Development of Integrated Environmental Pollution Index for Industrial Clusters

THESIS

Submitted in partial fulfillment
of the requirements for the degree of
DOCTOR OF PHILOSOPHY

By

AJIT KUMAR VIDYARTHI
ID No. 2009PHXF023P

Under the Supervision of

Prof. (Dr.) AJIT PRATAP SINGH
Professor, Civil Engineering Department

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE
PILANI (RAJASTHAN)

2016

BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE

PILANI (RAJASTHAN)

CERTIFICATE

This is to certify that the thesis entitled **"Development of Integrated Environmental Pollution Index for Industrial Clusters"** and submitted by **Mr. Ajit Kumar Vidyarthi** ID No. **2009PHXF023P** for award of Ph.D. Degree of the Institute, embodies original work done by him under my supervision.

Date: Signature in full of the Supervisor

Name in capital block letters: AJIT PRATAP SINGH

Designation: Professor and Head

ACKNOWLEDGEMENTS

I owe sincere thanks and deep sense of gratitude to my thesis supervisor Prof. Ajit Pratap Singh, Professor and Head Department of Civil Engineering, BITS Pilani for the recurrent critical appraisal as thesis guide during my doctoral research work. I am extremely grateful for his inspiring support, invaluable advice, valuable time and efforts during the course of my research work. He was exceptionally helpful and ever approachable. It has been a privilege for me to work under his guidance and this is truly a magnificent and enlightening experience in my life.

I express my deepest appreciation to Prof. Ravi Kant Mittal, Head of the Department, Civil Engineering Department and Prof. Manoj Kumar, former Head of the Department, Civil Engineering Department for their kind suggestions, moral support and assistance. The contributions of Prof. A. K. Sarkar, Dr. Anupam Singhal, Dr. Sanghmitra Kundu of Civil Engineering Department are acknowledged with high appreciation. Special thanks and appreciation is extended for their invaluable advice and moral support throughout the study as the members of Doctoral Advisory Committee (DAC).

Gratitude is also accorded to BITS, Pilani for providing all the necessary facilities to complete the research work. I would like to extend my gratitude to Prof. Souvik Bhattacharya, Vice Chancellor, BITS Pilani for giving me an opportunity to do research at this very reputed Institute. I also feel obliged to Prof. A. K. Sarkar, Director, BITS. Pilani - Pilani Campus for providing the necessary infrastructure and other facilities.

I also express my gratitude for the kind and affectionate enquiries about the work and the encouragement given by Prof. S. K. Verma, Dean, Academic Research Division and Prof. Hemant R. Jadhav, Associate Dean, Academic Research Division. My sincere thanks to Dr. Navin Singh and Dr. Sharad Shrivastava of the same Division.

Special thanks are also extended to all the experts who have given their useful opinion about rating of various components of evaluation process through survey questionnaire and group meetings. I also wish to acknowledge Mr. Amar Singh and Mr. Daleep Pareek for their cooperation during the preparation of this thesis. I express my thanks to Mr. R Srinivas, Mr. Makrand Wagale, Mr. Rahul Dandautiya and Mr. Karan Madan from BITS Pilani for his valuable inputs and support during my research. I acknowledge with great appreciation the unconditional support and help of all my friends during the research work.

Special thanks are extended to colleagues and friends of the Central Pollution Control Board, New Delhi for their help and support during the collection of field data.

Finally a very special expression of appreciation is extended to my beloved wife Mrs. Suniti Parashar who constantly gave emotional encouragement, bolstered my morale and always been a source of inspiration to me. My children Kaustubh Narain and Kaumudi also deserves appreciation for their patience and providing liberty to complete my work.

Ajit Kumar Vidyarthi

ID. NO. : 2009PHXF023P

ABSTRACT

Recently, environmental concerns have raised public awareness of important issues such as pollution, land use and natural resources which seriously demand for regulation. However, considerable increase in population, coupled with the mounting demands from society, have triggered rapid pace of industrialization and intensive resource extraction and pollution. Though economic growth and advancement in science and technology frontier bring positive changes in socio-economic demography, it has also been causing significant negative side effects on human health and environmental components. Depletion of natural resources, macro and micro climatic changes including global warming, acidification, air, soil and water pollutions have not only become a threat to biodiversity but also become a threat to human population itself. Pollution originating both from large-scale industries as well as small-scale industries contribute a significant part of total pollution especially in developing world, including India. The problem becomes even more aggravated due to unplanned growth of industrial clusters/townships wherein many of the industries have been flouting rules and norms. Many of these industries still rely on traditional technologies to produce end products with minimum production cost and expenditure at the expense of generating large amount of wastes and thus, polluting the environment in a big way. Therefore there is a need to formulate appropriate and effective policies to control pollution which can be implemented strictly in all kind of industries by proper enforcement drive.

The major challenge in implementing any policy of Environment Action Plans (EAP) is the identification of polluting industries and their location. This can be achieved by assessing the existing pollution emissions originated from different industry sources and taking corrective measures accordingly. However, it is also a difficult task for regulating agencies due to lack of reliable information on the nature and type of pollution emitting from different industrial plants and factories. The regulating agencies cannot simply set priorities for enforcing environmental regulations for industrial sectors to be targeted for greater intervention, or the geographical area where intervention should be focused in the absence of basic information.

It is therefore necessary to develop a simple screening methodology for identification of critical industrial sectors/ areas as the first step on the basis of available information of existing status of pollution level in these clusters/areas. Once the criticality level of these industrial sectors/ areas are known, they can be classified/grouped and detailed assessment

methodology can be applied further by the regulating agencies to prioritize their decisions of implementing environmental regulations so that the process of industrial development and economic growth can be ensured in an effective and sustainable manner.

The criticality level of any industrial cluster/area can be characterized by developing a conceptual model, which should deal with 3 important components: (i) type and source of pollutants available in the industrial cluster/area, (ii) mode of pollutant transport process through which the pollutants are transmitted into the atmosphere, and (iii) the receptors who are exposed to the said environment. The overall impact on environment by any industrial activity can be assessed effectively if the pollutant linkages pertaining to source, pathway and receptors can be developed with proper quantification using the base level information. It is clear that if all three pollutant linkages (source-pathway-receptor) are known, pollutants contamination can be quantified with their impacts using a robust methodology. The economic and environmental sustainability concerns have now attracted many researchers working in the areas of industrial planning, environmental science, environmental management and humanities and social sciences. Increasing pollution load is reaching beyond the carrying capacity of the environmental components including air, land and water. Furthermore, this is not just an environmental challenge, but synergistically a serious public health challenge as well. There is an urgent need to identify and grade the industrial clusters based on their pollution potential busing an objective and scientific framework and design action plans accordingly. The Integrated Environmental Pollution Index (IEPI) has been developed with the main objective of quantification of the state of environment and human health, determining and monitoring the effectiveness, of remedial actions, comparing alternate plans and policies in order to help environmental regulators, policy makers and decision-makers.

Integrated Environmental Pollution Index (IEPI) of an industrial cluster is conceptualized as a rational number on a graded defined scale to characterize the environmental quality for a given industrial cluster and its surroundings using an impact evaluation algorithm of sources, pathways and receptors. Increasing value of IEPI indicates severe adverse effects on environmental pathways and receptors and thus is an indicator of health hazards of human population and irretrievable losses of different components of environment. Thus the IEPI proposed herein serve as the warning or screening tool to group or prioritize industrial clusters needing interventions in graded manner under a systematic designed framework which is primarily based on basic information related to various aspects of pollution available at the corresponding industrial cluster/area.

The present study has been done to study the importance and the role-played by IEPI in quantifying the amount of industrial pollution of a particular cluster. This study has made an attempt to identify the major factors responsible to assess pollution status in industrial clusters, subsequent to which appropriate methodology have been proposed in Chapter 3. The assessment has been performed by combining the principles of Multi-attribute decision making analysis and fuzzy set theory in order to deal various factors associated with different components of the environment. The applicability and usefulness of the proposed methodology developed herein has been rationalized by evaluating IEPI for 15 different industrial clusters located in different parts of India which has been presented in Chapter 4. The study is focused on important components of environment, dealing primarily with quality aspects of air, surface water, and groundwater in these selected industrial areas. These 15 industrial clusters have been further categorized into 5 different types of industrial clusters namely, (i) steel producing industrial clusters/areas comprising of 3 main industrial clusters located in Durg-Bhillai, Durgapur and Jamshedpur, (ii) coal mining and thermal power plant areas comprising of 3 main industrial clusters located in Dhanbad, Korba and Singrauli, (iii) chemical industry areas comprising of 3 main industrial clusters located in Vapi, Ankleshwar and Ahmedabad, (iv) oil refinery areas comprising of 3 main industrial clusters located in Dighboi, Haldia and Panipat, and (v) mixed industrial areas comprising of 3 main industrial clusters located in Ghaziabad, Aligarh and Faridabad. A comparison of sector-wise IEPI values of various industrial sectors shows that the few of the steel producing industrial areas/ clusters and oil refinery areas/ clusters have relatively lesser IEPI score. These sectors are in general better planned and systematically developed with better environmental management infrastructure. Also these industrial areas/ clusters are defined by the presence of a few major and well organized industries which are held directly responsible for the environmental upkeep of the surrounding area. It has also been observed that the coal mining and thermal power plant areas/ clusters and the chemical industry areas/ clusters are relatively more polluted. These areas/ clusters are dominated by a large number of industries having distinctly different types of emissions and waste disposal. Also these areas are dominated by a large number of small and medium scale industrial operations which are privately owned and hence relatively less responsible collectively. The mixed industrial areas showed much variability in the IEPI score ranging from 66.27

to 91.18 out of a total score of 100 due to varying size and complex and varied mix of type of industries in a given area/ cluster.

In Chapter 5, the methodology has been further refined by developing corresponding indices through fuzzy logic-based model using appropriate aggregation function for various components of the environment. 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.

In Chapter 6, sensitivity analysis has been carried out for 5-typical industrial clusters (viz., Ankleshwar, Vapi, Jamshedpur, Haldia and Dighboi) 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 quality of any industrial cluster. The sensitivity analysis of IEPI function which takes into account the consideration of the weights attached to the factors, with respect to the change of values of two parameters is performed independently. The most significant variable, $A_1 = S_{c,i,j} + \Delta_{i,j}$ representing presence of toxin is varied from minimum to maximum value with other set of parameters having same value and how these two parameters influence the IEPI value has been assessed. In more general terms uncertainty and sensitivity analysis investigate the robustness of a study when the study includes some form of mathematical modelling.

The main purpose of this study has been to develop a conceptual model for establishment of pollution index of industrial clusters and to demonstrate its applicability under different scenarios by taking a number of case studies of various industrial clusters located in different parts of India. The cause-effect relationships can able to predict consequences likely to happen with respect to different 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 identifying critical industrial clusters. It would serve as a building block for taking decisions on identifying industrial clusters, which is lacking at present in Indian scenario. By using data on pollution in air, surface water, groundwater, one can also be able to identify critical component which may be vulnerable.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1
INTRODUCTION

1.1. Introduction

Industrial sectors are key to the economic growth of any society. It is essential for any nation to widen its development base to meet growing requirements. Many essential requirements have been fulfilled through different goods and services produced by the industry. For example, the production of food items (grains, vegetables, fruits etc.) requires sufficient quantity of agrochemicals and appropriate machinery. There exist a large number of industries varying in size of establishment, product development and type of technology used: be it small, medium and/or large-scale industries. They extract materials from the natural resources and inserts both products to meet changing needs and pollution into the human environment.

Firms involved in mineral processing, pulp and paper, iron and steel, tanneries, automobiles, oil refinery and chemicals, non-ferrous metals, coal mining and thermal power plant and electric power generation - all are the major polluters of our environment. They contaminate environment on different scale depending on their capacity, process treatment technologies and total pollution control investment. Although industrial sectors have the power to enhance or degrade the environment; there exists a trade-off between environmental protection and industrial development. It is therefore necessary to determine the status of pollution caused by the industrial clusters located in different regions so that effective strategies can be formulated to reduce the pollution.

Pollution originating both from large-scale industries as well as small-scale industries contribute a significant part of total pollution in a country like India where rapid industrial growth has been observed since the economic reforms which came in 1991. After economic reforms, there has been a substantial impact on manufacturing industry. These manufacturing units have not only increased in number but also there is significant increase in the production output among each of these individual manufacturing units. This rise in growth in the resource intensive manufacturing sector is enabled and facilitated by an ever-increasing rate of material use leading to severe impacts to the environment. Manufacturing processes take various materials/resources as input to produce end products as the output which are performed through sophisticated equipments. The entire process deals with different type of activities at different stages which are used to be quite complicated. In the process of product development, they also generate polluted streams, emissions, wastewater effluents and solid wastes. As natural resources and raw materials are finite, they would create serious security issues for these manufacturing industries in coming times due to overexploitation of these resources. Moreover, many of these industries still rely on traditional resource-intensive technologies to produce end products with minimum production cost and expenditure at the expense of generating large amount of wastes and thus, polluting the environment to a large extent. Therefore there is a need to formulate appropriate and effective policies to control pollution which can be implemented strictly for all kind of industries by proper enforcement drive. All industries should be encouraged to adopt best practices for sustainable consumption of resources by introducing efficient and effective tools and equipments. These best practices would help to alleviate the overall environmental impacts of these industries by reducing wastage of resources, which directly reduces the production of wastes, emissions and effluents. They should also have effective provision of treatment and disposal of wastes, emissions and effluents so that none or minimal environment impacts can take place at the end of the process.

Environmental pollution and related human health issues and ecological damage are a serious concerns since they have not only become a threat to biodiversity but also become a threat to human population itself. These environmental issues are of special importance since they affect both flora and fauna including human beings. They reduce expected life of people, slow down growth of the children and disturb the entire sustainable development process. The World Health Organization (WHO) estimated that more than 25 percent of all mortalities in the developing world are due to environmental factors which is quite alarming. The problem becomes even further aggravated due to unplanned growth of industrial clusters/townships wherein many of the industries have been flouting rules and norms. The major challenge in implementing any policy of Environment Action Plans (EAP) is the identification of polluting industries and their location. This can be achieved by assessing the existing pollution emissions originated from different industry sources and taking corrective measures accordingly. However, it is also a difficult task for regulating agencies due to lack of reliable information on the nature and type of pollution emitting from different industrial plants and factories. They need to monitor various environmental parameters regularly through an effective surveillance monitoring programme. The regulating agencies cannot simply set priorities for enforcing environmental regulations for industrial sectors to be targeted for greater intervention, or the geographical area where intervention should be focused in the absence of basic information. The biggest difficulty for identification of problematic areas in Indian context is the lack of data and absence of an objective methodology which can scrutinize and rank these areas for further decision making process.

The criticality level of any industrial cluster/area can be characterized by developing a conceptual model, which should deal mainly with 3 important components: (i) type and source of pollutants available in the industrial cluster/area, (ii) mode of pollutant transport process through which the pollutants are transmitted into the atmosphere, and (iii) the receptors who are exposed to the said environment. The overall impact on environment by any industrial activity can be assessed effectively if the pollutant linkages pertaining to source, pathway and receptors can be developed with proper quantification using the base level information. It is clear that if all three pollutant linkages (source-pathway-receptor) are known, pollutants contamination can be quantified with their impacts using a robust methodology. It is therefore necessary to develop a simple and robust methodology for rapid assessment to identify critical industrial sectors/ areas on the basis of base-level available information of existing status of pollutants (critical parameters) pertaining to information on source, characteristics of pathways and their impact on receptors in these clusters/areas. Once the criticality level of these industrial sectors/ areas are known, they can be classified/grouped to assess the extent of damage of environment. The detailed assessment methodology have to be applied further by the regulating agencies to prioritize their decisions of implementing environmental regulations so that the process of industrial development and economic growth can be ensured in an effective and sustainable manner.

The economic and environmental sustainability concerns have now attracted many researchers working in the areas of industrial planning, environmental science, environmental management and humanities and social sciences both at National and international levels. However, efforts made so far are marginal especially in context to remediation of critically polluted areas. Thus, there is an urgent need to identify and grade the industrial clusters based on their pollution potential busing an objective and scientific framework and design action plans accordingly. The Integrated Environmental Pollution Index (IEPI) has been developed with the main objective of quantification of the state of environment and human health, determining and monitoring the effectiveness of remedial action plans, comparing all possible alternate plans in order to develop decision support system for environmental regulators, policy makers and decision-makers.

Integrated Environmental Pollution Index (IEPI) of an industrial cluster is conceptualized as a rational number on a graded defined scale to characterize the environmental quality for a given industrial cluster and its surroundings using an impact evaluation algorithm of sources, pathways and receptors. The higher value of IEPI implies severe adverse effects on environmental pathways and receptors and thus is an indicator of health hazards of human population and irretrievable losses of different components of environment. The IEPI for assessing ecological damage aspects and human health concerns is expected to play a major role in decision making and planning which would facilitate sustainable development. Thus the IEPI proposed herein serve as the warning or rapid screening assessment tool to group or prioritize industrial clusters needing interventions in graded manner under a systematic designed framework.

1.2 Objectives of the Research

The purpose of this study is to develop an index which can help prioritize critically polluted industrial clusters/areas on the basis of available information on environmental components in objective manner. The base level information on environmental components and the cause-effect relationship needs to be established using a robust methodology. The methodology has be inclusive of various dimensions of pollution being captured by monitoring agencies and easy to monitor early warning symptoms. The index is aimed to be used as rapid assessment tool for quantification of the environmental health of an industrial cluster so that all possible alternative plans can be analyzed by the stakeholders to mitigate pollution problem effectively.

The main objectives set for the proposed research are to:

a) develop a model for evaluating the pollution level by deriving an index which will include all possible sources of environmental pollution, their pathways and receptor related information.

b) identify and classify the critically polluted industrial clusters/ areas on the basis of pollutant availability and their impact on sources, pathways and receptors so that not only appropriate remedial and mitigated action plans can be formulated in graded manner but also can be monitored centrally at the national level to improve the current status of environmental components e.g. air, ground water and surface water quality data, ecological damages and public complaints.

c) classify type of clusters viz. critically, severely and moderately polluted industrial clusters/areas on the basis of environmental pollution index so that economically feasible solution can be suggested by incorporating appropriate remedial action plans for environmental sustainability.

d) study the impact of various pollutants having different weights on the Integrated Environmental Pollution Index (IEPI) by conducting sensitivity analysis with respect to different aggregation functions and their attributes in the case studies of selected industrial areas/clusters.

1.3 Scope of the Research

Industrial clusters have become a major concern in recent years as they are polluting different components of the environment. This study deals with evaluation of pollution level in different industrial clusters by focusing on important components of environment, dealing primarily with quality aspects of air, surface water, groundwater. It incorporates the concept of multiple-attribute decision-making methods, fuzzy rule-based models (fuzzy set theory). Appropriate model has been developed to evaluate pollution sub-indices for air, surface water, groundwater respectively which were integrated to get an overall index.

The aggregation for overall index has also been done by developing corresponding indices through a fuzzy logic-based model. This study was conducted at 15 industrial clusters in India. The scope of the present study is limited to the following.

a) The proposed IEPI is aimed to evaluate the areas primarily affected due to industrial pollution only though it can be refined further for any other pollution.

b) The IEPI is aimed to assess the effect of pollution at local level around industrial clusters/ areas on the basis base level information. The global environmental issues have not been dealt while evaluating IEPI for different clusters.

c) The IEPI is not intended to reflect the potential release of pollutants in the area or in a nearby area accidentally.

1.4 Organization of the Research

Chapter-1 gives an introduction to industrial pollution assessment and thereby the various aspects used in the analysis. Further, objectives and scope of the present study have been delineated along with the organization of the work in the chapter.

Chapter-2 deals with the comprehensive literature review of the earlier methods used in the analysis along with theoretical considerations. The literature review presented in this chapter mainly covers four main topics: need for quantification, general structure for environmental indices and existing methods: descriptive and normative indices, challenges with the existing environmental indices and research gaps with the existing environmental indices and motivation of the present study. This chapter is essentially to review on the reported methods of environmental consequence estimation so that research gaps can be identified especially in context to assessment of hazards due to environmental release of emissions in industrial clusters/areas. The investigations of various authors 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.

Chapter-3 presents the development process of the Integrated Environmental Pollution Index (IEPI). This study has made an attempt to identify the major factors responsible to assess pollution status in industrial clusters, subsequent to which appropriate methodology have been proposed for evaluation of Integrated Environmental Pollution Index (IEPI) for assessing relative ranking of industrial areas/clusters on the basis of characteristics of hazardous pollutants used, produced or stored; potential releases into environment, characteristics of the pathways, and spatial distribution of the receptors in and around the area under investigation. The assessment has been performed using the concept of multi-attribute decision making analysis.

Chapter-4 deals with the application of the evaluation of IEPI to the polluted industrial clusters/areas located in different parts of India. The applicability and usefulness of the proposed methodology developed in Chapter 3 has been rationalized by evaluating IEPI for 15 different industrial clusters located in different parts of India. The study is focused on important components of environment, dealing primarily with quality aspects of air, surface water, and groundwater in these selected industrial areas. These 15 industrial clusters have been further categorized into 5 different types of industrial clusters namely, (i) steel producing industrial clusters/areas comprising of 3 main industrial clusters located in Durg-Bhillai, Durgapur and Jamshedpur, (ii) coal mining and thermal power plant areas comprising of 3 main industrial clusters located in Dhanbad, Korba and Singrauli, (iii) chemical industry areas comprising of 3 main industrial clusters located in Vapi, Ankleshwar and Ahmedabad, (iv) oil refinery areas comprising of 3 main industrial clusters located in Dighboi, Haldia and Panipat, and (v) mixed industrial areas comprising of 3 main industrial clusters located in Ghaziabad, Aligarh and Faridabad. A comparison of sector-wise IEPI values of various industrial sectors shows that the few of the steel producing industrial areas/ clusters and oil refinery areas/ clusters have relatively lesser IEPI score. These sectors are in general better planned and systematically developed with better environmental management infrastructure. Also these industrial areas/ clusters are defined by the presence of a few major and well organized industries which are held directly responsible for the environmental upkeep of the surrounding area. It has also been observed that the coal mining and thermal power plant areas/ clusters and the chemical industry areas/ clusters are relatively more polluted. These areas/ clusters are dominated by a large number of industries having distinctly different types of emissions and waste disposal. Also these areas are dominated by a large number of small and medium scale industrial operations which are privately owned and hence relatively less responsible collectively. The mixed industrial areas showed much variability in the IEPI score ranging from 66.27 to 91.18 out of a total score of 100 due to varying size and complex and varied mix of type of industries in a given area/ cluster.

Chapter-5 presents the improvisations over the IEPI and its application using fuzzy comprehensive assessment method by introducing appropriate aggregation function for various components of the environment. 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.

Chapter-6 presents sensitivity analysis which has been carried out for 5-typical industrial clusters (viz., Ankleshwar, Vapi, Jamshedpur, Haldia and Dighboi) 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 quality of any industrial cluster. The sensitivity analysis of IEPI function which takes into account the consideration of the weights attached to the factors, with respect to the change of values of two parameters is performed independently. The most significant variable, $A_1 = S_{c,i,j} + \Delta_{i,j}$ representing presence of toxin is varied from minimum to maximum value with other set of parameters having same value and how these two parameters influence the IEPI value has been assessed.

Chapter-7 summarizes and concludes the research work after all the results and their in-depth analysis. The insights gained through the present study is believed to be of pivotal significance in identifying critical industrial clusters. It would serve as a building block for taking decisions on identifying industrial clusters, which is lacking at present in Indian scenario.

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

A REVIEW OF LITERATURE ON QUANTIFICATION OF ENVIRONMENTAL CHARACTERISTICS

2.1 Introduction

Traditionally, the idea of protecting and managing environmental resources has been nurtured and treated as an important aspect in India. The purpose of traditional practices is to use nature's gifts gratefully and thus serve the nature leading to an impeccable harmony. People used to adopt best traditional conservation techniques in practice at large scale which also inspire others to follow. However, an exponential growth in science and technology, constantly upgrading life styles, urbanization, industrialization and expansion in infrastructure have led to severe degradation and pollution of the environment (Paliwal, 2006). Such degradation has manifested as pollution in land, air, and water resulting in in disruption of biodiversity and several potential health hazards which becomes even more challenging and severe in so called industrial clusters. The efforts made for remediation of industrial clusters which have been posing severe threat to both environment and public health are far from adequate. Thus, it is and urgent and essential task for the policy makers to address to this issue by identifying polluted industrial clusters, by classifying them in order of their severity of pollution and problematic dimensions. Once the industrial clusters are identified, their spatial boundaries and the degree of impact on the ecology can be estimated. The integrated remedial action plan can then be formulated and environmental planning process can be designed accordingly to develop certain mitigation measures against the pollution and also to revive the overall quality of the environment corresponding to the industrial clusters.

The planning and decision-making pertaining to environment and industrial clusters are often conflicting analysis that are characterized by certain environmental, social, political and economic value judgments. Numerous decision alternatives/strategies have to be taken into account in order to evaluate them with respect to various criteria resulting from an enormous amount of uncertain and inaccurate real life field data. Therefore, the proposed research has made an attempt to identify important environmental issues involved in a few selected industrial clusters of the country and developed a model for evaluating the existing pollution level in these industrial clusters by deriving an Environmental Pollution Index (EPI) for expressing the environmental status in the identified industrial clusters/areas.

2.2 Need for Quantification

In recent times, the problems caused by various types of pollution and its adverse impact on the ecosystems have been intensified with the increase in the scale of urbanization, industrialization and associated developmental activities including resource extraction, power generation, and infrastructure management etc. This has aroused the need to formulate an objective or quantitative method so as to facilitate graded quantification of the environmental conditions. In addition, the objective of achieving the environmental sustainability has become one of the primary focus of the inter-disciplinary researchers since last two decades (McMichael et al., 2003). The rapid rise in human population followed by swift increase in demands for materials and services has further prompted the need for resource extraction and industrial development resulting in environmental pollution. Resource diminution, acidification, global warming, eco-toxicity, air pollution, soil pollution, surface and ground water pollution, and human health effects are the some of the highly harmful and undesirable consequences/ impacts. Such impacts may be classified into two major groups as (i) impacts on eco-geological components and (ii) impacts on human health (Anuraj and Maiti, 2009). The corresponding pathways could be through either surface and ground waters, air, soil or a combination of these.

Methods like ecological impact assessment, environmental impact assessment, life cycle assessment, strategic environmental assessment etc., are used to evaluate the overall impact of evolving projects, processes and products on the various environmental segments. Some researchers have also used spatial mapping techniques such as geographic information systems (GIS) for better visualization of the overlapping consequences. Implementation of a spatially explicit modelling approach to deal with the dynamism imposed by heterogeneous but interlinked environmental segments is the need of the hour. It has been observed that the demand for developing an integrated approach to evaluate environmental status has been increased in many countries in recent times. Such an integrated approach is productive in evaluating sustainability dimensions of the developmental segments.

In the past, the has been various catastrophic and hazardous instances caused by industrial activities. The scale and extent of damage from such instances have emanated the public concerns about the environmental issues and emphasized the need for early warning systems to be put in place. Now a day, the environmental damage caused by industrial pollution has become a worldwide concern and thus, assessment of the degree of pollution caused by various parameters released due to several industrial operations has become an emphatic task for the environment engineers.

The accumulated/ integrated measurement of environmental sustainability or performance is usually expressed as Composite Environmental Index (CEI). It has evolved as a result of applying systems analysis approach. The composite index provides decision makers the aggregated environmental information, project progress evaluation, efficacy of the policies, comparisons and benchmarking with the good practices and thus simplifies the process of decision making (Esty et al., 2005). The composite indices also reduce the number of indicators by aggregating them by multiplicative, additive or a combination thereof to make the lump information easily communicable which can be easily understandable and assessable in a graded scale. Otherwise it is very difficult to evaluate the overall performance of the environment and trends on the grounds of multitude of environmental indicators representing various components. Otherwise it is a difficult and cumbersome task to evaluate the environmental performance in the realm of a large number of eclipsing environmental indicators.

The composite indices are very valuable for providing emphatic information pertaining to environment in a clear and concise manner to the various stakeholders including the non-technical ones. These are especially very useful for policy makers involved in environmental decision-making, although such experts may have several means for analyzing number of indicators. However, the decision makers are more inclined towards a defined integrated information such as the composite index (Kang, 2002). A number of studies have reported approaches for identifying and ranking industrial clusters by constructing indices in several alternative ways. These methods deal with wide range of case studies ranging from a definitive environmental theme to the entire economic–energy–environmental system or from a single nation/are to multiple nations/areas (Cormier and Suter, 2008; Gunasekera and Edwards, 2003; Kang, 2002; Sinclair and Diduck, 2005; Singh and Vidyarthi, 2008; Zhou et. al., 2005).

2.3 Existing Methods

The environmental consequences have been assessed by various situation specific methodologies as reported in literature. Each method or technique has certain advantages, disadvantages, limitations, and are applicable for different problems. These methods can be divided in two separate sets, (i) the techniques used for identifying and quantifying abnormal situations, i.e. environmental hazards; and, (ii) the techniques for quantifying planned emissions or releases or discharges from a source.

In recent times, the indices for inherent environmental safety and chemical process route selection have been developed utilizing the concepts of Boolean mathematics. The usage of fuzzy set theory for developing inherent safety index strengthen the effectiveness of the results (Anuraj and Maiti, 2009; Nasiri et al., 2007; Chakrabarti et al., 2015). As decisions pertaining to environment involves natural and multidimensional decision environments, hence there is certain uncertainty, and complexity associated with them. Such problems can be dealt of using Multi-Criteria Decision Approach (MCDA) methods. MCDA methods provide a systematic framework for collecting, storing, and processing all relevant information. As a decision-making tool, it can easily allow to incorporate environmental considerations into the analysis of a problem (Balasubramanim and Voulvoulis, 2005; Tzeng and Tsaur, 2002).

2.3.1 Environmental Indices: A General Structure

There are numerous techniques available for calculating environmental impact indices. They are primarily classified as two types, (i) indices derived on the basis of quantity of waste generated, and (ii) indices derived on the basis of relative environmental impact due to different key factors such as land usage, energy consumption pollutant emissions, as well as subjective parameters like aesthetic value.

The normal structure of environmental indices is shown in Fig 2.1. The relationship between input data, key indicators and indices is shown as a process flow. Identification of source and data collection of all relevant environmental themes as mentioned above is the first step involved in constructing an environmental index. The second step involves the integration of these data corresponding to environmental pathways indicators e.g., air, water, soil etc. The mathematical function of each indicator has been defined as the representative of the respective environmental components. The indicators serve as the inputs of a mathematical function which describe the overall state of the environment which is represented as a single crisp number i.e. Environmental Index.

It should also be noted that at each stage of this process, the detailed information is being lost on the one hand while simplicity and intelligibility of the environmental message is emphasized on the other. Evidently, there is no single "correct" way of aggregating e.g., air pollution data (ozone, hydrocarbon, particulates, nitrogen oxides, carbon dioxide etc.) to form an overall air quality indicator. There is always a certain degree of uncertainty associated with the choosing of an aggregation function. It depends on the components of the environmental described by the indicator and also on the kind of variables and their interdependencies (Ahlheim, 2005).

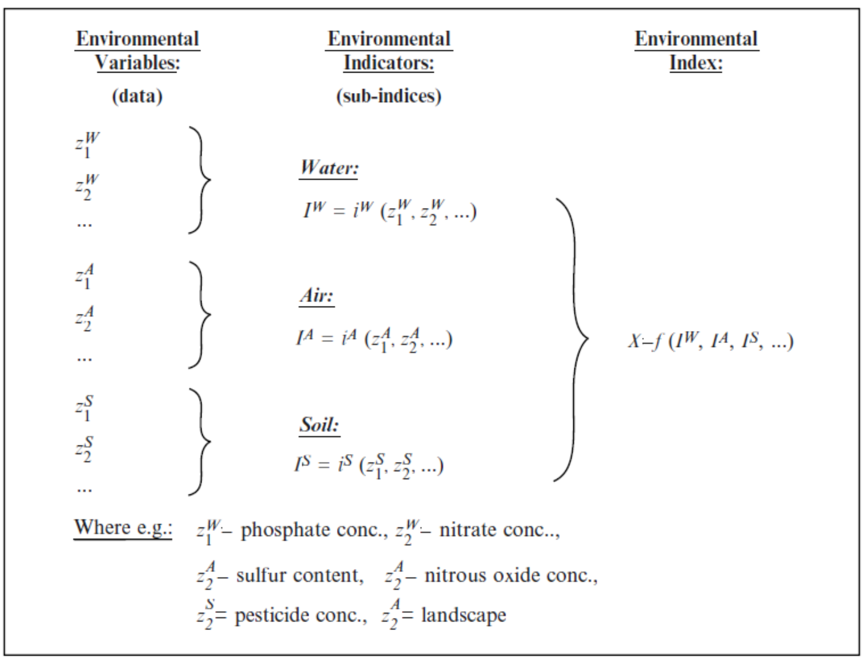

Figure 2.1: The relation among environmental input data, key indicators and indices (Ahlheim, 2005)

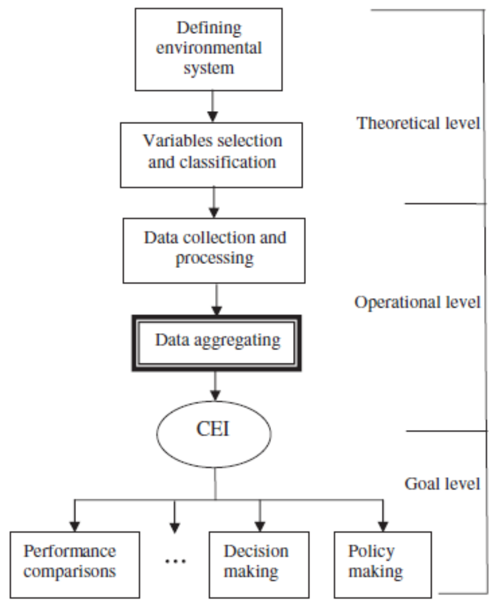

Figure 2.2: The CEI construction process

The following section outlines about some of the important environmental indices practiced in environmental monitoring, assessment and management.

2.4 Descriptive Environmental Indices Models

The descriptive indices normally consist of a two-step procedure as follows: (i) selection of suitable indicators representing the environmental issue, (ii) Aggregation of these indicators to obtain an overall index number using an appropriately selected aggregator function (Ahlheim, 2005). Some of the most popular descriptive indices include: (i) the Environmental Quality Index (EQI) for Canada; (ii) the Hope and Parker Index (HPI) for the UK (Hope and Parker, 1990); (iii) the Hope and Parker Index for France and Italy (Hope and Parker, 1995); (iv) the Mirror of Cleanliness (MoC) for the Netherlands (den Butter, 1992); (v) the Korean Composite Environmental Index (CEI) (Kang, 2002); and (vi the Ecological Dow Jones (EDJ) index (Brink et al., 1991).

2.5 Normative Environmental Indices Models

The normative indices use a pre-defined normative statement or goal to combine the measurement of certain indicator values. One of the forms of normative indices is achievement indices that measure and ascertain the degree to which a specific environmental goal (i. e. the normative statement) has been achieved. Another form involves comparison with the stated normative statement of intended sustainability goal. An example of normative index is the German Environmental Index (DUX), developed in 1999 for the purpose of evaluating the effectiveness of national environmental policy to the general public. Wheeler (2004) also proposed another public health related environmental index (HEI) which works around the stated public health goals. HEI, however, can incorporate at the most four health related indicators. The primary aim of this set of indicators is to provide information to the policy makers and the public about spatial inequity with respect to environmental (living) conditions in order to identify those regions within a country that should be given a due priority for improving upon the particular environmental segments.

The construction of normative indicators is based on the comparison of the measured environmental parameter, e.g., ambient pollutant concentration in a certain region, to a threshold value considered standard acceptable from a public health point of view. It is to be noted that this set of indicators is chosen based on experts' knowledge and past experience. The evaluation of ecological footprint (EF) is a popular example of sustainability index in the normative form (Rees, 1992, 2000, Chambers et al., 2000).

Hazardous ranking system (HRS) is another normative index adopted by Environment Protection Agency, United States (USEPA). It is a numerical calculation based screening system to assess the relative potential of hazardous waste sites posing a threat to human health or the environment. Four pathways are assessed under the HRS namely, ground and surface water; soil and air (EPA evaluation report, Aug. 2005).

There are a number of studies which assess status of pollution in air, surface water and groundwater environments. Contamination of air, surface water and groundwater by different industrial activities has also been highlighted in the literature.

Air Quality Index (AQI) adopted by various countries is calculated based on the pollutant concentration data which are compared with normative target values, using the following equation with linear interpolation for intermediate values.

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo}. \qquad (2.1)$$

Where, I_p = the index for pollutant p; BP_{Lo} = the breakpoint that is less than or equal to C_p; BP_{HI} = the breakpoint that is greater than or equal to C_p; I_{Lo} = the AQI value corresponding to BP_{Lo}; I_{Hi} = the AQI value corresponding to BP_{HI}; and C_p = the rounded concentration of pollutant p.

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 (EPA, 1998). 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. However, the main drawback of this approach was its eclipsing effect on index. 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; Chakrabarti et al., 2015).

Several studies have also been done by the researchers to evaluate status of surface water pollution 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 (Giri and Singh, 2014; Liou et al., 2004; Mourhir et al., 2014; Singh et al., 2015; Singh and Ghosh, 1999). Researchers have proposed weighting system for assigning importance weights for each indicator parameter/criteria. 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.

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 assessment (Singh and Ghosh, 2003; Tappeiner et al., 2007). Also, uncertainty associated with personal preferences and linguistic judgments of subject experts lead to impreciseness of the evaluation process. Artificial intelligence techniques have been applied as a tool to develop water quality index by several researchers (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 pollution (Ross, 2008; Zadeh, 1978).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 (Mahmood et al., 2017; Singh and Vidyarthi 2008; Singh, 2008; Singh and Dubey 2012; Singh et al., 2015; Zou et al. 2006).

The pollution status in groundwater has also been assessed by deriving indices to integrate/represent effects of important environmental indicators into a single value which can represent one of the possible grades of pollution in the ground water viz., very poor, poor, fair, good or excellent. Researchers have emphasized application of fundamentals of hydrochemistry in assessing the ground water quality (Hailin et al., 2011; Latha and Rao, 2012; Majandang and Sarapirome, 2013; Ramakrishnaiah et al., 2009; Rosemond et al., 2009; Srinivas et al., 2013). Sharma and Patel (2010) developed Ground Water Quality Index (GWQI) to determine pollution potential of ground water of Surat City, India. Adhikari et al. (2013) 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. Srinivas et al., (2015) have developed a fuzzy inference tool for estimating status of groundwater quality in Bikaner district in Rajasthan.

Although a wide spectrum of literature is available as cited above, it is felt that still there is a tremendous scope to develop a methodology for assessment of status pollution in air, surface water and groundwater quality in different industrial clusters in India.

2.6 Challenges with the Existing Environmental Indices

The existing environmental indices serve as a tool for effective communication between various stakeholders including environmental experts, politicians and the public at large. They also serve as a means of comparing and judging the environmental quality of different locations, of measuring the success of environmental policy or of informing the public on the developments or criticality of environmental quality in a certain geographic regions or city.

