IDENTIFICATION OF SOLID WASTE MANAGEMENT SITES FOR THE MUNICIPAL CORPORATIONS OF PUNJAB

A

Thesis

Submitted to

For the award of

DOCTOR OF PHILOSOPHY (Ph.D)

in

Geography

By

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Supervised By

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LOVELY FACULTY OF BUSINESS AND ARTS
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DECLARATION

I hereby declare that the thesis entitled **"Identification of Solid Waste Management Sites For Municipal Corporations of Punjab"** prepared and submitted by me under the supervision and guidance of Dr. Dheera Kalota, Assistant Professor in Geography, School of Arts and Languages, Lovely Professional University, Phagwara, Punjab (INDIA) as per the full requirement for the award of degree of Doctor of Philosophy (Ph.D.) in Geography is entirely my original work and all ideas and references have been duly acknowledged. It does not contain any work that has been submitted for award of any other degree or diploma of any other university.

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CERTIFICATE

This is to certify that the thesis titled **"Identification of Solid Waste Management Sites For Municipal Corporations of Punjab"** which is submitted by Mr. Kanwar Deepak for the award of degree of Doctor of Philosophy (Ph.D.) in Geography to the Lovely Professional University, Phagwara, Punjab (INDIA) has been carried out under my supervision and guidance. To the best of my knowledge, the present work is the result of his original investigation and study. No part of the thesis has ever been submitted for any other degree or diploma to any other university. The thesis is fit for the award of Doctor of Philosophy (Ph.D.) degree.

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ABSTRACT

Municipal solid waste is one of the major contributors in environmental pollution. Its generation has become a part of our living style and it is difficult to control the growth of solid waste. But if solid waste is managed at an appropriate site, it becomes a step closer towards healthy environment. Present study attempts to identify suitable sites for solid waste management for all the ten municipal corporations in Punjab. Remote Sensing and GIS technology is used for the purpose of identification of sites. The objectives of this study are to examine the existing processes, preparing of model for site identification and to identify three sites for each municipal corporation for solid waste management. Study areas for all the municipal corporations are defined by making a buffer of 10 km around the built up area of each municipal corporation and then clipping it with the state / district boundary. A total of nine variables are identified viz. landuse landcover, soil drainage, groundwater level, distance from city, distance from canals, distance from drains, distance from settlements or villages, slope and distance from roads. Role of variables is quantified by assigning percentage of influence to each variable and weightage on the scale of 1-5 to the subclasses of each variable. Spatial data analysis is accomplished with the help of various tools in ArcGIS. All spatial data is converted into raster format to apply Weighted Overlay Analysis which generates a new raster that categorizes the study area in various suitability zones alongwith suitability index from 1-5. The highly suitable areas are extracted to view in Google Earth for verification of machine generated results and also to locate sites within the highly suitable areas by once again considering the role of all the nine variables. All sites are validated by overlaying on the layers of each variable thus confirming the efficacy of site identification model. After validation, these sites are finalized for solid waste management.

PREFACE

Site identification for solid waste management remained neglected and is evident from the current situation in most cities of our country. Present study is undertaken to identify suitable sites for solid waste management for all the ten Municipal Corporations of Punjab State. Attempt has been made to use the latest tools of remote sensing and GIS or Geographic Information System for analysis.

I, earnestly recognize the contribution of Dr. Dheera Kalota who has been mentoring this work right from the very beginning. Her technical capabilities in the field of remote sensing and GIS benefitted me in handling tough situations during my research work. Her perseverance helped me to remain focused on the topic and also converted complex problems into simple solutions.

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1.	AHP	Analytical Hierarchy Process
2.	DEM	Digital Elevation Model
3.	Dept	Department
4.	Dist	District
5.	e.g.	exempli gratia
6.	ERDAS	Earth Resource Data Analysis System
7.	ESRI	Environmental Systems Research Institute
8.	et al	et alibi
9.	Fig	Figure
10.	GIS	Geographic Information System
11.	gms	Grams
12.	HPEC	High Powered Expert Committee
13.	i.e.	id est
14.	ICRIER	Indian Council for Research on International Economic Relation
15.	ISRO	Indian Space Research Organization
16.	J&K	Jammu and Kashmir
17.	km	Kilometer
18.	KML	Keyhole Markup Language
19.	m	Meter
20.	mbgl	Meters Below Ground Level
21.	MC	Municipal Corporation
22.	MCE	Multi Criteria Evaluation
23.	mt	Meter
24.	NIMBY	Not In My Backyard
25.	PMIDC	Punjab Municipal Infrastructure Development Company
26.	PPCB	Punjab Pollution Control Board
27.	PSCST	Punjab State Council for Science and Technology
28.	RS	Remote Sensing
29.	SAS Nagar	Sahibzada Ajit Singh Nagar
30.	sq km	Square Kilometer
31.	SRTM	Shuttle Radar Topography Mission
32.	SWM	Solid Waste Management
33.	TPD	Tons per day
34.	USGS	United States Geological Survey

Chapter – 1

INTRODUCTION

Health of environment is a growing concern for the cities of third world countries specially India. It has been observed that most of the Indian cities lack urban infrastructure for various services including solid waste management which results into deteriorating environment both in and around the cities (New Climate economy, 2016). Today urban planning needs to look beyond the expected population growth in order to meet the specific norms for various urban services including solid waste management. In terms of share in urban infrastructure investment for the period 2012-2031 the solid waste management gets only 1.6 % as against 55.8% of urban roads (High Powered Expert Committee, 2011). Thus the sector of solid waste management is being neglected not only by the people but also in the hands of government. Proper management of solid waste includes several aspects like recycling, reusing, incineration, composting, waste to energy conversion, proper land-filling etc. When all these processes are undertaken at an appropriate site, it becomes a step closer towards healthy environment.

1.1 Municipal Solid Waste

Municipal solid waste points to the everyday material discarded by people. It is mainly composed of household solid waste besides street waste, debris generated from demolition and construction activities, solid waste from institutional and commercial complexes etc. The household waste includes kitchen garbage, plastic bags, bottles, cans, newspaper, clothes, cardboard, packing material etc. Kitchen garbage constitutes the largest part that comprises of vegetable and fruit peels, leftover food etc. Different terms are used to define the municipal solid waste like garbage, trash, refuse, rubbish, litter, junk etc. Other kinds of solid wastes like industrial waste, biomedical waste, dead animals material and human fecal matter are beyond the purview of this study.

Solid Waste Management Rules, 2016 notified by 'Ministry of Environment, Forests and Climate Change', Government of India, define solid waste as "solid or semi-solid domestic waste, sanitary waste, commercial waste, institutional waste, catering and market waste and other non residential wastes, street sweepings, silt removed or collected from the surface drains, horticulture waste, agriculture and dairy waste, treated bio-medical waste excluding industrial waste, bio-medical waste and e-waste, battery waste, radio-active waste generated in the area under the local authorities and other entities" (Ministry of Environment ……, 2016a).

1.2 Statement of Problem

Identification of ideal site for solid waste management is a complicated and technical procedure requiring large volumes of spatial data (Karthiheyan and Yeshoda, 2016). Site is a place that is going to handle entire city's solid waste which can pollute and deteriorate the environment severely. No doubt all settlements are using some sites for dumping or managing the solid waste but are all these sites suitable for it. What are those factors that can affect site identification for solid waste management? What are possible threats that such sites can pose to the environment and the people? Were all these things considered before selection of sites? Looking at the current scenario of these sites, it appears that all such factors were ignored before site identification. An ideal site has to address all the factors that can contribute towards minimum pollution of environment. The selection process of suitable site must be based on some technical analysis of all the factors (Sharma et al., 2015).

