundary of Agartala Municipal Corporation (AMC) starts from here. Human interferences and some service sector industrial activities are seen in and around this location. To have an assessment of water quality just at panchayet and municipal border point of Agartala Municipal Corporation (AMC), this point was selected.

Sampling Site near Aralia Water Intake Point, West Tripura **(S6)**: Water from Haora river withdrawn at this point and distributed in the eastern part of the Agartala City after treatment. 3 MGLD capacity treatment plant is located here and one of biggest educational institution MBB College is very close (100 meter) from the intake point. This point was selected to determine impact of urbanization on water quality of the river.

Sampling Site near Bordowali Water Intake Point, West Tripura **(S7)**: Before reaching this point Haora River crossed almost 70% of the city area, accumulates lot of pollution load. From this intake point water is distributed after treatment for drinking purpose to the rest part of the Agartala City (Central Zone). This point was selected to obtain water quality status of Haora river within Agartala city area.

Sampling Site near Battala Crematorium, West Tripura **(S8)**: The largest crematorium of Tripura is located here. Just before the point selected, lots of solid waste and sewerage disposal is taking place. This location was selected to have an assessment about the pollution load on River Haora due to these activities.

Sampling Site near Dashami Ghat, West Tripura **(S9)**: This location is the designated immersion place declared by the Tripura State Pollution Control Board and District Administration for immersion of idols after Durga Puja and other religious festivals. Most of the pollution activities like solid waste disposal, sewerage disposal etc. are taking place on the Haora River between the stretches (Location Point S5 – S9). This point was selected to have an assessment on these activities.

Sampling Site near the last Point (in Indian Territory) on river Haora entering Bangladesh, West Tripura **(S10)**: Haora river flows to Bangladesh and having international significance. This location is the last point in Indian Territory. Some non point sources of pollution also add to the pollution load factors of the river apart from dilution due to increase in water volume by few drains which are mostly carrying water from agricultural fields. In international forum the Government of India has to provide details about the river flows and quality. This location was selected with this idea.

To get an insight into the computation of SWQI, water quality samples were taken from 10 sampling stations located along Haora river during March-April, 2010. The observed values are given in Tables 3.3 and 3.4.

Table 3.3: **Observed values of Surface Water Quality Parameters collected from sampling stations S1 to S5 of Haora River Basin, Tripura**

S. No	Water quality parameters	S1	S2	S3	S4	S5	Standard limit
1.	DO (mg/l)	7.2	6.21	5.6	6.73	6.24	6
2.	Total Coliform (MPN/100 ml)	110	220	180	350	540	500
3.	BOD_5 (mg/l)	1.9	2.2	2.1	2.8	3.5	3
4.	pH	7.65	7.68	7.73	7.60	7.34	6.5-8.5
5.	Temperatures (^{0}C)	28.5	29.0	30.5	29.5	30.0	-
6.	Nitrate (mg/l)	0.02	0.02	0.04	0.02	0.025	20
7.	Phosphate (mg/l)	0.010	0.017	0.017	0.019	0.020	-
8.	Total Dissolved Solid (mg/l)	144	156	152	168	174	500
9.	Total Suspended Solid (mg/l)	26	38	53	76	46	-
10.	Colour (1/m)	2.5	4.3	5.8	7.3	10.2	10
11.	Turbidity (NTU)	5	11	14	17	26	-
12.	Alkalinity (mg/l)	69.34	95.34	95.34	121.35	120.20	-
13.	COD (mg/l)	8	13	10	18	22	-
14.	Hardness (mg/l)	59.55	59.55	79.40	84.36	84.36	300
15.	Calcium (mg/l)	15.91	15.90	19.88	19.88	23.86	80.10
16.	Magnesium (mg/l)	4.8	4.78	7.23	8.44	6.02	24.28
17.	Chloride (mg/l)	7.2	9.6	9.6	12.0	9.6	250
18.	Nitrite (mg/l)	0.01	0.01	0.02	0.03	0.035	-
19.	Ammonical Nitrogen (mg/l)	Nil	Nil	0.010	0.014	0.016	1.2

Table 3.4: Observed values of Surface Water Quality Parameters collected from sampling stations S6 to S10 of Haora River Basin, Tripura

S. No	Water quality parameters	S6	S7	S8	S9	S10	Standard limit
20.	DO (mg/l)	6.2	**5.10**	6.25	6.40	**5.6**	6
21.	Total Coliform (MPN/100 ml)	920	1200	1600	1650	1800	500
22.	BOD_5 (mg/l)	3.9	4.3	7.2	7.8	8.6	3
23.	pH	7.12	7.36	7.63	7.88	8.10	6.5-8.5
24.	Temperatures (^{0}C)	29.0	29.5	30.0	30.0	30.5	-
25.	Nitrate (mg/l)	0.015	0.020	0.040	0.050	0.060	20
26.	Phosphate (mg/l)	0.025	0.035	0.040	0.050	0.065	-
27.	Total Dissolved Solid (mg/l)	182	170	165	188	220	500
28.	Total Suspended Solid (mg/l)	68	64	78	130	180	-
29.	Colour (1/m)	8.1	10.2	10.6	11.8	12.6	10
30.	Turbidity (NTU)	24	30	34	36	38	-
31.	Alkalinity (mg/l)	125.68	123.52	125.68	134.35	143.02	-
32.	COD (mg/l)	26	29	34	35	39	-
33.	Hardness (mg/l)	89.32	109.17	129.02	158.80	178.65	300
34.	Calcium (mg/l)	25.85	29.83	29.83	33.81	35.79	80.10
35.	Magnesium (mg/l)	6.02	8.42	13.26	18.08	21.63	24.28
36.	Chloride (mg/l)	19.2	21.6	21.6	24.0	24.0	250
37.	Nitrite (mg/l)	0.035	0.040	0.030	0.040	0.040	-
38.	Ammonical Nitrogen (mg/l)	0.016	0.018	0.021	0.020	0.025	1.2

3.3.1.5 Analysis and Development of Water Quality Index

As water quality index is an indicator to reflect the composite influence of a number of water quality parameters, it plays a significant role to allocate and predict its suitability for a specific beneficial use. These water quality parameters can be monitored to assess changes in the water which can be integrated further with its impact on human health, environment and the perception of decision makers.

The rating of each water quality parameters corresponding to measured value at specified sampling site is calculated using rating curves (Figures 3.3-3.10) and Tables 3.3 and 3.4. Based on the expert opinion and literature survey, the overall status of water quality is categorized into five grades ranging a scale from 0 to 100 as given in Table 3.5. Using equation (3.2) Surface Water Quality Index (SWQI) with respect to each sampling site has been evaluated as given in column (10) of Table 3.6. The overall SWQI score calculated herein is then compared against the scale given in Table 3.5 to determine status of water quality of the river. The stations belonging to higher SWQI are categorized as those possessing excellent water quality whereas the sampling stations with lower score of SWQI correspond with poor quality and thus require a higher attention to improve overall surface water quality than other sampling sites.

Table 3.5: Grades on Water Quality with different ranges

WQI Range	Quality
0-25	Extremely Poor
26-50	Poor
51-70	Medium/Fair
71-90	Good
91-100	Excellent

After identifying all relevant indicators, the sub-index scores of each water quality indicator were obtained with respect to each sampling station as given in Table 3.6. The overall score of SWQI at each station is evaluated using weighted average method as given in equation (3.2), by taking into consideration of the concentration of all important water quality parameters at the particular location. The water quality index (SWQI) derived for each sampling site represents the status of water quality in the river at that station. The SWQI score closer to zero indicates poor quality of water whereas higher values of SWQI represent better quality of river water as has been categorized into five classes in Table 3.5. The final score have been considered as an overall assessment of surface water quality at the specified sampling station.

Table 3.6: Computation of Sub-index of Surface Water Quality Parameters and Overall SWQI along Haora River Basin, Tripura

Sampling Stations (1)	Sub-Index Score correspond to given Water Quality Parameters										
	DO (2)	Total Coli-form (3)	BOD_5 (4)	pH (5)	Temp-erature (6)	Nitrate (7)	Phos-phate (8)	TDS (9)	Overall SWQI Score (10)	Rank (11)	Overall Status of Water (12)
S1	96.06	82.49	81.14	90	12.4	99.9	99.4	78.47	81.42	1	Good
S2	89.25	66.84	78.32	90	11.6	99.9	98.98	76.96	76.94	2	Good
S3	87.06	72.53	79.26	90	5	99.8	98.98	77.46	76.93	3	Good
S4	93.64	48.34	72.68	90	10.8	99.9	98.86	75.45	73.68	4	Good
S5	90.67	26.93	66.1	90	10	99.88	98.8	74.7	68.56	5	Medium
S6	89.18	26.25	62.34	90	11.6	99.93	98.5	73.69	67.79	6	Medium
S7	81.73	25.75	58.58	90	10.8	99.9	97.9	75.2	65.88	7	Medium
S8	90.74	25.03	44.96	90	10	99.8	97.6	75.83	65.66	8	Medium
S9	91.85	24.94	43.04	90	10	99.75	97	72.94	65.32	9	Medium
S10	87.06	24.67	40.48	86.5	5	99.7	96.1	68.91	62.70	10	Medium

Table 3.6 also shows the ranking of status of water quality for each station. Figure 3.11 also indicates the final SWQI scores with respect to all 10 sampling stations. The results indicate that the SWQI score ranges from 81.42 at sampling station S1 to 62.70 at sampling station S10. It is clear that water quality had been quite good from the origin station (S1) till sampling station (S4) near Chaturdash Devata Bari Bathing Ghat, Baldakhal Road, Khayerpur as evident from SWQI scores though, there was a gradual decrease in SWQI at downstream sampling stations. The water quality status has been categorized as medium class at the downstream sampling stations S5 to S10 which degrades gradually in the downstream stations. This is mainly due to gradual increase in BOD_5, Nitrate and TDS concentration in the river stretch from its source to the downstream stations. However, average values at these sampling stations have been found below the designated standard for a given criteria as specified by the Central Pollution Control Board, New Delhi.

The SWQI scores clearly demonstrate that water quality is either of good or medium class. The sampling station S1 (i.e. confluence point of two streams (the point of origin) of river Haora, West Tripura) has the highest score of 81.42 signifying good quality and is the most suitable among all sampling sites. This is due to the fact that there is no significant source of water pollution in and around sampling station S1 which is located under upper catchment of the river. The dissolved oxygen has been found the highest among all sampling stations with 7.2 mg/l as the average value which is above the prescribed limit (BIS: 6 mg/l). As depicted in Tables 3.3 and 3.4, there was gradual increase in the numbers of total coliform from source sampling station S1 to last sampling site (in Indian territory) i.e. S10.

The minimum bacterial contamination was observed at source of the river which increases further at the sampling stations located downstream of the river from S5 to S10. The organic pollution had also been low at sampling station S1 due to low concentration of BOD_5 as evident from Tables 3.3. The other water quality parameters such as pH, temperature, nitrate, phosphates and TDS have been below the permissible limit. However, this station may be affected by deforestation and other human interventions, which may endanger the sustainability of the river in terms of its water resources.

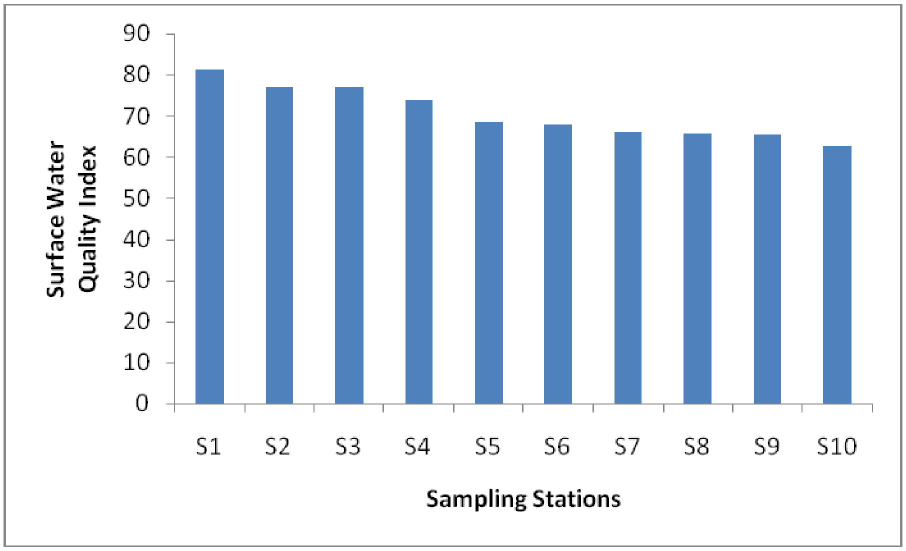

Fig. 3.11: Surface Water Quality Index Score at different Sampling Stations along Haora River

Similarly, observed values of all water quality parameters are within the prescribed limit at sampling stations S2, S3 and S4 with SWQI scores as 76.94. 76.93 and 73.68 respectively. Though there is reduction in dissolved oxygen concentration and slight increase in Total coliform, BOD_5, and total dissolved solids, water quality at these sampling sites are still under good condition. However, as most of the brickfields are located within this region, human interventions (such as supplying excess amount of sediments to the river, lifting water for making bricks and for other purposes, releasing excreta and other pollutants to the river) play important role in lowering SWQI scores at these stations.

The sampling stations S5 to S10 fall under medium water quality index with SWQI scores of 68.56, 67.79, 65.88, 65.66, 65.32 and 62.70 respectively. Tables 3.3 and 3.4 clearly show that there has been significant increase in total coliform, BOD_5 and total dissolved solids and reduction in dissolved oxygen at these sampling stations. These four water quality parameters have impacted SWQI scores. As sampling station S10 is the last point (in Indian territory) on river Haora entering Bangladesh, it has the lowest SWQI score of 62.70 due to the fact that DO is lowest with 5.6 mg/l as the average value at this station and total coliform is the highest among all stations with an average value of 1800/100 ml exceeding the standard limit of 500/100ml as prescribed by the Bureau of Indian Standard.

Though the availability of coliform bacteria in Haora river upstream of Ranir Bazaar is lower than the prescribed standard limit, they are beyond the tolerable limit from Ranir Bazaar to the last sampling station (S10) due to the disposal of organic wastes disposal into the river.

Though the maximum BOD_5 has been found 8.6 mg/l, it is also beyond the prescribed limit of 3 mg/l. Of course, all other parameters have been found well below the maximum permissible limit. The possible reason for this trend may be due to human activities which are now becoming predominant at these stations. Both sides of the river are densely settled with a number of slum areas. Huge amount of toxic substances, solid and liquid wastes are directly disposed into the river not only by the slum dwellers but also by other families surrounding the areas. A number of market areas, burning ghat, agricultural fields etc. also supply pollutants to the river.

In addition to large quantity of withdrawal of water through pumping stations near Ranir Bazaar, domestic and industrial wastes disposal lead to contaminate water at sampling stations S7 and S10. The similar situation occurs near Bordowali Water Intake Point and at the last point near Bangladesh Border. The upstream part of the river above Chandrapur receives less amount of sewage for which the BOD_5 content is within tolerable limit (3 mg/l). But it exceeds the prescribed limit at Chandrapur due to disposal of huge amount of solid and liquid wastes into the river. Thus depletion of DO has been observed at these stations.

The pH values remained almost constant for all the sampling stations. The temperature was ranging between 28.5^0C to 30.5^0C appeared to be normal. Other parameters like TDS, Phosphate, Nitrate etc. were within the permissible limit. The Parameters like BOD_5, COD and Total Coliform were constantly increasing from S1 to S10 which clearly indicate the deterioration of water quality of River Haora. As per this analysis, it is observed that the river Haora maintains good water quality in upstream regions. i.e. S1 to S4. In the downstream stretches especially S5 to S10 the overall status of water quality is medium. This is due to adding of sewage, drains discharging waste water and solid waste disposal into the Haora river.

A comprehensive analysis on spatial variations of water quality parameters has been performed by developing SWQI at 10 different sampling stations as shown in Figure 3.11. The indices computed in this process are simple and can be interpreted easily for public information. The water quality statuses were found to vary from medium to good water conditions as described above. The important parameters viz. total coliform, BOD_5, TDS, and dissolved oxygen were the responsible water quality parameters for lower values of SWQI which contribute significantly in lowering the status of water quality at the downstream stations.

The method presented in this section applies the concept of weighted average to calculate SWQI. The classifications for water quality status corresponding to different pollutants are not certain because their boundaries are generally not clear. The ambiguousness and inaccuracies due to these aspects can be handled by incorporating fuzzy concepts. Therefore, next section deals with evaluation of water quality index using fuzzy comprehensive analysis which seems to be particularly promising and applicable.

Though the above methodology clearly evaluates water quality status in the selected region, it would be better if the critical water quality parameters monitored regularly to analyze and simulate results on long-term basis. As huge amount of soil both from the river beds and valley side areas are being excavated and transported especially from Jirania to Chandrapur by which the normal gradient of the river is lost and proceeds towards decaying phase. The construction of road and bridge piers on/within the river bed, motor stands along the river bank (by filling the valley side areas), outlets of municipal garbage with the river without any treatment plant are some examples of such hindrances caused by the common people as well as from Government agencies.

3.3.2 Fuzzy Comprehensive Water Quality Index

3.3.2.1 Methodology Used

The concepts of fuzzy logic provide a framework to deal with the uncertainty and impreciseness present in the water quality problems. These concepts can develop appropriate decision support systems to analyze many real-life decision-making problems. For example, if it is required to assess and classify the objects for a decision-making problem, it is not necessary that the classification of the object would be clear and precise. In many cases no clear boundary exists among the objects, for instance, there is no clear boundary in the classification of good and bad water. Such ambiguity is handled by introducing membership functions for a given fuzzy set.

In fact a fuzzy set is a broadened version of a crisp set wherein an element belonging to a crisp set can either completely belong to that set or not belonging to it by any means, whereas fuzzy sets accommodate partial belongingness by defining appropriate membership function. In order to express vagueness involved in such expression, membership functions of different kinds are referred in the literature. In this study, two types of membership functions (i.e. triangular and Gaussian membership functions) have been used to define these sets. Triangular membership functions are generally expressed by three parameters *a, b* and *c* as given in equation (3.3) which can easily be derived from Figure 3.12.

$$\mu_A(x,a,b,c)=\begin{cases}0 & \text{if } x \le a\\ \dfrac{x-a}{b-a} & \text{if } x \in [a,b]\\ \dfrac{c-x}{c-b} & \text{if } x \in [b,c]\\ 0 & \text{if } x \ge c\end{cases} \tag{3.3}$$

Similarly, Gaussian membership curves as shown in Figure 3.13 depend on two parameters σ (the width of the curve) and *c* (point representing the maximum membership value) and are generally represented by equation (3.4):

$$f(x,\sigma,c)=\exp\left[\frac{-(x-c)^2}{2\sigma^2}\right] \tag{3.4}$$

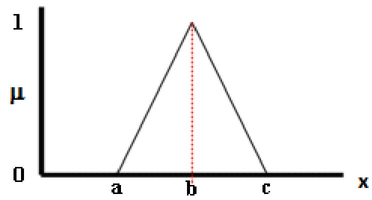

Figure 3.12. Triangular Membership Function

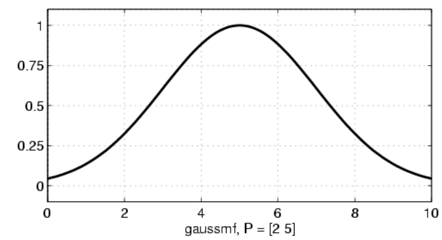

Figure 3.13. Gaussian Membership Function

A generalized flow chart representing the entire methodology to describe the evaluation of FCWQI using fuzzy decision support system for water quality assessment of Haora river basin has been shown in Figure 3.14. The quality of water can generally be defined differently depending on its different uses. Though the main focus of this study has been to develop comprehensive water quality index for domestic purposes, this technique can also be applied for other uses of water as well.

3.3.2.2 Conceptual framework for Development of an Index

In this chapter, the water quality index corresponding to various sampling stations along Haora river has been calculated by incorporating the fuzzy behavior in a decision making process. This procedure involves the following steps:

1. *Identification of water quality parameters*: A water quality parameter is any factor whose contamination may cause water unfit for its best designated use. In this study 8 parameters namely DO, BOD_5, Total Coliform, TDS, pH, Temperature, Nitrates and Phosphates have been taken into consideration to derive the water quality index with reference to its appropriateness to drinking water which can be considered as one of the most important usages of water.

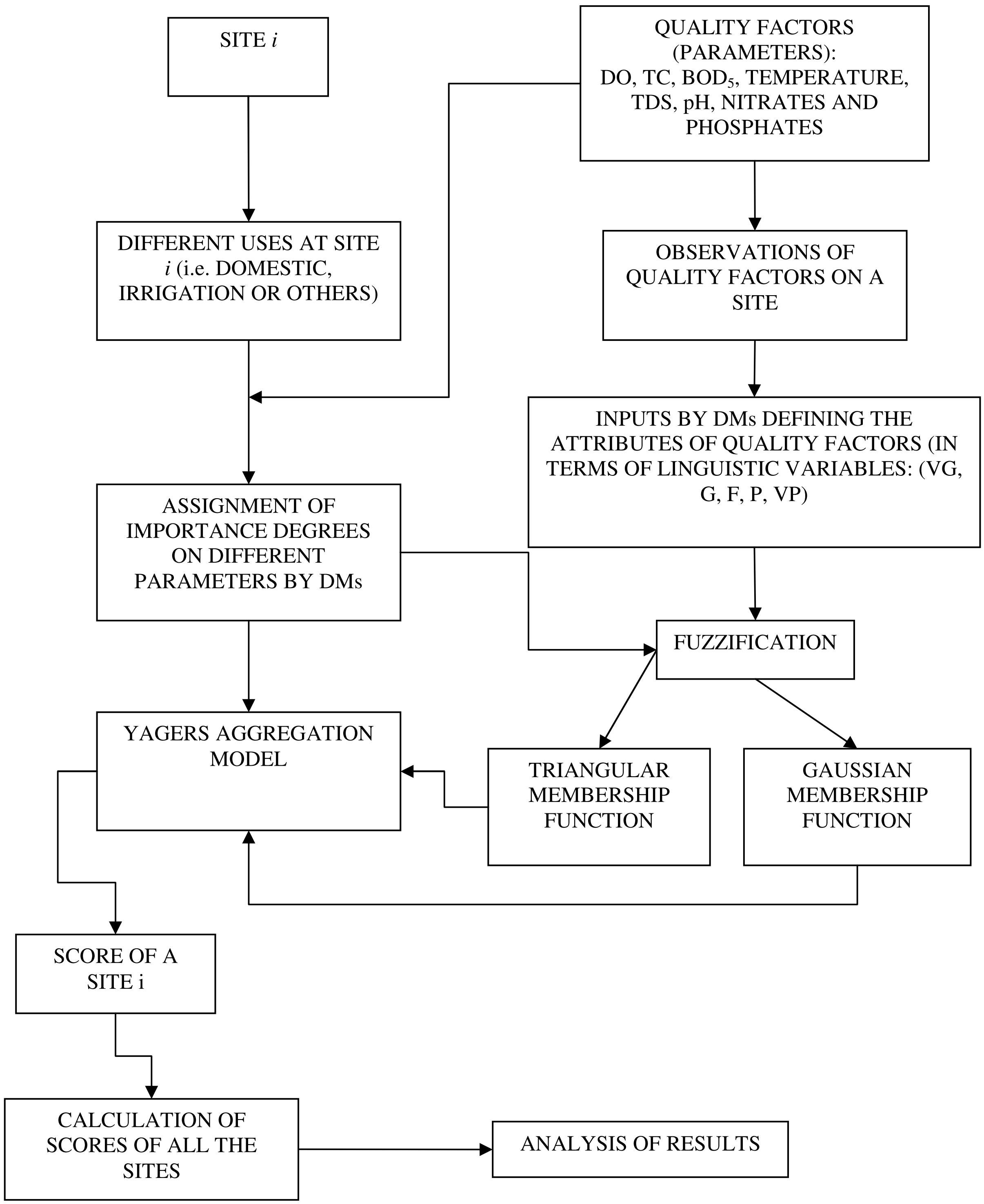

Figure 3.14: Fuzzy Decision Support System for Water Quality Assessment in a River

2. *Parametric Estimates and Attributes*: The next step involves the actual measurement of the afore-mentioned parameters. Generally, qualitative attributes of these parameters are defined by a group of water quality experts in terms of linguistic variables because they are subjective in nature. For example, a pH of 7.5 has no significance for a decision maker unless it has an attribute attached to it, i.e. whether the given pH is of high magnitude or low magnitude. In this study 5 attributes namely Very Poor (VP), Poor (P) Fair (F), Good (G), and Very Good (VG), have been considered by deriving Gaussian membership functions with (σ, c) values equal to (1, 1), (1, 2), (1, 3), (1, 4), and (1, 5) respectively as shown in Figure 3.15.

3. *Importance Degree of Parameters*: All the parameters listed above do not necessarily affect equally the water quality corresponding to a given beneficial use. For example temperature may not be as important as dissolved oxygen in a given specific use. Thus, it is necessary to assign importance degree to each water quality parameter. This is also done using linguistic variables namely Unimportant (U), Low Importance (L), Medium Importance (M), Very Important (V) and Extremely Important (E). These variables are also subjective in nature since they also depend on the inputs by decision makers. Triangular membership functions have been used to define these variables as shown in Figure 3.16. These importance degrees serve as weights for different parameters which are required for the calculation of water quality index. However, weights are considered to be crisp thus there is a need to determine representative values for afore-mentioned importance degrees. Based on centroid method, the representative value (w_i) can be calculated for each fuzzy set W_i using equation (3.5), where μ_{wi} is the value of membership function of fuzzy importance degree/weight (w):

$$w_i = \frac{\int_{w=0}^{1} w.\mu_{w_i}(w)\, dw}{\int_{w=0}^{1} \mu_{w_i}(w)\, dw} \quad (3.5)$$

The representative values for different importance degrees have been calculated using "*defuzz*" function of MATLAB with the integration of Figure 3.17 and equation 3.6. In this study, the centroid method is used to defuzzify the fuzzy set of importance degrees by evaluating centroid of the area represented by the different curves of U, L, M, V, and E.

However, there exist many other methods to defuzzify the fuzzy set, the details of which can be obtained elsewhere (Ross, 2008). These values are given in Table 3.7.

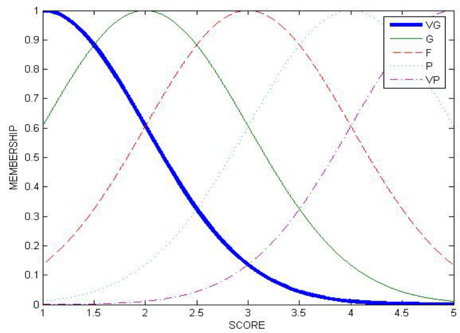

Figure 3.15. Gaussian Membership Function in Haora River Basin

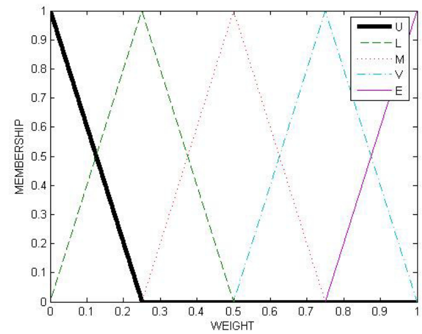

Figure 3.16. Triangular Membership Function in Haora River Basin

Table 3.7 Importance values of linguistic terms used to define Quality Parameters

Importance Factor	U	L	M	V	E
w_i	0.0833	0.25	0.5	0.75	0.9167

4. *Water Quality Index at different stations*: On the basis of observations on different parameters, the experts assign attributes to each parameter at different stations. The final water quality index is calculated by using Yager's *'max-min'* model. For n^{th} station, the quality index set $Q\tilde{I}_n$ is defined as per equation 3.6.

$$Q\tilde{I}_n = \bigcap_{i=1,2,...I} S_{i,n}^{w_{i,n}} = \underset{i=1,2,...,I}{\mathrm{Min}} \left\langle \left(\mu_{S_{i,n}}(s) \right)^{w_{i,n}} \right\rangle \tag{3.6}$$

Where $S_{i,n}$ denotes the score of an attribute assigned by the decision maker to i^{th} parameter at n^{th} sampling station and $\mu_{Si,n}$ is the membership function of score value s in fuzzy set S.

Once the quality index set $Q\tilde{I}_n$ is evaluated, the element with the maximum membership value can be obtained at the decision point in terms of reach quality index QI_n using the Yager's algorithm as expressed by the equation 3.7, where $\mu_{Qi,n}$ is the membership function of quality score value s in fuzzy set Q.

$$QI_n = \left\{ s \,|\, \mu_{Q_{i,n}}(s) = \text{Max}\left(QI_n\right) \right\} \quad (3.7)$$

Thus, the water quality index at various sampling locations along a river can be calculated.

3.3.2.3 Analysis and Development of Fuzzy Comprehensive Water Quality Index

The fuzzy comprehensive water quality index at different sampling stations along a river has been calculated by taking into consideration the measured values of eight water quality parameters which are given in Tables 3.3 and 3.4. These are Dissolved oxygen (DO), 5-day Biochemical oxygen Demand (BOD_5), Total Coliform (TC), pH, Temperature, Nitrates, Phosphates and Total Dissolved Solids (TDS). Based on the subjective judgments of the experts, the importance degrees of each water parameter as decided are given in Table 3.8. Attributes rating were also assigned with respect to all water quality parameters as given in Table 3.9 after taking opinion of the decision makers into consideration.

Table 3.8: The Importance degree of each Parameter based on opinion of the Decision Makers

Parameters	Importance Degree	Parameters	Importance Degree
DO	E	Temperature	M
TC	E	Nitrates	M
BOD_5	V	Phosphates	M
pH	V	TDS	L

Finally Yager's 'max-min' algorithm, given in equations (3.6) and (3.7), has been applied to find the FCWQI for all the selected stations along river Haora. For example, By Yager's algorithm the value of FCWQI for sampling station 1 (i.e. S1) is given by:

$$WQI = \bigcap (VG)^E (F)^E (G)^V (VG)^V (F)^M (VG)^M (VG)^M (G)^L \quad (3.8)$$

Table 3.9 Attributes rating of Water Quality Parameters based on testing results and Expert Opinion

Parameters / Stations	DO (mg/l)	Total Coliform (MPN/100 ml)	BOD_5 (mg/l)	pH	Temp (^{0}C)	Nitrates (mg/l)	Phosphates (mg/l)	Total Dissolved Solid (mg/l)
S1	VG	F	G	VG	F	VG	VG	G
S2	F	F	G	VG	F	VG	VG	G
S3	F	F	G	VG	P	VG	VG	G
S4	G	F	G	VG	P	VG	VG	G
S5	G	F	G	VG	P	VG	VG	G
S6	F	F	F	VG	F	VG	VG	G
S7	P	P	F	VG	P	VG	VG	G
S8	G	P	F	VG	P	VG	VG	G
S9	G	P	F	VG	P	VG	VG	G
S10	F	P	P	VG	P	VG	VG	G

In the equation 3.8, the importance degree and rating value of Dissolved Oxygen at sampling station 1 (i.e. S1) are E and VG (w_i = 0.9167) as obtained from Tables 3.8 and 3.9 respectively. It can be expressed as $(VG)^{0.9167}$ for DO at S1, i.e. membership value corresponding to a given score for 'VG' rating curve will be raised to the power of 0.9167 to get the respective membership value as depicted by the thin blue line in the Figure 3.17. Thus each point in the abscissa (x-axis) has a corresponding value on the ordinate (y-axis). This "corresponding y-axis value" will be raised to the power 0.9167. This is represented as the thin blue line in the Figure 3.17.

Similarly, rating and importance degree of Total Coliform, BOD_5, pH, Temperature, Nitrates, Phosphates and TDS were obtained as shown in Figure 3.17 by raising membership value of each attribute rating to the power of their respective importance degree corresponding to a given score. Different curves have been obtained with respect to all eight parameters for all ten sampling sites and the FCWQI at a given site was evaluated by Yager's max-min algorithm using MATLAB vesrsion 7.8.0. These curves are representing the attributes of different parameters (DO, TC etc.) assigned by the decision makers by taking into consideration of their importance degree. For example, the thick blue line represents TDS as one of the water quality parameter. The attribute assigned by the decision makers was 'G' and importance degree was 'L'. Hence the thick blue line represents the fuzzy set $(G)^L$. Similarly other lines can be derived for representing different parameters and their importance degrees. It can be observed that there is a little difference between the thick line (shown in Figure 3.15) and the thin line (shown in Figure 3.17) which is depicted for Dissolved Oxygen at sampling station S1 as 0.9167 is very close to 1. However, it is not true for phosphates which have 'VG' rating with moderate degree of importance with a value of 0.5.

FCWQI score at a site is then evaluated by integrating the effects of all parameters. Using Yager's Max-Min operator, a curve is drawn representing a score corresponding to minimum membership value which has essentially been obtained at the intersection of the curves for all parameters as shown in Figure 3.16. Finally, a score (on x-axis) corresponding to the maximum of minimum membership value at the above curve is derived which represents the Fuzzy Comprehensive Water Quality Index (FCWQI) at a site as shown in Figure 3.18. It is important to note that the dirtier the water, the higher will be the FCWQI. This implies that point with lowest FCWQI will be the purest. Similarly, Yager's max-min operation was applied for all sampling stations and scores of FCWQI were obtained for these stations as shown in Figure 3.19.

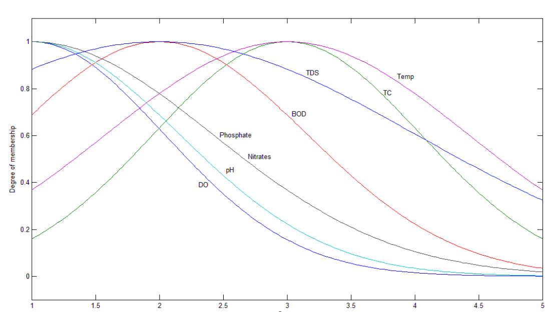

Figure 3.17 Final score of Water Quality Index for Station 1 (S1) Using Yager's Max-min operator

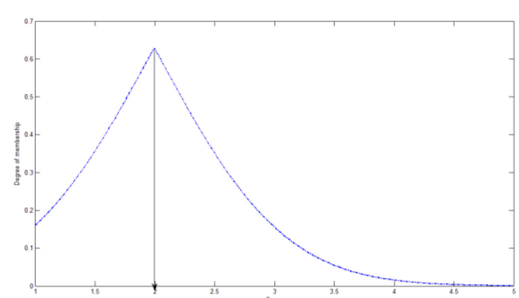

Figure 3.18 Final Score of Water Quality Index at Sampling Station 1 (S1) along River Haora

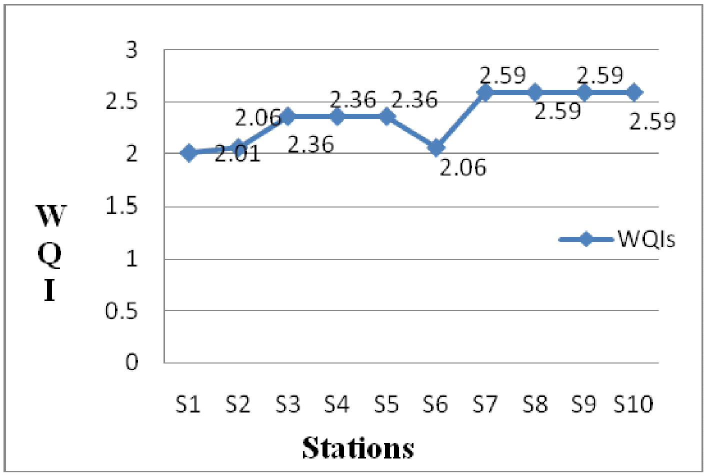

Figure 3.19 Water Quality Indices at different Sampling Stations along River Haora

3.4 Results and Discussion

The methodology developed in this chapter evaluates comprehensive water quality index of river Haora at ten different stations the values of which are shown in Figure 3.19. A useful application of proposed comprehensive technique for water quality management is to test the behavior of sensitivity of the model due to changes in water quality parameters. Once the comprehensive WQI at different sites are evaluated, sensitivity analysis has been carried out for each perturbing parameter separately so that the variations in FCWQI can be examined. In a few cases the combined effect of more than one parameter were also studied. If a small change in the parameter produces large changes in the final score of FCWQI, this score is said to be sensitive to the parameter and appropriate treatment methodologies/remedial action plans are to be worked out to improve final score of FCWQI at the specific site with respect to that parameter. If the final score is not sensitive to a perturbed parameter, it means that the present score is satisfactory. However, it must be ensured that in future the quality of the particular parameter is maintained at least at the present level.