On one hand, the environmental indices are expected to be easily interpreted by laymen and on the other hand, the information conveyed by them should not be too trivial or superficial. Such multipurpose nature of environmental indices gives rise to a dilemma. Their derivation inherently implies a reduction of complex multidimensional environmental specifics to a single crisp number which often results in a considerable loss of information as compared to the original data set belonging to the respective environmental component. The primary reason behind the popular acceptance of these indices instead of this loss of information is the aspect that more people will be able to appreciate a condensed form of information than in the complex data set of multi-variables. The challenge is in striking a balance between these two extremes. Furthermore, the composite indices usually contain more information except the ranking order of the environmental systems under consideration. For instance, the perception of the decision makers on three values of indices 0.9, 0.8 and 0.7 is usually different from that on 0.9, 0.7 and 0.1 in spite of having the same ranking orders. Therefore, the main challenge lies in expressing the representative information even if the order ranks of the indices given by different aggregating methods are consistent, it is still meaningful to further compare the methods when more emphasis is given to the relative values than to their ranking.

2.7 Research gaps with the Existing Indices and Motivation for the Study

One of the major concern is lack of availability of the basic environmental monitoring data. The incomplete information on environmental and public health impacts of pollutants, arbitrary selection of weights assigned to environmental themes, and a lack of rationale in the use of the index are some of the other problems to be dealt in the field of environmental index and its application. The comparison scale of index values used for to classification of critically polluted areas is also a debatable issue. One of the main experiences in the area of research related to environmental pollution index has been that the failure of reductionist approach in adequate analysis of complex, multidisciplinary, and large-scale problems. Further, they do not yield essential information about causes-effect relationships nor cross-linkages between various causes and various effects. Another major problem in deriving the index is to determine an appropriate aggregating method to combine/integrate the multi-dimensional environmental variables into an overall index. An environmental index is considered meaningful if the underlying ranking order is independent of the choice of the measurement units (den Butter et.

al., 1998). It has also been observed that the EPI aggregation using weighted geometric mean method are meaningful only when the environmental variables are strictly positive and ratio-scale is incomparable; weighted average method are mostly not meaningful (Kang, 2002). However, if the environmental parameters are normalized to make them dimensionless before aggregation, the index derived using weighted geometric mean and weighted average methods are both meaningful and the two methods become incomparable.

The problem of choosing an appropriate response function is also one of the important issues. Even if there are a large number of various environmental parameters, a sub-set of factors that have the main impact on the index are identified for further evaluation. Another major problem that challenge the authenticity of an integrated environmental index is the loss of information aggregating sub-indices The aggregating method that always result in loss of few information is considered better than the ones which result in considerable loss. A perfect aggregation method doesn't result in any loss of information.

It is also difficult to choose between comprehensibility and scientific profoundness. The computation of a pollution index has been particularly simplified to good extent by the usage of selected environmental quantities that are indicative of the selected environmental component. However, no solution can be proposed to evaluate the relative importance of the environmental components in a purely objective manner.

The investigations described in this literature review show that there is accelerated pace of research into environmental indices 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 pollution level in different components of environment, (2) methodology should be developed that can link/ integrate various parameters in more effective manner especially in context to India.

2.8 Summary

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 pollution assessment. However, very few field studies have been reported with a framework of improved problem formulation and solution techniques. The concept of fuzzy uncertainty, multidimensional and spatial characteristics of environmental phenomenon have also not been explored much for evaluating status of overall pollution especially in context to Industrial clusters in India.

Therefore, this prompts further investigation of deriving a framework for environmental pollution assessment in industrial clusters located in India with respect to following aspects:

- To present a systematic framework for deriving environmental pollution index for assessment of pollution in different clusters especially in context to India scenario.

- To know the status of pollution in air, surface water and groundwater in different industrial clusters located in different parts of Indian territory so that necessary remedial actions plans can be taken to minimize the pollution level.

- To develop a fuzzy comprehensive model to assess pollution in air, surface water and groundwater in selected industrial clusters located in different parts of Indian territory. This is needed to adopt a scientific approach for evaluating environmental pollution by incorporating concepts of multi-criteria evaluation method and fuzzy set theory.

- To demonstrate the cause-effect relationships for various attributes and their inter-relationships by applying the concept of sensitivity analysis which will ultimately help in arriving at the appropriate management options to improve the overall quality of environment in any of the selected industrial cluster.

Chapter 3
DEVELOPMENT OF INTEGRATED ENVIRONMENTAL POLLUTION INDEX

3.1 Introduction

The main aim of this research is to develop Integrated Environmental Pollution Index (IEPI) for different Industrial clusters located in different parts of the country which can assess quality of environment at the location of these industrial clusters. The IEPI has been developed to aid in prioritising the investigation of pollution level at different locations, particularly where various kinds of industrial activities have been carried out. The IEPI has been designed to identify and rank potential sites on the basis of magnitude of pollution/ contamination hazards produced by the industrial activities. Exposures to pollution remain a major source of degradation of environment in general and causing severe adverse health effects particularly throughout the world. Thus exposure of contaminated environment leads to a risk which can be characterized by a conceptual model, dealing with the identification of sources of pollution risk, the pathways for migration of contamination and the human and environmental receptors. The IEPI is therefore composed of three main components: *source, pathway and receptor* that are used to determine pollution level and an overall ranking of the industrial clusters.

Contamination of environment is caused if various chemicals, hazardous substances and wastes generated from industrial activities are released into the environment beyond their prescribed standards. The source of contamination is dependent on type of industrial activities through which specific pollutants are generated with different magnitude of toxicity. These sources can be categorised as point sources and non-point sources. Point sources are generally those sources that produce contaminants at a particular location. They can be originated from sources like industrial plants, municipal wastewater drains and any other industrial activities. A large number of pollutants are being generated at different processes of industrial production and treatment plants which have been released at a point into the environment through pipes and/ or drains or even when they emit from the source through smoke stacks. Pollutants from non-point sources (NPS) are also generated to contaminate environment. They are originated from many diffuse sources such as agricultural runoff derived from a catchment which flows further on the ground due to gravity, it carries away various pollutants available in the catchment, finally depositing them into a receiving water body such as a lake, river, coastal water, and even percolate into the groundwater. Air pollutants are also being discharged from non-point sources to the atmosphere by means of automobiles, small metal plating operations, cement industries, etc. It is also important to study about mode or pathway of spreading contamination that determines how and to what extent the contamination will migrate from a source and reaches to the receptors. The pathways which can be considered for transporting contamination may be air, surface water, groundwater and/or soil whereas a receptor is a human or an ecosystem that may be impacted by the exposure to the contaminant(s). A receptor may be a base resident or a worker, or a school child, or a marine or terrestrial ecosystem, adjacent to an industrial cluster or within the industry itself.

Therefore, the overall impact on environment by any industrial activity can be assessed effectively if the pollutant linkages pertaining to *source, pathway and receptor* are developed with proper quantification. It is clear that if all three pollutant linkages (source-pathway-receptor) are known, pollutants contamination can be quantified with their impacts. For example, an industrial cluster with high level of industrial activity (source) and an existing pathway for migration of a release of a contaminant and is habitat for a sensitive species (receptor) would rate higher than that with the same listed species but a historically low level of industrial activity.

In this chapter a methodology has been developed to devise IEPI by taking into consideration of source, pathway and receptor as the three important elements associated with contamination process in the environment. The data pertaining to these 3 components have been collected through a designed questionnaire. The questions are addressed to each of the three components: source, pathway receptor and the responses which classifies hazard category of each industrial cluster. The IEPI for a particular industrial cluster developed herein is based on a systematic-integrated approach to describe clearly about the overall condition of pollution in an industrial cluster with a single rational number. Sensitivity analysis has also been carried out to demonstrate the cause-effect relationships of selected attributes associated with these three components. Their inter-relationships have been devised to explore appropriate management options to improve overall quality of environment in the region. The present analysis and assessment of the overall pollution index through the novel IEPI methodology could help to establish distinct and immediate decision routes which had been elaborately discussed in this Chapter.

3.2 Methodology

In this study an integrated Environmental Pollution Index (IEPI) has been developed to evaluate status of pollution at different locations due to activities followed in industrial clusters by using two aggregating methods of Multi-Attribute Decision Making (MADM) process, viz. Simple Additive-Multiplicative Aggregating Method and Fuzzy Comprehensive Assessment Method (discussed in Chapter 5). To develop the integrated IEPI, the complete methodology has been summarized in the form of a flowchart as shown in Figure 3.1.

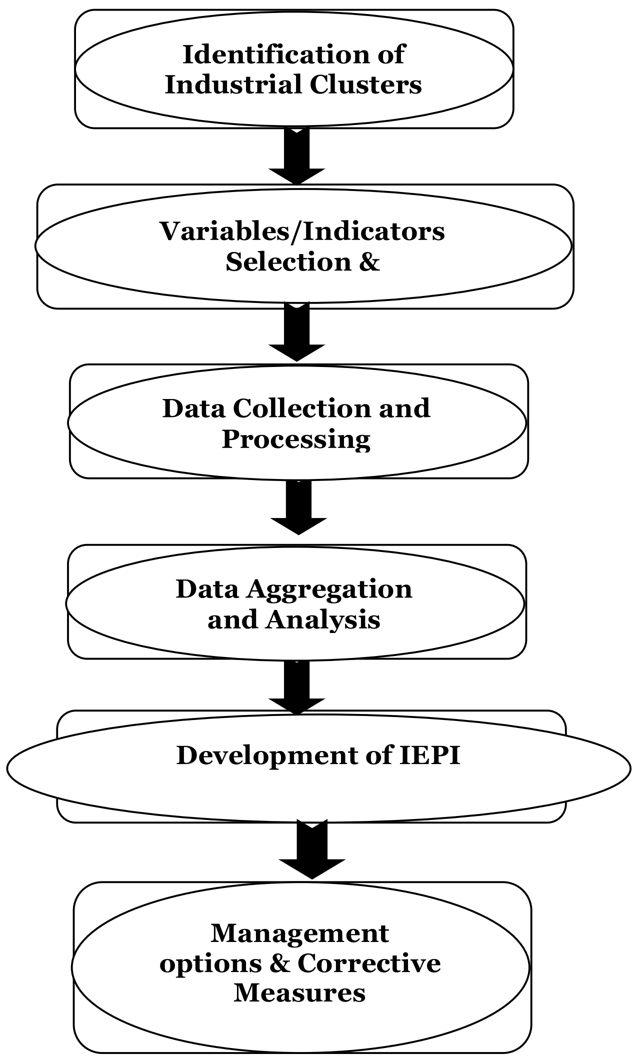

Figure 3.1: IEPI development process for Industrial Clusters

3.2.1 Integrated Environmental Pollution Index using Simple Additive-Multiplicative Aggregating Method

3.2.1.1 Components of Integrated Environmental Pollution Index

The pollution level assessment at a specified location can be performed by developing proper linkage among the three components of the environment viz. source, pathway and receptor. The identification of sources, pathway, and corresponding receptors is very critical. Once they are identified, key parameters (indicators) associated with each of these three components can be selected based on their importance and severity level. They are also dependent on type of hazardous wastes/materials used or produced in a particular industrial activity along with the current environmental conditions of the locations under investigation. Thus relevant spatial and temporal data corresponding to different components of environment (viz. air, land, water, and vegetation etc.) in the selected industrial clusters have been collected directly from field survey as well as from secondary sources. The data pertaining to these 3 components have also been collected through a designed questionnaire. The important parameters/indicators which are more sensitive to produce pollution have been considered as the criteria for evaluating overall pollution index with their relative degrees of importance because each of these parameters has its own significance on overall value.

The IEPI has been evaluated by considering critical parameters/indicators relevant to source, pathway and receptor. To select critical parameters; a questionnaire dealing with various parameters was sent to different experts consisting of professors, research scholars, field engineers across the country. The experts were invited to suggest changes if any and revise the scoring pattern accordingly. Total 55 experts were responded with their useful suggestions. Based on opinion of experts, methodology to select critical parameters/indicators were finalized. The data were analyzed by taking opinion of the experts from Indian Institute of Technology (IIT), Delhi, Central Pollution Control Board (CPCB), academic institutions like, IIT Kanpur, BITS Pilani, IIT Kharagpur, IIT Roorkee, Officials from National Environmental Engineering Research Institute (NEERI), Nagpur, Ministry of Environment and Forests (MoEF), New Delhi, TERI University, Public Health Departments and professionals from different industries, organizations, and NGOs. Finally status of pollution corresponding to a given industrial cluster has been evaluated as explained in the subsequent sections. The IEPI obtained through this process is serving as an early warning tool for rapid assessment of status of industrial clusters. The IEPI has been derived by integrating impacts of all relevant parameters using an additive-multiplicative algorithm. The individual score pertaining to all 3 categories of sources, pathways and receptors are evaluated, before they are integrated finally to evaluate an overall index score using an additive-multiplicative algorithm. The study helps to screen industrial cluster rapidly by classifying them into different categories on the basis of their severity level. The selected industrial clusters/areas can thus be classified in terms of priority of needing attention to adopt appropriate measures. A need-based detailed analysis can further be performed for these industrial clusters on the basis of their severity level to take remedial action plans for controlling pollution level.

3.2.2.2 Scoring Methodology

Industrial sites are generally heterogeneous in nature with regard to both the distribution of pollutants and also to the properties of the materials of medium that control the behavior of these pollutants. In contrast, atmospherically deposited pollutants tend to have variations in their distribution. The concentrations of these pollutants decrease gradually with the increase of distance from the source of pollutants. For example: upper horizons of the soil are contaminated to the greatest extent by atmospheric deposition as it is exposed much more with different industrial activities.

As mentioned earlier, impact of pollution can be assessed by considering 3 important components: (i) a type and source of pollutant, (ii) mode of pollutant transport process through which the pollutants are transmitted into the atmosphere, and (iii) the receptors who are exposed to the said environment. Thus the hazard assessment is a function of these 3 components viz. source of pollutants, pathway and receptor which can be expressed in following way:

$$\text{Hazard} = f(\text{Source of pollutants, Pathway, Receptor}) \tag{3.1}$$

Environmental hazards is dependent on source of pollutants through which various chemicals are released into the sources of air, water or land. Contaminated water sources and industrial accidents are also treated as the source of pollutants. Pathways can be air, water or land through which contaminants are being exposed to the receptors (viz. human, plants and animals). The pollutants can be transported through moving air or water, by gravity movement downslope, or by direct storage, collection and conveyance such as the spreading of waste materials on land. For example, a toxic chemical is released into the environment due to a road accident and a tanker spillage. The crashed tanker is therefore be the source of pollutants. Pathways for this hazardous chemical to become a problem may be through the air if it is a fine powder or volatile liquid, through the ground if it leaks onto a porous surface such as fields, or through water if it enters a water course. From here it may reach to a variety of receptors: plant life through soil or water, and then animal life directly or via eating the plants. Animal life may also be affected directly from exposure to airborne matter. Scoring methodology suggested in this research is useful to identify status of pollution and to know where the path from source to receptor can be interrupted or contamination is to be prevented. Initially, the relevant scores are estimated with respect to sources, receptors and pathways separately by integrating effects of selected parameters with their normalized values. Although this is a very simple conceptual model which does not take into account of variations in time and quantity, it does provide a useful basis to consider a process of assessment of pollution from sources and other environmental media. Each assessment component is, in fact, characterized by different parameters and aggregation formulas which are all presented in the following paragraphs.

3.2.2.2.1 Evaluation of Scores' of Source Components

In this step, Pollution Index at Source (PIS) are obtained for concerned pollutants with respect to each source of pollution in an industrial cluster. Thus the sources of contamination located in a particular industrial cluster under analysis should be identified first so that an appropriate pollution index score at the source can be estimated for those sources and substances.

The pollution index score at source (S) is estimated by taking into consideration of, (i) category of toxicants available at the source in a given industrial cluster, which essentially defines nature and type of toxicants and, (ii) rating of industrial activities due to their presence in a specific areal extent corresponding to that source. The nature and type of toxicants at the source are identified on the basis of their availability and maximum concentration collected during the characterization process or monitoring plans. It is suggested to consider three most critical pollutants for analysis. These pollutants have been classified into 3 groups, i.e. A, B and C as described in Table 3.1. The entire list of pollutants can be obtained from the Appendices I and II. Group C pollutants are considered to be more critical than those from group B and pollutants of 'A' group are the least critical. If there exists more than 3 pollutants from the same category (group), the top 3 pollutants which have maximum normalized concentrations can be considered as the critical parameters.

Table 3.1: Classification of pollutants depending upon their toxicity and carcinogenicity

Group	Description	Score
A	Substances (toxins) which show no acute or systemic signs	1
B	Substances (toxins) which are considered as the probable carcinogens or substances with some systemic toxicity which comes under Class 2 and 3 of USEPA classifications e.g. Polycyclic aromatic hydrocarbons (PAHs), Polychlorinated biphenyls (PCBs), PM_{10}, $PM_{2.5}$ and VOC's. (Appendix I can be referred for complete list of group B pollutants as specified by the CPCB, New Delhi).	2
C	Substances/carcinogens which show signs of significant systemic or organ system toxicity. Substances such as benzene, cadmium, hexachromium, lead, organophosphate, radionuclide, vinyl chloride fall in this category. (Appendix II can be referred for complete list of group C pollutants as specified by the CPCB, New Delhi).	5

The pollution index score at the ith source can be evaluated using equation (3.2):

$$S_{i,j} = Q_i\left(S_{c,i,j} + \Delta_{i,j}\right) \tag{3.2}$$

The $S_{i,j}$ is the total pollution index score at the ith source on the basis of information available on presence of toxins and type of industrial activities. The $S_{c,i,j}$ is the pollution index score due to 3 most critical pollutants (pollutants which have maximum normalized concentrations can be considered as the critical parameters) present at the ith source (in the region) with respect to the jth environment component depending upon their toxicity and carcinogenicity which can range from 1 (if substances (toxins) are without acute or systemic signs) to 5 (if substances/carcinogens show signs of significant systemic or organ system toxicity) as explained in Table 3.1. $\Delta_{i,j}$ is the penalty factor assigned at the ith source with respect to the jth environment component on the basis of criticality and occurrence of 3 most influencing parameters which ranges from 1 (if at least 2 out of 3 selected parameters fall under group B category and the remaining third one falls either under group A or group B category) to 2 (if all 3 selected parameters fall under the highest group C) as explained in Table 3.2. Q_i is the rating of industrial activities found at the source due to their presence in a specified areal extent as specified in Table 3.3. The rating of industrial activities at the ith source (Q_i) is obtained on the basis of number of both highly polluting industries and red category industries available within 10 km^2 of catchment area. The Central Pollution Control Board (CPCB), New Delhi has specified 17 types of industries under the category of highly polluting industries ($N_{17,i}$) and 54 types of industries under red category industries ($N_{54,i}$) separately (Appendix III and IV). Appendix III refers the comprehensive list of industries falling under the category of 17-highly polluting industries and Appendix IV lists industries falling under the category of 54-red category industries as specified by the CPCB. The overall score under this category is evaluated by multiplying the pollution index score due to 3 most critical pollutants present at the ith source with respect to the jth environment component ($S_{c,i,j}$) along with the penalty factor ($\Delta_{i,j}$) and the rating of industrial activities (Q_i) as described in equation (3.2). It can be inferred from Tables 3.1 to 3.3 that the total pollution index score ($S_{i,j}$) at any ith source with respect to the jth environment component may vary from 1 to 35.

Table 3.2: Penalty Score due to occurrence of most critical pollutants ($\Delta_{i,j}$)

S. No.	Pollutant 1	Pollutant 2	Pollutant 3	Penalty Score
1.	B/A	B	B	1.0
2.	B/A	B	C	1.5
3.	B/A	C	C	1.75
4.	C	C	C	2.0

Using equations (3.3a) to (3.3c), the rating score of industrial activities (Q_i) can be determined.

$$\left\{\begin{matrix} If\ N_{17,i} = 0\ to\ 1 \\ OR \\ If\ N_{54,i} = 0\ to\ 9 \end{matrix}\right\} \text{then } Q_i = 1.0 \text{ (Industrial activities are limited)} \quad (3.3a)$$

$$\left\{\begin{array}{c} If\ N_{17,i} = 2\ to\ 10 \\ OR \\ If\ N_{54,i} = 10\ to\ 100 \end{array}\right\} \text{then } Q_i = 2.5 \text{ (Industrial activities are moderate)} \quad (3.3b)$$

$$\left\{\begin{array}{c} If\ N_{17,i} > 10 \\ OR \\ If\ N_{54,i} > 100 \\ OR \\ If\ N_{17,i} > 2\ and\ N_{54,i} > 10 \end{array}\right\} \text{then } Q_i = 5.0 \text{ (Industrial activities are large)} \quad (3.3c)$$

Table 3.3: Rating of industrial activities in a region (Q_i)

S. No.	Group	Description	Score (Q_i)
1.	Limited	The industrial activities will fall under this group if there exists any one industry within 10 km^2 area or fraction as specified below: If $N_{17,i} = 0$ to 1 OR If $N_{54,i} = 0$ to 9	1.0
2.	Moderate	The industrial activities will fall under this group If $2 \le N_{17,i} \le 10$ OR If $10 \le N_{54,i} \le 100$	2.5
3.	Large	The industrial activities will fall under this group If $N_{17,i} > 10$ OR If $N_{54,i} > 100$ OR If $N_{17,i} > 2$ and $N_{54,i} > 10$	5.0

For example if there exists 9 mining industries, 4 thermal power plants, and 40 small scale industries in any ith industrial area, the rating score corresponding to industrial activities (Q_i) will be 5 due to the fact that both industries (i.e. mining industries and thermal power plants) fall under the category of 17-highly polluting industries (N_{17}) in the selected region with total $N_{17,i} = 13$ and hence $Q_i = 5$.

3.2.2.2.2 Evaluation of Pathway Scores

In this step, pollution index for pathway component (P_i) are obtained by taking into consideration of influencing pollutants with respect to each of the selected pathways in an industrial cluster. The pathways associated with possible contamination in a particular industrial cluster should be identified first so that an appropriate pollution index score can be estimated for a given pathway. As described earlier, pathways are treated as the route through which pollutants of concern migrates from the sources to the receptors available in the surroundings. The pathway is impacted by the pollutant source, exposure route, exposure locations and medium (ASTM, 1998). The spatio-temporal distribution of exposure to the pollutants can be analyzed using various models by incorporating spatial characteristics of each location and can be referred elsewhere (Pizzol et al., 2011).

The methodology proposed herein evaluates impact of pollutants through pathways by means of appropriate routes of contamination by identifying clearly each receptor and the possible sources of contamination. Once exposure pathways have been identified for each receptor, spatial relations are evaluated in order to establish the possible impacted receptors and the related pollution sources. The result of this assessment can be presented in tabular form describing each pollution source and the related impacted receptors. It is interesting to note that one particular pollutant source can affect many receptors and one receptor can also be harmed by many of the pollutant sources. A graphical example of such spatial relations is presented in Figure 3.2.

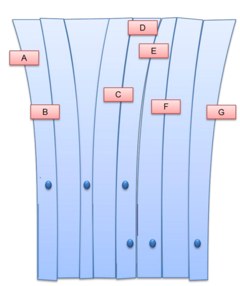

Figure 3.2: Pathways described by contamination plumes connecting sources (assigned by letters) and receptors

The impact score can be derived using interrelationships among pollutants, receptors and sources. If there are proper evidences of impact of pollutants on certain receptors, the impact evaluation on these receptors can be assessed by evaluating exceedance factors corresponding to these pollutants. The exceedance factor is evaluated as the ratio of mean observed concentration of a pollutant measured either annually (or 24-hourly basis) and prescribed standard limit of concentration of corresponding pollutant according to equation (3.4):

$$\text{Exceedance Factor, } E_{c,p,j} = \frac{C_{c,i,j}}{C_s} \tag{3.4}$$

Where $C_{c,i,j}$ = mean observed concentration of criteria pollutant in the ith industrial cluster corresponding to the jth environment component (pathway) and C_s = prescribed standard for concentration of criteria pollutant. The ambient environmental quality pertaining to a specified pathway (viz. air, surface water, ground water) has been classified into four main categories, critical pollution (C) if $E_{c,i,j}$ is more than 1.0; High pollution (H) if $E_{c,i,j}$ is between 0.75 and 1.0; Moderate pollution (M) if the $E_{c,i,j}$ is between 0.5 and 0.75; and Low pollution (L) if $E_{c,i,j}$ is less than 0.5 as described in Table 3.4. It can be inferred from values of above classification, that the industrial clusters falling under first (critical) category is actually violating the prescribed standards. In the second category (H) and third category (M), though prescribed standards are met presently, there is high and moderate possibility that industrial clusters falling under these categories respectively may violate the prescribed standards with varying magnitude in near future if pollution continues to increase. However, the industrial clusters falling under the last category (L) maintain ambient environmental quality standards very well and such areas are to be encouraged to maintain low pollution level by way of adopting pollution prevention and control measures.

The pollution index score with respect to jth pathway can be evaluated using equation (3.5):

$$P_{i,j} = \left[\left(P_{c,i,j} + \Delta_{i,j}\right) + P_{I,i,j} + P_{Eco,i,j}\right] \tag{3.5}$$

Here, $P_{i,j}$ is the total pollution index score with respect to the jth environment component (pathway) at an ith industrial cluster on the basis of information available on presence of ambient pollutant concentration and their impact on people and eco-geological features. The $P_{c,i,j}$ is the pollution index score due to 3 most influencing criteria pollutants occurring in the ith industrial cluster corresponding to the jth environment component (pathway) depending upon their relative observed concentration with the prescribed limit. It can range from 1 (if exceedance factor ($E_{c,p,j}$) is less than 0.5 for group C pollutants and is less than 1.0 for group A and B pollutants) to 8 (if exceedance factor ($E_{c,p,j}$) is more than 1.0 for group C pollutants and is more than 1.5 for group B and is more than 2.0 for group A pollutants) as explained in Table 3.4. $\Delta_{i,j}$ is the penalty factor assigned for ith sampling point of industrial cluster with respect to the jth environment component (pathway) on the basis of occurrence of 3 most influencing parameters which ranges from 1 (if at least 2 out of 3 selected parameters fall under 'high' category and the remaining third one falls under 'low' category) to 2 (if at least 2 out of 3 selected parameters fall under 'critical' category and the remaining third one falls either under 'critical' or 'high' or 'moderate' or 'low' category) as explained in Table 3.5.

$P_{I,i,j}$ is the pollution index score with respect to the jth environment component at ith industrial cluster due to impact of environmental pollutants on people. Evidences are obtained from reliable sources such as reports from print and electronic media, academic research, public interest litigations (PILs), published literature, hospital records, NGOs reporting etc. The scores range from 0 (if no reliable evidence is available) to 5 (if there is soundproof evidence of deaths or critical disease(s) which further lead(s) to deaths due to exposure of environmental pollutants in the region as explained in Table 3.6.

$P_{Eco,i,j}$ is the pollution index score with respect to the jth environment component at ith industrial cluster on the basis of impact of pollutants on eco-geological features. The evidences are obtained from reliable sources such as reports from print and electronic media, academic research, public interest litigations (PILs), published literature, hospital records, NGOs reporting etc. The scores range from 0 (if no reliable evidence is available) to 5 (there is proof of loss of significant damage to ecological features/biodiversity/flora/fauna due to exposure of pollutants in the region) as explained in Table 3.7. The overall score under this category is additive of $P_{c,i,j}$, $P_{I,i,j}$ and $P_{Eco,i,j}$ with the suitable penalty factor ($\Delta_{i,j}$) as described in equation (3.4). It can be inferred from Tables 3.4 to 3.7 that the total pollution index score ($P_{i,j}$) with respect to the jth environment component (pathway) at ith industrial cluster through can vary from 1 to 20.

Table 3.4: Classification of pollutants depending upon their exceedance factor ($P_{c,i,j}$)

Group	Description	Score ($P_{c,i,j}$)
Low pollution (L)	When the exceedance factor, $E_{c,p,j} < 0.5$ for group C pollutants OR $E_{c,p,j} < 1.0$ for group B pollutants OR $E_{c,p,j} < 1.0$ for group A pollutants	1
Moderate pollution (M)	If exceedance factor, $0.5 < E_{c,p,j} < 0.75$ for group C pollutants OR $1.0 < E_{c,p,j} < 1.25$ for group B pollutants OR $1.0 < E_{c,p,j} < 1.5$ for group A pollutants	3
High pollution (H)	If exceedance factor, $0.75 < E_{c,p,j} < 1.0$ for group C pollutants OR $1.25 < E_{c,p,j} < 1.5$ for group B pollutants OR $1.5 < E_{c,p,j} < 2.0$ for group A pollutants	5
Critical pollution (C)	If exceedance factor, $E_{c,p,j} > 1.0$ for group C pollutants OR $E_{c,p,j} > 1.5$ for group B pollutants OR $E_{c,p,j} > 2.0$ for group A pollutants (Appendix V can be referred for standard permissible limit for different pollutants as specified by the CPCB, New Delhi).	8

Table 3.5: Penalty Score ($\Delta_{i,j}$) due to occurrence of 3 most critical pollutants

S. No.	Pollutant 1	Pollutant 2	Pollutant 3	Penalty Score
1.	L	H	H	1.0
2.	M/H	H	H	1.25
3.	L/M	H	C	1.50
4.	H	H	C	1.75
5.	C/H/M/L	C	C	2.0

Table 3.6: Score due to evidence of adverse impact on people ($P_{I,i,j}$)

S. No.	Description	Score ($P_{I,p,j}$)
1.	If there is no reliable evidence of adverse impact on people of the region.	0.0
2.	If there is evidence of symptoms of exposure of pollutants with people in the region.	3.0
3.	If there is evidence of deaths or critical disease(s) which lead(s) to deaths due to exposure of environmental pollutants in the region.	5.0

Table 3.7: Score due to evidence of adverse impact on eco-geological features due to pollutants ($P_{Eco,i,j}$)

S. No.	Description	Score ($P_{Eco,i,j}$)
1.	If there is no reliable evidence of adverse impact on people of the region.	0.0
2.	If there is evidence of symptoms of exposure of pollutants with people in the region.	3.0
3.	If there is proof of loss of significant damage to ecological features/biodiversity/flora/fauna due to exposure of pollutants in the region.	5.0

3.2.2.2.3 Evaluation of Receptors Scores

It has been found that extent of exposure of pollutants does not only vary with the nature of the contamination but also on the natural characteristics of the receptors who are associated with contaminated environment. Thus, receptors' with different characteristics may be exposed to different severity levels of vulnerability (Al-Adamat et al., 2003; Babiker et al., 2005; Zaporozec, 2001). Assessment of vulnerability has been performed in many real life applications dealing with environmental and social aspects including human and ecological aspects of contamination (Aller et al., 1985; deFur et al., 2007; Zabeo et al, 2011), protection of various services related to the environment (Chachadi and Lobo-Ferreira, 2005; Sundaram et al., 2008), study of natural hazards and impact assessment of climate change (Fussel, 2007; Mc Fadden et al., 2007; Pizzol et al., 2011; Voice et al., 2006).

The vulnerability evaluation methodology can be subdivided into four different steps: identification of the potential receptors; selection of the attributes/parameters relevant for the assessment of vulnerability of each receptor; evaluation of normalized values of each of the attributes; integration of the normalized values of attributes in order to estimate the vulnerability of receptors by using proper aggregation function of multi-criteria decision making tools. Identification of receptors is the first step to be undertaken. The aim of the methodology is to prioritize sources of pollution on the basis of their impacts on environment and in particular on people associated within a specified boundary from the industrial pollution source. According to this aim, severity level of impacts of pollutants can be categorized on the basis of number of receptors affected by these pollutants as described in Table 3.8.

Vulnerability assessment of relevant receptors is performed by taking into consideration of three main parameters, (i) number of people likely to be affected within the boundary of 2 km from the source of industrial pollution (ii) severity level of exposure which can be represented by a surrogate number (SNLF) and additional risks associated with sensitive receptors. In the specific context, vulnerability effects due to contamination are mainly related to the exposure level of different pollutants on affected population. It is also based on the risks associated with sensitive receptors as they may suffer the most due to the exposure of pollutants. Thus the pollution index score with respect to receptors can be evaluated using equation (4.3):

$$R_{i,j} = \left[\left(R_{N,2,i,j}\right)\times\left(R_{SNLF,i,j} + \Delta_{SNLF,i,j}\right)\right] + R_{Sen,i,j} \qquad (3.6)$$

where $R_{i,j}$ is the total pollution index score obtained due to impact of ith industrial cluster on receptors with respect to the jth environment component affected within the specified boundary from the industrial pollution source. It also depends on presence of ambient pollutant concentration, level of exposure and additional risks associated with sensitive receptors.

The $R_{N,2,I,j}$ is the pollution index score due to number of people likely to be affected within the boundary of 2 km from the ith source of industrial pollution ($N_{2,i}$) with respect to the jth environment component. It can range from 1 (if affected population ($N_{2,i}$) is less than 5000) to 5 (if affected population ($N_{2,i}$) is greater than 200,000) as explained in Table 3.8. There is high risk of impact of industrial pollutants if more number of people are affected/exposed/vulnerable as evident from Table 3.8. Receptors which are not located within 2km boundary from the industrial pollution source have not been considered as they are less vulnerable. However, they can also be characterized by some low vulnerability score.

Table 3.8: Impact of industrial pollution and score due to affected number of people in a region ($R_{N,2,i,j}$)

S. No.	Group	Description	Score ($R_{N,2,i,j}$)
1.	Low	The impact of industrial activities will fall under this group if number of people likely to be affected within the boundary of 2 km from the source of industrial pollution is less than 5000 i.e. if $N_{2,i} < 5000$.	1.0
2.	Moderate	The impact of industrial activities will fall under this group if number of people likely to be affected within the boundary of 2 km from the source of industrial pollution is between 5000 and 50000 i.e. if $5000 \leq N_{2,i} < 50000$.	1.5
3.	High	The impact of industrial activities will fall under this group if number of people likely to be affected within the boundary of 2 km from the source of industrial pollution is between 50000 and 200000 i.e. if $50000 \leq N_{2,i} < 200000$.	3.0
4.	Very High/ Extreme	The impact of industrial activities will fall under this group if number of people likely to be affected within the boundary of 2 km from the source of industrial pollution is more than i.e. if $N_{2,i} > 200000$.	5.0

The $R_{SNLF,i}$ is the pollution index score evaluated on the basis of a surrogate number representing level of exposure (SNLF). SNLF is calculated using percent violation of ambient pollutant concentration, which can be evaluated using equation (3.7).

$$SNLF_{i,j} = \left[\left(\frac{No.of\ samples\ exceeded}{Total\ no.of\ samples}\right) \times E_{c,i,j}\right] \quad (3.7)$$

The values of $R_{SNLF,i,j}$ can vary from 1 (if level of exposure is low) to 3 (if level of exposure is critical) as explained in Table 3.9.

Table 3.9: Index score due to level of exposure represented by SNLF ($R_{SNLF,i,j}$)

S. No.	Group	Description	Score ($R_{SNLF,i,j}$)
1.	Low (L)	If $SNLF = 0$	1.0
2.	Moderate (M)	If $SNLF < 0.25$	1.5
3.	High (H)	If $0.25 < SNLF < 0.50$	2.0
4.	Critical (C)	If $SNLF > 0.50$	3.0

$\Delta_{SNLF,i,j}$ is the penalty factor assigned with respect to the ith industrial cluster on the basis of occurrence of 3 most influencing parameters which ranges from 1 (if at least 2 out of 3 selected parameters fall under 'high' category and the remaining third one falls under 'moderate' category) to 2 (if at least 2 out of 3 selected parameters fall under 'critical' category and the remaining third one falls either under 'critical' or 'high' or 'moderate' category) as explained in Table 3.10.

Table 3.10: Penalty Score ($\Delta_{SNLF,i,j}$) due to occurrence of 3 most critical pollutants

S. No.	Pollutant 1	Pollutant 2	Pollutant 3	Penalty Score
1.	L	H	H	1.0
2.	M/H	H	H	1.25
3.	L/M	H	C	1.5
3.	M/H	H	C	1.75
4.	C/H/M/L	C	C	2.0

The $R_{Sen,i,j}$ is the pollution index score evaluated on the basis of additional risk to the sensitive receptors. The values of $R_{SNLF,i,j}$ can vary from 0 (if there is no additional risk) to 5 (if there is additional risk) as explained in Table 3.11. It can be inferred from Tables 3.8 to 3.11 that the total pollution index score ($R_{i,j}$) with respect to receptors at ith industrial cluster corresponding to the jth environment component can vary from 1 to 30.

Table 3.11: Index score due to additional risk to sensitive receptors ($R_{Sen,i,j}$)

S. No.	Description	Score ($R_{Sen,i,j}$)
1.	If there is no additional risk	0.0
2.	If there is additional risk i.e. if there exists 500 sensitive people or a sensitive archaeological or historical or religious or national parks or sanctuary or ecological habitat fall within the boundary of 2 km from the source of industrial pollution.	5.0

3.2.2.2.4 Evaluation of Additional High Risk Element Scores

The additional pollution index score (R_{Add}) is to be assigned for an industrial cluster due to high risk on receptors associated with insufficient measures of pollution control corresponding to large-scale, medium-scale or small-scale industries. It also includes consideration of unorganized sector within the specified boundary from the industrial pollution source. The additional pollution index score (R_{Add}) is cumulative of Air Pollution Control Devises (APCDs), CETPs, ETPs and disorganized way of wastes disposal. The scoring procedures should be adopted as described below but assigned score should not exceed 20 under this category.

- If all the industries falling in an industrial cluster have adequate pollution control facilities for operation and maintenance (O&M) and fulfill the design criteria and the common facilities such as Common Effluent Treatment Plants (CETP)/ Common Hazardous Waste Disposal Facility (CHWDF)/ Final Effluent Treatment Plants (FETP) satisfy the prescribed standard of adequate capacity or operation/ maintenance and have state of the art technology, then additional pollution index score (R_{Add})= 0.
- If all the large industries falling in an industrial cluster have adequate pollution control facilities for operation and maintenance (O&M) and fulfill the design criteria but small and medium-scale industries do not have adequate facilities. The common facilities such as Common Effluent Treatment Plants (CETP)/ Common Hazardous Waste Disposal Facility (CHWDF)/ Final Effluent Treatment Plants (FETP) also satisfy the prescribed standard of adequate capacity or operation/ maintenance and are have state of the art technology, then additional pollution index score (R_{Add})= 2.5.
- If all the industries falling in an industrial cluster have adequate pollution control facilities for operation and maintenance (O&M) and fulfill the design criteria but the common facilities such as Common Effluent Treatment Plants (CETP)/ Common Hazardous Waste Disposal Facility (CHWDF)/ Final Effluent Treatment Plants (FETP) do not satisfy the prescribed standard of adequate capacity or operation/ maintenance and have inadequate capacity, then additional pollution index score (R_{Add})= 5.
- If all the large industries falling in an industrial cluster have adequate pollution control facilities for operation and maintenance (O&M) and fulfill the design criteria but small and medium-scale industries do not have adequate facilities. The common facilities such as Common Effluent Treatment Plants (CETP)/ Common Hazardous Waste Disposal Facility (CHWDF)/ Final Effluent Treatment Plants (FETP) also do

not satisfy the prescribed standard of adequate capacity or operation/ maintenance and have inadequate capacity, then additional pollution index score (R_{Add})= 10.