Where sites are arbitrarily selected, it is common to see unruly and disorderly dumping of solid waste which not only spoils the landscape but also pollutes the environment (Deswal and Laura, 2014). After dumping, the biodegradable waste starts decomposing. In this process microbial and chemical reactions take place resulting into the release of methane and carbon dioxide and other volatile organic compounds. This process starts one year after the dumping of solid waste in a landfill and continues for 15-25 years (Clark Energy, 2016a). Both methane and carbon dioxide are greenhouse gases and their release into the atmosphere needs to be checked. Such sites also attract insects and rodents that are capable of spreading diseases. Foul smell emanating from these sites is another distracting effect. Most of the landfills are not lined therefore, there is possibility of leaching of pollutants into underlying soil layer and even groundwater. If untreated industrial waste is dumped, it puts the environment at high risk of pollution because this waste contains many toxic elements. Many of these toxic elements are not biodegradable and once these enter in soil or groundwater there is no possibility of cleaning the environment (Clark Energy, 2016b).

1.3 Solid Waste Management in India

In India, the policy to manage solid waste is laid down by the 'Ministry of Environment'. Rules of solid waste management were reviewed after sixteen years and were announced on April, 05, 2016 (Ministry of Environment ……, 2016a). The new rules are not restricted to the administrative boundaries of cities but include even the urban agglomerations census towns and also the areas like notified industrial localities, areas controlled by the Railway, airport, airbases, ports and harbours in India. Besides these rules shall also apply to military installations, exclusive economic territories, State and Central government establishments, regions of sacred, spiritual, ancient and archival importance. That's why 'Municipal Solid Waste Management' is now called 'Solid Waste Management'. Now 'municipal' word has been removed. The waste processing facility from now on must be arranged and created by the administration at local level. As per the revised rules, new townships are required to have waste handling facility. In case of hilly areas, site for landfill is to be located in the adjoining plain areas in the vicinity of 25 kms. A committee has also been set up by the government to watch the execution of these rules.

Table 1.1 shows the annual generation of various types of solid wastes in India. Every year around 43 million tons of solid waste is collected out of which 11.9 million tons is treated and 31 million tons is disposed of in landfill sites. In other words 75-80% of solid waste is collected and only 22-28% is treated. Per capita solid waste generation is 200-600 grams per day in Indian cities which is growing at a very fast pace. It is expected that production of the solid waste may grow from 62 million tons to 165 million tons in 2031 and 436 million tons in 2050 (Ministry of Environment ……….., 2016a).

Table 1.1
Annual generation of various types of solid waste in India.

S. no.	Type of Waste in India	Generation / year
1	Total Solid Waste	62 million tons
2	Plastic waste	5.6 million tons
3	Bio-medical waste	0.17 million tons
4	Hazardous waste	7.90 million tons
5	e-waste	15 lakh tons

1.4 Solid Waste in Punjab

Everyday thousands of tons of solid waste is added in Punjab. Tale 1.2 depicts the status of solid waste in the state of Punjab. The Punjab Government has prepared a plan to manage the solid waste of all 167 number of urban local bodies in the state. This plan is known as 'Punjab Model Municipal Solid Waste Management Plan, 2017' (Punjab Pollution control Board, 2017).

Table 1.2
Status of solid waste in Punjab (Punjab Pollution Control Board, 2017).

S. no.	Solid Waste Status	Tons per day (TPD)
1	Solid Waste Generation	4544.35
2	Solid Waste Collected	4520.35
3	Solid Waste Treated	39.175
4	Solid Waste Landfilled	3278.6

This plan mentions 160 number of urban local bodies of the entire state and categorizes these in eight municipal solid waste clusters for setting up of Integrated Municipal Solid Waste Management Projects. A common action plan of 10 points is also prepared which is implemented by the Directorate of Local Government and monitored by Punjab Pollution Control Board. Further, among 160 number of urban local bodies, only 07 are implementing all the ten points while 100 are partially implementing and 53 are not implementing. All the urban local bodies are dumping the solid waste in open. All the concerned municipal corporations and councils have identified land for the Integrated Municipal Solid Waste Management Projects. The Department of Local Government, Punjab has not fixed any target date for the completion of projects (Punjab Pollution Control Board, 2017).

A non profit company has also been constituted by the Department of Local government namely PMIDC or Punjab Municipal Infrastructure Development Company. Besides several other projects, this company is also looking after six projects associated with the solid waste management in Patiala, Mohali, Jalandhar, Bathinda, Ludhiana and Amritsar (Punjab Municipal Infrastructure Development Company, 2009).

1.5 Review of Literature

At the onset of research, it is desirable to review the literature related with the topic of research. Studies are looked for that describe the latest scenarios of solid waste management in different areas; factors affecting site identification process and the methodology associated with the identification of sites. Review of these studies helped in gaining knowledge and exploring new connections of this topic with other issues. Theme wise description of these studies is presented below.

Variable Selection

- Dharanikota, A. (2013) in her thesis identified three sites for solid waste management in Kakinada city by using techniques of remote sensing and GIS. She analyzed several variables including landuse landcover, soil, geology, geomorphology, groundwater, infiltration and population. She used weighted overlay analysis by assigning 25% importance to landuse landcover, 25% to geomorphology, 25% to soil, 15% to groundwater table and 10% to groundwater quality.
- Sunder Rajan, S. et al. (2014) in their study located the appropriate sites to dispose of solid waste in city of Hosur in Krishnagiri district of Tamil Nadu.

This study deals with selecting suitable sites by integrating GIS techniques with the Remote Sensing. The study considered the factors of slope, channels of drainage, water bodies, population, road distance, distance from water bodies and distance from inhabited areas.

- Sharma, M. et al.(2015) in their study on Gwalior located appropriate site to discard solid waste with the help of geospatial techniques. They analyzed seven factors viz. rocks, surface of land, slope, landuse landcover, population data, roads distance and drainage distance. All these factors are analyzed with GIS techniques by applying weighted overlay analysis. In the end a map is generated categorizing the study area in various suitability zones for the disposal of solid waste.
- Pradhan, J. and Samanta K. (2015) use GIS techniques alongwith remote sensing to identify a site to discard solid waste in Rajarhat Gopalpur area of Kolkata in West Bengal. A variety of tools are used including weightage overlay analysis for identifying an appropriate site to discard the solid waste. Factors like landuse landcover, population data, slope, road distance, canal distance are used for the analysis.
- Jaybhaye, R. et al. (2014) did their study on the city of Pune for site identification to dispose of the municipal solid waste. Remote sensing data and topographical maps are used to do analysis in thematic layers. A total of nine factors are analyzed like roads, drainage, water bodies, geology, population data, slope and landuse landcover. All factors are standardized using multi-criteria analysis method. 1.07% area was found as highly suitable for the disposal of solid waste.
- Karthiheyan, P.N. and Yeshoda, L. (2016) attempted to locate a site for municipal waste disposal by applying techniques of remote sensing and GIS in Krishnagiri area of Tamil Nadu. Landuse landcover, soil, roads, geology, geomorphology and drainage are the factors considered for site selection. All these factors were assigned weight before applying the spatial analyst tool. Four locations were identified for the disposal of solid waste.

- Rinsitha, T. et al. (2013) made a study to find an apt site for dumping solid waste in the Chengalpettu town using GIS techniques and Remote Sensing. The factors of landuse land cover, geology, geomorphology, soil and tanks are used for analysis. The rank and weightage are based on pair-wise comparison matrix for various thematic maps which are overlaid using GIS technology. The resultant sites were categorized on the basis of suitability and most suitable sites are recommended.

- Nishanth, T. et al. (2010) made a study to find a proper site to discard the solid waste by using GIS and Remote Sensing techniques in the city of Kottayam. All criteria including rocks, slope, geomorphology, population, road distance, streams distance and drainage distance) are grouped in two categories: Physical and Socio-economic. A weightage is assigned to each criteria. In the end, three suitable sites are found in Manganam, Vadavathoor and Mulavattam.

- Choudhury, S. and Das, S. (2012) presented their study for Dharmanagar to locate an apt site for landfilling of solid waste. The study uses GIS and Remote Sensing techniques. In total seven factors were considered for site selection: Geomorphology, lithology, slope, drainage, stream, population and roads. On the basis of suitability five kinds of areas were demarcated for solid waste disposal using weighted overlay analysis.

- Eberechi, E. N. and Godwill, T. P. (2016) did a study on Ile-Ife city of Nigeria in order to select an appropriate site to discard the solid waste. The analysis is done using a total of six factors viz. Geology, settlement, soil, slope, water bodies and roads. Weights were assigned to each one of them on the basis of their importance. The study shows spatial Modeling Analysis to build the area suitable for siting dumpsite using multi-criteria analysis within the GIS environment.

