"FUZZY EXPERT SYSTEM BASED LANDFILL OPERATIONS MANAGEMENT ADVISOR AND CAPACITY ESTIMATION FOR LANDFILL ENGINEERING"

A dissertation report submitted in partial fulfilment of the requirements for the award of degree

of

Master of Technology

in

Artificial Intelligence & Artificial Neural Networks

By

APARNA NARAYANAN
R102212012

Under the Esteemed Guidance of

Dr Neelu J Ahuja
Associate Professor
CIT, UPES

Dr Kanchan Deoli Bahukhandi
Assistant Professor
HSE, UPES

Centre for Information Technology
University of Petroleum & Energy Studies
Bidholi, Via Prem Nagar, Dehradun, UK

MAY – 2014

CERTIFICATE

This is to certify that the project work entitled "**Fuzzy Expert System based Landfill Operations Management Advisor and Capacity Estimation for Landfill Engineering**" done by **Aparna Narayanan, R102212012** for partial fulfilment of the requirements for the award of the Degree of Masters of Technology in Computer Science & Engineering With Specialization in Artificial Intelligence and Neural Networks, to Centre For Information Technology, University of Petroleum & Energy Studies is a bonafide report of the work carried by them under our guidance and supervision.

To my best of knowledge, the literature embodied in this project work has not been submitted to any other University/Institute for the award of any degree or diploma.

Dr Neelu J Ahuja 19/5/2014
Internal Guide
Centre for Information Technology
UPES, Dehradun

Dr Manish Prateek
Associate Dean
Centre for Information Technology
UPES, Dehradun

Dr Kanchan Deoli Bahukhandi 19/5/14
Internal Guide
Health Safety and Environment
UPES, Dehradun

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis entitled '**Fuzzy Expert System based Landfill Operations Management Advisor and Capacity Estimation for Landfill Engineering'** in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Computer Science & Engineering With Specialization in Artificial Intelligence and Neural Networks and submitted in the Department of Centre for Information Technology, University of Petroleum & Energy Studies, Dehradun, is an authentic record of my own work carried out during a period from January, 2014 to May, 2014 under the supervision of Dr. Neelu J Ahuja, Associate Professor, CIT, UPES and Dr Kanchan Deoli Bahukhandi, HSE, UPES.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

Aparna

(APARNA NARAYANAN)

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

Date: 19/05/2014

Neelu 19/5/2014
Dr Neelu J Ahuja

19/5/14
Dr Kanchan Deoli Bahukhandi

The Dissertation Viva-Voce Examination of **Ms. Aparna Narayanan**, Roll No **R102212012** has been held on 07/05/2014.

Official/Department Stamp with signature head.

ACKNOWLEDGEMENT

I thankfully acknowledge the funding support received from Uttarakhand State Council for Science and Technology, Dehradun, Govt. of Uttarakhand, India, for carrying out the present work. The past solid waste generation data used for development and validation of the ANN model has been received from the municipal local collection authorities.

I wish to express my deep gratitude to my guides **Dr Neelu J Ahuja** and **Dr Kanchan Deoli Bahukhandi**, for all advice, encouragement and constant support they have given me throughout the project work. I would also like to thank **Mr Ritesh Saini, JRF** who provided appreciated assistance throughout the working of this project. This work would not have been possible without their support and valuable suggestions.

I sincerely thank our respected **Dr. Manish Prateek**, Associate Dean, for his great support in doing this project at **CIT**.

I am also grateful to **Dr. Kamal Bansal,** Director CoES, UPES for giving the necessary facilities to carry out the project work successfully.

I would like to thank all my **friends** for their help and constructive criticism during the project work. Finally I have no words to express my sincere gratitude to my **parents** who have shown me this world and for every support they have given me.

Name **Aparna Narayanan**

Roll No. **R102212012**

ABSTRACT

Solid waste management has become a pressing problem of each city. Proper management of solid waste can be possible only by planning in advance the disposal methods and strategies for the generated solid waste. This call for availability of the land required in future for the disposal of the said solid wastes that will be generated in future. For this purpose, a model needs to be developed which can use the quantity of futuristic solid waste generated as input to estimate the capacity of land required for its disposal in a landfill.

The futuristic values of the solid waste that will be generated are needed for the process of preplanning of waste management. The landfill capacity estimation model considers all the parameters that affect the remaining landfill capacity at any instance of time. The validation of this model was performed against the stipulated guidelines in the solid waste management handbook and further used to calculate the capacity of the landfill required for a bioreactor landfill for the city of Dehradun.

Once the landfill is operational, a multitude of problems could affect its daily running. A landfill operation management advisor has been developed to provide assistance to the landfill personnel. This system not only advises the manager with regards to the operational problems but also is an early warning system to reduce the catastrophic effects that could entail if corrective measures are not taken immediately. A Fuzzy Expert System has been developed for this purpose by the use of the technologies of FLEX and FLINT.

This entire project has been specifically developed for the planning of solid waste management for the city of Dehradun. The work is a part of project funded by Uttarakhand State Council for Science & Technology, Govt. of Uttarakhand, India.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1 INTRODUCTION

India is one of the fastest developing economies in the globe today. India is currently the second most populated county of the world second only to China. At the coming of the year of 2014, the Indian population has already surpassed the 1.26 billion target, accounting for nearly 18% of the world's population [1]. The recent population explosion has given to a radical increase in the human population and the associated activities have accelerated the phenomenon of urbanization in the past couple of decades. The present citizens of India are living in times of unprecedented economic growth, rising aspirations, and rapidly changing lifestyles, which will set up the expectations on public health and quality of life. Increasing the standard of living of millions of people has also created an increase in the consumption of energy and consumer commodities. This increase will probably place a vast amount of stress on the existing natural resources. The country is currently facing a standoff between its growing population and the available resources and services.

One of the after effects of human activities is the generation of solid waste. The amount of waste generated is directly relative to the economic growth and the consumption stages. Low income countries generally consume fewer goods and also use less recyclable materials as compared to their high income counterparts. Larger cities tend to produce higher amounts of solid waste as compared to the smaller cities and the rural areas. In spite of the rapid growth in the generation of solid waste throughout the country, at that place are not enough resources or adequate systems in place for the treatment of the generated waste.

As more and more people migrate toward urban areas, the uptake levels are likely to rise with the alteration in population, as are the rates of waste generation. Solid waste management is one such field where not enough natural resources are available to assume charge of the rapidly rising levels of generating solid waste. This has a substantial amount of impact on the area of land that is currently needed and will be called for in the future for the disposal of solid waste.

Proper municipal solid waste disposal systems to address the burgeoning amount of dissipation are not even in position. The current solid waste management services are inefficient and incur great losses [2]. If an appropriate management system is not applied for waste disposal, it will contribute to environmental pollution and also jeopardize the health of the masses. Improper solid waste management deteriorates public health, causes environmental pollution, accelerates natural resource degradation, causes climate change and greatly affects the quality of life of the citizens. Pollution of air, water or land results in long-term reduction of productivity leading to a deterioration of the economic condition of a country. Thus, controlling pollution to reduce the danger of poor health, to protect the natural environment and to contribute to our quality of life is a key element of sustainable growth

Municipal solid waste (MSW), usually known as trash, garbage, refuse or rubbish is a waste type, consisting of daily items that are discarded by the public. Municipal solid waste characteristics and quantities change significantly with time. The affecting factors include - change in the food consumption pattern, population growth, migration, underlying economic development, employment changes, weather conditions, geographical situation, hobbies, and household size [3]. Altogether, these elements, along with the impact of waste recycling influence the generation of solid waste tremendously. The ontogeny of a reliable model that could measure the impact of all elements that affect solid waste generation and its prediction would be a useful aspect in the process of management of solid waste generated. As this model would enable the authorities have prior intimation of the quantity of waste that could be engendered in the future and allow them to plan its disposal method accordingly.

1.1 Solid Waste in Dehradun

Dehradun being the capital of Uttarakhand is also a rail-head and one of the large urban centres in the state. This city is confronting the challenge of providing essential infrastructure to keep pace with the increase in population. Solid waste management is one among the major challenges faced by this city.

The major sources of municipal solid waste generation of Dehradun City include shops and commercial establishments, hotels and restaurants and fruit and vegetable markets on top of domestic sources [4]. Granting to the "Dehradun Nagar Nigam (DNN)" the metropolis on an average generates approximately 200 MT of MSW per day. The judgment is founded on the assumption of per capita generation @ 0.4kg/capita/day [5].

1.1.1 Waste Composition and Characteristics

The waste materials that the municipal solid waste is composed of can be grouped under the following classes [4]:

1. **Biodegradable Waste:** This includes matters like food and kitchen waste such as meat trimmings or vegetable peelings, yard or green waste and newspaper and so on.

2. **Recyclable materials:** Paper is also admitted in this category, but non-biodegradable items like glass, bottles, other plastics, aluminium cans, metals etc. fall into this segment.
3. **Inert waste:** Inert materials are those that are not necessarily toxic to all species but can be harmful or toxic to humans. Consequently, construction and demolition waste along with dirt, stones, debris, etc. are frequently categorized as inert waste.
4. **Composite waste:** Includes items that are composed of more than one material. For example, clothing and plastics such as children's toys are composite waste.
5. **Household hazardous waste:** This includes medicines, paint, batteries, light bulbs, fertilizer and pesticide containers and e-waste like old computers, printers, and cellular phones. Household hazardous waste cannot be reused or disposed of with other waste categories so many urban centres offer residents other options for hazardous waste disposal.

DNN has carried out MSW composition and characteristic analysis of solid waste in the city of Dehradun through Andhra Pradesh Technology Development and Promotion Centre [5]. The outcome of the analysis indicates the following composition of the city MSW.

Table 1-1: Waste Composition of Dehradun

Material	Constituent Composition (%)
Organic Matter/Bio-Mass	65.0
Paper	3.5
Rags/Textiles	6.0
Plastics	7.0
Glass	1.5
Rubber/Leather	1.5
Metal	0.5
Stones	8.0
Sand/Earth	7.0

Analysis was done on dry weight basis. The above result suggests that the city waste has a very high composition of organic matter (65%). Recyclable waste contributes about 20%, including 7% of plastics. Composition of inert substances is 15%. The pie chart below provides a graphical representation of the same [5].

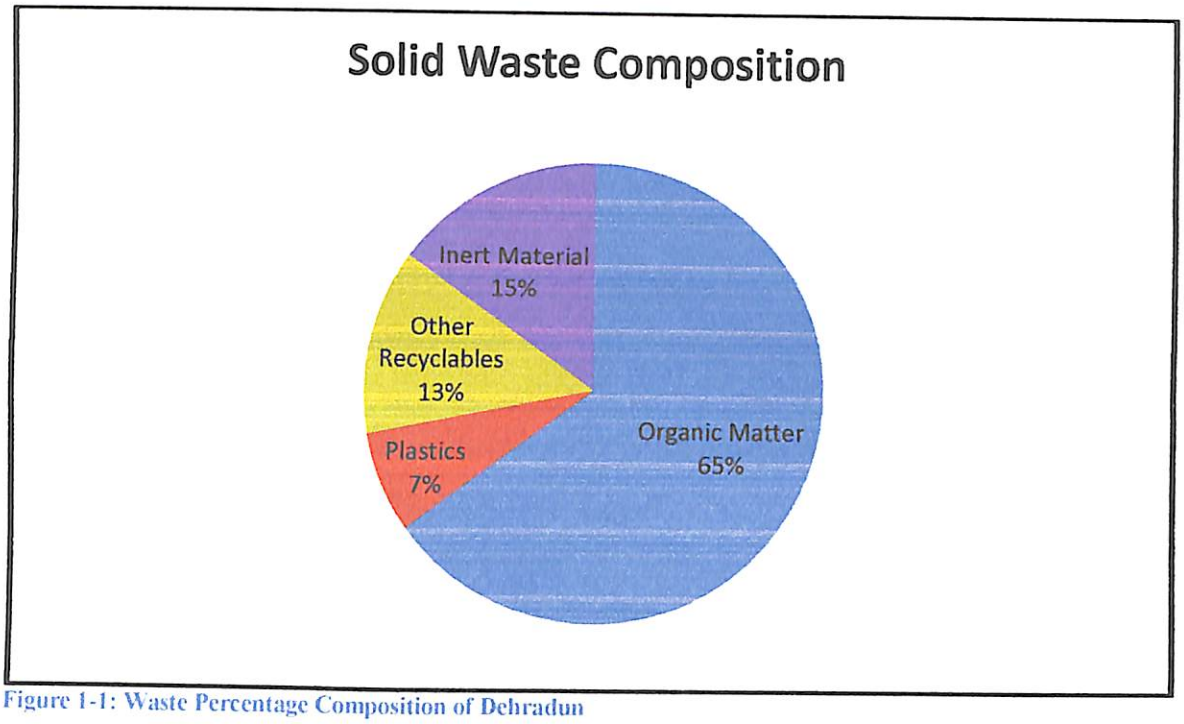


Figure 1-1: Waste Percentage Composition of Dehradun

1.1.2 Waste Disposal

There are various ways of disposing solid waste. The most commonly employed methods of disposal of solid waste are: recycling, composting, landfilling, and waste-to-energy via incineration. The municipal solid waste generated needs to be classified based on their disposal method. The biodegradable waste can be sent for composting. The recyclable materials can be sent for reuse and recycle and the inert waste need to be disposed of in a landfill. A complete list of waste disposal methods is provided in the table 1-2 [6].

Table 1-2: Waste Disposal Methods

Disposal Method	Type of waste	Description
Landfill	All	Burial of waste
Incineration	Solid organic waste	Thermal treatment
Recycling	Recyclables	Resource recovery and reuse
Composting	Biodegradable waste	Conversion to manure or fertilizer
Waste-to-energy	Non-recyclable materials	Combustion, gasification, anaerobic digestion etc.

The residues of the incinerations, the materials that cannot be distinctly identified and separated and those which cannot be disposed of anywhere else but are not hazardous in nature are disposed of in landfills.

1.1.3 Existing Solid Waste Management System

The arrangement that is currently in place is very minimalistic in nature. The existing solid waste collection system mainly comprises of

(i) Primary collection system: Collection from the doorstep by means of handcarts and cycle-rickshaw and

(ii) Secondary collection system: Collection through community bins/containers.

Accumulation of waste primarily includes wastes generated from street sweeping, cleaning of drains and domestic waste.

The Primary collection system exists in very few localities of the city, and covers about only 5-6% of the city population. In certain areas door-to-door collection is managed by individual agencies and Residents' Welfare Associations like Mohalla Swachata Samiti (MSS) [4]. Approximately 93 such MSS have been organized to encompass different regions of the city. Nevertheless, it is reported that these MSS are not performing satisfactorily. In the old city area no municipal collection facilities exist. Individual households usually obtain the services of a sweeper who collects wastes from houses daily. The collected wastes are dumped or thrown into the nearest surface drains and/or storm water nallahs. The river going past through these areas are substantially obstructed and silted due to this waste deposition.

The Secondary storage of solid waste is done by means of community containers having capacities of 0.45 m^3, 1m^3, 4.5 m^3 and 7.5 m^3. 274 such containers are located at different locations (also called collection points) of the city for secondary storage of solid waste. A few of these containers (0.45m^3 and 1 m^3) are open and attract animals [4].

Municipal Corporation sweepers and sanitary workers sweep solid wastes from the streets. They accumulate the collected waste into small heaps and subsequently load it manually or mechanically on to the solid waste transportation vehicles for onward transportation to the disposal site. The present collection and transportation system involves multiple handling of solid waste.

1.2 Problem

The city of Dehradun has not met its mandatory obligations under the Municipal Solid Wastes (Management and Handling) Rules, 2000 under the umbrella act "The Environment (Protection) Act, 1986" and is burdened with an inefficient collection system, lack of environmentally sound disposal site(s) and uncontrolled dumping at a site by a rivulet. It therefore calls for immediate and prolonged attempt to upgrade to a full service level [4].

Sweeping and SWM is done by the municipality, but it is very irregular and overall management is inadequate. SW situation is grim in many poverty pockets; on that point is no system of solid waste accumulation. The residents, therefore, dump waste openly on the street or in rivers or in the drain or down the hill slope. Many have appointed private sweepers for cleaning and pay them monthly, or waste disposal is done by self. The drainage and streets in the slums are either rarely cleaned or never cleaned at all. [4]

Table 1-3: Household Categorized Waste Disposal

Disposal Place	BPL (%)	Poor (%)	Lower-Middle (%)	Upper-Middle (%)	High (%)
In private bin for house collection	24.4	42.3	50.9	59.4	70.4
In community bin	21.1	10.1	20.2	15.2	9.9
Burn	13.3	5.2	3.9	2.2	2.8
Throw outside openly	41.1	42.3	25.9	23.9	16.9

Approximately 85% of the families do not practice waste segregation at the root. Municipal collection is not uniform in the city. Higher income groups usually appoint a private worker for solid waste collection and they pay for this monthly. Approximately 20 percent of the residents burn waste in the locality. Burning is more frequent in Below Poverty Line (BPL) localities. Of the sampled households 87 % sell old newspaper, plastic, glass, bottles, etc.