Detailed sensitivity analysis has been performed for different water quality parameters to assess their impact on FCWQI, especially those which have relatively low rating (poor or fair). Obviously the parameters with higher ratings (G or VG) do not contribute much in improving overall score of the water quality index. The ratings of a few selected parameters were modified to the next level (i.e. from poor to fair or fair to good) and revised score of the water quality indices at all ten stations were obtained as given in Table 3.10.

Table 3.10: Revised versus Original FCWQI score at different Sampling Stations

Station	Parameters	Original FCWQI	Improvement In Grade Of Quality Of Water	Revised FCWQI
S1	Total coliform	2.01	F to G	1.86
	Temp		F to G	2.01
	Combination of Total coliform and Temperature		F to G	1.51
S2	DO	2.06	F to G	2.06
	Total Coliform		F to G	2.06
	Temperature		F to G	2.06
	DO+ Total coliform		F to G	2.06
	DO+ Total coliform +Temperature		F to VG	2.01
S3	DO	2.36	F to G	2.36
	Total coliform		F to G	2.36
	Temperature		P to F	2.06
	Total coliform+Temperature		P to F	2.06
S4	Total coliform	2.36	F to G	2.38
	Temperature		P to F	2.06
	Total coliform +Temperature		P to F	2.06
S5	Total coliform	2.36	F to G	2.38
	Temperature		P to F	2.06
	Total coliform +Temperature		P to F	2.06
S6	DO	2.06	F to G	2.06
	Total coliform		F to G	2.06
	BOD_5		F to G	2.06
	DO+ Total coliform		F to G	2.06
	Total coliform + BOD_5		F to G	2.06
	Temperature		F to G	2.02
S7	DO	2.59	P to F	2.43
	Total coliform		P to F	2.44
	BOD_5		F to G	2.53
	Temperature		P to F	2.46
S8	DO	2.59	P to F	2.43
	Total coliform		P to F	2.44
	BOD_5		F to G	2.53
	Temperature		P to F	2.46

S9	DO	2.59	P to F	2.43
	Total coliform		P to F	2.44
	BOD_5		F to G	2.53
	Temperature		P to F	2.46
S10	DO	2.59	P to F	2.43
	Total coliform		P to F	2.44
	BOD_5		F to G	2.53
	Temperature		P to F	2.46

where, P = Poor; F = Fair; G = Good; VG = Very good

By keeping the rating levels fixed to those parameters which show 'Good' or 'Very Good' trend (i.e. higher order of ratings) at station 1 such as DO, BOD_5, pH, Nitrates, Phosphates, and TDS, sensitivity analysis clearly demonstrates that an improvement in individual rating of Total Coliform from fair to good, improves the final score of FCWQI from 2.01 to 1.86 whereas improvement in individual rating of temperature from fair to good does not change the FCWQI score. It remains as 2.01. It is also observed that an improvement in ratings of Total Coliform and temperature together from fair to good improves the overall score of FCWQI improves from 2.01 to 1.51 at sampling station 1. Thus combined effect of both the parameters is more effective in overall improvement of water quality at sampling station 1. It was interesting to observe that change in quality rating from fair to good of temperature alone had no impact on FCWQI score at this station. This is because most of the parameters of higher degree of importance are of higher rating at this station except for temperature (fair rating with moderate importance). Moreover, overall growth of Total Coliform depends on temperature and therefore the combined action is expected to be more effective. To improve Total Coliform from fair to good at this station (S1), there is a need to restrict human interference at this point of confluence.

It is also observed that an improvement in the ratings of DO, Total Coliform and temperature at station 2 from fair to good tends to provide the same revised final score of FCWQI of 2.06. Based on the magnitude of the variation in the final score of FCWQI, it appears that there is not much scope to improve FCWQI further until ratings of all three parameters change together from fair to very good which can slightly improve final score of FCWQI from 2.06 to 2.01. Similarly, it may also be observed that a change in water quality rating from fair to good with respect to DO and total coliform, FCWQI score of 2.06 does not change at station 3. However if combined effects of change of ratings of DO (from fair to good) and temperature (from poor to fair) is evaluated, it improves final score of FCWQI from 2.36 to 2.06. Also, combined effects of change of ratings of total coliform (from fair to good) and temperature (from poor to fair) improves final score of FCWQI from 2.36 to 2.06. Similarly, the changes in ratings levels of any parameter from fair to good at station 6 do not change the final score of FCWQI except temperature which improves it from 2.06 to 2.02.

Figure 3.19 shows that there is significant degradation of water quality at sampling stations S7, S8, S9 and S10 which have highest FCWQI values of 2.59 with marked worsening in key pollution indicators such as DO, BOD_5 and Temperature. This is due to the addition of excessive amount of untreated organic matters through various drains, increase in population in the basin and non-availability of dilution in the river downstream. The combined effect resulted in the disturbance in the river ecosystem to a larger extent at the downstream. The depletion of DO concentration, large numbers of Total Coliform and poor temperature are the major impacts at these 4 stations. If a change in water quality rating from poor to fair can be ensured with respect to DO, Total Coliform, Temperature and BOD_5, the final score of FCWQI can be improved from 2.59 to 2.43, 2.44, 2.46 and 2.53 respectively. It can be observed from the figure 3.19 that the FCWQIs are increasing in the downstream direction which implies that pollution increases in the downstream direction of the river. Figure 3.19 also demonstrates the variation of the average FCWQI's with respect to the given sampling stations.

It is very clear that highest FCWQI is observed at the last four sampling stations namely S7, S8, S9 and S10. This indicates higher level of pollution at these stations as compare to the values at S1 to S6. This is due to the constant increase in BOD_5 and Total Coliform from S1 to S10 and hence there is deterioration in water quality. It can also be seen that the FCWQI is lowest at the sampling station S1 which is nearest to the source of river Haora and hence the water here is of good quality.

The sensitivity analysis has been performed for different water quality parameters especially those which are having degrees of importance either very good or excellent because the parameters with lower degrees of importance may not contribute much to the final score of the water quality index. This kind of analysis helps to understand the stability of the indices, which in turn identify suitable parameters, the quality of which is to be changed and by what extent to improve the overall quality of water.

3.5 Summary

An attempt has been made in this chapter to develop a quantification technique for assessing status of water quality of river Haora using two approaches: (i) traditional WQI using SAW and (ii) FCWQI using fuzzy comprehensive technique.

Although, traditional WQI scores using SAW has produced authentic results in this case study, a number of uncertainties have not been incorporated in WQI system. It is therefore needed to seek a comprehensive approach to incorporate uncertainty aspects of water quality measurement, modeling, prediction, simulation, optimization and imprecise knowledge of interrelationships between pollutant dischargers and river bodies. Moreover, the requirement of standards of water quality depends upon its usage which requires different acceptable levels and importance weights for each indicator parameter corresponding to a given beneficial use. In this context, FCWQI using fuzzy comprehensive technique applied in this study has been found very effective. Also, uncertainty associated with personal preferences and linguistic judgments of subject experts and decision makers can also be treated in realistic manner while in identifying appropriate water quality parameters with their suitable weights. Thus the information collected from different sources with respect to water quality measurement, modeling, prediction, simulation, optimization can be integrated effectively under fuzzy multiple-usage framework which is missing in fixed crisp weighing system otherwise. The multiple-attribute analysis approach presented herein evaluates water quality index derived from various water quality parameters which are essentially examined against a number of standards to provide the quality attainments.

The importance of fuzzy set theory lies in the fact that the inputs given by the decision makers are subjective in nature. Thus fuzzy membership functions help in capturing the vagueness of these inputs. The present case study on Haora river has demonstrated applicability of both the methods. It was found that FCWQIs at four sampling stations out of ten were very high thus indicating very poor quality of water. The FCWQI was lowest at the station located at the most upstream part of the river. Through this method, it is possible to monitor the quality of water at any station over the years. A threshold value of FCWQI can be fixed by the concerned authority and remedial measures may be initiated as soon as the score goes below that value at a station. The sensitivity analysis helps in identifying the parameter which needs to be improved and also to what extent to make the overall quality of water over the threshold value. It clearly demonstrates how changes in water quality parameters have impacted the final score of the water quality index. This kind of analysis helps to understand the stability of the indices, which in turn helps to identify the parameters, the quality of which is to be changed and by what extent to improve the overall quality of water. Accordingly, alternative plans can be prioritized.

The methodology adopted in deriving FCWQI requires deliberations with all concerned stakeholders to understand their experience, preferences and expectations so that water quality evaluation system can be useful. In the present study the quality of water was determined from the point of domestic usage, but may also be used for other purposes as well. The methodology suggested in the study has numerous applications and can be used for formulating effective water management strategies such as prioritization of the water quality management plans, studies on impact analysis, prediction of water quality and so on.

As far as improvement in water quality of Haora river is concerned, it could be improved by preventing pollution caused along the river and implementing eco-friendly practices with viable solutions at brick fields situated along the river. In short term, the measures like the construction of baffle walls in the drains to trap solid wastes from flowing into the river and construction of obstruction walls, (wire mesh barricades on the drains, bridges and on the bank of small drains) along the drains to stop people from throwing garbage into the drains can be taken into consideration so that total coliform, BOD_5 concentration of the wastewater of the drain can be reduced. Mild steel gratings can also be provided to remove and collect suspended solids. Large scale afforestation program in the upstream will arrest soil erosion and reduce sedimentation load on the river to a considerable level. Thus the absorption and retention of water by soil and vegetation could take place. Vegetation cover at upstream of river will also slower down the surface runoff and ensure consistent supply of water to the river.

To save the lifeline of Agartala city, the river Haora, some immediate corrective actions should be taken considered. All stakeholders must join together to save the river. Some of the potential measures are mentioned below which can be addressed immediately:

i. upper catchment area of the river must be free from any kind of deforestation which will help for sustain water supply and also control excess sediment supply into the river.
ii. normal flow in the river should be maintained by preventing illegal and uncontrolled lifting of water and if require, it must be banned.
iii. natural grading of the river is severely affected because of the unscientific way of collection of sands from the river bed. Dredging to be done to maintain proper gradient along the river.
iv. river course is being shifted due to uncontrolled excavation of sands from both sides of the river valley. It has to be prevented immediately.
v. flood plains along the river are encroached due to activities related to brick fields. This is one of the main reasons of damage in the river course. Therefore activities related to brick fields should be stopped or they should be moved away at least 1km from the river course.
vi. all permanent structures like market place, motor stands etc. and settlements need to be shifted away from the river valley.
vii. untreated waste water should not be discharged into the river and waste water treatment plant need to be constructed in all identified locations. Only treated and monitored waste water can be discharged in the river.
viii. use of fertilizers, herbicides, pesticides and other insecticides along the river course must be regulated and monitored to prevent any pollution. Municipal solid waste and any other toxic waste cannot be allowed to be dumped in the river. Massive and continuous afforestation activities throughout year along the river course need to be taken up.
ix. people are to be sensitized about the life and importance of river for which massive awareness programme need to be taken up in the river course area.

CHAPTER 4

GROUNDWATER QUALITY ASSESSMENT IN HAORA RIVER BASIN

4.1 Introduction

Groundwater is a finite resource though it is replenishable through recharge from the rainfall, surface runoff, subsurface runoff and base flow. The seepage from water body can also contribute to the groundwater recharge. At present ground water in Haora river basin is mostly used for domestic and agricultural purposes. As per the report of Central Ground Water Board (CGWB), New Delhi, it has been found that ground water draft for irrigation is about 57% of the total ground water draft whereas remaining 43% accounts for drinking and other domestic purposes. Though the basin has irrigation potential of 20361 ha, about 19511 ha (≈96%) has to be fulfilled by the surface water schemes and remaining 4% or so has to be irrigated by groundwater sources. It is thus established that the ground water utilization is still in the initial stage in this basin.

Though the status of groundwater is better compared to that of surface water in Haora River basin, Agartala is already facing noticeable scarcity of ground water in several pockets due to the erratic and non-productive monsoon seasons in the recent past. Such trends in scarcity have been further compounded with an unprecedented requirement for fresh water owing to increase in population, growth in industrialization and low retention capacity of soils in this basin. Thus a distinct backdrop has been created wherein managing groundwater resources are posing a strategic and immediate challenge that need to be studied and addressed for the holistic development of Agartala. Further, it is becoming increasingly obvious that the availability and quality of groundwater will be impacted to a degree significant enough to be the precursor to various water borne epidemics. Safe drinking water is as essential as the clean air (TWAS, 2002). It is well known that groundwater contamination is harmful not only to crops and industrial products, but also to human health. It, therefore, becomes a social and academic exercise to monitor the quality of groundwater regularly and to devise a mechanism to protect it

(Singh and Singh, 2002; Srinivas et al., 2015). A timely study of groundwater quality assessment is not only essential but instrumental in taking appropriate remedial action plans for improving the quality.

In this chapter Groundwater Water Quality Index (GWQI) has been derived keeping in view of groundwater suitability for drinking purposes initially using Simple Additive Weighting (SAW) method which has later been compared with another method based on fuzzy set theory. In addition, the polluting parameters at each selected station have also been analyzed using Geographical Information System (GIS). The GWQI has been developed at each of the ten selected sampling stations located in the Haora River basin. The groundwater samples at these 10 sampling stations have been collected to perform physicochemical analysis of 10 important water quality parameters. These are pH, Total Hardness, Ca, Mg, Total Alkalinity, Nitrate Nitrogen, Chloride, Iron, Total Dissolved Solids (TDS), and Electrical Conductivity. The observed values of these parameters are compared with standards for drinking water quality as specified by Bureau of Indian Standards (BIS).

The groundwater samples collected from these stations are also classified by fuzzy comprehensive assessment model as per the criteria suggested by Singh et al. (2015). Base map of Haora river basin has been collected from the Tripura State Remote Sensing and Space Application Agency and sampling location coordinates have been taken using GPS. ArcGIS® Software (v 9.3) has been used for developing the thematic maps at various stages of this study.

The observed values collected through water quality testing are used to create attribute-database for preparing spatial maps. These maps would be beneficial to understand existing status of groundwater quality in some selected area of river basin. Finally, conclusions of this study have been drawn. The analysis of results concludes that that all sampling stations have high values of iron content in groundwater and therefore they require some degree of treatment before its consumption.

4.2 Background

In the past, various methods have been applied to determine status of groundwater quality by incorporating the impact of various water quality parameters. The groundwater quality indices are developed to integrate effects of important environmental indicators into a single value which can represent one of the possible grades of quality of water viz., very poor, poor, fair, good or excellent. These groundwater quality indices (GWQI) are generally derived by analyzing impact of pollutants on various water quality parameters so that sampling sites can be prioritized based on the GWQI score (Fulazzaky 2009; Singh and Ghosh, 1999; Srinivas et al., 2015).

Although a wide spectrum of literature is available for groundwater quality assessment, analysis and management as cited chapter 2, it is essential to perform groundwater quality assessment in Indian context especially in north-eastern region of the country. A timely study of groundwater quality assessment will not only essential but instrumental in taking appropriate remedial action plans for improving the quality, especially handling uncertainties components under different circumstances.

Keeping in view of above facts, it is felt to develop a methodology for assessment of status of groundwater quality in the north-eastern region of the country along Haora River. GWQI has been derived initially using Simple Additive Weighting (SAW) method which has later been compared with another method based on fuzzy set theory. In addition, the polluting parameters at each selected station have also been analyzed using GIS.

4.3 Description of Groundwater in Haora River Basin

All ten sampling stations are situated in the flood plains of the Haora River in the state of Tripura as shown in Figure 4.1. They receive an annual average rainfall of 1927 mm. The geological formations in the area consist of semi-consolidated rocks of friable sandstone, sandy shale of tertiary age. The unconfined aquifer is mainly tapped through shallow wells with a discharge of 5 to 15 Liters Per Second (LPS) in the valley areas whereas in the sandstone, the yield varies from 2 to 4 LPS. Presently, Tripura state has been categorized as safe zone by the CGWB.

Groundwater development in the deeper aquifers has also been established through construction of deep tube wells, the yield of wells tapping the sandstone areas varies from 25 to 40 LPS. There is no over exploited, critical and semi-critical zone. For artificial recharge (AR) to groundwater the numbers of feasible AR structures are: 300 check dams, 500 hydraulic-weirs, 1000 gabion structures, 240 roof-top water harvesting and developments of 100 springs.

Presently, the total irrigation utilization potential of Tripura is approximately 52616 ha. Groundwater in the study area under Haora river basin has shallow aquifer which exists mainly either in unconfined or semi-confined to confined aquifers. Generally, the aquifers of the study area are classified into two major categories: (i) shallow aquifer having depth upto 50 m bgl and (ii) deep aquifer containing depth ranging from 50 to 200 m bgl (Reddy and Rao, 2011). The depth to water levels in the phreatic aquifers ranges from less than 1 m bgl to more than 5 m bgl or so in the Haora River basin area. In general ground water movement is in west-north westerly direction.

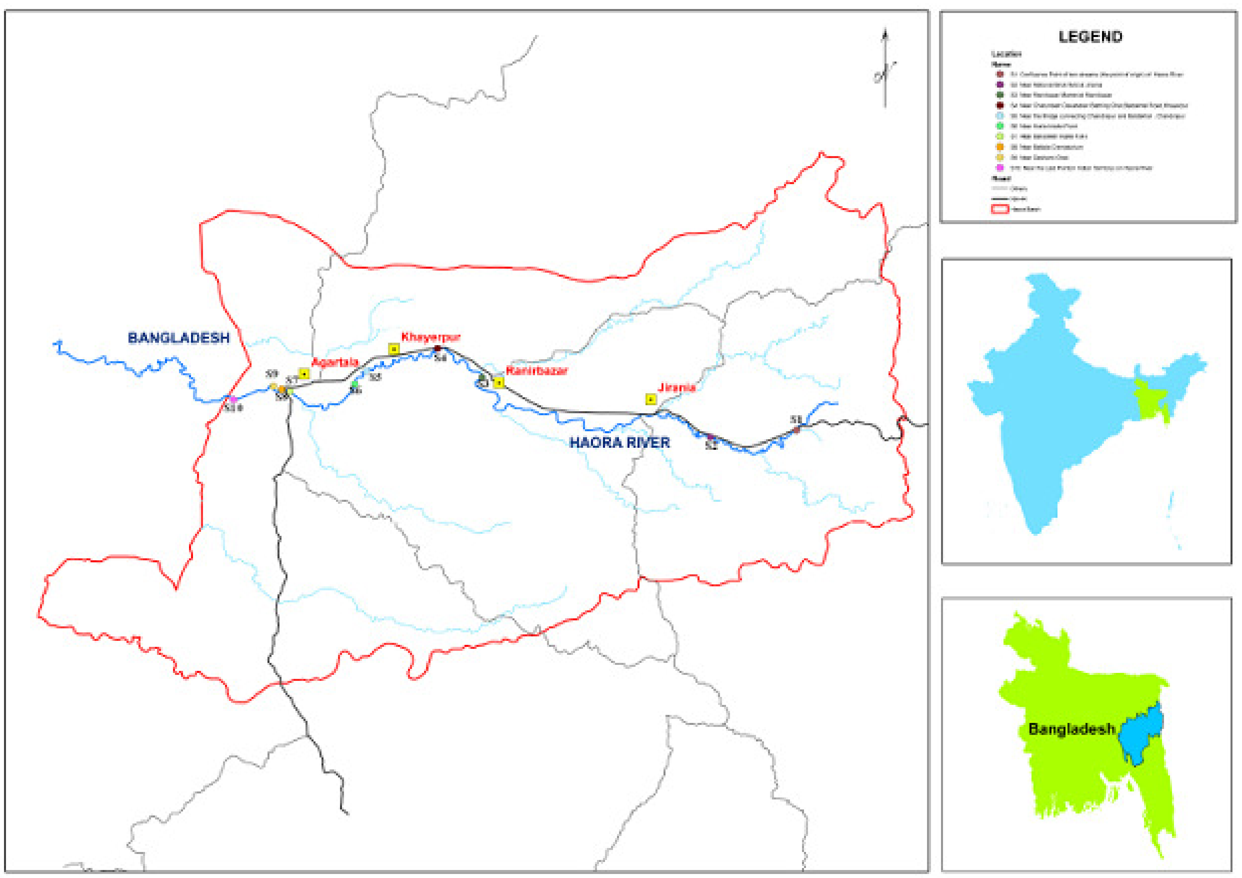

Figure 4.1: Location of Sampling Stations of Haora River Basin

4.4 Methodology

In this study an integrated Groundwater Quality Index (GWQI) has been developed to assess quality of groundwater at different locations in Haora River basin by using two aggregating methods of Mult-Attribute Decision Making (MADM) process, viz. Simple Additive Weighting Method and Fuzzy Comprehensive Assessment Method (Singh, 2008). To develop the integrated GWQI, the complete methodology has been summarized in the form of a flowchart as shown in Figure 4.2.

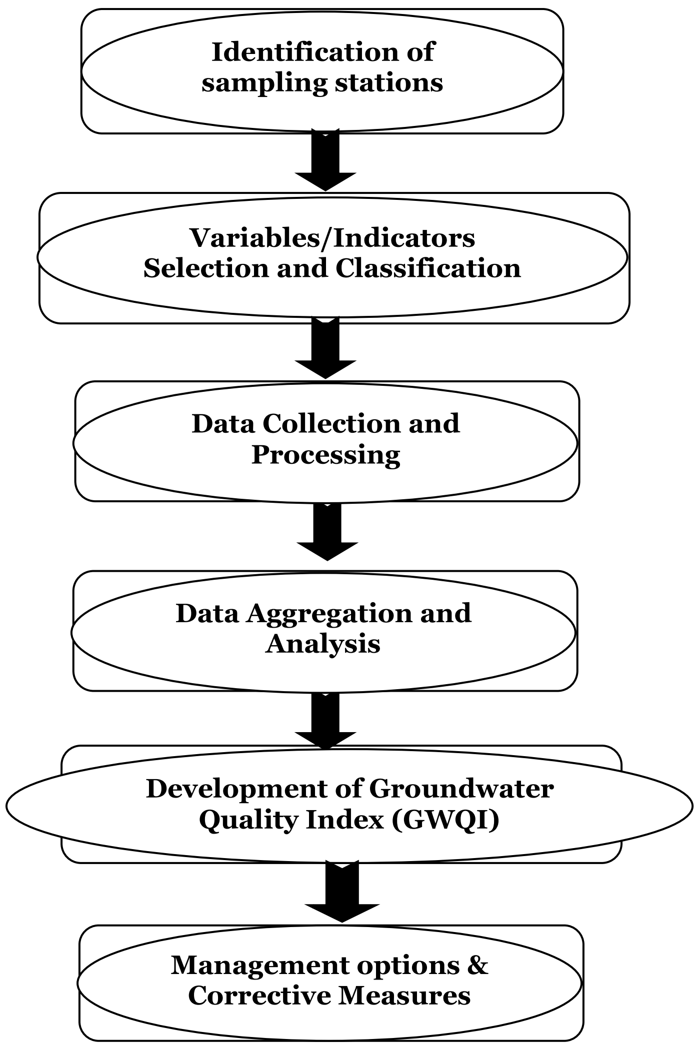

Figure 4.2: GWQI development process in Haora River Basin

4.4.1 Groundwater Quality Index using Simple Additive Weighting Method

4.4.1.1 Parameters for GWQI formulation

The selection of groundwater quality parameters (indicators) is critical. A list of indicators associated with groundwater samples were identified based on its different beneficial usage. Keeping in view of the importance of groundwater, samples have been collected from ten sampling stations during April, 2011. Groundwater samples were analyzed in terms of 10 parameters. These were pH, Total Hardness, Ca, Mg, Total Alkalinity, Nitrate Nitrogen, Chloride, Iron, Total Dissolved Solids (TDS), and Electrical Conductivity.

The samples of groundwater were taken from 10 bore-wells chosen at different sampling sites in Haora river basin. All the samples were preserved in dark boxes immediately just after collection which were analyzed in the laboratory on same day. The potable HANNA pH meter with model no. HI 28129 was used for measurement of pH whereas TDS/Conductivity meter with model no. HACH KIT 44600-00 was used for measuring TDS. The water samples were analyzed chemically using Spectrophotometer (Model 21D, USA) and titrimetric method as specified by USEPA (1974) and APHA (1980). The important water quality parameters which influence water quality for a given usage have been considered as the criteria for evaluating overall groundwater quality index with their relative degrees of importance because each of these parameters has its own significance on overall quality of water. Finally status of groundwater quality has been evaluated as explained in the subsequent sections.

4.4.1.2 Weighting of Water Quality Parameters

The importance weight of any i^{th} parameter (w_i) is assigned on the basis of relative importance of parameter among all given parameters for a given beneficial use. This can be determined either from the opinion of subject experts working for water quality management or by performing pair-wise comparisons of water quality parameters. The Analytical Hierarchy Process (AHP) has been applied to evaluate importance weight of each parameter (Saaty 1980). Over the years, AHP has been widely applied in real-life problems to weigh each criteria using various commercially available software packages as explained in literature review (Hastak, 1998; Hill et al., 2005; Marinoni, 2004; Thirumalaivasan et al., 2003; Ying et al., 2007). AHP performs pairwise comparisons between each pair of attributes on the basis of evaluation "how important one attribute is in comparison to other" done by the decision maker. The AHP algorithm is consists of following steps:

- A hierarchy of decision criteria (attributes) is developed and the alternative courses of actions are defined by developing interrelationships among these attributes.
- Relative weights of the attributes are evaluated by performing separately pair-wise comparisons for each set in the hierarchy and outcome of it is recorded in the form of a decision matrix.
- Relative weights of all criteria/attributes are evaluated by normalizing each column of the "decision matrix". An average of all elements of a column of the normalized matrix provides relative weight of respective criteria/attribute.
- Once relative weights are obtained for each criterion/attribute and priority vector's scores are generated locally corresponding to a given hierarchy level, the final score of each criteria/alternative is evaluated. These scores suggest ranking of each criteria/alternative. Aggregation is performed by multiplying score of local priority vectors of each set of criteria with the relative weights of the respective criteria corresponding to immediate previous hierarchy level.
- *Consistency Ratio*" (CR) should be checked to verify whether pair-wise comparisons performed in step 2 above are consistent enough because an absolute consistency is desirable for pair-wise comparison. On the basis of numerous empirical studies, it is suggested that the CR must be less than or equal to 0.10 so that inconsistency can be acceptable within the tolerable limit (Saaty, 1980).

In this study, the pair-wise comparisons of groundwater quality parameters have been performed by asking opinion of subject experts' about relative importance of any i^{th} water quality parameter over to j^{th} water quality parameter. The weightage of individual parameters has been obtained by the "*scale of relative importance*" using Saaty's (1980) 9-point scale as given in Table 4.1.

Table 4.1: Saaty's Original scale for pair-wise Comparison (Source: Saaty, 1980)

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	Intermediate values between the two adjacent judgments
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	Intermediate values between the two adjacent judgments
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	Intermediate values between the two adjacent judgments
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	Intermediate values between the two adjacent judgments
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If i^{th} activity has one of the above non-zero numbers assigned to it when compared with j^{th} activity , then j^{th} activity has the reciprocal value when compared with i^{th} one.	
1.1-1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

All water quality parameters should be compared with each other which can be expressed in the form of a decision square matrix, A. Any element a_{ij} of this pair wise comparison matrix represent the relative weight of the i^{th} water quality parameter in comparison with j^{th} water quality parameter so that $a_{ij} = 1/a_{ji}$, for all $i \neq j$, and $a_{ii} = 1$. They should also satisfy condition $a_{ik} = a_{ij}a_{jk}$ for all i, j, and k to produce consistency in the allocated weights. Such a matrix might exist if the a_{ij} are calculated from observed data collected from the field. It is also required to determine a vector, ω, of dimension n to satisfy condition of $A\omega = \lambda\omega$. In any matrix with this condition, ω is called as an eigenvector (of dimension n) and λ is known as Eigen value. If matrix is consistent, it satisfies the condition of $\lambda = n$.

While performing pair-wise comparisons among different attributes, it has been observed that many times human decisions are not consistent. Hence they do not satisfy the condition of $a_{ik} = a_{ij}a_{jk}$ which indicates that vector, ω, must satisfy another condition viz. $A\omega = \lambda_{max}\,\omega$ with $\lambda_{max} \geq n$. Any deviation in a value of λ_{max} with n is an indicator of the inconsistency made while performing pair-wise comparisons. Whereas if $\lambda_{max} = n$, it signifies that pair wise comparisons among all attributes are consistent. The consistency of pair-wise comparisons can be verified by deriving a Consistency Index (CI) using equation (4.1) which has been suggested on the basis of performance of random matrices with large samples by Saaty (1980). Finally, Consistency Ratio (CR) is obtained using equation (4.2). Pair-wise comparisons can be considerded consistent enough if consistency ratio does not exceed 0.1 as proposed by Saaty (1980). A constancy ratio of zero indicates that the decisions are perfectly consistent.

The step by step procedure for applying AHP methods is explained below:

Step 1: Considering expert's opinion, pair-wise comparisons of all water quality parameters with respect to a given usage are performed using Table 4.1 on Saaty’s 9-point scale. In this process, an expert provides relative rating of i^{th} water quality parameter by comparing it with j^{th} water quality parameter for each pair (i, j), considering only two criteria at a time. The relative weights of each water quality criteria are shown in the Table 4.2. The reciprocal ratings are shown in fractions. As in this case study there are ten water quality parameters, a 10x10 matrix has been derived while performing pair-wise comparisons which is given in Table 4.2.

Table 4.2: Pay-off matrix for Pair-wise comparison of Water Quality Parameters

Water Quality Parameters	Conductivity	TDS	pH	Total Hardness	Ca	Mg	Total Alkalinity	Nitrate Nitrogen	Chloride	Iron
Conductivity	1.00	0.50	0.33	0.33	0.33	0.33	0.50	0.20	0.25	0.20
TDS	2.00	1.00	0.25	0.50	0.50	0.50	0.50	0.14	0.17	0.33
pH	3.00	4.00	1.00	3.00	3.00	3.00	1.00	0.20	0.25	2.00
Total Hardness	3.00	2.00	1.00	1.00	1.00	1.00	2.00	0.14	0.20	0.33
Ca	3.00	2.00	1.00	1.00	1.00	1.00	1.00	0.14	0.20	0.33
Mg	3.00	2.00	1.00	1.00	1.00	1.00	1.00	0.14	0.20	0.33
Total Alkalinity	3.00	2.00	1.00	1.00	1.00	1.00	1.00	0.50	0.25	2.00
Nitrate Nitrogen	5.00	7.00	7.00	7.00	7.00	7.00	7.00	1.00	1.00	2.00
Chloride	4.00	6.00	5.00	5.00	5.00	5.00	5.00	0.50	1.00	1.00
Iron	2.00	3.00	3.00	5.00	3.00	3.00	3.00	0.33	0.50	1.00

Step 2: The normalized values of pair-wise comparison matrix is formulated by dividing each element of the matrix (i.e. Table 4.2) with sum of elements of respective columns. Finally, an average of all elements of a column of the normalized matrix provides relative weight of respective criteria/attribute which will known as weight vector. A commercially available software viz., Expert Choice developed by Expert Choice Inc., has been applied to complete all steps of AHP methodology for this case study. Weights corresponding to water quality parameters are evaluated with this approach which is shown in Figure 4.3.

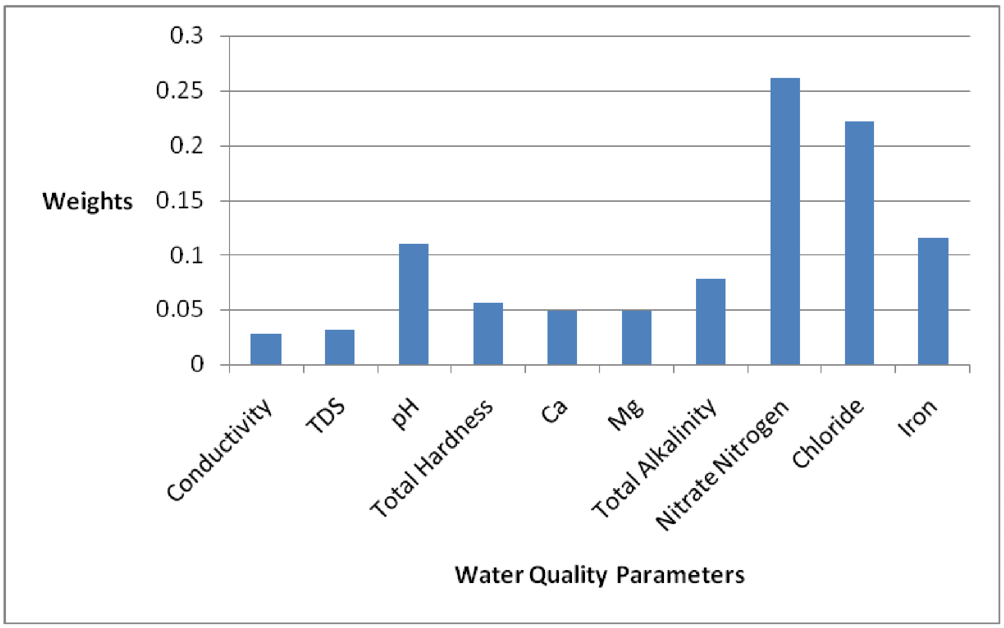

Figure 4.3: Final weights of Groundwater Quality Parameters

Step 3: The level of inconsistency is checked using equations (4.1) and (4.2) given below:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{(n-1)} \quad (4.1)$$

$$\mathrm{CR} = \frac{CI}{RI} \quad (4.2)$$

Where, CI is the inconsistency index, n is the dimension of payoff matrix which is same as number of water quality parameters to be considered for the analysis, λ_{max} is the true principal Eigen value which is evaluated by totaling the products of the column sums of the comparison matrix and the corresponding components of the normalized weights vector. The value of RI is dependent of the dimension of the matrix as specified in Table 4.3, in which the first row deals with the dimension of a given matrix, and the second row corresponds to index of consistency with respect to that dimension.

Table 4.3: Values of RI

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

In present case study, $CR = \frac{11.07437 - 10}{(10-1) \times 1.49} = 0.080 < 0.10$ (or less than 10%) so the evaluations are consistent.Thus the final weights (w_i) considered for each individual water quality parameters are same as given in Figure 4.3. Column 2 of Table 4.6 also represents importance weights of these ten water quality parameters on a scale of 0-1, with the understanding that 0 and 1 represent '*least important rating*' and '*extremely important rating*' respectively. The results shown in Table 4.6 shows that nitrate-nitrogen has the highest weight followed by chloride, iron and pH.

4.4.1.3 Evaluation of Rating of Groundwater Quality Parameters

Water quality parameters have been considered as the criteria for evaluating overall GWQI on the basis of their relative degrees of importance. These parameters are chosen based on various factors as specified earlier in this chapter.

In the present study, groundwater quality is assessed with respect to human consumption especially for drinking water. Ten water quality parameters were found suitable to derive a consistent GWQI. The experimental observed values of different water quality parameters collected from the groundwater at 10-sampling stations are shown in Table 4.4. In addition to the parameters mentioned in the Table 4.4, colour, odour, arsenic, sulfate, fluoride etc. were also measured but were found very low and almost same in all the stations. Therefore, they have been considered to have no significance for the present study.