- Mahmoud, A. H. (2015) did a case on Alexandria city of Egypt to site an incineration plant to dispose of the solid waste. All analysis for this study are based on GIS techniques which are used to develop a model for identifying a location for incineration plant. In total five criteria were considered viz. cost, landuse, electricity, road, land availability and transfer stations. By integrating all these criteria a composite index was suggested in order to locate the site for incineration plant.

- Fides, K. K. and Edward, H. W. (2014) did a study on locating a landfill site in Nakaru city of Kenya. Multi criteria analysis alongwith several other geospatial techniques are used to accomplish the task . In total seven variables are selected for the analysis using GIS techniques including spatial analytic tools. The criteria include landuse, slope, geology, soil, drainage, roads and protected areas. Assigning of weightage was based on the pair-wise comparison matrix for the selected variables. The maps of all the variables are overlaid on each other. 5.52% area was found most suitable for the landfill.

- Mohammedshum, A.A. et al. (2014) did a study on Wukro city in Tigray, Ethiopia to find an apt site to dispose of the solid waste of city. The study makes use of GIS techniques and remotely sensed data to accomplish the task. This study is based on MCE (multi criteria evaluation) using geospatial analysis tools. Two sites were identified on the basis of physical factors like landuse cover, slope, soil, geology and surface water.

- Emwandongo (2013) in his study on Ongata Rongai city of Kenya made use of remotely sensed data and GIS tools in order to find a site for Solid Waste Management. A variety of variables were considered for the analysis which include distance from the urban center, the distance to rivers, slope and land use types. All these key factors are analyzed to develop a Multi Criteria Decision Analysis model.

- Sener, S. et al. (2011) attempted to find a site for Senirkent-Uluborlu basin of Turkey to dispose of solid waste. GIS techniques including AHP methodology are used for the analysis of factors like rock surface, landuse, water bodies, groundwater level, lineaments, height, slope, and roads distance. All the criteria are assigned weights using AHP technique in GIS. The result declared that 96.3 % of area is not suitable for dumping solid waste.

Solid Waste Management

- Ministry of Environment, Forests and climate change (2016a) issued a notification on April, 08, 2016. It contains definition of areas on which the rules of solid waste management will apply; terminology, role of various government offices and employees; specifications for site selection and other related activities of solid waste management and in the end exhaustive forms seeking information related with the environment.

- Ministry of Environment, Forests and climate change (2016b) announced the Solid Waste management Rules on April, 05, 2016. These rules were revised after 16 years and now extend to all the urban as well as industrial areas. A central monitoring committee has also been formed under Environment Secretary to monitor the implementation of these rules.

- Deswal, M. and Laura, J.S. (2014) presented their study on Application of GIS in Municipal Solid Waste Management in India. In this study the problems associated with solid waste management are listed and potential of GIS in handling these problems is discussed. The features of GIS software like linking of spatial and non-spatial data and provision of querying are highlighted.

- Ministry of the Environment, Japan (2012) through Waste Management and Recycling Department Policy Planning Division, Office of Sound Material-Cycle Society (2012) described in detail the latest technologies to handle the solid waste in Japan. This publication of 30 pages is a useful guide to handle solid waste in India also.

- Syeda, M.A. et al. (2013) in their study 'Open dumping of municipal solid waste and its hazardous impact on soil and vegetation diversity at waste dumping sites of Islamabad city', assessed the impact of open waste dumping in soil contamination and its further effect on plant diversity. A comparative study is attempted by identifying two sample sites : one at open waste dumping site allocated by the capital development authority and the other at sub sectors of H-belt of Islamabad city. Wide differences are observed at two locations in terms of soil contamination and plant diversity.

- Singh, G. et al. (2016) in their study 'Solid Waste Management Scenario of Punjab', present the current scenario on solid waste management in the state of Punjab. It is highlighted that the waste generated in all the cities is often dumped in the open that releases greenhouse gases like methane and atmosphere gets polluted. State government has formulated a plan for the solid waste management for all the cities by arranging them in clusters. However modern plants of solid waste management are functional at two places only.
- Clark Energy (2016b) describes a good example of optimum utilization of landfill gas. This case study of Bernaraby landfill power plant of Queensland in Australia is the outcome of a business contract between Clarke Energy and GE's Jenbacher company. The Clarke Energy is to supply containerized gas engine for a new landfill gas power station at Benaraby. The landfill gas is a waste or by product of municipal solid waste decomposition but it can be tapped as a very useful energy resource.
- Harshani, H.M.D. et al. (2015) did a study for Colombo District of Sri Lanka in which properties of soil are analyzed where solid waste is discarded. In total three such solid waste disposal sites are selected for the analysis of soil. Purpose of the research is to recommend perfect cover soil properties for the prospective dump locations. Stress is laid on the absorptive nature of soil for such dumpsites.
- Sharma, P.D. (2009) maintains a weblog "Keeping World Environment Safer and Greener". In this blog a variety of studies are posted ranging from Eco-friendly technologies, Environment related summits across the globe, Environment related disasters. The link of posts contain 69 valuable studies. One of his study focuses on the management of solid waste Disposal as this issue concerns everyone and must be resolved to protect the environment. The weblog contains several techniques of solid waste disposal besides a discussion on the problems associated with the solid waste disposal.

- Zhu, D. et al. (2008) wrote a book to improve the handling of solid waste in India. This book is a benchmark for policymakers and planners. The book highlights the Solid Waste Management issues relating to developing countries like present scenario, system deficiencies, steps required to correct the solid waste management practices. Although the book is not India specific but covers most of South Asia.

- Puri, A. et al. (2008) critically evaluated the solid waste disposal practices in Jalandhar city and their effect on public health. The study is based on the survey of solid waste related diseases. In the end, it is pointed out that the waste management techniques in Jalandhar are very old and not satisfactory. These must be replaced with the new ones. Public awareness is extremely important and it can be achieved by organizing camps.

- Rick, L.B. (2016) explains the several waste treatment and disposal techniques. All the techniques discussed on this webpage are grouped in three categories: Thermal treatment, dumps and landfills and Biological waste treatment. Other links on this page provide useful information on recycling, organic farming and marketing of solid waste.

- Nnaji, C.C. (2015) explored the current status of urban solid waste in Nigeria. The study covers waste collection, waste generation, waste scavenging, waste dumping, waste discarding and the adverse impact on environment by damaging practices of waste handling. Presence of heavy metals is found in the dumping sites. Only secondary data is used in this study.

- Kashid, D.S. et al. (2015) in their study of Aurangabad city attempted the current allocation and relocation of the waste bins with the help of remotely sensed data & GIS tools. They suggested the total number of bins and their optimum location in the city. Road network and population density were considered in this study. Three proximity distances of 50, 75 and 100 meters were used to suggest optimum locations.

- Wai, Y.Y. et al. (2014) monitored the surface temperature of all the sites of Napean municipality, Ontario, Canada where solid waste is dumped. They studied the more than 400 multi-temporal satellite imageries acquired from USGS or United States Geological Survey. The images range from 1984 to 2011. It was discovered that the temperature of landfill site remains high than the circumambient temperature of atmospheric and vegetation.

- Tatva (n.d.) is one of India's largest and most diversified provider of waste management services. Using cutting edge technologies, it provides sustainable solutions to the numerous environmental problems including solid wastes. Government of India has already approved its several municipal solid waste and hazardous waste management projects at Coimbatore, Mumbai, New Delhi, Ankleshwar, Himachal Pradesh, Kerala Uttar Pradesh etc. Its website provides an exhaustive and meaningful information.
- Humes, E. (2013) has wonderfully explained the relationship of garbage with mankind in his book: ‘Garbology: Our Dirty Love Affair with Trash’. It is stated that on average a person in USA produces 102 tons of waste in his life time. Author elaborates the data related with waste, its consequences, and techniques to handle and hopes to find a way-out. He further goes to explain that garbage reveals our culture. His presentation has the capacity to change the perception of waste in reader’s mind.
- Chandrappa, R. and Das, D.B. (2012) wrote a book on the handling of solid waste wherein the fundamental processes of environment engineering are discussed. The book describes the problems of solid waste management. A brief history of solid waste has also been traced. The problem of waste is linked with the several economic and social factors besides suggesting the various techniques to handle it.
- Rogoff, M. and Clark, B. (2012) discuss the various options to manage the solid waste in their paper ‘Staying Informed on Solid Waste Disposal Options. The problem of privatization of waste management is discussed along with several problems associated with the handling of solid waste. The locus is more on the costs incurred on the solid waste management and the ways how these can be controlled.