The existing solid waste disposal site is located at Dateda Lakhond on Sahashradhara Road and at a distance of about 7 km from the town. The site (area approx. 4 ha) has been in use for the last 6 years. The solid waste brought to the site, is disposed into pre-excavated trench and covered with a layer of soil.

1.2.1 Key Issues and Current Deficiencies

The major issue with regards to SWM is that the DNN has failed to comply with the Municipal Solid Waste

(Management and Handling) Rules, 2000, in all aspects of SWM i.e. Collection, Storage, Transportation, Processing, Disposal of MSW of the city and Institutional Reform. Other important issues along with the insufficiencies in the present SWM system are counted as follows: [4]

1) ***Solid Waste Quantification and Characterization:*** Proper quantification of the waste is an important factor for the assessment of equipment, vehicles and manpower. Representative characterization of the city waste is essential for determining appropriate waste processing and disposal methods Quantification of the city solid waste has not considered the factor such as waste generation from sources other than domestic source.
2) ***Segregation of Waste at Source:*** At present, there is no segregation of waste at source.
3) ***Primary Collection of Waste:*** Present collection system is irregular, ineffective and inefficient. A substantial portion of the waste is left unattended. This waste not only degrades the environment, but also blocks storm water drains.
4) ***Safe Disposal of Waste:*** A part of the solid waste generated is disposed into open lands, streets, surface drain; hill slopes, etc. and sometimes burnt in open causing health hazards, public nuisance and degradation of the environment and aesthetics. The existing disposal site at Dateda Lakhond has the following major shortcomings:

Figure 1-2: Landfill site

(i) The disposal site was selected without fulfilling the site selection criteria
(ii) Unsegregated waste is discarded at the site without any processing.
(iii) Biodegradable wastes are not treated on an individual basis.
(iv) No provision for gas venting and leachate collection.
(v) No monitoring of level of pollution at the disposal site.
(vi) Lack of basic infrastructural facilities such as fencing, proper road, office building, and vehicle/equipment shed etc.

The major issues that need to be looked upon for proper Solid Waste Management are waste quantification, its disposal and management of the entire disposal operation. These aspects are fundamental to the proper preparation of solid waste management.

1.3 Purpose

Knowing the amount of generating waste is one of the most significant elements of the operations of the whole waste management operation. Determining the quantity of generating solid waste would be useful advance and would offer the time and opportunity for the waste management organizations to embrace the necessary steps required for the disposal capacity, machinery and required field for sanitary landfills in the near future. If this information is known well in advance to the concerned authorities, the complete process of solid waste disposal from collection to its disposal method, all could be planned well in advance and be more unionized and organized. This would result in a more effective solid waste management scheme for the city.

An important factor is the method of disposal of solid waste. Landfill is one such disposal method of solid waste. But the disposal of municipal solid waste in a landfill needs prior information about a few pertinent facts regarding the landfill. These facts are the lifetime of the landfill for which it would be active, the capacity of the landfill where the solid waste is dumped, the type of landfill to be constructed.

Presently, for the calculation of the capacity of the landfill, only a few guidelines provided by the Ministry of Urban Development (Government of India) in the Solid Waste Management Manual are available. At this point, no model existing currently that can estimate the capacity of the landfill that would be needed for the specified period of time based on the projection of the solid waste to be brought forth. A mathematical model that considers all the influential factors for the engineering of a sanitary landfill for the calculation of the capacity of the same would provide the concerned authorities the basis for the planning of a municipal landfill.

Due to the high importance of this factor viz. the capacity of the engineered landfill, for proper solid waste management, this project would primarily focus on the estimation of the quantity of landfill capacity required for the administration of the solid waste. This case of forecast would help in the provision of proper collection, management and disposal of the solid waste generated in the future and reduce environmental pollution.

Calculation of the landfill's volume is mainly in consideration with the designing of the said landfill. But other than its design, a proper management of its daily operations throughout the active life of the landfill and also a few years after that is also an extremely important. The appropriate management of the daily operation in a landfill would provide long term benefits to the city. This not only would account for the safe disposal of solid waste but also reduce its effects on the surrounding environment thus, avoid the depletion of the natural resources available to the surrounding areas.

Currently, there is no active municipal landfill in Dehradun for dispensing MSW. For long term planning of landfill for this city, a landfill advisor that would help the landfill manager in the smooth running of the daily operations of the landfill and provide emergency response procedures in case of operational problems occurring in the landfill that could lead to catastrophic results to the environment surrounding the engineered landfill.

The landfill manager employed would not have a lot of experience in the management of the landfill operations for the conditions that exist in Dehradun City. This would render him unable to manage and mitigate the problems that crop up during the operational phase of the landfill. An intelligent system that along with being an early warning system would also work as an advisor to the landfill manager and be helpful as a teaching assistant tool for all the landfill personnel who are working in the landfill. This would be an advance in educating all the landfill personnel in emergency response services.

Such an intelligent system that based on the current situation of the landfill is able to infer the possibility of occurrence of an unprecedented event during the landfill operations and provides appropriate advice to the manager becomes a useful tool for the landfill operation management. An expert system based on fuzzy inference would be the most suitable intelligent system in this case. An Expert System (ES) being a computer system that is able to emulate the decision making ability of a human expert i.e. solve complex problems by reasoning about knowledge represented primarily as if-then rules rather than conventional procedural code. The expert system mainly consists of two parts viz. the knowledge base and the inference engine. The knowledge base contains all the facts and rules. The inference engine applies the rules to known facts to deduce new facts. The facts and rules contained in the knowledge base are always considered to be true. But to predict the possibility of occurrence of a particular event based on the consideration that the facts or rules are not always true requires the use of fuzzy logic.

Fuzzy logic says that the facts have a degree of belongingness to being true which could range from a value of 0 to 1. Associating a probability with the facts and rules present in the knowledge base can be done by the integration of fuzzy logic with the reasoning capacity of expert systems. This integration would allow for the system to be an early warning system along with being an advisor for the landfill personnel.

1.4 Organization of Dissertation

After the introduction of the focus in this section along with the purpose of the research work, this dissertation details out the entire procedure carried out for the express purpose of achieving the objectives set forth. Chapter 2 provides a detailed summary of all the literary works that have been carried out in various parts of the world that pertain to the current area of focus. Chapter 3 specifies the objective of this research work and the detailed methodology to be followed to achieve the stated objective. Chapter 4 explains landfill in general, bioreactor landfill in specific and summarises the guidelines that any landfill being planned in India needs to follow. Chapter 5 details the model for capacity calculation during the planning of a municipal landfill. It also provides details with regards to modified model for landfill capacity estimation and the reasons for the necessary modifications and validates the revised model against its original counterpart. Chapter 6 provides details with respect to the fuzzy expert system developed to act as an early warning system and an advisor to the landfill manager along with the evaluation of the performance of the system. Chapter 7 provides all the results obtained during the course of this research work and discussion upon them. This is followed by conclusion and future extensions to the work done here in Chapter 8.

CHAPTER 2
LITERATURE REVIEW

2 LITERATURE REVIEW

A number of literature works have been published that concern themselves with various aspects of the entire process of solid waste management. These literary works range from a general overview of the current state of affairs with regards to the solid waste management to use of various models for foretelling the quantity of solid waste generated to the smallest element that influences the process of landfilling. A brief summary of all these are provided here.

2.1 Overview of current scenario of MSW

The current scenario of the municipal solid waste management, especially in India has a great number of snags and setbacks to it. PAMNANI, ARTI, et al. 2014 have provided an overview of the municipal solid waste management in major urban centres and small towns and their surrounding villages in India. A few pointers have also been provided as to in which area more focus is needed and management of the waste is required [2]. Gupta, Sumeet, et al. 2011 suggest a public private partnership model for the proper solid waste management for the city of Dehradun where the main source of revenue would be the electricity generated from the waste. Waste-to-energy method for waste disposal would be a reality in this case [5].

Kumar, Sunil, et al. 2009 along with providing an insightful overview of the municipal solid waste management have also delineated that to overcome the deficiencies in the existing MSWM systems, an indicative action plan incorporating strategies and guidelines that the municipalities can use to prepare specific plans for their own city. It has also been cited that a need exists to strengthen existing monitoring mechanisms, particularly from the point of view of implementation of the provisions made in MSW [7].

2.2 Parameters affecting solid waste

Solid waste generation is influenced by different factors, including the economic conditions, population growth, weather conditions, geographical situation, person's hobbies, and the household size.

Benı´tez et al. 2008 predicted the residential solid waste by developing a linear model with the explanatory variables, including education, income per household, and number of residents and per capita waste generated. Statistical tests were applied for the determination of the best model of all [8].

Dyson and Chang 2005 considered the effects of population, income level, and the dwelling unit size in a linear regression model which was unable to handle various issues. A new approach-system dynamics modelling- presents various trends of SWG in a fast growing urban area based on limited samples by the use of a simulation tool-Stella. [9].

Buenrostro et al. 2001 found that the income is an influential factor in Solid Waste Generated by forecasting the residential and non-residential solid waste by means of a multiple linear regression analysis. [10].

Beigl et al. 2004 estimated a model for the European cities, including the explanatory variables, such as GDP, infant mortality rate, and household size, which were termed as a core set of significant regional development indicators. Evaluation of the data collected by them indicated a significant relation between regional development and municipal solid waste generation. The proposed model would work as a decision support tool for municipal waste planners [11].

McBean and Fortin 1993 dealt with certain facets of municipal solid waste management by means of correlations between socioeconomic factors and solid waste composition and quantities. The model uses generation coefficients associated with individual material components to estimate the quantity of waste generated by the domestic and industrial sources [12]. Dayal et al. 1993 assessed the impact of the climatic conditions and socioeconomic status on solid waste characteristics [13].

2.3 Models

Once the study of the currently present system is completed, a model is needed, which would oversee the smooth engineering of all the phases of municipal solid waste management including its disposal in a landfill. Kollikkathara, Naushad, et al. 2010 developed a dynamic system which incorporates the complexity of the waste generation and management process to some extent for the Newark urban region in the US. This is accomplished through a combination of simpler sub-procedures that are connected together to make a solid. This dynamic system addresses the issues by fitting a model framework and being given a forecast simulation [14]. Ohman, K. V. H., et al. 2007 have discussed the use of the analytical hierarchy process (AHP) - a decision making tool to grant priority to the landfill engineering and operating objectives. The end that was inferred based on universal standards of concern found within the literature associated with landfill design and operation was that the AHP process appears, in concept, to be a beneficial tool for ranking in order of priority landfill design and operating objectives, covering objectives and parameters [15].

2.4 Landfill Design

The design of a landfill has a high significance not only on the waste being disposed in it but also to the surrounding environment. It should be taken care that any substance from the landfill should not endanger the soil, vegetation, water or any other natural resource in and around the landfill. As there is a limit on the volume of land available, the size of the landfill required has a high impact.

Renkow, Mitch, et al. 1996 have elaborated upon the various decisions that influence the structure of a new sanitary landfill and have addressed the specific matter of defining how big a landfill needs to be made [16].

2.5 Material Decomposition

The individual materials that constitute the waste that is disposed in the landfill have different physical and chemical properties. In different conditions each material would take part in a different manner. The following literature elucidates this aspect.

Warith, M. A. 2003 compared the performance of composite municipal landfill based on various parameters to a bio reactor landfill and concluded that the latter provides fasted decomposition due to the aerobic conditions present in the landfill [17].

Eleazer, William E., et al. 1997 have elucidated based on various laboratory tests conducted the decomposition of various materials present in a typical municipal solid waste and the amount of methane gas that each substance contributes to [18].

2.6 Settlement models

For the engineering of the landfill its lifetime and capacity needs to be adjudicated upon. This capacity depends upon not only the amount of generating solid waste for the period under consideration, but also the compression ratio of the waste and the settlement or decomposition of the waste over a long period of time in the engineered landfill.

Chen, Kuo-Sheng, et al. 2012 have specified a linear model which accounts for mechanical settlement and degradation processes to simulate the long term settlement behaviour of municipal solid waste landfill. The numerical approach, capable of coping with more general conditions, is also given to estimate the spatial and temporal distribution of landfill settlement.

The proposed model can simulate typical features of short- and long-term landfill settlement behaviours verified based on comparison between the simulation effects and field measurements of landfill settlement [19].

Bareither, Christopher A., et al. 2012 evaluated the effects of waste composition and decomposition on the shear strength of municipal solid waste based upon parameters decided by the Mohr-Coulomb failure criterion (friction angle and cohesion intercept). They reasoned that the friction angle increases with decreasing volatile solids or increasing decomposition and could find no connection between cohesion intercept and the level of waste decomposition [20].

Bareither, Christopher A., et al. 2011 evaluated scale effects, stress, waste segregation, and waste decomposition on the immediate compression behaviour of municipal solid waste. They were able to conclude a predictive relationship between compression ratio and the waste compressibility index (a function of dry weight water content, dry unit weight, and percent of biodegradable waste) [21].

Chen, Yunmin, et al. 2010 studied upon the biodegradation behaviour and the compression of municipal solid wastes. They found that the settlement resulting from creep was relatively insignificant when the biodegradation process was inhibited. Compression due to decomposition under optimal biodegradation conditions was found to be a lot larger than compression associated with creep. A one dimension compression model for MSW was proposed for the analysis of the mechanical compression and biodegradation compression under constant stress or multistep loading process [22]. Sivakumar Babu, G. L., et al. 2009 have in their paper proposed a generalized constitutive model for municipal solid waste, based along the framework derived from critical state concepts and incorporating the effects of mechanical creep and time-dependent degradation, to predict total landfill compression under incremental loading and with time. They further concluded that the proposed model predicted the total settlement in a range similar to the reported models that weigh all three components -mechanical, creep, and biodegradation-of the settlement [23].

Park, Hyun I., et al. 2007 analysed six existing settlement prediction models according to the three landfill categories viz. Type I, Type II and Type III based upon settlement activity levels. The models that were analysed were: the Gibson and Lo model (rheological model category), the hyperbolic function model, the logarithmic function model and the power creep law model (empirical model category), the Bjarngard and Edgers's model (soil mechanics-based model category) the biological model (biodegradation-induced model category). Established on their conclusions they recommend a specific prediction model to be employed for a certain class of landfill [24]. Ling, Hoe I., et al. 1998 have proposed a hyperbolic function as an improvement for long term settlement to simulate the settlement time relationship and likewise to observe the final settlement rate. The hyperbolic parameters reduce with an addition in water content of the waste material [25].

2.7 Factors affecting Landfill failure

Athanasopoulos, G., et al. (2013) based on the study of data collected following the slope failure at the Xerolakka Municipal Solid Waste landfill in Greece, concluded that the failure was amplified by the combined effects of various factors. These factors include inappropriate waste disposal practices, inadequate compaction, leachate and gas pressure generation and increased steepening of the landfill slopes. The analysis also indicated that rainfall was the major expediting factor, stating that the failure would not be incipient under dry conditions [26].

Towhata (2007) reported on the collapse of MSW landfill in Bandung City, Indonesia. Based on the analysis of the data collected, various issues and problems were reported like rainfall, improper waste disposal methods, etc. that led to the failure of landfill. The paper emphasises upon the need for the use of various safety measures regarding landfill operations and management. It also signifies the need for the installation of a warning system that facilitates the better running of the landfill and makes provision for the environmental and mechanical risks [27].

Dunnet (2004) highlighted the various issues with the South Fremantle landfill site including landfill gas production, groundwater contamination, waste settlement, health hazards and the potential for explosion based on the investigation conducted [28].

Stark et al. (2000) based on their investigations of landfill slope failure have provided their conclusion in their paper. The conclusions include factors like reappearance of cracking, 3D stability analysis, stress, strain, leachate generation, surface water flow and slope angle for the MSW landfill slope failure [29].

2.8 Landfill operational problems

Chun et al. (2012) have studied the adverse influences of landfill gas on the climate in and around Sudokwon Landfill Site, Korea. Additionally, they have analysed the amount of methane gas generated from the landfill during the various phases of the landfill. Based on the research work conducted they were able to conclude that work on various research and development on the intermediate covering system along with the fundamental enhancement on present landfill facility establishment standards and operating guidelines are required [30].