- If there is inadequate facilities both with respect to individual as well as common facilities, then additional pollution index score (R_{Add}) = 15 which is the highest penalty.

The scores are assigned with respect to the ith industrial cluster on the basis of occurrence of inadequacy of type of industries which ranges from 0 (if all facilities pertaining to large scale, small scale and common facilities are adequate category) to 20 (if all are inadequate) as explained in Table 3.12.

Table 3.12: Score for Additional High Risk Element (R_{Add})

S. No.	Large-Scale Industries	Small/ Medium -Scale Industries	Common Facilities for Pollution Control	Score (R_{Add})
1.	Adequate	Adequate	Adequate	0
2.	Adequate	Inadequate	Adequate	2.5
3.	Adequate	Adequate	Inadequate	5
4.	Adequate	Inadequate	Inadequate	10
5.	Inadequate	Inadequate	Inadequate	15

The treatment facilities are treated as inadequate if more than or equal to 10% units of industries are lacking with respect to proper design and/or operation and maintenance in small and medium scale industries OR if more than or equal to 2% units of industries are lacking with respect to proper design and/or operation and maintenance in large-scale industries or common facilities. The status reports of previous two years should be taken into consideration to decide the score for adequacy of facilities within the industries.

The overall pollution index score at any ith industrial cluster with respect to jth component of environment can be evaluated using equation (3.8):

$$IEPI_{i,j} = S_{i,j} + P_{i,j} + R_{i,j} + R_{Add,i,j} \tag{3.8}$$

In order to compare and integrate an overall pollution index score at any ith industrial cluster with respect to jth component of environment, various parameters have been considered using different classification tables as explained above which were derived on the basis of opinion of the experts. These classification tables have been produced on the basis of evidences (i.e. knowledge about the processes under analysis and opinion of the experts). However, the proposed methodology is a flexible tool which can be adapted to specific local contexts by selecting new appropriate parameters or modifying the proposed parameters classes and scores on the basis of expert knowledge on the local conditions. Classification tables are used to convert parameters' specific values into a given scale before integrating them into a single score pollution index score.

3.3 Summary

This chapter aims to develop a methodology to assess status of pollution in different industrial clusters by evaluating pollution index score for each industrial cluster. An industrial cluster can be assigned a rank on the basis of sources and magnitude of pollution for which necessary action plans can be formulated in order to achieve the good quality status of a given component of environment (air, surface water, groundwater etc.) so that prescribed standard of regulatory authorities can be satisfied. This goal is obtained by taking into account not only the levels of concentration of relevant substances in an industrial cluster but also by evaluating the appropriate scores for sources, pathway and receptors located in the specified industrial clusters.

The presented methodology is a flexible tool which can be adjusted to deal with different types of local conditions by modifying the proposed parameters and their normalization functions. This becomes useful for country like India where no proper methodology has been developed to assess pollution level in various industrial clusters or in a situations where data pertaining to various components of environment are lacking. The proposed methodology allows to take into consideration, the multiplicity of sources of pollution along with receptors affected within the specified area, to assess pollution index score of any industrial cluster. The analysis not only provides a ranking of these industrial clusters but also highlights sources of pollution that lead poor quality status of different components of environment. In the next chapter, pollution index scores have been evaluated for selected industrial clusters to illustrate the applicability of the methodology proposed herein.

Chapter 4

APPLICATION OF EVALUATION MODEL FOR SOME SELECTED INDUSTRIAL CLUSTERS

4.1 Introduction

In this chapter, pollution index score has been evaluated for different selected industrial clusters using the methodology presented in Chapter 3. Air, surface water and groundwater have been considered as the 3 different components of environment to evaluate pollution index score. Eleven attributes were considered to assess the air quality environment, thirty-two attributes for surface water environment and thirty-two attributes for groundwater environment. Finally, the methodology developed herein is applied for 15 industrial clusters to rank them on the basis of their pollution index scores. These industrial clusters have been categorized into 5 different types of industrial clusters. However, to demonstrate the complete methodology, Agra industrial cluster has been taken first as explained in section 4.1.

4.2 Agra Industrial Cluster in Uttar Pradesh

Agra city is among the most populous cities in Uttar Pradesh with the population of about 1,686,993 and the 19th most populous city in India as per 2011 census. It is situated on the banks of the river Yamuna. It is an important city which has been attracting a large number of tourists due to its many superb Mughal-era monuments and archeologically important buildings. The three most notable monuments which are also in the list of UNESCO world heritage sites, are the Taj Mahal, Fatehpur Sikri and Agra Fort. Agra is connected very well Delhi (240 km away) and Jaipur through National Highways. It is integral part of the Uttar Pradesh Heritage Arc, tourist circuit of UP state, along with Lucknow, the capital of Uttar Pradesh and Varanasi, the ancient holy city.

It has been reported that pollutant levels in the region are increasing day by day. Increasing vehicular pollution and smog are threatening the structures of the historic monuments, besides, adversely affecting the health of millions of people. Evidently, the pristine white marble of the Taj Mahal has been yellowing over the years, due to suspended particulate matter laden with the carbon and other deposits. A study in the year 2015 revealed that pollution levels in

Agra are even higher than those in Delhi and other neighboring areas. Keeping in view of these points, a case study of Agra has been taken into consideration.

4.2.1 Evaluation of Pollution Index Score due to air quality parameters

Air quality parameters have been considered to assess pollution index depending on their relative degrees of importance. The selection of these parameters to compute AQI depends on various factors such as importance and ratings of air quality parameters, availability of data and purpose of the index.

In this study, air quality parameters were measured at 2-sampling stations in Agra industrial cluster as shown in Table 4.1. Initially 12 air quality parameters have been considered to evaluate a reliable pollution index score. As evident from Table 4.1, these parameters are classified into three groups, i.e. A, B and C as described earlier in Table 3.1 and Appendices I and II. Many of these air quality parameters are found below detectable limit or non-existent. The pollutants falling under group C category are considered to be more hazardous (critical) than those fall under group B category and group A category. Therefore, pollutants falling under group C category are given top priority of consideration in the analysis. The normalized values of average of measured concentration of air quality parameters (exceedance factor) at 2-sampling stations in Agra shows that Benzopyrine (ng/m^3), Lead (Pb) (ng/m^3), Arsenic (As) (ng/m^3)-all 3 from group C category-can be considered as the critical parameters. These parameters have their normalized concentration value (exceedance factor) as 5.28, 3.24 and 2.95 respectively. The parameters belonging to group B and group A categories need not be considered for further analysis as they have less toxicity and carcinogenicity.

The overall pollution index score corresponding to air in Agra has been evaluated by evaluating pollution index score at the ith source on the basis of information available on presence of toxins and type of industrial activities ($S_{i,j}$), pollution index score with respect to the jth environment component (pathway) on the basis of information available on presence of ambient pollutant concentration ($P_{i,j}$), pollution index score obtained due to impact of ith industrial cluster on receptors with respect to the jth environment component affected within the specified boundary from the industrial pollution source ($R_{i,j}$) and the additional pollution index score (R_{Add}) which has been assigned for an industrial cluster due to high risk on receptors associated with insufficient measures of pollution control corresponding to large scale, medium or small scale industries. It also includes the consideration of unorganized sector within the specified boundary from the industrial pollution source. The evaluation of pollution index score corresponding to air quality in Agra has been evaluated using equation (3.8) and given in Table 4.2.

Table 4.1: Observed values of air quality parameters collected at 2-sampling stations in Agra, Uttar Pradesh

S. No.	Air Quality Parameter	Category of Pollutant	Nunhani, Agra	Nunhani, Agra	Average	Desirable Limit	Exceedance Factor (EF)
1	Ozone (O_3) (μg/m^3)	C	< 5	< 5	-	100	-
2	Lead (Pb) (ng/m^3)	C	2416.4	817.6	1617	500	**3.234**
3	Benzene (μg/m^3)	C	-	-	0	5	0.000
4	Benzopyrine (ng/m^3)	C	7.25	3.31	5.28	1	**5.28**
5	Arsenic (As) (ng/m^3)	C	17.1	18.4	17.75	6	**2.958**
6	PM_{10} (μg/m^3)	B	352	217	284.5	60	4.742
7	Nickel (Ni) (ng/m^3)	B	2.9	6.3	4.6	20	0.23
8	Carbon Monoxide (CO)(mg/m^3)	B	< 1	< 1	-	2	-
9	SO_2 (μg/m^3)	A	< 18	< 18	-	50	-
10	NO_2 (μg/m^3)	A	< 13	< 13	-	40	-
11	Ammonia (μg/m^3)	A	< 9	10.4	-	100	-

Table 4.2: Evaluation of pollution index score corresponding to air quality in Agra, U.P.

Parameters	Score	Remarks
$S_{c,i,j}$	5	The highest score among all 3 critical pollutants corresponding to source as explained in Table 3.1.
$\Delta_{i,j,s}$	2	The penalty score corresponding to criticality level of 3 selected pollutants corresponding to source as explained in Table 3.2.
Q_i	2.5	The rating of industrial activities at the ith source (Q_i) is obtained on the basis of number of both highly polluting industries and red category industries available within 10 km^2 of catchment area. There are 33 medium sized industries in Agra as explained in Table 3.3.
$S_{i,j}$	17.5	$S_{i,j} = Q_i\left(S_{c,i,j} + \Delta_{i,j}\right)$ from equation (3.2)
$E_{c,p}$	5.28	The highest score of exceedance factor among all 3 critical pollutants i.e. $E_{c,p} = Max\{E_{c,i,j}\}$ $i.e. E_{c,p} = Max\{3.24,\ 5.28,\ 2.95\}$ as explained by equation (3.4).
$P_{c,i,j}$	8.0	From Table 3.4, the highest score among all 3 critical pollutants corresponding to pathway. Here exceedance factor is more than 1.0 for group C pollutants
$\Delta_{i,j,p}$	2.0	From Table 3.5, the penalty score corresponding to criticality level of 3 selected pollutants corresponding to pathway. The exceedance factors corresponding to 3 parameters represent critical (Benzopyrine), critical (Lead) and critical (Arsenic).
$P_{I,i,j}$	3.0	There is reliable evidence of symptoms of exposure on People due to air pollution as explained in Table 3.6.
$P_{Eco,i,j}$	3.0	There is reliable evidence which demonstrates that there is risk to the Taj Mahal due to air pollution as explained in Table 3.7.
$P_{i,j}$	16.0	$P_{i,j} = \left[\left(P_{c,i,j} + \Delta_{i,j}\right) + P_{I,i,j} + P_{Eco,i,j}\right]$ from equation (3.5)
$R_{N2,i,j}$	5.0	As there are 500,000 people exposed from the industrial activities, the score is obtained on the basis of number of people (receptors) affected within the boundary of 2 km from the industrial cluster due to air pollution as explained in Table 3.8.
$R_{SNLF,i,j}$	3.0	From Table 3.9, The highest score among all 3 critical pollutants on the basis of a surrogate number representing level of exposure (SNLF) to the receptors in an industrial cluster with respect to air such that $R_{SNLF,i,j} = Max\{R_{SNLF,c,i,j}\}$ i.e. $Max\{3, 3, 3\}$ as explained in Table 3.9.

Parameters	Score	Remarks
$\Delta_{SNLF,i,j,r}$	2.0	From Table 3.10, the penalty score corresponding to criticality level of 3 selected pollutants corresponding to receptors. Here the SNLF corresponding to 3 parameters represent critical (Benzopyrine), critical (Lead) and critical (Arsenic) as explained in Table 3.10.
$R_{sen,i,j}$	5.0	There is a risk to the sensitive receptors. A large number of tourists are visiting the place who may get exposure of contaminated air as explained in Table 3.11.
$R_{i,j}$	30.0	$R_{i,j} = [(R_{N,2,i,j})\times(R_{SNLF,i,j} + \Delta_{SNLF,i,j})] + R_{Sen,i,j}$ from equation (3.6)
$R_{Add,i,j}$	5.0	Though most of the industries falling in this cluster have adequate pollution control facilities for operation and maintenance (O&M) and fulfill the design criteria, the common facilities such as CETP/FETP/CHWDF do not satisfy the prescribed standard of adequate capacity or operation/ maintenance of air quality management. Thus common facilities for pollution control are inadequate as explained in Table 3.12.
Air($IEPI_{i,j}$)	68.5	$IEPI_{i,j} = S_{i,j} + P_{i,j} + R_{i,j} + R_{Add,i,j}$ from equation (3.8)

4.2.2 Evaluation of Pollution Index Score due to surface water quality parameters

Surface water quality parameters have been considered to assess pollution index depending on their relative degrees of importance. All-important surface water quality parameters were selected to compute surface water quality index (SWQI) depends on various factors such as importance and ratings of surface water quality parameters, availability of data and purpose of the index.

In this study, water samples were collected from two locations in an industrial cluster. Initially 32 water quality parameters have been tested to evaluate a reliable pollution index score as shown Table 4.3. The observed values of different surface water quality parameters collected from the surface water at 2-sampling stations in Agra are shown in Table 4.3. As evident from Table 4.4, these parameters are classified into three groups, i.e. A, B and C as described earlier in Table 3.1 and Appendices I and II. Many of these surface water quality parameters are found below detectable limit or non-existent.

Table 4.3: Observed values of surface water quality parameters collected at 2-sampling stations in Agra, Uttar Pradesh

S. No.	Water Quality Parameter	Category of Pollutant	Near Mehtab Bag Ghat, Down Stream Agra	Near Kailash Ghat, UP stream, Agra	Average	Desirable Limit	Exceedance Factor (EF)
1	Oil & Grease (mg/L)	C	< 2	< 2	-	10	-
2	Arsenic (As) (mg/L)	C	0.01	0.01	0.01	0.1	0.100
3	Mercury (Hg) (mg/L)	C	< 0.001	< 0.001	-	0.001	-
4	Lead (Pb) (mg/L)	C	< 0.05	< 0.05	-	0.1	-
5	Cadmium (Cd) (mg/L)	C	< 0.01	< 0.01	-	2	-
6	Chromium VI (mg/L)	C	-	-	-	0.1	-
7	Cyanide (mg/L)	C	< 0.01	< 0.01	-	0.2	-
8	Phenolic Compounds (mg/L)	C	< 0.001	< 0.001	-	1	-
9	Residual Chlorine (mg/L)	B	< 0.2	0.49	-	1	-
10	COD (mg/L)	B	170	25	97.5	12.5	7.800
11	BOD_5 (mg/L)	B	68	10	39	5	7.800
12	Selenium (Se) (mg/L)	B	0.03	0.02	0.025	0.05	0.500
13	Nickel (Ni) (mg/L)	B	< 0.02	< 0.02	-	3	-
14	Fluoride (mg/L)	B	0.5	0.7	0.6	0.6	1.000
15	Sulphide (mg/L)	B	< 0.05	< 0.05	-	2	-
16	Vanadium (V) (mg/L)	B	< 0.1	< 0.1	-	0.2	-
17	Boron (B) (mg/L)	B	< 1	< 1	-		-
18	Suspended Solid (mg/L)	A	35	19	27	100	0.270
19	Ammonical Nitrogen (mg/L)	A	< 2	< 2	-	50	-
20	Kjeldhal Nitrogen (mg/L)	A	< 2	< 2	-	100	-
21	Free Ammonia (mg/L)	A	< 2	< 2	-	5	-
22	Copper (Cu) (mg/L)	A	< 0.05	< 0.05	-	3	-

S. No.	Water Quality Parameter	Category of Pollutant	Near Mehtab Bag Ghat, Down Stream Agra	Near Kailash Ghat, UP stream, Agra	Average	Desirable Limit	Exceedance Factor (EF)
23	Zinc (Zn) (mg/L)	A	< 0.1	< 0.1	-	5	-
24	Manganese (Mn) (mg/L)	A	0.27	0.5	0.385	2	0.193
25	Iron (Fe) (mg/L)	A	0.51	0.54	0.525	3	0.175
26	Dissolved Phosphate (mg/L)	A	10.2	7.9	9.05	5	1.810
27	Sodium Adsorption Ratio (SAR)	A	4.84	4.27	4.555		
28	Conductivity (μmhos/cm, 25ºC)	A	1501	1400	1450.5	2250	0.645
29	Total Coliform Organism (MPN/100ml)	B			0	200	0.000
30	pH	A	7.9	8.1	8	6.5 to 9.0	-
31	Dissolved Oxygen (mg/L)	A	4.6	5.6	5.1	80 to 100%	-
32	Nitrate (as Nitrogen) (mg/L)	A	0.95	1.3	1.125	10	0.113

The pollutants falling under group C category are considered to be more hazardous (critical) than those fall under group B category and group A category. Therefore, pollutants falling under group C category are given top priority of consideration in the analysis. The pollutants falling under group C category are considered to be more hazardous (critical) than those fall under group B category and group A category. Therefore, pollutants falling under group C category are given top priority of consideration in the analysis. Since Arsenic (As) is only parameter which is present from group 'C' category at this site, it has been considered as one of the critical pollutants. The remaining two critical pollutants can be selected from group B category on the basis of higher values of normalized concentrations (exceedance factor). Thus two other critical parameters, BOD_5 and Fluoride (F^-), are considered from group B pollutants which have their normalized concentration value (exceedance factor) as 7.8 and 1.0

respectively. The overall pollution index score corresponding to surface water in Agra has been evaluated by evaluating pollution index score at the ith source on the basis of information available on presence of toxins and type of industrial activities ($S_{i,j}$), pollution index score with respect to the jth environment component (pathway) on the basis of information available on presence of ambient pollutant concentration ($P_{i,j}$), pollution index score obtained due to impact of ith industrial cluster on receptors with respect to the jth environment component affected within the specified boundary from the industrial pollution source ($R_{i,j}$) and the additional pollution index score (R_{Add}) which has been assigned for an industrial cluster due to high risk on receptors associated with insufficient measures of pollution control corresponding to large scale, medium or small scale industries. It also includes the consideration of unorganized sector within the specified boundary from the industrial pollution source. The evaluation of pollution index score corresponding to surface water quality in Agra has been evaluated using equation (3.8) and given in Table 4.4.

4.2.3 Evaluation of Pollution Index Score due to groundwater quality parameters

Ground water quality parameters have been considered to assess pollution index depending on their relative degrees of importance. All-important surface water quality parameters were selected to compute surface water quality index (GWQI) depends on various factors such as importance and ratings of ground water quality parameters, availability of data and purpose of the index.

In this study, ground water samples were collected from two locations falling within the specified industrial cluster. Initially 32 water quality parameters have been tested to evaluate a reliable pollution index score as shown Table 4.5. The observed values of different surface water quality parameters collected from the ground water at 2-sampling stations in Agra are shown in Table 4.5. As evident from Table 4.5, these parameters are classified into three groups, i.e. A, B and C as described earlier in Table 3.1 and Appendices I and II. Many of these groundwater quality parameters are found below detectable limit or non-existent. By adopting the similar procedure as explained in earlier section, Arsenic (As) from group 'C' category has been considered as one of the critical pollutants at this site. The remaining two critical pollutants can be selected from group B category on the basis of higher values of normalized concentrations (exceedance factor). Thus two other critical parameters, BOD_5 and Fluoride (F), are considered from group B pollutants which have their normalized concentration value (exceedance factor) as 9.0 and 1.25 respectively.

Table 4.4: Evaluation of pollution index score corresponding to surface water quality in Agra, Uttar Pradesh

Parameters	Score	Remarks
$S_{c,i,j}$	5	The highest score among all 3 critical pollutants corresponding to source
$\Delta_{i,j,s}$	1.5	The penalty score corresponding to criticality level of 3 selected pollutants corresponding to source as explained in Table 3.2.
Q_i	2.5	The rating of industrial activities at the ith source (Q_i) is obtained on the basis of number of both highly polluting industries and red category industries available within 10 km^2 of catchment area. There are 33 medium sized industries in Agra as explained in Table 3.3.
$S_{i,j}$	16.25	$S_{i,j} = Q_i(S_{c,i,j} + \Delta_{i,j})$ from equation (3.2)
$E_{c,p}$	7.8	The highest score of exceedance factor among all 3 critical pollutants i.e. $E_{c,p} = Max\{E_{c,i,j}\}\ i.e. E_{c,p} = Max\{0.1,\ 7.8, 1.25\}$ as explained in by equation (3.4).
$P_{c,i,j}$	8.0	From Table 3.4, the highest score among all 3 critical pollutants corresponding to pathway. Here exceedance factor is more than 1.5
$\Delta_{i,j,p}$	1.5	From Table 3.4, the penalty score corresponding to criticality level of 3 selected pollutants corresponding to pathway. Here the exceedance factors corresponding to 3 parameters represent critical (BOD), moderate (Fluoride) and low (Arsenic)
$P_{I,i,j}$	0.0	No reliable evidence of exposure on People due to surface water as explained in Table 3.6.
$P_{Eco,i,j}$	3.0	There is reliable evidence of exposure of risk to sensitive receptors and Eco-geological features due to surface water as explained in Table 3.7.
$P_{i,j}$	12.5	$P_{i,j} = [(P_{c,i,j} + \Delta_{i,j}) + P_{I,i,j} + P_{Eco,i,j}]$ from equation (3.5)
$R_{N2,i,j}$	5.0	As there are 500,000 people exposed from the industrial activities, the score is obtained due to number of people (receptors) potentially affected within 2 km boundary from industrial cluster with respect to surface water as explained in Table 3.8.

Parameters	Score	Remarks
$R_{SNLF,i,j}$	3.0	From Table 3.9, The highest score among all 3 critical pollutants on the basis of a surrogate number representing level of exposure (SNLF) to the receptors in an industrial cluster with respect to surface water such that $R_{SNLF,i,j} = Max\{R_{SNLF,c,i,j}\}$ i.e. $Max\{1.0,\ 3.0, 3.0\}$ as explained in Table 3.9.
$\Delta_{SNLF,i,j,r}$	2.0	From Table 3.10, the penalty score corresponding to criticality level of 3 selected pollutants corresponding to receptors. Here the SNLF corresponding to 3 parameters represent critical (BOD_5), critical (Fluoride) and low (Arsenic) as explained in Table 3.10
$R_{sen,i,j}$	5.0	There is a risk to the sensitive receptors. A large number of tourists are visiting the place who may get exposure of contaminated surface water as explained in Table 3.11.
$R_{i,j}$	30	$R_{i,j} = [(R_{N,2,i,j})\times(R_{SNLF,i,j} + \Delta_{SNLF,i,j})] + R_{Sen,i,j}$ from equation (3.6)
$R_{Add,i,j}$	5	Though most of the industries falling in this cluster have adequate pollution control facilities for operation and maintenance (O&M) and fulfill the design criteria, the common facilities such as Common Effluent Treatment Plants (CETP)/Common Hazardous Waste Disposal Facility (CHWDF)/ Final Effluent Treatment Plants (FETP) do not satisfy the prescribed standard of adequate capacity or operation/ maintenance of surface water quality management. Thus common facilities for pollution control are inadequate as explained in Table 3.12.
Surface water ($IEPI_{i,j}$)	63.75	$IEPI_{i,j} = S_{i,j} + P_{i,j} + R_{i,j} + R_{Add,i,j}$ from equation (3.8)

The overall pollution index score corresponding to groundwater in Agra has been evaluated by evaluating pollution index score at the ith source on the basis of information available on presence of toxins and type of industrial activities ($S_{i,j}$), pollution index score with respect to the jth environment component (pathway) on the basis of information available on presence of ambient pollutant concentration ($P_{i,j}$), pollution index score obtained due to impact of ith industrial cluster on receptors with respect to the jth environment component affected within the specified boundary from the industrial pollution source ($R_{i,j}$) and the additional pollution index score (R_{Add}) which has been assigned for an industrial cluster due to high risk on receptors associated with insufficient measures of pollution control corresponding to large scale, medium or small scale industries. The evaluation of pollution index score corresponding to groundwater quality in Agra has been evaluated using equation (3.8) and given in Table 4.5.

Table 4.5: Observed values of groundwater quality parameters collected at 2-sampling stations in Agra, Uttar Pradesh

S. No.	Water Quality Parameter	Category of Pollutant	Near Agrawal Sc. Glass, Nunhai IA, Agra	HP, Near Nunhai Tiraha, Agra	Average	Desirable Limit	Exceedance Factor (EF)
1	Oil & Grease (mg/L)	C	-	-	-	10	-
2	Arsenic (As) (mg/L)	C	0.01	0.01	0.01	0.1	**0.100**
3	Mercury (Hg) (mg/L)	C	-	-	-	0.001	-
4	Lead (Pb) (mg/L)	C	-	-	-	0.1	-
5	Cadmium (Cd) (mg/L)	C	-	-	-	2	-
6	Chromium VI (mg/L)	C	-	-	-	0.1	-
7	Cyanide (mg/L)	C	-	-	-	0.2	-
8	Phenolic Compounds (mg/L)	C	-	-	-	1	-
9	Residual Chlorine (mg/L)	B	1.1	0.2	0.65	1	0.65
10	COD (mg/L)	B	35	190	112.5	12.5	9.000
11	BOD (mg/L)	B	14	76	45	5	**9.000**
12	Selenium (Se) (mg/L)	B	0.04	0.05	0.045	0.05	0.900
13	Nickel (Ni) (mg/L)	B	-	-	-	3	-
14	Fluoride (mg/L)	B	0.6	0.9	0.75	0.6	**1.250**
15	Sulphide (mg/L)	B	-	-	-	2	-
16	Vanadium (V) (mg/L)	B	-	-	-	0.2	-
17	Boron (B) (mg/L)	B	-	-	-		-
18	Suspended Solid (mg/L)	A	7	47	27	100	0.270
19	Ammonical Nitrogen (mg/L)	A	-	-	-	50	-

S. No.	Water Quality Parameter	Category of Pollutant	Near Agrawal Sc. Glass, Nunhai IA, Agra	HP, Near Nunhai Tiraha, Agra	Average	Desirable Limit	Exceedance Factor (EF)
20	Kjeldhal Nitrogen (mg/L)	A	-	-	-	100	-
21	Free Ammonia (mg/L)	A	-	-	-	5	-
22	Copper (Cu) (mg/L)	A	< 0.05	0.15	0.10	3	0.033
23	Zinc (Zn) (mg/L)	A	0.12	0.61	0.365	5	0.073
24	Manganese (Mn) (mg/L)	A	0.12	0.08	0.1	2	0.050
25	Iron (Fe) (mg/L)	A	0.46	5.68	3.07	3	1.023
26	Dissolved Phosphate (mg/L)	A	3.8	2	2.9	5	0.58
27	Souium Adsorption Ratio (SAR)	A	4.78	10.28	7.53		
28	Conductivity (µmhos/cm, 25ºC)	A	1730	5610	3670	2250	1.631
29	Total Coliform Organism (MPN/100ml)	B	-	-	-	200	0.000
30	pH	A	7.5	7.6	7.55	6.5 to 9.0	-
31	Dissolved Oxygen (mg/L)	A	6.2	4.7	5.45	80 to 100%	-
32	Nitrate (as Nitrogen) (mg/L)	A	6.2	22	14.1	10	1.410

Table 4.6: Evaluation of pollution index score corresponding to groundwater quality in Agra, Uttar Pradesh

Parameters	Score	Remarks
$S_{c,i,j}$	5	The highest score among all 3 critical pollutants corresponding to source
$\Delta_{i,j,s}$	1.5	The penalty score corresponding to criticality level of 3 selected pollutants corresponding to source as explained in Table 3.2.
Q_i	2.5	The rating of industrial activities at the ith source (Q_i) is obtained on the basis of number of both highly polluting industries and red category industries available within 10 km^2 of catchment area. There are 33 medium sized industries in Agra as explained in Table 3.3.
$S_{i,j}$	16.25	$S_{i,j} = Q_i(S_{c,i,j} + \Delta_{i,j})$ from equation (3.2)
$E_{c,p}$	9.0	The highest score of exceedance factor among all 3 critical pollutants i.e. $E_{c,p} = Max\{E_{c,i,j}\}$ $i.e. E_{c,p} = Max\{0.1,\ 9.0, 1.25\}$ as explained in by equation (3.4).
$P_{c,i,j}$	8.0	From Table 3.4, the highest score among all 3 critical pollutants corresponding to pathway. Here exceedance factor is more than 1.5
$\Delta_{i,j,p}$	1.5	From Table 3.5, the penalty score corresponding to criticality level of 3 selected pollutants corresponding to pathway. The exceedance factors corresponding to 3 parameters represent critical (BOD), high (Fluoride) and low (Arsenic).
$P_{I,i,j}$	0.0	No reliable evidence of exposure on People due to groundwater as explained in Table 3.6.
$P_{Eco,i,j}$	0.0	No reliable evidence of exposure on Eco-geological features due to groundwater as explained in Table 3.7.
$P_{i,j}$	9.5	$P_{i,j} = [(P_{c,i,j} + \Delta_{i,j}) + P_{I,i,j} + P_{Eco,i,j}]$ from equation (3.5)
$R_{N2,i,j}$	5.0	As there are 500,000 people exposed from the industrial activities, the score is obtained due to number of people (receptors) potentially affected within 2 km boundary from industrial cluster with respect to groundwater as explained in Table 3.8.
$R_{SNLF,i,j}$	3.0	From Table 3.9, The highest score among all 3 critical pollutants on the basis of a surrogate number representing level of exposure (SNLF) to the receptors in an industrial cluster with respect to groundwater such that $R_{SNLF,i,j} = Max\{R_{SNLF,c,i,j}\}$ i.e. $Max\{1.0,\ 3.0, 3.0\}$ as explained in Table 3.9.
$\Delta_{SNLF,i,j,r}$	2.0	From Table 3.10, the penalty score corresponding to criticality level of 3 selected pollutants corresponding to receptors. Here the SNLF corresponding to 3 parameters represent critical (BOD), critical (Fluoride) and low (Arsenic) as explained in Table 3.10

Parameters	Score	Remarks
$R_{sen,i,j}$	5.0	There is a risk to the sensitive receptors. A large number of tourists are visiting the place who may get exposure of contaminated groundwater as explained in Table 3.11.
$R_{i,j}$	30	$R_{i,j} = [(R_{N,2,i,j})\times(R_{SNLF,i,j} + \Delta_{SNLF,i,j})] + R_{Sen,i,j}$ from equation (3.6)
$R_{Add,i,j}$	5.0	Though most of the industries falling in this cluster have adequate pollution control facilities for operation and maintenance (O&M) and fulfill the design criteria, the common facilities such as CETP/FETP/CHWDF do not satisfy the prescribed standard of adequate capacity or operation/ maintenance of air quality management. Thus common facilities for pollution control are inadequate as explained in Table 3.12.
$IEPI_{i,j}$	60.75	$IEPI_{i,j} = S_{i,j} + P_{i,j} + R_{i,j} + R_{Add,i,j}$ from equation (3.8)

After calculating sub-indices score corresponding to each media, the aggregated IEPI Score can be calculated as is calculated using (4.1):

$$IEPI_i = \text{Max}\left(IEPI_{i,j}\right) + \left[\left\{100 - \text{Max}\left(IEPI_{i,j}\right)\right\}\times\frac{I_2}{100}\times\frac{I_3}{100}\right] \quad (4.1)$$

Where, $\text{Max}\left(IEPI_{i,j}\right)$ is the maximum sub-index and I_2 and I_3 are sub-indices of remaining other media.

The overall pollution index score of Agra industrial cluster at any ith industrial cluster with respect to jth component of environment has been evaluated which is summarized in Table 4.7.

Table 4.7: Evaluation of pollution index score in Agra, Uttar Pradesh

Media	$S_{i,j}$	$P_{i,j}$	$R_{i,j}$	R_{Add}	$IEPI_{i,j}$	$IEPI_i$
Air	17.50	16.00	30.00	5.00	68.50	80.70
Surface Water	16.25	12.50	30.00	5.00	63.75	
Ground water	16.25	9.50	30.00	5.00	60.75	

The overall pollution index score of Agra industrial cluster has been evaluated. Table 4.7 shows that pollution index score corresponding to air quality is higher than that of surface water and groundwater. Air is polluted in this industrial cluster due to the fact that there exist all 3 substances which show signs of significant systemic or organ system toxicity. They are

Benzopyrine, Lead and Arsenic. The exceedance factors corresponding to these 3 parameters also fall under critical conditions. The surrogate number representing level of exposure (SNLF) corresponding to these pollutants are also critical. Therefore, they contribute greatly in assigning higher score of pollution index both with respect to sources and pathway. The pollution index score corresponding to receptors (R_{ij}) and additional pollution index score (R_{Add}) are also high but these scores are same for surface water and groundwater.

As stated earlier, the high values of air pollution index in Agra has been found mainly due to the presence of higher concentration of Benzopyrine, Lead and Arsenic in the air leading to deterioration in air quality. The higher concentration of Benzopyrine is mainly generated by incomplete combustion of fuel and organic substances and due to the presence of large vehicular movements. One of the main sources of atmospheric Benzopyrine is burning of woods. It also occurs in all smoke resulting from the combustion of organic material, in coal tar and in fumes generated from automobile especially from diesel engines. Noticeable concentration of lead could be due to industrial activities related to utilities, lead-acid battery manufacturers, waste incinerators, metals processing and lead smelters and burning of scrap materials. In fact, scrap handling people are burning thousands of tyres and other scrap materials to extract iron. These materials are mainly obtained from the Army's scrap material market and dumping ground. The dense fumes have been observed every day which is arising from the road leading towards Cheelgharh, Chipitola from Bijlighar. These sources need to be especially curbed in order to reduce the overall pollution index for Agra. Possible strategies could be facilitating cleaner fuel and relocating the smelters away from the city area.

Surface and ground water pollution is also a serious issue. There is a need to facilitate the common facilities for treatment of effluents being discharged by small and medium scale industries, a stricter monitoring of the defaulters, encouraging upgradation of the effluent treatment plants, replacing/ refurbishing leaky pipelines and encouraging reuse/ recycle of treated wastewater.

4.3 Evaluation of IEPI for some selected Industrial Sectors

As explained above, IEPI was derived for few selected industrial clusters. These clusters have been classified into five groups as given below:

a. Steel Producing Industrial Areas

b. Coal Mining and Thermal Power Plant Areas

c. Chemical Industry Areas

d. Oil Refinery Areas

e. Mixed Industrial Areas

4.3.1 Steel Producing Industrial Areas

The iron and steel industry is one of the most energy and resource intensive sectors. It is also one of the major contributor of economy and growth of development in India. There is high demand of production from the manufacturing sectors. However, growth of productivity must be achieved by adopting efficient, effective and cleaner technologies. Therefore, the need of hour is to study the status of pollution to assess fulfillment of socio-economic, environmental, and development objectives in sustainable manner.

As per the report of World Steel Association (WSA), India has produced 50.1 million tonnes (MT) of crude steel during January–September 2010 and was placed fourth largest producer of crude steel during the period. It was reported that the steel consumption in domestic sector has grown by 9.8% to 29.82 million tonnes during April-September 2010. A critical study on factors like growth of industrial productivity in India will help to identify potential future development strategies that may lead towards a better practical and sustainable development path.

The two types of steel making technology that are in use today are the Electric Furnace (EF) and the Basic Oxygen Furnace (BOF). When making steel using BOF, coke which is the fuel and the carbon source, is produced through the process of heating coal at very high temperatures while in the absence of oxygen. However, this process releases a large amount of emission contributing to the air pollution. Quench water, which is the water used to cool the coke releases suspected carcinogens and volatile organic substances at the end of the heating process. These are the reasons why coke making is considered as one of the most important areas of environmental concerns in the iron and steel industries.

The main industrial towns of India are Durg-Bhillai in Chattisgarh, Bokaro and Jamshedpur in Jharkhand and Durgapur in West Bengal. The Integrated Environmental Pollution Index has been calculated for 3 steel producing industrial areas viz. Durg-Bhilai, Durgapur and Jamshedpur by evaluating sub-indices scores corresponding to air, surface water and groundwater as per the methodology presented in previous chapter.

4.3.1.1 Durg-Bhilai Industrial Area

Bhilai city is located in Durg district of Chhattisgarh state, India which is well known due to Bhilai steel plant. It is 25 kilometers west of Raipur, the capital city of Chhattisgarh. The city is well connected to the National Highway number 6 and main Howrah–Mumbai railway line. As per the 2011 census, it has a total population of 894,376 with 52% males population and 48% females population. The average literacy rate of Bhilai Nagar is over 90%, which is much higher than 59.5%, the national average literacy rate. Approximately 13% of the population is under the age of 6 years. Thus Bhilai has been considered as a city of immigrants who come from various corners of India for work and settled as the residents.

Pollution index scores have been derived by assessing pollution level in air, surface water and ground water components using 3 critical parameters related separately to each of these components. Three parameters have been identified based on their type, availability and toxicity level. Environmental monitoring data pertaining to these 3 components have been taken directly from Chattisgarh Pollution Control Board, Raipur.

Initially 12 air quality parameters have been considered. Many of these air quality parameters are found below detectable limit or non-existent. A thorough analysis shows that Respiratory Suspended Particulate Matter (RSPM in $\mu g/m^3$), Suspended Particulate Matter (SPM in $\mu g/m^3$), nitrogen oxides (NOx in $\mu g/m^3$) can be considered as the critical parameters for air component in this cluster. The first two pollutants (i.e. RSPM and SPM) are from group B category whereas NOx is from group ‘A’ category. The observed values of these 3 critical parameters have been given in Table 4.8.

Table 4.8: Ambient Air Quality Monitoring Data at Durg-Bhillai

(3 most critical pollutants)

Pollutant	Average concentration ($\mu g/m^3$)
RSPM	162.25
SPM	266.25
No_x	31.62

Source: Chattisgarh Pollution Control Board, 2012

On similar lines, BOD_5 and (mg/l), Total coliform (TC in No./100 ml) and electrical conductivity (EC in mho) can be considered as the 3 critical parameters for surface water component in this cluster. The first two pollutants (i.e. BOD_5 and TC) are from group B category whereas EC is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.9.

Table 4.9: Surface water Quality Monitoring Data at Durg- Bhillai

(3 most critical pollutants)

Pollutant	Average concentration
BOD_5	1.34 mg/l
TC	357 per 100 ml
EC	331.4 mho

Source: Chattisgarh Pollution Control Board, 2012

Total dissolved solids (TDS in mg/l), Iron (Fe in mg/l) and Zinc (Zn in mg/l) have been considered as the 3 critical parameters for ground water quality falling within this cluster. The first pollutant (i.e. TDS) belongs to group B category whereas Fe and Zn belong to group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.10.

Table 4.10: Groundwater Quality Monitoring Data at Durg-Bhillai (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
TDS	671.3
Fe	1.105
Zn	1.375

Source: Chattisgarh Pollution Control Board, 2012

The overall pollution index score of Durg-Bhilai industrial Area/cluster has been evaluated as given in Table 4.11. Table 4.11 shows that pollution index score corresponding to air quality is higher than that of surface water and groundwater. Air is polluted in this industrial cluster due to the fact that there exist all 3 substances which show signs of significant systemic or organ system toxicity. They are RSPM, SPM and NOx.