- Vaughn, J. (2008) has written a very informative book "Waste Management – A Reference Book'. After illustrating the history of solid waste the book discusses in detail the variety of solid waste types, their problems, controversies and sources before suggesting the popular and affordable solutions. The book also takes into account the Global waste management efforts while discussing the international conventions.
- Willen, J. (2008) in her thesis titled 'International trade with waste' highlighted the issue of international trade of waste. In her study she questioned if developed countries are using third world countries as garbage can or can it create a possible win-win situation. She discussed three case studies of China, India and Vietnam. She summed up that importing country of waste can affect positively as well as negatively.
- Ahmed, S.M. (2006) presented his thesis to Linkoping's University of Sweden in which he linked the planning of solid waste management with GIS. This study is done for Aurangabad city in which several issues related with solid waste management were considered like bin allocation, bin relocation, bin unsuitability, bin proximity etc. The study is an attempt to solve some if not all problems related with solid waste management.
- Tchobanoglous, G. and Kreith, F. (2002) have written a book 'Handbook on Solid Waste Management'. The book discusses various options to handle the solid waste. The author believes that the techniques to manage the solid waste must be environment friendly. While dealing with the problem of solid waste the social and economic aspect should also be considered.
- Baguchinsky, J. (1999) introduced us to a unique concept of 'Garbology' which otherwise was first used in University of Arizona, USA. Garbology as the name suggests is the study of garbage but it brilliantly highlights the importance of this neglected field of science that explains how useful our garbage can be if it is managed properly..
- Shah, K.L. (1999) has written a book on the fundamentals of techniques to handle different kinds of waste. It is a simple book that illustrates the ways to

handle the solid and hazardous waste. The book says we must not ignore the basic fundamentals before deciding the technique of waste management. The book also briefly deals with other disciplines like botany, chemistry, geography, geology hydrology etc.

- Qasim, S.R. and Chiang, W. (1994) in their book on the leaching from a landfill site and techniques to control it. The book presented an overview of the role of soil in the sanitary landfill leaching. Moisture routing and leachate generation mechanisms are discussed in detail in chapter 5. Other aspects of leaching like chemical characterization, leachate attenuation processes, leachate collection systems, natural soil sealants etc. are explained in detail. In the end leachate treatment technology is also suggested.

Current Scenario

- Punjab Urban Planning and Development Authority (2006, 2007, 2009, 2010) has published Master Plan Reports on all the major cities of the state. All reports were released at different points of time and planning period extends upto 2031. These reports provide a detailed description on the upcoming projects in the coming years. These reports include detailed report on the solid waste management and also the present sites where upcoming solid waste management projects are likely to be installed. Other parts of these reports cover the infrastructure, housing, landuse, transport, demography, heritage, tourism, developmental controls and zoning regulations.

- Punjab Pollution Control Board (2017) in its Annual Report to the Central Pollution Control Board for the period 01-01-2016 to 31-12-2016 presented a detailed description on the present state of affairs on solid waste management in the state of Punjab. It also brings out those urban bodies which are implementing, partially implementing and not implementing the rules as laid down by the ministry of forests, environment and climate change, government of India.

- Ajith, P.S. (2015) in his research on the efficacy of solid waste handling practices in the urban places of Kerala studied the present situation of solid waste management. He highlighted the local issues faced by the people as well as the administration with regard to the solid waste management. A detailed description is made on the methods and technologies involved in handling solid waste and also offered suggestions for the betterment of solid waste management.

- Central Ground Water Board, (2013) Government of India has published District Brochures for all the districts and states of India including the districts of the Punjab state. These brochures present a detailed report on several aspects like rainfall, climate, geomorphology, soils and groundwater scenario. Water level behavior is also depicted in the pre and post monsoon water level maps. Present status of groundwater development is also given besides groundwater management strategy.
- Statista (2018) is a statistics portal that provides statistics from more than 18000 sources. It depicts statistics on solid waste generation, the revenue generated from the treatment of solid waste treatment, forecast in revenue generation and several other kinds of statistics on different parts of the world.
- Economic and Statistical Organization, Punjab (2016) released its report 'Punjab at a Glance – 2016' in which it presented a synoptic view of the development and economy of Punjab state. Facts and explanation are helpful for those who are engaged in studies related with development and planning. Spatial comparative analysis is made possible by district wise presentation of data and temporal comparative analysis by presenting data on two points of time with a gap of ten years.
- Economic and Statistical Organization, Punjab (2012) in its report 'Environment Statistics of Punjab – 2011', lists all the aspects of the environment and explain each one of these explicitly. The Central Statistical Organization coordinates with the state to provide information on all the indicators of the environment for Punjab. Since Punjab state is one of the most environmentally affected state, this report provides sufficient material that can help in the sustainable development in the state.

Methodology

- Magesh, N.S. et al. (2012) in their study 'Delineation of groundwater potential zones in Theni District, Tamil Nadu using Remote Sensing, GIS and MIF techniques' delineated various groundwater potential zones for groundwater availability. lithology, slope, land-use, lineament, drainage, soil, and rainfall are factors that are considered for the study. All factors are arranged in layers and different weights are assigned to them. The obtained results divides the area in four categories of groundwater potential: very poor, poor, good and very good zones.
- Nagarajan, M. and Singh, S. (2009) in their study 'Assessment of groundwater potential zones using GIS technique' assessed 360 sq km of area in kattakulathur block in Tamil Nadu. Variety of factors are analyzed viz. geology, geomorphology, soil hydrological group, land use / land cover and drainage. All factors are arranged in layers and assigned weights to apply weighted overlay analysis. The resultant potential zones are categorized in poor, moderate and good zones.
- Karsauliya, S. (2014) did a study on using of remotely sensed data and GIS in Solid Waste Management: A Case Study of Surroundings of River Yamuna, India. She selected a total of 17 sites for solid waste management with the help of Weighted Criteria Analysis. She made use of ERDAS Imaging 10 and SRTM DEM 30mx30m. The study covers a large area along river Yamuna and is not specific to any city.
- Gomarasca, M. A. (2009) has written a book 'Basics of Geomatics'. The book attempts to link geography with other disciplines among which the discipline of computer science is the most important one. Such a branch of geography is often called geo-spatial information. It introduces several new techniques to study the surface of earth like laser scanning, global satellite positioning system, remote sensing, digital cartography etc.
- Keith, R.M. (2006) wrote a book 'Resource Management Information Systems'. The book basically deals with the physical resources of an area. By

using the remotely sensed data and GIS techniques, it helps to identify the appropriate information system. The book very brilliantly recognizes the needs of user and make things easier.

- Vyas, P.R. (2014) in his book gives a detailed description on using remotely sensed data and Geographic Information System (GIS). This book gives a basic understanding and the usage of these new technologies. It introduces to the latest techniques, applications and the upcoming technologies associated with remotely sensed data and GIS tools. Its first part covers basic concepts, the second part is on applications and third part is associated with the environment and regional planning.

- Ramachandran, J. et al. (2015) made a study to identify a site that can be used to handle the solid waste. The study is based on remotely sensed data and GIS for the city of Coimbatore. It is a multi-criteria study with geospatial analysis to locate sites. They used Weighted Overlay Analysis on a variety of factors. The entire study area is categorized in suitability zones. Present sites are compared with the results and found that present sites are located in moderately suitable zone and not highly suitable zone.