Rowe (2011) has discussed issues concerning landfill operations viz. landfill cover, waste placement, leachate recirculation, liner temperature, leachate characteristics, liner leakage, performance of geomembranes etc. Based on the analysis the paper has concluded that the adoption of a systems engineering approach for the design, construction and operation of MSW landfill would minimise the environmental impacts of the said landfill with the focus is on performance of the system as a whole instead of the singular components [31].

Chen et al. (2010) have focused upon the geotechnical issues that arise in a landfill in connection to waste and leachate flow, landfill gas generation, settlement of landfill, stability of waste mass etc. The major issue with the current landfill practices in China have been elucidated upon by the authors while the areas for future research work and development have also been mentioned [32].

Depountis et al. (2009) express various environmental problems associated with the development and operation of MSW landfill based on their study of two existing landfills in Greece. They have emphasized upon the recirculation of leachate as a better engineering practice [33].

Pivato (2011) has illustrated upon a suitable methodology for the evaluation of landfill liner failure viz. deductive analysis and predictive analysis. Both the methodologies have been compared and the results from each have been shown to be too conservative and not close to what could actually occur in reality [34].

Townsend et al. (2008) have consolidated their observations regarding the design, construction and monitoring of a bioreactor landfill as a manual that can be used as a reference for the planning and operation of a bioreactor landfill. Special emphasis has been placed upon leachate recirculation with the acceleration of the process of waste decomposition as a prime. The prominent issues of high rainfall levels and leachate management gave birth to the development of a bioreactor landfill with its control over looked upon by SCADA systems [35].

Ling et al. (1997) formulated equations for the determination of the factor of safety of landfill soil cover to seismic conditions. They concluded that finite slope analysis in comparison to infinite slope analysis has significant effect on the stability. The other factors that are influential were slope geometry, soil geomembrane direct sliding co- efficient, and adhesion, length and thickness of the soli cover [36].

2.9 Current focus

It can be observed from the literature that there is no information available on a model that would be able to prophesise about the size of the landfill that would be required for the disposal of the predicted quantity of the generating solid waste. So the current study would also focus upon the development of such a model based upon the various significant parameters.

This model would then be pitted against the guidelines provided by in the Solid Waste Manual for the corroboration of the model to the guidelines provided.

Foping et al. (2009) have spoken about the need for early warning system and how software could be developed for the same [53]. Dokas et al. (2009) have developed a Landfill operation management advisor by the use of techniques of fault tree analysis, fuzzy inference and an expert system. They were able to ascertain that this system not only worked as an advisor but also as an early warning system for the landfill manager and aid in emergency response [54].

For Dehradun city where in the current scenario where a landfill is still in its planning stages, such an advisor cum early warning system would be a useful tool in assisting the inexperienced manager for the management of the entire landfill operations and also reduce the chance for catastrophe.

CHAPTER 3
RESEARCH OBJECTIVE
AND
RESEARCH METHODOLOGIES

3 RESEARCH OBJECTIVE AND METHODOLOGY

The research objective of this work is to provide information and ideas with regards to the generation and disposal of municipal solid waste, thus enabling the municipal body to deliver a detailed program for solid waste management for the upcoming years.

The principle aim is to provide the municipality with models that would provide enough prior information for the proper disposal of the municipal solid waste. This prior information would be based upon how the generated solid waste has been dispensed of in the past and what kind of actions can be taken for its proper management.

Such a model holds two primary aims:

1. Based on the anticipated quantity of solid waste, approximation of the quantity of land that would be needed for the administration of the said solid waste.
2. An early warning system that would aid the landfill manager in emergency response and the daily management of the landfill operations.

For the development of such a model, a study of all those elements and features that bear upon the disposal of solid waste in a landfill need to be studied upon extensively. The survey of those elements that influence the remaining capacity of a landfill at any period of time and also the entire process of disposal of waste in landfills would build the foundation for the current research study. Along with this, a comprehensive study of operations that pertain to the landfilling of solid waste needs to be conducted.

3.1 Estimation of Landfill Capacity

Landfill capacity estimation on an enormous part depends upon the potential solid waste generated for the lifespan of the landfill. But other than solid waste there would be a number of other factors that need to be considered. This requires the need for study of the guidelines furnished by the Ministry of Urban Development (Government of India) in the solid waste management manual. In that respect it is a necessity for the study of all those factors which are involved in the engineering of a sanitary landfill.

3.1.1 Research objective

The principle aim is to formulate a model that would, based upon influential factors, be capable to calculate the capacity of landfill needed for the period under consideration. The futuristic projection obtained from the artificial neural network would be used for landfill capacity estimations.

The recognition of such a model can be carried out only by the extensive study of the guidelines provided and based along those guidelines, creating a model that factors in all the influential parameters, the range of values that each parameter can fall in, its relation to the size of the landfill and all the bread and butter and other infrastructure needed for the planned engineering of a municipal landfill. This work needs to be guided with special stress upon the composition of the waste disposed of in the landfill and all the minuscule process that it goes through in the landfill. The study also needs to encompass all the resultants that could be obtained from the engineered landfill and also the effect on the environment.

The establishment of the proposed model against the guidelines provided and the rules stated by the environmental protection authority is a must.

The main research aim of this task can be expressed as:

1. The devising of a model that could calculate the capacitance of the landfill required for the proper administration of the waste of Dehradun City and
2. To make sure the model follows all the stipulated guidelines of the Environmental Protection Agency and Ministry of Urban Development

3.1.2 Methodology for Landfill Capacity Estimation

The methodology to be followed to accomplish the above stated aims can be summed up in the observing stages:

1. A model for futuristic projection of quantity of solid waste generated
2. Type of Landfill to be engineered
3. The constitution of waste to be disposed of in it
4. The factors affecting the utilization of space in the landfill
5. Landfill capacity modelling
6. Adherence to the guidelines specified
7. Capacity estimation

The methodology followed under each point is explained in detail in the following sections.

3.1.2.1 A model for futuristic projection of quantity of solid waste generated

The values obtained from the projected value of the solid waste would become the primary input for the calculation of the capacity of the landfill required for the disposal of the same. This Weekly projected number would immediately relate to the size of the landfill required.

3.1.2.2 Type of Landfill to be engineered

It requires to be ruminated upon the kind of landfill being engineered in this instance. The landfill being engineered very much depends upon the type of waste the finally goes for disposal in the landfill. The condition under which the landfill would be operated is a necessary approach for the estimation of its capacity.

3.1.2.3 The constitution of waste to be disposed

The composition of the waste generated in the city and how much percentage of the composition would be dumped in the landfill is a necessary prerequisite for the calculation of landfill's capacity and providing other support structures. Particularly the amount of biodegradable waste in the landfill would cause more generation of methane gas. Other such developments need to be reflected upon before estimation of the capacity.

3.1.2.4 The factors affecting the utilization of space in the landfill

Most of the space being used up by the municipal solid waste dumped in the landfill, other factors like the backup infrastructure, and preventions in place to not pollute the environment in and around the landfill also requires space. The climatic conditions that could bear on the degradation process, the material used for covering over the solid waste, for the building of the protective layer and many more factors are there which may conduct to either increment or decrease in the available space for the disposal of solid waste. The influence degrees of all these factors need to studied upon.

3.1.2.5 Landfill capacity modelling

A model needs to be created based on all the extensive work conducted before this tone. This mathematical model should account for all the significant characteristics that influence the space consumption in an engineered landfill. This model should be able to estimate the required capacity if basic information is furnished to it about the quantity of solid waste generated and the respective values pertaining to each one of the parameters under consideration.

3.1.2.6 Adherence to the guidelines specified

Owing to the fact that there is no other existing model in place for landfill capacity estimation, the proposed model does not have a basis for comparison. Simply there are guidelines in place that any municipal sanitary landfill needs to abide by. So in this case a validation can be made only confirming of the proposed model follows all the guidelines and instructions and limits put down by the regime for the engineering of a landfill.

3.1.2.7 Capacity estimation

Once it has been confirmed that the proposed model adheres to the guidelines specified, an estimation of the capacity of the landfill required for the city of Dehradun for an approximated period of time needs to practiced.

3.2 Landfill operation advisor

For the development of the landfill advisor, there is a need to consider the day to day operations that take place in a landfill. The factors that influence the operation of the landfill, their levels of influence respectively are significant to the study.

3.2.1 Research objective

The principle objective is to model an early warning system that is able to warn the landfill manager about the emergency response procedures which need to be executed, to reduce the impact on surrounding environment. The modelling of such a system that aids the landfill manager in the day to day operations as well as the emergency situations can be attained by the utilization of an expert system with fuzzy inference.

The realization of such a model can be accomplished only by the extensive study of the fuzzy linguistic variables, fuzzy hedges, the various membership functions and the fuzzyfication and defuzzification methods that would affect the result that is obtained based on design chosen. This work has to be conducted with limited stress on fuzzy inference with expert systems where the user interacts with the expert system and provides the input.

The creation of linguistic variables and the assignment of membership functions to each variable are extremely important aspects of this research. The recognition of the effect each input data has on the fuzzyfication process is likewise very significant. This in turn moves us in the proper choice of the factors that affect the most significant landfill operations. The selection of the major landfill operations and problems that could arise in that work sector also meets a real vital role. Not all operational problems can be considered for modelling by use of fuzzy inference system, as in this case.

Once the most significant operational problems have been selected and the factors that affect them identified, the second most significant facet of this project is to create a fuzzy associative memory that links the parameters together for the process of obtaining inference. Various operational problems need to be examined and compiled together to capture the most significant ones and the most suitable membership function realised that defuzzifies with the least quantity of error in these values of parameters being monitored in a landfill planned for Dehradun City.

The main research aim of this task can be expressed as:

1. Compilation of the entire set operational problems list based upon the study of the landfill's everyday operations and identification of the influential factors.
2. Development of a fuzzy inference based expert system to model an early warning system for the city of Dehradun.

3.2.2 Methodology for Landfill operational Advisor development

The methodology to be followed to accomplish the above stated aims can be summed up in the observing stages:

1. Study of landfill operations.
2. Identification of problems.
3. Parameter Identification.
4. Fuzzy membership modelling.
5. Development of expert system.
6. Integration of fuzziness in expert system.

The methodology followed under each point is explained in detail in the next departments.

3.2.2.1 Study of landfill operations

Through the study of various research papers and books and articles in connection with landfill working, with focus upon the landfill operations manuals of various countries, all the landfill operations can be compiled. Based on the manuals and case studies of various existing operating landfills, the list of all operations can be compiled and studied upon in detail of each landfill operation.

3.2.2.2 Identification of problems

The study of operations would lead to the identification of all the problems that each operation could face. Identification of a list of all the entities that create operational problems in a landfill or could lead to landfill failures needs to be compiled.

3.2.2.3 Parameter Identification

Various parameters that affect the running of the landfill need to be chosen carefully based upon their degree of influence. The number of selected parameters needs to be scaled down to the most important ones and use them as input. Grounded in the data garnered in the above two methodologies, finally the set of parameters that would have the most deterrent effect on the proper running of the landfill.

3.2.2.4 Fuzzy membership modelling

Once the parameter set has been identified, they need to be separated into input and output parameters. The entire parameter set needs to be converted into fuzzy sets and membership functions need to be assigned to each fuzzy set by extensive study upon this field. After assignment of the membership functions, the fuzzy associative memory needs to be developed that contains a relation from the input parameter set to the output parameter set. A prototype of the program needs to be run by the use of Flint as a tool for fuzzyfication and defuzzification process.

3.2.2.5 Development of expert system

Flex would be used as a tool for the development of expert system. The use of frames as data structure in Flex tool would facilitate the development of the expert system. Along with this, the system needs to be data driven in nature i.e. based on the monitoring data entered by the landfill manager the expert system should be able provide appropriate response. The use of data driven triggers would facilitate such a development. The windows platform running Prolog language would form the basis for this entire development.

3.2.2.6 Integration of fuzziness in expert system

After the development of the expert system by Flex and the fuzzy variables in Flint by use of prolog as the language for coding, the two need to be integrated together to form a complete whole and work as one unit. They final fuzzy expert system needs to be tested to check for its performance accuracy.

CHAPTER 4
LANDFILL

4 LANDFILL

A landfill site is a site for the disposal of waste materials by burial and is the oldest form of waste treatment. The disposal of wastes by land filling or land spreading is the ultimate fate of all solid wastes, whether they are residential wastes collected and transported directly to a landfill site, residual materials from materials recovery facilities (MRFs), residue from the combustion of solid waste, compost, or other substances from various solid waste processing facilities. A modern sanitary landfill is not a dump; it is an engineered facility used for disposing of solid wastes on land without creating nuisances or hazards to public health or safety, such as the breeding of insects and the contamination of ground water.

Today, landfills are engineered to protect the environment and prevent pollutants from getting into the land and possibly polluting ground water in one of two ways [4].

1. Sanitary Landfill: Uses a clay liner to block pollutants from leaving the landfill.
2. Municipal solid waste landfill: Uses synthetic liners like plastic to separate the landfill's trash from the soil beneath it.
3. Bioreactor landfills: Also called 'wet landfills'. Adding moisture to the dissipation in a suitably designed and operated landfill increases its degradation, leading to less risk and a movement towards sustainability. Aerobic conditions can contribute to lower leachate treatment costs, reduced methane gas and fewer odours.

So for the proper provision of long term solid waste management there is not just a need for the projection of the amount of solid waste generated for the time period under consideration, but also the capacity of the landfill required for the administration of the said generated waste. A lot of factors affect the design of the landfill.

Open Dumping is the most common practice for waste disposal in India especially for a hilly region like Dehradun. This necessitates the want for the plan of an engineered landfill for waste disposal. A modern municipal landfill is utilized for waste disposal on land which is devoid of hazards to the environment or public health and safety. For the long term planning of an engineered landfill, a parcel of land should be available for the time period of consideration for dumping of solid waste in a planned manner which can handle the waste generated during the said period. This leads to various design considerations with regards to the engineering of the landfill.

Modern landfills are highly engineered containment systems, designed to minimize the impact of solid waste (refuse, fight, and garbage) on the environment and human health. In modern landfills, the waste is contained by a liner system. The main function of the liner system is to isolate the landfill contents from the environment and, thence, to protect the land and ground water from pollution originating in the landfill.

The greatest threat to ground water posed by modern landfills is leachate. Leachate consists of water and water-soluble compounds in the refuse that accumulate as water moves through the landfill. This water may be from rainfall or from the waste itself. Leachate may migrate from the landfill and contaminate soil and ground water, thus presenting a risk to human and environmental health.

Landfill liners are designed and constructed to create a barrier between the waste and the surroundings and to drain the leachate to collection and treatment facilities. This is performed to prevent the uncontrolled discharge of leachate into the surroundings.

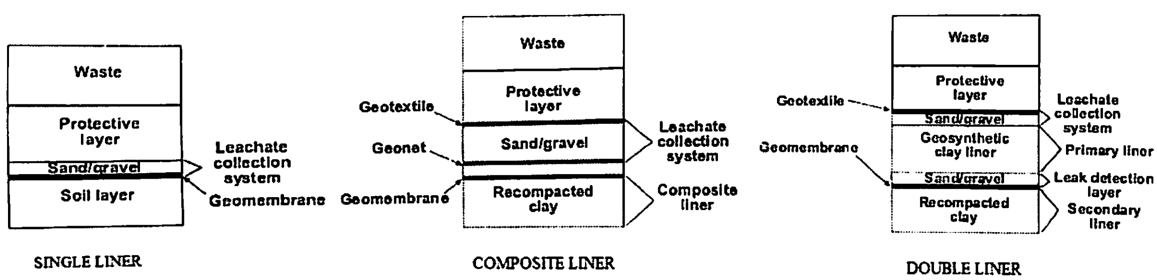


Figure 4-1: Liner systems

The potential threat presented by the waste determines the type of liner system required for each type of landfill. Liners may be described as single (also referred to as simple), composite, or double liners.

Table 4-1: Liner systems

S.No	Type of Liner	Composition
1	Single Liner	Clay liner
2	Composite Liner	Geomembrane in combination with a clay liner
3	Double Liner	Two single liners or two composite liners or a single and a composite liner

Composite-liner systems are more effective at limiting leachate migration into the subsoil than either a clay liner or a single geomembrane layer. At least a composite liner is required for municipal solid waste landfill as they are more effective at limiting leachate migration into the subsoil than a single liner. In Double-Liner Systems, The upper (primary) liner usually functions to collect the leachate, while the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. A landfill also has a Leachate Collection Systems Integrated into it system. This collection system is composed of sand and gravel or a geonet. A geonet is a plastic net-like drainage blanket. In this stratum is a series of leachate collection pipes to drain the leachate from the landfill to holding tanks for storage and eventual treatment.