Table 4.11: Evaluation of pollution index scores for Durg-Bhilai Industrial Area

Criteria	$S_{i,j}$	$P_{i,j}$	$R_{i,j}$	R_{Add}	$IEPI_{i,j}$	$IEPI_i$
Air	7.5	11	14	10	42.5	
Surface Water	7.5	4	11	10	32.5	49.04
Ground water	5	11	9	10	35	

It is apparent that individual EPI values for Durg-Bhilai industrial area are less than 45 on a scale of 100, which shows relatively more industries are compiling to the prescribed standards of emissions and discharges.

4.3.1.2 Durgapur Industrial Area

Durgapur city is located in Bardhaman district of Indian state of West Bengal which is well known due to one of the largest industrial units in the state, i.e. Durgapur Steel Plant. It is 160 kilometers from Kolkata, the capital city of West Bengal and metropolitan city of eastern India. This huge industrial township is located between Ajoy and Damodar river basins. The city is well connected to the National Highway number 19 (NH 19) and State highway number 9 (SH 9) and Asian Highway 1 (AH 1). AH1 connects many Asian countries including Japan, Korea Vietnam, China and Turkey, etc. As per the 2011 census, it has a total population of

492,996 with 53% males population and 47% females population. The average literacy rate of Durgapur is over 75%, which is higher than 59.5%, the national average literacy rate. Approximately 10% of the population is under the age of 6 years. Steel Authority of India Limited has one of its largest integrated steel plants in this city. This industrial town has a large number of chemical, manufacturing, metallurgical and other engineering units, thermal power plants.

As explained earlier, pollution index scores have been derived by assessing pollution level in air, surface water and ground water components using 3 critical parameters related to each of these components. Three parameters have been identified based on their type, availability and toxicity level. Environmental monitoring data pertaining to ambient quality of air , surface water and ground water have been taken directly from West Bengal Pollution Control Board, Kolkata.

Initially 12 air quality parameters have been considered. Many of these air quality parameters are found below detectable limit or non-existent. A thorough analysis shows that Respiratory Suspended Particulate Matter (RSPM in $\mu g/m^3$), Carbon Monoxide (CO in $\mu g/m^3$), nitrogen oxides (NOx in $\mu g/m^3$) can be considered as the critical parameters for air component in this cluster. The first two pollutants (i.e. RSPM and CO) are from group B category whereas remaining third pollutant (i.e. NOx) is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.12.

Table 4.12: Ambient air quality monitoring of Durgapur town (3 most critical pollutants)

Pollutant	Average concentration (($\mu g/m^3$)
RSPM	153.6
CO	0.95
Nox	56.96

Source: WB SPCB report (AAQM data for PCBL, Durgapur, October 2012)

On similar lines, Biochemical oxygen demand at 5 days (BOD_5 in mg/l), Lead (Pb in mg/l) and Arsenic (As in mg/l) can be considered as the 3 critical parameters for surface water component in this cluster. The first pollutant (i.e. BOD_5) is from group B category whereas remaining two pollutants (i.e. Pb and As) are from group ‘C’ category. The observed values of these 3 critical parameters have been given in Table 4.13.

Table 4.13: Surface water quality monitoring of Damodar river, Durgapur

Pollutant	Average concentration (mg/l)
BOD_5	1.9
Pb	11.38
As	5.88

Source: WB SPCB report (Surface water quality data for Damodar river, Durgapur, 2012)

Iron (Fe in mg/l), Zinc (Zn in mg/l) and Cadmium (Cd in mg/l) have been considered as the 3 critical parameters for ground water quality falling within this cluster. The first two pollutants (i.e. Fe and Zn) belong to group A category whereas remaining third pollutant (Cd) belongs to group ‘C’ category. The observed values of these 3 critical parameters have been given in Table 4.14.

Table 4.14: Ground water quality monitoring of Durgapur Industrial Area

Pollutant	Average concentration (mg/l)
Fe	0.56
Zn	0.467
Cd	0.001

Source: W.B. SPCB report (Groundwater analysis report of Durgapur, 2012)

The overall pollution index score of Durgapur industrial Area/cluster has been evaluated and given in Table 4.15. Table 4.15 shows that pollution index score corresponding to surface water is higher than that of air and groundwater. Surface water is polluted in this industrial cluster due to the fact that two out of three pollutants are from group ‘C’ category which show signs of significant systemic or organ system toxicity. The concentration of these two parameters are also quite high.

Table 4.15: Evaluation of pollution index scores for Durgapur Industrial Area

Criteria	IEPI Value
Air	56.5
Surface Water	66
Ground water	50
Overall IEPI of the Area	75.60

It is apparent that individual EPI values for Durgapur industrial area are equal to or greater than 50 on a scale of 100, whereas overall IEPI of the area is above 75. It can also be seen from Table 4.15 that the surface water EPI is of relatively higher value as compared with the air and groundwater EPIs. Thus, there is urgent need to pay attention for improving quality of surface water, air and ground water by ensuring these parameters within the prescribed standards of emissions and discharges. It is required to upgrade effluent treatment plants and stricter monitoring of the water polluting units so that surface water quality can be improved.

4.3.1.3 Jamshedpur Industrial Area

Jamshedpur city is located in East Singhbhum district of Indian state of Jharkhand which is well known due to many industrial units and companies. Tata industrial group has established a number companies in this city. Many organizations like Tata Steel (10th largest steel manufacturing company of the world), Tata Power, Tata Motors, Tata Technologies Limited, Tata Consulting Engineers, Tata Consultancy Services, BOC Gases, Lafarge Cement, Praxair, Telcon, Timken India, Tinplate etc. make this city a major industrial area in Eastern India.

It is also known as industrial capital of Jharkhand or steel city or Tatanagar which has the credit of having establishment of first private iron and steel company of India. This huge industrial township is located at the confluence of Subarnarekha and Kharkai river basins. Jamshedpur is surrounded by the area which is rich in natural minerals, including coal, bauxite, manganese, iron ore and lime, which creates it a favorable place for different types of industrial activities.

The city is well connected to the National Highway numbers 32, 33 (NH 32, NH 33) and 4-lane Expressway. As per the 2011 census, it has a total population of 1,134,788 with 53%

males population and 47% females population. The average literacy rate of Jamshedpur is over 83%, which is higher than 59.5%, the national average literacy rate. Approximately 11% of the population is under the age of 6 years. The city has one of the largest and oldest iron and steel producing plant of India, which is Tata Steel. This industrial city has also over 1,200 small and medium-scale industries in the locality of Adityapur which is located in Jamshedpur. The city also has a large number of industrial plants related to iron and steel manufacturing, tinplate production, truck manufacturing metallurgical, cement and other small and medium-scale industries, and other technological units.

On similar lines as explained in the case of Durg-Bhilai and Durgapur industrial areas, pollution index scores have also been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air , surface water and ground water have been taken directly from Jharkhand State Pollution Control Board, Ranchi and Jamshedpur.

A thorough analysis shows that Nickel (Ni in $\mu g/m^3$), Benzene (in $\mu g/m^3$), Particulate Matter of size 10 micrometer or less (PM_{10} in $\mu g/m^3$) has been considered as the critical parameters for air component in this cluster. The two pollutants (i.e. Ni and PM_{10}) are from group B category whereas remaining third pollutant (i.e. Benzene) is from group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.16.

Table 4.16 Average air pollutant concentration at Jamshedpur
(3 most critical pollutants)

Pollutant	**Average concentration ($\mu g/m^3$)**
Ni	16.93
Benzene	3.0
PM_{10}	270.5

Source: Jharkhand State Pollution Control Board, Ranchi, 2012

For assessing pollution level in surface water in this cluster, Phenolic compounds (in mg/l), Manganese (Mn in mg/l) and Fluoride (F^- in mg/l) has been considered as the 3 critical parameters. The first pollutant (i.e. Phenolic compounds) is from group 'C' category, the second pollutant (i.e. Mn) is from group 'A' category and remaining third pollutant (i.e. F^-) is from group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.17.

Table 4.17: Surface water Quality Data for Jamshedpur

(3 most critical pollutants)

Pollutant	Average concentration (mg/l)
Phenolic Compounds	0.91
Mn	0.705
F-	0.265

Source: Provided by SGS India Pvt. Ltd

Fluoride (F^- in mg/l), Iron (Fe in mg/l) and Nitrate (NO_3^- in mg/l) have been considered as the 3 critical parameters for ground water quality falling within this cluster. The two pollutants (i.e. F^- and NO_3^-) belong to group 'B' category whereas remaining third pollutant (Fe) belongs to group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.18.

Table 4.18: Ground water Quality Data for Jamshedpur

(3 most critical pollutants)

Pollutant	Average concentration (mg/l)
F-	0.20
Fe	0.275
NO_3	10.165

Source: Provided by SGS India Pvt. Ltd

The overall pollution index score of Jamshedpur industrial Area has been evaluated and given in Table 4.19.

Table 4.19: Evaluation of pollution index scores for Jamshedpur Industrial Area

Criteria	IEPI Value
Air	69.00
Surface Water	65.50
Ground water	38.00
Overall IEPI of the Area	76.72

From Table 4.19, it can be observed that individual EPI values obtained for Jamshedpur industrial area are equal to or greater than 38 on a scale of 100 with scores of 69.00, 65.50 and 38.00 for air, surface water and groundwater respectively. The overall IEPI of the area is above 75. It can also be seen from Table 4.19 that the pollution index score of air is close to surface water but higher than that of groundwater. Air and surface water both are polluted in this industrial cluster due to the fact that air pollutants not only fall either under group B (i.e. Ni and PM_{10}) or group C (i.e. Benzene) but they also have been found in significant quantity. Similarly, in the case of surface water, 2 out of 3 pollutants fall either under group B (i.e. F^-) or group C (i.e. Phenolic compounds) with sufficient concentration. Thus they may show signs of significant systemic or organ system toxicity. Thus, there is urgent need to pay attention for improving quality of air and surface water by ensuring these parameters within the prescribed standards of emissions and discharges. It is required to upgrade effluent treatment plants and stricter monitoring of the air and water polluting units so that quality of both air and surface water within the industrial cluster can be improved.

4.3.1.4 Comparative study of the areas

A comparison of the IEPI values of the three selected industrial areas is presented in Table 4.20.

Table 4.20: Comparison of IEPI values among three steel producing industrial areas

Industrial Area	IEPI Value
Durg-Bhillai	49.04
Durgapur	75.60
Jamshedpur	76.72

From the above table, it can be inferred that Jamshedpur and Durgapur industrial clusters are polluted heavily with their pollution index scores of 76.72 and 75.60 respectively. Large scale industrial activities have been taking place in these industrial clusters. Durg-Bhillai with moderate scale of industrial activities together with an efficient water and wastewater treatment plant has the least IEPI value.

4.3.2 Coal Mining and Thermal Power Plant Area

Coal mining and production plays a very important role in resource extraction and manufacturing industry. It is also one of the major source of fossil fuel which contributes significantly in the economic growth of any nation. India has over 267 billion tonnes of coal reserves (fourth highest coal reserves of the world) which may last over a century or so. In general, coal is used to generate energy and over 53% of coal has been used up in India for generation of electricity. India's electricity consumption per person is approximately 635 units which is expected to increase manifold in the forthcoming decades. In India, coal has been used to generate energy twice as compare to that produced from the oil. However, energy generated from coal worldwide is approximately 30% less than that that generated from the oil.

There are two simple methods of mining: Surface mining and deep underground mining. The coal is extracted from coal seams. The extraction materials depends on the geology, depth, seams characteristics and many other environmental factors. Coals extracted either from surface or underground mines may require first cleaning of coal in a primary plant. The selection of mining methods depends mainly on depth and thickness of the coal seam and density of the overburden materials. Seams closer to the surface with depths less than about 50 m or so are usually surface mined whereas that located with 50 to 100 m are usually deep underground mined. Technical and economic feasibility studies are performed to evaluate its quality and quantity of coals extracted from these mines. The assessment is done using various criteria such overburden characteristics; regional geologic conditions; coal seams characteristics: its continuity, depth, structure, thickness and quality; roof and floor characteristics of seams: tensile and compressive strength of materials above and below the seams; climate; topography: slope and altitude; land ownership and accessibility; availability of labor and materials; surface water and groundwater characteristics and drainage patterns; client requirements: quality grade, tonnage and destination; and capital cost investment requirements.

Extraction of coal and associated industrial activities have severe impact on environment of surroundings. It has been revealed that there has been very high content of sulphate, total dissolved solids, iron and hardness in mine water content. Acidity in mine drainage also plays an important role in the mining areas. Biological contamination in the mine water has also been observed in many case studies. A large quantity of polluted water moves into mines which further joins either groundwater or channeled into the stream which causes pollution in streams and groundwater. Other supplementary processes such as coal beneficiation and primary preparation plant are also responsible to produce a large quantity of water effluent which affect the surrounding environment and reduces biodiversity. The requirements of coal and thermal power plants are increasing day by day. However, required coals have to be extracted by adopting efficient, effective and cleaner technologies. Therefore, the need of hour is to study the status of pollution to assess fulfillment of socio-economic, environmental, and development objectives in sustainable manner.

There are many coal and thermal plant industrial areas in India. The largest and oldest coal field of India is Raniganj, which is located in West Bengal. Jharia (second largest), Bokaro, Giridih, Karanpura, Ramgarh, Daltonganj are in Jharkhand. Singrauli, Suhagpur, Johilla, Umaria, Satpura coal fields are located in Madhya Pradesh. Talcher, Himgiri, Rampur are located in Orissa and Korba and Bisrampur mines are located in Chattisgarh state. The Integrated Environmental Pollution Index has been calculated for 3 main coal and thermal plant industrial areas viz. Dhanbad in Jharkhand, Korba in Chattisgarh and Singrauli in Madhya Pradesh by evaluating sub-indices scores corresponding to air, surface water and groundwater as per the methodology presented in previous chapter.

4.3.2.1 Dhanbad Industrial Area

Dhanbad city is located in Indian state of Jharkhand. A number of industries have been established in this city. Coal-mining, coal cleaning and washing and coke making are the main industrial activities operated in the city. Therefore, it is also named as the 'Coal Capital of India' due to coal mining activities at large and has the credit of having some of the largest mines of India. Some of the well-known industries which operate coal mines in this city are Bharat Coking Coal Limited (BCCL) and Eastern Coalfields Limited (ECL): both are branches of Coal India Limited, Indian Iron and Steel Company (IISCO which is now part of Steel Authority of India Limited) and Tata Steel. BCCL and ECL have been operating coal mines in the city at the larger scale, and have both underground mines and open cast mines, whereas Tata Steel has been operating mostly with the underground mines.

Damodar river is flowing through this industrial city. Gobai, Irji, Jamunia, Katri and Khudia are other rivers flowing through the district. The city is well connected to the National Highway numbers 18, 19 (NH 18, NH 19) and Golden Quadrilateral network, and Asian Highway 1 (AH 1) and main Howrah–New Delhi railway line. Dhanbad is placed 42nd rank in population amongst other cities in India. As per the 2011 census, it has a total population of 2,684,487 with 53% males population and 47% females population. The average literacy rate of Dhanbad is over 80.78%, which is higher than 59.5%, the national average literacy rate. Approximately 10.57% of the population is under the age of 5 years.

On similar lines as explained earlier, pollution index scores have also been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from Jharkhand State Pollution Control Board, Ranchi. A thorough analysis shows that Respiratory Suspended Particulate Matter (RSPM in $\mu g/m^3$), Suspended Particulate Matter (SPM in $\mu g/m^3$), nitrogen oxides (NO_x in $\mu g/m^3$) can be considered as the critical parameters for air component in this cluster. The first two pollutants (i.e. RSPM and SPM) are from group B category whereas NOx is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.21.

Table 4.21: Air Quality Monitoring Data of Dhanbad Region (3 most critical pollutant)

Pollutant	Average Concentration($\mu g/m^3$)
RSPM	183
NO_X	30.2
SPM	310.57

Source: JSPCB 2011 : Ambient air quality monitoring of Dhanbad region

Total Suspended Solids (TSS in mg/l), Total Dissolved Solids (TDS in mg/l), and Chemical oxygen demand (COD in mg/l) can be considered as the 3 critical parameters for surface water component in this cluster. The first pollutant (i.e. TSS) is from group 'A' category whereas remaining two pollutants (i.e. TDS and COD) are from group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.22.

Table 4.22 Surface water Monitoring Data of Dhanbad Region (3 most critical pollutant)

Pollutant	Average Concentration (mg/l)
TSS	66.96
TDS	479.3
COD	61.3

Source: JSPCB 2011: Ambient air quality monitoring of Dhanbad region

Total Coliform (TC in MPN), Total Dissolved Solids (TDS in mg/l), and Hardness (in mg/l) can be considered as the 3 critical parameters for groundwater component in this cluster. One pollutant (i.e. hardness) is from group 'A' category whereas remaining two pollutants (i.e. TC and TDS) are from group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.23.

Table: 4.23 Groundwater Monitoring Data of Jharkhand Region (3 most critical pollutant)

Pollutant	Average Concentration
TC (MPN)	4500
TDS (mg/l)	850
Hardness (mg/l)	930

Source: JSPCB 2011: Groundwater monitoring of Dhanbad region

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Dhanbad industrial area has also been evaluated as shown in Table 4.24.

Table 4.24: Evaluation of pollution index scores for Dhanbad Industrial Area

Criteria	IEPI Value
Air	61.50
Surface Water	62
Ground water	64
Overall IEPI of the Area	77.72

From Table 4.24, it can be observed that individual EPI values obtained for Dhanbad industrial area are equal to or greater than 61.50 on a scale of 100 with scores of 61.50, 62.00 and 64.00 for air, surface water and groundwater respectively. The overall IEPI of the area is above 75. It can also be seen from Table 4.24 that the pollution index scores are very close to each other though groundwater has the highest score. In all three components, two out of three pollutants not only fall under group 'B' category but they also have been found in significant quantity. This is the main reason for higher individual scores of these components which further lead to high score of 77.72 for overall IEPI. Thus they may show signs of significant systemic or organ system toxicity. Thus, it is essential to pay attention for improving quality of all components (i.e. air, surface water and groundwater) by ensuring these parameters within the prescribed standards of emissions and discharges. It is required to upgrade effluent treatment plants and stricter monitoring of the air, surface water and groundwater polluting units so that quality of environment within the industrial cluster can be improved.

4.3.2.2 Korba Industrial Area

Korba city is located in Indian state of Chhattisgarh. It is 200 kilometers from Raipur, the capital city of Chhattisgarh. The city is well connected to the National Highway number 200, State Highways and Howrah–Nagpur-Mumbai railway line. As per the 2011 census, it has a total population of 1206563 with 50.74% males population and 49.26% females population. The average literacy rate of Korba district is over 73.22%, which is much higher than 59.5%, the national average literacy rate. Approximately 12% of the population is under the age of 6 years. A number of coal mines have been developed in Korba. Gevra area of Korba has one of the biggest coal mines of Asia. Other coal mines located in Kusmunda and Dipka locality also comes within Korba coalfield industrial area.

Coal-mining and power generation are the main industrial activities operated in the city. Therefore, it is also named as the 'power capital of Chhattisgarh'. Korba is rich in all the essential raw materials needed for power generation, including ample amount of coal and water. Such types of favorable conditions exhibit that this city has enough potential to develop itself for different other types of industrial activities.

Some of the well-known thermal power plants which generate electricity of about 3650 MW in this city are Korba super thermal power plant (KSTPS) (a unit of NTPC Limited), BCPP, Chhattisgarh state electricity board (CSEB) east and west. In addition to thermal power plants, Bango hydroelectric power station also generates electricity. The South eastern coal fields ltd. (SECL), a coal company under the Coal India Limited has many of its important mines in Korba district. Bharat Aluminium Company (BALCO) is another industrial giants which is located in the district. Korba has an excellent green forest cover.

Pollution index scores have been derived by assessing pollution level in air, surface water and ground water components using 3 critical parameters related separately to each of these components. Three parameters have been identified based on their type, availability and toxicity level. Environmental monitoring data pertaining to these 3 components have been taken directly from Chattisgarh Pollution Control Board, Raipur.

A thorough analysis shows that Respiratory Suspended Particulate Matter (RSPM in $\mu g/m^3$), Suspended Particulate Matter (SPM in $\mu g/m^3$), nitrogen oxides (NOx in $\mu g/m^3$) can be considered as the critical parameters for air component in this cluster (Sulphur dioxide (SO_2 in $\mu g/m^3$) can be neglected being low). The first two pollutants (i.e. RSPM and SPM) are from group B category whereas NOx is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.25 which has been taken from Chhattisgarh State Pollution Control Board, Raipur.

Table 4.25: Ambient Air quality data in Korba region

S. No.	Location	Temporary Township				Near MGR				Near DM Plant			
		SO_2	NO_2	RSPM	SPM	SO_2	NO_2	RSPM	SPM	SO_2	NO_2	RSPM	SPM
1.	10;00 PM to 02:00 am	6	37	119	329	13	47	209	453	5	37	129	308
2.	02:00 AM to 6:00 AM	7	32			6	40			BDL	28		
3.	6:00 AM to 10:00 AM	6	47	247	436	5	37	448	834	6	40	102	285
4.	10:00 AM to 02:00 PM	5	24			9	53			10	21		
5.	2:00 PM to 6:00 PM	BDL	32	242	475	BDL	40	315	594	8	32	124	334
6.	6:00 PM to 10:00 PM	BDL	36			5	26			6	46		
24 Hours Average		4	35	203	413	06	41	324	627	05	34	118	309

Source: Chhattisgarh State Pollution Control Board, 2011 (All parameters are in $\mu g/m^3$; BDL Below Detectable Limit)

For assessing pollution level in surface water in this cluster, Biochemical Oxygen Demand (BOD_5 in mg/l), Fluoride (F^- in mg/l) and Total Suspended Solids (TSS in mg/l) have been considered as the 3 critical parameters. The first two pollutants (i.e. BOD_5 and F^-) are from group 'B' category, and remaining third pollutant (i.e. TSS) is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.26.

Table 4.26: Surface water quality in Korba region (3 most critical pollutants)

Pollutant	Average Concentration (mg/l)
BOD_5	5.1
F-	1.0
TSS	162.2

Source: Chhattisgarh State Pollution Control Board Annual Report 2011

Fluoride (F^- in mg/l), Iron (Fe in mg/l) and Zinc (Zn in mg/l) have been considered as the 3 critical parameters for ground water quality falling within this cluster. The two pollutants (i.e. Fe and Zn) belong to group 'A' category whereas remaining third pollutant (F^-) belongs to group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.27.

Table 4.27: Groundwater quality in Korba region (3 most critical pollutants)

Pollutant	Average Concentration (mg/l)
F-	1.02
Zn	1.50
Fe	3.6

Source: Chhattisgarh State Pollution Control Board Annual Report 2011

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Dhanbad industrial area has also been evaluated as shown in Table 4.28.

Table 4.28: Evaluation of pollution index scores for Korba Industrial Area

Criteria	IEPI Value
Air	76
Surface Water	69
Ground water	59
Overall IEPI of the Area	85.77

From Table 4.28, it can be observed that individual EPI values obtained for Korba industrial area are 69.00, 59.00 and 76.00 out of total score of 100 for air, surface water and groundwater respectively. The overall IEPI of the area is above 85. It can also be seen from Table 4.28 that the pollution index score is very high with respect to air. In air and surface water components, two out of three pollutants not only fall under group 'B' category but they also have been found in significant quantity. This is the main reason for higher individual scores of these components which further lead to high score of 85.77 for overall IEPI. Thus, it is essential to pay attention for improving quality of all components (i.e. air, surface water and groundwater) by ensuring these parameters within the prescribed standards of emissions and discharges. It is required to upgrade effluent treatment plants and stricter monitoring especially for those units which pollute air, surface water and groundwater so that quality of environment within the industrial cluster can be improved.

4.3.2.3 Singrauli Industrial Area

Singrauli industrial area is located partly in Singrauli district of Indian state of Madhya Pradesh and partly in southern part of Sonebhadra district of Uttar Pradesh. It is well-known due to coal mining activities and the development of coal-based thermal power plants in the region. Organizations like Northern Coalfields Limited feeds coal to many cement, chemical and power plants and other technological units which are located within Singrauli Industrial area. Some of these industries are Anpara Power Plants, Coal India Limited, DB Power Limited, Essar Power Limited, Hindalco Industries Limited, IDL Explosives Limited, National Thermal Power Corporation Limited, Obra Thermal Power, Reliance Power Limited, Renusagar Power Plant, Rihand Hydro Power. They make this region a major industrial hub of energy sector. All these industrial developments have only been possible due to availability amount of mineable reserves of Coal. With many billion tons of coal already being mined during the past 35 to 40 years, it still has coal reserve of more than 8.7 billion tones. As per the 2011 census, it has a total population of 1,178,132 with 52.19% males population and 47.81% females population. The average literacy rate of Jamshedpur is over 62.36%, which is higher than 59.5%, the national average literacy rate.

Pollution index scores have been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from Madhya Pradesh State Pollution Control Board, Bhopal. A thorough analysis shows that respiratory suspended particulate matter (RSPM in $\mu g/m^3$), nitrogen oxides (NOx in $\mu g/m^3$) and Sulfur dioxide (SO_2 in $\mu g/m^3$) can be considered as the critical parameters for air component in this cluster. The first pollutant (i.e. RSPM) is from group B category whereas remaining other two pollutants (i.e. NOx and SO_2) is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.29.

Table 4.29: Air Quality Monitoring Data of Singrauli Region

Pollutant	Average Concentration($\mu g/m^3$)
RSPM	104.75
Nox	48
Sox	12.25

Source: MPPCB 2011: Ambient air quality monitoring of Singrauli region

For assessing pollution level in surface water in this cluster, Mercury (Hg in mg/l), Chemical Oxygen Demand (COD in mg/l) and Total Suspended Solids (TSS in mg/l) have been considered as the 3 critical parameters. One pollutant (i.e. Hg) is from group 'C' category, second pollutant (i.e. COD) is from group 'B' category and remaining third pollutant (i.e. TSS) is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.30.

Table 4.30: Surface water Monitoring Data of Singrauli Region

Pollutant	Average Concentration (mg/l)
Mercury	0.005
COD	1057
TSS	358.8

Source: MPPCB 2011: Ambient air quality monitoring of Singrauli region

Mercury (Hg in mg/l), Total dissolved solids (TDS in mg/l) and Fluoride (F^- in mg/l) have been considered as the 3 critical parameters for ground water quality falling within this cluster. The two pollutants (i.e. TDS and F^-) belong to group 'B' category whereas remaining third pollutant (Hg) belongs to group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.31.

Table: 4.31: Groundwater Monitoring Data of Singrauli Region

Pollutant	Average Concentration (mg/l)
Mercury	0.0026
TDS	632.4
F-	1.01

Source: MPPCB 2011: Groundwater monitoring of Singrauli region

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Singrauli region has also been evaluated as shown in Table 4.32.

Table 4.32: Evaluation of pollution index scores for Singrauli Industrial Area

Criteria	IEPI Value
Air	74
Surface Water	64.75
Ground water	64.00
Overall IEPI of the Area	84.77

From Table 4.32, it can be observed that individual EPI values obtained for Singrauli industrial area are 74.00, 64.75 and 64.00 out of a total score of 100 for air, surface water and groundwater respectively. The overall IEPI of the area is close to 85. It can also be seen from Table 4.32 that the pollution index score is very high with respect to air. In both surface water and groundwater of the region, group 'C' pollutant mercury has been found due to increase in coal mining activities and the rapid development of coal-based thermal power plants in the region. It has led to severe air, surface water and groundwater pollution. Power plants in the area are emitting gases along with which mercury is also being released in the air, surface water and groundwater. Mercury is one of the natural components of coal, which is a neurotoxin and probably one of the most harmful pollutants. As large amount of coal is burned at high temperature above 1,100 °C in the thermal power plants, a sizable amount of mercury is being released into the atmosphere. A sufficient fraction of it is not only coming back to the land, surface water and ground water after cooling down and condensation process but also joins the environment through run-off from coal mines. It is reported that a thermal power plant of capacity of 1,000 MW is releasing approximately 500 kg of mercury every year in Singrauli region. RSPM has also been found in ambient air in sufficient quantity. This is the main reason for higher individual scores of these components which further lead to high score of overall IEPI. There are evidences of serious health problems among the people residing in this region. As many other power companies are expected to come in this region, it may further lead to severe problems if not proper attention is given to improve quality of all components (i.e. air, surface water and groundwater) by ensuring these parameters within the prescribed standards of emissions and discharges. It is required to upgrade effluent treatment plants and stricter monitoring especially for those units which pollute air, surface water and groundwater so that quality of environment within the industrial cluster can be improved.

4.3.2.4 Comparison of the three areas

A comparison of the IEPI values of the three selected industrial areas is presented in Table 4.33.

Table 4.33: Comparison among IEPI values for the three areas

Area	IEPI Value
Dhanbad	77.72
Korba	85.77
Singrauli	84.77

From the above table, it can be inferred that Korba and Singrauli industrial clusters are polluted heavily with their pollution index scores of 85.77 and 84.77 respectively. Large scale industrial activities such as coal mining activities and power generation through coal-based thermal power plants in the region have been taking place in these industrial clusters though Dhanbad has relatively low pollution index as compare to other two.

4.3.3 Chemical Industry Areas

The chemical industries are used to generate various types of chemicals. Raw products such as air, minerals, water, oil, natural gas, metals are being used to convert them into more than 70,000 different types of products by these chemical industries. Now a days different types of plastics and polymers have been derived to fulfill our needs which cover about 80% of the industrials output worldwide. These plastics and polymers are derived in different forms which are very commonly found in the market such as polycarbonate, polyethylene, polyethylene terephthalate, polypropylene, polystyrene and polyvinyl chloride. Chemicals are used to fulfill our requirements in terms of agricultural inputs, construction materials, manufacturing products, service industries and wide variety of consumer goods. It is interesting to note that chemical industries themselves utilize about 25% percent of their own products in one way or another. Textiles, rubber items, plastic products, petroleum refining, apparel, pulp and paper, primary metals etc. are considered as the major industrial customers. In India, the areas where the chemical industries are established are at Ankleshwar. Vapi, Ahmedabad in the state of Gujrat. The effluents from chemical industries pollute the nearby water source making the chemical industrial areas one of the most polluted areas of India. The Integrated Environmental Pollution Index has been calculated for 3 main chemical industrial areas viz. Ankleshwar, Vapi and Ahmedabad by evaluating sub-indices scores corresponding to air, surface water and groundwater as per the methodology presented in previous chapter.

4.3.3.1 Vapi Industrial Area

Vapi industrial area is located in Valsad district in Indian state of Gujarat. It is about 28 km towards south from Valsad district headquarter and about 120 km towards south from Surat. A number of chemical industries have been established in this city. Production of dyes, paints, pesticides, dye intermediaries and chemical distillation are the main industrial activities operated in this industrial area which constitute about 70% of the total industrial activities. Other major industries are related to computer hardware and software, food products, glass, paper and pulp, plastics and rubber, packaging, pharmaceuticals, textiles, wood, engineering workshops etc. Therefore, it is also named as the 'Chemical City'. Some of the well-known chemical industries in this region are Aarti Industries Limited, Bayer Vapi Private Limited, Hubergroup India Private Limited, Lathia Rubbers, Kampun Polymers, and Sangir Plastics, Sarna Chemicals, Supreet Chemicals, Themis Industries, United Phosphorus Limited, Unique Star Alliance Tools Manufacturing Private Limited. Some of the textile industries are Alok industries, Welspun Terry Towels, Century Textiles and Raymonds Limited which operate their production and manufacturing plants in the region. Damanganga river is flowing through this industrial city. The city is well connected to the National Highway numbers 8 (NH 8), and Mumbai-Vadodara railway line. Vapi is also directly connected to two union territories, i.e. Dadra-nagar haveli and Daman. As per the 2011 census, it has a total population of 1,63,630. Vapi industrial township has the largest Common Effluent Treatment Plant (or CETP) to treat effluent/ pollutants generated from small-scale industries before the effluent is finally released into the river Daman Ganga.

Pollution index scores have been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from Gujarat pollution control board. A thorough analysis shows that Benzene (Benzene in $\mu g/m^3$), respiratory suspended particulate matter (RSPM in $\mu g/m^3$) and Volatile organic compounds (VOCs in $\mu g/m^3$) can be considered as the critical parameters for air component in this cluster. The first pollutant (i.e. RSPM) is from group B category whereas remaining other two pollutants (i.e. Benzene and VOCs) are from group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.34.

Table 4.34: Average air pollutant concentration at Vapi (3 most critical pollutants)

Pollutant	Average concentration ($\mu g/m^3$)
Benzene	38.8
RSPM	208.5
VOCs	802.5

Source: Gujarat Pollution Control Board 2012

On similar lines, Ammonia-Nitrogen (NH_3-N in mg/l), Chemical oxygen demand (COD in mg/l) and Oil and grease (O & G in mg/l), can be considered as the 3 critical parameters for surface water component in this cluster. The first pollutant (i.e. NH_3-N) is from group 'A' category, second pollutant (i.e. COD) is from group 'B' category and remaining other pollutant (i.e. O & G) is from group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.35.

Table 4.35: Surface water quality in Vapi (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
NH_3-N	85.8
COD	622.2
O &G	12.5

Source: Gujarat Pollution Control Board 2012

Ammonia-Nitrogen (NH_3-N in mg/l), Cadmium (Cd in mg/l) and Mercury (Hg in mg/l) have been considered as the 3 critical parameters for ground water quality falling within this cluster. The first pollutant (i.e. NH_3-N) is from group 'A' category whereas the remaining two pollutants (i.e. Cd and Hg^-) belong to group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.36.

Table 4.36: Groundwater quality in Vapi (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
NH_3-N	31.5
Cd	0.01
Mercury	0.00176

Source: Gujarat Pollution Control Board 2012

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Vapi industrial cluster has also been evaluated as shown in Table 4.37.

Table 4.37: Evaluation of pollution index scores for Vapi Industrial Area

Criteria	IEPI Value
Air	84.75
Surface Water	83.50
Ground water	77.75
Overall IEPI of the Area	94.62

From Table 4.37, it can be observed that individual EPI values obtained for Vapi industrial area are 84.75, 83.50 and 77.75 out of a total score of 100 for air, surface water and groundwater respectively. The overall IEPI of the area is close to 95 which is very high. It can also be seen from Table 4.37 that the pollution index score is very high with respect to air. In ambient air of the region, two pollutants (i.e. Benzene and VOCs) out of 3 chosen pollutants fall under group 'C' category. RSPM, a 'B' category pollutant has also been found in air in sufficient quantity. In surface water, score is high because one pollutant (i.e. Oil & Grease) out of 3 chosen pollutants belong to group 'C' category which shows signs of significant systemic or organ system toxicity. In the groundwater of the region, two pollutants (i.e. Cd and Hg) out of 3 chosen pollutants fall under group 'C' category due to high operations of chemical plants. The occurrences of these pollutants with significant magnitude has led severe pollution in air, surface water and groundwater. Chemical plants in the area are discharging effluents and emitting polluted gases along with critical pollutants into surface water, groundwater and air. Benzene, VOCs, Mercury and Cadmium are the toxins and are very harmful pollutants to the health. Vapi can be ranked as the one of the most polluted industrial cluster in India as a result of poor quality of air, surface water and groundwater caused by several chemical industries. There are evidences of serious health complaints among the people residing in this region due to emissions of harmful pollutants (such as Benzene, VOCs, Mercury and Cadmium etc.) generating from chemical factories.

Though, Vapi industrial township has the largest Common Effluent Treatment Plant (or CETP) to treat effluent/ pollutants generated from small-scale industries, fate of pollutants are required to be studied properly so that effectiveness of such CETP can be analyzed . This becomes even more important when Vapi has the maximum number of Kraft paper (more than 20 within a peripheral distance of 20 km) and duplex board paper mills in India. The effectiveness of treatment plants needs to be studied immediately so that they can be upgraded if found necessary. Immediate actions and stricter monitoring are essential to identify polluting industries so that quality of all components environment (i.e. air, surface water and groundwater) within the industrial cluster can be improved by ensuring pollutants within the prescribed standards of emissions and discharges.

.4.3.3.2 Ankleshwar Industrial Area

Ankleshwar industrial area is located in Bharuch district in Indian state of Gujarat. It is about 10 km from Bharuch district headquarter. More than 5000 chemical industries (both large and small-scale) have been established in this cluster. Production of dyes, paints, pesticides, and chemicals and pharmaceuticals are the main industrial activities operated in this industrial area. Some of the well-known chemical industries in this region are Cadila Healthcare, Mahrshee Laboratories, Lupin Limited, Resins and Plastics Limited, Pragati Chemicals Limited, Sanofi Aventis, Rabipur pharmaceuticals and Bayer agro chemicals and Asian Paints which operate their production and manufacturing plants in the region. There is also branch office of Oil and Natural Gas Corporation Limited (ONGC). The city is well connected to the National Highway numbers 8 (NH 8) connecting Mumbai and New Delhi. It is also connected to western railway line. As per the 2011 census, it has a total population of 1,40,839 with 53% males population and 47% females population. Approximately 13% of the population is under the age of 6 years.

Pollution index scores have been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from Gujarat pollution control board. A thorough analysis shows that Benzene (Benzene in $\mu g/m^3$), respiratory suspended particulate matter (RSPM in $\mu g/m^3$) and Ammonia (NH_3 in $\mu g/m^3$) can be considered as the critical parameters for air component in this cluster. These pollutants (i.e. Benzene, RSPM and NH_3) fall under group 'C', 'B' and 'A' category respectively. The observed values of these 3 critical parameters have been given in Table 4.38.

Table 4.38: Average air pollutant concentration at Ankleshwar (3 most critical pollutants)

Pollutant	**Average concentration ($\mu g/m^3$)**
Benzene	35.83
RSPM	235
NH_3	209

Source: Gujarat Pollution Control Board 2012

Ammonia-Nitrogen (NH_3-N in mg/l), Phenol (in mg/l) and Oil and grease (O & G in mg/l), can be considered as the 3 critical parameters for surface water component in this cluster. The first pollutant (i.e. NH_3-N) is from group 'A' category whereas the remaining two pollutants (i.e. Phenol and O&G) belong to group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.39.

Table 4.39: Surface water quality in Ankleshwar (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
NH_3-N	64
Phenol	11.4
O and G	17.17

Source: Gujarat Pollution Control Board 2012

Ammonia-Nitrogen (NH_3-N in mg/l), Phenol (in mg/l) and Lead (Pb in mg/l), can be considered as the 3 critical parameters for surface water component in this cluster. The first pollutant (i.e. NH_3-N) is from group 'A' category whereas the remaining two pollutants (i.e. Phenol and Pb) belong to group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.40.