- Faiz, S. (2012) adopts a unique approach to study geography in his book 'Geographical Information Systems and Spatial Optimization'. The book studies the several concepts of Geographic Information System and optimization. Its focus is on the integration of spatial strategies so that the same can be applied to more practical applications. While dealing with the integration it quantifies the results so that the presentation in the form of diagrams and mapping becomes easier.

- Olusina, J. O., Shyllon D. O. (2014) analyzed the suitability in order to find a proper site for the city of Lagos in Nigeria which can be used for landfilling. The study makes use of remotely sensed data and several GIS techniques including multi criteria evaluation. A total of fourteen variables were analyzed and each variable was weighted by using Multi-Criteria Evaluation. 2.6% of the study area was found as most appropriate for landfilling.

- Shakeel, K.M. et al. (2015) analyzed the suitability of a site that can be used for solid waste management in Khulna city of Bangladesh. The study uses Multi Criteria Analysis. The weighted overlay analysis of ArcMap categorized the area in various suitability zones. Three categories of areas were identified as not suitable, moderately suitable and most suitable.
- Yazdani, M. et al. (2015) made a study on Tonekabon city of northern Iran for which a site is identified where solid waste can be managed. The study is based on geographic information system. The study was undertaken to check whether the present landfill site is at suitable location or not. In total 12 criteria were used and their digital maps were made in GIS environment. It was found that the current landfill site is not at appropriate location and there are several other better locations for landfill.
- Ebistu, T.A. and Minale, A.S. (2013) did a study for Bahir Dar Town of Ethiopia where a suitable site can be located for the solid waste management. A variety of GIS techniques and remotely sensed data are used in the analysis. The study mainly uses spot image of 5m resolution, digital elevation model or DEM of 30 m spatial resolution and the topographic maps. Several maps were generated by overlaying and analysis of appropriateness using GIS tools and remotely sensed data.
- Chang, C. (2003) has authored a technical book on Remote Sensing: 'Hyperspectral Imaging: Techniques for Spectral Detection and Classification'. The book is basically based on the research in Remote Sensing Signal and Image Processing Laboratory at University of Maryland, USA. This book introduces to the useful and upcoming techniques of hyperspectral imaging.
- Collins, M.G. et al. (2001) made a study on 'Landuse Suitability Analysis in United States'. It is highlighted that several techniques of spatial analysis are used in landuse plans and site identification. They traced the historical developments since the beginning of 20^{th} century and in the end concluded with the latest advancements such as neural computing and evolutionary

programming. It is a good work for exploring the new advancements in spatial analysis.

Urbanization

- Kalota, D. (2015) in her research paper studies the sprawling of Ludhiana city by using landscape metrics. The study is based on the satellite imageries and toposheets. Annual growth rate and landscape metrics are measured on the basis of extracted built up area. Study is conducted using satellite imageries and toposheets from 1955-2009. Impact of urban sprawl on the environment is also assessed with the help of landscape metrics.

- Singh Paramjit, Singh Balwinder (2015) did a study on the structure and pattern of urbanisation in Punjab. It is a macro level analysis which reveals that majority of growing urban population is absorbed by big urban centres and cause multiple problems including lack of basic amenities, infrastructural deficiencies, slum growth, urban poverty etc. Although there is not much change in urban density but the urban area has almost tripled during 1971-2001.

- Singh, R. and Kalota, D. (2019) in their study on Ludhiana city "Urban Sprawl and its impact on Generation of Urban Heat Island" described the impact of rapid urbanization on the landuse patterns which in turn lead to the environmental problems. Further it adversely affect the quality of life. Satellite imageries and topographical sheets are used in the analysis using GIS techniques. It is found that unplanned and haphazard growth led to aggressive expansion of the built up areas in Ludhiana city.

- High Powered Expert Committee (2011) published its report on Indian Urban Infrastructure and Services. This committee (HPEC) is set up by Ministry of Urban Development, Government of India. The report attempts to calculate the investment required for urban infrastructure services including solid waste management. It is found that the share of street lights and solid waste are minimum (0.6% and 1.6%) against the 55.8% of urban roads.

- New Climate Economy (2016) released its synthesis paper titled 'Better Cities, Better Growth: India's Urban Opportunity' (2016) highlights the case studies of four cities of India: Surat, Pune, Indore and Bangalore. The paper depicts the worsening status of current model of Urbanization where households are compelled to avail costly basic urban services which are to be provided by the state. Examples from Surat and Pune depict solid waste as a resource.
- Mahey, K. and Tripathi, S. (2016) empirically analyzed the economic and urban growth in Punjab state. The research portrayed the patterns and trends of urbanization in the state of Punjab in the recent past. It is found that urban places are growing speedily because growth of urban people is higher than the growth of total population. Urban population is absorbed more in the bigger cities. Urban growth is also linked with the roads, educational institutions, electricity connections. The paper also attempts to connect urbanization with economic growth.
- Minakshi, et al. (2017) in their paper on the city of Amritsar of Punjab, geospatially analyzed the patterns of urban sprawl. They analyzed satellite imageries from 1972-2015 in order to quantify the spatial patterns of urban sprawl for Amritsar. The trends are studied by using Shannon's entropy by modeling the values for different grids and also by interpolation function in GIS environment to get entropy surface for every image. Values of entropy index reveal dispersed urban growth which is indicative of urban sprawl.

1.6 Research Gaps

After having perusal of the above cited literature it appears that only limited studies have been undertaken on the topic of site identification for solid waste management. Even these limited studies focus on a single city only and there is dearth of exhaustive studies that involve several cities of a state considering wide range of variables. Further, even among these limited studies the variables of soil drainage and groundwater are not considered by all. It is also observed that among these limited studies no study relates to the state of Punjab and majority of these relate to the cities of southern India like Kakinada (Dharanikota, 2013), Hosur (Sunder Rajan et al., 2014), Kottayam (Nishanth et al., 2010), Chengalpattu (Rinsitha et al., 2014), Pune (Jaybhaye et al., 2014) etc. Studies that relate to the state of Punjab describe only the current status and do not focus on the site identification for solid waste management (Punjab Pollution control Board, 2017).

The present study considers a wide range of variables numbering nine that are capable of affecting the site identification for solid waste management for all the ten municipal corporations in the state of Punjab. The process of identification of site for solid waste management is a technical and sensitive issue therefore every selected site must satisfy all the factors. Any laxity in this process can put the environment at risk. The present study analyzes each factor explicitly for its role in the site identification process. Any suitable site that is identified for the solid waste management is not the result of any single factor but a combination of several factors put together (Nishanth et al., 2010). Factors that are being considered in the present study are landuse landcover, soil drainage, groundwater level, distance from city, distance from canals, distance from drains, distance from settlements, slope and distance from roads. Further, these factors do not affect site identification equally but differently. Some factors are more important than others. Factor that affects the most is given maximum importance and vice versa. To do this, effect of all the factors are quantified. All factors have their subclasses and those subclasses are also weighed differently because effect of all the subclasses also varies and that too is quantified. Since it becomes a very complex setting, some technical and precise tool is required to handle it. Remote Sensing and GIS (Geographic Information System) look very attractive widgets to calculate this complexity and generate a simple, precise and meaningful result in the form of suitable areas for solid waste management. All the factors therefore are analyzed in the form of spatial data in ArcGIS software which offer plentiful tools for the analysis.

1.7 Objectives

Any study needs to have clear and specific objectives in order to reach the desired goal. Clearly stated objectives help in focusing and avoid cluttering. Present study has the following three objectives.

1. To critically examine the existing processes of solid waste management.
2. To prepare a model for site identification that can be implemented in other locations as well.
3. To identify suitable sites for solid waste management.

First objective is achieved by describing the current scenarios of all the municipal corporations. The second objective is achieved by preparing a model based on nine factors that are being considered for site identification. A concise and targeted methodology using remote sensing and GIS techniques can accomplish this task decisively. For the third objective, sites are marked as polygons for all the municipal corporations of Punjab to manage the solid waste.

1.8 Scope of Study

The present study focuses on the site identification for municipal solid waste management in all the municipal corporations of Punjab. In this study only the municipal solid waste is being considered and its definition as provided by the 'Ministry of environment, forest and climate change', Government of India has been mentioned earlier in this chapter (para 1.1). Other solid wastes like industrial waste, biomedical waste, dead animals material and human fecal matter are beyond the purview of this study.