In double-liner systems, the upper drainage layer is the leachate collection system, and the lower drainage layer is the leak detection system. The leak detection layer contains a second set of drainage pipes. The presence of leachate in these pipes serves to alert landfill management if the primary liner has a leak. Constituents of the lining system are protected by a layer that minimizes the potential for materials in the landfill to puncture the lining.

The generation of leachate is caused mainly by precipitation percolating through the waste deposited in a landfill. Once in contact with decomposing solid waste, the percolating water becomes contaminated and if it then flows out of the waste material it is termed leachate. Additional leachate volume is produced during this decomposition of carbonaceous material producing a wide range of other materials, including methane, carbon dioxide and a complex mixture of organic acids, aldehydes, alcohols and simple sugars.

Table 4-2: Components of Liner system

Components	Constituent material	Size
Clay Liner	Clay	1 meter thick
Geomembrane	Polyvinyl Chloride or High density polyethylene	>1.5mm
Geonet	Plastic drainage blanket used in place of sand /gravel	30 cm thick
Geotextile	Protect geomembrane from puncture	20-30cm thick

The above values are as per the guidelines provided in solid waste management manual. This report suggests an improvement in the existing model for estimating the capacitance of a landfill for the city of Dehradun. The existing model is validated by the government of India. The proposed model takes into account more specific factors specifically for Dehradun city. Further the two models are compared a reason for the deviation from the existing model is provided.

4.1 Bioreactor Landfill over Traditional Landfill

The traditional municipal solid waste landfill has various environmental concerns surrounding the quality of leachate and decomposition processes which occur in the landfill. As leachate generation directly depends upon the time, reducing the time period for degradation would as a result reduce leachate and the requirement for its treatment and methane gas generation. This would also aid in reducing gas emissions post closure of the landfill while allowing for landfill gas (primarily methane) harvesting during the active period of the landfill. The collected gas could become a source of fuel for multiple other processes.

For an Indian scenario, as the composition of municipal solid waste mostly contains biodegradable substances, increasing the rate of biological activity would sufficiently reduce the time period of degradation of MSW. This can be achieved in a bioreactor landfill. The use of a bioreactor landfill would in essence change the goal of landfilling from storage to the treatment of solid waste.

A bioreactor landfill can have its working under either aerobic conditions or anaerobic conditions or both. Various techniques can be utilized for the enhancement of the degradation process viz. shredding of waste, leachate recirculation and addition of nutrients and sludge. In effect a bioreactor landfill is utilized to control the environmental conditions inside the landfill with minimized risk to the surroundings and the public in general.

In essence the planning and design of a bioreactor landfill requires knowledge of landfill design, operation, waste stream characteristics, dynamics of waste degradation etc.

4.2 Importance of Capacity

For planning purpose the designing of the landfill has the most significance. This design needs to take into its considerations the various landfill procedures and the environmental conditions existing within the landfill, the support infrastructure and the municipal solid waste generated for the operational period of the landfill. The measure of solid waste that can be dispensed in the landfill depends very much upon the volume that the landfill is capable of holding. Primarily, a bioreactor landfill is engineered for the treatment of the municipal waste.

During its active life, the landfill should be capable of storing all the waste that is dispensed in it. While planning for the construction of a landfill its capacity is of prime importance for waste treatment. This implores the need for estimation of the capacity of the landfill to be engineered.

4.3 Solid Waste Management Manual Guidelines

The solid waste management manual by the government of India contains the guidelines that any engineered landfill in India needs to follow [4]. This is the general directive that needs to be adopted before the engineering of a new sanitary landfill. To make it easier to understand the guidelines are summarised in the following section.

As per the guidelines provided, any municipal landfill's capacity depends on the following factors:

1. The Liner System
2. The cover material used
    a. Daily cover
    b. Intermediate cover
    c. The final cover
3. The compacted density of the waste
4. The amount of settlement due to
    a. Stress
    b. Biodegradation

4.3.1 Density

The density of the waste very much depends upon the waste composition and the degree of compaction i.e.

Density of Waste -> Waste composition + Degree of compaction

It has been stipulated that the density is between the ranges of 0.4t/cu.m-1.25t/cu.m. But for planning purposes the values provided in the table 6-3 are utilized.

Table 4-3: Density for planning purpose

Waste type	Density
Biodegradable waste	0.85 t/cu.m
Inert waste	1.1 t/cu.m

4.3.2 Settlement Rate

The settlement rate is as per UK Environmental Protection Agency. Initially it is taken to be about 12-17% but for long term settlement the value goes as high as 20%. The values to be considered during the planning phase are summarised in table.

Table 4-4: Planning Settlement Rate

Waste type	Settlement Rate
Biodegradable waste	10%
Inert waste	5%

4.3.3 Soil Cover

The soil cover used summarised in table below

Table 4-5: Soil cover summary

Soil Cover	Quantity
Daily cover by machine	150mm
Daily cover manually	100mm
Sides and lift height	1.5-2m
Intermediate cover	45-60 cm

4.3.4 Liner system

The liner system consists of the leachate drainage system along with the barrier layer. The summary of the liner system is provided in table 6-2. Additionally it has been stipulated that the leachate drainage layer should have its permeability at the rate of 10^{-2}cm/sec. The permeability of the clay layer should not be more than 10^{-7} cm/sec.

CHAPTER 5
LANDFILL CAPACITY ESTIMATION

5 LANDFILL CAPACITY ESTIMATION

For the city of Dehradun on an average it gets approximately 200 MT of MSW daily. The average waste production is 0.4 kg/capita. Sources like commercial establishments, fruit and vegetable markets, small-scale industries, etc., lead to the MSW generation of Dehradun [5]. Established on the analysis done on dry weight basis the Physical Composition and Characteristics of MSW are as follows:

As indicated in Table 1-1, the majority part of the waste produced in Dehradun is constituted of organic matter [5] with fewer amounts of recyclables and inert items. Generally, in India, paper even though being recyclable is not much sent to the landfill.

The quantity of waste paper is much less, as even the quantity thrown away is picked up by people for its use as a fuel and also for packaging of materials / food sold by road side hawkers. The plastics, rubber and leather contents are lower than the paper content, and do not exceed 1% except in metropolitan cities. Also, the metal content is as low as <1%. These low values are essentially due to the large scale recycling of these constituents. This same scenario is present in Dehradun city also.

The content of the landfill needs to admit the following specifications: The liner system, the cover material (medium and final), the compacted density of the wasteland, the amount of settlement due to stress and bio degradation.

5.1 Landfill Capacity Estimation Model

The existing landfill capacity estimation model is based upon the Solid waste manual issued by the government of India. All the information provided in the Solid Waste Management Manual has been utilized and elucidated the capacity calculation by the use of equations provided in the section below [4].

As a general directive to be followed before engineering a sanitary landfill, Government of India has issued a Solid Waste Management Manual [4]. The manual provides a landfill capacity estimation model to approximate capacity of landfill over a given period of time

To calculate the capacity of landfill for *n* years the following equations are used where n is the proposed active life of the landfill.

Total volume of compacted waste in *n* years ($V_W(m^3)$) is given by equation 1

$$V_w = \frac{T}{w} \qquad \text{Equation 1}$$

Where *T* (Tonnes) is the total waste generated in n years, *w* (tonnes/m^3) is density of the waste.

Total volume of daily cover in *n* years ($V_d(m^3)$) is given by equation 2

$V_d = ctr * V_w$ Equation 2

Where *ctr* is cover to refuse ratio

Total volume required for components of liner system and of cover system ($V_c(m^3)$) is given by equation 3

$V_c = k\,V_w$ Equation 3

Volume likely to become available due to settlement /biodegradation of waste (V_s (m^3)) is given by equation 4

$V_s = s * V_w$ Equation 4

Where *s* is the settlement rate

First estimate of landfill capacity (C_i (m^3)) is given by equation 5

$C_i = V_w + V_d + V_c - V_s$ **Equation 5**

Capacity of the landfill excluding the cover and liner system ($C(m^3)$) is given by equation 6

$C = V_w + V_d - V_s$ **Equation 6**

Equation 6 gives the capacity of landfill for *n* years without incorporating space for infrastructure, liner and final cover. Equation 6 has been used to estimate the capacity of landfill required for a sample period of 5 years. The result obtained from equation 6 is presented in the table below.

Table 5-1: Landfill capacity estimate by use of existing equations

Number of Years	Landfill capacity estimate(m^3)
1	34498083.53
2	109821744.5
3	215925972.2
4	369516832.1
5	562579252.4

The values for the specified constants have been picked up from the Solid Waste Management manual [4].

The above given model does not accept into its account the composition of the waste generated. This composition varies from place to place. Even for India the waste composition in the metro city is extremely different from the waste composition of the small town and villages [7]. But the classification of waste (as given for Dehradun city in figure 1-1) also varied from hilly region to plains and metropolitan cities. So the composition of waste that actually is dumped in the landfill would vary depending on the area the waste is from. The values of **m** and **k** provided above are fixed while planning for a landfill. But which value needs to be debated is not specific.

This problem is mitigated in the proposed model. It not only considers settlement differently but also incorporates the settlement rate of individual materials present in the generated waste. So based on the individual constituent of the waste the proposed model can be utilized as a specialized variant of the existing model specifically designed for the city of Dehradun.

5.2 Modified/revised Landfill Capacity Estimation Model

As the capacity of the landfill is contingent on the following specifications- The liner system, The cover material (intermediate and final), the compacted density of the waste, the amount of settlement due to stress and bio degradation, there is a requirement to incorporate the effects of each one of these on the landfill being planned.

Also the waste that goes into the landfill is not composed of only one kind of material but a combination of various kinds with each having a different decomposition rate. Specifically, for a situation like in Dehradun city, where there is no other alternate form of waste disposal, almost all the collected waste would be dispensed off in the proposed landfill. Therefore, the varied settlement rate forms, most significant factor for the calculation of the landfill volume needed.

Based on the specified influencing factor stated above, the standard equations particularly focused to a traditional landfill have been modified, aligning them to a bioreactor landfill for specific Dehradun settings.

Section below presents the modified equations for landfill capacity estimation for n years that can be used for both the traditional and bioreactor landfill.

The total waste generated (T(Tonnes)) for n years is given by equation 7

$$T = \sum_n G_i$$ **Equation 7**

Where G_i (Tonnes) is the amount of waste generated each year

Compacted solid waste for each year (V_{iw}((m^3))) is given by equation 8

$$V_{iw} = \frac{G_i}{w}$$ **Equation 8**

Where w(t/ (m^3)) is density of the waste

Amount of cover needed each year (V_{id} ((m^3))) is given by equation 9

$$V_{id} = ctr * G_i$$ **Equation 9**

Amount of waste left after settlement each year (V_{is} ((m^3))) is given by equation 10

$$V_{is} = (1 - S) * G_i$$ **Equation 10**

Total amount of solid waste in the landfill at the end of year 1 (L_1 ((m^3))) is given by equation 11

$$L_1 = V_{1w} + V_{1d} = \frac{G_1}{w} + (ctr * G_1)$$ **Equation 11**

Amount of solid waste in the landfill at the end of year 2 settlement of solid waste till year 1 in addition to the new solid waste for year 2 is given by equation 14

$$L_2 = \frac{G_2}{w} + (ctr * G_2) + (1 - S) * L_1$$ **Equation 12**

$$L_2 = \frac{G_2}{w} + (ctr * G_2) + (1 - S) * \left(\frac{G_1}{w} + (ctr * G_1)\right)$$ **Equation 13**

$$L_2 = \left(\frac{1}{w} + ctr\right)[G_2 + (1 - S) * G_1]$$ **Equation 14**

Amount of solid waste in the landfill at the end of year 3 settlement of solid waste till year 2 in addition to the new solid waste for year 3 is given by equation 17

$$L_3 = \frac{G_3}{w} + (ctr * G_3) + (1 - S) * L_2$$ **Equation 15**

$$L_3 = \frac{G_3}{w} + (ctr * G_3) + (1 - S) * \left(\frac{G_2}{w} + (ctr * G_2) + (1 - S) * \left(\frac{G_1}{w} + (ctr * G_1)\right)\right)$$ **Equation 16**

$$L_3 = \left(\frac{1}{w} + ctr\right)\left[G_3 + (1 - S)G_2 + (1 - S)^2 * G_1\right]$$ **Equation 17**

By proof of mathematical induction, inducing this equation for n years

$$L_n = \left(\frac{1}{w} + ctr\right)\left[G_n + (1 - S)G_{n-1} + (1 - S)^2 * G_{n-2} + \cdots + (1 - S)^{n-1} * G_1\right]$$ **Equation 18**

It can be summarised as in equation 19

$$L_n = \left(\frac{1}{w} + ctr\right)\left[\sum_{i=1}^{n}(1 - S)^{n-i} * G_i\right]$$ **Equation 19**

This can be further modified to include the individual settlement rates of various compositions of materials in solid waste as in equation 20

$$L_n = \left(\frac{1}{w} + ctr\right)\left[\sum_{i=1}^{n}\sum_j(1 - S_j)^{n-i} * G_{ij}\right]$$ **Equation 20**

Where

S_j is the individual settlement rate of each material

G_{ij} is the amount of solid waste for year i for the constituent material j

Table 5-2: Landfill capacity estimate for bioreactor landfill

Number of Years	Landfill capacity estimate(m^3)
1	28518415.72
2	85884372.78
3	158933578
4	258969818.8
5	374956896.7

Equation 20 has been used to estimate the capacity of a bioreactor landfill required for a sample period of 5 years. The result obtained from equation 20 is presented in the table 4. The values for the constants used have been picked up from the Solid Waste Management manual [4].

Over and above the capacity of the landfill based on the proposed model, 15% more space needs to be provided for infrastructural support, liner system and the final cover [4]. But as all the extra system and support would be fixed and same in most of the cases, it is only the internal environmental conditions that turn out to be the most influencing factors.

5.3 Validation and Advocacy of the Modified Model

The above given model does not take into account the composition of the waste generated. This composition varies from place to place. Even in India the waste composition in the metropolitan city is highly different from the waste composition of smaller towns and villages [2]. But the classification of waste (as given for Dehradun city in figure 1-1) also varied from hilly region to plains and metropolitan cities. So the composition of waste that actually is dumped in the landfill would vary depending on the area the waste is from. The values of constants used in the existing landfill capacity estimation model are used based on the assumption that only one kind of waste ends up being disposed of in the landfill. There is no consideration that a varied combination of wastes that could be dispensed of in the landfill, this would require the use of multiple values for the constants during the planning of the proposed municipal landfill.

This problem is mitigated in the proposed model. It not only considers settlement differently but also incorporates the settlement rate of individual materials present in the generated waste. Therefore, based on the individual constituent of the waste the proposed model can be used as a specialised version of the existing model specifically designed for the city of Dehradun.

The existing and the proposed model like a parent and child have particular differences with the latter being more specific in nature and the former a more generalised case. The latter is more flexible and is easily adaptable depending on the parameters under consideration. The former is more rigid in its nature with the use of only single values for the constants for the approximate projections of the capacity of the landfill needed.

The characteristic difference between the two models is elucidated in the table below:

Table 5-3: Model Comparison

Features	Proposed Model	Existing Model
Liner system	Taken as a whole	Taken as a whole
Cover material	Final cover, daily cover, intermediate cover	All three considered together
Compacted density of solid waste	Can be separate for constituent materials	Taken as a whole
Settlement rate	Can be separate for constituent materials	Taken as a whole
Composition	Considered	Not taken into consideration
Place	Can be easily adopted depending on the place	More suitable for class I cities

Assuming the same values for various constants used in the equations of both the models, they were compared for a sample period of 5 years. The result of comparing both the models is pictured in the graph below.