The overall score of GWQI at a sampling site should be evaluated by converting rating of all the parameters on the same scale because many water quality parameters may have different rating scales due to their different measurement units (Hebert and Keenleyside, 1995). This can be done by normalizing actual measured values with standard values prescribed by the Bureau of Indian Standard (BIS) before aggregating (Zeleny, 1982; Chang and Yeh, 2001). Thus normalized rating of any i^{th} parameter (q_i) can be evaluated using a linear transformation function (which is also called as utility function) as given by equation (4.3):

$$q_i = \left(\frac{c_{i,actual} - c_{i,ideal}}{c_{i,standard} - c_{i,ideal}} \right) \times 100 \qquad (4.3)$$

In equation (4.3), $c_{i,actual}$, $c_{i,standard}$ and $c_{i,ideal}$ are the actual observed value, standard value and ideal value of the i^{th} water quality parameter respectively. The standard values for drinking water quality standards with respect to an individual parameter have been considered as prescribed by the BIS (1991).

In equation (4.3), $c_{i,actual}$ is the actual measured value of the i^{th} water quality parameter, $c_{i,standard}$ is the standard value of the i^{th} water quality parameter [as prescribed by the BIS (1991) drinking water quality standards for individual parameter], and $c_{i,ideal}$ is the ideal value (for pH, it is considered as 7; and for all remaining parameters, as zero). The standard values ($c_{i,standard}$) considered for each individual water quality parameters have been shown in Table 4.4. Equation (4.3) normalizes the effect of all water quality parameters and evaluates the normalized values indicating that "*greater the deviation from the minimum value- worse the impact*" (hence lower value is preferred) as shown in Table 4.5.

Table 4.4: Observed values of Groundwater Quality Parameters collected from Sampling Stations S1 to S10 of Haora River Basin, Tripura

Sl. No.	**Water Quality Parameters**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**Standard Value ($c_{i,std}$)**
1.	Total Dissolved Solid (mg/l)	110	120.0	197.0	83.0	282.0	80.0	144.0	159.32	194.0	206.50	**200**
2.	pH	7.54	6.5	6.9	6.6	6.9	6.0	6.9	7.74	7.0	7.62	6.5-8.5
3.	Total Hardness (mg/l)	48.04	64.0	78.72	52.70	78.72	40.0	66.81	70.85	76.35	78.29	300
4.	Ca (mg/l)	10.15	16.03	14.57	9.16	14.57	8.0	11.66	12.65	16.03	14.23	75
5.	Mg (mg/l)	7.05	5.8	10.18	7.29	10.18	4.8	9.16	6.92	8.84	7.34	30
6.	Total Alkalinity (mg/l)	49.8	90	48.50	30.70	56.52	56.0	34.50	50.69	42.16	48.35	200
7.	Nitrate Nitrogen (mg/l)	0.013	0.012	0.92	0.35	1.09	0.015	1.02	0.79	0.96	0.68	50
8.	Chloride (mg/l)	14.40	11.3	5.92	2.46	8.76	0.6	7.30	12.20	5.84	12.46	250
9.	Iron (mg/l)	1.52	2.26	3.02	2.58	3.80	2.37	6.70	2.32	2.58	0.52	0.3
10.	Conductivity (micro-mhos/cm)	172	160	303	128	433	110	221	256	298.5	307.26	500

4.4.1.4 Evaluation of the Groundwater Quality Index (GWQI)

After identifying all relevant indicators, the scores of each indicator were integrated into an additive single-index value at particular sampling station. The value can be viewed as an overall assessment of groundwater quality at the sampling station, reflecting geological formations, depth of water, aquifer characteristics, management practices or land use effects on groundwater. As the weighted method has been popularly applied for solving the multi-criteria analysis problems (Guh, 1997; Byeong-Seok and Park, 2008; Chang, 2013), this study evaluates the total scores for each station according to the normalized values of water quality parameter and their weights. The total score for each station is calculated by equation (4.4).

A higher GWQI score indicates poorer overall quality of water at that station, and a GWQI score ranging from 0 to 0.25 classifies groundwater quality as very good whereas if it ranges from 0.76 to 1.00, it indicates that water quality is very poor. Thus, the water quality improvement is required in priority at those stations. Mathematically, the simple additive method to calculate GWQI is expressed using equation (4.4):

$$GWQI = \sum_{i=1}^{m} \frac{w_i q_i}{w_i} \qquad (4.4)$$

where, m is number of criteria/attribute which define overall GWQI (in this case they are water quality parameters), w_i is weight of i^{th} water quality parameters and q_i is rating score for i^{th} water quality parameters obtained from actual measured values at a given sampling site. If the scale for weight is such that $\sum_{i=1}^{n} w_i = 1$, the GWQI can also be expressed using equation (4.5):

$$GWQI = \sum_{i=1}^{m} w_i q_i \qquad (4.5)$$

The weighs derived in earlier sections (Figure 4.3) for each water quality parameter [i.e. W = $\{W_1, W_2, W_3, \ldots, W_{10}\}$ = {0.031, 0.11, 0.056, 0.049, 0.049, 0.078, 0.262, 0.222, 0.115, 0.028} where $0 \leq w_i \leq 1$], have been used to calculate GWQI using equation (4.5). The results of GWQI with respect to all ten sampling stations are shown in Table 4.6 which is a dimensionless number.

Table 4.5: Computation of Normalized Rating of Water Quality Parameters

Water Quality Parameters	Weights AHP	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10
Total Dissolved Solid	0.031	0.55	0.60	0.99	0.42	1.41	0.40	0.72	0.80	0.97	1.03
pH	0.11	0.36	0.50	0.10	0.40	0.10	1.00	0.10	0.49	0.00	0.41
Total Hardness	0.056	0.16	0.21	0.26	0.18	0.26	0.13	0.22	0.24	0.25	0.26
Ca	0.049	0.14	0.21	0.19	0.12	0.19	0.11	0.16	0.17	0.21	0.19
Mg	0.049	0.24	0.19	0.34	0.24	0.34	0.16	0.31	0.23	0.29	0.24
Total Alkalinity	0.078	0.25	0.45	0.24	0.15	0.28	0.28	0.17	0.25	0.21	0.24
Nitrate Nitrogen	0.262	0.00	0.00	0.02	0.01	0.02	0.00	0.02	0.02	0.02	0.01
Chloride	0.222	0.06	0.05	0.02	0.01	0.04	0.00	0.03	0.05	0.02	0.05
Iron	0.115	1.52	2.26	3.02	2.58	3.80	2.37	6.70	2.32	2.58	0.52
Conductivity	0.028	0.34	0.32	0.61	0.26	0.87	0.22	0.44	0.51	0.60	0.61

Table 4.6: Computation of GWQI based on observed data

Water Quality Parameters	Weights	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Total Dissolved Solid	0.031	0.017	0.019	0.031	0.013	0.044	0.012	0.022	0.025	0.030	0.032
pH	0.11	0.040	0.055	0.011	0.044	0.011	0.110	0.011	0.054	0.000	0.045
Total Hardness	0.056	0.009	0.012	0.015	0.010	0.015	0.007	0.012	0.013	0.014	0.015
Ca	0.049	0.007	0.010	0.010	0.006	0.010	0.005	0.008	0.008	0.010	0.009
Mg	0.049	0.012	0.009	0.017	0.012	0.017	0.008	0.015	0.011	0.014	0.012
Total Alkalinity	0.078	0.019	0.035	0.019	0.012	0.022	0.022	0.013	0.020	0.016	0.019
Nitrate Nitrogen	0.262	0.000	0.000	0.005	0.002	0.006	0.000	0.005	0.004	0.005	0.004
Chloride	0.222	0.013	0.010	0.005	0.002	0.008	0.001	0.006	0.011	0.005	0.011
Iron	0.115	0.175	0.260	0.347	0.297	0.437	0.273	0.771	0.267	0.297	0.060
Conductivity	0.028	0.010	0.009	0.017	0.007	0.024	0.006	0.012	0.014	0.017	0.017
	GWQI	**0.30**	**0.42**	**0.48**	**0.40**	**0.59**	**0.44**	**0.88**	**0.43**	**0.41**	**0.22**
	Rank	**2**	**5**	**8**	**3**	**9**	**7**	**10**	**6**	**4**	**1**

The groundwater quality index (GWQI) derived for each sampling site represents the status of groundwater quality at that station. The GWQI score closer to zero indicates good quality of ground water, and as its value increases, water quality becomes poor in context to human consumption. The water quality status can be categorized into five classes as given in Table 4.7. The computed GWQI at chosen sampling sites have been compared with these five classes of GWQI. The stations belonging to lower GWQI are categorized as very good quality whereas the sampling stations with highest GWQI correspond with poor quality and require a higher attention to improve overall water quality than other areas.

Table 4.7: Classification of GWQI in Haora River Basin, Tripura

Sl. No.	GWQI	Ground Water Quality Status
1.	0-0.25	Very good
2.	0.26-0.50	Good
3.	0.51-0.75	Poor (Moderately polluted)
4.	0.76-1.00	Very poor (Severely Polluted)
5.	>1.00	Unfit for consumption

Table 4.6 shows the ranking of status of ground water quality for each station. The results indicate that the overall water quality ranges from 0.22 at station S10 to 0.88 at S7 which reveal a specific trend of fluctuations. The sampling station 10 (i.e. the last sampling station located in Indian Territory on Haora River Basin) has minimum score of 0.22 signifying very good quality and is most suitable for drinking water supply. As the values of conductivity, TDS, total hardness, iron, chloride, ions of calcium and magnesium are low at this sampling station, they lower GWQI score in overall perspective. However, sampling stations S5 and S7 exhibit poor and very poor quality of groundwater respectively. The higher values of GWQI at these sampling sites have been found due to the presence of elevated iron content in the groundwater leading to reduction in water quality at these stations. The iron content is also released slowly from geologic materials. The excess content of iron exceeding 1 mg/l in groundwater occurs generally in geologic formations constituting with higher iron content, such as Cretaceous and Precambrian deposits. The presence of iron in the groundwater may be due to iron minerals which exist in the rocks/soils, corroded iron-fitting of water supply and wastewater disposal

systems, pollution by organic wastes. Some of the rock types especially dark muddy lime stones, shale and sandstones have very high iron concentrations. Groundwater from peat areas show evidences of having higher iron content. The organic wastes from septic tank systems, sewerage systems and other sources form carbon dioxide and oxygen deficient conditions which allow wastewater to percolate into the groundwater along with iron content.

Iron is known as secondary contaminant which affects aesthetic aspects of groundwater especially taste and appearance rather than producing detrimental effect on health. However, it may lead to liver disease and gastroenterological problems if groundwater with high iron content is consumed for long time. When iron-prone water is used for tea, coffee, or alcoholic beverages, they have unpleasant taste with a black and inky appearance. Vegetables cooked in iron-rich waters become dark and unappetizing (Hem, 1970; Lee and Werner, 1960; Morris, 1952). The remaining sampling stations [at Confluence (S1), near national brick field at Jirania (S2), near Ranir Bazar Market (S3), near Chaturdash Devata Bari Bathing Ghat, Khayerpur (S4), near Aralia Water Intake Point (S6), near Battala Crematorium (S8) and near Dashami Ghat, (S9)] show good groundwater quality. However, ordinary reduction in water quality has been observed at these sites compared to sampling site S10 as given in Table 4.6.

4.4.2 Groundwater Quality Index using Fuzzy Theory

Fuzzy Set Theory (FST) has been proven to be an effective method to analyze many real-life decision-making problems especially when there exists no clear boundary in classifying their objects. Fuzzy set theory describes the imprecisely defined “classes” by deriving membership functions for these classifications.

The membership functions can be derived by expressing qualitative terms into a number ranging from zero (absolutely not belonging) to unity (fully belonging) (Borja et al., 2007; Wallin et. al; 2003). For instance, if we want to assess quality of groundwater in terms of two qualitative terms i.e. good and bad. The ambiguity may occur in classifying these two qualitative terms because water which is good for some body may be bad for others.

A generalized approach to apply fuzzy concepts in groundwater quality assessment has been discussed in following sections.

Let U = {u} represents a finite set elements wherein grade of membership function is denoted as $\mu_G(U)$. The value of $\mu_G(U)$ gives the degree of belongingness of the element U to the membership function of good grade "G" (say Good). For example U is the set of the different assessment factors representing the status of overall water quality at different sampling sites. The function $\mu_G(U)$ can be assigned any value between 0 and 1. There are mainly seven components of the proposed fuzzy comprehensive assessment model. These include assessment criterion set, weights set, assessment class set, membership function, fuzzy relation matrix, fuzzy combination and fuzzy assessment matrix which have been explained in the following sections.

4.4.2.1 Assessment criterion set

The first step in assessing status of water quality is to identify prominent water quality parameters which represent state of water quality for a given use. These water quality parameters are used to evaluate a score corresponding to a grade in terms of membership functions. It will enable a decision maker to demonstrate how these water quality parameters impact the status of overall quality of groundwater at a given station (Sharifi and Herwijnen, 2003; Singh and Vidyarthi, 2008).

The set U is described as an assessment factor set representing water quality parameters to be determined and is represented as $U = \{U_1, U_2, U_3 \ldots U_m\}$. These factors are important in the overall evaluation process. In this study, ten important water quality parameters (assessment factor) have been selected to assess water quality status corresponding to specified class of assessment.

4.4.2.2 Assessment class set

Bureau of Indian standard has recommended three grades of classification of water quality while formulating the specification for drinking water (IS 10500: 1991). The first grade deals with the desirable limit which satisfies the aspiration level of water quality managers and water users up to the maximum extent. The second grade deals with the values which are in excess than those specified under 'desirable limit' causing water unsuitable, but still may be tolerated up to the limits prescribed under 'permissible limit in the absence of alternate source' in the IS code. However, third grade comprises of any value above permissible limit which makes the water quality unfit for domestic uses and will have to be rejected. This classification can be represented by the set G consisting of all evaluation classes such that $G = \{G_1, G_2, \ldots, G_n\}$ where $G_1, G_2, \ldots, G_n$ are evaluation classes for n grades. For example, three grades in the assessment can be given as G= {desirable, permissible, unfit}.

These three grades describe the significance of all 10 water quality parameters to assess groundwater quality at a sampling station. The classification of these grades with respect to each assessment factor is given in Table 4.8.

Among them, G_1 stands for the desirable condition demonstrating the best water quality expressed in terms of a given parameter. In this case, water quality is very good and there is very little scope for improving status of water quality. Therefore, the situation of water resources supply is optimistic; G_3 stands for the worst situation indicating that water quality has degraded significantly and hence is unfit for consumption. The situation of G_2 is between G_1 and G_3 representing a level of degradation of water quality to a moderate extent, but still has certain potential for its consumption after some degree of treatment.

4.4.2.3 Weights set

The impact of water quality parameters on overall evaluation of quality of water varies greatly depending on their importance and characteristics, a weight set, $W = \{W_i,$: i is a natural number and $1 \le i \le m$ }, representing the weight of each water quality parameter.

4.4.2.4 Fuzzy relation matrix

An element of a relation matrix R of a fuzzy set is described by a membership function $\mu_{ij}(x)$ where x is the actual value of a given criterion. The element $\mu_{ij}(x) = \mu_R(U_i, G_j)$ (i and j are natural numbers; $i \in [1, m]$, $j \in [1, n]$); $\mu_{ij} \in [0, 1]$ of the relation matrix R is the value of membership function of any criterion U_i, with respect to an evaluation class G_j. If the value of membership for a given criteria 'm' with respect to evaluation class 'n' is assumed as $\mu_{mn}(x)$, the relation matrix R of a fuzzy set can be expressed using equation 4.6:

$$R = \begin{bmatrix} \mu_{11}(x) & \mu_{12}(x) & \mu_{13}(x) & \ldots & \mu_{1n}(x) \\ \mu_{21}(x) & \mu_{22}(x) & \mu_{23}(x) & \ldots & \mu_{2n}(x) \\ \vdots & \vdots & \vdots & \ldots & \vdots \\ \mu_{m1}(x) & \mu_{m2}(x) & \mu_{m3}(x) & \ldots & \mu_{mn}(x) \end{bmatrix} \tag{4.6}$$

Several fuzzy based algorithms are available to smoothed out membership functions between the two grades by eliminating discrepancy of assessment values (Gao et al., 2006). It is assumed that the membership function of midpoint of grade G2 (intermediate interval) should be assigned a score of 1 and the membership degree in the two marginal points should be assigned a score of 0.5. It should decrease linearly from midpoint to these two points. According to the above algorithm (Chen et al. 1989; 1994; Singh et al. 2007), elements of fuzzy relation matrix have been derived by evaluating membership function of any of the ten water quality parameters (U_1, U_2, …, U_{10}) with respect to the three classification grades using equation (4.7) to (4.9):

$$\mu_{G1}(U_i) = \begin{cases} 0.5\left(\dfrac{k_2 + k_1 - 2U_i}{k_2 - U_i}\right) & \text{for } k_1 > U_i \\ 0.5\left(\dfrac{k_2 - U_i}{k_2 - k_1}\right) & \text{for } k_1 \le U_i < k_2 \\ 0 & \text{for } U_i \ge k_2 \end{cases} \tag{4.7}$$

$$\mu_{G2}(U_i)=\begin{cases}0.5\left(\dfrac{k_2-k_1}{k_2-U_i}\right) & \text{for } U_i<k_1\\[2ex] 0.5\left(\dfrac{k_2+U_i-2k_1}{k_2-k_1}\right) & \text{for } k_1\le U_i<k_2\\[2ex] 0.5\left(\dfrac{2k_3-k_2-U_i}{k_3-k_2}\right) & \text{for } k_2\le U_i<k_3\\[2ex] 0.5\left(\dfrac{k_3-k_2}{U_i-k_2}\right) & \text{for } k_3\le U_i\end{cases} \tag{4.8}$$

$$\mu_{G3}(U_i)=\begin{cases}0.5\left(\dfrac{2U_i-k_2-k_3}{U_i-k_2}\right) & \text{for } k_3\le U_i\\[2ex] 0.5\left(\dfrac{U_i-k_2}{k_3-k_2}\right) & \text{for } k_2\le U_i\le k_3\\[2ex] 0 & \text{for } U_i\le k_2\end{cases} \tag{4.9}$$

4.4.2.5 Fuzzy combination and Fuzzy evaluation matrix

Once fuzzy relation matrix R is derived, it is necessary to aggregate the effects of all critical parameters with their relative weights into an overall combined matrix. This is useful to respective experts/stakeholders to constitute a unified basis for comparison of status of water quality at selected stations. The elements of fuzzy combination matrix can be derived using equation (4.10).

$$B=W\bullet R=\begin{bmatrix}W_1 & W_2 & W_3 \dots W_m\end{bmatrix}\bullet\begin{bmatrix}\mu_{11}(x) & \mu_{12}(x) & \dots\ \mu_{1n}(x)\\ \mu_{21}(x) & \mu_{22}(x) & \dots\ \mu_{2n}(x)\\ \vdots & \vdots & \dots\ \vdots\\ \mu_{m1}(x) & \mu_{m2}(x) & \dots\ \mu_{mn}(x)\end{bmatrix} \tag{4.10}$$

Using equation (4.10), fuzzy combination matrix $B=\lfloor b_j \rfloor_{1\times n}$ is evaluated at each station. Finally the integrated assessment value F_k is evaluated at any k^{th} station by integrating effects of all grades using equation (4.11):

$$F_k = \frac{\sum_{j=1}^{n} b_j \alpha_j}{\sum_{j=1}^{n} b_j} \qquad (4.11)$$

Where b_j (j = 1,..,n) are the elements of fuzzy combination matrix representing integrated assessment value at each sampling station corresponding to all possible grades. The value of F_k is the comprehensive grade of water quality at a given station k. In order to express the status of water quality with a single index value, a simple defuzzification process has been adopted in which grades have been assigned a value ranging from 0 to 1 on the basis of their relative importance. As there are three grades in this case study, decision maker can assign a higher value for α_1 corresponding to a grade falling under 'desirable' category. The unfit category may be assigned α_3 value as 1- α_1.

The permissible category of water quality can be given $\alpha_2 = \frac{\alpha_1 + (1-\alpha_1)}{2}$. If [$\alpha_1, \alpha_2, \alpha_3$ = 0.95,0.50 0.05], the GWQI score with respect to each grade at a given station is calculated using above equations and total score at each station is computed by defuzzifyng fuzzy score using equation (4.12):

$$F_k = \mu_{G1}(S_n)\times 0.95 + \mu_{G2}(S_n)\times 0.50 + \mu_{G3}(S_n)\times 0.05 \qquad (4.12)$$

The value obtained by the above process gives a qualitative measure of the influential degree of water quality parameters in assessing quality of groundwater. If the final score is higher, the water quality is better. The process of a comprehensive fuzzy evaluation is explained in Figure 4.4.

4.5 Results and Discussion

The classification grades G_i and the critical points k_j have been decided based on the practical significance of each parameter as suggested by Bureau of Indian Standard (BIS). For example, the assessment factor, TDS can be classified into three grades in which 200 mg/l is considered as the critical value between G_1 and G_2, and 1000 mg/l between G_2 and G_3, which means that TDS of 200 mg/l can be regarded as the boundary point of grade at the interface of the desirable limit and the permissible grades whereas 1000 mg/l can be considered as boundary point of another grade at the interface of the permissible and the unfit condition as shown in Table 4.8.

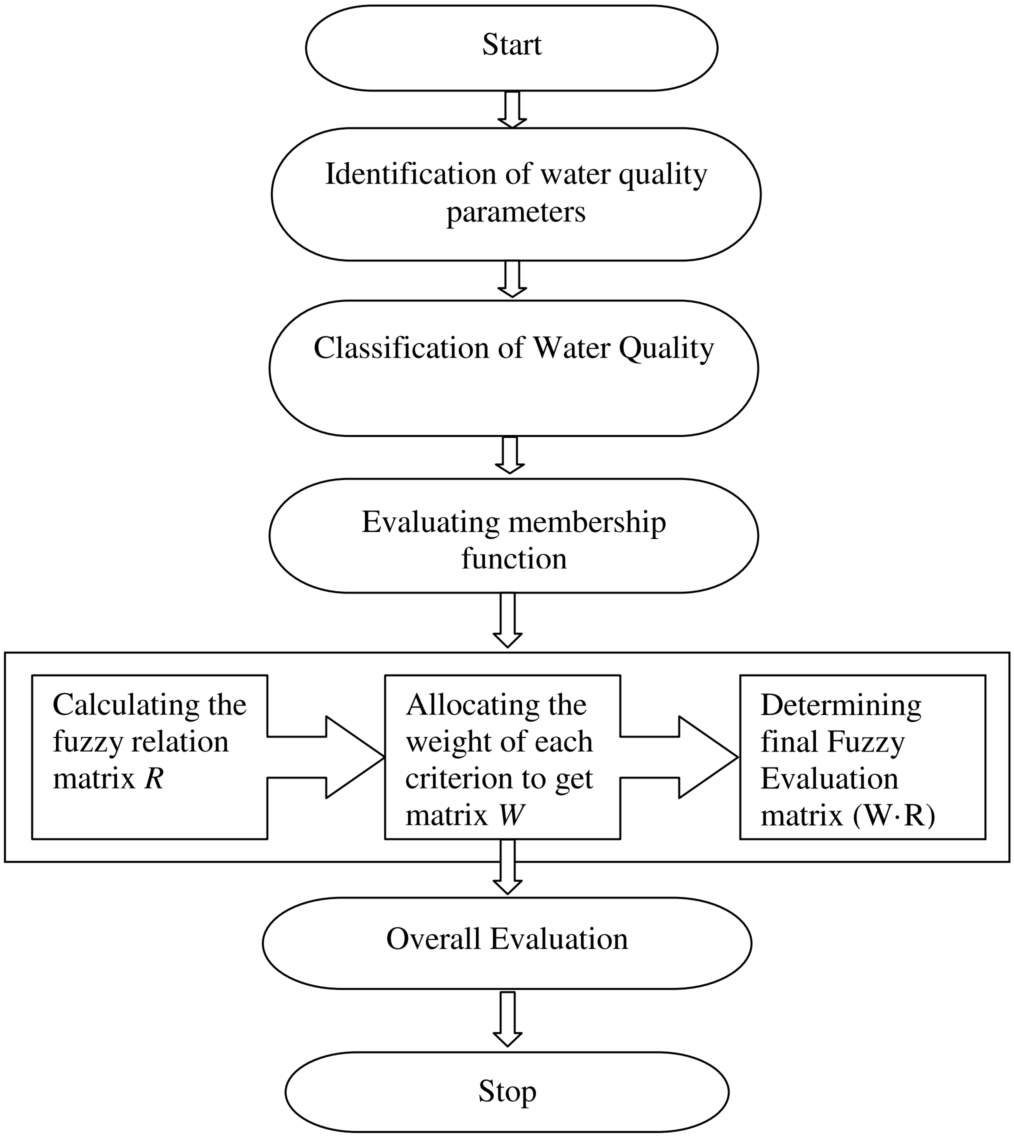

Figure 4.4: Integrated Fuzzy Assessment Model

Substituting the corresponding values of U_i and k_i using Tables 4.8 and Table 4.9 into equations (4.7) to (4.9), the membership function of assessment factor U_i with respect to grade G_j (i.e. $\mu_{G_j}(U_i)$ is calculated. The fuzzy relation matrix R at each sampling station is calculated accordingly. The importance weight of each parameter as given in Figure 4.3, has been considered to calculate integrated fuzzy assessment values using equation (4.10) [i.e. $W = \{W_1, W_2, W_3, W_4, W_5\ W_6, W_7, W_8, W_9, W_{10}\}$ = {0.031, 0.11, 0.056, 0.049, 0.049, 0.078, 0.262, 0.222, 0.115, 0.028} where $0 \leq w_i \leq 1$] and listed in Table 4.10. The final fuzzy integrated assessment values are also calculated using equations (4.11) and (4.12) as given in the last column of Table 4.10. These values are given as 0.726, 0.713, 0.73, 0.72, 0.726, 0.691, 0.73, 0.713, 0.736, and 0.772 corresponding to sampling sites S1, S2, S3, S4, S5, S6, S7, S8, S9 and S10 respectively.

From Table 4.10 and Figure 4.5, it is clear that all sampling stations have higher integrated fuzzy assessment value with respect to grade G_1 (i.e. μ_{G1}) than that with respect to G_2 and G_3 (i.e. $\mu_{G1} > \mu_{G2} > \mu_{G3}$) and therefore the water quality status primarily falls under desirable condition. However, comparisons of the membership values with respect to G1, G2 and G3 indicate that μ_{G2} values are quite close to μ_{G1} values especially at sampling stations S2, S8 and S10. That is to say, although water quality status at all sampling stations falls under desirable condition, there are significant fractions of membership values which lie within the permissible category (i.e. second grade of water quality) due to presence of higher content of iron and other contaminants. Although there is no alarming situation, there must be a regular mechanism to monitor groundwater quality in addition to sensitizing local population to control pollution in the region. Appropriate mitigation measures should be taken so that transition does not happen from permissible category to the unfit category (i.e. third grade of water quality) in due course of time and quality of groundwater can be maintained in good condition.

It is also inferred that while sampling station S10 achieves the desirable grade condition (G_1) with a membership value of 0.604, it also has the highest and lowest membership values of 0.396 and 0.00 under permissible limit grade (G_2) and unfit grade (G_3) respectively among all sampling stations. It is also observed that sampling station S6 has integrated assessment value of 0.691 which is the lowest score. This validates the statement that there is requirement of improvement of water quality by addressing issues of excess iron content and low pH. The sampling stations S10 scores 0.772 which is the highest integrated assessment score. The status of groundwater quality could be graded in decreasing order of integrated assessment values as S10, S9, S3, S7, S1, S5, S4, S2, S8, and S6.

Table 4.9 gives the memberships of ten water quality parameters as assessment factors with respect to the three classifications at all sampling stations. These scores can essentially help to explore the problem areas in context to overall groundwater quality assessment at a particular station. For example, memberships of water quality parameter pH to any i^{th} grade G_i show that the most serious problem at sampling station S1 is the poor condition of pH. The values of membership function of iron with respect to i^{th} grade 'G_i' indicate that water quality is extremely poor in context to iron at sampling stations S10. Thus, if the issues related to excess iron and pH can be addressed at sampling stations S10 in an effective manner, the overall water quality can be achieved at the desired level. In fact the excess iron content is responsible factor to cause reduction in overall score representing groundwater quality at all the sampling stations as can be inferred from the 4^{th} row from bottom of Table 4.9. The status of water quality in terms of all other water quality parameters (except iron) demonstrates permissible to desirable conditions at these sampling stations. Therefore, it is high time to focus on reducing excess content of iron, and building up the consciousness among masses of not polluting this precious resource in order to improve overall groundwater quality in the region.

GIS-based maps have also been developed on the basis of observed values of water quality parameters and final scores obtained from two approaches to demonstrate spatial variations at all sampling stations in Haora River basin. An application of Geographic Information System (GIS) tool essentially generates parameter maps which can easily be interpreted with overall analysis. An input database is formed to feed observed values of the water quality parameters including TDS, pH, total hardness, total alkalinity, calcium hardness, magnesium hardness, nitrate nitrogen, chloride, iron and electrical conductivity which were collected from 10 groundwater sampling stations using ArcGIS© software of Environmental Systems Research Institute Inc (ESRI, 1999). Finally, composite groundwater quality index maps are obtained for the Haora river basin based on two proposed index techniques.

Table 4.8: Classification of Grade values and Critical points

Index	Classification grade values of G_i			Values of critical points, k_i		
	Desirable (G_1)	**Permissible (G_2)**	**Unfit (G_3)**	**k_1**	**k_2**	**k_3**
Total Dissolved Solid (mg/l)	<200	200-1000	>1000	200	600	1000
pH	7	6.5-8.5	<6.0 and >8.5	7 7	7.75 6.5	8.5 6
Total Hardness (mg/l)	<300	300-600	>600	300	450	600
Ca (mg/l)	<75	75-200	>200	75	137.5	200
Mg (mg/l)	<30	30-150	>150	30	90	150
Total Alkalinity (mg/l)	<200	200-600	>600	200	400	600
Nitrate Nitrogen (mg/l)	<50	50-100	>100	50	75	100
Chloride (mg/l)	<250	250-1000	>1000	250	625	1000
Iron (mg/l)	<0.3	0.3-1.0	>1.0	0.3	0.65	1
Conductivity (micro-mhos/cm)	<500	500-1500	>1500	500	1000	1500

Table 4.9: Computation of membership values of Water Quality Assessment Factors at each Station with respect to a grade

Water quality parameters	Grade	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
TDS	G1	0.59	0.58	0.50	0.61	0.40	0.62	0.56	0.55	0.51	0.49
	G2	0.41	0.42	0.50	0.39	0.60	0.38	0.44	0.45	0.49	0.51
	G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pH	G1	0.14	0.00	0.40	0.10	0.40	0.00	0.40	0.01	0.50	0.09
	G2	0.86	1.00	0.60	0.90	0.60	0.50	0.60	0.99	0.50	0.91
	G3	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00
Total Hardness	G1	0.81	0.81	0.80	0.81	0.80	0.82	0.80	0.80	0.80	0.80
	G2	0.19	0.19	0.20	0.19	0.20	0.18	0.20	0.20	0.20	0.20
	G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	G1	0.75	0.74	0.75	0.76	0.75	0.76	0.75	0.75	0.74	0.75
	G2	0.25	0.26	0.25	0.24	0.25	0.24	0.25	0.25	0.26	0.25
	G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg	G1	0.64	0.64	0.62	0.64	0.62	0.65	0.63	0.64	0.63	0.64
	G2	0.36	0.36	0.38	0.36	0.38	0.35	0.37	0.36	0.37	0.36
	G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Alkalinity	G1	0.71	0.68	0.72	0.73	0.71	0.71	0.73	0.71	0.72	0.72
	G2	0.29	0.32	0.28	0.27	0.29	0.29	0.27	0.29	0.28	0.28
	G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	G1	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
	G2	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloride	G1	0.69	0.69	0.70	0.70	0.70	0.70	0.70	0.69	0.70	0.69
	G2	0.31	0.31	0.30	0.30	0.30	0.30	0.30	0.31	0.30	0.31
	G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	G1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
	G2	0.20	0.11	0.07	0.09	0.06	0.10	0.03	0.10	0.09	0.81
	G3	0.80	0.89	0.93	0.91	0.94	0.90	0.97	0.90	0.91	0.00
Conductivity	G1	0.70	0.70	0.64	0.71	0.56	0.72	0.68	0.66	0.64	0.64
	G2	0.30	0.30	0.36	0.29	0.44	0.28	0.32	0.34	0.36	0.36
	G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4.10: Fuzzy Integrated Assessment Values

Sl. No.	Sampling Stations	Fuzzy Integrated Assessment Values	Final Score
1.	S1	[0.595 0.313 0.092]	0.726
2.	S2	[0.576 0.321 0.103]	0.713
3.	S3	[0.618 0.276 0.107]	0.730
4.	S4	[0.594 0.302 0.105]	0.720
5.	S5	[0.611 0.280 0.109]	0.726
6.	S6	[0.583 0.259 0.158]	0.691
7.	S7	[0.622 0.266 0.112]	0.730
8.	S8	[0.577 0.320 0.103]	0.713
9.	S9	[0.630 0.266 0.105]	0.736
10.	S10	[0.604 0.396 0.000]	0.772

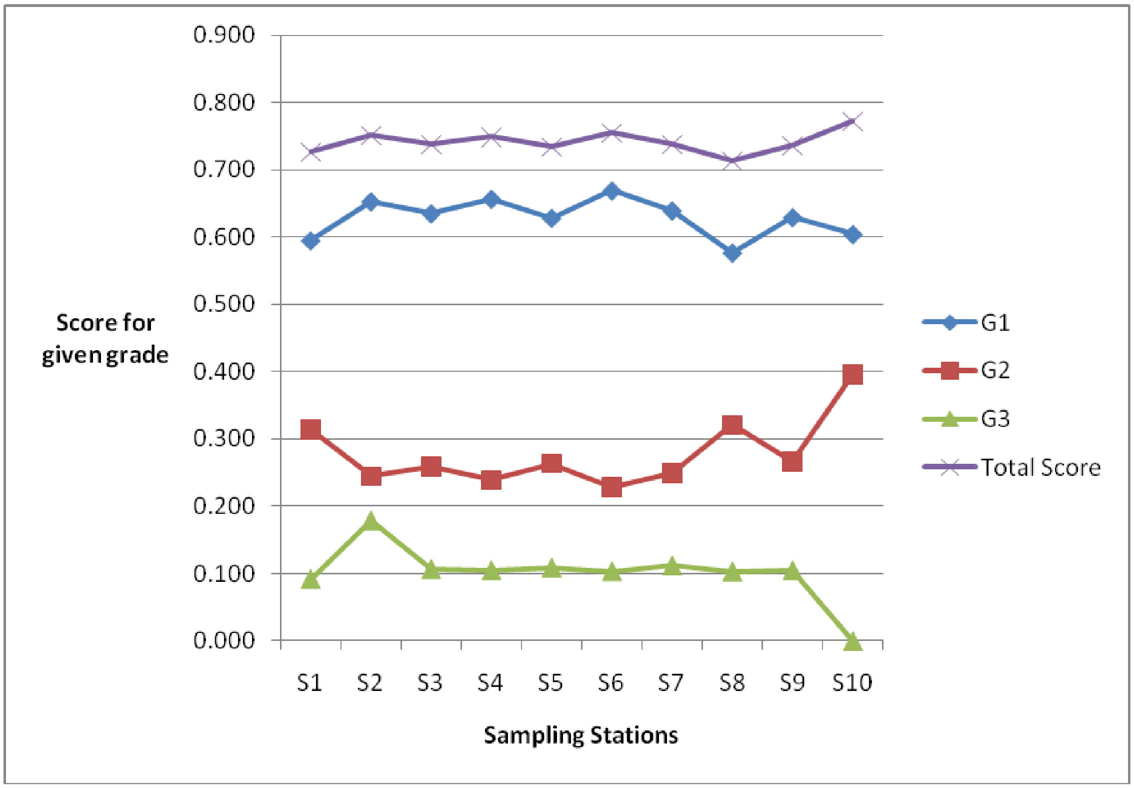

Figure 4.5: Comprehensive Evaluation of Water Quality Assessment

The proposed GWQI index is evaluated by integrating effects of ten groundwater quality parameters that impact the potability of drinking water in the region. The geo-statistical analyst tool within ArcMap® 9.3 has been used. The input map of Haora River basin is first geo-referenced using the latitude and longitude coordinates of sampling stations. Then the water quality parameter values and final indices values have been imported into the GIS database which has been used to plot the spatial distributions of these parameters using inverse distance weighted interpolation technique. The overall Ground Water Quality Index (GWQI) and Fuzzy Ground Water Quality Index (FGWQI) are also plotted to study the spatial variation in overall quality of ground water as depicted in Figures 4.6 and 4.7. The final map can be used as a reference for future water management plans, groundwater remediation plans and the degree of water treatment required as a function of location in a particular region. From the map, it can be observed that the region around station 10 constitutes good water quality in both conventional as well as fuzzy methods. An application of Geographic Information System (GIS) tool generates useful maps pertaining to integrated assessment score which can easily be interpreted spatially by visualizing maps and making comparative evaluations.