Table 4.40: Groundwater quality in Ankleshwar (3 most critical pollutant)

Pollutant	Average concentration (mg/l)
NH_3-N	83.2
Phenol	14.1
Pb	0.057

Source: Gujarat Pollution Control Board 2012

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Ankleshwar industrial cluster has also been evaluated as shown in Table 4.41.

Table 4.41: Evaluation of pollution index scores for Ankleshwar Industrial Area

Criteria	Modified IEPI Value
Air	84.50
Surface Water	84.75
Ground water	84.75
Overall IEPI of the Area	95.67

From Table 4.41, it can be observed that individual EPI values obtained for Ankleshwar industrial area are 84.50, 84.75 and 84.75 out of a total score of 100 for air, surface water and groundwater respectively. The overall IEPI of the area is over 95 which is very high. It can also be seen from Table 4.40 that the pollution index score is very high with respect to all 3 components i.e. air, surface water and groundwater and are very close to each other. In ambient air of the region, Benzene is from group 'C' category. RSPM, a 'B' category pollutant has also been found in air in sufficient quantity. In surface water, score is high because two pollutants (i.e. Oil & Grease and Phenol) out of 3 chosen pollutants belong to group 'C' category which shows signs of significant systemic or organ system toxicity. In the groundwater of the region, two pollutants (i.e. Phenol and Pb) out of 3 chosen pollutants fall under group 'C' category due to high operations of chemical and pharmaceutical plants. The occurrences of these pollutants with significant magnitude has led severe pollution in air, surface water and groundwater. Chemical and pharmaceutical plants in the area are discharging effluents and emitting polluted gases along with critical pollutants into surface water, groundwater and air. Benzene, Phenol, Lead and Oil and grease are the toxins and are very harmful pollutants to the health. Vapi can be ranked as the one of the most polluted industrial cluster in India as a result of poor quality of air, surface water and groundwater caused by several pharmaceutical and chemical industries. There are evidences of serious health complaints among the people residing in this region due to emissions of harmful pollutants.

4.3.3.3 Ahmedabad Industrial Area

Ahmedabad city is located in Indian state of Gujrat and is the largest city of the state and is well known due to industrial and economic activities in the state. It is 30 kilometers from Gandhinagar, the state capital. This city is located on the banks of river Sabarmati River. The city is well connected to the National Highway number 8 (NH 8) connecting New Delhi to Mumbai, National Highway number 8C (NH 8C) connecting Gandhinagar, National Expressway Number 1 (part of Golden Quadrilateral) connecting to Vadodara and western railway line. As per the 2011 census, it has a total population of 6,352,254 with 52.71% males population and 47.29% females population. The average literacy rate of Ahmedabad is over 89.62%, which is higher than 59.5%, the national average literacy rate. This industrial town has a large number of chemical, manufacturing and textile industries. Therefore, it is also named as the Manchester of the East' due to textile industry at large.

For IEPI calculation the air, surface water and groundwater analysis data was obtained from Gujrat Pollution Control Board (Table 4.42 to 4.44).

Table 4.42: Average air pollutant concentration in Ahmedabad (3 most critical pollutants)

Pollutant	**Average concentration (µg/m^3)**
Benzene	5.16
As	3.675
PM_{10}	685.2

Source: Gujarat Pollution Control Board 2012

Table 4.43: Surface water quality in Ahmedabad (3 most critical pollutants)

Pollutant	**Average concentration (mg/l)**
BOD	201.66
F-	1.53
NO_3	22.75

Source: Gujarat Pollution Control Board 2012

Table 4.44: Groundwater quality in Ahmedabad (3 most critical pollutants)

Pollutant	**Average concentration (mg/l)**
BOD	5.5
F-	1.35
NO3	35.45

Source: Gujarat Pollution Control Board 2012

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Ahmedabad industrial cluster has also been evaluated as shown in Table 4.45.

Table 4.45: Evaluation of pollution index scores for Ahmedabad Industrial Area

Criteria	IEPI Value
Air	63.25
Surface Water	67.75
Ground water	59.5
Overall IEPI of the Area	79.75

4.3.3.4 Comparison of the three area

A comparison of the IEPI values of the three selected industrial areas is presented in Table 4.46. As can be seen in Table 4.46, IEPI of Ankleshwar is 95.67 which makes it one of the most polluted industrial areas. Vapi with a score of 94.62 is also severely polluted. Constant monitoring and an efficient mitigation system is necessary to keep the increasing industrial pollution in those two areas.

Table 4.46 Comparison among IEPI values for the three areas

Area	IEPI Value
Vapi	94.62
Ankleshwar	95.67
Ahmedabad	79.75

4.3.4 Oil Refinery Industry Area

In oil or petroleum refinery, crude oil is processed and refined into different suitable petroleum products, such as diesel fuel, gasoline, heating oil, liquefied petroleum gas (LPG), kerosene and asphalt base. Oil refineries are usually large spreading industrial facilities with large piping systems to carry fluid streams from one large chemical processing unit to another. Oil refineries can be considered as one type of chemical plants which process petroleum products. The crude oil feedstock is used to be processed in a production plant. The bulk liquid products are stored in a tank farm (usually called an oil depot) which is generally located at or near an oil refinery.

An oil refinery is an important part located at the downstream side of an overall petroleum industrial establishments.

Although in India, mineral oil resources are found mainly in three important basins such as Mumbai High and Cambay Basin, Upper Assam or the Naharkatia-Moran region, processing of petroleum is done through different oil refineries which are spread in different parts of the country. The main oil refineries in India are located at Dighoi, Mumbai, Kayali, Barauni, Haldia, Mathura, Vishakhapatnam, Mangalore etc.

During the refining process, these refineries release different type of pollutants into the atmosphere which lead to substantial amount of air pollution, industrial wastewater effluents, odor and noise health problems in the nearby areas. There are also chances of risks associated with industrial accidents such as fire and explosion. Though most of the refineries have been using different equipment and technology to minimize pollution and comply with the prescribed standards of pollution control boards and environmental protection regulatory agencies, there is genuine public demand to restrict release of contaminants at public places.

The Integrated Environmental Pollution Index has been calculated for 3 main areas where oil refineries are located by evaluating sub-indices scores corresponding to air, surface water and groundwater as per the methodology presented in previous chapter.

4.3.4.1 Digboi Industry Area

Digboi industrial area is located in Indian state of Assam and is also named as the "Oil City of Assam" due to availability of crude oil in the area. It has the oldest running oilfield in the world. It is about 510 kilometers north east of Guwahati. It is also the Headquarter of Assam Oil Division of Indian Oil Corporation Limited. The city is well connected to the proper roadways which link Digboi Oil town to other towns and Dibrugarh-New Delhi railway line via New Tinsukia Junction. As per the 2001 census, it had a total population of 16,584 with 52% males population and 48% females population. The average literacy rate of Digboi is over 82%, which is higher than 59.5%, the national average literacy rate. Approximately 10% of the population is under the age of 6 years.

Pollution index scores have been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from Assam pollution control board.

Respiratory Suspended Particulate Matter (RSPM in $\mu g/m^3$), Suspended Particulate Matter (SPM in $\mu g/m^3$), nitrogen oxides (NOx in $\mu g/m^3$) can be considered as the critical parameters for air component in this cluster. The first two pollutants (i.e. RSPM and SPM) are from group B category whereas NOx is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.47.

Table 4.47: Average air pollutant concentration in Digboi (3 most critical pollutants)

Pollutant	**Average concentration ($\mu g/m^3$)**
RSPM	40
SPM	99.25
Nox	20

Source: Assam Pollution Control Board, 2012

Chromium (Cr in mg/l), Zinc (Zn in mg/l) and BOD_5 and (mg/l) can be considered as the 3 critical parameters for surface water component in this cluster. These pollutants (i.e. Cr, Zn and BOD_5) fall under group 'C', 'A' and 'B' category respectively. The observed values of these 3 critical parameters have been given in Table 4.48.

Table 4.48: Surface water quality in Digboi (3 most critical pollutants)

Pollutant	**Average concentration (mg/l)**
Cr	0.16
Zn	0.36
BOD_5	11

Source: Pollution Control Board, Assam, Water Quality Monitoring Data of Digboi 2012

Iron (Fe in mg/l), Total dissolved solids (TDS in mg/l), and Chloride (Cl^- in mg/l) have been considered as the 3 critical parameters for ground water quality falling within this cluster. The first pollutant (i.e. Fe) belongs to group 'A' category whereas TDS and Cl^- belong to group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.49.

Table 4.49: Groundwater quality in Dighboi (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
Fe	0.5
TDS	286
Cl-	18

Source: Pollution Control Board, Assam, Groundwater Quality Monitoring Data of Digboi, 2012

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Digboi industrial cluster has also been evaluated as shown in Table 4.50.

Table 4.50: Evaluation of pollution index scores for Digboi Industrial Area

Criteria	IEPI Value
Air	32.50
Surface Water	41.00
Ground water	33.00
Overall IEPI of the Area	47.33

4.3.4.2 Haldia Industrial Area

Haldia industrial area is located in East Midnapore district in Indian state of West Bengal. It is about 50 kilometers southwest of Calcutta near the mouth of the Hooghly River. It has also been developed as a major trade port for Kolkata. Some of the well-known industries in this region are Exide Limited, Haldia Petrochemicals, Hindustan Lever Limited, Indian Oil Corporation Limited (IOCL), Shaw Wallace, South Asian Petrochemicals Limited and Tata Chemicals, in addition to various light industries. Mitsubishi Chemical Corporation (MCC) has also its Terephthalic Acid Producing Plant in Haldia. The city is well connected to Kolkata by both roadways and railway lines. It is also connected through inland waterway (National Waterway Number 1) of 1620 km long running from Allahabad across Ganges, Bhagirathi and Hooghly river system to Haldia. As per the 2011 census, it had a total population of 200,762 with 52.22% males population and 47.78% females population. The average literacy rate of Digboi is over 89.06%, which is higher than 59.5%, the national average literacy rate. Approximately 10.52% of the population is under the age of 7 years.

Pollution index scores have been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from West Bengal pollution control board.

Benzene (in $\mu g/m^3$), Benzopyrene (in $\mu g/m^3$) and Carbon Monoxide (CO in $\mu g/m^3$ has been considered as the critical parameters for air component in this cluster. The two pollutants (i.e. Benzene and Benzopyrene) are from group 'C' category whereas remaining third pollutant (i.e. CO) is from group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.51.

Table 4.51: Ambient Air Quality Monitoring Data for Haldia, W.B.
(3 most critical pollutants)

Pollutant	Average concentration ($\mu g/m^3$)
Benzene	3
Benzopyrene	0.5
CO	2.5

Source: SGS India Ltd, 2012

Mercury (Hg in mg/l), Cyanide (CN in mg/l) and Phenolic compounds (in mg/l), have been considered as the 3 critical parameters for surface water quality falling within this cluster. All three pollutants belong to group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.52.

Table 4.52: Surface water Quality Data for Haldia, W.B. (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
Hg	0.0015
CN	0.18
Phenolic Compounds	0.17

Source: SGS India Pvt. Ltd, 2012

For assessing pollution level in groundwater in this cluster, COD (in mg/l), Fluoride (F^- in mg/l) and Phenolic compounds (in mg/l) have been considered as the 3 critical parameters. The first two pollutants (i.e. COD and F^-) fall under group 'B' category whereas the third pollutant (i.e. Phenolic compounds) is from group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.48.

Table 4.53: Ground water Quality Data for Haldia, W.B. (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
COD	17
F-	0.22
Phenolic Compounds	0.22

Source: SGS India Pvt. Ltd, 2012

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Haldia industrial cluster has also been evaluated as shown in Table 4.54.

Table 4.54: Evaluation of pollution index scores for Haldia Industrial Area

Criteria	IEPI Value
Air	65.75
Surface Water	72.50
Ground water	65.50
Overall IEPI of the Area	84.34

4.3.4.3 Panipat Industrial Area

Panipat is located in Indian state of Haryana and an ancient and historic city. It is about 90 kilometers north from New Delhi and 170 kilometers south of Chandidgarh. It is well known for handloom weaving industry, textiles and carpets and one of the biggest centre for quality blankets and carpets in India. Some of the well-known heavy industries in this region are Indian Oil Corporation's refinery, National Fertilizers Limited plant, National Thermal Power Corporation etc. As of 2011 India census, Panipat had a population of 4,42,277. Males constitute 53.58% of the population and females 46.42%.

Pollution index scores have been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from Central pollution control board, New Delhi.

Benzopyrene (in $\mu g/m^3$), Arsenic (As in $\mu g/m^3$), and Nickel (Ni in $\mu g/m^3$) have been considered as the critical parameters for air component in this cluster. The two pollutants (i.e. Benzopyrene and As) are from group 'C' category whereas remaining third pollutant (i.e. Ni) is from group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.55.

Table 4.55: Ambient Air Quality Monitoring Data for Panipat (3 most critical pollutants)

Pollutant	Average concentration ($\mu g/m^3$)
Benzopyrene	9.8
As	5.2
Ni	49.55

Source: Central Pollution Control Board, New Delhi 2012

For assessing pollution level in surface water in this cluster, BOD_5 (in mg/l), Arsenic (As in mg/l) and Fluoride (F^- in mg/l) have been considered as the 3 critical parameters. The two pollutants (i.e. BOD_5 and F^-) fall under group 'B' category whereas the third pollutant (i.e. As) is from group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.56.

Table 4.56: Surface water Quality Monitoring Data for Panipat (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
BOD_5	23
As	0.01
F-	0.17

Source: Central Pollution Control Board, New Delhi 2012

For assessing pollution level in groundwater in this cluster, BOD_5 (in mg/l), Fluoride (F^- in mg/l) and Nitrate (NO_3 in mg/l) have been considered as the 3 critical parameters. The two pollutants (i.e. BOD_5 and F^-) fall under group 'B' category whereas the third pollutant (i.e. NO_3) is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.57.

Table 4.57: Ground water Quality Monitoring Data for Panipat (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
BOD	21
F-	0.95
NO_3	9.55

Source: Central Pollution Control Board, New Delhi 2012

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Panipat industrial cluster has also been evaluated as shown in Table 4.58.

Table 4.58: Evaluation of pollution index scores for Panipat Industrial Area

Criteria	IEPI Value
Air	62.5
Surface Water	60.25
Ground water	61.50
Overall IEPI of the Area	76.33

4.3.4.4 Comparison of the three areas

A comparison of the IEPI values of the three selected industrial areas is presented in Table 4.59.

Table 4.59: Comparison IEPI values for the three areas

Area	IEPI Value
Digboi	47.33
Haldia	84.34
Panipat	76.33

From the above table, it can be inferred that Haldia industrial cluster is polluted heavily with its pollution index scores of 84.34. The surface water has the highest pollution sub index score because all three selected parameters (i.e. Mercury, Cyanide and Phenolic compounds) not only belong to group 'C' category but also their presence is significant. Large scale industrial activities from industries such as Exide Limited, Haldia Petrochemicals, Hindustan Lever Limited, Indian Oil Corporation Limited (IOCL), Shaw Wallace, South Asian Petrochemicals Limited and Tata Chemicals are responsible for high score of IEPI in Haldia. The refineries along with petrochemical industries discharge a number of carcinogenic pollutants and each one of these pollutants have a high value of exceedance factor. The IEPI score is low for Digboi as compare to Haldia and Panipat. This is due to the fact that Digboi has very less industries which also have lesser population. They also have technically efficient clean development mechanism to limit the discharges within permissible limit and for them exceedance factor is comparatively less.

4.3.5 Mixed Industrial Areas

Industrialization and urbanization provide a variety of opportunities to fulfill social objectives such as employment, gender equality, poverty eradication, labor standards, and greater access to resources and infrastructure. However, they may lead to negative impacts on environment, causing air and water pollution, climate change, losses of natural resources, biodiversity, and species. The Integrated Environmental Pollution Index has been calculated for three selected areas where rapid urbanization and industrialization have taken place due to population growth and development of infrastructure facilities.

4.3.5.1 Ghaziabad Industrial Area

Ghaziabad is located in Indian state of Uttar Pradesh. It is also known as "Gateway of UP" because it is very close to New Delhi. As per the 2011 census, it had a total population of 4,681,452 with 53% males population and 47% females population. The average literacy rate of Ghaziabad is over 93.81%, which is higher than 59.5%, the national average literacy rate. Ghaziabad has made a tremendous headway in industrial development during the last two decades. It has not only become one of the most important industrial districts of the state but also has come up on the industrial map of the country. One of the important factors that have given rise to its covetous position in industrial activities is proximity to New Delhi. The other contributing factors are well-knit road links and other infrastructural facilities. Ghaziabad has now become an industrial city consisting of various manufacturing activities pertaining to bicycles, diesel engines, automobile pistons and rings, glassware, heavy chains, electroplating, liquor, paint and varnish, picture tubes, pottery, railway coaches, tapestries, vegetable oil, pharmaceuticals, etc. It is one of the most industrialized cities in Uttar Pradesh. It is clear that a study on environmental impact of industrial development in Ghaziabad is of primary importance in order to assess the quality of environmental services and public health status in this area. Since, water, air and land are the three major component of any terrestrial ecosystem and periodic assessment of the quality of these important components may clear the picture of overall environmental quality.

Pollution index scores have been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from Central pollution control board, New Delhi.

Respiratory Suspended Particulate Matter (RSPM in $\mu g/m^3$), Suspended Particulate Matter (SPM in $\mu g/m^3$), Sulphur di oxide (SO_2 in $\mu g/m^3$) have been considered as the critical parameters for air component in this cluster. The first two pollutants (i.e. RSPM and SPM) are from group B category whereas SO_2 is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.60.

Table 4.60: Average air pollutant concentration in Ghaziabad (3 most critical pollutants)

Pollutant	Average concentration (ug/m^3)
RSPM	359.85
SPM	862.47
Sox	123.28

Source: Central Pollution Control Board, New Delhi 2012

Cadmium (Cd in mg/l), Lead (Pb in mg/l) and Biochemical oxygen demand at 5 days (BOD_5 in mg/l) can be considered as the 3 critical parameters for surface water component in this cluster. The two pollutants (i.e. Cd and Pb) are from group 'C' category whereas the remaining one pollutant (i.e. BOD_5) belong to group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.61.

Table 4.61: Surface water quality in Ghaziabad (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
Cd	0.95
Pb	1.05
BOD_5	21.8

Source: Central Pollution Control Board, New Delhi 2012

Cadmium (Cd in mg/l), Lead (Pb in mg/l) and Fluoride (F^- in mg/l) can be considered as the 3 critical parameters for surface water component in this cluster. The two pollutants (i.e. Cd and Pb) are from group 'C' category whereas the remaining third pollutant (i.e. F^-) belong to group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.62.

Table 4.61: Groundwater quality in Ghaziabad (3 most critical pollutants)

Pollutants	Average concentration (mg/l)
Cd	0.9
Pb	6.56
F-	1.7

Source: Central Pollution Control Board, New Delhi 2012

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values have been calculated. The overall pollution index score of Ghaziabad industrial cluster has also been evaluated as shown in Table 4.63.

Table 4.63: Evaluation of pollution index scores for Ghaziabad Industrial Area

Criteria	IEPI Value
Air	71
Surface Water	81.75
Ground water	72.75
Overall IEPI of the Area	91.18

4.3.5.2 Aligarh Industrial Area

Aligarh is located in Indian state of Uttar Pradesh. It is about 140 kilometers southeast from New Delhi. This industrial township is located in the middle land between the Ganges and the Yamuna river basins. The city is well connected to the National Highway numbers 91, 93 (NH 91, NH 93) and 6 Lane Noida-Agra Expressway and Northern railways. As per the 2011 census, Aligarh district has a total population of 36,73,849 with 53% males population and 47% females population. The average literacy rate of Aligarh is over 69.61%, which is higher than 65.4%, the national average literacy rate. Aligarh is one of the largest manufacturers of locks, brass fittings and hardware goods in India. Plastic and iron toy pistols, belts and badges for schools, handcuffs are also manufactured in Aligarh. Aluminum, iron, bronze and zinc products are also manufactured in the city. Aligarh is also a bulk producer of zinc die cast parts by hot chamber die casting process. Consumption of zinc alloy in Aligarh is the highest which is more than the rest of India. About 100 tonnes of brass and 50 tonnes of zinc are being processed every day.

Pollution index scores have been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from Uttar Pradesh Pollution Control Board.

Particulate Matter of size 10 micrometer or less (PM_{10} in μg/m^3), Benzopyrene (in μg/m^3) and Arsenic (As in μg/m^3) have been considered as the critical parameters for air component in this cluster. The two pollutants (i.e. Benzopyrene and As) are from group 'C' category whereas remaining third pollutant (i.e. PM_{10}) is from group 'B' category. The observed values of these 3 critical parameters have been given in Table 4.64.

Table 4.64: Average air pollutant concentration in Aligarh (3 most critical pollutants)

Pollutant	Average concentration (ug/m^3)
PM10	140.25
Benzopyrene	3.19
As	15.5

Source: Uttar Pradesh Pollution Control Board 2012

Biochemical oxygen demand at 5 days (BOD_5 in mg/l), Manganese (Mn in mg/l) and Iron (Fe in mg/l) have been considered as the 3 critical parameters for both surface water and groundwater falling within this cluster. The two pollutants (i.e. Mn and Fe) belong to group 'A' category whereas remaining third pollutant (i.e. BOD_5) belongs to group 'B' category. The observed values of these 3 critical parameters have been given in Tables 4.65 and 4.66.

Table 4.65: Surface water quality in Aligarh (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
BOD_5	62.03
Mn	0.165
Fe	0.905

Source: Uttar Pradesh Pollution Control Board 2012

Table 4.65: Groundwater quality in Aligarh (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
BOD_5	14.09
Mn	0.17
Fe	0.39

Source Uttar Pradesh Pollution Control Board 2012

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values are being calculated (Table 4.67).

Table 4.67: Evaluation of pollution index scores for Aligarh Industrial Area

Criteria	IEPI Value
Air	56.875
Surface Water	48
Ground water	45
Overall IEPI of the Area	66.27

4.3.5.3 Faridabad Industrial Area

Faridabad is located in Indian state of Haryana. It is a well-known industrial area situated in the National Capital Region bordering New Delhi. This industrial township is located in the middle land between the Ganges and the Yamuna river basins. The city is well connected to the National Highway numbers 2 and connected to North-Central railway lines. As per the 2011 census, Aligarh district has a total population of 1,404,653 with 53.42% males population and 46.58% females population. The average literacy rate of Aligarh is over 83.04%, which is higher than 65.4%, the national average literacy rate.

Faridabad is the industrial hub of Haryana. It is one of the largest manufacturers of Heena Production from the agricultural sector while tractors, motorcycles, switch gears, refrigerators, shoes and tyres are the famous industrial products of the city. It is a home to hundreds of large scale companies like ABB, ACE, ACC, Auto Ignition Limited, Bhartia cutler hammer, Escorts, Havell's, Indian Oil (R&D), JCB, L&T, Star Wire India Limited, Yamaha, Knorr Bremse, GoodYear, Whirlpool, etc.

Pollution index scores have been derived for this industrial cluster by assessing pollution level in air, surface water and ground water components using 3 critical parameters. Environmental monitoring data pertaining to ambient quality of air, surface water and ground water have been taken directly from Central Pollution Control Board, New Delhi.

Benzene (in $\mu g/m^3$), Benzopyrene (in $\mu g/m^3$) and Arsenic (As in $\mu g/m^3$) has been considered as the critical parameters for air component in this cluster. All three pollutants (i.e. Benzene, Benzopyrene and Arsenic) are from group 'C' category. The observed values of these 3 critical parameters have been given in Table 4.68.

Table 4.68: Average air pollutant concentration in Faridabad (3 most critical pollutant)

Pollutant	Average concentration (ug/m^3)
Benzene	3
Benzopyrene	9.54
As	4.8

Source: Central Pollution Control Board, New Delhi 2012

For assessing pollution level in surface water in this cluster, Biochemical Oxygen Demand (BOD_5 in mg/l), Fluoride (F^- in mg/l) and Phosphate (PO_4^{3-} in mg/l) have been considered as the 3 critical parameters. The first two pollutants (i.e. BOD_5 and F^-) are from group 'B' category, and remaining third pollutant (i.e. PO_4^{3-}) is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.69.

Table 4.69: Surface water quality at Faridabad (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
BOD_5	103.3
F-	0.775
PO_4^{3-}	13.9

Source: Central Pollution Control Board, New Delhi 2012

Biochemical Oxygen Demand (BOD_5 in mg/l), Fluoride (F^- in mg/l) and Nitrate (NO_3 in mg/l) have been considered as the 3 critical parameters to assess pollution level in groundwater in this cluster,. The first two pollutants (i.e. BOD_5 and F^-) are from group 'B' category, and remaining third pollutant (i.e. NO_3) is from group 'A' category. The observed values of these 3 critical parameters have been given in Table 4.70.

Table 4.70: Groundwater quality at Faridabad (3 most critical pollutants)

Pollutant	Average concentration (mg/l)
BOD	13.3
F-	0.75
NO_3	15.65

Source: Central Pollution Control Board, New Delhi 2012

As per the baseline data and other necessary information the individual air, surface water, groundwater EPI values are being calculated (Table 4.71).

Table 4.71: Evaluation of pollution index scores for Faridabad Industrial Area

Criteria	IEPI Value
Air	70.5
Surface Water	61.0
Ground water	64.75
Overall IEPI of the Area	82.15

4.3.5.4 Comparison of the three areas

A comparison of the IEPI values of the three selected industrial areas is presented in 4.72.

Table 4.72 Comparison among IEPI values for the three areas

Area	IEPI Value
Ghaziabad	91.18
Aligarh	66.27
Faridabad	82.15

From the above table, it can be seen that Ghaziabad is polluted heavily with pollution index score of 91.18 due to large scale industrial activities and heavy metal pollution whereas Aligarh with much less scale of industrial activities has a medium IEPI score. Air has the highest pollution sub index score because two critical parameters (i.e. RSPM and SPM) not only belong to group 'B' category but also have very high concentration.

The Residual Suspended Particulate Matter (RSPM) and Suspended Particulate Matter (SPM) in the industrial areas of this region have gone up significantly. The air has got much filthier than it used to be five years back. A major reason for this is that there is not only significant increase in number of vehicles (at least five-fold increase) on the city's roads but also industrial activities have increased 3 times. Large scale industrial activities such as dyeing units, paper plants, diesel engines, automobile pistons and rings, meat processing plants and many more hazardous chemical and manufacturing units pertaining to bicycles, glassware, heavy chains, electroplating, liquor, paint and varnish, picture tubes, pottery, railway coaches, tapestries, vegetable oil, pharmaceuticals, etc. are responsible for high score of IEPI in air, surface water and groundwater in Ghaziabad. In Sahibabad industrial area alone, there are about 400 highly polluting units, consisting of hundreds of dyeing units, paper plants, meat processing plants and other hazardous industrial units. There are about 90 brick kilns which are continuously emitting poisonous smoke/gases without any compliance to pollution control norms. There is no effective pollution enforcement plan in the region. Pollution index scores corresponding to both surface water and groundwater are also very high due to the fact that two out of three pollutants (i.e. Cd and Pb) not only belong to group 'C' category but also have their significant presence in ambient air. Industries located in this area discharge a number of carcinogenic pollutants and each one of these pollutants have a high value of exceedance factor. The IEPI score is low for Aligarh as compare to Ghaziabad and Faridabad. This is due to the fact that Aligarh has very less industries.

4.4 Analysis of the IEPI for the selected Industrial Sectors

A sector – wise ranges of IEPI scores is presented in Table 4.73 below. A comparison of IEPI values of various industrial sectors shows that the few of the steel producing industrial areas/ clusters (range 49.04 – 75.72) and oil refinery areas/ clusters (range 47.33 – 84.34) have relatively lesser IEPI score. The sectors with lower IEPI are in general better planned and systematically developed with better environmental management infrastructure. Also these industrial areas/ clusters are defined by the presence of a few major and well organized industries which are held directly responsible for the environmental upkeep of the surrounding area.

Table 4.73: Sector wise summary of IEPI scores

S. No.	Industrial Sector/ group	IEPI score range
1.	Steel Producing Industrial Areas (Durg-Bhillai, Durgapur and Jamshedpur)	49.04 – 75.72
2.	Coal Mining and Thermal Power Plant Areas (Dhanbad, Korba and Singrauli)	77.72 – 85.77
3.	Chemical Industry Areas (Vapi, Ankleshwar and Ahmedabad)	79.75 – 95.67
4.	Oil Refinery Areas (Dighboi, Haldia and Panipat)	47.33 – 84.33
5.	Mixed Industrial Areas (Ghaziabad, Aligarh and Faridabad)	66.27 – 91.18

It can be seen that the coal mining and thermal power plant areas/ clusters (IEPI values ranging from 77.72 to 85.77) and the chemical industry areas/ clusters are relatively more polluted (IEPI values ranging from 79.75 to 95.67). These areas/ clusters are dominated by a large number of industries having distinctly different types of emissions and waste disposal. Also these areas are dominated by a large number of small and medium scale industrial operations majority of which are privately owned and hence relatively less responsible collectively. Mixed industrial areas showed much variability in the IEPI score (ranging from 66.27 to 91.18) due to varying size, complex and varied mix type of industries in a given area/ cluster.

Overall, the IEPI scores are towards alarming level except for a very few industrial areas/ clusters. This indicates severe/ critical pollution levels and warrants necessary mitigate and remedial measures in order to sustain the industrial growth.

4.5 Summary

Industrial clusters which were established more than decades ago have now started contaminating significantly to different components of environment due to lack of proper action plans. It is very essential to monitor quality of environment in effective and efficient way. It becomes even more important in context to India, second most populous country, which is now being considered as one of the attractive destinations for investment due to large domestic consumer base and cheap labor for basing manufacturing and other industrial activities to serve the world market. Industries will definitely grow many-fold in years to come.

Though it is an opportunity to grow and perform well as a nation but it will also be a threat to the global environment including economic and social welfare. There are evidences of serious health problems among the people residing in different parts of these industrial clusters. As there are many industries in these areas which have been growing further, it may further lead to severe problems if not proper attention is given to improve quality of all components (i.e. air, surface water and groundwater) by ensuring these parameters within the prescribed standards of emissions and discharges using suitable treatment technology with sufficient capacity. Thus, there must be a regular mechanism to monitor quality of air, surface water and groundwater in addition to sensitizing all industries to control pollution in the region. It is now high time for regulating agencies to put honest efforts in the direction of implementing stricter monitoring especially for those units which pollute air, surface water and groundwater so that quality of environment within these industrial clusters do not only degrade further but also be improved at desirable level within the stipulated time frame. It has been observed that enforcement is not effective at all in many of the industrial clusters. These agencies should not only believe in issuing notices to polluting units for following compliance to pollution control norms but must enforce that polices formulated by them to control discharge of industrial pollutants are fully implemented in an effective manner. Polluting industries must be levied heavy penalty and can even face closure if they are not able to control pollutant emissions from their outlets.

CHAPTER 5

ENVIRONMENTAL IMPACT ASSESSMENT OF INDUSTRIAL CLUSTERS USING FUZZY DECISION ANALYSIS

5.1 Introduction

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 an environment 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 can be applied using fuzzy comprehensive assessment model. The model deals with assessment criterion set, weights set, assessment class set, membership function, fuzzy relation matrix, fuzzy combination and fuzzy assessment matrix which are explained in the following sections.

In chapter 4, the pollution indices were calculated separately for air, surface water and groundwater and lastly, aggregated to obtain the average IEPI value for each of the industrial cluster using equation (4.1). In this chapter, a few industrial clusters have been considered to evaluate overall IEPI for these industrial clusters using fuzzy comprehensive assessment model. Appropriate fuzzy rule base has been derived for sub-indices score of air, surface water and groundwater land and data are analyzed. This step helps in demarking the pollution intensity in various industrial clusters using fuzzy decision analysis.

5.2 Methodology

An integrated Air Pollution Index (IEPI) has been developed to assess quality of environment in different industrial clusters using Fuzzy Comprehensive Assessment Method (Tao and Xinmiao, 1998; Yan-jun and Mu-zhuang, 2007; Singh, 2008*;* Singh et al., 2015*)*. The results obtained from this method have been compared with those obtained using equation (4.1). To develop the integrated Air Pollution Index (IEPI), the complete methodology is summarized in the form of a flowchart as shown in Figure 5.1.

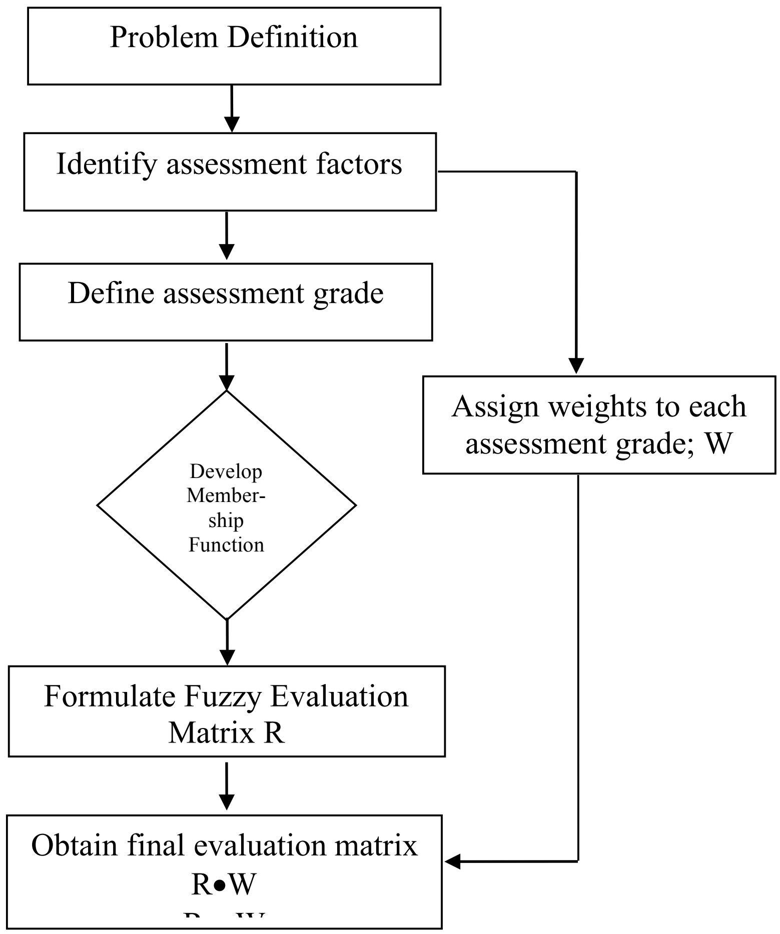

Fig. 5.1. Flow-chart of Integrated Fuzzy Assessment Model

5.2.1 Integrated Fuzzy Assessment Model

The integrated fuzzy assessment model is the application of fuzzy set theory, in which the aspiration levels concerning different objectives and classifications are not ordinary numbers, rather fuzzy numbers. The details of the topic can be found elsewhere (Sakawa 1993; Singh et al., 2007; Singh 2008 and Singh and Shrivastava, 2014).

For example, to assess the water quality of a stream, it is difficult to define a boundary between higher and lower water quality. There is a kind of ambiguity generated because of the absence of clear defined boundary between these objects. Fuzzy logic is a super set of conventional (or

Boolean) logic and contains similarities and differences with Boolean logic. The traditional Boolean logic uses 0 or 1 to describe the membership relation between one specific object and the class of this kind of objects. When, the object belongs to that class, the value of the characteristic function that describes the membership relation between one specific object and classification is 1, whereas the value is 0 when the specific object doesn't belong to the class completely. Using fuzzy logic it is easy to calculate the degree of an object to which it is a member. The grade of membership function can be achieved by adopting the concept of a membership function to assign a number ranging from zero (absolute not belonging) to unity (fully belonging) according to the degree of belongingness to each element.

5.2.1.1 Assessment criterion set

The first step in assessing status of pollution level is to identify prominent indicators/parameters which represent state of quality of environment. These indicators 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 indicators impact the status of overall quality of environment at a given station (Sharifi and Herwijnen, 2003; Singh and Vidyarthi, 2008).

The set U is described as an assessment factor set representing status of an environment 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, 3 important indicators (components or assessment factors) have been selected to assess overall status of environment.

5.2.1.2 Assessment class set

Each assessment criteria are 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 quality of the corresponding component of the environment. In this case, quality of environmental components such as air, surface water or groundwater is considered as good and pollution level is low hence scope for improving the quality status of environment is minimal. Therefore, the status of envirionment is optimistic; G_5 stands for the worst situation which is unfit and will have to be rejected. It indicates that 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 quality to the extent moderate, poor and very poor respectively, and require attention to improve the quality.

5.2.1.3 Weights set

As different components of environment may have different influences on the overall assessment of pollution index or quality of environment, a weight set, $W = \{W_1, W_2, \ldots, W_m\}$, represents importance weights of each component.

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 5.2.1.3.1 below.

5.2.1.3.1 Weighting of Environmental Components using AHP

The importance weight of any i^{th} component of environment (w_i) is assigned on the basis of relative importance of the component among all given components of environment in an industrial cluster. This can be determined either from the opinion of subject experts working in the area of pollution studies and environmental engineering or by performing pair-wise comparisons of these components. 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 (Hill et al., 2005; Thirumalaivasan et al., 2003). 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 components of environment (viz. air, surface water and groundwater) have been performed by asking opinion of subject experts' about relative importance of any i^{th} component over the j^{th} component. The weightage of individual component has been obtained by the "scale of relative importance" using Saaty's (1980) 9-point scale as given in Table 5.1.

All components 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} component in comparison with j^{th} component 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 $\lambda = n$.

Table 5.1: 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.

Table 5.2: Pair-wise comparison of different components of environment

Parameters	Air	Surface water	Ground water
Air	1.00	2.00	0.50
Surface water	0.50	1.00	1/3
Groundwater	2.00	3.00	1.00

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. 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 (5.1) 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 (5.2). Pair-wise comparisons can be considered 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 components of environment (viz. air, surface water and groundwater) are performed using Table 5.1 on Saaty's 9-point scale. In this process, an expert provides relative rating of i^{th} component by comparing it with j^{th} component for each pair (i, j), considering only two criteria at a time. The reciprocal ratings are shown in fractions. As in this case study there are three components, a 3x3 matrix has been derived while performing pair-wise comparisons which is given in Table 5.2.

Step 2: The normalized values of pair-wise comparison matrix is formulated by dividing each element of the matrix (i.e. Table 5.2) 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 be 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 components are evaluated accordingly.

Step 3: The level of inconsistency is checked using equations (5.1) and (5.2) given below:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{(n-1)} \tag{5.1}$$

$$CR = \frac{CI}{RI} \tag{5.2}$$

Where, CI is the inconsistency index, n is the dimension of payoff matrix which is same as number of components 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 5.3, 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 5.3: 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, $CR=\frac{3.005-3}{(3-1)\times 0.58}=0.0043<0.10$ (or less than 10%) so the evaluations are consistent. Thus the final weights (w_i) considered for each individual component are obtained after performing pair-wise comparisons of each component with respect to other components. The relative weights of air, surface water and ground water have been evaluated as 0.297, 0.163 and 0.540 respectively using Analytical Hierarchy Process (AHP) with consistency 0.0043.