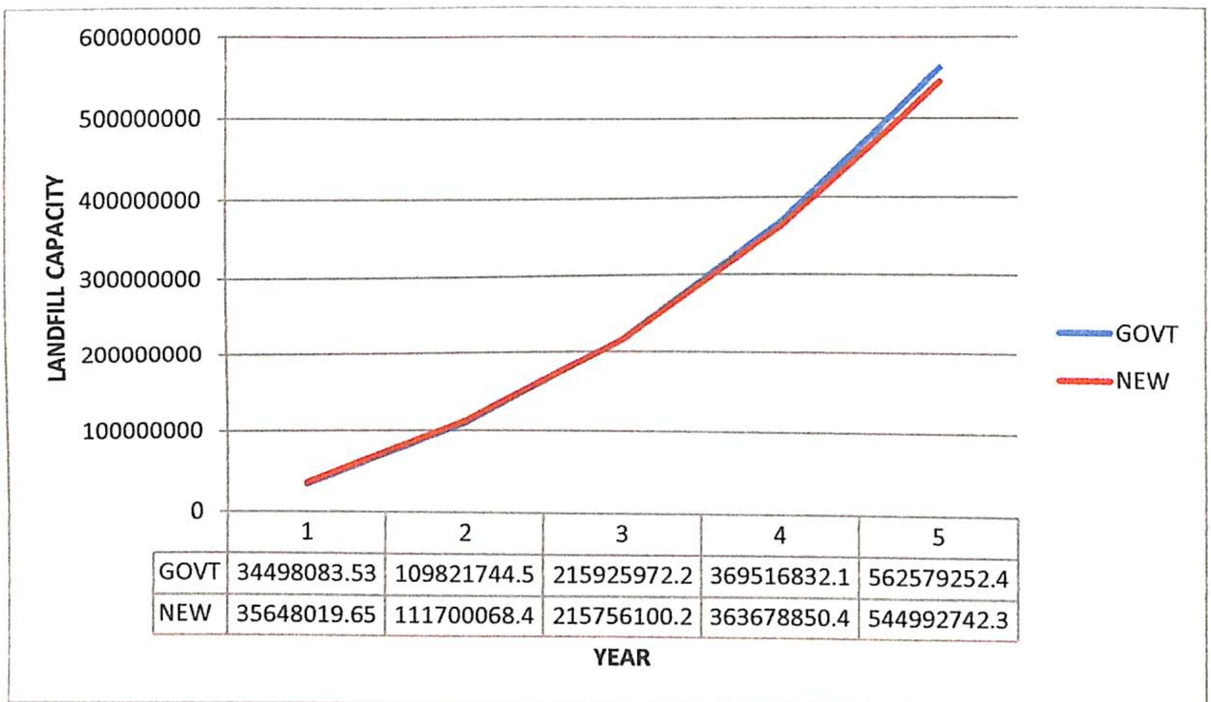


Figure 5-1: Model Comparison

This figure 5-1 clearly indicates that the resultant capacity calculation in both the cases is almost same. Hence validating that, for the case of traditional landfilling procedure, either of the two equations can be utilized.

CHAPTER 6
LANDFILL OPERATION ADVISOR

6 LANDFILL OPERATION ADVISOR

Several solid waste management systems are in place throughout the world. Each body that is responsible for the solid waste management has its own manual detailing all the steps that form the big picture of solid waste management [37] [38] [39] [40] [41]. Waste management includes in a broad sense the collection, transportation and the disposal of municipal solid waste. Disposal of waste includes various methods like composting, recycling, incineration, landfill etc. Each of these disposal operations, being engineered process, have their own operational problems. The consequences of the operational problems in SWM facilities, depending on their nature and severity, range from minor infrastructure damages or simple nuisance problems to critical events, which can lead to the loss of human lives or even to disasters. An ''operational problem'' could be any situation during the operation of a facility, which is undesirable from an environmental, economic, social, and operational perspectives. In the context of landfills, such operational problems could be the surface and subsurface fires, windblown litter, traffic problems, and problems regarding the leachate and gas management, together with accidents and fatal injuries. An indicative example of a disaster that is related to land disposal of waste is that happened in the Leuwigajah dumpsite in Indonesia, where after 3 days of heavy rainfall 2,700,000 m3 of waste started sliding down the valley, killing 147 people [27]. Several types of events like: bad weather conditions, equipment malfunction, wrong operation practice, and also issues like bad design, human, organizational and communication errors can be combined appropriately and can lead to critical operational problems and disasters. Unfortunately, there is a gap in the existing knowledge with respect to the factors that contribute to the occurrence of incidents and accidents in SWM facilities for Dehradun city.

6.1 Operations

Operating procedures at a sanitary landfill are determined by many factors, which vary depending on each site. The landfill operational plan prepared as a part of the designing procedure serves as the primary resource document, providing the technical details of the landfill and procedures for constructing the various engineered elements. Since a landfill is constructed and operated over number of years, it is important that personnel continually consult the plan to assure conformance with the plan over the long term. Operating procedures must be noted so that an accurate record is maintained. Changes in operating procedures often need regulatory agency approval, and careful planning is necessary to make a smooth transition to a revised operating plan.

Development of the complete landfill may be divided into stages, some of which are completed many years after the opening of the site. As with other construction projects, all the work should be documented. While commonly overlooked in landfill construction, documentation can be invaluable when questions arise in the future regarding the adequacy of site construction. Documentation is important for proving to regulatory authorities and local committees of concerned citizens that design standards are actually being implemented.

6.1.1 Waste Placement

The main purpose of landfill is waste disposal thus, waste movement and compaction being the most important activity. Waste movement is usually confined to the spreading of wastes on the working face with compactors or dozers after the wastes are deposited by the truck. Movement over long distances is inefficient with this equipment.

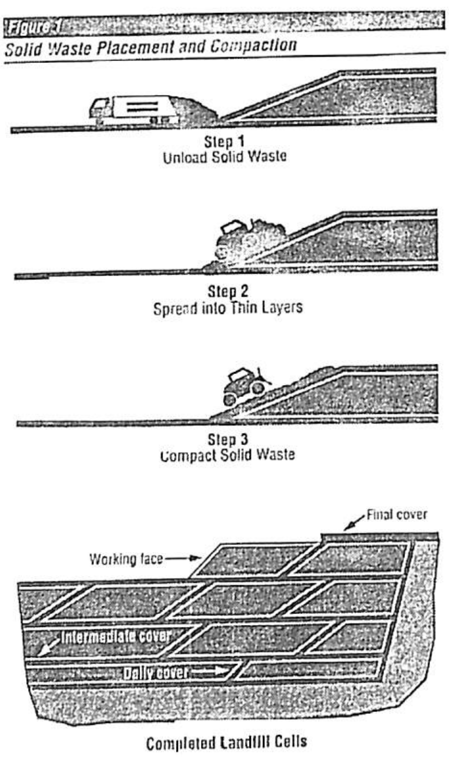


Figure 6-1: Waste compaction operation

Figure 6-1 shows a typical operation. Periodically, usually daily, the compacted waste is covered with earth and a new cell is started. An alternative to soil cover is the use of manufactured foams or temporary blankets. Foams require specialized application equipment to spray the material onto the compacted waste. Blankets can be lifted into place with a crane, or specially equipped tracked excavator, and then removed the following day before waste placement begins. At some sites, wastes may be deposited at the top of the working face, making it easier to spread the wastes over the face. Litter control may be more of a problem when this procedure is used.

6.1.2 Compaction requirements

Degree of compaction is a critical parameter for extending the useful life of a landfill. For achieving high in-place waste densities, a compactor may be necessary. A minimum in-place compaction density of 1,000 pounds per cubic yard is recommended. The number of passes that the machine should make over the wastes to achieve optimum compaction depends upon machine wheel pressure, waste compressibility, land and fuel requirements, labour costs, and work load. Generally, three to five passes are recommended to achieve optimum in place waste densities. Although additional passes will compact the waste to a greater extent, the return on the effort diminishes beyond six passes. An experienced operator will know if additional passes will result in greater compaction.

The working face slope will also affect the degree of compaction achieved. As the slope increases, vertical compaction pressure decreases. The highest degree of compaction is achieved at the grade with the least slope; however, the feasibility of flat working face grades has to be weighed against the larger area over which the solid wastes must be spread.

6.1.3 Weather conditions

Cold weather brings many problems in starting and operating machinery, keeping employees comfortable, and obtaining cover material. Equipment manufacturers can offer recommendations for cold weather starting and operating. Cabs, proper clothing, and employee facilities will help improve employee comfort.

Wet weather problems are especially serious with soils that have high silt or clay content. When wet, these soils become very muddy, and provision should be made to continue operation in areas of the fill that are less susceptible to problems.

Wet weather plans should include measures to reduce tracking of mud from the landfill onto the road system and provisions for cleaning trucks.

6.1.4 Litter and fire control

Litter does not seriously damage the environment, yet it is perhaps the most persistent operational problem cited by surveys. Its seriousness is due, in part, to bad public image. Waste discharging procedures, orientation of the working face to the wind, existence or absence of nearby wind shielding features, and waste type and preparation all play a role in solving the litter control problem. Unloading wastes at the bottom of the working face can help. Here the wind cannot pick up materials as easily as when wastes are deposited at the top of the working face.

If the trench method is used, it is often recommended that the trench be at right angles to the wind. An open landscape will allow the wind to blow unimpeded, thereby increasing the likelihood of litter. Planting trees or constructing berms can reduce the wind velocity and, hence, litter problems. Portable fences are often used to catch the litter, followed by manual cleaning of the litter fence and the area downwind of the working face. The fence should be cleaned at least daily. An alternative approach, which has been particularly effective at small sites, is to require all wastes to be bagged for pickup.

Dust can also be a nuisance at landfills, both to employees and neighbours. Water wagons can be used to control dust. Calcium chloride is also used for dust control, since it absorbs moisture from the air.

Fires within the waste are best controlled by digging out the combusting material and covering it with dirt. Each equipment operator should have a fire extinguisher readily available. Expensive pieces of equipment should be protected with automatic fire detection and suppression equipment. Water wagon equipment can be used for fire control. Also, arrangements should be made with local fire-fighters to establish procedures for extinguishing landfill fires.

6.1.5 Human Input

To maintain an efficient landfill operation, employees must be carefully selected, trained, and supervised. Proper landfill operation depends on good employees. Along with equipment operators, other necessary employees may include maintenance personnel, a scale operator, labourers, and a supervisor. People will also be needed to keep financial and operating records. The landfill manager should have experience in operation of an advanced technology landfill and, in addition, receive technical and managerial training. Several institutions and associations conduct training courses for landfill operators.

6.1.6 Accidents are preventable

Accidents are expensive, with hidden costs often several times more than the readily apparent costs. Solid waste personnel work in all types of weather situations, with many different types of heavy equipment, with a variety of materials presenting diverse hazards, and in many different types of settings.

The types of accidents possible at landfills include direct injury from explosion or fire; inhalation of contaminants and dust; asphyxiation due to workers entering a poorly vented leachate collection system, manhole, or tank; falls from vehicles; accidents associated with the operation of heavy earth-moving equipment; attempting to repair equipment while the engine is operating; exposure to extreme cold or heat; or traffic accidents at or near the site.

6.2 Operational problems

The day to day operation of a bioreactor landfill is never smooth sailing. There are various processes that occur in parallel for the smooth running of an engineered bioreactor landfill. Each of these processes depends upon various factors. Any deviation from the norm could create a multitude of problems that could affect the smooth running of the landfill. A comprehensive list based upon the information gathered in the knowledge acquisition phase of the development of the landfill advisor has been provided in the table A-1 in Annexure A.

Other than the ones specified in the table there are a multitude of other minor problems faced by the people who are working in the landfill arena. Out of the entire list provided in the table A-1 above, the most important ones and the once with the maximum impact on the working of the landfill are chosen as the set of root problems for the development of the landfill advisor. The selection of these problems were based upon the prioritizing by the landfill expert and the most influential to working of the landfill as provided in the literary solid waste management manuals of various countries [37][38][39][40][41]. A list of these is provided in the table 6-1 below:

Table 6-1: List of operation problems selected

Problem Category	Operational Problem
Miscellaneous problems	Surface fire Subsurface fire Uncontrolled storm water runoff Rainy weather
Leachate related problems	Leachate collection and drainage system failure Overflow of leachate collection holding ponds Leachate seeps Leachate holding ponds about to fill/ overflow

Human related Problems	Landfill Machinery hit person People with cigarettes in the work face
Environment	Odour Gas Migration
Landfill Liner	Liner leakage
Landfill Gas	High Methane generation

6.3 Parameter selection

The selected operational problems listed out in table 6-1 are affected by various environmental factors. The selection of these is an extremely important aspect of applying focus to each operational problem selected.

Table 6-2: Decision Parameters

Problem Category	Operational Problem	Decision parameters
Miscellaneous problems	Surface fire Subsurface fire Uncontrolled storm water runoff Rainy weather	Phase completion Landfill Gas, Air in Landfill Rainfall Rainfall
Leachate related problems	Leachate collection and drainage system failure Overflow of leachate collection holding ponds Leachate seeps Leachate holding ponds about to fill/ overflow	Leachate Leachate Rainfall, Temperature in Landfill Leachate
Human related Problems	Landfill Machinery hit person People with cigarettes in the work face	Human Efficiency Incinerating devices
Environment	Odour Gas Migration	Gas, Air Quality Index Gas, Leachate
Landfill Liner	Liner leakage	Leachate, Water Quality Index
Landfill Gas	High Methane generation	Gas

The above stated decision parameters are utilized for the system development. These parameters have been selected based upon the landfill operation manuals [37] [38] [39] [40] [41].

6.4 Technology Used

The development of the landfill advisor was accomplished by combining the technology of an expert system with the technique of fuzzy logic inference system. The expert system development was accomplished by the use of FLEX tool which has been developed by LPA associates the basis for which is the language of prolog (WINPROLOG 4.8). For the fuzzy inference part, the tool used is FLINT again developed by Logic Programming Associates. This tool provides fuzzy logic inference and has an extremely smooth integration with WINPROLOG.

The main idea behind the use of the above stated technology is to develop (a) a useful tool for the inexperienced landfill manager, because it correlates events that are common during landfill operations (b) Reliable tool , because their possibility estimations should have no significant differences in comparison with the ones proposed by the advisor. (c) easy to use, (d) friendly to use

6.5 Fuzzy membership functions

The deciding parameters identified based on their priority, need to be researched upon and assigned membership functions based on their behaviour in the active landfill site. The list of deciding parameters are also those parameters which are regularly being monitored in and around the landfill. So for these parameters the landfill manager would input numerical values. These numerical values need to be fuzzified based on the given membership function for that parameter. This can be achieved by the use of FLINT tool.

The major considerations need to be provided to the selection of membership functions for all the in use parameters listed out in table

Table 6-3: Parameters as input/output

Sr. No	Parameter	Unit	Input parameter	Output Parameter
1	Temperature	°C	Yes	No
2	Rainfall	mm	Yes	No
3	Air Quality Index (AQI)		Yes	No
4	Air (inside landfill)	%	Yes	No
5	Efficiency (Human)	%	Yes	No
6	Incinerators (in human possession)	%	Yes	No
7	Phase Completion (Active part)	%	Yes	No
8	Water Quality Index (WQI)		Yes	No
9	Landfill Gas		Yes	Yes
10	Leachate		Yes	Yes
11	Surface Fire	Probability	No	Yes

12	Subsurface Fire	Probability	No	Yes
13	Odour	Probability	No	Yes
14	Gas Migration	Probability	No	Yes

The membership function defined for the fuzzy variable temperature has been shown in the figure 6-2. These ranges and end points for the membership function has been decided based upon the literature studied [43] [44]. Similarly the fuzzy membership functions for all the other fuzzy variables have been decided upon by the study of literature [45][46][47][48][49][50][51][52] and manuals [37][38][39][40][41][42] available for each parameter.