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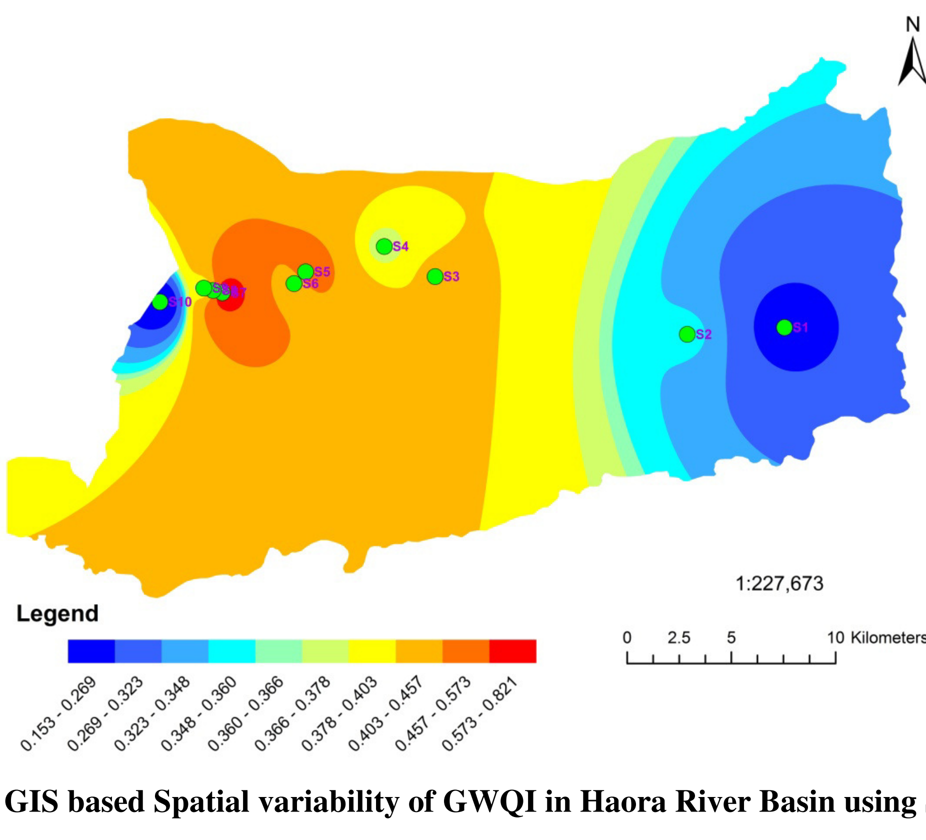

Figure 4.6: GIS based Spatial variability of GWQI in Haora River Basin using SAW

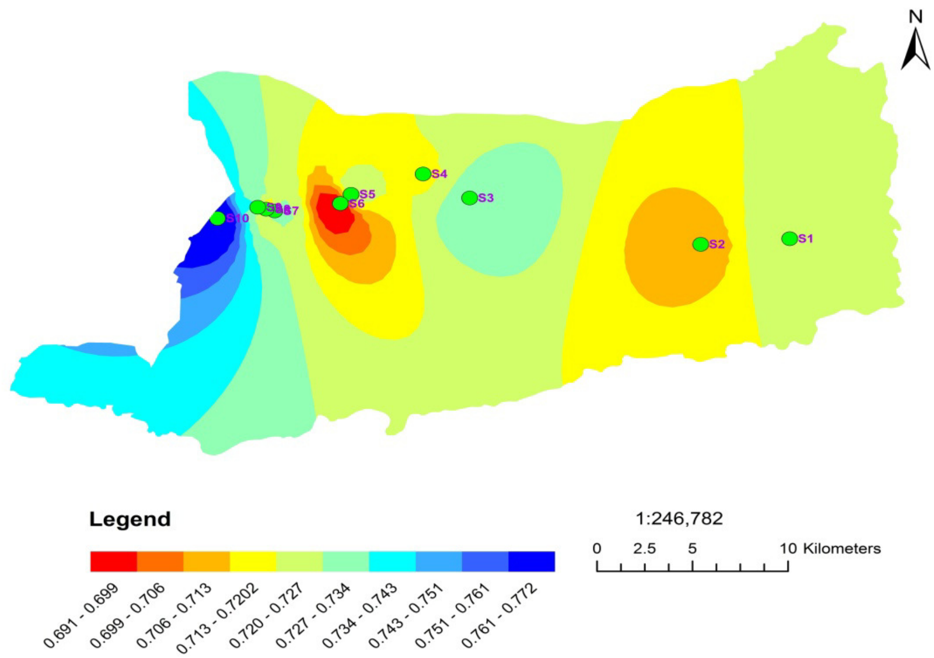

Figure 4.7: GIS based spatial variability of FGWQI in Haora River Basin using Fuzzy Set Theory

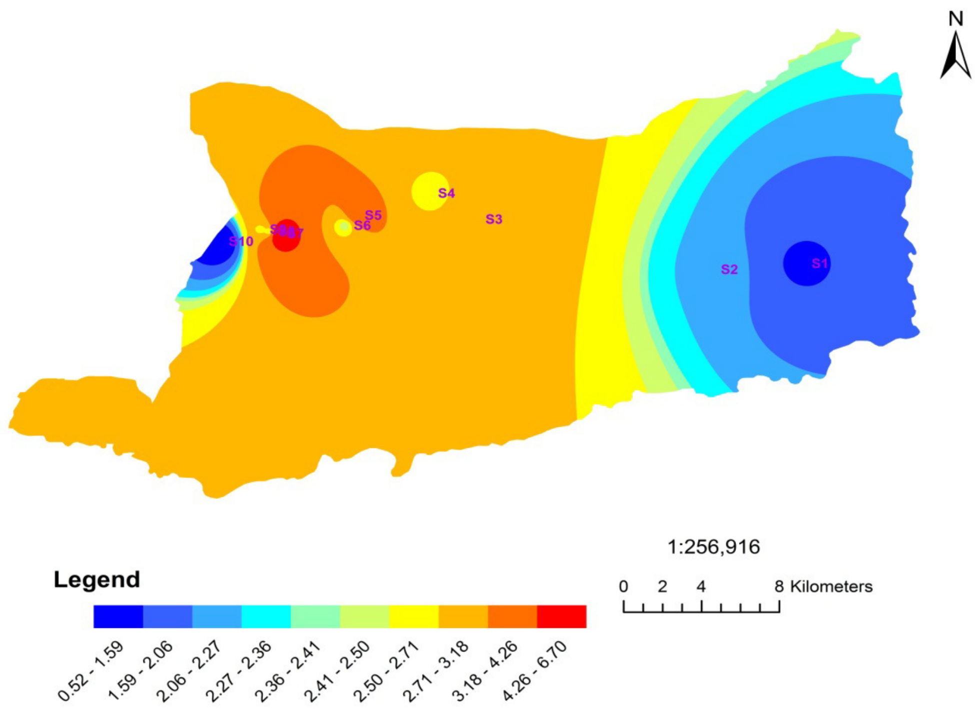

Figure 4.8: GIS based spatial variability of Iron in Haora River Basin

The GWQI and FGWQI evaluated herein clearly demonstrate the spatial distribution of these indices using geographical information system (GIS) tool. The spatial variation of individual water quality parameters have been shown on maps as well. GIS plays an important role in formulating basis for visualizing maps and making comparative assessments, making the assessment analysis simple, easy and effective so that it can be conveyed to decision makers and managers.

In the two indices based maps, areas with bad water quality are shown in red and areas with best water quality are shown in blue. The range of intermediate colours between blue and red depict increasing contamination in ground water. From the map, it can be observed that the region around station 10 constitutes good water quality in both conventional as well as fuzzy method. In the conventional SAW based approach, the map depicts that the region around S1 and S10 have good water quality whereas S7 has the worst water quality, as a result of excess iron content. Regions around stations S5 and S6 are moderately polluted. In the fuzzy approach, S10 has the best water quality whereas S6 being the worst as a result of excess iron content and low pH value. Regions around stations S2 and S4 are moderately contaminated. Almost all stations apart from S10 are severely hit by excess iron content in ground water, as evident from spatial variation map of iron shown in Figure 4.8.

4.6 Summary

In this study an integrated groundwater quality index (GWQI) has been developed to assess quality of groundwater at different location in Haora River basin by using two aggregating methods of Multiple-Attribute Decision Making Process, namely the Simple Additive Weighting (SAW) and the Fuzzy Comprehensive Assessment (FCA) methods.

This study presented a method that integrates AHP and fuzzy logic to assess status of groundwater quality and prioritize sampling stations as per their final scores which will be useful to adopt remedial action plans. It provides a systematic way of expressing qualitative rating using linguistic terms while recognizing differences of opinion of subject experts.

The fuzzy comprehensive assessment model provides enough scope to experts for assigning different membership grades corresponding to different categories of water, viz. desirable, permissible, and unfit.

Membership functions of ten water quality parameters (indicators) are obtained. Weights of each water quality parameters have been assigned using AHP. The methodology proposed in this case study can be very well applied in condition assessment of other environmental problems wherein qualitative ratings are viable under multi-attributes framework. Of course, different membership functions and weight factors are required to establish proper framework depending upon the specific type of problems. Thus, these methods should be used for assessing groundwater quality condition and prioritizing the sampling sites so that better informed realistic approaches can be made available to implementing agencies and practitioners.

In the conventional Simple Additive Weighting (SAW) Method applied in this study, the normalized ratings have been calculated using equation (4.3). Since the iron content at most of the stations exceeds the standard limit prescribed by regulatory bodies by a large amount, the normalized ratings (q_i) for these stations become very high in magnitude compared to the values for other water quality parameters. Except iron, all other parameters are either less than or close to the standard values established by the guidelines of water regulatory bodies. When these normalized ratings are aggregated in accordance with their respective weights using equation (4.5), the parameter with higher values will guide the overall rankings. Therefore, the overall ranking is influenced to a great extent by iron ratings and it can be said that other parameters get subdued in their effect on the overall groundwater quality index and the rankings. This is a major drawback of the conventional method.

In the fuzzy comprehensive evaluation method, the membership value cannot exceed one for any of the parameters and hence the contribution of all the parameters is observed in the overall fuzzy index and rankings. For example, the iron content and pH value at sampling station S6 are 2.37 mg/l and 6 respectively. Their ratings in the conventional approach are 2.37 and 1. When these ratings are aggregated with respect to their weights, iron guides the overall value since it is much larger in magnitude due to which contribution of mainly iron is observed. In fuzzy approach, the membership values corresponding to the observed iron content of 2.37 mg/l and pH value of 6 are 0.90 and 0.50 respectively. Since both values are between 0 and 1, when aggregation is done to determine the overall ranking, importance of both parameters is taken into consideration. Thus the fuzzy approach ensures that the contribution of all parameters is reflected in the final ranking. Fuzzy method is recommended over the conventional method for similar studies in future as the fuzzy index best represents the water quality status at a sampling station.

It can be said that fuzzy comprehensive assessment method is more inclusive method of groundwater quality assessment and takes into consideration all the parameters for the purpose of index construction and prioritization. Based on these merits of fuzzy method, it is recommended over the conventional method for all future studies as it is the true combined indicator of water quality at a sampling station. SAW method on the other hand, focuses more on the parameters faring worse and the rankings evaluated by this method, also echo this behavior. For example, if two stations are compared on the basis of two parameters under study and for station 1, the two parameters are in "*heavily polluted*" and "*not polluted*" categories respectively whereas for station 2, both the parameters are in "*moderately polluted* " category, then the fuzzy method will rank station 2 as more polluted whereas SAW method will rank station 1 more polluted. Thus SAW method results way towards the parameter with extreme rating while fuzzy method result is based on balanced consideration of contribution from all parameters under study. Also, it is clear that comprehensive groundwater quality indices will have certain limitations especially when selected parameters are inappropriate in defining these indices. In that case they will produce ambiguous results and therefore it is necessary that all important parameters should be identified with proper care.

CHAPTER 5

AIR QUALITY ASSESSMENT IN HAORA RIVER BASIN

5.1 Introduction

Good quality air provides a healthier environment for sustenance and maintenance for living entities. Good quality air means clean, fresh and unpolluted air. However, human activities have significant impact on the quality of air. Air quality assessment has been a difficult task for environmental engineers as it requires assessment of several pollutants emerged from different energy and industrial processes. A number of monitoring programs have been undertaken in the past throughout the world to determine the impact of several pollutants on the quality of air by using concentration of various air pollutants. These pollutants have been classified into two categories (i) macro pollutants such as Suspended Particulate Matter (SPM), PM_{10}, Sulfur Dioxide (SO_2), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), and (ii) micro pollutants such as Lead (Pb) (Daly and Zannetti, 2007). Particulate matter consists of solid and liquid particles having sizes ranges from 0.005 to 100 µm. These particles are also known as aerosols which are present in the atmosphere in the form of dust, smoke, dust, fumes, and smog and are harmful at high concentration.

As discussed in earlier chapters, an individual pollutant often does not signify the status of quality of air to all the stakeholders including decision makers and pollution control agencies, and in particular to the society. There is a need to develop a framework to assess quality status by integrating impact of all individual pollutants. This type of assessment will enable stakeholders to analyze severity of air pollution in an effective, straightforward and efficient manner. Once quality of air is assessed, important management issues can be addressed to combat serious threat occurring to the public health (Dholakia et al., 2014; British Medical Association, 2014). A relationship can be developed between human activities and development process. Analysis can also be performed by evaluating tradeoffs effects between policies pertaining to air pollution control and effectiveness of pollution control equipments (Davies and Mazurek, 2014; Morgenstern, 2014).

In this chapter, air quality index has been developed by collecting data through ambient air sampling at 10-sampling sites. Samples are collected from the air after pollutants from the various sources have been thoroughly dispersed and mixed together under natural meteorological conditions. The study will serve as a basis for assessing which precautionary steps require to be addressed if air pollution levels rise beyond the prescribed standards. Policy makers can evaluate health effects, determine the compliance with air quality standards prescribed by CPCB, and predict the effects of proposed new sources of air pollution so that air pollution control strategies can be formulated in an effective manner, if required.

5.2 Background

The Central Pollution Control Board, New Delhi, India formulated certain guidelines and standards to regulate environmental quality (CPCB, 2000). Generally environmental quality is considered as poor or good by comparing the observed values to that of prescribed standards (Banerjee and Srivastava, 2011; Nagendra et al., 2007).

In this chapter, Air Quality Index (AQI) at 10 sampling stations have been derived, the detailed methodology of which is explained in following section.

5.3 Methodology

On similar lines as discussed in chapter 4, an integrated Air Quality Index (AQI) has been developed to assess quality of air at different locations in Haora river basin using two aggregating methods: modified EPA method with maximum operator as the aggregation function of Multiple Attribute Decision Making (MADM) process (Chen et al., 1992*)* and the Fuzzy Comprehensive Assessment Method (Tao and Xinmiao, 1998; Yan-jun and Mu-zhuang, 2007; Singh, 2008*;* Singh et al., 2015*).* The results obtained from both the methods have been compared and limitations of EPA method have been identified. To develop the integrated AQI, the complete methodology is summarized in the form of a flowchart as shown in Figure 5.1.

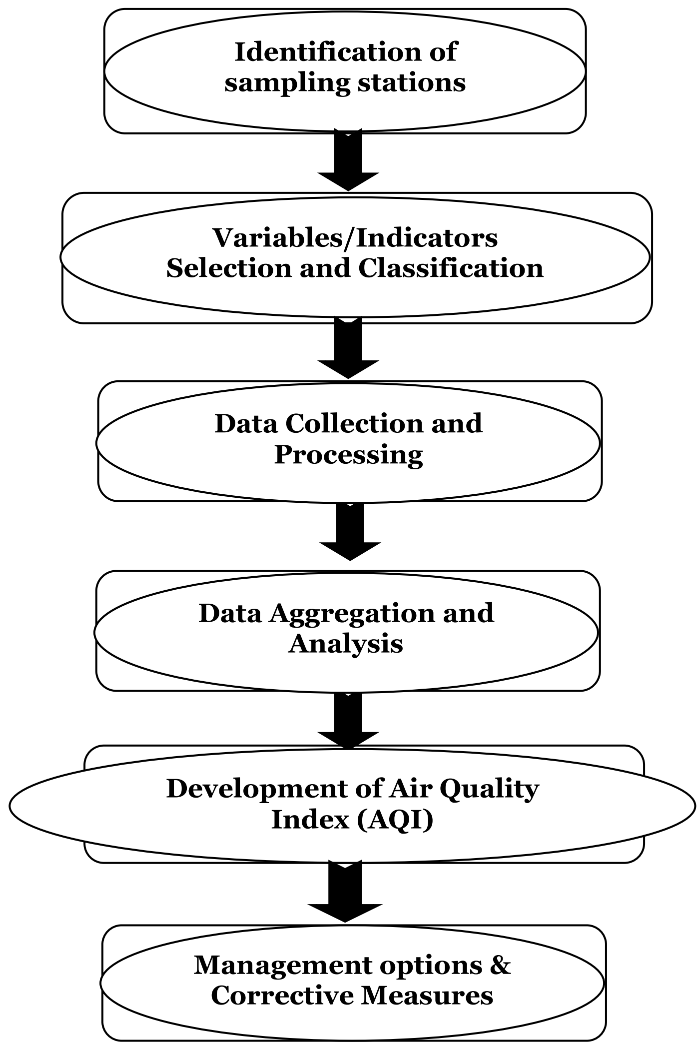

Figure 5.1: AQI development process in Haora River Basin

5.3.1 Parameters for Air Quality Index (AQI) formulation

Air quality characteristics have been obtained by measuring the standards of quality of air in terms of various macro and micro air pollutants which depend on the type of emission sources available in a regional system. The major emission sources of air pollutants are vehicular movements, industrial activities, brickfields and thermal power plants. Therefore, it is essential to maintain air quality within the prescribed safe limit by adopting efficient and cost-effective measures of planning and management so that air pollution can be controlled in an effective manner.

The air pollutants may commonly be classified as macro and micro pollutants as discussed before. The other frequently used method of classification of major pollutants is to classify them as primary and secondary pollutants. If emission of pollutants takes place directly from the sources, they are called primary pollutants. The main primary pollutants are: hydrogen sulphide, sulfur dioxide, carbon monoxide, carbon dioxide, nitric oxide, inorganic gases such as hydrogen fluoride and radioactive compounds, ash, fumes, mist and spray, smoke, dust etc. The secondary pollutants are generated in the atmosphere by chemical reactions between primary pollutants and other atmospheric elements. Various factors such as concentration of reactants, the amount of moisture present in the atmosphere, degree of photo activation, climatic conditions, and local topography etc. influence the reaction mechanism. The main secondary air pollutants are sulfur trioxide, aldehydes, Peroxyacetyle nitrate (PAN), nitrogen dioxide, ozone, and various salts of nitrate and sulphate etc. Of all the primary pollutants, the five major air pollutants of concern are: oxides of nitrogen, carbon monoxide, sulfur oxides, particulate matter, and hydrocarbons. Ozone is another pollutant which is of great concern to environmentalists and researchers. Some important pollutants which are essential to evaluate air quality at a given sampling station are described below:

Particulate Matter

Particulate matter refers to the non-gaseous component of the atmosphere. These can be inert or extremely reactive. There are various elements which constitute particulate matter as described below:

Dust: Natural disintegration of rock and soil generally produce dust. The mechanical processes of grinding and spraying also generate dust. It could be removed from the atmosphere by action of gravity and other inertial processes due to large settling velocities.
Smoke: They are fine particles with a size varying from 0.01 µm to 1 µm which are formed by combustion or other chemical processes.
Fumes: These are solid particles normally released from chemical or metallurgical processes.

Aerosol: Most of these particles are under one micrometer in size and have measurable settling velocities. Those below submicroscopic size found in urban air are the ones causing significant damage to human health.

Nitrogen Oxides

There are various types of nitrogen oxides which are expressed generally as NO_x. Most emissions are initially in the form of nitric oxide (NO), which by itself is not harmful at usually available concentrations in the atmosphere and hence not considered as an air pollutant. However, NO is oxidized to NO_2, which in the presence of sunlight can further react with hydrocarbons (in a polluted atmosphere) to form photochemical smog which is harmful. NO_2 is converted to nitric acid (HNO_3) when it reacts with hydroxyl ion (OH^-). The nitric acid is one of the responsible elements which contribute acid rain. Although nitric oxide (NO) is a colourless, odourless gas produced by fuel combustion, NO_2 is pungent, irritating gas that tends to give smog a reddish brown color. Stationary sources are the major contributors of nitrogen oxides, although mobile sources are also important.

Hydrocarbons

These gaseous and volatile liquid may be saturated or unsaturated, branched or straight-chained or ring structured. Methane is the most abundant hydrocarbon constituting about 40 to 80 percent of the total hydrocarbon present in the urban atmosphere in the saturated class. Alkenes and acetylenes are of the unsaturated class.

The hydrocarbons in air themselves alone cause no harmful effects. There are of major concern only when they in the presence of sunlight and Nitrogen Oxides form Ozone. Methane has very low photochemical activity compared to all the other hydrocarbons.

Carbon Monoxide

It is the largest constituent of pollutants in urban atmosphere. It is colorless, odourless and has a strong affinity to hemoglobin in the bloodstream. So, it is a dangerous asphyxiant. The rate of oxidation of carbon monoxide to carbon dioxide in presence of atmospheric oxygen has been found to be very slow. Smoke and exhaust fumes of burning coal, gas or oil are the main sources of CO.

Oxides of Sulfur

Sulfur Oxide has a sharp, pungent odour. It is moderately soluble in air forming a weakly acidic solution of sulfurous acid. It is oxidized slowly in clean air to sulfur trioxide. Sulfur Trioxide is generally emitted along with sulfur dioxide, at about 1-5% of the SO_2 concentration. Both the gases are quickly washed out of the atmosphere by rain or settle out as aerosols. For this reason the mass of sulfur dioxide in clean dry air is so small compared to annual emissions from sources.

There are various adverse effects of air pollution which can be classified on the basis of their severity into two types, (i) acute effects or (ii) chronic effects. An acute effect shows itself after a short time of exposure to air pollutants at high concentrations, and chronic effects become evident only after continuous exposure to low levels of air pollutants. The latter are difficult to identify and isolate immediately.

In this study air samples have been collected from surrounding areas of the 10 sampling stations located along Haora River which are explained in previous chapters. A total of 10 parameters were sampled though finally six pollutants have been considered because these six pollutants are generally emitted in relatively large quantities by various sources in the region and may tend to threaten human health or welfare at larger scale. The six pollutants are nitrogen dioxide, sulfur dioxide, carbon monoxide, PM_{10}, suspended particulate matter, and lead. The major reason of the ever increasing problem of air pollution is the combustion of fossil fuels for vehicles, operations of brickfields and other industrial and domestic activities.

Among commercial fuels, coal is the greatest contributor to air pollution followed by fuel oils and mobile sources. In addition to burning of fuels, major industries like steel, paper and pulp, textiles, cement and sulfuric and nitric acid plants contribute relatively small but significant amounts of air pollutants to the Nation's atmosphere. Since most of the industries are located in urban areas, these add to the pollution burden of the urban areas significantly.

5.3.2 Study Area

With rapid increase in population and uncontrolled industrialization, it is felt that air quality should be assessed along Haora river especially in and around Agartala, the capital city of Tripura state. Keeping in view of growing concerns of air pollutants, it is necessary to formulate and develop a comprehensive framework for air quality assessment and management so that not only the specific actions can be formulated to combat air pollution but also a systematic methodology could be applied by the pollution control boards or any other environmental protection agencies who are responsible to minimize air pollution.

With the aforementioned concerns in mind, the study focused to establish a methodology of air quality assessment along Haora river basin. The ten sampling stations have been chosen to determine the air quality index, which are well represented by considering different factors like demography, pollution load, and industrial activity.

The first sampling site is near the confluence of two streams of river Haora, in West Tripura. This is the origin point of Haora river and National Highway number 44 is passing through this station. This location has been chosen to assess the impact of tourism, foothills. This location also provides information about the impact of vehicular movement on National highway. All other sampling stations were selected based on the same interest i.e. effect of anthropogenic activities. All sites have been shown in Figure 4.1. The details of these sampling stations are given:

Sampling station **(S1):** Confluence point of two streams (the point of origin) of river Haora, West Tripura

Sampling station **(S2):** Near National Brick Field at Jirania, West Tripura

Sampling station **(S3):** Near Ranir Bazar Market, West Tripura

Sampling station **(S4):** Near Chaturdash Devata Bari Bathing Ghat, Baldakhal Road, Khayerpur, West Tripura

Sampling station **(S5):** Near the Bridge on Haora River connecting Chandrapur and Baldakhal, Chandrapur, West Tripura

Sampling station **(S6):** Near Aralia Water Intake Point, West Tripura

Sampling station **(S7):** Near Bordowali Water Intake Point, West Tripura

Sampling station **(S8)** Near Battala Crematorium, West Tripura

Sampling station **(S9):** Near Dashami Ghat, West Tripura

Sampling station **(S10):** Near the last Point (in Indian Territory) on river Haora entering Bangladesh, West Tripura

5.3.3 Monitoring and Analysis of Air Samples

SO_2, NO_2, Suspended Particulate Matter (SPM) (size greater than 10 µm), and PM_{10} (size less than 10 µm) were monitored by a respirable dust sampler (RDS APM 460BL, Envirotech, New Delhi, India) . The GF/A glass microfiber filter paper (Whatman, England) of 8 × 10 inch size were used to measure PM_{10} and the SPM was measured by collecting the heavier particles in plastic cups attached at an outlet of cyclone. Both before and after air quality monitoring the filter paper was conditioned in a desiccator for 24 hours and weighed on a weighing balance (Precisa, Germany) with the sensitivity of 0.001 gm. To avoid any chances of contamination and moisture absorption the conditioned and weighed filter paper was placed in cloth-lined envelope and taken for monitoring. Average flow rate of 1.2 m^3 /min is to be maintained while monitoring PM. The manometer reading was taken 3 or 4 times in a day to maintain the flow rate variations within 1.1–1.3 m^3 /min. The average flow rate was finally considered for computing the total amount of air sampled. Air quality monitoring was done during April to June 2012 continuously for 24 hours and average value has been adopted. The gaseous pollutants were monitored using the Envirotech APM 411TE Thermo-electrically Cooled

Gaseous Sampler (Envirotech, New Delhi) attached with RDS. SO_2 and NO_2, were monitored at a constant flow rate of 1 liter per minute by bubbling ambient air through the liquid absorbing medium. To determine the ambient SO_2 concentrations the improved West and Gaeke method with potassium- tetracholoromercurate as the absorbing medium [IS: 5182 (Part 2) 2001] was used and the modified Jacob and Hocheiser method [IS: 5182 (Part 6) 2006] with a solution of sodium hydroxide and sodium arsenite was used for determination of NO_2. Gaseous pollutants present in the ambient air were absorbed in the respective absorbing medium and analyzed spectrophotometrically (Varian, USA) at 560 and 540 nm for SO_2 and NO_2, respectively. Table 5.1 illustrates the actual observed concentrations of important pollutants at selected sampling stations.

5.4 Development of Air Quality Index

There exist several guidelines and standards pertaining to air quality in the literature (Banerjee and Srivastava, 2011). The Central Pollution Control Board (CPCB), New Delhi has notified standards and guidelines for air quality. Some of the important acts in force in India related to air quality regulation and pollution prevention are the Air (prevention and control of pollution) Act (1981), the Motor Vehicles Act (1988), the Central Motor Vehicles Rules (1989) and the Environmental Protection Act (1986). These standards and guidelines address individual pollutants and are developed based on highest percentile values over various averaging periods (Rao et al., 2002; CPCB, 2000, 2003; Beig and Gunthe, 2004). According to the notification of the Central Pollution Control Board (CPCB), New Delhi, the residential and industrial areas have now the same National Ambient Air Quality Standards (NAAQS).

Air quality assessment and pollution measures should serve two purposes: (i) they should provide an insight to the general public through a meaningful assessment of severity (status) of air pollution so that they can be informed about the pollution level and its associated health risks (ii) they should capable to analyze tradeoffs effects between policies pertaining to air pollution control and effectiveness of pollution control equipments.

Table 5.1 Analytical Report of Air Samples on and around Haora River Tripura

Sl. No	Name of the Block Area	Duration of Sampling	Average Temp (°C)	Average Humidity (%)	Conc. Of SPM (μg/m³)	Conc. Of PM_{10} (μg/m³)	Conc. Of SO_2 (μg/m³)	Conc. Of NO_2 (μg/m³)	Conc. Of CO (mg/m³)	Conc. of Pb (μg/m³)
1.	S1	24 hours Average	29.0	82.0	142.31	130.6	12.14	30.04	BDL	BDL
2.	S2	24 hours Average	28.5	80.0	330.70	310.39	18.32	32.18	BDL	BDL
3.	S3	24 hours Average	30.5	80.0	403.37	386.65	16.636	30.11	BDL	BDL
4.	S4	24 hours Average	30.0	82.0	410.55	390.85	18.27	49.38	BDL	BDL
5.	S5	24 hours Average	29.0	78.0	167.38	155.55	10.68	19.30	BDL	BDL
6.	S6	8 hours Average	30.0	68.0	420.02	400.10	27.05	46.82	0.52	0.36
7.	S7	8 hours Average	29.0	64.0	684.95	528.80	30.54	62.43	0.7	0.92
8.	S8	24 hours Average	30.0	78.0	590.46	572.14	28.42	59.54	0.35	0.20
9.	S9	24 hours Average	30.0	80.0	327.72	305.79	18.54	39.09	BDL	BDL
10.	S10	24 hours Average	30.0	80.0	189.69	176.88	18.12	32.15	BDL	BDL

Therefore, air quality indices have been derived using two methods viz. modified EPA method using maximum operator of MADM process, and the Fuzzy Comprehensive Assessment Method which have been explained in following sections. The results are analyzed using a series of observations which essentially serve the purpose of indication of the air quality status in the selected region.

5.4.1 Air Quality Index using Modified EPA Method

The National Ambient Air Quality Standards was notified by the Ministry of Environment and Forest (MoEF), Govt. of India, vide gazette notification, G.S.R826 (E), dated 16.11.2009 by amending the Environment (Protection) Rules 1986. The revised Indian National Ambient Air Quality Standards (NAAQS) of some of the air pollutants of interest are summarized in Table 5.2.

In recent years, air quality indices (AQIs) are derived to assess the severity of air pollution and its adverse impact on health. Each air quality parameter (pollutant) has been considered as the criteria for evaluating overall AQI. Six important air pollutants were considered to formulate AQI. Their concentration were monitored at 10-sampling stations. The measured values of these parameters are shown in Table 5.1. In addition to the parameters mentioned in the Table 5.1, average temperature, average humidity, weather condition, odour/smell were also measured but were found of not much significance for the present study.

Table 5.2: National Ambient Air Quality Standards (MoEF Gazette, 2009)

Sl. No.	Pollutant	Time Weighted Average	Industrial Area Residential, Rural & other Areas	Ecologically sensitive area (Notified by Central Govt)	Methods of measurement
1	Sulphur Dioxide(SO_2), $\mu g/m^3$	Annual Avg*	50.0	20.0	-Improved West and Gaeke method -Ultraviolet fluorescence
		24 hours**	80.0	80.0	
2	Oxides of Nitrogen as NO_2, $\mu g/m^3$	Annual Avg*	40.0	30.0	-Modified Jocob and Hochheise (Sodium Arsenite) -Chemiluminescence
		24 hours**	80.0	80.0	
3	Particulate matter, (size less than 10µm), $\mu g/m^3$	Annual Avg*	60.0	60.0	-Gravimetric -TOEM -Beta attenuation
		24 hours**	100.0	100.0	
4	Particulate matter (size less than 2.5 µm), $\mu g/m^3$	Annual Avg*	40.0	40.0	Gravimetric -TOEM -Beta attenuation
		24 hours**	60.0	60.0	
5	Lead (Pb), $\mu g/m^3$	Annual Avg*	0.50	0.50	-AAS/ICP method for sampling on EPM2000 or Equivalent Filter paper -ED-XRF using Teflon filter paper
		24 hours**	1.0	1.0	
6	Carbon Monoxide (CO), mg/m^3	8 hours**	2.0	2.0	-Non Dispersive Infra Red (NDIR) spectroscopy
		1 hour	4.0	4.0	
7	Ozone, $\mu g/m^3$	8 hours**	100.0	100.0	-Photometric -Chemiluminescence -Chemical method
		1 hour	180.0	180.0	
		24 hours**	60.0	60.0	

- *Annual Arithmetic mean of minimum 104 measurements in a year taken twice a Week 24 hourly at uniform interval,
- ** 24 hourly / 8 hourly or 1 hourly monitored values as applicable shall be complied with 98% of the time in a year. However, 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.
- MoEF: Ministry of Environment and Forest, Government of India.

In order to evaluate AQI score at a given sampling station, there is a need to evaluate the air quality index corresponding to each parameter on the basis of their observed concentration. In the present study, AQI scores have been derived using piecewise linear function to relate observed concentrations of air pollutants to a normalized number as a pollution sub-index with respect to concentration value of each parameter. Several researchers have assessed AQI considering piecewise linear functions to analyze air quality under different environmental conditions (EPA 1998; Nagendra et al. 2007; Sharma et al. 2003). The formulation of AQIs is a two step process: (i) derivation of sub-indices scores for each pollutant, and (ii) the aggregation of sub-indices to determine effective AQI using concepts of breakpoints. The piecewise linear function is used for relating the actual air pollution concentrations (of each pollutant) to a normalized number (i.e. sub-index). Sub-indices for each pollutant are categorized on the basis of the scale ranging from 0 to 500. The observed concentration of each pollutant is converted into a number between 0 and 500. The sub-indices of 0, 100, 200,…, 500 are referred to as "breakpoints." The pollution concentration between the two breakpoints should be interpolated linearly using equation (5.1).

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} \times \left(C_p - BP_{Lo}\right) + I_{Lo} \qquad (5.1)$$

Where I_p = the index for pollutant p

C_p = the rounded concentration of pollutant p

BP_{Hi} = the high breakpoint concentration (that is greater than or equal to C_p)

BP_{Lo} = the low breakpoint (that is less than or equal to C_p)

I_{Hi} = the prescribed AQI value corresponding to BP_{Hi}

I_{Lo} = the prescribed AQI value corresponding to BP_{Lo}.