The scores are relative and 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 was given to the groundwater by the experts as with score of equal importance as in the locality of these industrial clusters, people rely mainly on the groundwater and it may have severe impact on flora and fauna if contaminated. Moreover, pollution in groundwater is more or less an irreversible process. In spite of tremendous progress in technology advancement, restoration and treatment of polluted groundwater is a difficult task. It requires substantial investment for a long time, which is not realistic in present day context, especially in developing countries like India.

5.2.1.4 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 5.3:

$$R = \begin{bmatrix} \mu_{11}(x) & \mu_{12}(x) & \mu_{13}(x) & \ldots & \mu_{1n}(x) \\ \mu_{21}(x) & \mu_{22}(x) & \mu_{23}(x) & \ldots & \mu_{2n}(x) \\ \vdots & \vdots & \vdots & & \ldots \vdots \\ \mu_{m1}(x) & \mu_{m2}(x) & \mu_{m3}(x) & \ldots & \mu_{mn}(x) \end{bmatrix} \tag{5.3}$$

All elements of fuzzy relation matrix have been derived using Table 5.4 (derived from chapter 4) and Table 5.5 (derived on the basis of opinion of experts).

The values of grades G_i and the corresponding critical points were decided based on the practical significance of each component in context to locality of different industrial clusters. For example, the assessment factor, air, can be classified into five grades. Though the assessment class "moderate" has been expressed conventionally in the range between 20-40, it has been expressed by the trapezoidal membership function ranging from 10-45 (i.e. 10, 20, 35, 45) under fuzzy environment. The grade classifications of all three components are listed in Table 5.5.

The membership function of any components (U_1, U_2, U_3) have been evaluated with respect to five classification-grades. For example, membership of air component with respect to different grades can be evaluated using equations (5.4) to (5.8).

$$\mu_G(S_n) = \begin{cases} -0.0667(S_n - 15) + 1 & \text{for } 0.0 \le S_n \le 15 \\ 0; & \text{otherwise} \end{cases} \tag{5.4}$$

$$\mu_M(S_n) = \begin{cases} 0.1(S_n - 10) & \text{for } 10.0 \le S_n \le 20 \\ 1 & \text{for } 20.0 \le S_n \le 35 \\ -0.1(S_n - 45) & \text{for } 35.0 \le S_n \le 45 \\ 0; & \text{otherwise} \end{cases} \tag{5.5}$$

$$\mu_P(S_n) = \begin{cases} 0.1(S_n - 35) \text{ for } 35.0 \le S_n \le 45 \\ 1 \quad \text{for } 45.0 \le S_n \le 60 \\ -0.1(S_n - 70) \text{ for } 60.0 \le S_n \le 70 \\ 0; \quad \text{otherwise} \end{cases} \tag{5.6}$$

$$\mu_{VP}(S_n) = \begin{cases} 0.1(S_n - 60) \text{ for } 60.0 \le S_n \le 70 \\ 1 \quad \text{for } 70.0 \le S_n \le 85 \\ -0.1(S_n - 95) \text{ for } 85.0 \le S_n \le 95 \\ 0; \quad \text{otherwise} \end{cases} \tag{5.7}$$

$$\mu_S(S_n) = \begin{cases} 0.0667(S_n - 85) \text{ for } 85.0 \le S_n \le 100 \\ 1; \quad \text{for } S_n \ge 100 \\ 0; \quad \text{otherwise} \end{cases} \tag{5.8}$$

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

Table 5.4: Pollution Index Score of Different Industrial Clusters

S. No.	Name of the Industrial Cluster	Air Pollution Index	Surface Water Pollution Index	Groundwater Pollution Index
1.	Durg-Bhilai	42.50	32.50	35.00
2.	Durgapur	56.50	66.00	50.00
3.	Jamshedpur	69.00	65.50	38.00
4.	Dhanbad	61.50	62	64
5.	Korba	69	59	76
6.	Singraulli	74	64.75	64
7.	Vapi	84.75	83.50	77.50
8.	Ankleshwar	84.50	84.75	84.75
9.	Ahmedabad	63.25	67.75	59.5
10.	Dighboi	32.5	41	33
11.	Haldia	65.75	72.50	65.50
12.	Panipat	62.5	60.25	61.5
13.	Ghaziabad	71	81.75	72.75
14.	Aligarh	56.875	48	45
15.	Faridabad	70.5	61	64.75

Table 5.5: 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		
	Air	Surface water	Groundwater
Good	Triangular (0, 0, 15)	Triangular (0, 0, 15)	Triangular (0, 0, 15)
Moderate	Trapezoidal (10, 20, 35, 45)	Trapezoidal (10, 20, 35, 45)	Trapezoidal (10, 20, 35, 45)
Poor	Trapezoidal (35, 45, 60, 70)	Trapezoidal (35, 45, 60, 70)	Trapezoidal (35, 45, 60, 70)
Very poor	Trapezoidal (60, 70, 85, 95)	Trapezoidal (60, 70, 85, 95)	Trapezoidal (60, 70, 85, 95)
Severe	Triangular (85, 100, 100)	Triangular (85, 100, 100)	Triangular (85, 100, 100)

5.2.1.5 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 environmental pollution index in different industrial clusters. The elements of fuzzy combination matrix can be derived using equation (5.9).

$$B = W \bullet R = \begin{bmatrix} W_1 & W_2 & W_3 \dots W_m \end{bmatrix} \bullet \begin{bmatrix} \mu_{11}(x) & \mu_{12}(x) & \dots \mu_{1n}(x) \\ \mu_{21}(x) & \mu_{22}(x) & \dots \mu_{2n}(x) \\ \vdots & \vdots & \dots \vdots \\ \mu_{m1}(x) & \mu_{m2}(x) & \dots \mu_{mn}(x) \end{bmatrix} \quad (5.9)$$

Using equation (5.9), fuzzy combination matrix $B = \lfloor b_j \rfloor_{1\times n}$ is evaluated for each industrial cluster. Finally, the integrated assessment value F_k is evaluated at any k^{th} industrial cluster by integrating effects of all grades using equation (5.10):

$$F_k = \frac{\sum_{j=1}^{n} b_j \alpha_j}{\sum_{j=1}^{n} b_j} \quad (5.10)$$

Where b_j (j = 1,..,n) are the elements of fuzzy combination matrix representing integrated assessment value at each industrial cluster corresponding to all possible grades. The value of F_k is the comprehensive grade of status of environment for a given industrial cluster k. In order to express the status of pollution 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. These grades are further represented by the triangular membership functions as specified in Table 5.6. The membership function for each parameter corresponding to a given grade at a particular station can be derived accordingly.

Table 5.6: Fuzzy Membership functions for different grades of overall AQI Score (S_n)

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

If [$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ = 0.0, 0.25 0.5, 0.75, 1.0], the overall integrated environmental pollution index score with respect each grade for a given industrial cluster is calculated using above equations and total score for each industrial cluster is computed by defuzzifyng fuzzy score using equation (5.11):

$$F_k = \mu_{G1}(S_n)\times 0.00 + \mu_{G2}(S_n)\times 0.25 + \mu_{G3}(S_n)\times 0.5 + \mu_{G4}(S_n)\times 0.75 + \mu_{G5}(S_n)\times 1.0 \qquad (5.11)$$

On the basis of final score, environmental status for each industrial cluster has been ranked. If the final score is lower, the quality of environment is better.

5.3 Results and Discussions

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 5.5. The membership functions of all components have been derived with respect to five classification-grades on the basis of their calculated sub-indices on pollution. The fuzzy relation matrix R at each sampling station is calculated accordingly. The importance weight of each component as stated earlier has been considered to calculate integrated fuzzy assessment values using equation (5.9) [i.e. $W = \{W_1, W_2, W_3\} = \{0.297, 0.163, 0.540\}$ where $0 \le w_i \le 1$] and given in Table 5.7.

Table 5.7: Computation of membership values of various environmental component for selected industrial clusters with respect to a grade

Industrial Clusters	Membership grades for air Component					Membership grades for surface water					Membership grades for groundwater				
	G1	G2	G3	G4	G5	G1	G2	G3	G4	G5	G1	G2	G3	G4	G5
Durg-Bhilai	0	0.25	0.75	0	0	0	1	0	0	0	0	1	0	0	0
Durgapur	0	0	1	0	0	0	0	0.4	0.6	0	0	0	1	0	0
Jamshedpur	0	0	0.10	0.90	0	0	0	0.45	0.55	0	0	0.7	0.30	0	0
Dhanbad	0	0	0.85	0.15	0	0	0	0.8	0.2	0	0	0	0.6	0.4	0
Korba	0	0	0.1	0.9	0	0	0	1	0	0	0	0	0	1	0
Singraulli	0	0	0	1	0	0	0	0.525	0.475	0	0	0	0.6	0.4	0
Vapi	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0
Ankleshwar	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0
Ahmedabad	0	0	0.675	0.325	0	0	0	0.225	0.775	0	0	0	1	0	0
Digboi	0	1	0	0	0	0	0.4	0.6	0	0	0	0.7	0.3	0	0
Haldia	0	0	0.4	0.6	0	0	0	0	1	0	0	0	0.45	0.55	0
Panipat	0	0	0.75	0.25	0	0	0	0.975	0.025	0	0	0	0.85	0.15	0
Ghaziabad	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0
Aligarh	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0
Faridabad	0	0	0	1	0	0	0	0.9	0.1	0	0	0	0.525	0.475	0

Table 5.8: Fuzzy Integrated Assessment Values

Industrial Clusters	G1	G2	G3	G4	G5	Final Score	Rank
Durg-Bhilai	0.000	0.777	0.223	0.000	0.000	0.306	2
Durgapur	0.000	0.000	0.902	0.098	0.000	0.524	5
Jamshedpur	0.000	0.378	0.265	0.357	0.000	0.495	3
Dhanbad	0.000	0.000	0.707	0.293	0.000	0.573	8
Korba	0.000	0.000	0.193	0.807	0.000	0.702	12
Singraulli	0.000	0.000	0.410	0.590	0.000	0.648	10
Vapi	0.000	0.000	0.000	1.000	0.000	0.750	14
Ankleshwar	0.000	0.000	0.000	1.000	0.000	0.750	15
Ahmedabad	0.000	0.000	0.777	0.223	0.000	0.556	7
Dighboi	0.000	0.902	0.098	0.000	0.000	0.274	1
Haldia	0.000	0.000	0.362	0.638	0.000	0.660	11
Panipat	0.000	0.000	0.841	0.159	0.000	0.540	6
Ghaziabad	0.000	0.000	0.000	1.000	0.000	0.750	13
Aligarh	0.000	0.000	1.000	0.000	0.000	0.500	4
Faridabad	0.000	0.000	0.430	0.570	0.000	0.642	9

Table 5.7 lists the memberships of three environmental components as assessment factors with respect to the five classifications for 15 different industrial clusters. These scores can essentially help to explore the problem areas in context to overall environmental pollution attention at a particular industrial cluster. For example, memberships of air pollution index corresponding to G_4 (i.e. very poor) show that industrial clusters such as Singraulli, Vapi, Ankaleshwar, Ghaziabad, and Faridabad have very high score (i.e. 1.0). Thus the air quality of these industrial clusters is very poor. Similarly, memberships of surface water component corresponding to G_4 (i.e. very poor) also indicate that surface water quality is very poor in industrial clusters such as Vapi, Ankaleshwar, Haldia and Ghaziabad, because they have their membership functions as 1.0. The membership value of groundwater component corresponding to G_4 (i.e. very poor) is also 1.0 in industrial clusters such as Korba, Vapi, Ankaleshwar and Ghaziabad which clearly explains about the existence of very poor quality of groundwater or high pollution index of groundwater.

Thus, if the issues related to air pollution, surface water pollution and groundwater pollution can be addressed in these industrial clusters in an effective manner, the overall quality of environment can be achieved at the desired level. In fact the high concentration of air pollutants and water pollutants are responsible factors to increase overall scores in these clusters (as explained in chapter 4) leading the degradation of overall quality of the environment as can be inferred from Table 5.7. Therefore, it is high time to focus on reducing excess of these pollutants, and building up the consciousness among masses for not polluting further so that overall quality of environment in these clusters can be improved.

The final fuzzy integrated assessment values are also calculated using equations (5.10) and (5.11) as listed in the Table 5.8. These values are given as 0.306, 0.524, 0.495, 0.573, 0.702, 0.648, 0.750, 0.750, 0.556, 0.274, 0.660, 0.540, 0.750, 0.500 and 0.642 for industrial clusters Durg-Bhilai, Durgapur, Jamshedpur, Dhanbad, Korba, Singraulli, Vapi, Ankleshwar, Ahmedabad, Dighboi, Haldia, Panipat, Ghaziabad, Aligarh, and Faridabad respectively. From Table 5.8, it is clear that sampling stations Digboi and Durg-Bhilai have higher integrated fuzzy assessment value with respect to grade "moderate" than that with respect to all other grades and therefore the overall quality status of environment falls under “good” condition with their ranking order 1 and 2 respectively. In fact, there exist zero scores corresponding to very poor and severe conditions for these two industrial clusters. All industrial clusters have zero scores corresponding to severe classification. Though sampling stations Korba, Haldia, Singrauli, Faridabad, Dhanbad and Ahmedabad score 0.193, 0.362, 0.410, 0.430, 0.707 and 0.777 respectively under "Poor i.e. G3 grade" condition, they also score 0.807, 0.638, 0.590, 0.570, 0.293 and 0.223 respectively under "Very Poor i.e. G4 grade" condition. The combined effect of these scores of these score leads to increase the pollution level in the respective industrial cluster and hence they get lower ranks as specified in Table 5.8. Similarly, Vapi, Ankleshwar, Ghaziabad clusters score 1.0 each under "Very Poor" condition along with the overall fuzzy IEPI score of 0.750 each. They have been assigned the lowest rank implying highest level of pollution.

5.4 Summary

A fuzzy based decision analysis has been presented in this study to assess impact of different industrial clusters on 3 important components of environment viz. air, surface water and groundwater. The final IEPI score evaluated in Chapter 4 is based on the basis of maximum sub-indices score in each industrial cluster though remaining two lower sub-indexes derived from other components are also incorporated. The fuzzy comprehensive analysis method presented in this chapter 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 environmental pollution index using fuzzy comprehensive analysis method seem to be particularly promising and better over method presented in Chapter 4.

Fifteen industrial have been compared to explain working and implementation of the ranking algorithm. These clusters are Durg-Bhilai, Durgapur, Jamshedpur, Dhanbad, Korba, Singraulli, Vapi, Ankleshwar, Ahmedabad, Dighboi, Haldia, Panipat, Ghaziabad, Aligarh, and Faridabad. To get a better insight, integrated environmental pollution index scores were classified into three components of environment: air, surface water and groundwater.

These scores obtained in Table 5.7 are useful to explore the problem areas in context to specific component of environmental pollution of a given industrial cluster. It has been inferred that five industrial clusters, namely Singraulli, Vapi, Ankaleshwar, Ghaziabad, and Faridabad have 'very poor' quality of air with highest membership score of 1.0 corresponding to grade G_4. The degradation in air quality at Singarulli is mainly due to high concentrations of RSPM. Two pollutants (i.e. Benzene and VOCs of group C category) and RSPM of 'B' category are responsible for air pollution in Vapi area whereas group 'C' Pollutant Benzene and RSPM are the main cause of air pollution in Ankleshwar. Two group 'B' pollutants (viz. RSPM and SPM) are the cause of air pollution in Ghaziabad. Three group 'C' pollutants (viz. Benzene, Benzopyrene and Arsenic) are the main source of air pollution in Faridabad industrial area. These fine pollutants 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.

Similarly, surface water condition has been found 'very poor' in Vapi, Ankaleshwar, Haldia and Ghaziabad industrial clusters. Similarly, 'very poor' condition of groundwater has been found in Korba, Vapi, Ankaleshwar and Ghaziabad clusters.

There are evidences of serious health problems among the people residing in this region. As there are many industries in these areas which have been growing further, it may further lead to severe problems if not proper attention is given to improve quality of all components (i.e. air, surface water and groundwater) by ensuring these parameters within the prescribed standards of emissions and discharges. It is required to upgrade effluent treatment plants and stricter monitoring especially for those units which pollute air, surface water and groundwater so that quality of environment within the industrial cluster can be improved. The prime health effects caused by excess of these pollutants may be premature death; irritation of respiratory and cardiovascular disease, cancer etc. Thus, there must be a regular mechanism to monitor quality of air, surface water and groundwater in addition to sensitizing all industries 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. Thus if immediate steps are not taken soon to control pollution it will be difficult to reverse the process.

CHAPTER 6

SENSITIVITY ANALYSIS OF IEPI

6.1 Introduction

Sensitivity analysis (SA) is the study of how the variation in the output of a mathematical model can be apportioned, qualitatively or quantitatively if there exist different sources of variation in the input of the model. In more general terms sensitivity analysis investigates the robustness of a study by demonstrating cause-effect relationship using a mathematical model. The results obtained through this process are useful to the decision makers to choose the best option as per their objectives, requirements, resources and capacity.

The methodology developed in chapter 3 evaluates integrated environmental pollution index (IEPI) for selected industrial cluster. A useful application of the methodology is to test the behavior of sensitivity of the model due to changes in different factors. If IEPI for different industrial sites are evaluated, sensitivity analysis can be carried out for each perturbing parameter separately to assess the variations in IEPI. Based on the requirement of the decision maker, the combined effect of more than one parameter can also be studied, if required. If a small change in the parameter produces large changes in the final score of IEPI, this score is said to be sensitive to the parameter and appropriate treatment methodologies/remedial action plans are to be worked out to improve or satisfy the final score of IEPI obtained for an industrial cluster with respect to the chosen parameter. If the final score is not sensitive to a perturbed parameter, it means that the present score is satisfactory. By knowing sensitiveness of each parameters, decision makers can prioritize his/her decisions of making improvements among those parameters so that overall IEPI can be minimized to improve quality of environment in a specific industrial cluster.

6.2 Sensitivity analysis of IEPI with presence of toxin

As shown in equation (3.8), the overall pollution index score for any ith industrial cluster with respect to jth component of environment is a function of the pollution index score due to information available on presence of toxins and type of industrial activities (i.e. $S_{i,j}$), pollution index score due to information available on presence of ambient pollutant concentration and their impact on people and eco-geological features (i.e. $P_{i,j}$), pollution index score obtained due to impact of ith industrial cluster on receptors affected within the specified boundary from the industrial pollution source (i.e. $R_{i,j}$) and additional pollution index score (R_{Add}) assigned for an industrial cluster due to high risk on receptors associated with insufficient measures of pollution control corresponding to large-scale, medium-scale or small-scale industries.

The pollution index score due to information available on presence of toxins and type of industrial activities (i.e. $S_{i,j}$) is further a function of $S_{c,i,j}$ (i.e. the pollution index score due to 3 most critical pollutants present at the source depending upon their toxicity and carcinogenicity) and $\Delta_{i,j}$ (i.e. penalty factor) and Q_i (i.e. type of industrial activities at the source). Thus, the information available on presence of toxins (including penalty factor) can be taken as one of the decision variables (factors) to perform sensitivity analysis. The other consideration may be availability of type of industrial activities (i.e. Q_i).

Let A_1 is the score based on information available on presence of toxins (including penalty factor) then it can be expressed as $A_1 = S_{c,i,j} + \Delta_{i,j}$. If scores pertaining to presence of toxins (including penalty factor) are varied from minimum to maximum values while keeping other parameters (factors) same, sensitivity analysis of EPI can be performed to assess presence of toxins influence the EPI scores derived for an industrial cluster with respect to a given environmental component.

For the analysis, 5 industrial areas have been selected to demonstrate the methodology. They are Ankleshwar, Digboi, Vapi, Jamshedpur and Haldia.

6.2.1 Sensitivity analysis of EPI for Ankleshwar

Air, surface water and groundwater EPI values have been calculated for Ankleshwar with respect to different values of A1 representing presence of toxins with penalty factor. Figures 6.1 shows variation of air, surface water and groundwater EPI with different A1 scores varying from minimum (i.e. 1.0) to maximum (i.e. 7.0) while keeping other parameters (factors) same.

It has been observed that the reduction in A1 score pertaining to presence of toxins (including penalty factor) in Ankleswar industrial cluster from its present value of 6.5 to desirable value of 1.0 tends to reduce air EPI score from 84.50 to 57.00 (32.54%). Based on the magnitude of the variation in the final score of EPI, it appears that there is significant scope to improve EPI if toxicity level in this cluster is reduced by adopting appropriate mitigating measures and adoption of cleaner technology options coupled with improved infrastructure for effluent and waste management. Clearly one should restrict emissions of pollutants falling in the category of B (e.g. RSPM) and C (e.g. Benzene) to achieve A1 score as 1.0 so that EPI score remain up to 57.00. Similarly, air EPI scores of 62.0, 67.0, 85.75 and 87.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.75 and 7.0 respectively as shown in Fig. 6.1. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the air. In that case if A1 score in Ankleswar industrial cluster increases from its present value of 6.5 to expected value of 7.0, air EPI score increases from 84.50 to 87.00 (2.95%) stating that severity of air pollution level in the area will further increase.

It can also be inferred that the reduction in A1 score pertaining to presence of toxins (including penalty factor) in Ankleswar industrial cluster from its present value of 6.75 to desirable value of 1.0 tends to reduce scores of surface water EPI and groundwater EPI score from 84.75 to 51.00 (39.82%) and 84.75 to 52.00 (38.64%) respectively. Based on the magnitude of the variation in the final score of EPI, it is clear that there is significant scope to improve surface water EPI by reducing toxicity level in the cluster using appropriate mitigating measures and cleaner technology options for industrial effluent and wastewater treatments. Clearly one should restrict discharging of pollutants falling in the category of C (e.g. Phenol and Oil and Grease) and ensuring absence of B group water pollutants to achieve A1 score as 1.0 so that surface water EPI score remains 51.00. Similarly, surface water EPI scores of 59.0, 65.50, 83.50 and 86.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.5 and 7.0 respectively as shown in Fig. 6.1. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the air. In that case if A1 score in Ankleswar industrial cluster increases from its present value of 6.75 to expected value of 7.0, surface water EPI score increases from 84.75 to 86.00 (1.47%) stating that severity of surface water pollution level in the area will further increase.

Figure 6.1 also shows that groundwater EPI scores of 57.0, 65.5.0, 83.00 and 86.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.5 and 7.0 respectively. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the air. In that case if A1 score in Ankleswar industrial cluster increases from its present value of 6.75 to expected value of 7.0, groundwater EPI score increases from 84.75 to 86.00 (1.47%) stating that severity of air pollution level in the area will further increase. The percentage increase in groundwater EPI is low because existing air EPI is already very high (i.e. 84.50) indicating that this cluster is highly polluted under present scenario.

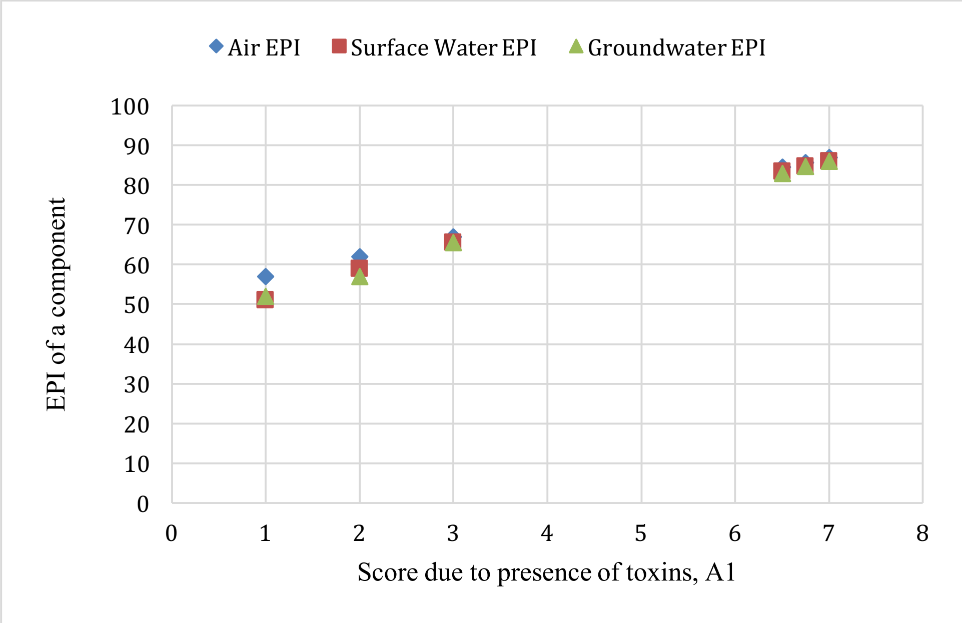

Fig. 6.1: Variation of air, surface water and groundwater EPI scores with A1 scores for Ankleshwar

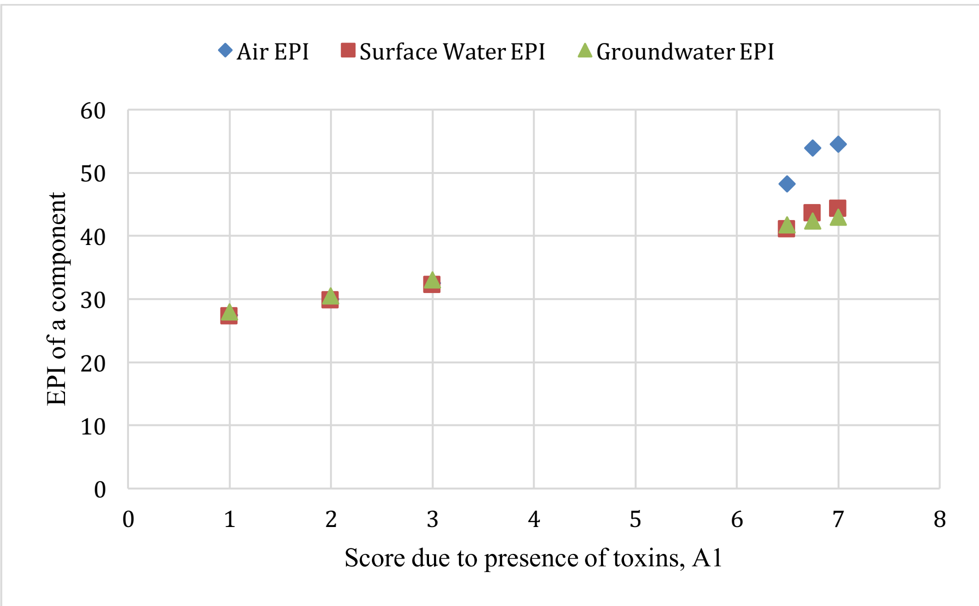

Fig. 6.2: Variation of air, surface water and groundwater EPI scores with A1 scores for Digboi

6.2.2 Sensitivity analysis of EPI for Digboi

Air, surface water and groundwater EPI values have been calculated for Digboi with respect to different values of A1 (representing presence of toxins). Figures 6.2 shows variation of air, surface water and groundwater EPI with different A1 scores varying from minimum (i.e. 1.0) to maximum (i.e. 7.0) while keeping other parameters same.

If A1 score (i.e. the score representing presence of toxins with penalty factor) in Digboi industrial cluster is reduced from its present value of 3.0 to desirable value of 1.0 (say) then air EPI score is reduced from 32.50 to 27.5 (15.38%). Thus reduction in score due to presence of toxins from 3.0 to 1.0 in Digboi has less variation in air EPI score as compare to Ankleshwar. This may be due to the fact that Digboi is one of the least polluted industrial cluster among all 15 clusters taken for the study. However, there is still a scope to improve air EPI if toxicity level in this cluster is reduced by adopting appropriate mitigating measures and adoption of cleaner technology options for emissions of gaseous pollutants. Clearly one should restrict emissions of pollutants of category 'B' (e.g. RSPM, SPM) and ensuring absence of any group "C" air pollutant to achieve A1 score as 1.0 so that air EPI score remains 27.50. Similarly, air EPI scores of 30.0, 48.25, 53.88 and 54.50 can be obtained with respect to A1 score of 2.0, 6.5, 6.75 and 7.0 respectively as shown in Fig. 6.2. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the air. In that case if A1 score in Digboi industrial cluster increases from its present value of 3.0 to expected value of 7.0, air EPI score increases from 32.50 to 54.50 (67.69%) stating that there will be significant increase in severity of air pollution level in the area. Therefore, if number of industries are to be increased in this cluster, it is necessary to implement effective and efficient action plans from the beginning itself so that air pollution can be minimized.

It can also be inferred that the reduction in A1 score pertaining to presence of toxins (including penalty factor) in Digboi industrial cluster from its present value of 6.5 to desirable value of 1.0 tends to reduce scores of surface water EPI from 41.00 to 27.25 (50.49%). Based on the magnitude of the variation in the final score of surface water EPI, it is clear that there is significant scope to improve surface water EPI by reducing toxicity level in the cluster using appropriate mitigating measures and cleaner technology options for industrial effluent and wastewater treatments. Clearly one should restrict discharging of pollutants falling in the category of B (e.g. BOD_5) and C (e.g. total chromium) to achieve A1 score as 1.0 so that surface water EPI score remains 27.25. Similarly, surface water EPI scores of 29.75, 32.25, 43.625 and 44.25 can be obtained with respect to A1 score of 2.0, 3.0, 6.75 and 7.0 respectively as shown in Fig. 6.2.

Figure 6.2 also shows that if A1 score pertaining to presence of toxins (including penalty factor) in Digboi industrial cluster is reduced from its present value of 3.0 to desirable value of 1.0, it will reduce scores of groundwater EPI from 33.00 to 28 (15.15%). Thus reduction in score due to presence of toxins from 3.0 to 1.0 in Digboi has less variation in groundwater EPI score as compare to Ankleshwar. This may be due to the fact that Digboi is one of the least polluted industrial cluster among all 15 clusters taken for the study. It can also be observed that groundwater EPI scores of 30.50, 41.75, 42.38 and 43.00 can be obtained with respect to A1 score of 2.0, 5.5, 6.75 and 7.0 respectively. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the groundwater. In that case if A1 score in Digboi industrial cluster increases from its present value of 3.0 to expected value of 7.0 (say), groundwater EPI score increases from 33.00 to 43.00 (30.30%) stating that severity of groundwater pollution level in the area will increase significantly.

6.2.3 Sensitivity analysis of EPI for Vapi

Air, surface water and groundwater EPI values have been calculated for Vapi with respect to different values of A1 (representing presence of toxins). Figures 6.3 shows variation of air, surface water and groundwater EPI with different A1 scores varying from minimum (i.e. 1.0) to maximum (i.e. 7.0) while keeping other parameters same.

It has been inferred that the reduction in A1 score (representing presence of toxins with penalty factor) in Vapi industrial cluster is reduced from its present value of 6.75 to desirable value of 1.0 (say) then air EPI score is reduced from 84.75 to 56.00 (33.92%). Thus reduction in score due to presence of toxins from 6.75 to 1.0 in Vapi has almost similar variation in air EPI score as obtained in Ankleshwar. This may be due to the fact that Vapi is also one of the most polluted industrial cluster among all 15 clusters taken for the study.

Thus, air EPI can be improved if toxicity level is reduced by adopting appropriate mitigating measures and adoption of cleaner technology options for emissions of gaseous pollutants. Clearly one should not only restrict emissions of air pollutants of group ‘C’ (e.g. Benzene, VOCs) and group ‘B’ (e.g. RSPM) but also ensure absence of these air pollutants in future to achieve A1 score as 1.0 so that air EPI score remains 56.00. Similarly, air EPI scores of 61.0, 66.0, 83.50 and 86.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.5 and 7.0 respectively as shown in Fig. 6.3. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the air. In that case if A1 score in Vapi industrial cluster increases from its present value of 6.75 to expected value of 7.0, air EPI score increases from 84.75 to 86.00 (1.47%) stating that severity of air pollution level in the area will further increase though the percentage increase in air EPI is low because existing air EPI is already very high (i.e. 84.75) indicating that this cluster is highly polluted under present scenario.

It can also be inferred that the reduction in A1 score pertaining to presence of toxins (including penalty factor) in Vapi industrial cluster from its present value of 6.5 to desirable value of 1.0 tends to reduce scores of surface water EPI score from 83.50 to 45.00 (46.11%). Based on the magnitude of the variation in the final score of EPI, it is clear that there is significant scope to improve surface water EPI by reducing toxicity level in the cluster using appropriate mitigating measures and cleaner technology options for industrial effluent and wastewater treatments. Clearly one should not only restrict discharging of surface water pollutants of group 'C' (e.g. Oil and Grease) and group 'B' (e.g. COD) but also ensure absence of these surface water pollutants in coming future to achieve A1 score equal to 1.0 so that surface water EPI score remains 45.00. Similarly, surface water EPI scores of 60.50, 65.50, 84.75 and 86.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.75 and 7.0 respectively as shown in Fig. 6.3. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the air. In that case if A1 score in Vapi industrial cluster increases from its present value of 6.5 to expected value of 7.0, surface water EPI score increases from 83.50 to 86.00 (2.99%) stating that severity of surface water pollution level in the area will further increase.

Figure 6.3 also shows that if A1 score pertaining to presence of toxins with penalty factor in Vapi industrial cluster is reduced from its present value of 6.75 to desirable value of 1.0, it will reduce scores of groundwater EPI from 77.50 to 44.00 (43.23%). The percentage reduction of groundwater EPI is quite high which may be due to the fact that groundwater condition in Vapi industrial cluster is also highly polluted.

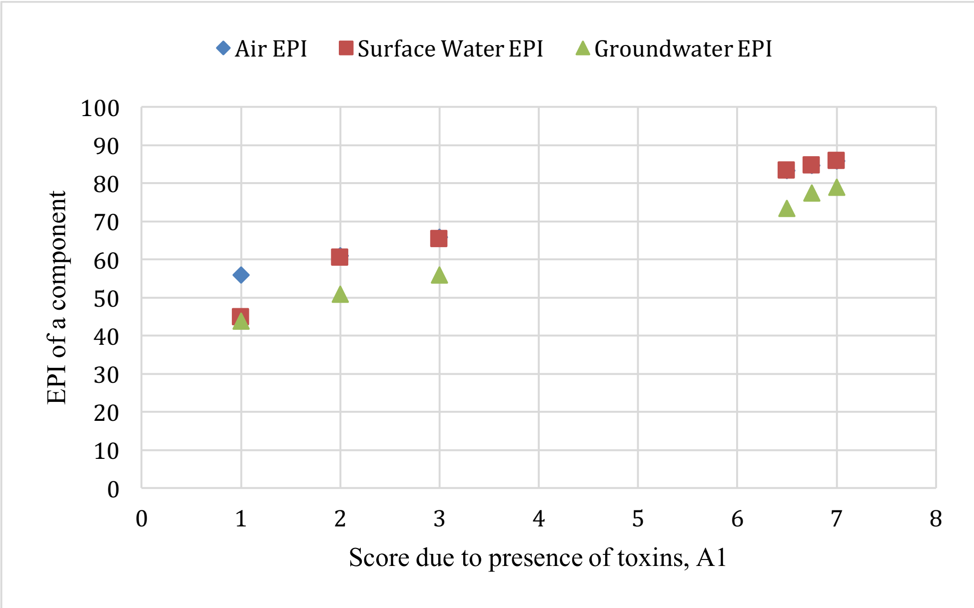

Fig. 6.3: Variation of air, surface water and groundwater EPI scores with A1 scores for Vapi

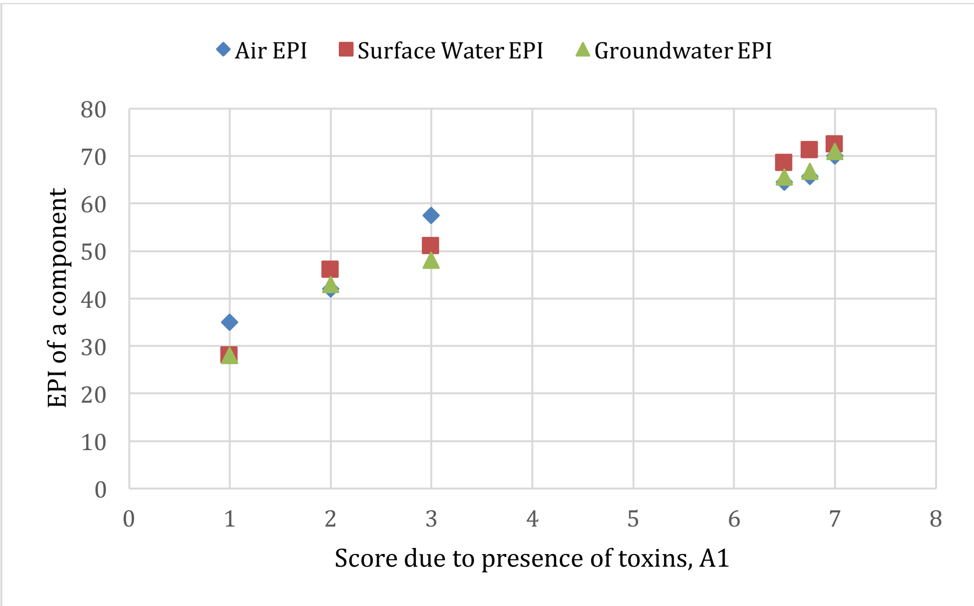

Fig. 6.4: Variation of air, surface water and groundwater EPI scores with A1 scores for Haldia

Figure 6.3 also shows that groundwater EPI scores of 51.0, 56.00, 73.50 and 79.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.5 and 7.0 respectively. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the groundwater. In that case if A1 score in Vapi industrial cluster increases from its present value of 6.75 to expected value of 7.0, groundwater EPI score increases from 77.50 to 79.00 (1.93%) stating that severity of air pollution level in the area will further increase though the percentage increase in air EPI is quite low because existing groundwater EPI is already very high (i.e. 77.50) indicating that this cluster has high groundwater pollution under present scenario.

6.2.4 Sensitivity analysis of EPI for Haldia

On similar lines as explained earlier sections, air, surface water and groundwater EPI values have been calculated for Haldia with respect to different values of A1. Figures 6.4 shows variation of air, surface water and groundwater EPI with different A1 scores varying from minimum (i.e. 1.0) to maximum (i.e. 7.0) while keeping other parameters same.

It has been inferred that the reduction in A1 score in Haldia industrial cluster is reduced from its present value of 6.75 to desirable value of 1.0 (say) then air EPI score is reduced from 65.75 to 35.00 (46.77%). This may be due to the fact that Haldia is also one of the highly polluted industrial cluster among all 15 clusters taken for the study.

Thus, air EPI can be improved if toxicity level is reduced by adopting appropriate mitigating measures and adoption of cleaner technology options for emissions of gaseous pollutants. Clearly one should not only restrict emissions of air pollutants of group ‘C’ (e.g. Benzene, Benzopyrene) and group ‘B’ (e.g. CO) but also ensure absence of these air pollutants in future to achieve A1 score as 1.0 so that air EPI score remains 35.00. Similarly, air EPI scores of 42.0, 57.50, 64.50 and 70.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.5 and 7.0 respectively as shown in Fig. 6.4. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the air. In that case if A1 score in Haldia industrial cluster increases from its present value of 6.75 to expected value of 7.0, air EPI score increases from 65.75 to 70.00 (6.46%) stating that severity of air pollution level in the area will further increase though the percentage increase in air EPI is relatively low indicating that this cluster is polluted enough under present scenario.