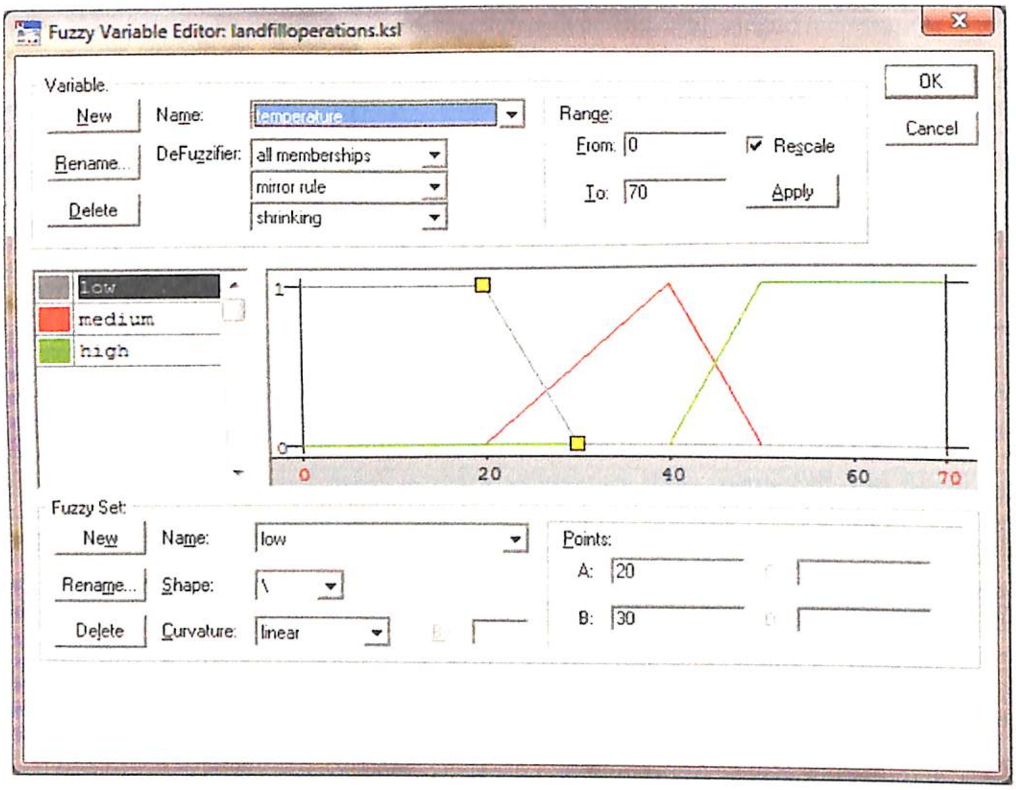


Figure 6-2: Fuzzy membership function for temperature fuzzy variable

Once the membership functions have been defined, the fuzzy associative memory is created for the output fuzzy variables to aid in inference making. Figure 6-3 below show one such example for leachate generation.

```
% FAM - Fuzzy Associative Memory

fuzzy_matrix leachate_value
   temperature  *  rainfall   ->  leachate         ;

      low          *  low        ->  low          ;
      low          *  medium     ->  low          ;
      low          *  high       ->  medium       ;

      medium       *  low        ->  low          ;
      medium       *  medium     ->  medium       ;
      medium       *  high       ->  large        ;

      high         *  low        ->  medium       ;
      high         *  medium     ->  large        ;
      high         *  high       ->  large        .
```

Figure 6-3: Fuzzy associative memory

6.6 Expert system

The expert system is developed by the use of FLEX tool. The use of frames as a data structure has been utilized along with data driven programming. Here based on the monitoring data input by the landfill manager, the corresponding advice is provided.

The Landfill advisor is a small module which constitutes of a fuzzy logic based expert system that is able to infer decisions based upon the inference provided by the use of fuzzy logic system. These decisions are made based on the input of the monitored data by the landfill personal. The monitored data i.e. crisp values are then converted into fuzzy values based on the chosen membership functions. These memberships functions where chosen based on the currently available range of monitoring data with regards to en engineered bioreactor landfill.

6.6.1 The workflow

First stage: the landfill manager accesses the landfill advisor software. On access of the software, the manager is provided with a set of questions that encompass the various monitored values with regards to the landfill environment.

Second Stage: Based on the input provided by the landfill manager, i.e. the values of various affecting parameters, they are further passed to the flint software for the fuzzyfication by means of the flex expert system.

Third Stage: The values input by the manager are converted into fuzzy values by means of a fuzzy membership function. This membership functions for each of the monitored values are already present in flint. The membership functions have been chosen based upon the literary works on the various monitored parameters in a landfill. After the fuzzyfication of the input values they are passed back to the flex expert system for further analysis.

Fourth Stage: As more than one operational problem could occur at a time due to a dynamic change in the values of the monitored parameters, a few parameter values are calculated by defuzzification process and passed on to the flex expert system. This stage is repeated till a value is available for each one of the causal parameters taken into consideration in this case.

Fifth Stage: Based on the values retained by the combination of various causal parameters and the combined range in which they fall, the expert system activates the inference engine for use of the forward chaining methodology to arrive at a particular conclusion.

Sixth Stage: Once the goal is reached by the expert system, based on the fuzzy values of the causal parameters an appropriate response is provided to the landfill manager as to what the situation is, what are the various responses that can be taken and what has caused the problem along with suitable advice that the manager could follow.

Referring to the scenario, each advice corresponds to a specific basic event. Also, the corresponding solutions are displayed in a ranking manner based on the fuzzy importance measure value of each basic event. Moreover, the system informs the user if the analysed problem could possibly generate any other operational problems.

6.7 Evaluation of the system

The landfill advisor needs to be tested under various test cases and its performance needs to be evaluated under each case provided. These database of test cases comprised of various synthetic events and actual emergency situations that have occurred in landfills around the globe.

The input was provided to the advisor of the various monitored values under each of the test cases. The results provided by the advisor in the case of the real situations ended up in providing early warning system for each case. For the synthetic cases it provided results as expected in accordance with the landfill experts.

The advisor was able to identify more than 80 percent of the causes and the early warning signals as stored in the knowledge base of the expert system. Most of these cases were with regards to the landfill operations, excluding the involvement of the human factor.

In cases where the human factor is involved the results provided a little less accurate result. A more in depth study needs to be conducted to incorporate all those cases where the problem occurs due to human involvement. As these could be either a coincidence or a deliberate act.

CHAPTER 7
RESULTS AND DISCUSSION

7 RESULTS AND DISCUSSION

The results of the project have been provided in this section.

7.1 Landfill Capacity Estimation Model

About 200MT of MSW is generated daily in the city of Dehradun. On an average, the per capita waste production turns out to be 0.4 kg. The generation of MSW gets its contributions from sources like fruit and vegetable markets, commercial establishments, small-scale industries, etc.

7.1.1 Input of solid waste quantity for landfill capacity estimation

To provide a ballpark figure with regards to the dimensions of the planned landfill, the amount of solid waste generated for the entire period of running of the said landfill needs to be reckoned. The projected measure of solid waste can be obtained from the modelling of a Nonlinear Autoregressive Neural Network (MATLAB) on the currently available solid waste data for the city of Dehradun. The modelled neural network results after the assessment of different architectures of the network. The architecture of the network is modified by changing the number of hidden layers (1-2) and the number of neurons (5-20) in each hidden layer, the training algorithms and the activation/ transfer function.

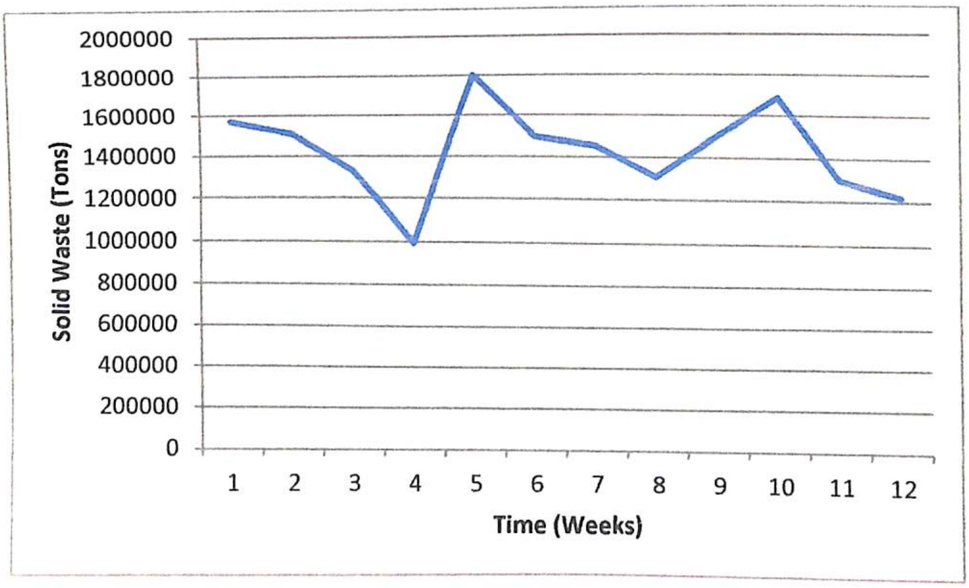


Figure 7-1: Projection of ANN for 3 month period

The architecture which provided the best performance results is chosen –hidden layer containing 17 neurons in the first layer and 5 neurons in the second layer with sigmoid activation function-to simulate the futuristic projections of municipal solid waste for the city of Dehradun. This projection of municipal waste aids in the estimation of the capacity of the landfill. The figure 6-1 depicts the projection of solid waste for the next 3 months. This could be utilized to project up to the time period of consideration i.e. the active life of the landfill.

7.1.2 Input of solid waste for a bioreactor landfill

Paper even though being recyclable is not much sent to the landfill. The quantity of waste paper is much less, as even the quantity thrown away is picked up by people for its use as a fuel and also for packaging of materials / food sold by road side hawkers. The plastics, rubber and leather contents are lower than the paper content, and do not exceed 1% except in metropolitan cities. The metal content is also low, (less than 1%). These low values are essentially due to the large scale recycling of these constituents.

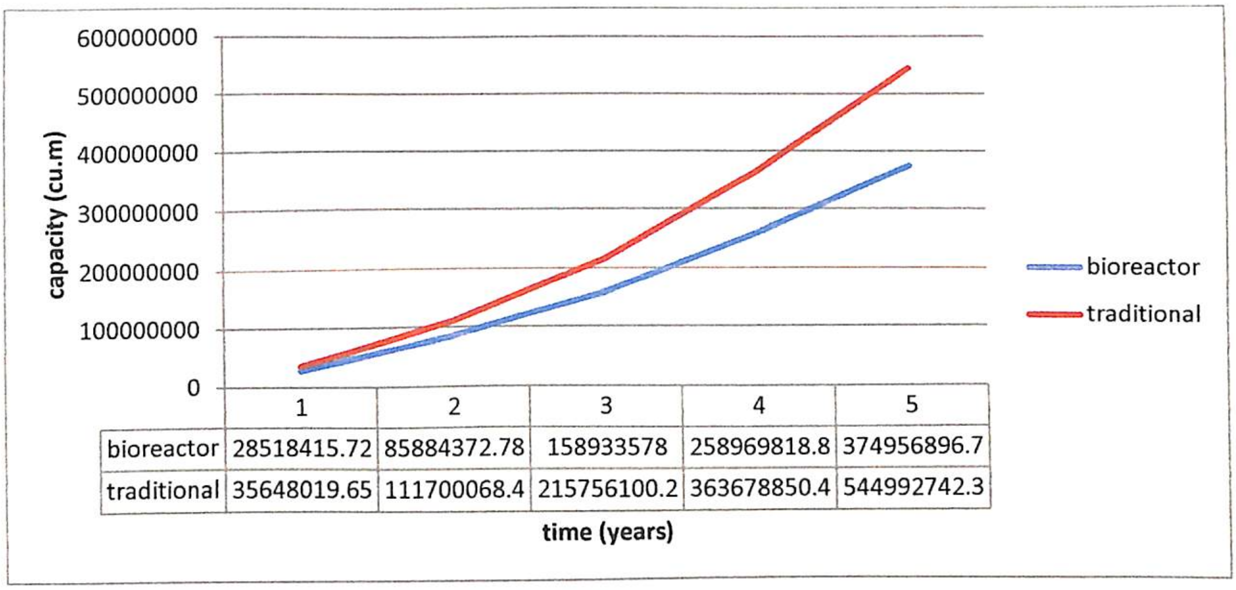
In a similar manner, as most of the recyclable materials are either recycled or reused in one form or another, the composition of waste that is dispensed off in the landfill reduces to only biodegradable material and inert waste. Thus, out of the total quantity of solid waste that is generated for the city, only 80% of it is used for landfilling.

7.1.3 Landfill Capacity needed for Dehradun City

It can be seen from the figure 5-1 that the existing model and the modified model provide the same results in spite of the proposed model being more refined and taking into account the settlement over a period of time with variation in it. The compaction ratio, settlement rate, the cover ratio and the amount of solid waste generated and the age of the landfill having taken as same for both the models while validation.

A major difference between the two models is with respect to the calculation of the amount of daily cover required. The existing landfill capacity estimation model calculates the volume of daily cover required with compacted density of the solid waste generated as base. The modified landfill capacity estimation model calculates the same with raw weight of the solid waste generated as base, in turn, allowing for more volume of daily cover. As Dehradun city's climate is usually rainy, this is a decided advantage. A comparison graph is provided below that depicts the landfill capacity required for the treatment of solid waste of Dehradun. The required capacity for a traditional landfill and of a bioreactor landfill for a sample period of 5 years has been compared. The graph clearly shows that a bioreactor landfill requires decidedly less volume of land for waste disposal in a marked contrast to the traditional landfill.

The existing model assumes that the entire solid waste generated for the city goes to the landfill for dumping. In the modified model more alternative approaches are being used like recycling, composting and incineration before sending their residues over to the landfill dump site. The proposed model has this factor incorporated into it.



	1	2	3	4	5
bioreactor	28518415.72	85884372.78	158933578	258969818.8	374956896.7
traditional	35648019.65	111700068.4	215756100.2	363678850.4	544992742.3

Figure 7-2: Comparison of a bioreactor with traditional landfill on basis of capacity

Figure 6-2 presents the landfill capacity calculated for proposed bioreactor landfill for Dehradun city, for a period of 5 years. Constant values have been used from Solid Waste Management Manual and waste composition details have been used for data available for Dehradun city (as shown in figure 1-1).

The total amount of landfill capacity required for a period of 5 years for a bioreactor landfill for the city of Dehradun is 474320474 m^3. This number includes the amount required for landfill liner, the infrastructural support and the final cover.

7.2 Landfill operation advisor

The Landfill Operation Advisor was taken for a complete test run, the results of which have been shown the following sections. The running of the landfill advisor starts from the welcome page shown in figure.

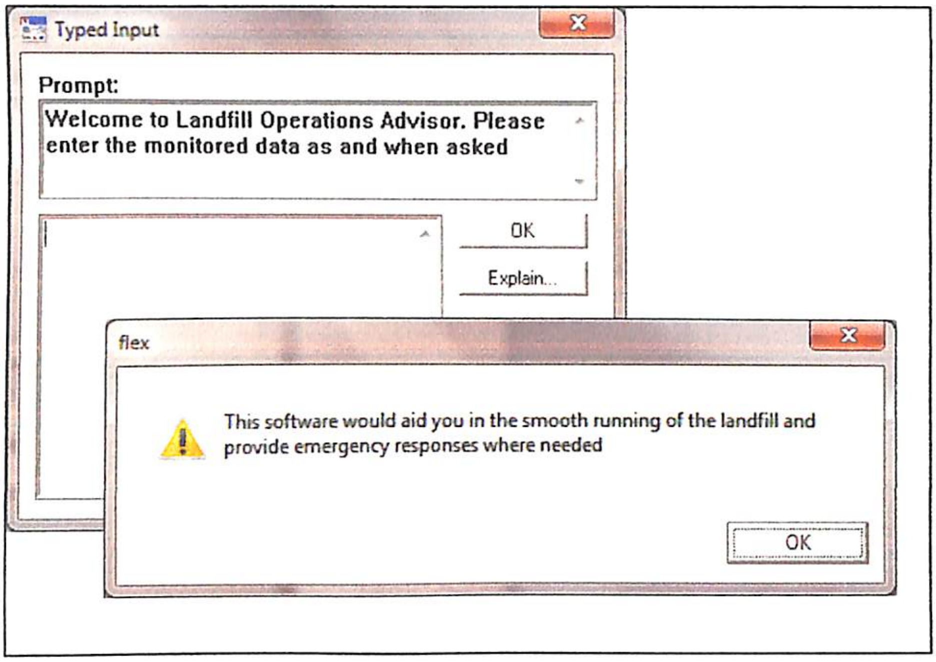


Figure 7-3: Landfill Advisor Welcome page

7.2.1 Questions Asked

The set of questions asked haven been shown in the following figures.