Table 5.3 outlines the value of sub-index and the breakpoint concentrations of the specific pollutants which are essentially used in the derivation of AQI. The breakpoint concentrations were adopted on the basis of standards set by NAAQS for industrial, residential, rural, and other areas as prescribed in Table 5.2 and also the outcome of various epidemiological studies indicating the risk associated with pollutants concentrations on health (EPA, 1998; Nagendra et al., 2007; and Sharma et al., 2003). In fact Table 5.3 depicts the piecewise linear relationship for sub-index scores (Sharma et al., 2003). In this study, AQI has been evaluated by deriving different sub-indices values by incorporating effects of selected pollutants like SO_2, Carbon monoxide, NO_2, PM_{10} and SPM and Lead. The maximum value among the sub-indices of all responsible pollutants (i.e. maximum operator) has been considered to evaluate final overall AQI at a given sampling station.

Table 5.3: Sub-index and breakpoint Pollutant concentration for Indian Air Quality Index corresponding to different Pollutants

Sl No.	Index	Category	SO_2 (24 hr avg) (µg/m^3)	NO_2 (1-hr avg) (µg/m^3)	SPM (24-hr avg) (µg/m^3)	CO (8-hr avg) (mg/m^3)	Pb (24-hr avg) (µg/m^3)	PM_{10} (24-hr avg) (µg/m^3)	$PM_{2.5}$(24-hr avg) (µg/m^3)
1.	0-100	G	0-80	0-80	0-200	0-2	0-1	0-100	0-400
2.	101-200	M	81-367	81-180	201-260	2.1-12	1-1.5	101-150	400-550
3.	201-300	P	368-786	181-564	261-400	12.1-17	1.5-2.25	151-350	550-700
4.	301-400	VP	787-1572	565-1272	401-800	17.1-35	2.25-3.25	351-420	700-900
5.	401-500	S	>1572	>1272	>800	>35	>3.25	>420	>900

Where, G: Good; M: Moderate; P: Poor; VP: Very Poor; S: Severe

After identifying all relevant indicators, the sub-index scores of each pollutant indicator were obtained with respect to each sampling station as given in Table 5.5. The overall score of AQI at each station is evaluated using the maximum operator. The maximum values of sub-indices among all parameters are taken to represent the overall AQI score at a given sampling station. The value can be viewed as an overall assessment of air quality at the sampling station.

The AQI has been obtained using equation (5.1), by taking into consideration of the concentration of individual pollutants at the particular location. The air quality index (AQI) derived for each sampling site represents the status of air quality at that station. The AQI score closer to zero indicates good quality of air, and as its value increases, air quality becomes poorer. The air quality status can be categorized into five classes as depicted in Table 5.4. The calculated AQI at chosen sampling stations have been compared with these five classes of AQI.

Table 5.4: Classification of AQI in Haora River Basin, Tripura

Sl. No.	AQI	Air Quality Status
1	0-100	Good
2	101-200	Moderate
3	201-300	Poor (polluted)
4	301-400	Very poor (Polluted)
5	401-500	Severe

Table 5.5 shows the ranking of air quality for each station. Figure 5.2 also indicates the summary of the AQI values with respect to all 10 sampling stations. The results clearly indicate that the AQI score ranges from 160.80 at sampling station S1 to 484.68 at sampling station S8 which reveal a specific trend of fluctuations. Though the AQI scores clearly demonstrates that none of the sampling station has clean air, the sampling station S1 [i.e. confluence point of two streams (the point of origin) of river Haora, West Tripura] has the minimum score of 160.80 signifying moderately good quality and is the most suitable among all sampling sites. This is due to the fact that there are no significant sources of air pollution in and around sampling station S1 and adequate fresh air is available. The contribution of PM_{10} is the least at this station due to its lower concentration. The 24 hours-average values of SO_2 and NO_2 have been below detectable level (BDL) and below the maximum permissible limit as prescribed by NAAQS.

Table 5.5: Computation of Sub-index of Air Quality Parameters and Overall AQI

Sampling Stations	Sub-Index Score correspond to given Air Quality Parameters							
	SO_2	NO_2	CO	Pb	PM_{10}	SPM	AQI Score	Rank
S1	15.18	37.55	0	0	160.8	71.16	160.8	**1**
S2	22.9	40.23	0	0	280.29	250.64	280.29	**5**
S3	20.8	37.64	0	0	352.15	301.59	352.15	**6**
S4	22.84	61.73	0	0	358.18	303.37	358.18	**7**
S5	13.35	24.13	0	0	203.26	83.69	203.26	**2**
S6	33.81	58.53	26	36	371.45	305.72	371.45	**8**
S7	38.18	78.04	35	92	460.84	371.45	460.84	**9**
S8	35.53	74.43	17.5	20	484.68	348.01	484.68	**10**
S9	23.18	48.86	0	0	278.01	248.52	278.01	**4**
S10	22.65	40.19	0	0	213.87	94.85	213.87	**3**

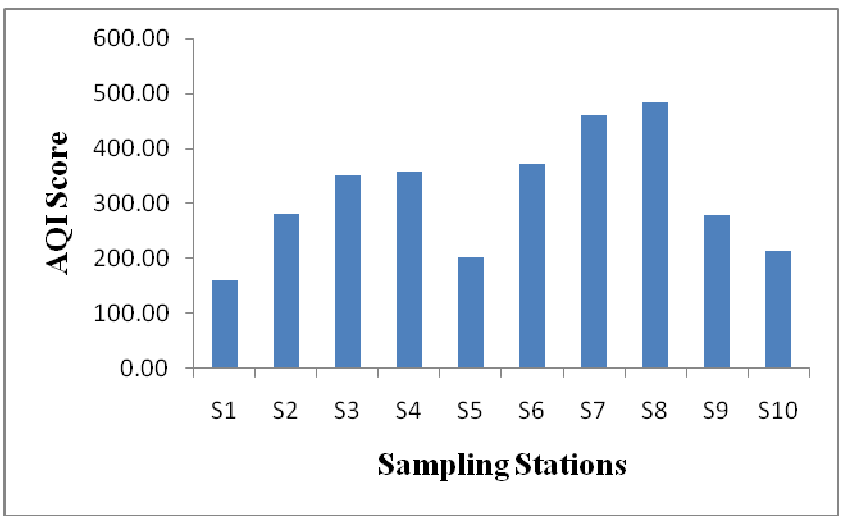

Figure 5.2: Air Quality Index Score at different Sampling Stations along Haora River

Though the concentrations of five major pollutants are within the prescribed limit at sampling station S5, AQI score is 203.26. Air is polluted at this sampling station due to the fact that measured PM_{10} concentration is 155.55 µg/m^3. The main source of this may be because of carrying soil and sand from neighbouring places in open trucks and vehicular movements at sampling station S5. Similarly, sampling stations S2, S9, and S10 fall under poor air quality index with AQI scores of 280.94, 278.00 and 213.87 respectively. Though sampling station S10 is near the last Point (in Indian Territory) on river Haora entering Bangladesh, it has third lowest AQI score of 213.87, due to the fact that the 24 hours-average values of SO_2 and NO_2 have been found well below the maximum permissible limit. The possible reason for this trend may be that human activities are not very predominant at this station. The sampling stations S3, S4, and S6 fall under the category of very poor air quality index with their scores of 352.15, 358.17 and 371.41 respectively. Finally, sampling stations S7 and S8 have severe air pollution levels with their AQI scores of 460.84 and 484.68 respectively. The high values of AQI at these two stations have been found to be mainly due to the presence of higher PM_{10} concentration in the air leading to deterioration in air quality at these stations. The higher concentration of PM_{10} is attained mainly due to the presence of large vehicular movements. In fact there is gradual increase in AQI values from sampling stations S1 to S4 and then S6 to S8. Though the 24 hours-average SO_2 and NO_2 values have been found well below the prescribed maximum permissible limit as prescribed by NAAQS, PM_{10} is present in excess at all stations with its concentration beyond 300.0 $\mu g/m^3$ at S2, S3, S4, S6, S7, S8 and S9.

This may be due to dust coming out from brickfields, air pollution and smoke coming out from the small scale automobile and wielding shops on the road, carrying of construction materials like sand, bricks, stone chips and cement in open trucks and vehicular movements on highways. At the sampling stations S7 and S8, the AQI scores are 460.84 and 484.68 respectively. The AQI scores are comparatively higher at these two sampling locations may be due to a number of human activities. One of the biggest bus terminus of the state along with stand point of smaller vehicles (auto rickshaw and taxi) and a big market is very close to the Stations S7 and S8. Vehicular pollution due to huge traffic congestion and idling of vehicles are taking place all the time in this area which is responsible for higher AQI.

Table 5.5 clearly shows that there has been significant increase in the both PM_{10} and SPM concentrations at the sampling stations S7 and S8 (even greater than 500 $\mu g/m^3$). In fact these two parameters have been found exceeding the standards at all sampling stations. It is observed that SPM exceeds the NAAQS prescribed limit which is 100 $\mu g/m^3$, at all the ten sampling sites. At sampling sites S7 (i.e. Near Nagerjala on NH-44, 150 meter from Bardowali Intake Point) and

S8 (i.e. Near Battala Crematorium on NH-44, 150 meter from crematorium), the concentration is maximum and highest average concentration value of 684.95 µg/m^3 is found at S7. Though the concentration of PM_{10} is the lowest at sampling station S1 among all ten stations, but it exceeds the 24-hours average concentration limit of NAAQS (60 µg/m^3) at all the sampling stations. The highest being at S8 with an average value of 572.14 µg/m^3. It is interesting to observe that the monitored concentrations of remaining air pollutants, viz. SO_2 and NO_2, CO and lead are found well below the prescribed NAAQS.

Spatial variations of air pollutants have been evaluated by developing AQI at 10 different sampling stations as shown in Figure 5.3. The air pollution levels were found to vary and falls under 4 classifications ranging from severe air pollution to moderately clean air (except good air condition) as described above. The two important parameters viz. PM_{10} and SPM were the responsible pollutant for higher values of AQI which contribute significantly in lowering the status of air quality.

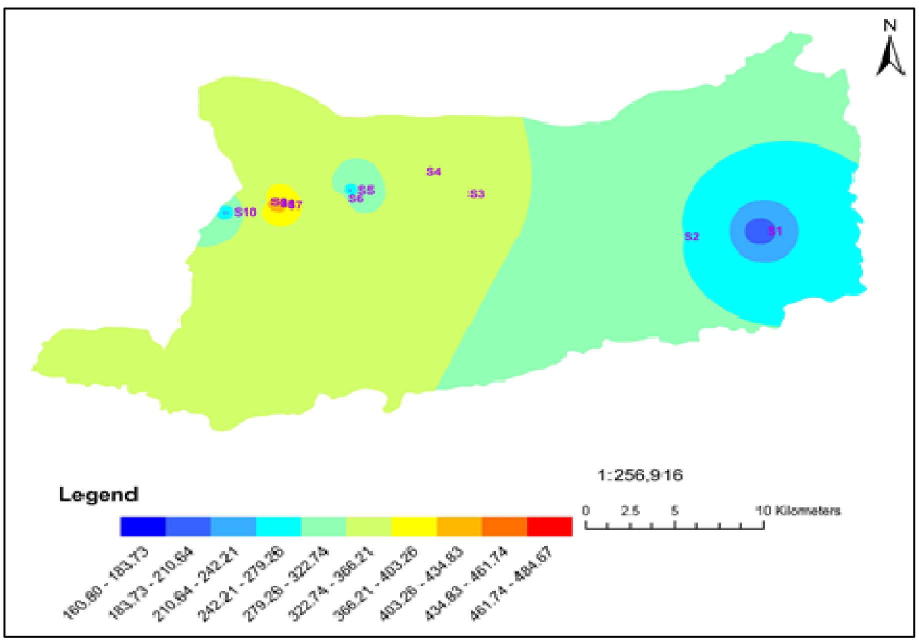

Figure 5.3: Spatial distribution map of AQI using modified EPA method

This method presented in this section applies the concept of maximum operator to calculate AQI. Thus it considers the maximum value among all sub-indexes derived from the pollutants at a particular station to define the overall AQI. In fact values pertaining to lower sub-indexes derived from other pollutants are discarded which is the main limitation of this approach. This is mainly due to the fact additive or synergistic effects of pollutants on the human health are generally excluded while deriving index value. Moreover, the break points used for evaluation of air quality indices are also not defined by USEPA when NO_2 concentrations are less than 0.65 ppm. Another important point is that AQI evaluation system proposed by USEPA is not usable presently in several parts of the world due to non-availability of $PM_{2.5}$ concentration (Cheng et al., 2007). The ordinal scale used to describe the pollution level of the pollutant in the form of sub-index has also been used to define overall aggregate index though the severity of the pollution level described by the aggregate index is not linear with sub-index scores. The boundaries of break points corresponding to different pollutants are also not certain. The ambiguousness and inaccuracies due to these aspects can be handled by incorporating fuzzy concepts. Therefore, next section deals with evaluation of air quality index using fuzzy comprehensive analysis method which seems to be particularly promising and applicable.

Though the above methodology clearly evaluates air quality status in the selected region, it would be better if the critical air pollutants monitored regularly to perform long-term temporal and spatial analysis.

5.4.2 Air Quality Index using Fuzzy Comprehensive Analysis Method

Air quality index determination using fuzzy comprehensive analysis (FCA) has been performed by adopting similar steps as described in Section 4.4.2 of Chapter 4.

5.4.2.1 Assessment criterion set

The air quality parameters have been used to evaluate a score corresponding to a grade in terms of membership functions. It will enable a decision maker to demonstrate how these parameters (pollutants) impact the status of overall quality of air at a given station. The set U is described as an assessment criteria set representing water quality parameters to be determined and is represented as $U = \{U_1, U_2, U_3 \ldots U_m\}$. In this study, six parameters have been considered to evaluate status of air quality corresponding to specified class of assessment. They play major role in the overall evaluation process.

5.4.2.2 Assessment class set

On similar lines as explained in previous chapter, each assessment criteria is expressed in terms different grades on the basis of satisfaction/aspiration level of pollution control agencies and the general public or society at large. This classification can be represented by the set G consisting of all evaluation classes such that G = {Good (G_1), moderate (G_2), poor (G_3), very poor (G_4), severe (G_5)}. These five grades describe the significance of six air quality parameters for assessing status of air quality at chosen sampling stations. The classification of these grades with respect to each assessment factor is given in Table 5.7. Among them, G1 stands for the desirable condition demonstrating the best air quality expressed in terms of a given parameter. In this case, air quality is considered as good and hence scope for improving status of air quality is minimal. Therefore, the situation of air is optimistic; G_5 stands for the worst situation which is unfit and will have to be rejected. It indicates that air quality has degraded significantly. The situations of G_2, G_3, and G_4 lie between G_1 and G_5 representing a level of degradation of air quality to the extent moderate, poor and very poor respectively, and require attention to improve the quality.

5.4.2.3 Weights set

As different air quality parameters have different influences on the overall assessment of air quality, a weight set, W = {W_1, W_2, …, W_m}, represents the weight coefficients of each air quality parameter. The normalized comparison matrix is derived by dividing elements of each column of the pair-wise comparison matrix given in Table 5.6 by the sums of the elements of respective columns. The weight set with respect to air quality parameter has been derived using Analytical Hierarchy Process (AHP) as explained in the Section 4.4.1.2. Based on the opinion of the decision makers, the pair-wise comparisons of all parameters are performed using Table 4.1 on Saaty's 9-point scale. The relative weights of each air quality criteria are shown in the Figure 5.4. The reciprocal ratings are shown in fractions. As in this case study there are six air quality parameters, a 6x6 pair-wise comparison matrix has been derived while performing pair-wise comparisons which is given in Table 5.6.

Table 5.6: Pair-wise comparison of Air Quality Parameters

Parameters	SO_2	NO_x	CO	Pb	PM_{10}	SPM
SO_2	1.00	3.00	5.00	2.00	1.00	1.00
NO_x	0.33	1.00	3.00	0.50	0.33	0.33
CO	0.20	0.33	1.00	0.25	0.20	0.20
Pb	0.50	2.00	4.00	1.00	0.50	0.50
PM_{10}	1.00	3.00	5.00	2.00	1.00	1.00
SPM	1.00	3.00	5.00	2.00	1.00	1.00

After performing pair-wise comparisons of air quality parameters with respect to all parameters, weights of each parameter have been evaluated as shown in Figure 5.4.

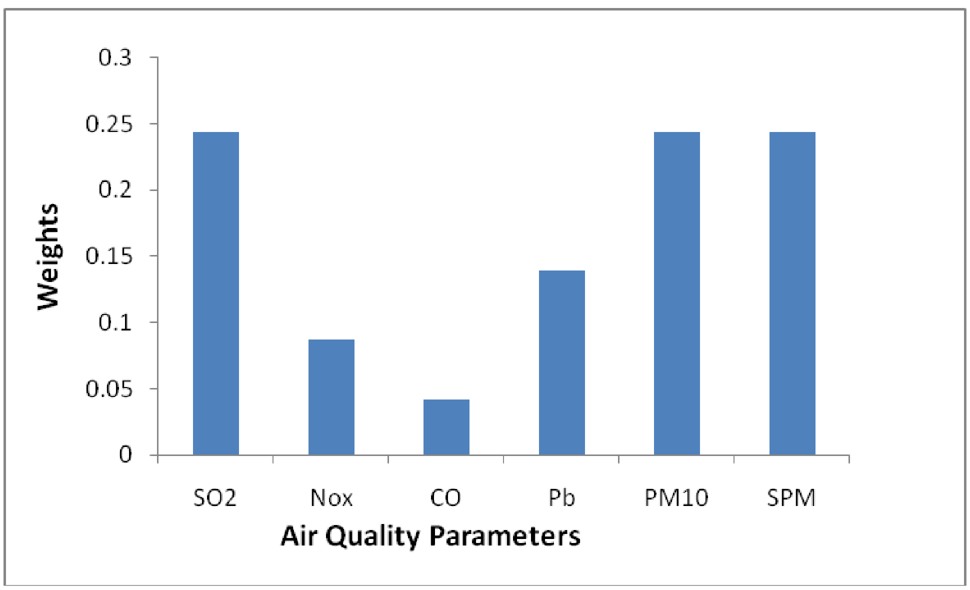

Figure 5.4: Final weights of Air Pollutants

The final weights (w_i) for each air pollutants shown in Figure 5.4 are essentially given on a scale of 0-1, with 0 being '*not at all important'* and 1 being '*extremely important*'. It is evident from the results that relatively higher importance with score of equal importance was realized on 3 parameters viz., SO_2, SPM and PM_{10} followed by lead, NO_2 and CO respectively.

5.4.2.4 Fuzzy relation matrix

An element of a relation matrix R of a fuzzy set is described by a membership function $\mu_{ij}(x)$ where x is the actual value of a given criterion. The element $\mu_{ij}(x) = \mu_R(U_i, G_j)$ (i and j are natural numbers; $i \in [1, m]$, $j \in [1, n]$); $\mu_{ij} \in [0, 1]$ of the relation matrix R is the value of membership function of any criterion U_i, with respect to an evaluation class G_j. If the value of membership of a given criteria 'm' with respect to evaluation class 'n' is assumed as $\mu_{mn}(x)$, the relation matrix R of a fuzzy set can be expressed using equation 5.2:

$$R = \begin{bmatrix} \mu_{11}(x) & \mu_{12}(x) & \mu_{13}(x) & \ldots & \mu_{1n}(x) \\ \mu_{21}(x) & \mu_{22}(x) & \mu_{23}(x) & \ldots & \mu_{2n}(x) \\ \vdots & \vdots & \vdots & \ldots & \vdots \\ \mu_{m1}(x) & \mu_{m2}(x) & \mu_{m3}(x) & \ldots & \mu_{mn}(x) \end{bmatrix} \tag{5.2}$$

The membership functions between the two grades should be smoothed by eliminating discrepancy of assessment values as explained section 4.4.2.4 of Chapter 4. Accordingly, elements of fuzzy relation matrix have been derived using Table 5.4 and Table 5.6.

The values of grades G_i and the corresponding critical points were decided based on the practical significance of each parameter as suggested by Sharma et al. (2003). For example, the assessment factor, PM_{10}, can be classified into five grades. Though the assessment class "moderate" has been expressed conventionally in the range between 100-150, it has been expressed by the trapezoidal membership function ranging from 80-170 (i.e. 80, 120, 130, 170) under fuzzy environment so that 100 µg/l is treated as the critical value between good (G_1) and moderate (G_2), and 150 µg/l between moderate (G_2) and poor (G_3). Thus PM_{10} with 100 µg/l concentration can be regarded as the boundary point of grade at the interface of the good and moderate grades whereas 150 mg/l can be considered as boundary point of another grade at the interface of the moderate and poor conditions. The grade classifications of the six parameters are listed in Table 5.7.

Table 5.7: Grade classification of Parameters along with their Membership functions

Linguistic description of Air Quality	Grade classification of parameters (G_i) along with their membership functions					
	SO_2	NO_2	CO	Pb	PM_{10}	SPM
Good	Triangular (0, 0, 160)	Trapezoidal (0, 0,30, 130)	Triangular (0, 0, 4)	Trapezoidal (0, 0,0.75, 1.25)	Trapezoidal (0, 0, 80, 120)	Trapezoidal (0, 0, 170, 230)
Moderate	Trapezoidal (0.0, 160, 327, 407)	Triangular (30, 130, 230)	Trapezoidal (0, 4, 10, 14)	Triangular (0.75, 1.25, 1.75)	Trapezoidal (80, 120,130, 170)	Triangular (170, 230,300)
Poor	Trapezoidal (327, 407, 746, 826)	Trapezoidal (130, 230, 514, 614)	Trapezoidal (10, 14, 15, 19)	Trapezoidal (1.25, 1.75, 2, 2.5)	Trapezoidal (130, 170, 320, 380)	Trapezoidal (230, 290, 370, 430)
Very poor	Trapezoidal (746, 826, 1532, 1612)	Trapezoidal (514, 614, 1000, 1544)	Trapezoidal (15, 19, 30, 40)	Trapezoidal (2, 2.5, 3, 3.5)	Trapezoidal (320, 380, 400, 440)	Trapezoidal (370, 430, 770, 830)
Severe	Triangular(1532, 1612, 1612)	Triangular (1000, 1544, 1544)	Triangular (30, 40, 40)	Triangular (3, 3.5, 3.5)	Triangular (400, 440, 440)	Triangular (770, 830, 830)

The membership function of any of the six air quality parameters (U_1, U_2… U_6) have been evaluated with respect to five classification-grades. For example, membership of SO_2 with respect to different grades can be evaluated using equations (5.3) to (5.7).

$$\mu_G(S_n) = \begin{cases} -6.25\times10^{-3} S_n + 1.0 & \text{for } 0.0 \le S_n \le 160 \\ 0 \text{ otherwise} \end{cases} \tag{5.3}$$

$$\mu_M(S_n) = \begin{cases} 6.25\times10^{-3} S_n & \text{for } 0.0 \le S_n \le 160 \\ 1 & \text{for } 160 \le S_n \le 327 \\ -1.25\times10^{-2} S_n + 1.0 & \text{for } 327 \le S_n \le 407 \\ 0 \quad \text{otherwise} \end{cases} \tag{5.4}$$

$$\mu_P(S_n) = \begin{cases} 1.25\times10^{-2} S_n & \text{for } 327 \le S_n \le 407 \\ 1 & \text{for } 407 \le S_n \le 746 \\ -1.25\times10^{-2} S_n + 1.0 & \text{for } 746 \le S_n \le 826 \\ 0 & \text{otherwise} \end{cases} \quad (5.5)$$

$$\mu_{VP}(S_n) = \begin{cases} 1.25\times10^{-2} S_n & \text{for } 746 \le S_n \le 826 \\ 1 & \text{for } 826 \le S_n \le 1532 \\ -1.25\times10^{-2} S_n + 1.0 & \text{for } 1532 \le S_n \le 1612 \\ 0 & \text{otherwise} \end{cases} \quad (5.6)$$

$$\mu_S(S_n) = \begin{cases} 1.25\times10^{-2} S_n & \text{for } 1532 \le S_n \le 1612 \\ 1 & \text{for } S_n \ge 1612 \\ 0 & \text{otherwise} \end{cases} \quad (5.7)$$

Similarly, the membership function of any other air parameters can be derived with respect to five classification-grades.

5.4.2.5 Fuzzy assessment matrix

Once fuzzy relation matrix R is derived, it is necessary to aggregate the effects of all critical parameters with their relative weights into an overall combined matrix. This is useful to respective experts/stakeholders to constitute a unified basis for comparison of air quality status at different stations. The elements of fuzzy combination matrix can be derived using equation (5.8).

$$B = W \bullet R = [W_1 \ \ W_2 \ \ W_3 \ldots W_m] \bullet \begin{bmatrix} \mu_{11}(x) & \mu_{12}(x) & \ldots \ \mu_{1n}(x) \\ \mu_{21}(x) & \mu_{22}(x) & \ldots \ \mu_{2n}(x) \\ \vdots & \vdots & \ldots \ \vdots \\ \mu_{m1}(x) & \mu_{m2}(x) & \ldots \mu_{mn}(x) \end{bmatrix} \quad (5.8)$$

Using equation (5.8), fuzzy combination matrix $B = [b_j]_{1\times n}$ is evaluated at each station. Finally the integrated assessment value F_k is evaluated at any k^{th} station by integrating effects of all grades using equation (5.9):

$$F_k = \frac{\sum_{j=1}^{n} b_j \alpha_j}{\sum_{j=1}^{n} b_j} \qquad (5.9)$$

where b_j (j = 1,..,n) are the elements of fuzzy combination matrix representing integrated assessment value at each sampling station corresponding to all possible grades and α_j is the permissible category of air quality. The value of F_k is the comprehensive grade of air quality at a given station k. The status of quality of air can finally be expressed with a single index value using a simple defuzzification process wherein grades of overall AQI have been assigned a value ranging from 0 to 1 on the basis of their relative importance. These grades are further represented by the triangular membership functions as specified in Table 5.8 and shown in Figure 5.5. The membership function for each parameter corresponding to a given grade at a particular station can be derived as explained in 5.4.2.4.

Table 5.8: Fuzzy Membership functions for different grades of Overall AQI Score (S_n)

Linguistic description	Ratings with triangular elements
Very poor	(0.0, 0.0, 0.25)
Poor	(0.0, 0.25, 0.50)
Fair	(0.25, 0.50, 0.75)
Good	(0.50, 0.75, 1.0)
Very good	(0.75, 1.0, 1.0)

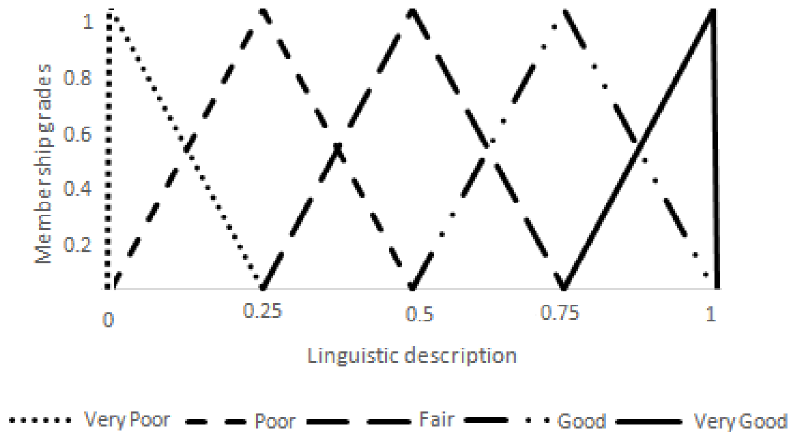

Figure 5.5: Linguistic description vs. Membership functions

If [$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ = 0.0, 0.25 0.5, 0.75, 1.0], the AQI score with respect each grade at a given station is calculated using above equations and total score at each station is computed by defuzzifyng fuzzy score using equation (5.10):

$$F_k = \mu_{G1}(S_n)\times 0.00 + \mu_{G2}(S_n)\times 0.25 + \mu_{G3}(S_n)\times 0.5 + \mu_{G4}(S_n)\times 0.75 + \mu_{G5}(S_n)\times 1.0 \qquad (5.10)$$

On the basis final score, air quality status at each station has been ranked. If the final score is lower, the air quality is better.

5.5 Results and Discussion

The membership function of assessment factor U_i with respect to grade G_j (i.e. $\mu_{G_j}(U_i)$ is calculated using Table 5.7. The membership functions of all air parameters (pollutants) have been derived with respect to five classification-grades on the basis of their observed values. The fuzzy relation matrix R at each sampling station is calculated accordingly. The importance weight of each air quality parameter as given in Figure 5.4**,** has been considered to calculate integrated fuzzy assessment values using equation (5.8) [i.e. W = {W_1, W_2, W_3, W_4, W_5 W_6} = {0.24475, 0.0873276, 0.0419, 0.1395, 0.24375, 0.24375} where $0 \leq w_i \leq 1$] and given in Table 5.9.

Table 5.9 lists the memberships of six air quality parameters as assessment factors with respect to the five classifications at all sampling stations. These scores can essentially help to explore the problem areas in context to overall air quality assessment at a particular station. For example, memberships of air quality parameter PM_{10} to G_i show that the most serious problem of sampling stations S7 and S8 is the severe condition of PM_{10}. Similarly, memberships of air quality parameter SPM to G_i indicate that air quality is very poor in context to SPM at sampling stations S7 and S8. Thus, if the issues related to PM_{10} and SPM can be addressed at sampling stations S7 and S8 in an effective manner, the overall air quality can be achieved at the desired level. In fact the high concentration of PM_{10} and SPM are responsible factors to increase overall scores at these stations leading the air quality the worst as can be inferred from Table 5.9. Therefore, it is high time to focus on reducing excess PM_{10} and SPM, and building up the consciousness among masses for not polluting further so that overall quality of air in the region can be improved.

The final fuzzy integrated assessment values are also calculated using equations (5.9) and (5.10) as listed in the Table 5.10. These values are given as 0.066, 0.251, 0.345, 0.357, 0.104, 0.371, 0.459, 0.445, 0.253, 0.149 for sampling sites S1, S2, S3, S4, S5, S6, S7, S8, S9 and S10 respectively. From Table 5.10 and Figure 5.6, it is clear that sampling stations S1, S5, and S10 have higher integrated fuzzy assessment value with respect to grade "Good" than that with respect to all other grades and therefore the overall air quality status falls under Good condition with their ranking order 1, 2 and 3 respectively. In fact scores corresponding to very poor and severe conditions at these stations are nil. Though sampling stations S2 and S9 score 0.483 and 0.476 respectively under "Good" condition, they also score 0.488 and 0.488 respectively under "Poor" condition. The combined effect of these scores (due to effect of various parameters) leads to increase the pollution level and hence they rank 4 and 5 respectively. Similarly sampling stations S3, S4, and S6 score 0.487, 0.468, 0.451 respectively under "Good" condition along with the score 0.379, 0.408, and 0.446 respectively under "Very Poor" condition. Thus leading to ranking order as 6, 7 and 8 respectively.

The sampling stations S7 scores 0.383, 0.130, 0.00, 0.244 and 0.244 corresponding to good, moderate, poor, very poor and severe conditions respectively whereas sampling station S8 scores

0.44, 0.073, 0.00, 0.244 and 0.244 respectively corresponding to these five grades. It is also interesting to note that score corresponding to "good" condition is higher at S8 than S7, therefore air quality status at S8 is better than S7. Thus sampling stations S8 and S7 have been ranked as 9 and 10 respectively. Although there is no alarming situation at 5 sampling sites S1, S2, S5, S9, S10, the remaining 5 sampling stations demonstrate air quality status from very poor to severe with S8 and S7 being the worst. The degradation in air quality at these stations is mainly due to high concentrations of PM_{10} and SPM, while the concentrations of SO_2, NO_2, CO and Pb were found well within the permissible values. These fine particulate matters (especially SPM and PM_{10}) develop toxic conditions which affect immune system of all living things. Fine particulates enter into the respiratory system which irritate lung tissues and cause long-term effects on human organs. The prime health effects caused by excess PM may are premature death; irritation of respiratory and cardiovascular disease, which can be observed from increased hospital admissions, less attendance in schools, alterations in functions of lung and increased respiratory symptoms; alterations to lung tissues and structure etc. Thus, there must be a regular mechanism to monitor air quality in addition to sensitizing local population to control pollution in the region. Appropriate mitigation measures should be taken so that quality status remains within moderate to good condition in due course of time.

The ranking scores of sampling sites S1, S3, S4, S5, S6 and S10 are same in both the methods. The sampling station S2 and S9 has been ranked as 4 and 5 by the FCA method whereas these two sampling stations have been ranked 5 and 4 respectively as far as modified EPA method is concerned. Similarly, sampling stations S7 and S8 have been ranked as 10 and 9 by the FCA method whereas these two sampling stations have been ranked 9 and 10 respectively as far as modified EPA method is concerned. As the final AQI score by modified EPA method is evaluated on the basis of maximum operator. Thus, it considers the maximum value among all sub-indexes derived from the pollutants at a particular station to define the overall AQI. In fact the lower sub-indexes derived from other pollutants were not considered which is the main limitation of the method. However, fuzzy comprehensive analysis method not only incorporates the additive or integrated effects of all responsible pollutants but also addresses successfully issues pertaining to ambiguousness and inaccuracies. Clearly, evaluation of air quality index using fuzzy comprehensive analysis method seem to be particularly promising and better over modified EPA method.

Table 5.9: Computation of membership values of Air Quality Assessment factors at each Station with respect to a grade

Air quality parameters	Grade	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
SO_2	G1	0.924	0.886	0.896	0.886	0.933	0.831	0.809	0.822	0.884	0.887
	G2	0.076	0.115	0.104	0.114	0.067	0.169	0.191	0.178	0.116	0.113
	G3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	G4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	G5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO_2	G1	1.000	0.978	0.999	0.806	1.000	0.832	0.676	0.705	0.909	0.979
	G2	0.000	0.022	0.001	0.194	0.000	0.168	0.324	0.295	0.091	0.022
	G3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	G4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	G5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CO	G1	1.000	1.000	1.000	1.000	1.000	0.870	0.825	0.913	1.000	1.000
	G2	0.000	0.000	0.000	0.000	0.000	0.130	0.175	0.088	0.000	0.000
	G3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	G4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	G5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pb	G1	1.000	1.000	1.000	1.000	1.000	1.000	0.660	1.000	1.000	1.000
	G2	0.000	0.000	0.000	0.000	0.000	0.000	0.340	0.000	0.000	0.000
	G3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	G4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	G5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PM_{10}	G1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	G2	0.985	0.000	0.000	0.000	0.361	0.000	0.000	0.000	0.000	0.000
	G3	0.015	1.000	0.000	0.000	0.639	0.000	0.000	0.000	1.000	1.000
	G4	0.000	0.000	1.000	1.000	0.000	0.997	0.000	0.000	0.000	0.000
	G5	0.000	0.000	0.000	0.000	0.000	0.003	1.000	1.000	0.000	0.000
SPM	G1	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.672
	G2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.328
	G3	0.000	1.000	0.444	0.324	0.000	0.166	0.000	0.000	1.000	0.000
	G4	0.000	0.000	0.556	0.676	0.000	0.834	1.000	1.000	0.000	0.000
	G5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5.10: Fuzzy Integrated Assessment Values

Sampling Stations	G1	G2	G3	G4	G5	Final Score	Rank
S1	0.738	0.259	0.004	0.000	0.000	0.066	1
S2	0.483	0.030	0.488	0.000	0.000	0.251	4
S3	0.487	0.025	0.108	0.379	0.000	0.345	6
S4	0.468	0.045	0.079	0.408	0.000	0.357	7
S5	0.740	0.104	0.156	0.000	0.000	0.104	2
S6	0.451	0.061	0.041	0.446	0.001	0.371	8
S7	0.383	0.130	0.000	0.244	0.244	0.459	10
S8	0.440	0.073	0.000	0.244	0.244	0.445	9
S9	0.476	0.036	0.488	0.000	0.000	0.253	5
S10	0.647	0.109	0.244	0.000	0.000	0.149	3

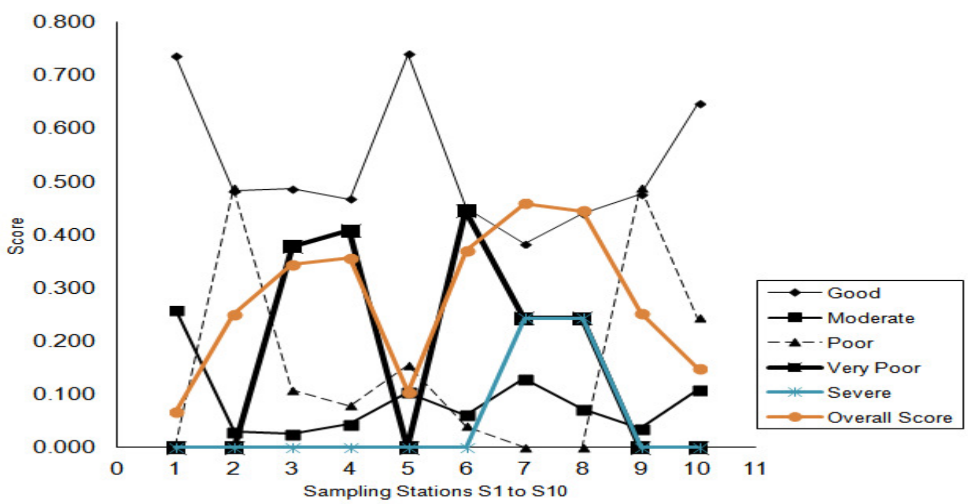

Figure 5.6: Comprehensive Evaluation of Air Quality Assessment

GIS-based maps have also been developed on the basis of observed values of air pollutants concentration and final scores obtained from two approaches to demonstrate spatial variations at all sampling stations in Haora River basin. An application of Geographic Information System (GIS) tool essentially generates parameter maps which can easily be interpreted with overall analysis. An input database is formed to feed observed values of all six parameters including SO_2, NO_2, CO, Pb, PM_{10} and SPM. which were collected from 10 groundwater sampling stations using ArcGIS. Finally, composite air quality index maps are obtained for the Haora river basin based on two proposed index techniques.