The ten municipal corporations of Punjab that are being considered for site identification are Amritsar, Pathankot, Hoshiarpur, Jalandhar, Phagwara, Ludhiana, Moga, Bathinda, Patiala and Mohali. Three sites for each municipal corporation are identified thus making a total of 30 sites for ten municipal corporations.

1.9 Significance of Study

The present study locates suitable sites by identifying and weighing variety of factors. These sites for solid waste management protect the environment and offer a clean and healthy surroundings to the people. Such identification of sites minimizes or does not pollute the soil, groundwater, canals, drains or rivers. Siting is done in such a manner that residential areas get a healthy and clean environment for the inhabitants.

Sites are identified in such a manner that it is easy to transport the solid waste on daily basis from city to the site for quick and efficient disposal. Sites are located in those areas where surface runoff as well as stagnant water cannot affect the site easily.

1.10 Organization of Thesis

The present research work is organized in the form of chapters. It begins with the chapter of Introduction that deals with the statement of problem, review of literature, objectives and significance of study. In the second chapter of study area and current scenario, all the municipal corporations are listed, their study areas are defined, and current scenario of each municipal corporation is explained. In third chapter of methodology the collection, generation and processing of spatial data is discussed. Fourth chapter deals with the model for site identification in which all the components of model are explained including description of weighted overlay analysis. The fifth chapter deals with the site identification for five municipal corporations of Majha and Doaba areas. The last chapter is like continuation of chapter five in which sites are identified for the remaining five municipal corporations of Punjab that lie in the Malwa region. Finally, the total research work is summed up in summary and conclusions.

1.11 Conclusion

Solid waste management is a noteworthy issue for the planners specially in the modern environment conscious society. Identifying a suitable site for solid waste management is even more high-priority issue that must be addressed. There are a variety of factors that can contribute towards site selection for solid waste management. Each factor must be analyzed in proportion to its importance and the same for the subclasses of all the factors. Remotely sensed data and GIS (geographic information system) offer a wide range of tools that can help in analyzing the varying role of all the factors and their subclasses. This is high time that sites for solid waste management are identified for all the ten municipal corporations in Punjab where the current scenario is compelling.

Chapter – 2

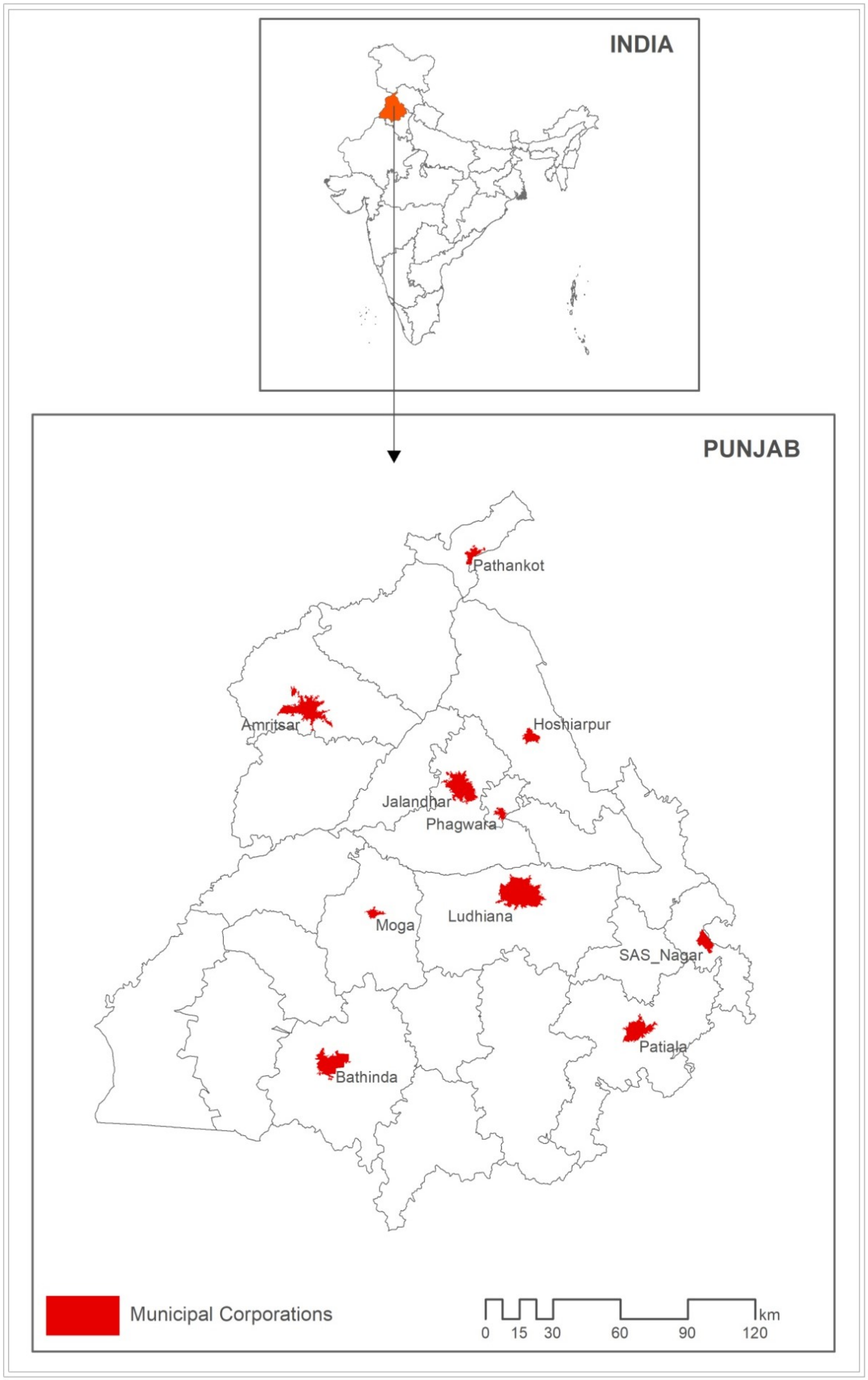
STUDY AREA AND CURRENT SCENARIO

Any geographic study belongs to some part on the surface of earth which becomes its study area. In other words the Study Area is marked by spatially defining the geographic boundaries. The present study pertains to site identification for solid waste management of municipal corporations of Punjab. So here the study area relates to the municipal corporations of Punjab state. In this chapter the boundaries of the study area are marked and justified. Current scenario of solid waste management in each municipal corporation is elaborated. Site that is currently serving for solid waste management is also discussed for each municipal corporation.

2.1 Punjab – the state of study area

The state of Punjab lies in the northern part of India. This state is predominantly a plain area except northeastern border where Shiwalik hills can be seen. Three major rivers drain the state of Punjab viz. Sutlej, Ravi and Beas. Originally the literal meaning of Punjab is land of five rivers namely Sutlej, Beas, Ravi, Jhelum and Chenab. As a result of partition in 1947 and subsequent division in 1966 as a result of states reorganization, today's Punjab became much smaller in size covering an area of 50,362 sq km which is 1.53% of country's total geographical area (http://punjab.gov.in/state-profile). Union territory of Chandigarh is the capital of Punjab. Around 28 million people inhabit this state which makes around 2.2 % of country's total population. 37.48% of state's population live in urban areas and remaining 62.52% in the rural areas (Census of India, 2011). There are 167 urban local bodies of which 56 are Nagar Panchayats, 25 Class-III towns, 47 Class-II towns 28 Class-I towns and 10 Municipal Corporations (Department of Local Government, Punjab, 2016). Present study focuses these 10 municipal corporations viz. Amritsar, Pathankot, Jalandhar, Phagwara, Hoshiarpur, Ludhiana, Moga, Bathinda, Patiala and SAS Nagar or Mohali for identification of suitable sites to manage the solid waste. All the ten municipal corporations of Punjab can be seen in fig. 2.1 . It is observed that

Figure 2.1: Location of Municipal Corporations of Punjab



municipal corporations are more concentrated in the central parts of the state. The boundaries are marked by the built up areas of the municipal corporations.