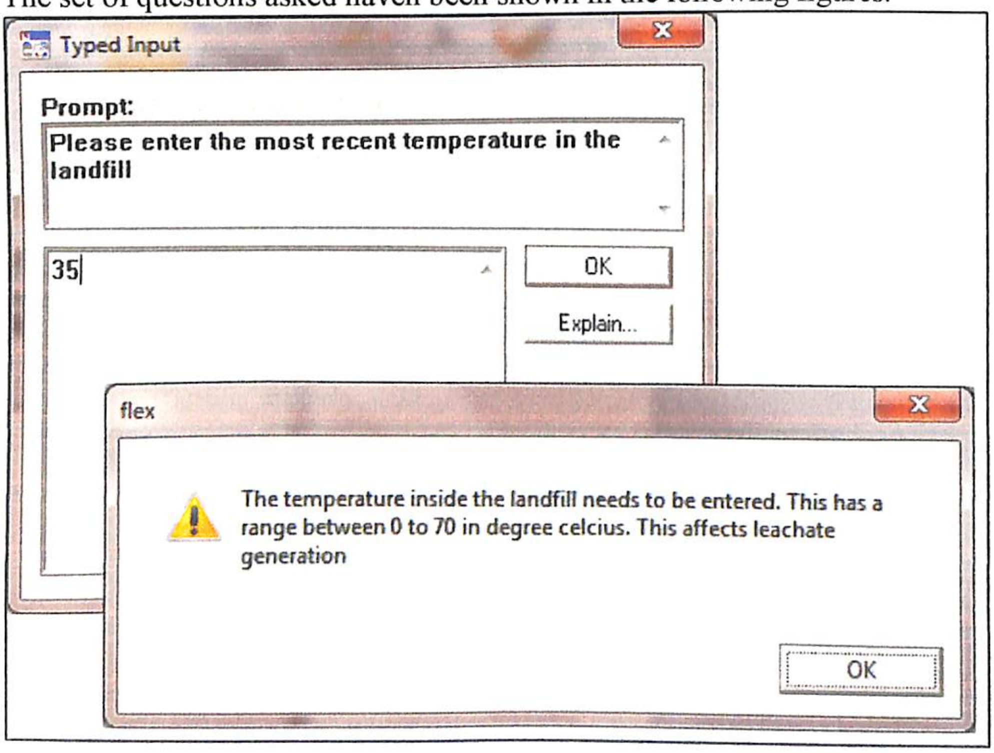


Figure 7-4: Question- temperature variable

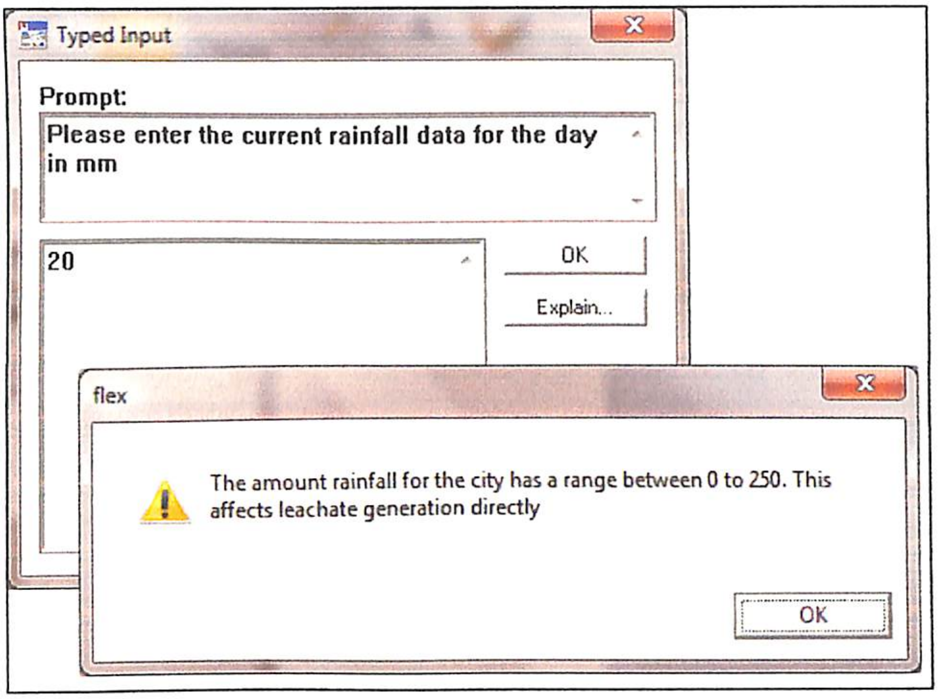


Figure 7-5: Question- Rainfall variable

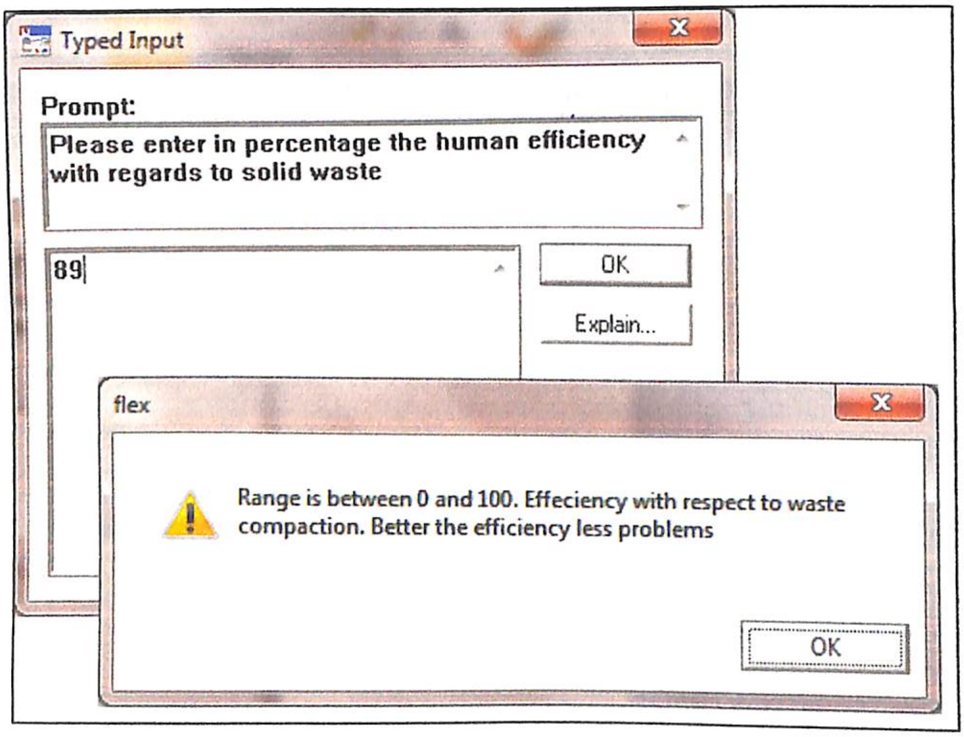


Figure 7-6: Question- human efficiency

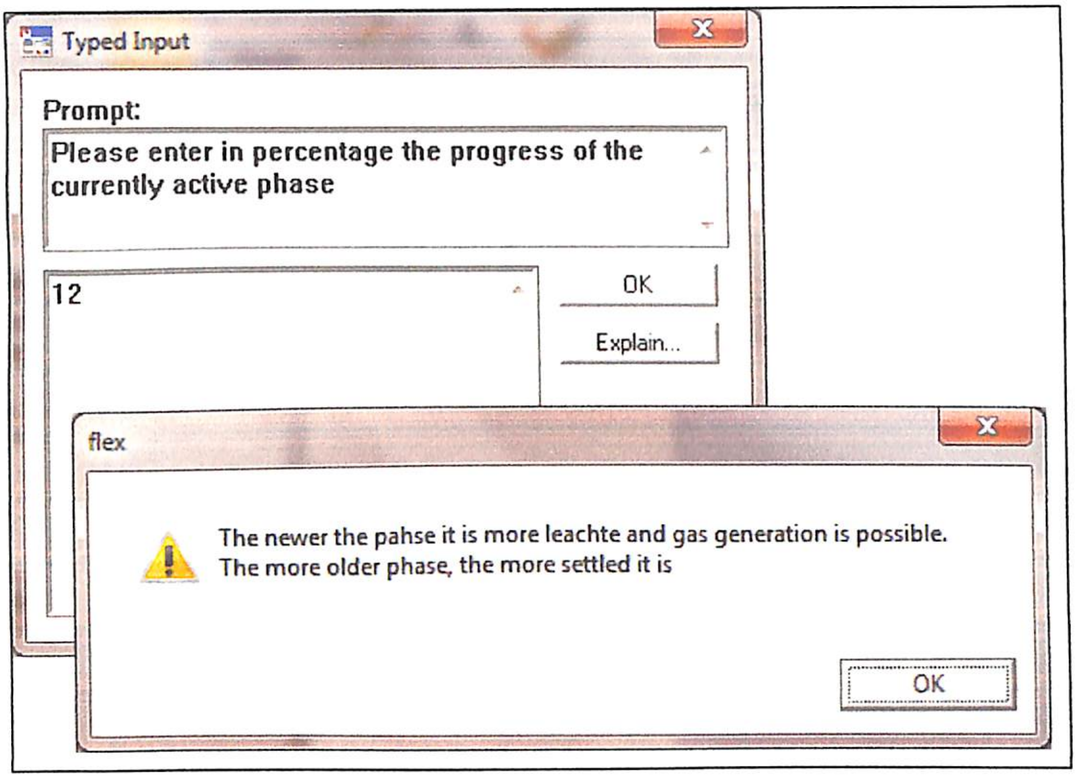


Figure 7-7: Question- Active Phase

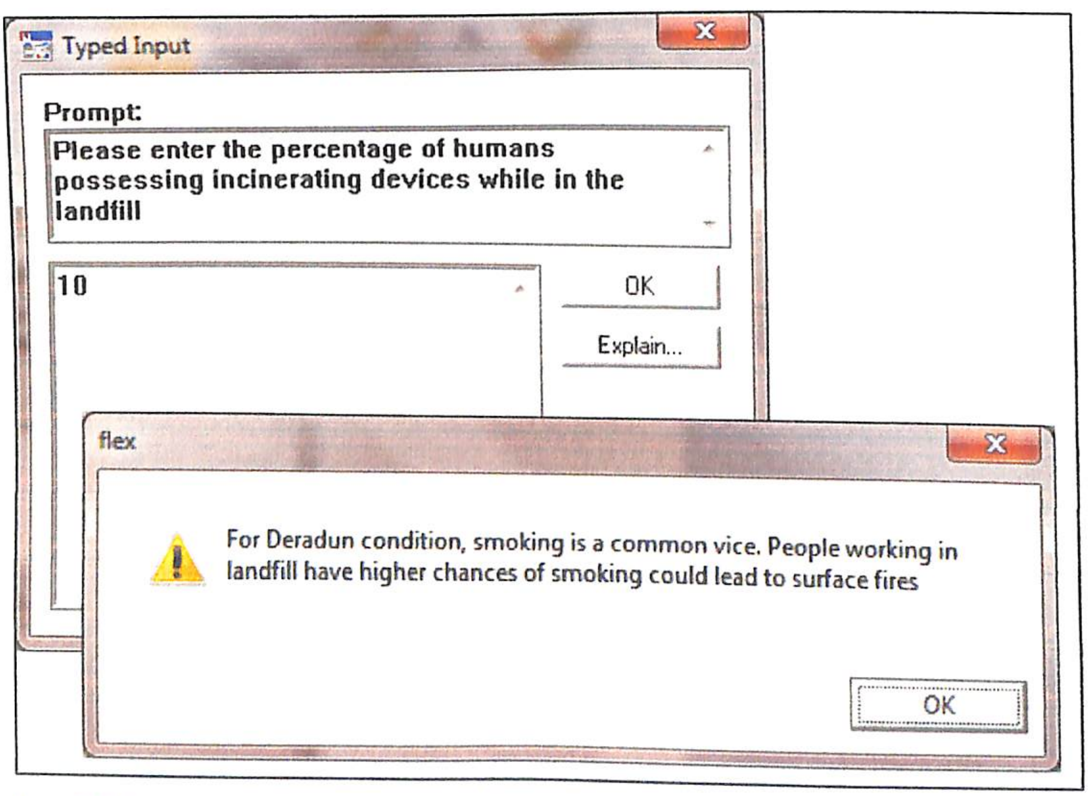


Figure 7-8: Question- Incinerating Devices

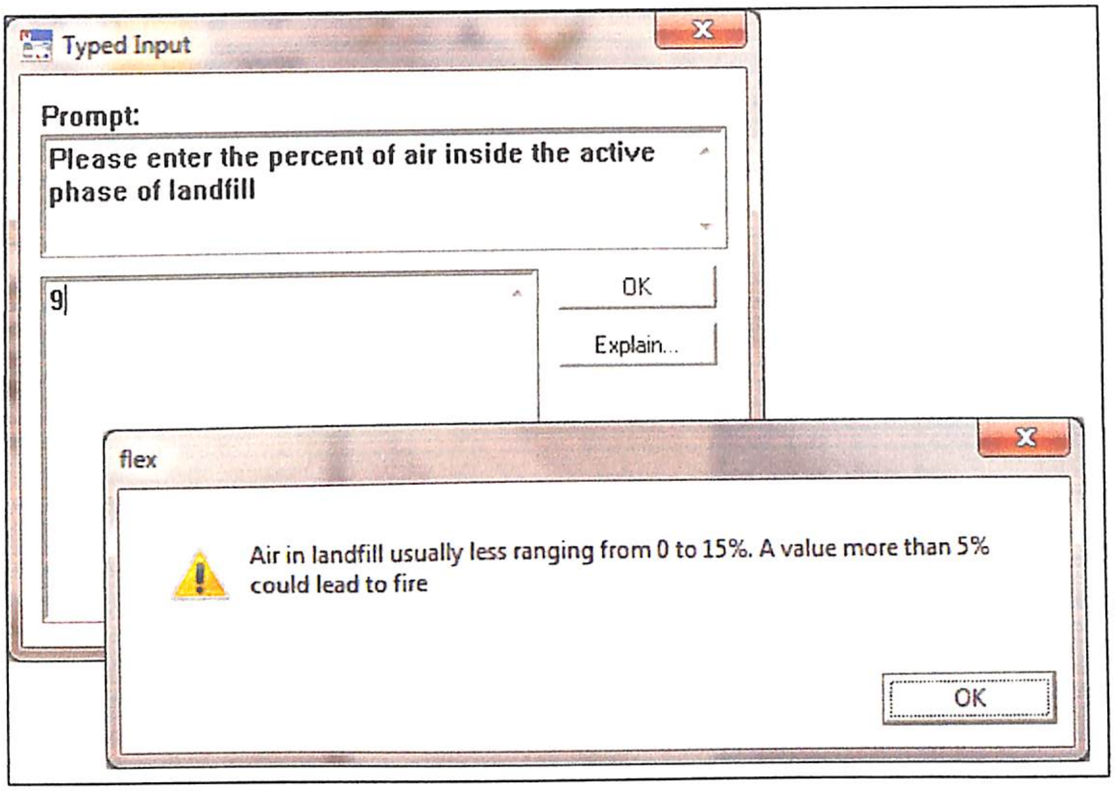


Figure 7-9: Question- Air in landfill

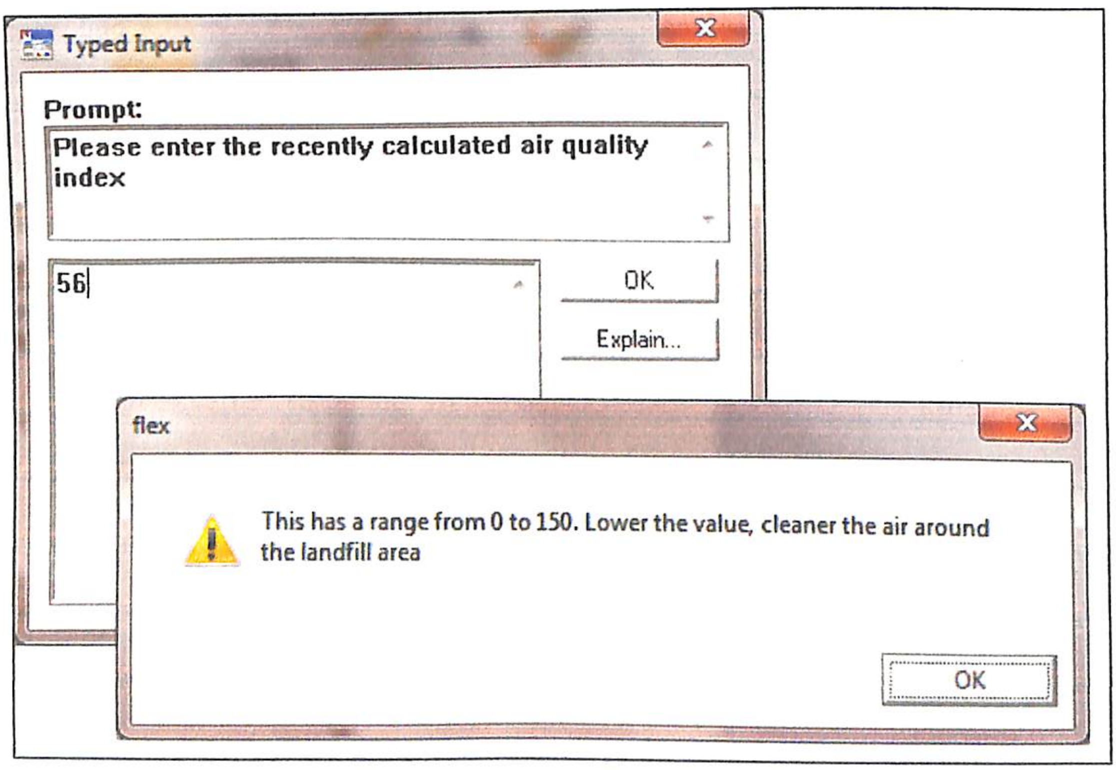


Figure 7 10: Question-Air quality index

7.2.2 Output

```
| ?- landfilloperation.
Input of monitored values:The current landfill temperature is: 35
The current rainfall is: 20
The current air quality index is: 56
The current amount of air inside landfill is: 9
The current human work efficiency for solid waste is: 89
The current landfill phase completed percent is: 12
The current usage of incinerating device by humans is: 10

the calculated values are:The current leachate generated is: 0
The current landfill gas generated is: 1247.4358974359
The current probability of a surface fire is: 54.1666666666667
The current probability for a subsurface fire is: 50
The current amount of odour from landfill is: 45
The current probability of gas migration is: 60
emergency response category :surface fire
 advice: bury the buring material in a separate pit and cover it
emergency response category :sub surface fire
 advice: insert liquid inside
```

Figure 7-11: Output

The above shown figure shows a complete running of the software for one particular case. In this manner there are multitudes of different scenario that could happen and help the manager in providing appropriate emergency response.