The proposed AQI is evaluated by integrating effects of six air pollutants that impact the quality of air in the region. The geo-statistical analyst tool within ArcMap® 9.3 has been used. The input map of Haora River basin is first geo-referenced using the latitude and longitude coordinates of sampling stations. Then the air quality parameter values and final indices values have been imported into the GIS database which has been used to plot the spatial distributions of these parameters using inverse distance weighted interpolation technique. The Air Quality Index (AQI) using modified EPA method and Fuzzy Air Quality Index (FAQI) are also plotted to study the spatial variation in overall quality of air as depicted in Figures 5.3 and 5.8. The final map can be used as a reference for future air management plans, air remediation plans and the degree of air treatment required as a function of location in a particular region. From the map, it can be observed that the regions around S1, S3, S4, S5, S6 and S10 constitute good air quality in both methods. An application of Geographic Information System (GIS) tool generates useful maps pertaining to integrated assessment score which can easily be interpreted spatially by visualizing maps and making comparative evaluations.

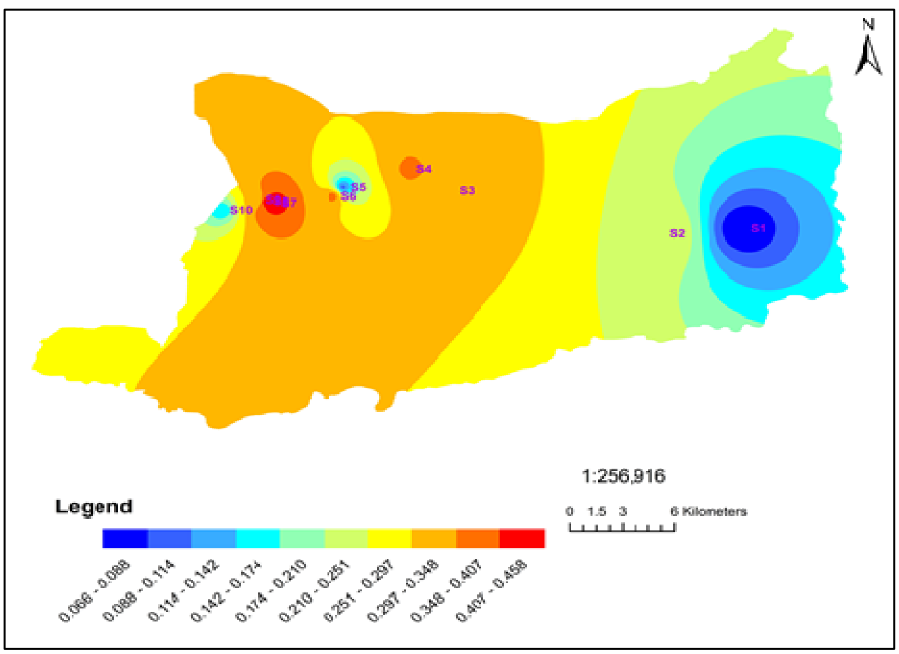

Figure 5.7: GIS based spatial variability of FAQI in Haora River Basin using Fuzzy Set Theory

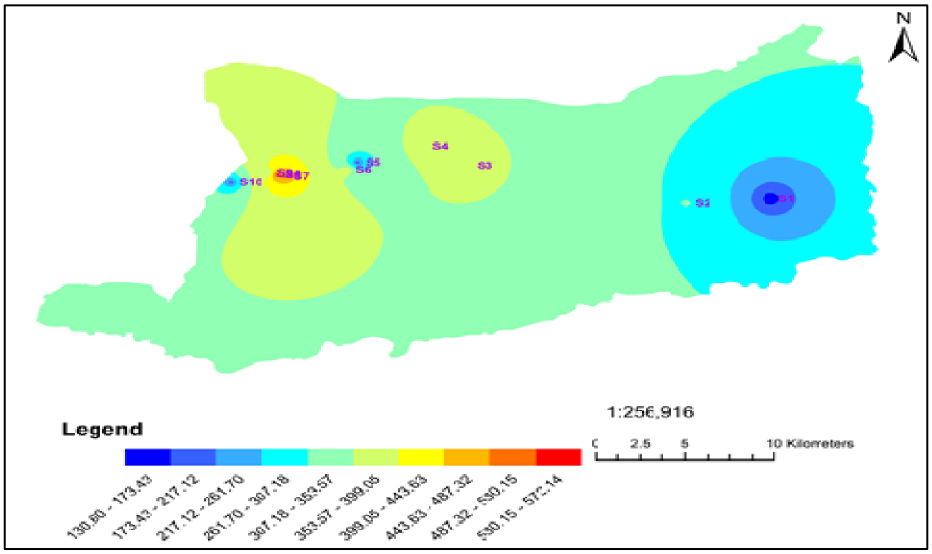

Figure 5.8: GIS based spatial variability of PM_{10} in Haora River Basin

The AQI and FAQI evaluated herein clearly demonstrate the spatial distribution of these indices. The spatial distribution of individual air pollutants have been shown on maps as well. GIS plays an important role in formulating basis for visualizing maps and making comparative assessments, making the assessment analysis simple, easy and effective so that it can be conveyed to decision makers and managers. The final map can be used as a reference for future air management plans, air remediation plans and the degree of air treatment required as a function of location in a particular region.

In the two indices based maps, areas with bad air quality are shown in red and areas with best air quality are shown in blue. The range of intermediate colors between blue and red depict increasing contamination in air. From the map, it can be observed that the region around station 10 constitutes good air quality in both conventional as well as fuzzy method. In the conventional approach (modified EPA Method), the map depicts that the region around S1 and S10 have good air quality whereas S8 has the worst air quality, as a result of excess PM_{10}, SPM and NO_2 content. Regions around stations S6 and S7 are moderately polluted. In the fuzzy approach, S1 has the best air quality and S7 has the worst.

5.6 Summary

Similar to chapter 4, in this chapter also, an integrated AQI has been developed to assess quality of air at different location in Haora River basin by using two aggregating methods of Multiple-Attribute Decision Making Process, namely the Simple Additive Weighting (SAW) and the Fuzzy Comprehensive Assessment (FCA) methods.

The air pollution levels at different sampling stations in and around Agartala were found between the moderate and severe conditions which have AQI scores varying from 160.80 at sampling station S1 to 484.68 at sampling station S8 using modified EPA method whereas it ranges from 0.066 at sampling station S1 to 0.459 at sampling station S7 using fuzzy comprehensive analysis method. By both the methods it is inferred that PM_{10} and SPM were the responsible pollutants for the higher index score at all stations. It is expected that pollution load may further be increased due to construction developments, vehicular movements, urbanization and other industrial activities. It is therefore important to focus not only on the critical air pollutant (PM_{10} and SPM) but also all other air pollutants. For effective assessment of air quality, there is also need to study the impact of reaction mechanisms involved in polluting air through these critical pollutants which are affected by factors like reactant's concentration, climatic conditions, availability of moisture content in the atmosphere, and local topography. Thus, both spatial and temporal variations of pollutants should be analyzed at all sampling stations on long-term basis. It would be better if the critical air pollutants are monitored regularly in the selected region. It is also suggested that air quality should be maintained within the prescribed and safe limit by adopting efficient and cost-effective measures of planning and management.

The final AQI score by modified EPA method is evaluated on the basis of maximum operator. Thus it considers the maximum value among all sub-indexes derived from the pollutants at a particular station to define the overall AQI. In fact the effects of lower sub-indexes derived from other pollutants were not considered which is the main limitation of the method. In modified EPA method, there is also uncertainty in discriminating break points needed for calculating value of sub-indices corresponding to different pollutants.

However, fuzzy comprehensive analysis method not only incorporates the additive or integrated effects of all responsible pollutants but also addresses successfully issues pertaining to ambiguousness and inaccuracies. It should also be noted that though it is now recommended to measure $PM_{2.5}$, in various guidelines, a major part of the nation is still not able to implement proposed AQI system recommended by these guidelines due to non-availability of $PM_{2.5}$ measurement equipments.

Thus, there must be a regular mechanism to monitor air quality in addition to sensitizing local population to control pollution in the region. Appropriate mitigation measures should be taken so that quality status remains within moderate to good condition in due course of time. Public awareness and participation can also play a key role in maintaining good condition of air quality. A long-term spatial and temporal variation of pollutants at all sampling stations is also recommended. It would be better if the critical air pollutants are monitored regularly in the selected region in addition to sensitizing local population to control pollution in the region. It is also suggested that air quality should be maintained within the prescribed and safe limit by adopting efficient and cost-effective measures of planning and management. Appropriate mitigation measures should be taken so that quality status remains within moderate to good condition in due course of time. To this end, public awareness and participation is seen to play a key role in maintaining good condition of air quality. Widespread environmental education is suggested to promote understanding of linkages between air pollution and its impact on health. Media, which is the fourth pillar of the nation must participate actively in rising awareness about significance of quality of air and its impact on health.

CHAPTER 6

ENVIRONMENTAL QUALITY ASSESSMENT IN HAORA RIVER BASIN USING PUBLIC PERCEPTIONS

6.1 Introduction

In this chapter, environmental quality has been analyzed using a public perception's based survey questionnaire. It demonstrates how perceptions of the public can be used to perform an effective analysis for a complex and dynamic environment consisting of both the physical and social environments along Haora river, especially at Agartala. As per 2011 census, the population of Agartala city was estimated to be 399,688 and the literacy rate (94%) was higher than the national literacy rate (74.04%). The city is administered by the Agartala Municipal Corporation (AMC) with the population 438,408 in geographical area of 76.504 square km. Agartala falls under humid subtropical climate with large amounts of rain throughout the year. The temperature varies between 18 °C in winter to the 25 °C in the summer. The average annual precipitation is around 2100 mm.

The study attempts to assess ward-wise quality of environment in Agartala city on the basis of "perceptions survey" conducted among individuals about their experiences and to determine the relationship among specific attributes of different components of environment. This "perceptions survey" included questions which allowed respondents to rate the performance of forty seven attributes deemed significantly for assessment of the environmental quality. Respondents were asked about their physical environment, neighbourhood environment and social environment. Ten attributes were used to assess the physical environment, twenty three attributes for their neighbourhood environment and nine attributes for social environment. Five attributes have also been considered to assess the respondents' view on their usual perceptions of overall quality of environment. The performance of these attributes have been rated by measuring them either on 4-point scales anchored by the attributes of ‘highly satisfied’ and ‘not acceptable’ or on 3-point attribute scales anchored by ‘intolerable’ and ‘negligible’. In general, people of AMC are concerned about environmental issues and vocal about gradual deterioration of quality of life of the city.

6.2 Background

Assessment of environmental quality can be performed by taking into consideration of various attributes in the process of evaluation. Some of these attributes/criteria can be considered pertaining to the quality indices of air, water, solid waste management, vegetation, transportation etc. These attributes can be considered to assess overall quality of environment in different AMC wards which can be addressed using multiple-criteria decision-making (MCDM) tool (Liang and Wang, 1991). The TOPSIS (i.e. Technique for order preference by similarity to an ideal solution), a very popular MCDM tool, has been used widely in different real life situations (Hwang and Yoon, 1981).

In this tool, decision maker first specifies an ideal point the components of which are the subjective or computed best values of the different criteria. The alternative with smaller distance from ideal point is considered the best one. Similarly, the decision maker can also specify nadir point indicating the worst values of the criteria. In such cases, the alternative with largest distance from the nadir is considered as the best option (Hwang and Yoon, 1981). The TOPSIS methods used earlier could not successfully incorporate uncertainty associated with human judgements, as most of the analyses were performed using crisp values. The analysis pertaining to crisp data sometimes does not reflect real-life situations since the rating and weights of attributes associated with decision making problems are often expressed in linguistic manner. Thus, for a more realistic approach an effective and rational decision making endeavor, linguistic assessments need to be incorporated instead of a sole reliance on numerical values.

However, in order to ensure compatibility between the fuzzy (or non-fuzzy) evaluation values of all criteria, the fuzzy (or non-fuzzy) evaluation values of the objective criteria must be converted into a compatible scale (into dimensionless indices) (Liang and Wang, 1991). Hsu and Chen (1997) have proposed a method for conversion wherein a fuzzification process has been suggested to convert linguistic terms/variables into triangular fuzzy numbers.

The fuzzy based TOPSIS approach has been used by the several researchers to analyze various decision making problems (Chen, 2001 and Chu, 2002). The concepts of fuzzy set theory were incorporated in the classical TOPSIS methods to deal with linguistic variables for selecting plant location (Yong, 2006). Moreover, existing fuzzy based TOPSIS methods involve complex and numerous computations which require a large set of data and time for deriving results. Yong (2006) introduced an advanced fuzzy TOPSIS methodology to simplify the computation by expressing linguistic terms in the form of triangular fuzzy numbers. The final results obtained in the form of fuzzy triplets are converted into crisp value using defuzzification process. The positive and negative ideal solution could then be evaluated using the crisp value. Kuo et al. (2007) have also performed decision-making process using positive and negative ideal points obtained through fuzzy TOPSIS method. However, the outcome of existing fuzzy TOPSIS methods is a fuzzy number which is not efficient enough to provide a satisfactory or a universal ranking solution to all cases and situations. Such kind of ambiguity can be dealt by using a modified fuzzy TOPSIS model which is proposed in the present study.

6.3 Methodology

The objectives of the present study are:

(1) to measure, analyse and study public viewpoint, options and their perceptions on various environmental issues to provide appropriate framework for upgrading status of quality of environment and suggest course of action for improvement of quality of air, water, transport, waste management and as such the overall environment; and

(2) to explore co-relationships among responses from public and environmental behaviour obtained from the questionnaire.

6.3.1 Creation of Income Groups

To assess the public perception and attitude of people residing in Agartala Municipal Corporation (AMC) area a survey questionnaire was conceptualized, designed and developed. Based on statistical advice a target of 450 people was set as the sample size population. Thus a total of 450 survey forms were distributed and a door to door households survey was conducted in different wards along with the questionnaire on selected environmental variables which had been prepared under the guidance of experts. All 35 wards of AMC were considered with 12 households in each ward. Households were also categorized into 3 income groups. Thus, the total surveyed household count stood at 420 and the entire survey was conducted within two months during February-March, 2012.

The questionnaires have also been developed to gather information on the urban environment. Three income groups have been considered from each ward of "Agartala Municipal Corporation". They have been classified on the basis of monthly income. Since income has increase after 6th Pay Commission implementation in 2008 and value of money has increased against US Dollar, the income groups were taken as given in Table 6.1.

Table 6.1: Household's Income

Group Classification	Income Level (INR per month)
High income	50,000 and above
Middle income	25,000 to 50,000
Lower income	Less than 25,000

6.3.2. Methodology for Selecting Individual Respondents

The individual respondents have been selected on the basis of number of wards, educational background, occupation including their income, duration of their stay in the city and their gender. The literate population of the society has been surveyed for data collection and analysis through questionnaire so that difficult aspects of the scaled questionnaire can be addressed effectively during the survey.

Thus this study is limited primarily on the basis of perceptions of the literate population. Responses were collected from all the 35 wards of the city in a controlled manner. Though respondents from high and middle income group were having qualification of graduation or master's degree, low-income group respondents were having primary education as their minimum qualification. All the respondents were of at least 21 years age who has been residing in Agartala City for 5 years or more. A map depicting AMC wards is given in Figure 6.1.

The survey questionnaire was derived broadly on the basis of four criteria, namely physical environment, neighbourhood environment, social environment, and overall perception on quality of environment. Physical environment was further classified in to 10 categories viz. air quality, vegetation, water quality, water bodies, noise pollution, transportation, waste management, natural calamities and visual quality. Air quality consisted of 3 variables. These are adequacy of flow of air, and its quality (odor, smell, particulate matter, SPM etc.). Water quality was classified based on taste and physical appearance. Based on the opinion of experts, all important attributes corresponding to each criteria have been identified which are summarized in Figures 6.2 and 6.3.

The questionnaire was prepared by doing extensive literature review, collecting opinion of experts and residents residing in the AMC area. Respondents have also shared their age, sex, education standard, occupation, monthly income, number of family members, length of residency and home address. The questions were posed with respect to each attribute of a given criteria and the responses as received were recorded in terms of specified rating scales (the form of perception of stakeholders) such as highly satisfied (HS), moderately satisfied (MS), unsatisfied, not acceptable or intolerable, tolerable, negligible or comfortable, not responded or heavy, moderate, light, negligible or never, occasional, always or good, medium, lower, negligible or weak, moderate, strong. Survey answers were coded and entered into Microsoft Excel for analysis. The sample Survey Questionnaire is given in Appendix 1.

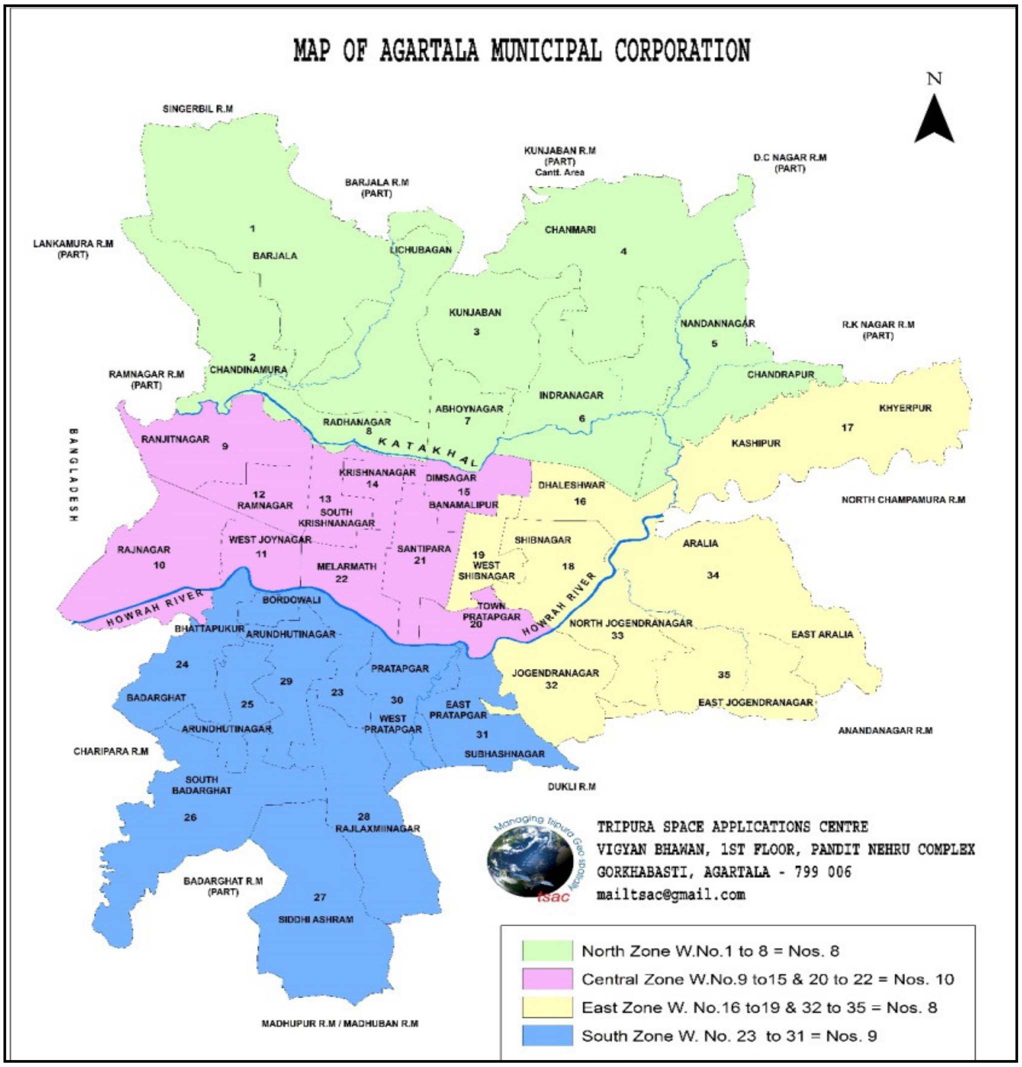

Figure 6.1: Map representing all 35 AMC Wards of Agartala city

Based on the perceptions received from survey for all variables against each category of different sections, ranks of each AMC wards are determined corresponding to physical environment, neighborhood environment, social environment and overall environment. The ward-wise overall environment quality has been assessed by analyzing the perceptions on physical, neighbourhood and social environment and the ranks are determined by analyzing the results using expert choice and Fuzzy TOPSIS methodologies as explained in subsequent sections. The same methodologies have also been applied to analyze the perceptions of respondents corresponding to next hierarchy level/sub-criteria especially, for physical environment to rank the AMC wards. The important sub-criteria are air quality, water quality, quality of transport, and waste management.

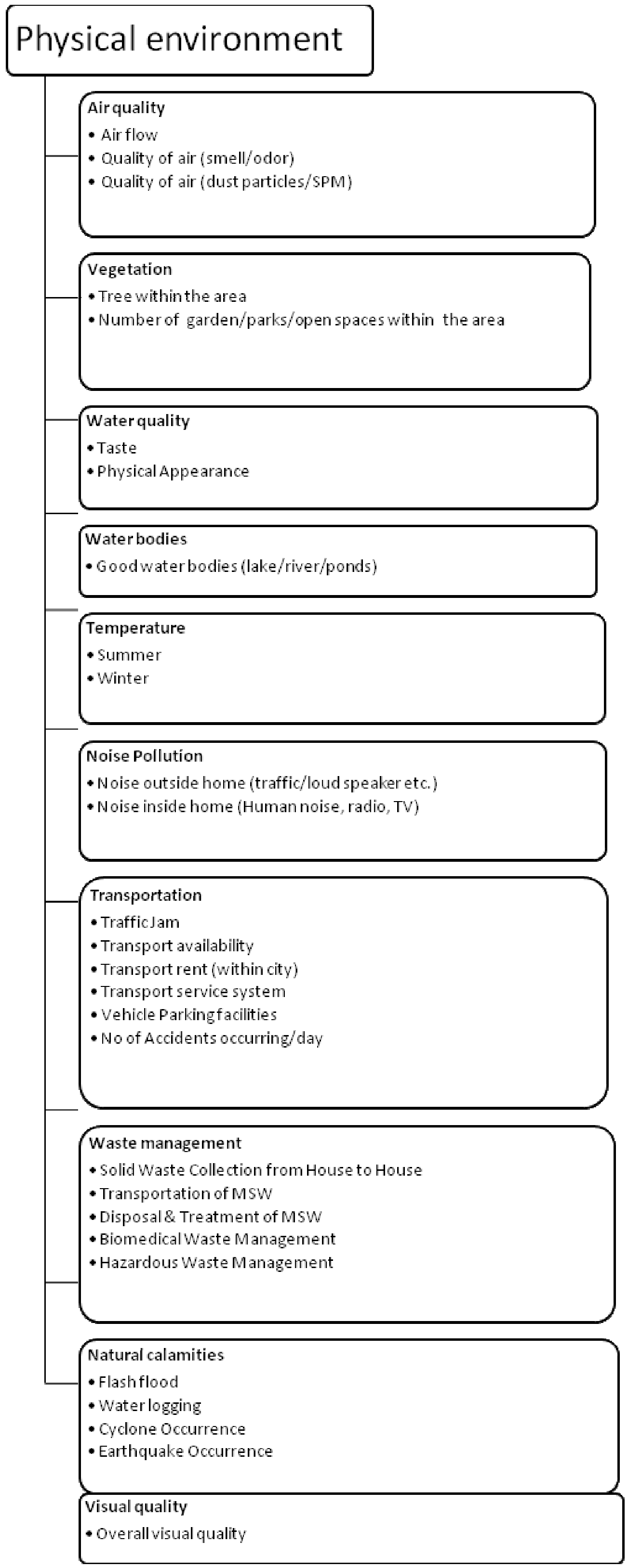

Figure 6.2: Fundamental Hierarchy of Physical Environment

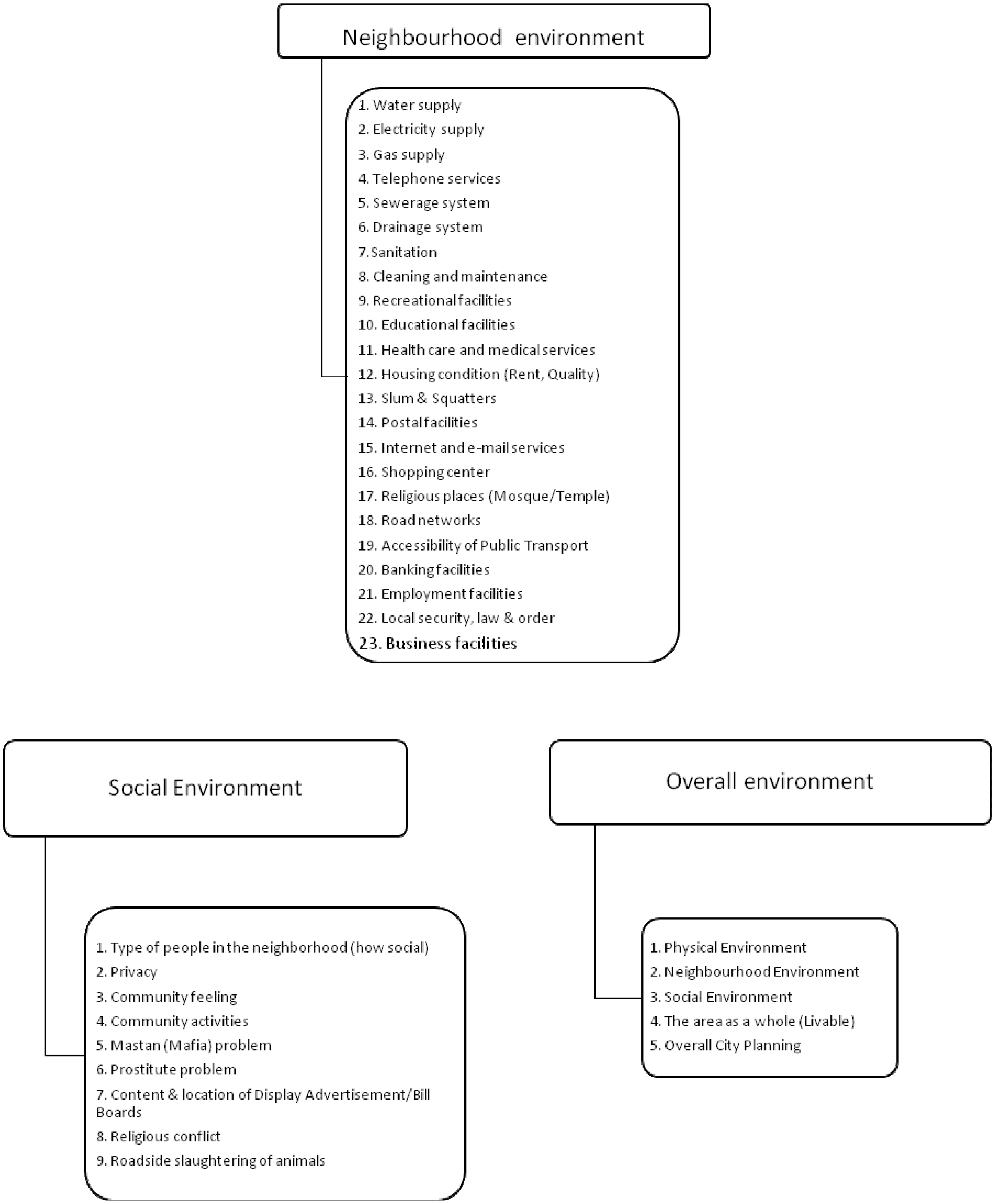

Figure 6.3: Fundamental hierarchy of Neighbourhood, Social and Overall Environment

6.3.3 Weighting of Environmental Groups and Variables

On the basis of opinion of the subject experts, the pair-wise comparisons are performed for all criteria/attributes using Table 4.1 as defined on the Saaty's 9-point scale. The relative weights of each environmental groups/criteria expressed qualitatively as given in the Tables 6.2 with a matrix size of 3x3. Though there were 10 attributes under physical environment, it is revealed that the four-most important attributes under physical environment category are air quality, water quality, transportation and solid waste management. Therefore these 4 attributes have only been considered for further analysis as given in Table 6.3.

Table 6.2: Pair-wise comparison of Environmental Groups

Environmental groups	Physical environment	Neighbourhood environment	Social environme nt
Physical environment	Equal	Moderately strong	Strong
Neighbourhood environment	Moderately weak	Equal	Moderate
Social environment	Weak	Moderately weak	Equal

Table 6.3: Pair-wise comparison of four important Parameters of Physical Environment

Variables	Air quality	Water quality	Transportation	Solid waste management
Air quality	Equal	Moderately strong	Strong	Moderately strong
Water quality	Moderately weak	Equal	Strong	Moderately strong
Transportation	Weak	Weak	Equal	Weak
Solid waste management	Moderately weak	Moderately weak	Strong	Equal

Using AHP's steps as explained in Chapter 4, weights of each environmental group have been evaluated on a scale of 0-1, with 0 being 'not at all important' and 1 being 'extremely important' as given in Table 6.4.

Table 6.4: Final weights of each Environmental Group

Environmental groups	**Final weights**
Physical environment	0.637
Neighbourhood environment	0.258
Social environment	0.105

Table 6.5: Final weights of four important Parameters of Physical Environment

Parameters	**Final weights**
Air quality	0.502
Water quality	0.257
Transportation	0.059
Solid waste management	0.183

It is observed from the analysis of results shown in Table 6.4 that physical environment is relatively more important, followed by neighbourhood environment and social environment. Similarly, it can be inferred from Table 6.5 that air quality is relatively more important followed by water quality, solid waste management and transportation.

6.3.4 Fuzzy Based Techniques of Order Preference by Similarity to Ideal Solution (Fuzzy-TOPSIS)

This section is divided in to two sub-sections. In the first section, rankings of all 35 AMC wards with respect to physical, neighborhood and social environments are determined, using which overall ranking of the wards are obtained. In the second section, rankings of all 35 AMC wards are obtained with respect to air quality, water quality, transportation and waste management. The analysis pertaining to second part has been consciously performed as these four underlying factors were discerned to be of primary concern to the people. Thus, determinations of the ward rankings corresponding to these four primary factors were deemed prudent to provide greater clarity to the decision makers to ascertain appropriate and effective mechanisms for the improvement of the wards under study.

Since many potential criteria pertaining to quality of air, water, vegetation and transportation exist while assessing quality of environment in different AMC wards; therefore, ranking of these wards can be considered as MCDM problem. These problems can be solved using a modified fuzzy based TOPSIS approach wherein fuzzy numbers with triangular membership function are used to represent ratings and weights of different alternatives and criterion. These ratings and weights are multiplied using fuzzy multiplication operator and results are converted into crisp numbers by applying concepts of graded mean method. The positive-ideal solution and negative-ideal solution are then evaluated easily without ranking fuzzy numbers. Thus, the distance from the positive ideal solution and the negative ideal solution are estimated, which makes the proposed method much more interactive and effective than existing methods. The step by step procedure of Fuzzy TOPSIS methodology is given in Figure 6.4.

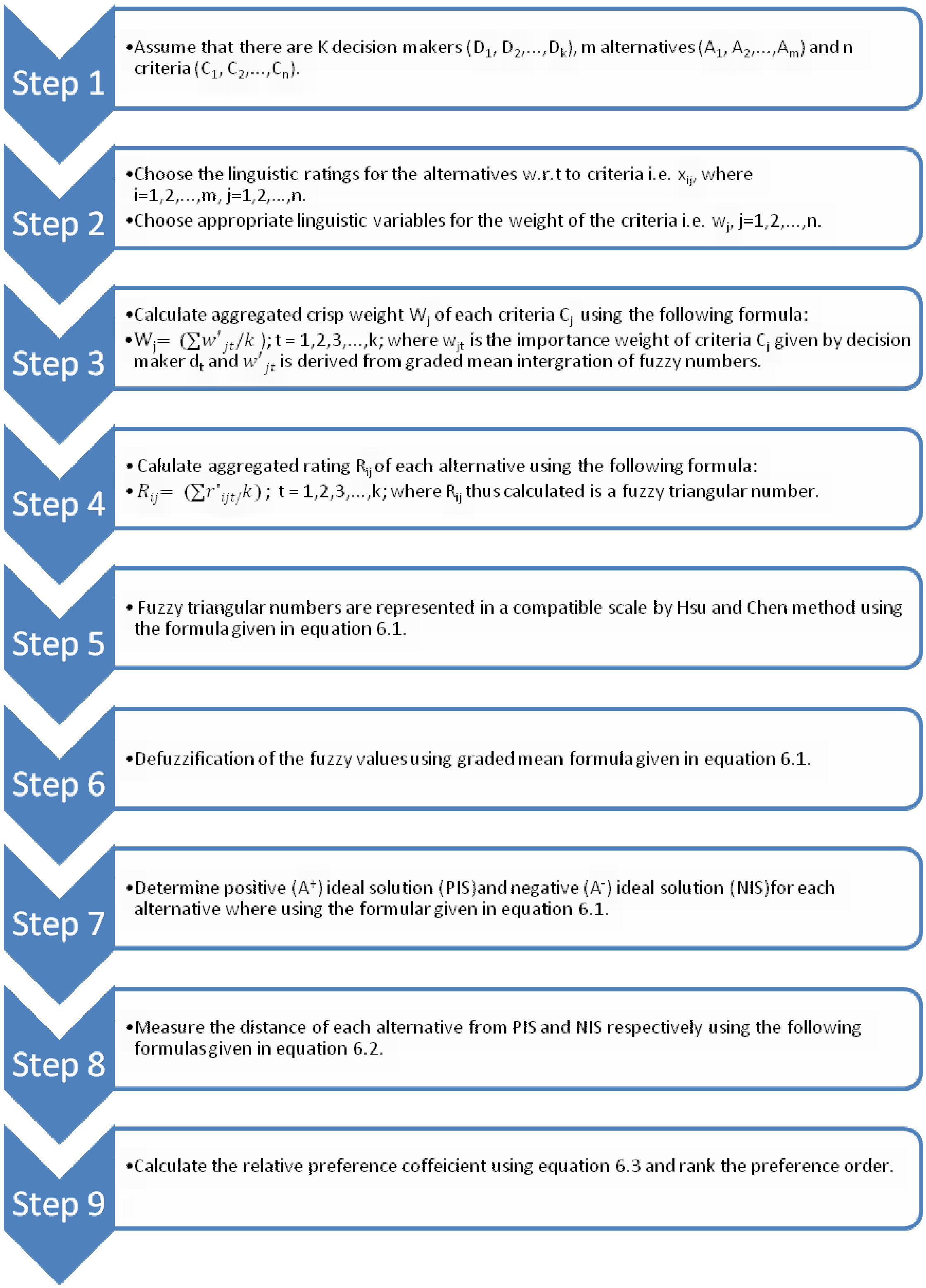

Figure 6.4: Fuzzy TOPSIS methodology for Environmental Quality Assessment

6.3.5 Determining ranks of AMC Wards corresponding to environmental groups

In this section, 35 AMC wards are ranked corresponding to physical, neighbourhood, social and overall environment. The stepwise methodology is described as follows:

Step 1: First, the numbers of responses obtained from a given ward have been analyzed corresponding to each component, viz., physical, neighborhood and social environments. The ward-wise responses that fall into categories of 'highly satisfied' and 'moderately satisfied' with respect to each component of the environment are considered. These responses are then expressed in linguistic terms by comparing actual number of responses received under these categories with the total number of responses corresponding to each component of the environment in a given ward. For example, column (4) of Table 6.6 represents ward-wise linguistic/qualitative assessment for physical environment. Similar methodology has been applied for all other components of the environment.