2.2 Defining the Study Area

All the ten municipal corporations support large populations and the purpose of this study is to locate a suitable site for solid waste management of these cities. To define the study area a buffer of 10 km is made around all the municipal corporations. This buffer area starts from the outer limit of the city and extends upto 10 km in all directions. Purpose of making this buffer area is to avoid locating the site inside the city. Considering the urban growth, it is desirable to locate the site at a sufficient distance from city. Moreover, locating site for solid waste management close to any human settlement will not satisfy the rules of solid waste management as defined by the 'Ministry of environment, forests and climate change', Government of India. The residents also object to locating such sites in their neighbourhood. The attitude of 'Not in my Backyard' (NIMBY) has been recognized by the government also (Ministry of Urban Development, 2016).

Table 2.1
Area covered by study area of each municipal corporation in sq km

S. no.	Municipal Corporation	Study Area in sq km
1.	Amritsar	960
2.	Pathankot	380
3.	Jalandhar	641
4.	Phagwara	217
5.	Hoshiarpur	576
6.	Ludhiana	865
7.	Moga	558
8.	Bathinda	955
9.	Patiala	755
10.	SAS Nagar (Mohali)	417
	Total	6324

Considering the adverse impact on the environment and the health of people it is advisable to mark a buffer around the city to identify site for solid waste management (Nishanth et al., 2010). Distance of 10 km is suggested so that the site is located within 10 km area from the city's outer limit. This distance is neither too short for urban growth nor too long for vehicles to carry solid waste to disposal site everyday. When site is located in 10 km buffer from the outer limit of city, it is farther by a few more km from the centre of the city. So distance longer than this becomes too long for the vehicles that make several trips everyday to transport the solid waste from collection points to the disposal site.

2.3 Distribution of Study Areas in Punjab

There are three broad divisions of Punjab : Majha, Doaba and Malwa. These divisions are made on the basis of three major rivers of the state viz. Sutlej, Ravi and Beas. Area between Ravi and Beas is Majha area; area between Beas and Sutlej is Doaba area and area south of Sutlej river is the Malwa area. Of the ten municipal corporations Amritsar and Pathankot fall in Majha area; Jalandhar, Phagwara and Hoshiarpur fall in Doaba area and Ludhiana, Moga, Bathinda, Patiala and SAS Nagar fall in Malwa area. Study Area of each municipal corporation is explained below.

2.3.1 Current Scenario and Defining Study Area of Municipal Corporations of Majha Area

a. Amritsar

The Amritsar municipal corporation lies in the northern part of the state and southern part of Amritsar district. This study area is close to the international border with Pakistan in the west. Predominantly it is a flat area and is situated between river Ravi in the west and Beas in the east. As per Census 2011 Amritsar city and its outgrowths have population of 11.83 lakh with decadal growth rate of 15.47%.

The daily solid waste generation of Amritsar municipal corporation is around 600 tons which is being disposed of in a landfill site situated in Bhagtanwala area. This site of 8.1 acre in area lies within the city and has been in use since 25 years and likely to used for 15 more years. It is also proposed that this site is going to be upgraded to handle solid waste of adjoining seven more urban local bodies. Local residents are strongly opposing it and the issue was even raised in the parliament (Hindustan Times, Feb 02, 2015). Two more sites are under development at village Fatehpur and village Bhrariwal. The

Fatehpur site is 6 km from city with an area of 5.8 hectare and Bharariwal site is 5 km from the city with an area of 2.65 hectare. A total of 2406 workers are involved in the handling of solid waste besides 10 trucks and 76 tractor trolleys and 7 front end loaders to load solid waste into trucks and trolleys (Punjab Urban Planning and Development Authority, 2010a).

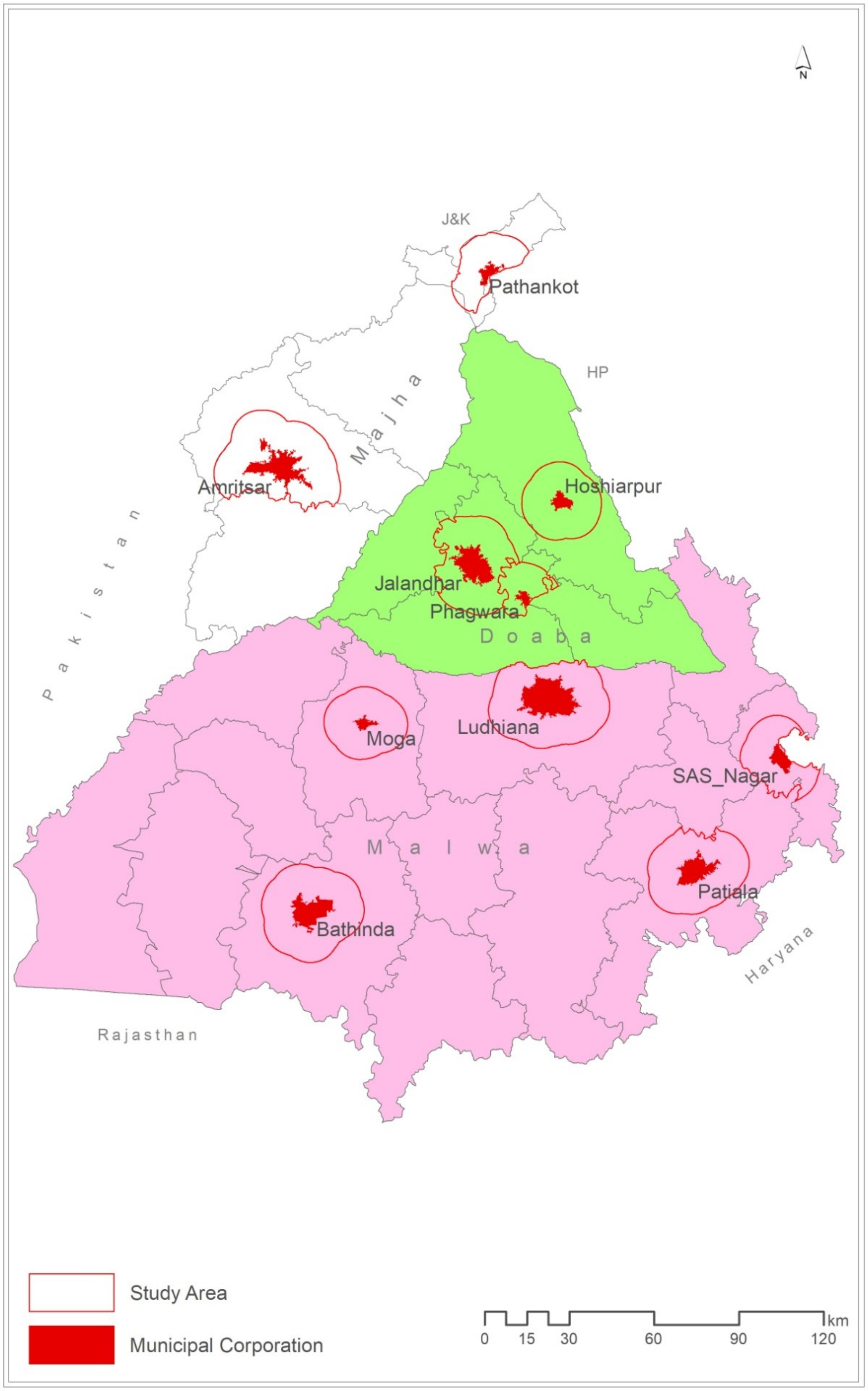
To define the study area for Amritsar municipal corporation a buffer of 10 km is made around the city. This study area intersects with the district boundary of Amritsar. The area of adjoining Tarn Taran district is therefore clipped and not included in the study area for Amritsar Municipal Corporation. This study area spreads over an area of 960 sq km where suitable sites are to be located for solid waste management. It is the largest study area of all the municipal corporations in the present study.

b. Pathankot

Pathankot is the northernmost municipal corporation of the Punjab state in Pathankot district which has been recently formed on 27 July, 2011 (Pathankot District, 2011). The study area of Pathankot municipal corporation is bounded by J&K state in the west and Himachal Pradesh state in the east. The northeastern part of this study area is covered with Siwalik hills but remaining area is flat sloping southwards. Numerous drains flow in this study area. As per Census 2011, the total population of Pathankot urban agglomeration is 1,60,509 with decadal growth rate of -0.48%.