CHAPTER 8
CONCLUSION AND FUTURE SCOPE

8 CONCLUSION AND FUTURE SCOPE

The conclusion and future scope of this research work has been presented in the following sections.

8.1 Conclusion

Based on the study of composition of solid waste, its generation and disposal, a bioreactor landfill is recommended for over a traditional landfill for the proper solid waste management in Dehradun city. For the planning of a MSW landfill, its capacity depends on factors like the cover, solid waste and settlement rate of individual constituents of the material in the landfill.

Specifically for the city of Dehradun taking into consideration the nature and composition of the solid waste and the varied settlement rates, the proposed model estimates the capacity required for the proposed bioreactor landfill. It takes as input the projected quantity of solid waste for Dehradun city and gives as output the estimated capacity required for the construction of a landfill in Dehradun city for the specified period of time during which the landfill would be in use.

The objectives of this system in the framework of the SWM industry is the provision of timely warning of imminent dangers so that the managers and personnel could have time to prepare their strategy and actions accordingly to prevent it. This has been achieved by the combination of the technologies of Expert System (ES) technologies together with basic principles of the theory of fuzzy logic to develop a EWS for landfill operations.

The main characteristic of the advisor is that of the use of frames as knowledge modelling and representation and fuzzy logic for reasoning technologies. This allows the advisor to assess the possibility of the occurrences of operational problem and provide valuable advice that includes corrective actions and emergency response procedures for the mentioned operational problems.

These actions can be implemented not only by the personnel of the organization at the tactical and operational levels to avoid or to reduce their risk and to be prepared for effective response but also by the people living close to landfills, which are affected by their operations.

This prototype being specifically designed for Dehradun conditions was able to satisfactorily provide results as expected by the landfill expert. This software could further be worked upon for the inclusions of more problems and the changing landfill environment as pertaining to a bioreactor landfill.

8.2 Future scope

Landfill capacity estimation equations have been modified primarily on the basis of the varied settlement rate of the solid waste. Other influencing factors can also be considered for equation modification for capacity calculation.

Landfill Operations advisor software can be further expanded by the inclusion of the more number of operational problems than considered in this case. Other than this, uncertainty in the rules could be used for a more advancements in the advisor. Various analytical hierarchy procedures could be used for the depiction of the flow of the operational problems.

REFERENCES

REFERENCES

1. http://www.populationofindia.info/
2. Pamnani, Arti, and Meka Srinivasarao. "Municipal Solid Waste Management in India: A Review and Some New Results."*International Journal of Civil Engineering* (2014).
3. Ali Abdoli, M., Falah Nezhad, M., Salehi Sede, R. and Behboudian, S. (2012), Longterm forecasting of solid waste generation by the artificial neural networks. Environ. Prog. Sustainable Energy, 31: 628–636. doi: 10.1002/ep.10591
4. Ministry of Urban Development, Government of India, Manual on "Municipal Solid Waste Management" (May 2000).
5. Gupta, Sumeet, and Ashish Kumar. "PPP in Solid Waste Management: A Study of Dehradun City in Uttarakhand." *IUP Journal of Infrastructure* 9.2 (2011).
6. http://en.wikipedia.org/wiki/Waste_management
7. Kumar, Sunil, et al. "Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: an insight." *Waste Management* 29.2 (2009): 883-895.
8. Benítez, Sara Ojeda, et al. "Mathematical modeling to predict residential solid waste generation." *Waste Management* 28 (2008): S7-S13.
9. Dyson, Brian, and Ni-Bin Chang. "Forecasting municipal solid waste generation in a fast-growing urban region with system dynamics modeling." *Waste Management* 25.7 (2005): 669-679.
10. Buenrostro, Otoniel, Gerardo Bocco, and Javier Vence. "Forecasting generation of urban solid waste in developing countries—A case study in Mexico." *Journal of the Air & Waste Management Association* 51.1 (2001): 86-93.
11. Beigl, P., et al. "Forecasting municipal solid waste generation in major European cities." *iEMSs 2004 International Congress: Complexity and Integrated Resources Management, Osnabrueck, Germany*. 2004.
12. McBean, Edward A., and Michael HP Fortin. "A forecast model of refuse tonnage with recapture and uncertainty bounds." *Waste management & research* 11.5 (1993): 373-385.
13. Dayal, Gopal, et al. "Impact of climatic conditions and socio-economic status on solid waste characteristics: A case study." *Science of the total environment*136.1 (1993): 143-153.
14. Kollikkathara, Naushad, Huan Feng, and Danlin Yu. "A system dynamic modeling approach for evaluating municipal solid waste generation, landfill capacity and related cost management issues." *Waste management* 30.11 (2010): 2194-2203.
15. Ohman, K. V. H., et al. "Development of a landfill model to prioritize design and operating objectives." *Environmental monitoring and assessment* 135.1-3 (2007): 85-97.
16. Renkow, Mitch, and Andrew G. Keeler. "Determining the optimal landfill size: is bigger always better?." *Journal of environmental management* 46.1 (1996): 67-75.
17. Warith, M. A. "Solid waste management: new trends in landfill design."*Emirates Journal for Engineering Research* 8.1 (2003): 61-70.

18. Eleazer, William E., et al. "Biodegradability of municipal solid waste components in laboratory-scale landfills." *Environmental Science & Technology*31.3 (1997): 911-917.
19. Chen, Kuo-Sheng, Rong-Her Chen, and Chia-Nan Liu. "Modeling municipal solid waste landfill settlement." *Environmental Earth Sciences* 66.8 (2012): 2301-2309.
20. Bareither, Christopher A., Craig H. Benson, and Tuncer B. Edil. "Effects of waste composition and decomposition on the shear strength of municipal solid waste." *Journal of Geotechnical and Geoenvironmental Engineering* 138.10 (2012): 1161-1174.
21. Bareither, Christopher A., Craig H. Benson, and Tuncer B. Edil. "Compression behaviour of municipal solid waste: Immediate compression." *Journal of Geotechnical and Geoenvironmental Engineering* 138.9 (2011): 1047-1062.
22. Chen, Yunmin, et al. "Secondary compression of municipal solid wastes and a compression model for predicting settlement of municipal solid waste landfills."*Journal of geotechnical and geoenvironmental engineering* 136.5 (2010): 706-717.
23. Sivakumar Babu, G. L., et al. "Prediction of long-term municipal solid waste landfill settlement using constitutive model." *Practice periodical of hazardous, toxic, and radioactive waste management* 14.2 (2009): 139-150.
24. Park, Hyun I., et al. "Parameter evaluation and performance comparison of MSW settlement prediction models in various landfill types." *Journal of Environmental Engineering* 133.1 (2007): 64-72.
25. Ling, Hoe I., et al. "Estimation of municipal solid waste landfill settlement."*Journal of Geotechnical and Geoenvironmental Engineering* 124.1 (1998): 21-28.
26. Athanasopoulos, G., et al. "The December 29th 2010 Xerolakka Municipal Solid Waste Landfill Failure." *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris*. 2013.
27. Towhata, Ikuo. "On Failure of Municipal Waste Landfill." *Progress in Landslide Science*. Springer Berlin Heidelberg, 2007. 147-149.
28. Dunnet, Samantha C. "Current issues at the South Fremantle landfill site, Western Australia." *Rural and Remote Environmental Health* 3.1 (2004): 40-51.
29. Stark, Timothy D., et al. "Municipal solid waste slope failure. II: Stability analyses." *Journal of geotechnical and geoenvironmental engineering* 126.5 (2000): 408-419.
30. Chun, Seung Kyu, and Young Shin Bae. "An impact analysis of landfill for waste disposal on climate change: Case study of 'Sudokwon Landfill Site 2nd Landfill'in Korea." *Korean Journal of Chemical Engineering* 29.11 (2012): 1549-1555.
31. Rowe, R. Kerry. "Systems engineering: the design and operation of municipal solid waste landfills to minimize contamination of groundwater." *Geosynthetics International* 18.6 (2011): 391-404.
32. Chen, Yun-Min, and Tony LT Zhan. "Environmental geotechnics related to landfills of municipal solid wastes." *Advances in Environmental Geotechnics*. Springer Berlin Heidelberg, 2010. 132-152.

33. Depountis, Nikos, George Koukis, and Nikos Sabatakakis. "Environmental problems associated with the development and operation of a lined and unlined landfill site: a case study demonstrating two landfill sites in Patra, Greece."*Environmental geology* 56.7 (2009): 1251-1258.
34. Pivato, Alberto. "Landfill liner failure: an open question for landfill risk analysis."*Journal of Environmental Protection* 2 (2011): 287.
35. Townsend,T., Kumar,D., Ko,J. (2008). Bioreactor Landfill Operation: A Guide for Development, Implementation and Montoring: version 1.0 (July 1, 2008). Prepared for the Hinkley Centre for Solid and Hazardous Waste Management, Gainesville, FL.
36. Ling, Hoe I., and Dov Leshchinsky. "Seismic stability and permanent displacement of landfill cover systems." *Journal of Geotechnical and Geoenvironmental Engineering* 123.2 (1997): 113-122.
37. “Landfill Guidelines: Towards Sustainable Waste Management in New Zealand.” Ministry for the Environment, New Zealand, 2000.
38. “Landfill Operations Involving Potentially Explosive Atmosphere”, 1st ed., Environmental Services Associations, London, 2007.
39. “Solid Waste Landfill Guidance”, Section 9, Department of Environmental Quality, Oregon, USA
40. “Guideline-Landfill Sitting, Design, Operation and Rehabilitation”, version 2, Department of Environment and Heritage Protection, Government of Queensland, Australia, 2013.
41. “Environmental Guidelines: Solid Waste Landfill”, Environmental Protection Authority, ISBN 073103774X, 1996.
42. “Landfill Operations at Baxland”, Thiess Services PTY LTD, Australia
43. Yesiller, Nazli, James L. Hanson, and H. Yoshida. "Landfill temperatures under variable decomposition conditions." (2011): 1055.
44. Yesiller, Nazli, and James L. Hanson. "Analysis of temperatures at a municipal solid waste landfill." (2003): 1.
45. Basistha, Ashoke, D. S. Arya, and N. K. Goel. "Spatial distribution of rainfall in Indian himalayas–a case study of Uttarakhand region." *Water resources management* 22.10 (2008): 1325-1346.
46. Sontakke, N. A., Nityanand Singh, and H. N. Singh. "Instrumental period rainfall series of the Indian region (AD 1813—2005): revised reconstruction, update and analysis." *The Holocene* 18.7 (2008): 1055-1066.
47. Chauhan, Avnish, et al. "Ambient air quality status in Uttarakhand (India): a case study of Haridwar and Dehradun using air quality index." *J Am Sci* 6.9 (2010): 565-574.
48. Ramakrishnaiah, C. R., C. Sadashivaiah, and G. Ranganna. "Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India." *Journal of Chemistry* 6.2 (2009): 523-530.

49. Vasanthavigar, M., et al. "Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India."*Environmental monitoring and assessment* 171.1-4 (2010): 595-609.

50. Warith, Mostafa. "Bioreactor landfills: experimental and field results." *Waste management* 22.1 (2002): 7-17.

51. Morris, J. W. F., et al. "Findings from long-term monitoring studies at MSW landfill facilities with leachate recirculation." *Waste Management* 23.7 (2003): 653-666.

52. Benson, C. H., et al. "Practice review of five bioreactor/recirculation landfills."*Waste Management* 27.1 (2007): 13-29.

53. Foping, Franclin S., et al. "On Using Software as a Service to Deploy an Early Warning Service." *International Conference on Enterprise Information Systems and Web Technologies*. 2009.

54. Dokas, Ioannis M., Dimitris A. Karras, and D. C. Panagiotakopoulos. "Fault tree analysis and fuzzy expert systems: Early warning and emergency response of landfill operations." *Environmental Modelling & Software* 24.1 (2009): 8-25.

ANNEXURE

ANNEXURE A

Landfill Operational Problems:

This annexure contains the table containing the list of all operational problems.

Table A- 1: Landfill Operational Problems

Categories	Problem
Environment	Dust Vector-Rodents Water Ponding Insects Litter Odour Noise
Working Area and Perimeter	Wide working front Working front near landfill border Soft spots in the working front Wires tipped in working front Bulky waste tipped in working front Low litter fence performance Perimeter fencing problem Small distance between the landfill reception and the public roads
Transportation Problems	Wheel cleaning facility problem not available Delays during unloading of the collection vehicles Mud and debris on the public highway Obstructed movement of collection vehicles Dry dirt roads Inadequate road width Muddy roads Potholes in the road Rutty road Steep point in the road
Infrastructure problem	Landfill machinery damage Machinery without backup warning device Problem with compactor operator Problem with loading machinery
Waste problems	Waste mixture problem during compaction Large height of waste layering during compaction Inefficient lead checking Waste disposal in wrong place High discharging waste point Prohibited waste tipped in the landfill Unsatisfactory waste compaction
	Offensive/Malodorous wastes Cannery waste Dusty incoming waste Lightweight incoming waste Dead animals Seaweed

	Sludge Incoming smoking/ burning loads Uncontrolled appliances/demolition waste/ tires
Cover problems	Depression in the surface of the landfill Lift slopes problem Potholes in the fill Sink holes on the landfill surface Unavailability of waste cover material Erosion cuts of the landfill cover Impermeable intermediate cover layer Partially covered/ uncovered waste Waste covering activities Waste cover compaction problem
Human related problems	Landfill machinery hit person Unauthorized people in tipping area Human activities near the landfill Problem with excavation machinery operator Problem with gate keeper Problem with landfill night guard Problem with landfill truck drivers Problem with leading machinery operator Problem with the spotter People with cigarettes in the work face Unauthorized people in the landfill
Landfill gas related problems	No available gas combustion facility Overdrawing of landfill gas extraction wells Problems with gas combustion facilities Smoke or combustion gasses escapes out of fissures
Leachate related problems	Leachate collection and drainage system failure Overflow of leachate collection holding ponds Leachate seeps High leachate levels above liner Large filling rates of leachate holding ponds Leachate holding ponds about to fill/ overflow Leachate holding ponds without aeration or chemical treatment/ cover
Miscellaneous problems	Surface fire Subsurface fire Uncontrolled storm water runoff Rainy weather Warm weather Windy weather conditions

ANNEXURE B

Sample of programs:

In the present work, study has been carried out on solid waste generated, its composition for Dehradun city. Along with this study has also been carried out on waste disposal methods with focus on landfill design, its construction and operations. For landfill capacity estimation, solid waste generated for Dehradun city has been taken as input. Further, the standard data constant's values from the Solid Waste Management Manual have been utilized.

For Landfill Operations Advisor, the programming was done using prolog as the coding language by use of WINPROLOG 4.8. The tools FLEX and FLINT were also smoothly integrated for the development of the early warning system.

All the above discussed data and code and procedures are available with the author of this dissertation who can be contacted for any queries/ suggestion/further elaborations/descriptions. As the data is voluminous and the program codes are about more than 700 lines, they have not been printed in this report.