Step 2: Using triangular fuzzy membership functions for different linguistic grades as specified in Table 6.6, these assessments have been converted in to fuzzy triangular numbers (triplets) as shown in Table 6.7.

Step 3: The fuzzy triangular numbers (triplets) thus obtained are converted into aggregate rating r_{ij} corresponding to each component using equation 6.1 as introduced in Hsu and Chen method (Hsu and Chen, 1997). The values of rating are also given in Table 6.8.

$$r_{ij} = \left(\frac{1}{c_{ij}}, \frac{1}{b_{ij}}, \frac{1}{a_{ij}} \right) \qquad (6.1a)$$

where r_{ij} is the fuzzy triangular number .

If v' = (x, y, z) is a fuzzy triangular number, it can be converted in to a crisp value (v) using formula given in equation 6.1.

$$v = \frac{1}{6}(x + 4y + z) \qquad (6.1b)$$

Table 6.6: Linguistic representation of responses of the people corresponding to Physical Environment

Ward No. (1)	No. of responses Highly Satisfied (HS) (2)	No. of responses Moderately Satisfied (MS) (3)	Linguistic representation (4)	Ward No. (1)	No. of responses Highly Satisfied (HS) (2)	No. of responses Moderately Satisfied (MS) (3)	Linguistic representation (4)
1	36	183	F	19	37	180	G
2	84	84	F	20	60	264	G
3	92	100	F	21	20	212	G
4	120	114	F	22	40	211	F
5	96	66	F	23	52	172	F
6	32	160	F	24	24	132	P
7	60	192	F	25	72	132	F
8	0	192	P	26	54	174	F
9	68	176	G	27	64	176	F
10	84	108	F	28	72	120	P
11	21	153	F	29	36	168	F
12	12	219	G	30	48	204	G
13	22	145	F	31	36	264	G
14	36	174	F	32	36	228	G
15	19	211	G	33	0	216	F
16	28	204	G	34	108	156	G
17	24	174	F	35	60	252	G
18	55	103	P				

where, VG = Very good; G = Good; F = Fair; P = Poor and VP = Very poor

Table 6.7: Linguistic ratings of the variables

Linguistic representation	(a, b, c)
Very poor (VP)	(1,3,5)
Poor (P)	(3,5,7)
Fair (F)	(5,7,9)
Good (G)	(7,9,10)
Very Good (VG)	(9,10,10)

Table 6.8: Ward-wise Fuzzy membership ratings of responses corresponding to Physical Environment

Ward no	Fuzzy triplets (a, b, c)			Aggregate rating r_{ij}			Crisp	Ward no	Fuzzy triplets (a, b, c)			Aggregate rating r_{ij}			Crisp
1	5	7	9	0.11	0.14	0.20	0.15	19	7	9	10	0.10	0.11	0.14	0.11
2	5	7	9	0.11	0.14	0.20	0.15	20	7	9	10	0.10	0.11	0.14	0.11
3	5	7	9	0.11	0.14	0.20	0.15	21	7	9	10	0.10	0.11	0.14	0.11
4	5	7	9	0.11	0.14	0.20	0.15	22	5	7	9	0.11	0.14	0.20	0.15
5	5	7	9	0.11	0.14	0.20	0.15	23	5	7	9	0.11	0.14	0.20	0.15
6	5	7	9	0.11	0.14	0.20	0.15	24	3	5	7	0.14	0.20	0.33	0.21
7	5	7	9	0.11	0.14	0.20	0.15	25	5	7	9	0.11	0.14	0.20	0.15
8	3	5	7	0.14	0.20	0.33	0.21	26	5	7	9	0.11	0.14	0.20	0.15
9	7	9	10	0.10	0.11	0.14	0.11	27	5	7	9	0.11	0.14	0.20	0.15
10	5	7	9	0.11	0.14	0.20	0.15	28	3	5	7	0.14	0.20	0.33	0.21
11	5	7	9	0.11	0.14	0.20	0.15	29	5	7	9	0.11	0.14	0.20	0.15
12	7	9	10	0.10	0.11	0.14	0.11	30	7	9	10	0.10	0.11	0.14	0.11
13	5	7	9	0.11	0.14	0.20	0.15	31	7	9	10	0.10	0.11	0.14	0.11
14	5	7	9	0.11	0.14	0.20	0.15	32	7	9	10	0.10	0.11	0.14	0.11
15	7	9	10	0.10	0.11	0.14	0.11	33	5	7	9	0.11	0.14	0.20	0.15
16	7	9	10	0.10	0.11	0.14	0.11	34	7	9	10	0.10	0.11	0.14	0.11
17	5	7	9	0.11	0.14	0.20	0.15	35	7	9	10	0.10	0.11	0.14	0.11
18	3	5	7	0.14	0.20	0.33	0.21								

Step 4: The fuzzy triangular numbers of aggregate ratings are converted in to crisp values using the formula given in equation 6.1. These values are listed in Table 6.8 (last column).

Step 5: The crisp values obtained in step 4 and the weights of different components of environment (viz. physical, neighbourhood, social environments) obtained as given in Table 6.3 of earlier section are then aggregated to obtain the final decision matrix as given in Table 6.9. The final decision matrix has been derived to represent final crisp value corresponding to physical, neighbourhood and social environments. These values are used to rank AMC wards corresponding to physical, neighbourhood and social environments as shown in Figures 6.5, 6.6 and 6.7.

Table 6.9: Final scores of Physical, Neighbourhood, Social and Overall Environment

Ward no.	Physical	Neighborhood	Social	Overall	Ward no.	Physical	Neighborhood	Social	Overall
1	0.090	0.045	0.021	0.038	19	0.070	0.031	0.021	0.017
2	0.090	0.089	0.021	0.114	20	0.070	0.021	0.018	0.006
3	0.090	0.031	0.026	0.021	21	0.070	0.024	0.026	0.013
4	0.090	0.031	0.018	0.018	22	0.090	0.024	0.021	0.008
5	0.090	0.045	0.038	0.052	23	0.090	0.024	0.021	0.008
6	0.090	0.024	0.021	0.007	24	0.130	0.045	0.038	0.054
7	0.090	0.031	0.026	0.080	25	0.090	0.045	0.021	0.041
8	0.130	0.031	0.026	0.040	26	0.090	0.045	0.021	0.039
9	0.070	0.031	0.026	0.024	27	0.090	0.024	0.018	0.008
10	0.090	0.031	0.026	0.080	28	0.130	0.024	0.021	0.017
11	0.090	0.024	0.021	0.008	29	0.090	0.031	0.021	0.023
12	0.070	0.024	0.021	0.006	30	0.070	0.024	0.021	0.008
13	0.090	0.031	0.021	0.023	31	0.070	0.021	0.021	0.005
14	0.090	0.031	0.021	0.018	32	0.070	0.024	0.026	0.013
15	0.070	0.024	0.026	0.013	33	0.090	0.045	0.021	0.049
16	0.070	0.031	0.021	0.017	34	0.070	0.024	0.038	0.032
17	0.090	0.045	0.026	0.041	35	0.070	0.031	0.026	0.020
18	0.130	0.031	0.026	0.040					

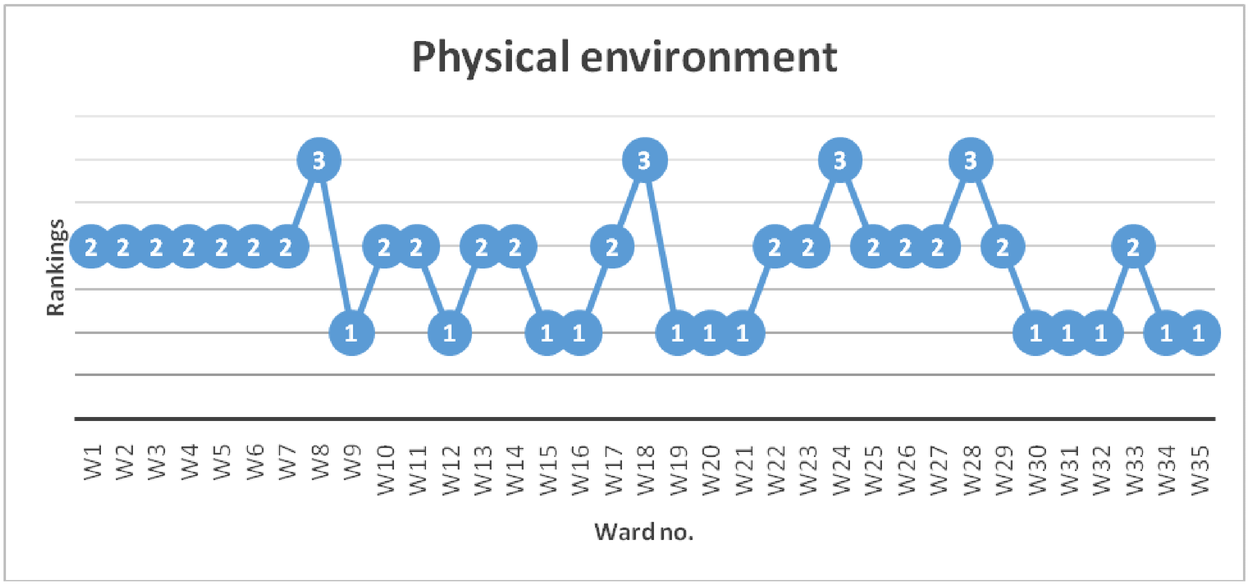

Figure 6.5: Rankings of AMC Wards corresponding to Physical Environment

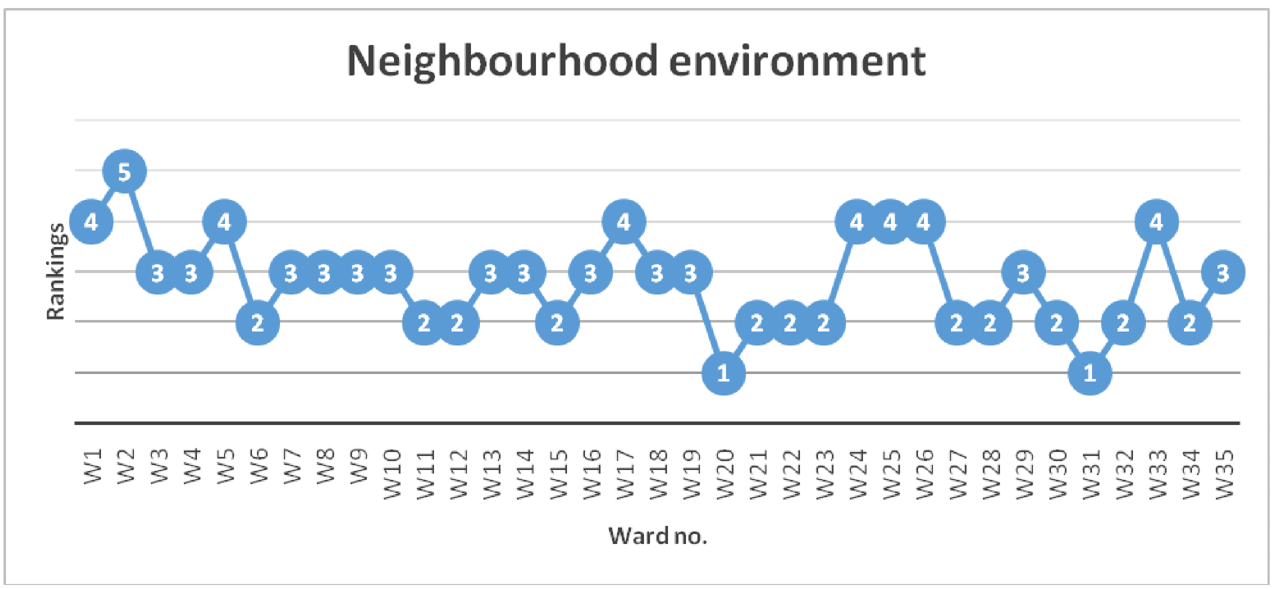

Figure 6.6: Rankings of AMC Wards corresponding to Neighbourhood Environment

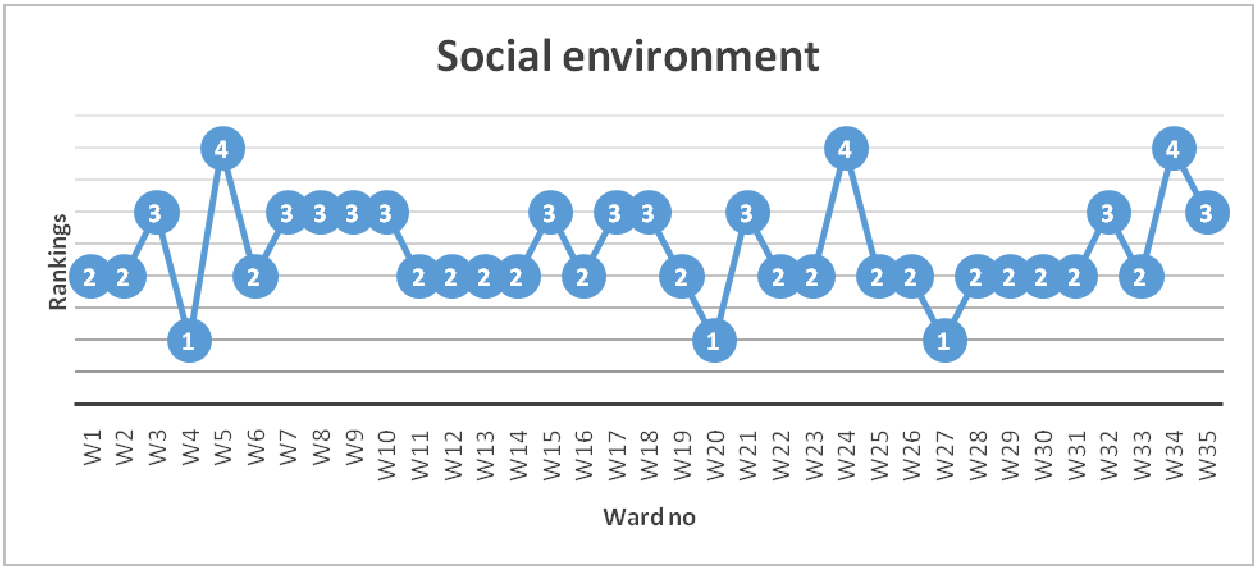

Figure 6.7: Rankings of AMC Wards corresponding to Social Environment

Step 6: The final decision matrix obtained in step 5 is aggregated to determine positive (A^+) ideal solution (PIS) for each AMC ward using equation (6.2a). Similarly, negative (A^-) ideal solution (NIS) for each AMC ward is determined using equation (6.2b).

$$A^+ = \left(\tilde{v}_1^*, \tilde{v}_2^*, ..., \tilde{v}_n^*\right) \quad (6.2a)$$

$$A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_n^-\right) \quad (6.2b)$$

where

$$\tilde{v}_j^* = \max_{i=1,2,...,m} \left(\tilde{v}_{ij}\right) \text{and } \tilde{v}_j^- = \min_{i=1,2,...,m} \left(\tilde{v}_{ij}\right) \quad (6.2c)$$

Table 6.10: Calculations of Closeness Coefficient

Ward no	d+	d-	Closeness coefficients	Normalized values	Ward no	d+	d-	Closeness coefficients	Normalized values
1	0.144	0.025	0.146	0.038	19	0.159	0.011	0.064	0.017
2	0.124	0.094	0.432	0.114	20	0.167	0.004	0.021	0.006
3	0.149	0.013	0.080	0.021	21	0.160	0.008	0.049	0.013
4	0.155	0.011	0.069	0.018	22	0.158	0.005	0.031	0.008
5	0.132	0.032	0.196	0.052	23	0.158	0.005	0.031	0.008
6	0.158	0.004	0.025	0.007	24	0.125	0.032	0.204	0.054
7	0.149	0.066	0.306	0.080	25	0.144	0.026	0.155	0.041
8	0.143	0.026	0.153	0.040	26	0.144	0.025	0.147	0.039
9	0.155	0.016	0.092	0.024	27	0.159	0.005	0.032	0.008
10	0.149	0.066	0.306	0.080	28	0.152	0.010	0.063	0.017
11	0.158	0.005	0.031	0.008	29	0.153	0.014	0.086	0.023
12	0.164	0.004	0.025	0.006	30	0.164	0.005	0.030	0.008
13	0.153	0.014	0.086	0.023	31	0.165	0.003	0.019	0.005
14	0.153	0.011	0.069	0.018	32	0.160	0.008	0.049	0.013
15	0.160	0.008	0.049	0.013	33	0.144	0.033	0.188	0.049
16	0.159	0.011	0.066	0.017	34	0.152	0.021	0.121	0.032
17	0.140	0.026	0.155	0.041	35	0.155	0.013	0.077	0.020
18	0.143	0.026	0.153	0.040					

Step 7: Using PIS and NIS for each AMC ward, the distances of each ward from A^+ and A^- have been calculated using equation (6.3). The measure of the distance of each ward from PIS (i.e. d^+) and NIS (i.e. d^-) has been evaluated which are given in Table 6.10.

$$d^+ = \sqrt{\sum_{j=1}^{n}\left(\tilde{v}_{ij} - \tilde{v}_j^*\right)^2} \qquad (6.3a)$$

$$d^- = \sqrt{\sum_{j=1}^{n}\left(\tilde{v}_{ij} - \tilde{v}_j^-\right)^2} \qquad (6.3b)$$

Step 8: The ward-wise closeness (relative preference) coefficients have been calculated corresponding to each component and preference order is ranked using equation (6.4):

$$CC_i = \frac{d^-}{d^+ + d^-} \text{ for } i = 1,2,...,m \qquad (6.4)$$

The normalized score of closeness coefficient is also obtained which is listed in the last column of Table 6.10. These scores represent status of overall environment using fuzzy TOPSIS. AMC wards can be ranked using these scores for assessing status of overall environment as shown in Figure 6.8 and Table 6.9.

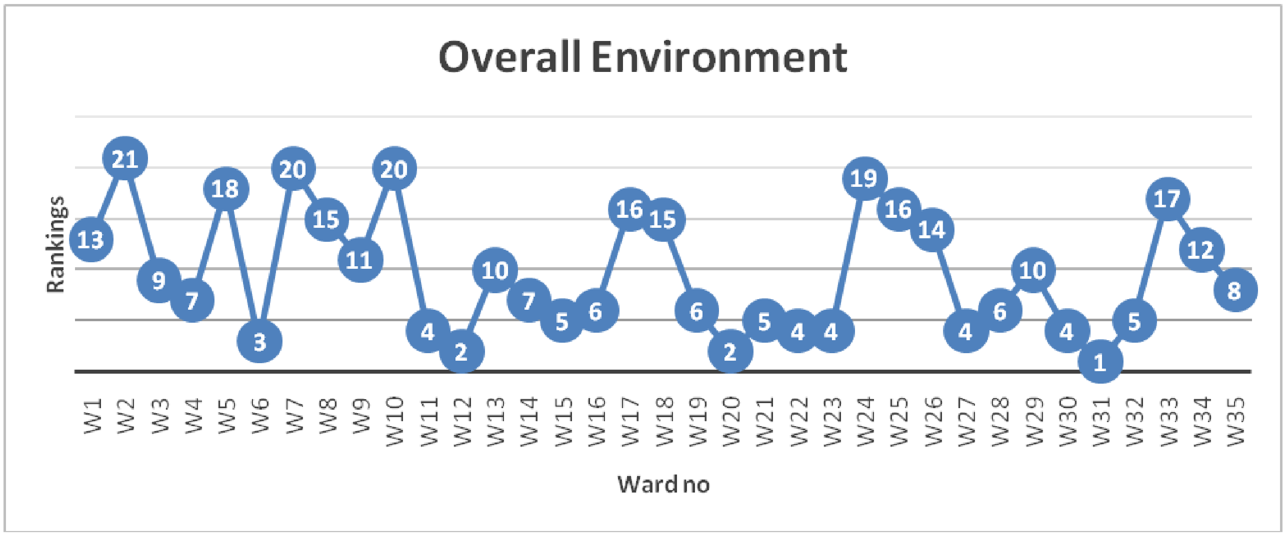

Figure 6.8: Rankings of AMC Wards with respect to Overall Environment using Fuzzy TOPSIS

6.3.6 Determination of Rankings of AMC Wards corresponding to Primary concerns

During the survey, it has been observed that primary concerns of the people were that of the qualities of air, water, transport and waste management. Among all the various categories of physical, neighbourhood, and social environment, the above mentioned factors are the one's which demanded serious and urgent improvements. Therefore, in this section, the same Fuzzy TOPSIS methodology, used in the earlier section, has been applied to determine the rankings of the various AMC wards with respect to each of these four primary concerns of people. The scores of different AMC wards thus obtained were then used to obtain the overall ranking of the AMC wards with respect to these primary factors.

The steps followed in this procedure, are similar to the steps followed in the earlier section. The rankings of AMC wards obtained with respect to air quality, water quality, transport quality and waste management are given in Figures 6.9-6.12 respectively.

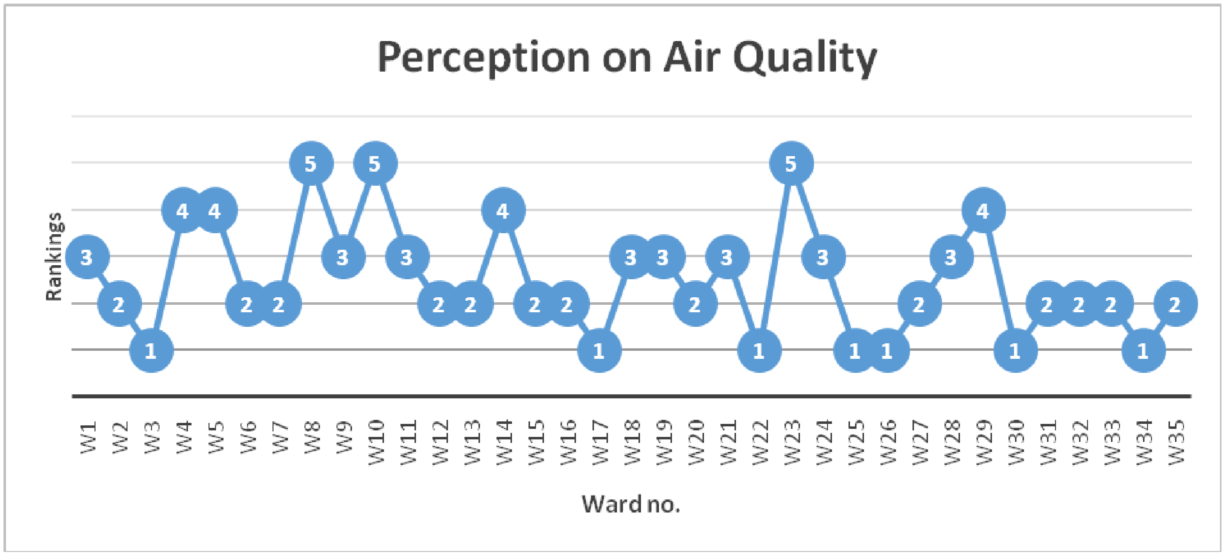

Figure 6.9: Rankings of Wards corresponding to Air Quality

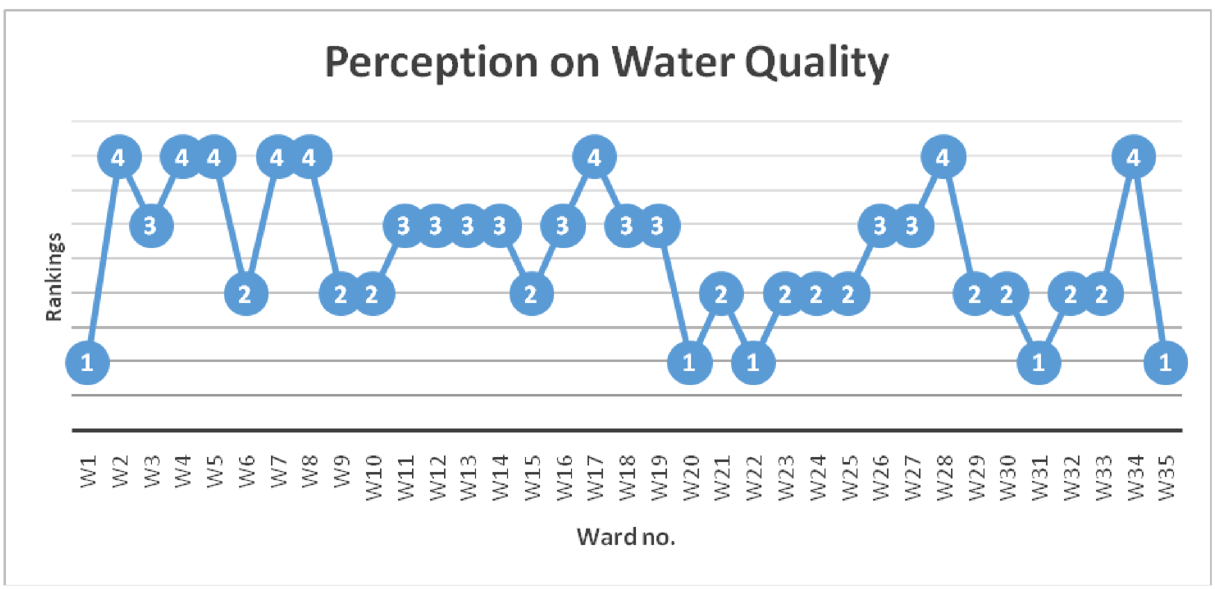

Figure 6.10: Rankings of wards corresponding to Water Quality

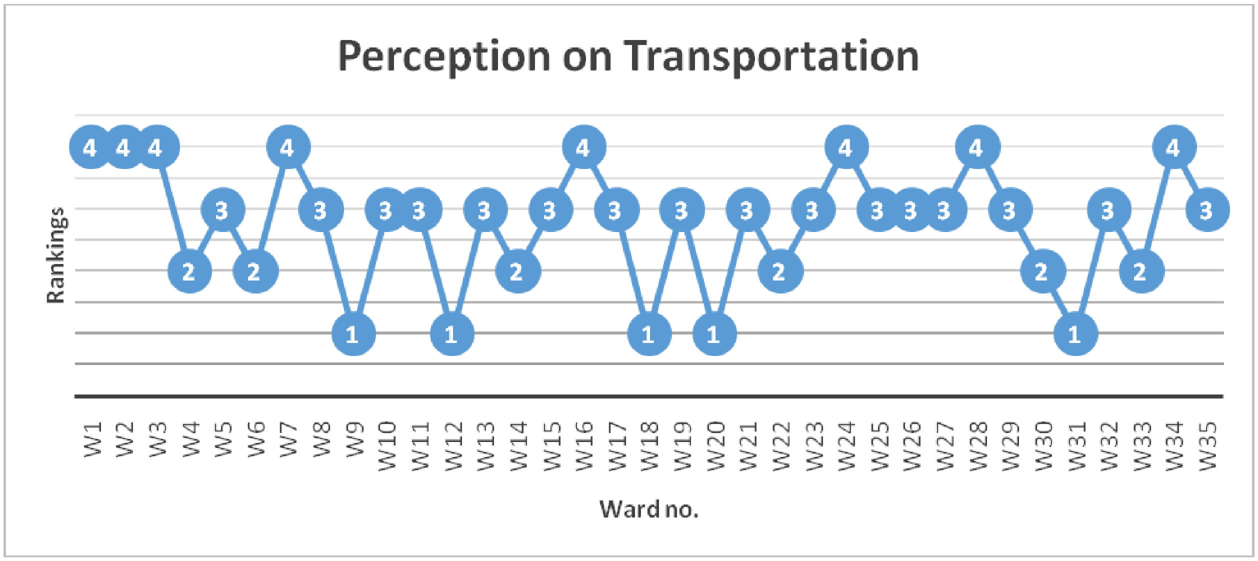

Figure 6.11: Rankings of Wards corresponding to Transportation

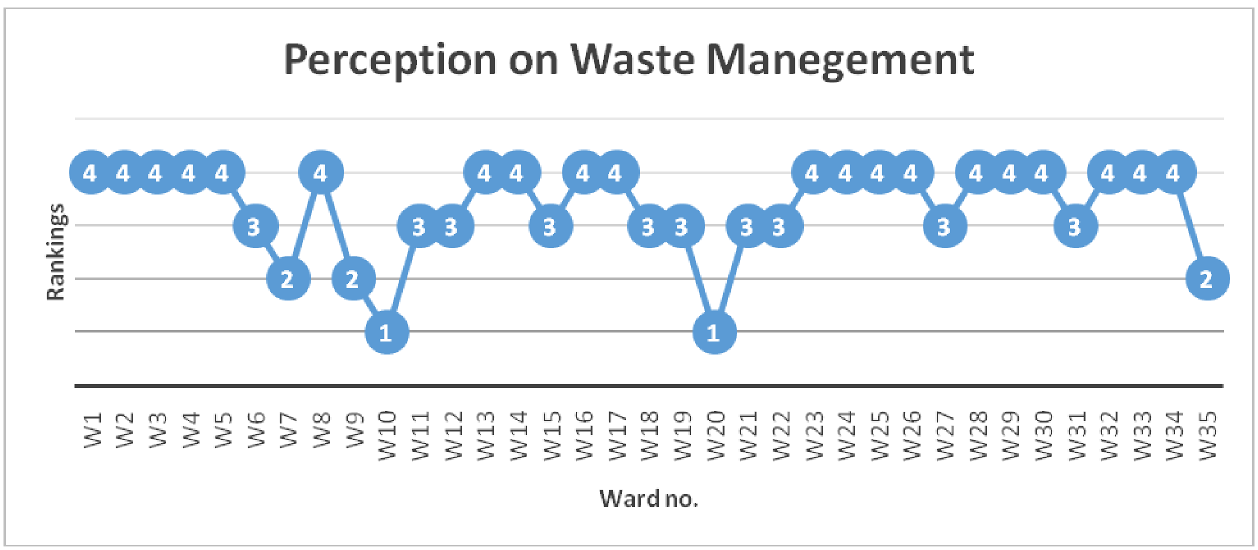

Figure 6.12: Rankings of Wards corresponding to Waste Management

The scores of various AMC wards were aggregated using step 6, 7, and 8 of fuzzy TOPSIS methodology which explained in Figure 6.4 to obtain the overall rankings of the wards with respect to these four primary factors as shown in Figure 6.13.

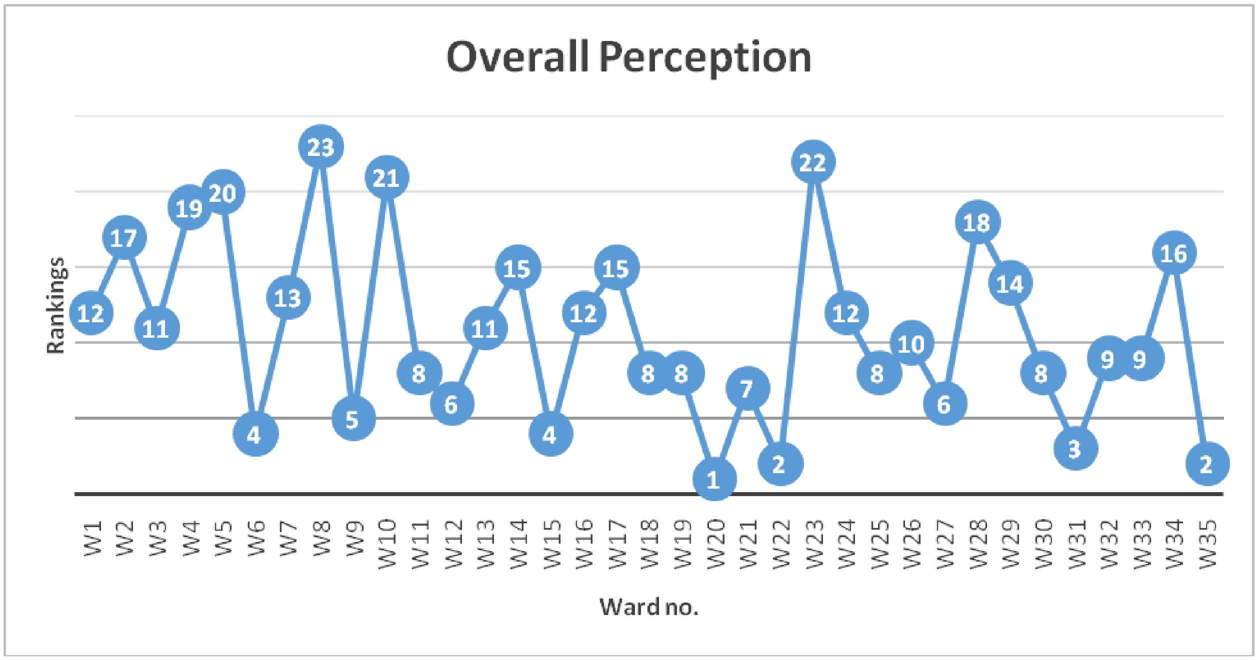

Figure 6.13: Rankings of Wards w.r.t. Overall Perception

6.4 Results and Discussion

In this study, the perceptions of the people based on quality of environment have been assessed at all the AMC wards which would be useful in designing future environmental valuation studies. A questionnaire broadly divided in to four sets namely physical environment, neighborhood environment, social environment, and overall environment has been used for analyzing the individual perceptions on environment quality. Expert choice software is used under the guidance of experts to obtain the importance of three different sets of the questionnaire and fuzzy TOPSIS methodology is used to obtain the score of each AMC wards corresponding to first three set of questionnaire and based on score, a rank is provided to each ward. These results are further aggregated to obtain the rankings of the AMC wards corresponding to overall environment. Similar techniques are used to rank the AMC wards with respect to air quality, water quality, transportation and solid waste management.

It can be clearly inferred from Figure 6.5 that ward numbers W9, W12, W15, W16, W19, W20, W21, W30, W31, W32, W34 and W35 secured rank 1 with a least score of 7 on a scale of 100.