It can also be inferred that the reduction in A1 score pertaining to presence of toxins in Haldia industrial cluster from its present value of 7.0 to desirable value of 1.0 tends to reduce scores of surface water EPI score from 72.50 to 28.00 (61.37%). Based on the magnitude of the variation in the final score of EPI, it is clear that there is significant scope to improve surface water EPI by reducing toxicity level in the cluster using appropriate mitigating measures and cleaner technology options for industrial effluent and wastewater treatments. Clearly one should not only restrict discharging of surface water pollutants of group 'C' (e.g. Hg, CN and Phenolic compounds) and group 'B' but also ensure absence of these surface water pollutants in future to achieve A1 score equal to 1.0 so that surface water EPI score remains 28.00. Similarly, surface water EPI scores of 46.00, 51.00, 68.50 and 71.25 can be obtained with respect to A1 score of 2.0, 3.0, 6.5 and 6.75 respectively as shown in Fig. 6.4.

Figure 6.4 also shows that if A1 score pertaining to presence of toxins with penalty factor in Haldia industrial cluster is reduced from its present value of 6.5 to desirable value of 1.0, it will reduce scores of groundwater EPI from 66.50 to 28.00 (57.25%). The percentage reduction of groundwater EPI is quite high which may be due to the fact that groundwater condition in Haldia industrial cluster is also polluted enough.

Figure 6.4 also shows that groundwater EPI scores of 43.0, 48.00, 66.75 and 71.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.75 and 7.0 respectively.

6.2.5 Sensitivity analysis of EPI for Jamshedpur

On similar lines as explained earlier sections, air, surface water and groundwater EPI values have been calculated for Jamshedpur with respect to different values of A1. Figures 6.5 shows variation of air, surface water and groundwater EPI with different A1 scores varying from minimum (i.e. 1.0) to maximum (i.e. 7.0) while keeping other parameters same.

It has been inferred that the reduction in A1 score in Jamshedpur industrial cluster is reduced from its present value of 6.5 to desirable value of 1.0 (say) then air EPI score is reduced from 69.00 to 35.00 (65.21%). This may be due to the fact that Jamshedpur is also polluted enough among all 15 clusters taken for the study.

Thus, air EPI can be improved if toxicity level is reduced by adopting appropriate mitigating measures and adoption of cleaner technology options for emissions of gaseous pollutants. Clearly one should not only restrict emissions of air pollutants of group 'C' (e.g. Benzene) and group ‘B’ (e.g. Ni, PM_{10}) but also ensure absence of these air pollutants in future to achieve A1 score as 1.0 so that air EPI score remains 24.00. Similarly, air EPI scores of 42.0, 51.50, 73.75 and 75.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.75 and 7.0 respectively as shown in Fig. 6.4. If there is an expansion plan in the industrial cluster with the similar facilities as exist today, it is expected to increase toxicity level in the air. In that case if A1 score in Jamshedpur industrial cluster increases from its present value of 6.5 to expected value of 7.0, air EPI score increases from 69.00 to 75.00 (8.70%) stating that severity of air pollution level in the area will further increase though the percentage increase in air EPI is relatively low indicating that this cluster is polluted enough under present scenario.

It can also be inferred that the reduction in A1 score pertaining to presence of toxins in Jamshedpur industrial cluster from its present value of 7.0 to desirable value of 1.0 tends to reduce scores of surface water EPI score from 65.50 to 25.00 (61.83%). Based on the magnitude of the variation in the final score of EPI, it is clear that there is significant scope to improve surface water EPI by reducing toxicity level in the cluster using appropriate mitigating measures and cleaner technology options for industrial effluent and wastewater treatments. Clearly one should not only restrict discharging of surface water pollutants of group ‘C’ (e.g. Phenolic compounds) and group ‘B’ (e.g. Fluoride) but also ensure absence of these surface water pollutants in future to achieve A1 score equal to 1.0 so that surface water EPI score remains 25.00. Similarly, surface water EPI scores of 30.00, 35.00, 66.75 and 70.00 can be obtained with respect to A1 score of 2.0, 3.0, 6.75 and 7.0 respectively as shown in Fig. 6.5.

Figure 6.5 also shows that if A1 score pertaining to presence of toxins with penalty factor in Jamshedpur industrial cluster is reduced from its present value of 2.0 to desirable value of 1.0, it will reduce scores of groundwater EPI from 38.00 to 33.00 (13.16%). Figure 6.5 also shows that groundwater EPI scores of 43.0, 60.50, 60.75 and 62.00 can be obtained with respect to A1 score of 3.0, 6.5, 6.75 and 7.0 respectively.

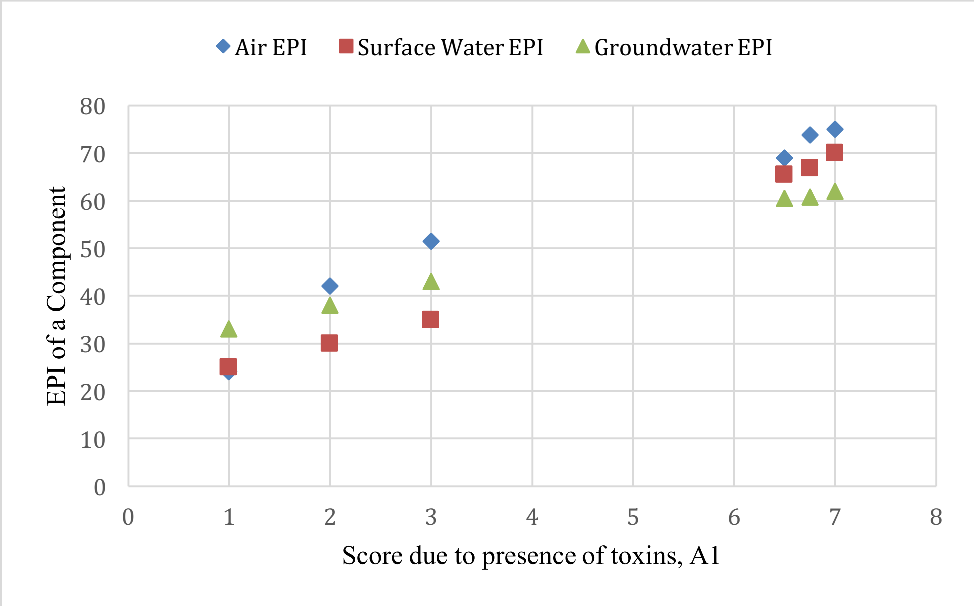

Fig. 6.5: Variation of air, surface water and groundwater EPI scores with A1 scores for Jamshedpur

6.3 Sensitivity analysis of EPI with Expansion of the Industrial Areas

As the EPI calculations are based on a number of parameters including industrial activity, air quality, surface and ground water quality, land environment, ecological and population of the study area. This part of the sensitivity analysis addresses how the EPI values change with the expansion of an industrial area. A case of expansion of steel manufacturing project of JSW Plant at Toranagallu Karnataka have been taken using EPI score. The data are obtained from the EIA report and secondary sources of the data.

Scale of Industrial activities in the area

- R17 industries- 3 Types
    - Integrated Steel and Iron Industry (1 No.)
    - Thermal power plant (JTPCL) (1 Nos.)
    - Cement Manufacturing Industry (1 No.)
- R54 industries -3 Types
    - **Steel and steel products** (5 Nos. namely, Bawalka Steel Tubes, Hospet Steel, Kalyani Steel, Mukund Steel, Bellary Steel)
    - **Iron Industries** (3 Nos. of Industries involving heat treatment, namely Kirlosker Ferroalloys, Padvanth Ferroalloys and Kariaganur Sponge Iron Plant)

- **Mining and Ore Beneficiation**

Table 6.1 and 6.2 present the predicted air quality due to proposed expansion for 10 million tonnes/year (MTPA) and 16 million tonnes/year (MTPA) respectively.

Table 6.1: Predicted Air quality data for 10 MTPA at JSW Plant at Toranagallu

24 Hours average value (in µg/m³)											
AAQ location	**X**	**Y**	**Base data NOx**	**Pred. NOx**	**Total NOx**	**Base data SO_2**	**Pred. SO_2**	**Total SO_2**	**Base data PM_{10}**	**Pred. PM_{10}**	**Total PM_{10}**
A1	3900	8000	12.1	10.39	22.49	11.30	13.17	24.47	32.00	93.60	125.60
A2	7700	8250	12.8	17.39	30.19	11.70	21.97	33.67	40.00	91.91	131.91
A3	7400	10400	13	4.74	17.74	11.90	5.89	17.79	40.00	57.86	97.86
A4	12750	11600	12.4	17.04	29.44	11.40	20.95	32.35	33.00	63.47	96.47
A5	18750	6000	12.4	8.67	21.07	11.30	7.56	18.86	35.00	62.74	97.74
A6	2900	15700	11.9	14.48	26.38	11.00	18.34	29.34	32.00	132.93	164.93
A7	8250	12250	12.1	7.32	19.42	11.10	9.45	20.55	31.00	113.57	144.57
A8	10150	15350	12.9	11.27	24.17	11.80	13.51	25.31	49.00	56.36	105.36
A9	25650	11500	16.1	12.21	28.31	14.70	15.23	29.93	46.00	69.15	115.15
A11	6250	17250	13.5	8.79	22.29	10.00	11.10	21.10	39.00	69.28	108.28

(**Source:** for Monitored value – EIA Report. Prediction: by AERMOD)

Table 6.2: Predicted Air quality data for 16 MTPA at JSW Plant at Toranagallu

24 hours average value (in µg/m³)											
AAQ location	**X**	**Y**	**Base data NOx**	**Pred. NOx**	**Total NOx**	**Base data SO_2**	**Pred. SO_2**	**Total SO_2**	**Base data PM_{10}**	**Pred. PM_{10}**	**Total PM_{10}**
A1	3900	8000	16.6	11.05	27.65	15.5	10.33	25.82	95	179.23	274.61
A2	7700	8250	16.6	16.39	32.99	13.6	13.25	26.85	78	328.92	406.92
A3	7400	10400	17	5.74	22.74	14.6	6.38	20.98	78	155.09	233.09
A4	12750	11600	15.8	15.35	31.15	13.1	14.26	27.36	61	320.47	381.47
A5	18750	6000	17.1	15.09	32.19	14.3	15.35	29.65	78	152.00	230.00
A6	2900	15700	15.7	14.89	30.59	13	13.67	26.67	60	232.62	292.62
A7	8250	12250	16	11.46	27.46	13.7	14.84	28.54	60	424.83	484.83
A8	10150	15350	16	12.15	28.15	13.2	11.74	24.94	63	167.70	230.70
A9	25650	11500	20	11.19	31.21	15	9.80	25.19	96	202.41	298.64
A11	6250	17250	19.54	9.35	28.89	14.10	10.08	24.19	72	147.25	219.21

(**Source:** for Monitored value – EIA Report. Prediction: by AERMOD)

Table 6.3 presents the past, present and predicted population for the study region and Tables 6.4 and 6.5 presents the data for surface water quality and ground water quality for the study region respectively.

Table 6.3: Population of study area

S. No.	Name of Village	1991	2001	2010	Geometrical mean	Forecasted Population in 2020
1	Anantpur	2216	2661	3443	2728	6171
2	Avinamagadu		402			
3	Ayanahalli		1964			
4	Bannihatti	1175	1528	2059	1546	3605
5	Bhujaganagar		4672			
6	Bevinahalli		1337			
7	Gadiganur	3788	4513	6007	4683	10690
8	Chikkantapur	871	1094	1455	1115	2570
9	Gangalpur		672			
10	Kodalu	1359	1616	2134	1673	3807
11	Kurekuppa		10817			
12	Lingadahalli		1137			
13	Madapura		439			
14	Muraripur	820	1138	1444	1105	2549
15	Talur	2472	4343	4176	3552	7728
16	Nagalpura	1173	1684	1973	1574	3547
17	Taranagar	4473	5377	6762	5458	12220
18	Toranagallu	4395	6324	11496	6836	18332
19	Vaddu	2557	5652	11908	5562	17470
20	Yelebenchi		3860			

Table 6.4: Surface water monitoring of the study area at JSW project site at Toranagallu

S. No.	Parameters	SW1	SW2	SW3	SW4
1.	pH	8.27	8.40	8.41	8.36
2.	Dissolved Oxygen, mg/l	6.10	5.92	5.82	6.18
3.	BOD (3 days at 27°C), mg/l	4.0	5.0	5.0	3.0
4.	Colour, Hazen Units	39	45	55	39
5.	Fluoride (as F) , mg/l	0.64	0.79	0.79	0.78
6.	Cadmium (as Cd), mg/l	<0.01	<0.01	<0.01	<0.01
7.	Chloride (as Cl), mg/l	34	41	47	22
8.	Hexavalent Chromium (as Cr_6^+), mg/l	<0.01	<0.01	<0.01	<0.01
9.	Cyanide (as CN), mg/l	Nil	Nil	Nil	Nil
10.	Total Dissolved Solids, mg/l	180	188	225	102
11.	Selenium (as Se), mg/l	<0.01	<0.01	<0.01	<0.01
12.	Sulphate (as SO4)	23	26	31	16
13.	Lead (as Pb), mg/l	<0.01	<0.01	<0.01	<0.01
14.	Copper (as Cu), mg/l	<0.01	<0.01	<0.01	<0.01
15.	Arsenic (as As), mg/l	<0.01	<0.01	<0.01	<0.01
16.	Phenolic Compounds (as C_6H_5OH), mg/l	<0.001	<0.001	<0.001	<0.001
17.	Iron (as Fe), mg/l	1.60	1.75	1.82	1.32
18.	Zinc (as Zn), mg/l	<0.01	<0.01	<0.01	<0.01
19.	Oil & Grease, mg/l	Nil	Nil	Nil	Nil
20.	Nitrates (as NO3), mg/l	17.4	21.4	23.2	11.8
21.	Totral hardness (as $CaCO_3$), mg/l	-	-	-	-
22.	Residual Free Chlorine (as Cl_2), mg/l	Nil	Nil	Nil	Nil
23.	Mercury(as Hg),mg/l	<0.01	<0.01	<0.01	<0.01
24.	Boron(as B), mg/l	<0.01	<0.01	<0.01	<0.01
25.	Total Nitrogen (as N), mg/l	12.9	16.0	16.5	12.5
26.	Chemical Oxygen Demand, mg/l	20	24	24	14
27.	Temperature in Degree Celsius	25.3	26.0	27.3	25.7
28.	Odour	NP*	NP*	NP*	NP*
29.	Taste	Agreeable	Agreeable	Agreeable	Agreeable
30.	Turbidity, NTU	30	39	44	28

(Source : 10 MTPA EIA report), *NP = No Problem and SW1, SW2, SW3,SW4 are the surface water monitoring locations.

Table 6.5: Groundwater analysis of the study area at JSW project site at Toranagallu

S. No.	Parameters	Norms		Results			
		Desirable limits *	Permissible limits **	GW1	GW2	GW3	GW4
1	Color, Hazen Units	5	25	<5	<5	<5	<5
2	Odour	Un obj.	Un obj.	Un obj.	Un obj.	Un obj.	Un obj.
3	Taste	Agreeable	Agreeable	Agreeable	Agreeable	Agreeable	Agreeable
4	Turbidity, NTU	5 max.	10	<5	<5	<5	<5
5	pH	6.5-8.5	6.5 – 8.5	7.96	8.11	7.85	8.46
6	Total Hardness (as $CaCO_3$), mg/l	300	600	112	107	51	158
7	Iron (as Fe), mg/l	0.3	1	0.17	0.24	0.17	0.21
8	Chloride (as Cl),mg/l	250	1000	99	60	55	105
9	Fluoride (as F), mg/l	1	1.5	1.24	1.32	1.03	0.82
10	Dissolved Solids,	500	2000	324	306	166	437
11	Calcium (as Ca), mg/l	75	200	27	26	12	38
12	Magnesium(as Mg), mg/l	30	100	11	11	5	15
13	Copper(as Cu), mg/l	0.05	1.5	<0.05	<0.05	<0.05	<0.05
14	Manganese (as Mn), mg/l	0.1	0.3	< 0.1	< 0.1	< 0.1	<0.1
15	Sulphate (as SO4), mg/l	200	400	39	36	24	59
16	Nitrate (as NO3), mg/l	45	100	10.9	21.5	16.1	20.4
17	Phenolic compounds (as C_6H_5OH), mg/l	0.001	0.002	< 0.001	< 0.001	< 0.001	< 0.001
18	Mercury,(as Hg), mg/l	0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001
19	Cadmium (as Cd), mg/l	0.01	0.01	< 0.01	<0.01	<0.01	<0.01
20	Selenium (as Se), mg/l	0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
21	Arsenic (as As), mg/l	0.05	0.05	< 0.05	<0.05	<0.05	<0.05
22	Cyanide (as CN), mg/l	0.05	0.05	< 0.05	<0.05	<0.05	<0.05
23	Lead (as Pb), mg/l	0.05	0.05	< 0.05	<0.05	<0.05	<0.05
24	Zinc (as Zn), mg/l	5	15	< 0.1	< 0.1	< 0.1	< 0.1
25	Anionic Detergents, mg/l	0.2	1	< 0.2	< 0.2	< 0.2	< 0.2
26	Chromium (as Cr), mg/l	0.05	0.05	<0.05	<0.05	<0.05	<0.05
27	Mineral Oil, mg/l	0.01	0.03	< 0.01	< 0.01	< 0.01	<0.01
28	Alkalinity(as $CaCO_3$), mg/l	200	600	26	71	80	120
29	Aluminium (as Al), mg/l	0.03	0.2	< 0.1	< 0.1	< 0.1	< 0.1
30	Boron (as B), mg/l	1	5	< 0.1	< 0.1	< 0.1	< 0.1
31	Coliform Organisms, (MPN/100ml)	***		11	11	10	9

(Source: 10 MTPA EIA report), GW1, GW2, GW3, GW4 refers to the four monitoring locations.

Toxins were difficult to be taken because the exact concentration of the heavy metals were not mentioned in the EIA Report. In an Integrated Iron & Steel Industry, wastewater generated from coke oven by-product plant is considered to be the most polluting. The wastewater effluent contains toxic chemicals like phenol, cyanide and ammonia, which are harmful to the receiving water-bodies when discharged untreated/partially treated. Using above data, EPI values with respect to air, surface water and ground water for the study region have been evaluated as shown in Tables 6.6, 6.7 and 6.8 respectively.

Table 6.6: Comparison of air EPI values

Parameters	**Scenario**	
	JSW, Toranagallu at 10 MTPA	**JSW, Toranagallu at 16 MTPA**
$A_1 = S_{c,i,j} + \Delta_{i,j,s}$	2	2
$A_2 = Q_i$	5	5
$B_1 = P_{c,i,j} + \Delta_{i,j,p}$	3	6
$B_2 = P_{I,i,j}$	3	3
$B_3 = P_{Eco,i,j}$	3	3
$C_1 = R_{N2,i,j}$	3	5
$C_2 = R_{SNLF,i,j} + \Delta_{SNLF,i,j,r}$	3	3
$C_3 = R_{sen,i,j}$	5	5
$D = R_{Add,i,j}$	5	10
Air EPI	38	52

Table 6.7: Comparison of surface water EPI values

Parameter	Industrial Areas	
	JSW (Toranagallu)	JSW (Toranagallu) 16 MTPA
$A_1 = S_{c,i,j} + \Delta_{i,j,s}$	5.5	5.5
$A_2 = Q_i$	5	5
$B_1 = P_{c,i,j} + \Delta_{i,j,p}$	2	2
$B_2 = P_{I,i,j}$	3	3
$B_3 = P_{Eco,i,j}$	3	3
$C_1 = R_{N2,i,j}$	3	5
$C_2 = R_{SNLF,i,j} + \Delta_{SNLF,i,j,r}$	1	1
$C_3 = R_{sen,i,j}$	5	5
$D = R_{Add,i,j}$	5	10
Surface water EPI	48.5	55.5

Table 6.8: Comparison of groundwater EPI values

Parameter	Industrial Areas	
	JSW (Toranagallu)	JSW (Toranagallu) 16 MTPA
$A_1 = S_{c,i,j} + \Delta_{i,j,s}$	3	3
$A_2 = Q_i$	5	5
$B_1 = P_{c,i,j} + \Delta_{i,j,p}$	2	2
$B_2 = P_{I,i,j}$	3	3
$B_3 = P_{Eco,i,j}$	3	3
$C_1 = R_{N2,i,j}$	3	5
$C_2 = R_{SNLF,i,j} + \Delta_{SNLF,i,j,r}$	1	1
$C_3 = R_{sen,i,j}$	5	5
$D = R_{Add,i,j}$	5	10
Groundwater EPI	36	43

The EPI scores and their comparison with respect to two scenarios have been presented in Table 6.9.

Table 6.9: Comparison of EPI values

Parameter	Scenario	
	JSW, Toranagallu at 10 MTPA	JSW, Toranagallu at 16 MTPA
Air EPI	38	52
Surface water EPI	48.5	55.5
Groundwater EPI	36	43
IEPI	55.54	65.45

The comparison of IEPI values for the pre and post expansion scenarios demonstrates the utility of the proposed index for estimating the carrying capacity of the industrial area in terms of whether the area will become severely/ critically polluted due to proposed expansion plan. The appropriate mitigating measures and adoption of cleaner technology options coupled with improved infrastructure for effluent and waste management is warranted if the IEPI score are likely to become higher and fall under critical category due to proposed expansion plan. Such an analysis could be used to find out the maximum potential growth scenarios of the existing as well as proposed industrial areas/ clusters.

6.4 Summary

As discussed in this chapter, A1 score pertaining to presence of toxins with penalty factor is reduced, there will be reduction in the air, surface water and groundwater EPI scores which has been illustrated by taking into consideration of five different industrial clusters in section 6.2. The percentage of reduction of EPI scores are varying considerably in different clusters. The variation depends on percentage change in A1 score, type of component of environment (i.e. air, surface water and groundwater) and the industrial cluster itself. The effect was much more pronounced in the case of Digboi where the EPI scores were considerably less than the other areas. So the effect of change is much more pronounced where the score of other factors are comparatively less. A1 factor being multiplicative increases the EPI score in those cases whereas for other areas the change of score is more or less similar. It has also been observed that EPI scores evaluated with respect to source and pathway are also sensitive to concentration of pollutants. Also, if all pollutants belong to same category (Say ‘A’ group) and fall within the prescribed standard, scores pertaining to receptors and pathway are minimum but when concentration of even 1 out 3 chosen pollutants falling in the same group increases to more than the permissible limit, scores with respect to receptors changes significantly.

CHAPTER 7

CONCLUSIONS

Through the course of this study, an attempt has been made to formulate, test and improve an environmental tool to assess the pollution potential of industrial clusters/areas in India. Several existing methods and approaches have been thoroughly investigated and analyzed before commencing the work on this project. Various issues related to selection of variables and response functions have been resolved by the brain storming workshop involving a group of experts while formulating the IEPI.

This index provides a comprehensive tool for determining the environmental problems of an area which can further be used to improve the mitigation facilities in these areas. The source-pathway-receptor approach considered while formulating this tool covers the basic linkages in the ecological process as opposed to other existing indices. Also, this is easy to use and does not involve complex calculations.

Though efforts have been made to perfect the process of IEPI application to industrial areas, there are still some parameters that need to be improved further e.g. inconsistency in pollution data available with the authorities; irregular environmental monitoring for data collection; absence of evidences of adverse impact on human or ecology.

The present IEPI could be used for initial environmental assessment of the industrial areas/clusters based on ground information. Constant and intensive environmental surveillance of the critically polluted areas should be done to assessment the various environmental indicators and investigate the status of environmental resources including land, vegetation, air and water and plan for remedial actions. It is suggested that as the step II a comprehensive analysis of spatial and temporal data/ information shall be done for the identified critical areas. Action plans should be subsequently developed in consultation with, local stakeholders, experts and policy makers. The outcome shall be used for preparing *action plan* for remediation.

The present IEPI is intended to act as an *early warning tool*, which is easy and quick to use. It can help in categorizing the industrial clusters/areas in terms of *priority* of needing attention.

The estimation of IEPI should be a dynamic and ongoing process and continuously additional data and information in assessing IEPI should be done.

A comparison of IEPI values of various industrial sectors shows the steel producing industrial areas/ clusters ranging from 49.04 to 75.72) and oil refinery areas/ clusters ranging from 47.33 to 84.33 have relatively lesser score. These sectors are in general better planned and systematically developed with better environmental management infrastructure. Also these industrial areas/ clusters are defined by the presence of a few major and well organized industries which are held directly responsible for the environmental upkeep of the surrounding area.

It can be seen that the coal mining and thermal power plant areas/ clusters (IEPI values ranging from 77.72 to 85.77) and the chemical industry areas/ clusters are relatively more polluted with IEPI values ranging from 79.75 to 95.67. These areas/ clusters are dominated by a large number of industries having distinctly different types of emissions and waste disposal. Also these areas are dominated by a large number of small and medium scale industrial operations which are privately owned and hence relatively less responsible collectively.

Mixed industrial areas showed much variability in the IEPI scores ranging from 66.27 to 91.18 due to varying size, complex and varied mix type of industries in a given area/ cluster.

The final fuzzy integrated assessment values are also calculated and the values are given as 0.306, 0.524, 0.495, 0.573, 0.702, 0.648, 0.750, 0.750, 0.556, 0.274, 0.660, 0.540, 0.750, 0.500 and 0.642 for industrial clusters Durg-Bhilai, Durgapur, Jamshedpur, Dhanbad, Korba, Singraulli, Vapi, Ankleshwar, Ahmedabad, Dighboi, Haldia, Panipat, Ghaziabad, Aligarh, and Faridabad respectively. The analysis showed that the sampling stations of Digboi and Durg-Bhilai have higher integrated fuzzy assessment value with respect to grade "moderate" than that with respect to all other grades and therefore the overall air quality status falls under Good condition with their ranking order 1 and 2 respectively. In fact, there exist zero scores corresponding to very poor and severe conditions for these two industrial clusters. All industrial clusters have zero scores corresponding to severe classification. Jamshedpur industrial cluster has been assigned the scores of 0.378, 0.265 and 0.357 with respect to "Moderate i.e. G2", "Poor i.e. G3" and "Very Poor i.e. G4" conditions respectively with an overall fuzzy IEPI score of 0.495. The combined effect of scores with respect to these 3 grades has led it to be in the 3rd rank of less polluted industrial cluster. Aligarh industrial cluster has a full score of 1.0 with respect to "Poor i.e. G3" condition along with an overall fuzzy IEPI score of 0.50. Though eight industrial clusters namely, Durgapur, Panipat, Ahmedabad, Dhanbad, Faridabad, Singraulli, , Haldia and Korba have been assigned scores of 0.902, 0.841, 0.777, 0.707, 0.430, 0.410, 0.362 and 0.193 respectively under "Poor i.e. G3" condition, they also score 0.098, 0.159, 0.223, 0.293, 0.570, 0.590, 0.638 and 0.807 respectively under "Very Poor i.e. G4" condition. The combined effect of scores with respect to these grades leads to increase the pollution level in the respective industrial cluster and hence they have been assigned their ranks in the ascending order of pollution level. Similarly, Ankleshwar, Ghaziabad and Vapi clusters have been assigned the highest score of 1.00 each under "Very Poor i.e. G4" condition along with the overall fuzzy IEPI score of 0.75 each. They have been assigned the highest rank implying highest level of pollution.

The fuzzy comprehensive analysis method presented in this study 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 environmental pollution index using fuzzy comprehensive analysis method seem to be particularly promising and better over the earlier method.

Overall, the IEPI scores are towards alarming level except for a very few industrial areas/ clusters such as Digboi and Durg-Bhilai. This indicates severe/ critical pollution levers and warrants necessary mitigate and remedial measures in order to sustain the industrial growth. Comparison of IEPI values for the pre and post expansion scenarios show the utility of the proposed index for estimating the carrying capacity of the industrial area in terms of whether the area will become severely/ critically polluted due to proposed expansion. The appropriate mitigate measures and adoption of cleaner technology options coupled with improved infrastructure for effluent and waste management is warranted if the IEPI score are likely to become higher and fall under critical category due to proposed expansion. Such an analysis could be used to find out the maximum potential growth scenarios of the existing as well as proposed industrial areas/ clusters.

There are still aspects that need to be improved upon including consistency in pollution monitoring data available with the pollution control authorities; selection of sampling locations for the environmental monitoring and collection of data on adverse effect on eco-geological features and human population due to industrial pollution. Furthermore, The individual weightages of each of the parameter in IEPI calculation algorithm can be assessed using decision-making tools like Analytical Network Process and also the IEPI aggregate function can be reviewed and compared with the existing functions available in literature.

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 like India. The comprehensive data of pollutants of air, surface water and groundwater releasing from individual industries/facilities in different industrial clusters will certainly improve the accuracy of environmental pollution index 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 context to industrial clusters of India, especially in extracting information for environmental quality monitoring, assessment and management.

The methodology presented in this study is very useful in developing different strategies for monitoring, assessment and management of growth of industrial clusters. It can be used as an early warning tool to identify pollution conditions on the basis of ambient environmental conditions which have been impacting due to toxicity of pollutants emitting during different manufacturing and industrial processes in different industrial clusters. The factors used for deriving IEPI plays a vital role in assessing overall pollution status in an industrial cluster. It is pertinent to mention that data used to calculate different factors associated with IEPI is based on the opinion of decision makers and therefore these data may be biased if decision makers are not chosen correctly. As pollution index score due to impact of environmental pollutants on people and eco-geological features are based on some evidences obtained from reliable sources such as reports from print and electronic media, academic research, public interest litigations (PILs), published literature, hospital records, NGOs reporting etc., there may be chances of an underestimation of IEPI scores (or biasness) if there is no clear reporting on impact of emissions on environment in spite of occurrences of such incidents in an industrial cluster. The results thus obtained can only be indicators of actual emissions. Thus the formulation for IEPI developed in this study is not intended as an alternative to proper monitoring of pollution sources but to provide regulatory agencies with information that can help to prioritize the monitoring effort in allocating proper resources in effective and efficient way.

REFERENCES

Adhikari K., Chakraborty B., Gangopadhyay A., "Assessment of Irrigation Potential of Ground Water Using Water Quality Index Tool". *Asian Journal of Water, Environment and Pollution*. 2013, 10(3): 11-21.

Ahlheim M., Fr¨Or O. "Constructing a Preference-Oriented Index of Environmental Quality" *Advances in Public Economics: Utility, Choice and Welfare*. 2005, 151-172.

Al-Adamat R. A., Foster I. D., Baban S. M. "Groundwater vulnerability and risk mapping for the Basaltic aquifer of the Azraq basin of Jordan using GIS, remote sensing and DRASTIC". *Applied Geography*. 2003, 23(4) :303–24.

Aller L., Bennett T., Lehr J. H., Petty R. J. "DRASTIC: a standardized system for evaluating groundwater pollution potential using hydrogeologic settings" National Water Well Association, Worthington, Ohio, USA. 1987, 163.

Arunraj N. S., Maiti J. "Development of environmental consequence index (ECI) using fuzzy composite programming". *Journal of Hazardous Materials*. 2009, 162(1): 29–43

Kenith B. H., *Superfund Risk Assessment in Soil Contamination Studies*. Third Volume ASTM Special Technical Publication. 1998.

Babiker I.S., Mohamed M. A., Hiyama T., Kato K. "A GISbased DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, Central Japan" *Science of the Total Environment*. 2005, 345(1):127–40.

Balasubramaniam A., Voulvoulis N. (2005), "The appropriateness of multicriteria analysis in environmental decision-making problems". *Environmental Technology*. 2005, 26(9): 951-962.

Ba´rdossy A., Duckstein L., *Fuzzy rule-based modeling with applications to geophysical, biological and engineering systems*. CRC Press, Boca Raton, Florida. 1995.

Bishoi B., Prakash A., Jain V. K., "A comparative study of air quality index based on factor analysis and US-EPA methods for an Urban Environment". *Aerosol and Air Quality Research*. 2009, 9(1): 1-17.

Chachadi A. G., Lobo-Ferreira J. P. “Assessing aquifer vulnerability to sea-water intrusion using GALDIT method: Part 2 – GALDIT Indicator Descriptions. IAHS and LNEC” Proceedings. The fourth inter Celtic colloquium on hydrology and management of water resources, Universidade do Minho, Guimarães, Portugal, 2005.

Chakrabarti S., Singh A. P., Kumar S. “Assessment of Air Quality in Haora River Basin”. *Pollution Research*. 2015, 34 (3): 215-222.

Cormier S. M., Suter G. W. “A Framework for Fully Integrating Environmental Assessment” *Environmental Management*. 2008, 42:543-556.

DeFur P. L., Evans G. W., Hubal E. A. C., Kyle A. D., Morello-Frosch R. A., Willams D. R. “Vulnerability as a function of individual and group resources in cumulative risk assessment” *Environmental Health Perspective*. 2007, 817-824.

Discoli C. A. “Urban environmental impact matrices development: assessment indices incorporation” *Building and Environment*. 2005, 40: 915–928.

EPA (Environmental Protection Agency), *National Air Quality and Emissions Trends Report* 1997, EPA 454/R- 98-016. 1998.

EPA Practices for Identifying and Inventorying Hazardous Sites Could Assist Similar Department of the Interior Efforts, Report No. 2005-P-00020, 2005.

Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI), 2009 Available from: http://www.cpcb.nic.in; http:// www.epa.gov/airnow; http://www.wikipedia.com.

Fussel H. M. “Vulnerability: a generally applicable conceptual framework for climate change research”. *Global Environmental Change*. 2007, 17:155–167.

Gunasekera, M.Y., Edwards D. W. “Estimating the environmental impact of catastrophic chemical releases to the atmosphere: An index method for ranking alternative chemical process routes” *Process Safety and Environmental Protection*. 2003, 81(6): 463-474.

Fein J. A., Lavalle J. M., Ginsburgt K. R., Giardiano A. P. “A methodology to maximize resident input in improving a pediatric rotation”. *Archives of Pediatrics and Adolescent Medicine*. 1997, 151: 840-844.

Giri S., Singh A. K. “Assessment of Surface Water Quality Using Heavy Metal Pollution Index in Subarnarekha River, India”. *Water Quality, Exposure and Health*. 2014, 5(4): 173-182.

Goodman C.M. “The Delphi Technique: a critique” *Journal of Advanced Nursing*. 1987, 12: 729-734.

Hailin Y., Ligang X., Chang Y., Jiaxing, X., “Evaluation of groundwater vulnerability with improved DRASTIC Method”. *Procedia Environmental Sciences*. 2011, 10: 2690–2695.

Hill M. J., Braaten R., Veitch S. M., Lees B. G., Sharma S., “Multi-criteria decision analysis in spatial decision support: the ASSESS analytic hierarchy process and the role of quantitative methods and spatially explicit analysis”. *Environmental modelling & software*. 2005, 20(7): 955-976.

Kang S. M.A. “Sensitivity analysis of the Korean composite environmental index”. *Ecological Economics*. 2002, 43: 159-174.

Kumar D., Alappat B. J. “Selection of appropriate aggregate function for calculating Leachate Pollution Index”. *Journal of Hazardous ,Toxic and Radioactive Waste Management*. 2004, 8(4): 253-264.

Kaufman A., Gupta M. M., *Introduction to fuzzy arithmetic, theory and application*. Van Nostrand Reinhold, New York, USA. 1991, 351.

Latha S. P., Rao N. K., “An integrated approach to assess the quality of groundwater in a coastal aquifer of Andhra Pradesh, India”. *Journal of Environmental Earth Science*. 2012, 66: 2143–2169.

Lee J. H., An K. G., “Integrative restoration assessment of an urban stream using multiple modeling approaches with physical, chemical, and biological integrating indicators”. *Ecological Engineering*. 2014, 62: 153-167.

Liou S. M., Lo S. L., Wang S. H., “A Generalized water quality index for Taiwan”. *Environmental Monitoring and Assessment*. 2004, 96: 35–52.

Mahmood K., Batool S. A., Chaudhary M.N., Haq Z. “Ranking criteria for assessment of municipal solid waste dumping sites”. *Archives of Environmental Protection*. 2017, 43(1): 95–105.

Majandang J., Sarapirome S. "Groundwater vulnerability assessment and sensitivity analysis in NongRua, KhonKaen, Thailand using a GIS-based SINTACS Model". *Environmental Earth Sciences*. 2013, 68: 2025–2039.

Marchini A., Facchinetti T., Mistri M. "F-IND: A framework to design fuzzy indices of environmental conditions" *Ecological Indicators*. 2009, 9: 485 – 496.

Mc Fadden L., Nicholls R. J., Vafeidis A. T., Tol R. S. "A methodology for modelling coastal space for global assessment" *Journal of Coast Research*. 2007, 23(4):911–920.

Mourhir A., Rachidi T., Karim M., "River water quality index for Morocco using a fuzzy inference system". *Environmental Systems Research*. 2014, 3(1): 1-12.

Mostafaei A., "Application of Multivariate Statistical Methods and Water-Quality Index to Evaluation of Water Quality in the Kashkan River". *Environmental management*. 2014, 53(4): 865-881.

Nasiri F., Maqsood I., Huang G., Fuller N. "Water Quality Index: A Fuzzy River-Pollution Decision Support Expert System". *Water Resources Planning and Management*. 2007, 133: 95-105.

Nunes C., Soares A. "Stochastic environmental research risk assessment". *Ecological modeling*. 2007, 201: 118–126.

Ott W. R "*Environmental Indices: theory and practice*" Ann Harbor Science Publications, Ann Arbor, Michigan. 1978.

Pizzol L., Critto A., Agostini P., Marcomini A. "Regional risk assessment for contaminated sites Part 2: ranking of potentially contaminated sites" *Environment International*. 2011, 37: 1307-1320.

Pykh Y. A., Elizabeth K. T., Grant W. E. "An overview of systems analysis methods in delineating environmental quality indices" *Ecological Modelling*. 2000, 130: 25-38.

Ramakrishnaiah C. R., Sadashivaiah C., Ranganna G., "Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India". *Journal of Chemistry*. 2009, 6(2): 523-530.

Ravinder R., Kesavan R., Thilagaraj P., “Assessment of Air Quality in Commercial Places of Chennai through Air Quality Index”. *Advanced Materials Research*. 2014, 984: 1190-1194.

Rosemond S. D., Duro C. D., Dube M., Comparative analysis of regional water quality in Canada using the water quality index. *Environmental Monitoring and Assessment*. 2009, 156: 223–240.

Ross T. J., *Fuzzy Logic with Engineering Applications*, (2nd Ed.), John Wiley and Sons, New Delhi. India. 2008.

Rowe G., Wright G. “The Delphi Technique as a forecasting tool: issues and analysis”. *International Journal of Forecasting*. 1999, 15: 353-375.

Satty T. L. “*Decision making with dependence and feedback: The Analytic Network Process”* RWS Publications, Pittsburg. 1996.