This is evident as more than fifty percent of the respondents are either highly satisfied or moderately satisfied with the quality of physical environment in these wards. However, ward numbers W8, W18, W24 and W28 secured lowest rank with a maximum score of 13 out of 100 as more than sixty percent of the respondents belonging to these wards are either not satisfied or consider quality of physical environment as unacceptable. As far as neighbourhood environment is concerned (Figure 6.6), ward numbers W20 and W31 secured the highest rank with a score 2.1 on the scale of 100. In these wards, more than sixty percent of the respondents are either highly or moderately satisfied. Ward number, W2 has obtained the lowest rank with a maximum score of 8.9 on the scale 100 as more than sixty percent of the respondents residing in this ward are unsatisfied with the quality of neighborhood environment.

Figure 6.7 clearly depicts the ranks of AMC wards with respect to the social environment. Ward numbers W4, W20 and W27 are given the highest rank as they are having the least score of 1.8 on the scale of 100 as more than eighty percent of the respondents of these wards are either highly or moderately satisfied. On the other hand, ward numbers W5, W24 and W34 secured the lowest rank as more than fifty percent of the respondents of these wards are unsatisfied with the quality of social environment. By aggregating the results of physical, neighbourhood and social environment with the help of fuzzy TOPSIS methodology, overall environment quality of each ward is obtained as described in Figure 6.8. It is evident from Figure 6.8 that ward number W31 is the best ward and ward number W2 is the worst ward corresponding to overall quality of environment. If figures 6.5, 6.6, and 6.7 are closely observed, it can be easily concluded that ward number W31 has secured good rank corresponding to physical, neighbourhood as well as social environment and hence securing highest rank with respect to overall environment is justified. However, ward number W2 has not secured good ranks anywhere and hence; it expected to be the worst ward when analyzed with respect to overall environment as shown in Figure 6.8.

Figures 6.9-6.12 describe the rankings of the AMC wards corresponding to air quality, water quality, transportation and waste management respectively. It is very interesting to note at this stage of analysis that the stations chosen for evaluating the air and groundwater quality index in

Chapter 4 and Chapter 5 are situated in some of these AMC wards (Table 6.11). Therefore, a very emphatic comparison can be drawn from the results obtained from Chapter 4 and Chapter 5.

Table 6.11: Sampling Stations and corresponding Wards

Station	Location	Ward number
S4	Near Chaturdash Devata Bari Bathing Ghat, Baldakhal Road, Khayerpur, West Tripura	W17
S5	Near the Bridge on Haora River connecting Chandrapur & Baldakhal, Chandrapur, West Tripura	W34
S6	Near Aralia Water Intake Point, West Tripura	W18 & W33
S7	Near Bordowali Water Intake Point, West Tripura	W22 & W23
S8	Near Battala Crematorium, West Tripura	W24 & W11
S9	Near Dashami Ghat, West Tripura	W24 & W11
S10	Near the last Point (in Indian Territory) on Haora River entering Bangladesh, West Tripura	W10

Figure 6.9 clearly depicts that ward numbers W3, W17, W22, W25, W26, W30 and W34 are having the best quality of air as perceived by the respondents surveyed in the study. However, ward numbers W8, W10 and W23 are the one's having lowest ranks. The comparison between the air quality indexes of stations calculated in Chapter 5 and the rankings of the wards (Figure 6.9) where these stations are located provides very important information. Figure 5.2 suggests that there is light air pollution at sampling stations S1 and S5 and all the remaining stations S2, S3, S4, S6, S7, S8, S9 and S10 fall under the category of high air pollution levels. The comparison of results obtained in this chapter shows that at some places, perceptions of the respondents are quite dissimilar to the objective measure of air quality as performed in Chapter 5. For example, the air quality index of stations S7, S8 and S9 is very high (more than 200), as shown in Figure 5.2 indicating severe pollution in these regions, however the wards in which they are located (Figure 6.9) are perceived by the respondents in slightly different manner. Ward number W22 is having highest rank and whereas, ward number W11 and W24 are given rank 2

and 3 respectively by the respondents. Station S4 is located in ward number W17 which is perceived by the respondents as the one having very good quality opposite to the results obtained by evaluating air quality index. Similar responses are recorded for station S6 as well.

At the same time, people's perception and objective measures does have similar results at some places. Station S5 is located in ward number W34 which has secured highest rank. This shows that people's perception of air quality at station S5 is exactly similar to the objective measure (air quality index). Station S7 located at ward number W23 which has secured lowest rank is also been perceived as the one having worst air quality justifying the results obtained by objective analysis.

Figure 6.10 ranks the AMC wards corresponding to water quality, where ward numbers W1, W20, W22, W31 and W35 are perceived as the one's having best quality of water. Ward numbers W2, W4, W5, W7, W8, W17, W28 and W34 are given the lowest rank by the respondents of the survey. The sampling station S10, located at ward number W10 has a minimum groundwater quality index of 0.22 as calculated in Chapter 4, signifying very good quality water and most suitable for drinking water supply. When compared to the results obtained from Figure 6.10, it is observed that ward number W10 has secured rank 2 by the respondents surveyed in the study which converges with the results obtained by calculating groundwater quality index. Sampling station S5 located in ward number 34 exhibits poor ground water quality as per the objective measure which is justified by the perceptions of respondents as ward number W34 secured lowest rank.

However, there is some divergence in the perception of the respondents when asked about the water quality of ward numbers W22 and W23. According to the respondents, these wards are having best quality of water with ward number W22 and W23 securing rank 1 and rank 2 respectively (Figure 6.10). But objective measure of water quality at the station S7, located at these wards suggests that, this station has very poor quality of water. Stations S8 and S9, each located at wards W11 and W24 are having good water quality as per the objective analysis done by calculating groundwater quality index which is justified by the perceptions of the respondents as they give rank 2 and 3 for ward numbers W24 and W11 respectively.

Ranks of AMC wards corresponding to transportation quality is given in Figure 6.11. Ward numbers W9, W12, W18, W20 and W31 secured highest rank as more than seventy percent of the people residing in these wards are either highly satisfied or moderately satisfied with the transportation quality. Figure 6.12, gives the rankings of the wards corresponding to solid waste management where wards W10 and W20 secured highest rank with more than eighty percent of respondents being in the category of either highly satisfied or moderately satisfied.

The results indicate that respondents having good educational qualifications and socio-economical backgrounds were well conversant to provide their view point on assessment of quality of environment. It was also observed that age group of the surveyed person had a distinct effect on their respective opinions: it was found that the quality of different environmental groups was overestimated by the younger generation while the educated elderly groups of people have underestimated the quality. Overall, the information provided by respondents was relevant and scientific which can be used for future analysis and prediction. The analysis is supportive and promising as the environmental monitoring can be performed in an economical manner. However, perceptions based approaches can lead to differ in analysis results as compared with those obtained from experiments used in Chapter 4 and Chapter 5, which needs to be improved commensurately to avoid lag between individual judgments and experimental observations.

6.5 Summary

In this study, the perceptions of the people on environmental quality have been assessed at all the AMC wards, the results of which were compared from the objective or experimental measures. A questionnaire broadly divided in to four distinct categories, namely physical, neighborhood, social, and overall environment had been designed based on a well defined scale for analyzing an individual perception on the quality of the environment. The Expert choice software is used under the guidance of experts to obtain the importance of the attributes namely physical, neighborhood and social environment. The importance of weights of various parameters corresponding to each of these attributes is further obtained using the same technique. Fuzzy based TOPSIS approach has been applied to obtain the score of each AMC wards corresponding to these attributes and based on score, a rank is provided to each ward. A very emphatic comparison has been performed between the results obtained by evaluating water and air quality index at several stations in Chapters 4 and 5 with the results obtained in this chapter. The results of comparison shows that at some places, perceptions of the respondents are quite dissimilar to the objective measure of air quality as performed in Chapter 5.

The comparative study showed that the proposed perception methodology could concur with significant majority with the corresponding results of the objective measures of air and water as concluded in the preceding chapters. However, at some places, perceptions of the respondents were evidently quite dissimilar to the objective measure of water and air quality as performed in Chapters 4 and 5. The apparent divergence in the expected congruence of the explored methodologies to identify the indices of environmental quality at the sampling stations, strongly stress the need to include opinion of public perception, particularly when the environmental quality of a site varies significantly from its average. The results of the present study helped to establish the perception survey methodology as a pragmatic tool that future research dedicated to the cause of establishing a holistic index of environmental quality, stands to benefit significantly from a synergetic effort of both scientific study with accurate measurements and perception based study.

CHAPTER 7

CONCLUSIONS

The requirement of environmental quality assessment along Haora river basin has been introduced in chapter 1, which also focuses on importance of the topic. The investigations described in chapter 2 of literature review demonstrated the accelerated pace of research into various evaluation techniques. Major advances have been made in the various facets of analytical formulation and solution methodologies committed to the control paradigms of different kinds of environmental pollution faced by our civilization. The key aspects of recent research investigated in literature review are: (i) advancements of formulation and solution techniques for assessing quality of environment with respect to surface water, groundwater and air; (ii) methods that integrate all the important criteria with suitable assessment techniques under a multi-criteria decision making framework. It has also been inferred that significant development took place in the area of environmental quality assessment over the last 40 years. However, very few field studies have been found wherein fuzzy logic based multi-criteria decision making tools have been used to design strategies for managing environment quality. However, existing literature indicates that there exists no such study of interest, especially in context to north-eastern region along the Haora river. Thus, it was felt that there should be proper environmental quality assessment and management with regard to the north-eastern region of the country.

A comprehensive study on the contemporary status of the environmental quality indices have been performed with respect to surface water, groundwater and air pollutants along the Haora River. The SWQI, GWQI and AQI have been derived for 10 sampling stations along Haora River basin using both traditional and fuzzy comprehensive techniques. The study demonstrates how these indices vary spatially. In order to deal qualitative information received from public perceptions on quality of environment, fuzzy logic based approaches have also been applied in addition to traditional methods of assessment.

In Chapter 3, an attempt has been made to develop a quantification technique for assessing the water quality status in the Haora river basin. Two distinct methodologies were adopted, of which, one was based on the traditional Water Quality Index (WQI) approach using Simple Additive Weighting (SAW). The other, was based on a unique, and pragmatic Fuzzy Comprehensive Water Quality Index (FCWQI) platform utilizing the fuzzy comprehensive technique by integrating fuzzy logic concepts with the multiple-attribute decision-making techniques. The motivation for the development of such a FCWQI platform stemmed from the pivotal necessity to address the omnipresent uncertainties that arise out of the measurement of water quality parameters, spatial distributions over the water basin and more importantly to encompass the various definitions of water quality as dictated by the intended area of its usage – factors which have, but, received little attention till date as evident from existing literature dedicated in establishing a rational index of estimation of water quality.

Furthermore, as the traditional WQI approach is critically dependent on the expert opinion of the individual Decision Maker (DM) in the assignment of the associated weights of the chosen water quality parameters, a distinct order of uncertainty is invoked during the WQI evaluation based upon the personal preferences and linguistic judgments due to the inherent subjective nature of water quality assessment. Moreover, in terms of the desired outputs, overlapping between linguistic categories are often evident in the definitions used to interpret the quality of water which increase with the number of the required quality indices deemed appropriate to address the corresponding quality of the water under study. Thus, the inherent traditional fixed crisp weighting methodology of the WQI approach falls short of the crucial necessity to address the underlying uncertainties in establishing a robust and holistic qualitative platform to model the desired indices of water quality.

To this end, the proven capabilities of the fuzzy set theory in successfully capturing the underlying '*vagueness*' of an input system has been harnessed in developing an innovative water quality indexing platform which not only was able to numerically model the requisite indices but could effectively encapsulate and interpret its qualitative aspects with commendable accuracy. Moreover, the developed FCWQI methodology integrated the principle of multiple-attribute decision-making to promulgate effective policy decisions in face of the necessity to address several water quality parameters simultaneously that needed to be incorporated in the present study, each of which, were identified with its own standard index of quality. Further, a detailed sensitivity analysis was undertaken to identify the principal parameters which needed to be addressed at each of the locations under study in order to improve the corresponding index of the overall quality of water beyond the designated threshold value appropriated for the initiation of remedial measures.

Although, traditional WQI scores using SAW has produced authentic results in the present case study, FCWQI analysis at four out of the chosen ten sampling stations were found to be high, indicating very poor quality of water, which was not apparent from the traditional WQI analysis. The FCWQI methodology could clearly identify and thus demonstrate the relative significance and impact of the individual parameters of water quality on the final score of the water quality index. Thus, the FCWQI analytical methodology proved itself an effective appraising platform to understand the stability of the quality indices under study, which in turn could help to ascertain the penalizing parameters and the extent to which its quality need to be changed in order to improve the overall quality of water.

The methodology adopted in deriving FCWQI requires deliberations with all concerned stakeholders to understand their experience, preferences and expectations so that water quality evaluation system can be useful. In the present study the quality of water was determined from the point of domestic usage, but may also be used for other purposes as well. The methodology suggested in the study has numerous applications and can be used for formulating effective water management strategies such as prioritization of the water quality management plans, studies on impact analysis, prediction of water quality and so on. The present analysis and assessment of the overall water quality index through the novel FCWQI methodology could help to establish distinct and immediate decision routes which had been elaborately discussed in Chapter 3.

In Chapter 4, an integrated Groundwater Quality Index (GWQI) has been developed to assess the hydro-chemical characteristics of groundwater in the Haora river basin, with reference to its suitability for human consumption. The study was inspired by the imperative need to respond to the strategic and immediate challenges of scarcity of ground water that has become increasingly evident in several pockets of the basin. This was primarily attributed to the erratic and non-productive monsoon seasons in the recent past compounded with the problems of an unprecedented requirement for fresh water arising from population growth, industrialization and low retention capacity of soils in the basin. The GWQI formulation was based on the principles of Multiple Attribute Decision Making (MADM), and has been projected through two aggregating methods, namely, the Simple Additive Weighting Method (SAW) and the Fuzzy Comprehensive Assessment Method. In addition, the polluting parameters at each selected station have also been analyzed using Geographical Information System (GIS). Base map of the Haora river basin had been collected from the Tripura State Remote Sensing and Space Application Agency and the sampling location coordinates had been recorded with the help of GPS. ArcGIS® Software (v 9.3) has been used for developing the thematic maps at various stages of this study. The GWQI has been developed at ten selected sampling stations located in the Haora River basin. The groundwater samples at these sampling stations have been collected to perform physicochemical analysis of 10 important water quality parameters namely Total Dissolved Solid (TDS), pH, Total Hardness, Ca, Mg, Total Alkalinity, Nitrate Nitrogen, Chloride, Iron and Electrical Conductivity. The observed values of the chosen water quality parameters were compared with the drinking water standards laid by Bureau of Indian Standards (BIS). Application of the conventional Simple Additive Weighting (SAW) Method applied through the traditional basis of normalized ratings yielded results which were found to be singularly dominated by the iron content at most of the stations while the effect of the other involved groundwater quality parameters remained eclipsed in the GWQI based station rankings. This was due to the fact that the sampled iron content of the groundwater at the concerned stations far exceeded the standard limit prescribed by regulatory bodies. To address this major drawback of the conventional method, a more integrated approach to interpret the groundwater quality was sought for the sake of a greater transparency of the effects of the other water quality parameters on the GWQI which lay latent in the SAW endeavor. To this end, a Fuzzy Comprehensive Assessment Method has been proposed wherein AHP and fuzzy logic concepts have been integrated to assess status of groundwater quality along Haora river. It prioritizes sampling stations as per their final scores which is useful to adopt remedial action plans. It provides a systematic way of expressing qualitative rating using linguistic terms while recognizing differences of opinion of subject experts. The fuzzy comprehensive assessment model provides enough scope to experts for assigning different membership grades corresponding to different categories of water, viz. desirable, permissible, and unfit. Membership functions of ten water quality parameters (indicators) are obtained. Weights of each water quality parameters have been assigned using AHP. In contrast to the traditional SAW approach, the membership value in the fuzzy comprehensive evaluation method cannot, by its inherent design, exceed the rationale of unity for any of the chosen parameters which ensured a reflection of the contribution of all the involved water quality parameters in the overall fuzzy GWQI and rankings. It was thus established that the fuzzy comprehensive assessment method is a more inclusive method of groundwater quality assessment and takes into consideration all the parameters for the purpose of index construction and prioritization. Based on these merits of fuzzy method, it is recommended over the conventional method for all future studies as it is the true combined indicator of water quality at a sampling station. The proposed Fuzzy method is thus recommended over the conventional method for similar studies in future as the fuzzy index represents the water quality status best at a sampling station. SAW method on the other hand, is influenced unilaterally by the parameters faring worse and the corresponding rankings evaluated by this method, also echo this behavior. Thus SAW method results way towards the parameter with extreme rating while fuzzy method result is based on balanced consideration of contribution from all parameters under study. The methodology proposed in this case study can be very well applied in condition assessment of other environmental problems wherein qualitative ratings are viable under multi-attributes framework. Of course, different membership functions and weight factors are required to establish proper framework depending upon the specific type of problems. Thus, these methods should be used for assessing groundwater quality condition and prioritizing the sampling sites so that better informed realistic approaches can be made available to implementing agencies and practitioners. In future studies, fuzzy based GWQI computational methods as in the present study reserves its rightful significance to be employed as a holistic tool in assessing groundwater quality conditions and prioritizing the sampling sites in order to establish better informed rational pathways that can be made available to implementing agencies and practitioners for an effective solution to ground water quality problems.

In chapter 5, a comprehensive study on spatial variations of air quality has been performed at the ten sampling stations along the Haora river basin in line with the preceding studies. To this end, an integrated Air Quality Index (AQI) has been developed to assess the quality of air at different locations in Haora river basin using two aggregating methods namely the modified EPA method with maximum operator as the aggregation function of MADM process and the Fuzzy Comprehensive Assessment Method. The results obtained from both the methods have been compared and the inherent limitations of the EPA method were identified. The air pollution levels at different sampling stations in and around Agartala vary from moderate to severe conditions. Both the methods were conclusive of the fact that, PM_{10} and SPM were the primary pollutants for the higher AQI values recorded at a given study location. The two distinct methodologies adopted in establishing the AQI indices at each sampling station clearly indicated the latent shortcomings of the traditional and prevalent EPA method which is essentially based on the maximum operator concept to calculate AQI. Thus it considers the maximum value among all sub-indexes derived from the pollutants at a particular station to define the overall AQI. In fact values pertaining to lower sub-indexes derived from other pollutants are discarded which is the main limitation of this approach. This is mainly due to the fact additive or synergistic effects of pollutants on the human health are generally excluded while deriving index value. Moreover, the break points used for evaluation of air quality indices are also not defined by USEPA. Another important point is that AQI evaluation system proposed by USEPA is not usable presently in several parts of the world due to non-availability of $PM_{2.5}$ concentration. The ordinal scale used to describe the pollution level of the pollutant in the form of sub-index has also been used to define overall aggregate index though the severity of the pollution level described by the aggregate index is not linear with sub-index scores. The boundary of break points corresponding to different pollutants are also not certain. The ambiguousness and inaccuracies due to these aspects can be handled by incorporating fuzzy concepts.

As the present study expects the contemporary pollution load to be increased significantly in the immediate future due to construction activities, vehicular movements, urbanization and other industrial activities, it is deemed necessary to focus not only on the critical air pollutant (PM_{10} and SPM) but also on all other air pollutants. For effective assessment of air quality, it is seen essential to study the impact of reaction mechanisms involved in polluting air through these critical pollutants. The reaction mechanisms are dependent on several factors such as reactant's concentration, availability of moisture content in the atmosphere, climatic conditions, etc. It would be better if the critical air pollutants are monitored regularly in the selected region in addition to sensitizing local population to control pollution in the region. It is also suggested that air quality should be maintained within the prescribed and safe limit by adopting efficient and cost-effective measures of planning and management. Appropriate mitigation measures should be taken so that quality status remains within moderate to good condition in due course of time. To this end, public awareness and participation is seen to play a key role in maintaining good condition of air quality.

Chapter 6 has been dedicated in exploring the potential of public perceptions in establishing a temporal and spatial index of quality in the variation of environment in the Haora river basin, especially at Agartala, in context of its physical and social paradigms contained in the respective neighbourhoods of the study locations. The perception study was motivated by the need to establish a qualitative database to help ascertain, not only the significant factors of degradation in environmental quality but also to help outline the best possible practices for its management to enhance the desired attributes of quality under study. To this end, the overall environmental quality was analyzed ward-wise using a survey questionnaire, to which the elected respondents provided their perception ratings on the performance of forty seven attributes which were deemed significant for assessment of the environmental quality, out of which ten attributes were used to assess the physical environment, twenty three for their respective neighborhood environment and nine attributes for social environment. Five attributes have also been considered to assess the respondents' view on their usual perceptions of the overall quality of environment. The performance of these attributes have been rated by measuring them either on 4-point scales anchored by the attributes of 'highly satisfied' and 'not acceptable' or on 3-point attribute scales anchored by 'intolerable' and 'negligible'. The individual respondents have been selected on the basis of number of wards, educational background, occupation including their income, duration of their stay in the city and their gender. Sixty-six per cent of the survey respondents were male and rest were females. The study being in essence of a MCDM problem, the Expert Choice® software has been explored under the guidance of experts to obtain the importance of the attributes namely that of the physical, neighborhood and social environment. The importance weights of various parameters corresponding to each of these attributes were further obtained using the same technique. An innovative extension of the Fuzzy TOPSIS methodology was articulated to obtain the score of each AMC wards corresponding to these attributes and a corresponding rank was provided to each ward based on the computed score. These results were further aggregated to obtain the rankings of the AMC wards corresponding to the index of overall environment. Similar techniques were employed to rank the AMC wards with respect to air quality, water quality, transportation and solid waste management. Keeping in view the essential need to incorporate the qualitative aspects of human perception to a number, a more pragmatic approach to the classical TOPSIS methodology was endeavored. This was deemed necessary to establish an effective decision making mechanism for a rational interpretation of the received linguistic and qualitative responses. This was achieved through a fuzzification process as per the Hsu and Chen method wherein the linguistic terms or variables were mapped as triangular fuzzy numbers. The results of the perception survey were extensively compared with that obtained by evaluating air and water quality index at the corresponding stations highlighted within the scope of study of Chapters 4 and 5. The comparative study showed that the proposed perception methodology could concur with significant majority with the corresponding results of the objective measures of air and water as concluded in the preceding chapters. However, at some places, perceptions of the respondents were evidently quite dissimilar to the objective measure of water and air quality as performed in Chapters 4 and 5. The apparent divergence in the expected congruence of the explored methodologies to identify the indices of environmental quality at the sampling stations, strongly suggest to handle the notion of individual perception, especially when environmental quality of the site is different from the average quality. The results of the present study helped to establish the perception survey methodology as a pragmatic tool that future research dedicated to the cause of establishing a holistic index of environmental quality, stands to benefit significantly from a synergetic effort of correctness of measurements.

The present endeavor encompasses a comprehensive effort to identify and define the indices of environmental quality mainly through the portals of surface water, groundwater and air in the Haora river basin. For the evaluation of the pertinent quality indices of the parameters of surface water, groundwater and air, two distinct methodologies were employed, of which one was based on the traditional and prevalent weighted approach and the other based on innovative extensions of the principles envisaged in classical fuzzy theory. Comparison of the two methodologies clearly highlighted the superiority and robustness of the developed fuzzy platforms in determining the environmental quality indices of each of the parameters under study. It could effectively address the inherent uncertainties involved in the evaluation, modeling and interpretation of sampling data, which was, but beyond the scope of the traditional weighted approaches employed to the same effect. Further, a parallel perception survey was undertaken to complement the analytical recourses in attaining the objectives of establishing a holistic index of environmental quality in the present research. The results of the perception survey, though in majority, indicated a significant agreement to the conclusions obtained from the analytical methodologies that had been perused, did exhibit distinct divergence in the opinion of some of the attributes of water and air quality under study when compared to the corresponding results obtained during the previous evaluation of the objective measures. The observed divergences, established the pivotal necessity to incorporate the salient aspects of a dedicated perception survey as a standalone platform of validation for any intended analytical methodology dedicated in establishing the environmental quality indices at a given location of interest. Though instances of such perception survey in environmental paradigms have been evident in existing literature, there has hardly been any effort to harness the synergistic benefits of a perception survey and analytical effort to design a pragmatic platform of quality index evaluation for effective promulgation and disbursement of environmental remedial policies. It is in this respect that the present study reserves it's unique footprint as a proven platform to be perused in future research endeavors in environmental quality assessment.

There is a lot of scope develop extensions of the proposed study. However, lack of sufficient and accurate data is of prime concern. This is even more acute in developing countries. The ward-wise comprehensive data of air pollution, water pollution, solid waste management, noise pollution, population density, traffic congestion etc. in the case study area will improve the environmental quality evaluation process proposed herein. This was observed to be the ordinary limitations of the present research. In fact, the present study highlights that there is a significant requirement for applied research in the north-eastern region of the country, especially in extracting information for environmental quality monitoring, assessment and management.

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APPENDICES

APPENDIX 1

Questionnaire Survey on
Assessment of Urban Environmental Quality

A Case Study of Agartala City Serial no:

Name of the Respondents: ……………………………….

AMC Ward no…… Locality ………………………………………………. House no

Road no/Name…………………………………………………. ………

A. Household information

1. Age …………. 2.Sex: Male/Female 3.Education …….… 4. Occupation……………..…

5. Monthly Income ………… 6. Number of family members…………7.Duration of living in this city ………. 8. Previous residence…...................... 9. Reason of migration...............

B. Indicators of Quality of Urban Environment.

B.1: Respondents perception of the quality of **physical environment** in the instant Neighborhood.

1.1 Information on Air quality

Variables	Perception			
	Highly Satisfied	Moderately Satisfied	Unsatisfied	Not Acceptable
a. Adequacy of air flow				
b. Quality of air (smell/Odour)				
c. Quality of air (dust particles/SPM)				

1.2 Information on Vegetation Quality

Variables	Perception			
	Highly Satisfied	Moderately Satisfied	Unsatisfied	Not Acceptable
a. On adequacy of tree within your neighborhood.				
b. Number of garden/parks/open spaces within your neighborhood.				

1.3 Information on Water Quality

Variables	Perception		
	Intolerable	Tolerable	Negligible
a. Water quality (taste)			
b. Water quality (physical appearance)			

1.4 Information on Water Bodies

Variables	Perception			
Number of good water bodies (lake/river/ponds) within your neighborhood.	Highly Satisfied	Moderately Satisfied	Unsatisfied	Not Acceptable

1.5 Information on Temperature

Variables	Perception			
	Intolerable	Tolerable	Comfortable	Not responded
a. Summer temperature				
b. Winter temperature				

1.6 Information on Noise Pollution

Variables	Perception			
	Highly Satisfied	Moderately Satisfied	Unsatisfied	Not Acceptable
a. Noise felt outside the home(traffic/loud speaker etc)				
b. Noise felt inside home (human noise, radio, TV etc)				

1.7 Information on Transportation Factor

Variables	Perception			
	Heavy	Moderate	Light	Negligible
a. Traffic jam				
	Perception			
	Highly Satisfied	Moderately Satisfied	Unsatisfied	Not Acceptable
b. Transport availability				
c Transport rent (within city)				
d. Transport service system				
e. Vehicle Parking facilities				
f. No of Accidents Occurring/day				

1.8 Information on Waste Management

Variables	Perception			
	Highly Satisfied	Moderately Satisfied	Unsatisfied	Not Acceptable
a. Solid Waste Collection from House to House				
b. Transportation of MSW				
c. Disposal & Treatment of MSW				

d .Biomedical Waste Management				
e. Hazardous Waste Management				

1.9 Information on Natural Calamities/ Disaster Factor:

Variables	Occurrence			Perception		
	Never	Occasional	Always	Intolerable	Tolerable	Negligible
a. Flash flood						
b. Water logging						
c. Cyclone Occurrence						
d. Earthquake Occurrence						

1.10 Information on Visual Quality

Variables	Standard			
	Good	Medium	Lower	Negligible
Over all visual quality				

2. Respondents Perception of Quality of Neighborhood Facilities/Environment

Facilities	Perception			
	Highly Satisfied	Moderately Satisfied	Unsatisfied	Not Acceptable
1.Water supply				
2.Electricity supply				
3.Gas supply				
4.Telephone services				
5.Sewerage system				
6.Drainage system				
7.Sanitation				
8.Cleaning & maintenance				
9.Recreational facilities				
10.Educational facilities				
11.Health care & medical services				
12.Housing condition				
13.Slum & squatters				
14.Postal facilities				
15. Internet & e-mail facilities				
16.Shoping center				
17.Religious places				
18.Road network				
19.Local security, law & order				
20.Accessibility of public transport				
21. Banking facilities				

22. Employment facilities				
23.Business facilities				

3. Respondents perception of quality of social environment in the immediate neighborhood

Variables	Perception			
	Highly Satisfied	Moderately Satisfied	Unsatisfied	Not Acceptable
a. Type of people in the neighborhood (how social)				
b. Privacy				
c. Community feeling.				
d. Community activities				
e. Mastan(Mafia) problem				
f. Prostitute problem				
g. Content & location of Display Advertisement/Bill Boards				
h. Religious conflict				
i. Road side Slaughtering of Animals				

4. Respondents perception on comprehensive environmental group

Comprehensive opinion group	Degree of opinion of the perception		
	Weak	Moderate	Strong
a. The physical environment.			
b. The Neighborhood environment			
c. The social environment.			
d. The area as a whole (Livable)			
e. Overall City Planning			

Please Tick (√) in appropriate Box of your choice.

Thanks for all kinds of help. ____________ **Data Collected by**

Date……………………….

____

Signature of Respondent

Additional Information (If any)

LIST OF PUBLICATIONS

1. Singh A.P., S. Chakrabarti, and S. K. Dubey (2012), Managing Water Quality of a River Basin Using Fuzzy Water Quality Index, in Proceedings National Seminar on Recent Trends in Geo-Environmental Engineering (RTGEE-2012), during March 17-18, 2012 at M.B.M Engineering College Jodhpur, p. 83-88. ISBN No. 978-81-924038-0-9

2. Singh A.P., S. Chakrabarti, A. K. Sarkar and S. K. Dubey (2012), Fuzzy water quality index and sensitivity analysis: a comprehensive technique for water quality management of a river basin, in 5th International Perspective on Water Resources & the Environment Conference (IPWE 2012), during January 5-7, 2012 at Marrakech, Morocco.

3. Chakrabarti S. and A. P. Singh (2011), "Impact of Small Scale Industries on Haora River at Agartala: Crisis Management and Challenges", paper presented in a National Seminar on "Emerging Trends in Science and Technology" during March 25 – 26, 2011 organized by the Faculty of Science and Technology, ICFAI University, Tripura

4. Chakrabarti S., Singh, A. P., and Kumar, S., (2015) 'Assessment of Air Quality in Haora River Basin', Pollution Research, Volume 34 (3), 215-222.

5. Singh A. P., Srinivas R., Kumar S. and Chakrabarti S., (2015) 'Water quality assessment of a river basin under Fuzzy Multi-Criteria Framework', Int. J. Water, Volume 9(3), 226-247.

6. Jamatia A., Chakraborty S., and Chakrabarti S., (2014) 'Surface Water Quality Assessment of the Jirania Brick Cluster – A Case Study', International Journal of Engineering Research and Application, Volume 4(6).

BRIEF BIOGRAPHY OF CANDIDATE

SUMANTA CHAKRABARTI

DEGREE POSITION

Graduated in Civil Engineering from Tripura Engineering College (presently known as National Institute of Technology, Agaratala) under Tripura University securing First Class in 1993.

Obtained another professional degree Bachaelor in Law from Tripura Govt. Law College under Tripura University in 1998.

Selected by Foreign and Commonwealth Office (FCO) as British Chevening Scholar and completed Post-Graduate Level Course on Environmental Management from the Institute For Development, Policy & Management (IDPM), University of Manchester, United Knigdom in 2002.

WORK EXPERIENCE

Deputy Registrar	National Institute of Technology, Agartala, Tripura, India *August 2011 – Present* Holding the Charge of Registrar from June 04,2012 and continuing.
Environmental Engineer	Tripura State Pollution Control Board (TSPCB) under Department of Science, Technology & Environment (DST&E), Government of Tripura June 2009 to August,2011
Project Director	Tripura Renewable Energy Development Agency(TREDA)under Department of Science, Technology & Environment, Government of Tripura *February,2007 to June ,2009*
Assistant Environmental Engineer	Tripura State Pollution Control Board (TSPCB) under Department of Science, Technology & Environment (DST&E), Government of Tripura *March,1996 to February,2007*

PROFESSIONAL HONORS, AWARDS & FELLOWSHIPS

- United Kingdom's Foreign and Commonwealth Office (FCO) awarded the British Chevening Scholarship for Young Indian Environmental Managers 2002 in the Institute for Development Policy & Management, University of Manchester, United Kingdom.

- Awarded International Visitors Leadership Programme by Department of States, United States of America on Urban Environmental Issues during February 03-24, 2005.

- Awarded Fulbright Fellowship in 2010 by the Department of States, United States of America and worked in United States Environmental Protection Agency (USEPA) during the fellowship period.

- Presently the Board Member of the Tripura State Pollution Control Board (TSPCB) nominated by the Government of Tripura which is the apex regulatory authority in the state. TSPCB is advising the State Government on any matter concerning prevention, control and abatement of pollution and responsible for implementation of environmental acts, rules and regulations in the State of Tripura.

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Dr Ajit Pratap Singh, is the Dean (Admissions and Instruction Division) and Professor at Civil Engineering Department of Birla Institute of Technology and Science, Pilani, Rajasthan, India. He has more than twenty years of teaching, research, and administrative experience in Environmental Engineering and Sustainable Water Resources Management with a special focus on water quality and quantity assessment, water conservation, water pollution analysis, prediction and management in Surface Water (especially Rivers basin planning and Lakes), watershed hydrology and Groundwater Contaminant Transport modeling, Pavement Analysis, Design and Management, Fuzzy-based Decision Making, Simulation and Mathematical Modeling. He obtained his B.E (Hons.) Civil, M.E. (Civil) and Ph.D. in Environment Engineering and Water Resources Planning & Management from Birla Institute of Technology and Science, Pilani, Rajasthan, India.

Prof. Singh has published more than 60 research papers in different Journals and International conference proceedings of his area of interest. He is a fellow of Institution of Engineers (India), Fellow of Indian Association of Hydrologists (FIAH), member of Indian Society of Hydraulics, Indian Association for Solid Waste Management (IASWM), Indian Water Works Association (IWWA), and Institution of Public Health Engineers, India, and Member of Eastern Asia Society for Transportation Studies (EASTS) etc.

He has taught as many as 18 different courses of Civil Engineering such as Environmental Engineering, Hydraulics and Fluid Mechanics, Water and Wastewater Treatment, Water

Resources Engineering, Waste Management Systems, Environmental Pollution Control, Transportation Engineering, Transport Phenomena I, and Geographical Information Systems and so on. Time to time Dr. Ajit has also delivered invited talks for various training programmes and workshops. He had also been appointed expert of various examinations/recruitments held at different institutions in the past. Prof Singh has evaluated eight Ph.D. Thesis in the field of environmental engineering and pollution research. Prof. Singh has worked as a member of various technical advisory committees of national/international conferences and has also been working as a third party expert for various projects under JNNURM, PMGSY projects funded by national and state governments. He has been nominated as one of the working group experts of National Institute of Hydrology, Roorkee, Ministry of Water Resources, Government of India.

He has been actively involved in reviewing various research papers submitted in his field to Journals of International and National repute such as Journal of Water Resources Management, Springer, Journal Environmental Monitoring and Assessment, Springer, Journal of Environment Management, Elsevier, International Journal of Environmental Engineering Science (IJEES), Elsevier Journal of Colloids and Surfaces A: Physicochemical and Engineering Aspects (COLSUA), Journal of Environmental Planning and Management (JEPM), African Journal of Agricultural Research (AJAR) and various Scientific and Engineering conferences etc.