Saaty T. L., *The Analytic Hierarchical Process*. New York: McGraw-Hill. 1980, 841.

Sakawa M., *Fuzzy Sets and Interactive Multiobjective Optimization*, Plenum Press, New York, USA. 1993.

Schultink G. “Critical environmental indicators: performance indices and assessment models for sustainable rural development planning” *Ecological Modelling*. 2000, 130: 47-58.

Sengupta B., Sharma M., Shukla P., Maheshwari M., “Air quality index for data interpretation and public information”. Proceedings of International Conference on Air Quality Index and Emission inventory for Delhi, Centre for Science and Environment, New Delhi, India, June, 2000.

Sharma V. K., “Development of air quality indices for Mumbai, India”. *International Journal of Environment and Pollution*. 1999, 11(2): 141-146.

Sharma M., Pandey R., Maheshwari M., Sengupta B., Shukla B. P., Gupta N. K., Johri S., “Interpretation of Air Quality Data Using an Air Quality Index for the City of Kanpur, India”. *Journal of Environmental Engineering and Science*. 2003, 2: 453–462.

Sharma N. D., Patel J. N., “Evaluation of groundwater quality index of the urban segments of Surat City, India”. *International Journal of Coal Geology*. 2010, 4: 1-4.

Silvert W. "Fuzzy indices of environmental conditions". *Ecological Modelling*. 2000, 130: 111–119.

Sinclair A. J., Diduck A. P. "Public involvement in Canadian environmental assessment: enduring challenges and future directions". *Environmental Impact Assessment: Practice and Participation*. 2005, 53-74.

Singh A. P., "An Integrated Fuzzy Approach to Assess Water Resources' Potential in a Watershed". *Icfai Journal of Computational Fluid Mathematics*. 2008, 1(1): 7-23.

Singh A. P., Chakrabarti S., Dubey S. K., "Managing water quality of a river basin using fuzzy water quality index", Proceedings national seminar on recent trends in geo-environmental engineering (RTGEE-2012), M.B.M Engineering College Jodhpur, March 17-18, 2012, 83-88.

Singh A. P., Dubey S. K., "Optimal selection of a landfill disposal site using a modified fuzzy utility approach". *Fuzzy Information and Engineering*. 2012, 4(3): 313-338.

Singh A. P., Ghosh S. K., "Water Quality Index of River Yamuna". *Pollution Research*. 1999, 18(4): 435-439.

Singh A. P., Ghosh S. K., "*Uncertainty Analysis in River Basin Water Quality Management in Integrated Water Resources Planning and Managemen*t". K. Srinivasa Raju, A.K.Sarkar, M.L.Dash (Ed.), Integrated Water Resources Planning and Management. Jain Brothers, New Delhi, India. 2003, 260-268.

Singh A. P., Ghosh S. K., Sharma P., "Water quality management of a stretch of river Yamuna: An interactive fuzzy multi-objective approach". *Water Resources Management*. 2007, 21: 515-532.

Singh A.P., Shrivastava P., "A Comparative Study on Water Quality Assessment of a River Using AHP And PROMETHEE Techniques". *Proceedings of 19th international conference on Hydraulics, Water Resources, Coastal and Environmental Engineering (Hydro 2014 International), Bhopal*, 2014, 19: 880-890.

Singh A. P., Srinivas R., Kumar S., Chakrabarti S., "Water quality assessment of a river basin under Fuzzy Multi-Criteria Framework". *International Journal of Water*. 2015, 9(3): 226-247.

Singh A. P., Vidyarthi A. K., “Optimal allocation of landfill disposal site: A fuzzy multi-criteria approach”. *Iranian Journal of Environmental Health Science & Engineering*. 2008, 5(1): 25-34.

Singh R. K., Datta M., Nema A. K. “A new system for groundwater contamination hazard rating of landfills”. *Journal of Environmental Management*. 2009, 91: 344-357.

So´lnes J. “Environmental quality indexing of large industrial development alternatives using AHP” *Environmental Impact Assessment Review*. 2003, 23: 283–303.

Srinivas R., Bhakar P., Singh A. P., “Groundwater Quality Assessment in some selected area of Rajasthan, India Using Fuzzy Multi-Criteria Decision Making Tool”. ICWRCOE'15, *Aquatic Procedia*, 2015, 4: 1023–1030.

Srinivas Y., Oliver D. H., Raj A. S., Chandrasekar N., “Evaluation of groundwater quality in and around Nagercoil town, Tamilnadu, India: an integrated geochemical and GIS approach”. *Applied Water Science*. 2013, 3(3): 631-651.

Stigter T.Y., Ribeiro L., Dill A. C. “Application of a groundwater quality index as an assessment and communication tool in agro-environmental policies – Two Portuguese case studies”. *Journal of Hydrology*. 2006, 327: 578– 591.

Sundaram V. L., Dinesh K., Ravikumar G., Govindarajalu D. “Vulnerability assessment of seawater intrusion and effect of artificial recharge in Pondicherry coastal region using GIS”. *Indian Journal of Science and Technology*. 2008, 1 : 1-7.

Tappeiner G., Tappeiner U., Walde J., “Integrating disciplinary research into an interdisciplinary framework: A case study in sustainability research”. *Environmental Modeling Assessment*. 2007, 12: 253-256.

Thirumalaivasan D., Karmegam M., Venugopal K., “AHP-DRASTIC: software for specific aquifer vulnerability assessment using DRASTIC model and GIS”. *Environmental Modelling & Software*. 2003, 18(7): 645-656.

Tzeng, G. H., Tsaur S. H., Laiw Y., Opricovic S. “Multi-criteria analysis of environmental quality in Taipei: public preference and improvement strategies”. *Journal of Environmental Management*. 2002, 65:109-120.

Voice M., Harvey N., Walsh K. “Vulnerability to climate change of Australia's Coastal Zone: analysis of gaps in methods. Data and system thresholds” *Report to the Australian Greenhouse Office. Canberra: Department of the Environment and Heritage*. 2006, 120.

Yale Center for Environmental Law & Policy. 2008. Environmental Performance Index (EPI) Report 1st edition, Yale.

Zadeh L. A., “Fuzzy sets as a basis for a theory of possibility”. *Fuzzy Sets and Systems*. 1978, 1: 3-28.

Zabeo A., Pizzol L., Agostini P., Critto A., Giove S., Marcomini A. “Regional risk assessment for contaminated sites part 1: vulnerability assessment by multicriteria decision analysis”. *Environ International*. 2011, 37: 1295–305.

Zaporozec A. Contaminant source inventory. In: Zaporozec A, editor. Groundwater contamination inventory. A methodological guideline. Paris, France: UNESCO; 2001.

Zhouv P., Ang B.W., Poh K. L. “Comparing aggregating methods for constructing the composite environmental index: An objective measure” *Ecological Economics*. 2006, 59: 305 – 311.

Zou Z. H., Yun Y., Sun J. N., “Entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment”. *Journal of Environmental Sciences*. 2006, 18(5): 1020-1023.

Appendix I

Group B: Probable Human carcinogens

- Acrylamide

Adriamycin

- Androgenic (anabolic) steroids
- Aristolochic acids (naturally occurring mixtures of)
- Azacitidine
- Bischloroethyl nitrosourea (BCNU)
- Captafol
- Chloramphenicol
- a-Chlorinated toluenes (benzal chloride, benzotrichloride, benzyl chloride) and benzoyl chloride (combined exposures)
- 1-(2-Chloroethyl)-3-cyclohexyl-1-nitrosourea (CCNU)
- 4-Chloro-ortho-toluidine
- Chlorozotocin

Cisplatin

- *Clonorchis sinensis* (infection with)
- Cyclopenta[cd]pyrene
- Dibenz[a,h]anthracene
- Dibenzo[a,l]pyrene
- Diethyl sulfate
- Dimethylcarbamoyl chloride
- 1,2-Dimethylhydrazine
- Dimethyl sulfate

Epichlorohydrin

- Ethyl carbamate (urethane)
- Ethylene dibromide
- N-Ethyl-N-nitrosourea
- Etoposide
- Glycidol
- Indium phosphide

IQ (2-Amino-3-methylimidazo[4,5-f]quinoline)

- Kaposi's sarcoma herpesvirus/human herpesvirus 8

- Lead compounds, inorganic
- 5-Methoxypsoralen
- Methyl methanesulfonate
- N-Methyl-N´-nitro-N-nitrosoguanidine(MNNG)
- N-Methyl-N-nitrosourea
- Nitrate or nitrite (ingested) under conditions that result in endogenous nitrosation
- Nitrogen mustard
- N-Nitrosodiethylamine
- N-Nitrosodimethylamine
- Phenacetin
- Procarbazine hydrochloride
- Styrene-7,8-oxide
- Teniposide
- Tetrachloroethylene
- Trichloroethylene
- 1,2,3-Trichloropropane
- Tris(2,3-dibromopropyl) phosphate
- Ultraviolet radiation A
- Ultraviolet radiation B
- Ultraviolet radiation C
- [Urethane: see Ethyl carbamate]
- Vinyl bromide (Note: For practical purposes, vinyl bromide should be considered to act similarly to the human carcinogen vinyl chloride.)
- Vinyl fluoride (Note: For practical purposes, vinyl fluoride should be considered to act similarly to the human carcinogen vinyl chloride
- PM_{10} and $PM_{2.5}$

Mixtures

- Creosotes
- Diesel engine exhaust
- High-temperature frying, emissions from
- Hot mate
- Household combustion of biomass fuel (primarily wood), indoor emissions from
- Non-arsenical insecticides (occupational exposures in spraying and application of)

- Polychlorinated biphenyls

Exposure circumstances

- Art glass, glass containers and pressed ware (manufacture of)
- Carbon electrode manufacture
- Cobalt metal with tungsten carbide
- Hairdresser or barber (occupational exposure as a)
- Petroleum refining (occupational exposures in)
- Shiftwork that involves circadian disruption
- Sunlamps and sunbeds (use of)

Source: International Agency for Research on Cancer "Probably carcinogenic to humans" (Group 2A as per USEPA)

Appendix II

Group C: Known human carcinogens

- 4-Aminobiphenyl
- Arsenic and arsenic compounds
- Asbestos
- Azathioprine
- Benzene
- Benzidine
- Benzo[a]pyrene
- Beryllium and beryllium compounds
- N,N-Bis(2-chloroethyl)-2-naphthylamine (Chlornaphazine)
- Bis(chloromethyl)ether and chloromethyl methyl ether (technical-grade)
- 1,3-Butadiene
- 1,4-Butanediol dimethanesulfonate (Busulphan; Myleran)
- Cadmium and cadmium compounds
- Chlorambucil
- 1-(2-Chloroethyl)-3-(4-methylcyclohexyl)-1-nitrosourea (Methyl-CCNU; Semustine)
- Chromium[VI]
- Ciclosporin
- Cyclophosphamide
- Diethylstilbestrol
- Dyes metabolized to benzidine
- Epstein-Barr virus
- Erionite
- Estrogen-progestogen menopausal therapy (combined)
- Estrogen-progestogen oral contraceptives (combined)
- Estrogens,
- Estrogens, steroidal
- Estrogen therapy, postmenopausal
- Ethanol in alcoholic beverages
- Ethylene oxide
- Etoposide in combination with cisplatin and bleomycin

- Formaldehyde
- Gallium arsenide
- [Gamma Radiation: see X- and Gamma (g)-Radiation]
- Helicobacter pylori (infection with)
- Hepatitis B virus (chronic infection with)
- Hepatitis C virus (chronic infection with)
- Human immunodeficiency virus type 1 (infection with)
- Human papillomavirus types 16, 18, 31, 33, 35, 39, 45, 51, 52, 56, 58, 59 and 66 (Note: The HPV types that have been classified as carcinogenic to humans can differ by an order of magnitude in risk for cervical cancer)
- Human T-cell lymphotropic virus type I
- Melphalan
- 8-Methoxypsoralen (Methoxsalen) plus ultraviolet A radiation
- Methylenebis(chloroaniline) (MOCA)
- MOPP and other combined chemotherapy including alkylating agents
- Mustard gas (Sulfur mustard)
- 2-Naphthylamine
- Neutrons
- Nickel compounds
- N'-Nitrosonornicotine (NNN) and 4-(N-Nitrosomethylamino)-1-(3-pyridyl)-1-butanone (NNK) *Opisthorchis viverrini* (infection with)
- [Oral contraceptives, combined estrogen-progestogen: see Estrogen-progestogen oral contraceptives (combined)]
- Oral contraceptives, sequential
- Phosphorus-32, as phosphate
- Plutonium-239 and its decay products (may contain plutonium-240 and other isotopes), as aerosols
- Radioiodines, short-lived isotopes, including iodine-131, from atomic reactor accidents and nuclear weapons detonation (exposure during childhood)
- Radionuclides, a-particle-emitting, internally deposited (Note: Specific radionuclides for which there is sufficient evidence for carcinogenicity to humans are also listed individually as Group 1 agents)

- Radionuclides, b-particle-emitting, internally deposited (Note: Specific radionuclides for which there is sufficient evidence for carcinogenicity to humans are also listed individually as Group 1 agents)
- Radium-224 and its decay products
- Radium-226 and its decay products
- Radium-228 and its decay products
- Radon-222 and its decay products
- *Schistosoma haematobium* (infection with)
- Silica, crystalline (inhaled in the form of quartz or cristobalite from occupational sources)
- Solar radiation
- Talc containing asbestiform fibres
- Tamoxifen (Note: There is also conclusive evidence that tamoxifen reduces the risk of contralateral breast cancer)
- 2,3,7,8-Tetrachlorodibenzo-para-dioxin
- Thiotepa
- Thorium-232 and its decay products, administered intravenously as a colloidal dispersion of thorium-232 dioxide
- ortho-Toluidine
- Treosulfan
- Vinyl chloride
- X- and Gamma (g)-radiation

Mixtures

- Aflatoxins (naturally occurring mixtures of)
- Alcoholic beverages
- Areca nut
- Betel quid with tobacco
- Betel quid without tobacco
- Coal-tar pitches
- Coal-tars
- Herbal remedies containing plant species of the genus Aristolochia
- Household combustion of coal, indoor emissions from
- Mineral oils, untreated and mildly treated

- Phenacetin, analgesic mixtures containing
- Salted fish (Chinese-style)
- Shale-oils
- Soots
- Tobacco, smokeless
- Wood dust

Exposure circumstances

- Aluminum production
- Arsenic in drinking-water
- Auramine production
- Boot and shoe manufacture and repair
- Chimney sweeping
- Coal gasification
- Coal-tar distillation
- Coke production
- Furniture and cabinet making
- Hematite mining (underground) with exposure to radon
- Involuntary smoking (exposure to secondhand or 'environmental' tobacco smoke)
- Iron and steel founding
- Isopropyl alcohol manufacture (strong-acid process)
- Magenta production
- Painter (occupational exposure as a)
- Paving and roofing with coal-tar pitch
- Rubber industry
- Strong-inorganic-acid mists containing sulfuric acid (occupational exposure to)
- Tobacco smoking and tobacco smoke

Source: International Agency for Research on Cancer "Carcinogenic to humans" (Group 1)

Appendix III

List of 17 categories of highly polluting industries

1. Aluminium smelting
2. Basic Drugs & Pharmaceuticals Manufacturing
3. Caustic Soda
4. Cement (200 TPD and above)
5. Copper Smelting
6. Dyes & Dye Intermediate
7. Fermentation (Distillery)
8. Fertilizer
9. Integrated Iron & Steel
10. Leather Processing including Tanneries
11. Oil Refinery
12. Pesticide Formulation & manufacturing
13. Pulp & Paper (30 TPD and above)
14. Petrochemical
15. Sugar
16. Thermal Power
17. Zinc Smelting

Appendix IV

List of the 54 Red Categories

1. Anodizing
2. Asbestos and asbestos based industries
3. Automobiles Manufacturing/ assembling
4. Ceramic/ Refractories
5. Chemical, petrochemical and electro chemicals including manufacture of acids such as Sulphuric Acid, Nitric Acid, Phosphoric Acid etc.
6. Cholrates, perchlorates and peroxides
7. Cholrine, Fluorine, bromine, iodine and their compounds
8. Coke making, coal liquefaction, coaltar distillation or fuel gas making
9. Common Effluent Treatment Plant
10. Dry coal processing/ Mineral processing industries like ore sintering, palletisation etc.
11. Explosives including detonatros, fuses etc.
12. Fermentation industry including manufacture of yeast, beer etc.
13. Fire crackers
14. Foundries
15. Glass and fibre glass production and processing (excluding moulding)
16. Glue and gelatin
17. Heavy, Engineering
18. Hospitals
19. Hot mix plants
20. Hydrocyanic acid and its derivatives
21. Incineration Plants
22. Industrail carbon including electrodes and graphite blocks, activated carbon, carbon black etc.
23. Industrail or inorganic gases namely (a) Chemical gases: Acetylene, Hydrogen, Chlorine, Fluorine, Ammonia, Sulphur Dioxide, Ethylene, Hydrogen Sulphide, Phosphine, (b) Hydrocarbon Gases: Methane, Butane, Ethane, Propane
24. Industry or process involving electroplating operations
25. Industry or process involving foundry operations.

26. Industry or process involving metal treatment or process such as pickling, paint stripping, heat treatment, phosphating or finishing etc.
27. Lead re-processing & manufacturing including lead smelting
28. Lime manufacturing
29. Lubricating oils, greases or petroleum – bases products
30. Milk processing and dairy products (Integrated Project)
31. Mining and ore-beneficiation
32. Organic Chemical Manufacturing
33. Parboiled rice mills
34. Paints and Varnishes (excluding blending/ mixing)
35. Petroleum products manufacturing & Oil/ Crude oil/ residues reprocessing
36. Phosphate rock processing plants
37. Phosphorous and its compounds
38. Photographic films and chemicals
39. Pigments and Intermediates
40. Potable alcohol (IMFL) by blending or distillation of alcohol
41. Power generating plants (excluding D.G. Sets)
42. Processes involving chlorinated hydrocarbons
43. Ship Breaking
44. Slaughter houses and meat processing industries
45. Steel and steel products including coke plants involving use of any of the equipment's such as blast furnaces, open furnace, induction furnace or an arc furnace etc. or any of the operations or processes such as heat treatment, acid pickling, roiling or galvanizing etc.
46. Stone Crushers
47. Surgical and medical products involving prophylactics and latex
48. Synthetic detergent and soap.
49. Synthetic fibre including rayon, tyre cord, polyester filament yarn
50. Synthetic resins
51. Synthetic rubber excluding moulding
52. Tobacco products including cigarettes and tobacco processing
53. Vegetable oils including solvent extracted oils, hydrogenated oils

54. Yarn and Textile processing involving scouring, bleaching, dyeing, printing or any effluent/ emission generating process.

Appendix V

Environnemental Standards

Ambient Air Quality Standards

रजिस्ट्री सं॰ डी॰ एल॰-33004/99 REGD. NO. D. L.-33004/99

भारत का राजपत्र

The Gazette of India

असाधारण

EXTRAORDINARY

भाग III—खण्ड 4

PART III—Section 4

प्राधिकार से प्रकाशित

PUBLISHED BY AUTHORITY

सं. 217] नई दिल्ली, बुधवार, नवम्बर 18, 2009/कार्तिक 27, 1931

No. 217] NEW DELHI, WEDNESDAY, NOVEMBER 18, 2009/KARTIKA 27, 1931

राष्ट्रीय परिवेशी वायु गुणवत्ता मानक

केन्द्रीय प्रदूषण नियंत्रण बोर्ड

अधिसूचना

नई दिल्ली, 18 नवम्बर, 2009

सं. बी-29016/20/90/पी.सी.आई.-I.—वायु (प्रदूषण निवारण एवं नियंत्रण) अधिनियम, 1981 (1981 का 14) की धारा 16 की उपधारा (2) (एच) द्वारा प्रदत्त शक्तियों का प्रयोग करते हुए तथा अधिसूचना संख्या का.आ. 384(ई), दिनांक 11 अप्रैल, 1994 और का.आ. 935 (ई) दिनांक 14 अक्टूबर, 1998 के अधिक्रमण में केन्द्रीय प्रदूषण नियंत्रण बोर्ड इसके द्वारा तत्काल प्रभाव से राष्ट्रीय परिवेशी वायु गुणवत्ता मानक अधिसूचित करता है, जो इस प्रकार है:-

राष्ट्रीय परिवेशी वायु गुणवत्ता मानक

क्र. सं.	प्रदूषक	समय आधारित औसत	परिवेशी वायु में सान्द्रण		
			औद्योगिक, रिहायशी, ग्रामीण और अन्य क्षेत्र	पारिस्थितिकी य संवेदनशील क्षेत्र (केन्द्र सरकार द्वारा अधिसूचित)	प्रबोधन की पद्धति
(1)	(2)	(3)	(4)	(5)	(6)
1	सल्फर डाई आक्साइड (SO_2), µg/m³	वार्षिक* 24 घंटे**	50 80	20 80	-उन्नत वेस्ट और गाईक -पराबैंगनी परिदीप्ती
2	नाइट्रोजन डाई आक्साइड (NO_2), µg/m³	वार्षिक* 24 घंटे**	40 80	30 80	-उपांतरित जैकब और हॉचाइजर (सोडियम-आर्सेनाईट) -रासायनिक संदीप्ति
3	विविक्त पदार्थ (10माइक्रान से कम आकार)या PM_{10}, µg/m³	वार्षिक* 24 घंटे**	60 100	60 100	-हराल्मिक विश्लेषण -टोयम -बीटा तनुकरण पद्धति

4187 GI/2009 (1)

4	विविक्त पदार्थ (2.5 माइक्रान से कम आकार या $PM_{2.5}$, $\mu g/m^3$	वार्षिक* 24 घंटे**	40 60	40 60	-हरात्मक विश्लेषण -टोयम -बीटा तनुकरण पद्धति
5	ओजोन (O_3) $\mu g/m^3$	8 घंटे** 1 घंटा**	100 180	100 180	-पराबैंगनी द्वीप्तिकाल -रासायनिक संदीप्ति -रासायनिक पद्धति
6	सीसा (Pb) $\mu g/m^3$	वार्षिक* 24 घंटे**	0.50 1.0	0.50 1.0	ई.पी.एम 2000 या समरूप फिल्टर पेपर का प्रयोग करके AAS/ICP पद्धति -टेफलॉन फिल्टर पेपर का प्रयोग करते हुए ED-XRF
7	कार्बन मोनोक्साइड (CO) mg/m^3	8 घंटे** 1 घंटा**	02 04	02 04	-अविपेक्षी अवरक्त (NDIR) स्पैक्ट्रम मापन
8	अमोनिया (NH_3) $\mu g/m^3$	वार्षिक* 24 घंटे**	100 400	100 400	-रासायनिक संद्वीप्ती -इण्डोफिनॉल ब्ल्यू पद्धति
9	बैन्जीन (C_6H_6) $\mu g/m^3$	वार्षिक*	05	05	- गैस क्रोमेटोग्राफी आधारित सतत् विश्लेषक -अधिशोषण तथा निशोषण के बाद गैस क्रोमेटोग्राफी
10	बैन्जो (ए) पाईरीन (BaP) केवल विविक्त कण, ng/m^3	वार्षिक*	01	01	-विलायक निष्कर्षण के बाद HPLC/GC द्वारा विश्लेषण
11	आर्सेनिक (As) ng/m^3	वार्षिक*	06	06	-असंवितरक अवरक्त स्पैक्ट्रामिती ई.पी.एम. 2000 या समरूप फिल्टर पेपर का प्रयोग करके ICP/AAS पद्धति
12	निकिल (Ni) ng/m^3	वार्षिक*	20	20	ई.पी.एम. 2000 या समरूप फिल्टर पेपर का प्रयोग करके ICP/AAS पद्धति

* वर्ष में एक समान अतंरालों पर सप्ताह में दो बार प्रति 24 घंटे तक किसी एक स्थान विशेष पर लिये गये न्यूनतम 104 मापों का वार्षिक अंकगणीतीय औसत ।

** वर्ष में 98 प्रतिशत समय पर 24 घंटे या 8 घंटे या 1 घंटा के मानीटर मापमान, जो लागू हो , अनुपालन कये जाएंगे । दो प्रतिशत समय पर यह मापमान अधिक हो सकता है, किन्तु क्रमिक दो मानीटर करने के दिनों पर नहीं ।

टिप्पणी:

1. जब कभी और जहां भी किसी अपने-अपने प्रवर्ग के लिये दो क्रमिक प्रबोधन दिनों पर मापित मूल्य, ऊपर विनिर्दिष्ट सीमा से अधिक हो तो इसे नियमित या निरंतर प्रबोधन तथा अतिरिक्त अन्वेषण करवाने के लिये पर्याप्त कारण समझा जायेगा ।

संत प्रसाद गौतम, अध्यक्ष

[विज्ञापन-III/4/184/09/असा.]

टिप्पणी: राष्ट्रीय परिवेशी वायु गुणवत्ता मानक संबंधी अधिसूचनाएँ, केन्द्रीय प्रदूषण नियंत्रण बोर्ड द्वारा भारत के राजपत्र आसाधरण में अधिसूचना संख्या का.आ. 384 (ई), दिनांक 11 अप्रैल, 1994 एवं का. आ. 935 (ई), दिनांक 14 अक्टूबर, 1998 द्वारा प्रकाशित की गयी थी ।

NATIONAL AMBIENT AIR QUALITY STANDARDS
CENTRAL POLLUTION CONTROL BOARD
NOTIFICATION
New Delhi, the 18th November, 2009

No. B-29016/20/90/PCI-L—In exercise of the powers conferred by Sub-section (2) (h) of section 16 of the Air (Prevention and Control of Pollution) Act, 1981 (Act No.14 of 1981), and in supersession of the Notification No(s). S.O. 384(E), dated 11th April, 1994 and S.O. 935(E), dated 14th October, 1998, the Central Pollution Control Board hereby notify the National Ambient Air Quality Standards with immediate effect, namely:-

NATIONAL AMBIENT AIR QUALITY STANDARDS

S. No.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial, Residential, Rural and Other Area	Ecologically Sensitive Area (notified by Central Government)	Methods of Measurement
(1)	(2)	(3)	(4)	(5)	(6)
1	Sulphur Dioxide (SO_2), µg/m³	Annual* 24 hours**	50 80	20 80	- Improved West and Gaeke -Ultraviolet fluorescence
2	Nitrogen Dioxide (NO_2), µg/m³	Annual* 24 hours**	40 80	30 80	- Modified Jacob & Hochheiser (Na-Arsenite) - Chemiluminescence
3	Particulate Matter (size less than 10µm) or PM_{10} µg/m³	Annual* 24 hours**	60 100	60 100	- Gravimetric - TOEM - Beta attenuation
4	Particulate Matter (size less than 2.5µm) or $PM_{2.5}$ µg/m³	Annual* 24 hours**	40 60	40 60	- Gravimetric - TOEM - Beta attenuation
5	Ozone (O_3) µg/m³	8 hours** 1 hour**	100 180	100 180	- UV photometric - Chemilminescence - Chemical Method
6	Lead (Pb) µg/m³	Annual* 24 hours**	0.50 1.0	0.50 1.0	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper - ED-XRF using Teflon filter
7	Carbon Monoxide (CO) mg/m³	8 hours** 1 hour**	02 04	02 04	- Non Dispersive Infra Red (NDIR) spectroscopy
8	Ammonia (NH_3) µg/m³	Annual* 24 hours**	100 400	100 400	-Chemiluminescence -Indophenol blue method

(1)	(2)	(3)	(4)	(5)	(6)
9	Benzene (C_6H_6) µg/m³	Annual*	05	05	- Gas chromatography based continuous analyzer - Adsorption and Desorption followed by GC analysis
10	Benzo(a)Pyrene (BaP) - particulate phase only, ng/m³	Annual*	01	01	- Solvent extraction followed by HPLC/GC analysis
11	Arsenic (As), ng/m³	Annual*	06	06	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper
12	Nickel (Ni), ng/m³	Annual*	20	20	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper

* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

** 24 hourly or 08 hourly or 01 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Note. — Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigation.

SANT PRASAD GAUTAM, Chairman
[ADVT-III/4/184/09/Exty.]

Note: The notifications on National Ambient Air Quality Standards were published by the Central Pollution Control Board in the Gazette of India, Extraordinary vide notification No(s). S.O. 384(E), dated 11th April, 1994 and S.O. 935(E), dated 14th October, 1998.

Printed by the Manager, Government of India Press, Ring Road, Mayapuri, New Delhi-110064
and Published by the Controller of Publications, Delhi-110054.

General Standards for Discharge of Environment Pollutants Part A: Effluents

General Standards for Discharge of Environment Pollutants: Effluent

(Source: The environment (Protection) Rules, 1986)

S. No.	Parameter	Standards			
		Inland surface water	Public sewers	Land for irrigation	Marine coastal areas
		(a)	(b)	(c)	(d)
1.	Colour and odour	-	-	-	-
2.	Suspended solids mg/l, Max.	100	600	200	(a) For process waste water 100 (b) For cooling water effluent 10 percent above total suspended matter of influent
3.	Particular size of suspended solids	Shall pass 850 micron IS Sieve	-	-	(a)Floatable solids, max. 3 mm (b) Settleable solids, max 850 microns
[2]4.	***	*	*	*	*
5.	pH value	5.5 to 9.0	5.5 to 5.5 to 9.0	5.5 to 9.0	
6.	Temperature	Shall not exceed 5°C above the receiving water temperature	-	-	Shall not exceed 5°C above the receiving water temperature
7.	Oil and grease mg/l Max.	10	20	10	20
8.	Total residual chlorine mg/l Max.	1.0	-	-	1.0
9.	Ammonical nitrogen(as N), mg/l Max.	50	50	-	50
10	Total Kjeldahl nitrogen(as NH_3) mg/l, Max	100	-	-	100
11.	Free ammonia (as NH_3) mg/l, Max	5.0	-	-	5.0
12.	Biochemical Oxygen demand (5 days at 20°C) mg/l Max.	30	350	100	100
13.	Chemical Oxygen demand, mg/l Max.	250	-	-	250
14.	Arsenic (as As), mg/l Max.	0.2	0.2	0.2	0.2
15.	Mercury (As Hg.) mg/l Max.	0.01	0.01	-	0.01
16.	Lead (as Pb) mg/l, Max.	0.1	1.0	-	2.0
17.	Cadmium (as Cd) mg/l, Max.	2.0	1.0	-	2.0

18.	Hexavalent chromium (as $Cr^{+}6$), mg/l, Max.	0.1	2.0	-	2.0
19.	Total chromium (as Cr) mg/l, Max.	2.0	2.0	-	2.0
20.	Copper (as Cu) mg/l, Max.	3.0	3.0	-	3.0
21.	Zinc (as Zn.) mg/l Max.	5.0	15	-	15
22.	Selenium (as Se.) mg/l, Max.	0.05	0.05	-	0.05
23.	Nickel (as Ni) mg/l, Max.	3.0	3.0	-	5.0
[2]24.	***	*	*	*	*
[2]25.	***	*	*	*	*
[2]26.	***	*	*	*	*
27.	Cyanide (as CN) mg/l Max.	0.2	2.0	0.2	0.2
[2]28.	***	*	*	*	*
29.	Fluoride (as F) mg/l Max.	2.0	15	-	15
30.	Dissolved phosphates (as P), mg/l Max.	5.0	-	-	-
[2]31.	***	*	*	*	*
32.	Max.	2.0	-	-	5.0
33.	Phenolic compounds(as C_6H_5OH) mg/l Max.	1.0	5.0	-	5.0
34.	Radioactive material (a) Alpha emitter micro curie/ml	10^{-7}	10^{-7}	10^{-8}	10^{-7}
	(b) Beta emitter micro curie/ml	10^{-6}	10^{-6}	10^{-7}	10^{-6}
35.	Bio-assay test	90%survival of fish after 96 hours in100% effluent	90%survival of fish after 96 hours in100% effluent	90%survival of fish after 96 hours in100% effluent	90%survival of fish after 96 hours in100% effluent
36.	Manganese (as Mn.) mg/l	2	2	-	2
37.	Iron (as Fe) mg/l	3	3	-	3
38.	Vanadium (as V)	0.2	0.2	-	0.2
39.	Nitrate Nitrogen mg/l	10	-	-	20
[2]40.	***	*	*	*	*

1. Schedule VI inserted by Rule 2(d) of the Environment (Protection), Second Amendment Rules, 1993 notified vide G.S.R. 422(E) dated 19.05.1993, published in the Gazette No. 174 dated 19.05.1993.
2. Omitted by Rule 2(d)(i) of the Environment (Protection) Third Amendment Rules, 1993 vide Notification No. G.S.R. 801 (E) dated 31.12.1993

Table: Use based classification of surface waters in India

Designated-Best-Use	Class of water	Criteria
Drinking Water Source without conventional treatment but after disinfection	A	1. Total Coliforms OrganismMPN/100ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 6mg/l or more 4. Biochemical Oxygen Demand 5 days 20^oC 2mg/l or less
Outdoor bathing (Organised)	B	1. Total Coliforms Organism MPN/100ml shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 5mg/l or more 4. Biochemical Oxygen Demand 5 days 20^oC 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	1. Total Coliforms Organism MPN/100ml shall be 5000 or less 2. pH between 6 to 9 3. Dissolved Oxygen 4mg/l or more 4. Biochemical Oxygen Demand 5 days 20^oC 3mg/l or less
Propagation of Wild life and Fisheries	D	1. pH between 6.5 to 8.5 2. Dissolved Oxygen 4mg/l or more 3. Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	E	1. pH between 6.0 to 8.5 2. Electrical Conductivity at 25^oC micro mhos/cm Max.2250 3. Sodium absorption Ratio Max. 26 4. Boron Max. 2mg/l

The entire water resources of the country were classified according to their designated best uses and a “Water Use Map” was prepared. For identification of the water bodies or their parts where water quality is at variance with water quality criteria, it was felt important to measure water quality of that water body or its part. It would help in preparation of “Water Quality Map” of India. The idea was to superimpose “Water Quality Map” on “Water Use Map” to identify the water bodies or their parts, which are in need of improvement (restoration). Subsequently through a wide network of water quality monitoring, water quality data are acquired. A large number of water bodies were identified as polluted stretches for taking appropriate measures to restore their water quality. Today almost all policies and programmes on water quality management are based on this concept including the Ganga Action Plan and National River Action Plans.

Appendix VI
Exceedance Factor Calculation

The ambient environmental (ambient air/ surface water/ ground water) quality has been categorized into four broad categories based on an Exceedance Factor (the ratio of annual (or 24-hourly) mean observed concentration of a pollutant and prescribed standard limit of concentration of corresponding pollutant). The Exceedance Factor (EF) is calculated as follows:

Exceedance Factor = {Observed mean concentration of criteria pollutant / Prescribed standard for the respective pollutant and area class}

The four environmental quality categories are:

- Critical pollution (C) : when EF is more than 1.0;
- High pollution (H) : when the EF is between 0.75 - 1.0;
- Moderate pollution (M) : when the EF between 0.5 – 0.75; and
- Low pollution (L): when the EF is less than 0.5.

It can be inferred from values of above classification, that the industrial clusters falling under first (critical) category is actually violating the prescribed standards. In the second category (H) and third category (M), though prescribed standards are met presently, there is high and moderate possibility that industrial clusters falling under these categories respectively may violate the prescribed standards with varying magnitude in near future if pollution continues to increase. However, the industrial clusters falling under the last category (L) maintain ambient environmental quality standards very well and such areas are to be encouraged to maintain low pollution level by way of adopting pollution prevention and control measures.

LIST OF PUBLICATIONS

- Vidyarthi, A.K., Singh, A. P. and Shrivastava, P. (2015) "Environmental Impact Assessment of Industrial Clusters in Central India Using Fuzzy Decision Analysis", Industrial Pollution Control, Volume 31(2), 213-221.
- Singh, A. P. and Vidyarthi, A.K. (2017) "Status of Environmental Pollution in Agra Industrial Cluster: An IEPI Approach", Pollution Research (Accepted for publication).
- Singh A. P. and Vidyarthi, A. K. (2008), "Optimal allocation of landfill disposal site: A fuzzy multi-criteria approach", Iranian Journal of Environmental Health Science & Engineering, Vol. 5(1), pp. 25-34.
- Singh, A. P., Shrivastava, P. and Vidyarthi, A. K. (2016). "Potential Impacts of Climate Change in Water Resources Management of Chittorgarh, District, Rajasthan, India" in International Conference on Water, Environment, Energy and Society (ICWEES-2016) organized jointly by the Texas A & M University, Texas, USA and AISECT University, Bhopal, India, March 15 – 18, 2016.

BRIEF BIOGRAPHY OF CANDIDATE

Shri AJIT KUMAR VIDYARTHI

Scientist 'E',

Central Pollution Control Board (CPCB)

(Ministry of Environment, Forests & Climate Change, Govt. of India),

'Parivesh Bhawan', East Arjun Nagar, Delhi-110 032,

Email: ajitvidyarthi@yahoo.co.in, akvidyarthi@gmail.com, vidyarthi.cpcb@nic.in

Shri Ajit Kumar Vidyarthi has been working in CPCB since last 17 years with experience in the field of industrial pollution control, municipal solid wastes and sewage management. He is B.E. in Civil Engineering and M.E. in Civil Engineering with specialization in Environmental Engineering. He has been presently posted as Scientist 'E'. He has successfully carried out implementation of some of the flagship programmes, namely, 'Charter for Water Recycling and Pollution Prevention in Pulp & Paper Industries in Ganga River Basin States', and pioneered the work to evolve the method and mechanism for Comprehensive Environmental Pollution Index (CEPI) for characterization of environmental quality of industrial clusters.

Shri Vidyarthi has published more than 10 research papers in different Journals and conference proceedings and also written/ edited more than 10 books/ reports published by CPCB. He is a fellow of Indian Pulp & Paper Technical Association (IPPTA).

He has been In-charge; Pollution Control Implementation in Agro based industries- Pulp & Paper, Tea and Coffee since 2010. He successfully carried out implementation of Phase-I of the "Charter for Water Recycling and Pollution Prevention in Pulp & Paper Industries in Ganga River Basin" in 2012-14 in the identified clusters of Uttarakhand and Uttar Pradesh. The Charter implementation programme was a stepping stone towards River Ganga Pollution Control. He is also nodal officer for the one of the flagship programme for implementation of Phase-II of the 'Charter for Water Recycling and Pollution Prevention in Pulp & Paper Industries in Ganga River Basin States' launched in February 2015 in nine Ganga River Basin States.

Previously, he also pioneered the work to evolve the method and mechanism for 'Comprehensive Environmental Pollution Index' (CEPI) for characterization of environmental quality of industrial clusters. Environmental assessment of 88 known prominent industrial clusters in the country was carried out using the CEPI criteria and 43 Critically Polluted Clusters were identified.

BRIEF BIOGRAPHY OF SUPERVISOR

Dr. AJIT PRATAP SINGH
Professor
Civil Engineering Department,
Birla Institute of Technology and Science,
Pilani – 333 031, Rajasthan. India
Email: apsbits@gmail.com,
aps@pilani.bits-pilani.ac.in

Dr Ajit Pratap Singh, is the 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 75 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.