Daily generation of solid waste in Pathankot is around 50 tons. A total of 245 employees are engaged in solid waste disposal with 10 vehicles. The solid waste is being disposed of at Rara village to the northwest of city (Punjab Urban Planning and Development Authority, 2010c). This site lies on the periphery of the city on the banks of Khadi Nalla. The solid waste is dumped without any segregation in a stretch of 700-800 meters. No scientific technique is used in disposing of the solid waste.

Figure 2.2: Location of Municipal Corporations in Regions of Punjab



When a buffer of 10 km is drawn around the city of Pathankot to define its study area, some part of it falls in J&K state and very large part falls in Himachal Pradesh. Remaining clipped part that remains in the district as study area is of 380 sq km where suitable sites can be identified for solid waste management.

2.3.2 Current Scenario and Defining Study Area of Municipal Corporations of Doaba Area

a. Jalandhar

Jalandhar municipal corporation lies almost in the middle of Jalandhar district. The study area of this municipal corporation is characterized by absolute flatness. As per Census 2011 the total population of Jalandhar urban agglomeration was 8,74,412 with decadal growth rate of 18.3%.

Everyday around 350 tons of solid waste is generated in the city. Per capita generation of solid waste in Jalandhar MC is 500 gm as against 300-450 gm in other cities of the country and it can be attributed to living style of the people and the economic character of the city. The solid waste is dumped in an unscientific way at a site situated at Wariana which is just 14 acres in area. At Wariana site a small treatment plant is installed but it is hardly functional. The toxic industrial waste is dumped in the open which is capable of polluting soil and even groundwater through leaching. A total of 3662 personnel with 74 vehicles are engaged in solid waste disposal (Punjab Urban Planning and Development Authority, 2009b).

Since Jalandhar district is situated in the middle of Punjab state, it is bounded by several districts around it. When a buffer of 10 km is made around the city of Jalandhar to define its study area, it covers some parts of Kapurthala district on both sides i.e. east as well as west side. When the study area is clipped with the district boundary, around 641 sq km remains in Jalandhar district for the identification of sites to manage solid waste. Hence this 641 sq km of area becomes the study area of Jalandhar municipal corporation.

b. Phagwara

The municipal corporation of Phagwara lies in the Kapurthala district. It is a small city both in terms of population as well as area. As per Census 2011, the total population of Phagwara urban agglomeration was 1,17,966 growing at a decadal growth rate of 13.3%.

A total of 300 workers are associated with the solid waste disposal alongwith several vehicles. The project of solid waste management was started with great zeal and enthusiasm but it ended up with only mechanical collection of solid waste and that too without segregation. After collection the solid waste is being dumped at Hargobindpur site near Bhogpur and Khurampure villages on Phagwara Hoshiarpur road. Modern machinery is being used in leveling the solid waste at the dumping site (Municipal Corporation Phagwara).

The Kapurthala district is not geographically contiguous. The larger part with Kapurthala city lies to west of Jalandhar district and the other smaller part with Phagwara city lies to the east of Jalandhar district. It is the smallest study area of all the municipal corporations. When a buffer of 10 km is drawn to define the study area, very large part of it falls in the adjoining districts of Jalandhar, Nawanshahr and Hoshiarpur districts. Only 217 sq km remains in the Kapurthala district for site identification for solid waste management.

c. Hoshiarpur

Hoshiarpur municipal corporation lies almost in the middle of Hoshiarpur district which is bounded by Shiwalik hills in the east. Some part of its study area is covered with the Shiwalik hills in the northeast. Remaining part is almost flat sloping towards west. As per the census 2011 the total population of Hoshiarpur city was 1,68,653 growing at decadal rate of 11.25%. Everyday around 70 tons of solid waste is generated which is handled by 384 workers with the help of several vehicles. A site has been selected and being used for dumping of solid waste at Piplanwala but still a large amount of solid waste is dumped in a drain called Bhangi Choe besides several other locations. Therefore heaps of waste are often seen in many parts of the city where waste keeps on decaying and emitting foul smell. During rainy season the situation worsens (Punjab Urban Planning and Development Authority, 2010b); see also Kaur, H., 2016).

The district of Hoshiarpur is situated in the northeastern part of Punjab and also shares its boundary with the state of Himachal Pradesh. When a buffer of 10 km is made around the city of Hoshiarpur to define its study area, only a fractional part (0.97 sq km) of it falls in adjoining Jalandhar district but most part of it remains in the Hoshiarpur district. Its study area covers an area of 576 sq km where suitable sites are to be identified for solid waste management.

2.3.3 Current Scenario and Defining Study Area of Municipal Corporations of Malwa Area

a. Ludhiana

The municipal corporation of Ludhiana lies in the district of Ludhiana. The district of Ludhiana is situated almost in the middle of Punjab state. River Sutlej flows along its northern boundary with Jalandhar district. It is the largest municipal corporation of Punjab in terms of population. Relief of this study area is characterized by flatness. As per figures of Census 2011 the total population of Ludhiana city was 16,18,879 growing at a decadal rate of 13.6%.

Per capita waste generation is around 535 gm and everyday around 850 tons of solid waste is generated in the city. High per capita generation of solid waste indicates the living style of people and the economic character of the city. Ludhiana municipal corporation has engaged 3664 workers and deployed 68 vehicles to carry solid waste daily to the disposal sites. At present Ludhiana municipal corporation has three sites to manage its solid waste. First site of 10 acres lies at Jainpur but this site has been totally filled up and has been officially closed however still some solid waste is being dumped here. The other two sites are situated at Jamalpur in 25 acres and Noorpur Bet in 21 acres. Jamalpur site is being used for dumping of solid waste in an unscientific way and is likely to cater for next 25 years. Land at Noorpur Bet is purchased by the corporation exclusively to install a solid waste treatment plant. (Punjab Urban Planning and Development Authority, 2007).

Its study area is third largest after Amritsar and Bathinda covering 865 sq km. When buffer of 10 km is drawn around the city of Ludhiana city to define its study area, some of its northern part falls in adjoining Jalandhar district. After clipping the remaining portion of 865 sq km is thus available to identify suitable sites for solid waste management.

b. Moga

Moga municipal corporation lies in Moga district which is situated west of Ludhiana district. The relief of this study area is characterized by absolute flatness. As per figures of Census 2011 the total population of Moga metropolitan area was 1,63,397. The decadal (2001-2011) growth rate of Moga city was 17.2%.

Everyday around 60 tons of solid waste is generated in the city of Moga. The task of handling solid waste of Moga municipal corporation is assigned to a company ‘Jindal Urban Waste Management Limited’ which started its work in 2013 by hiring 181 employees. The company discontinued the task within two years as a result of legal proceedings and has sought damages of Rs 480 crore from the municipal corporation of Moga. The legal proceedings of Moga MC are also linked with the solid waste management of Jalandhar municipal corporation because that is also assigned to the same company. In such a scenario the condition of solid waste management is pathetic in Moga (Narula, 2014).

It is a small city and when a buffer of 10 km is drawn around it to define the study area, the entire polygon of study area remains within Moga district. No part of it falls in adjoining districts. Its study area covers an area of 558 sq km where suitable sites for solid waste management can be identified.

c. Bathinda

Municipal corporation of Bathinda lies in Bathinda district. This district is situated in the southwestern Punjab and shares its southern boundary with the state of Haryana. Relief of its study area is absolutely flat. As per Census 2011 figures the total population of Bathinda city was 2,85,788 growing at a decadal rate of 23.9%.

In Bathinda municipal corporation the per capita generation of solid waste is to the tune of 350 gm per day and everyday a total of 102 tons of solid waste is generated. This waste is being disposed of in the form of landfill at a site measuring 36 acres situated behind Roshan Lal Oil Mill on Mansa road. Present site is likely to serve for another 10 years. The present site is not lined and solid waste is disposed of in an unscientific way. The solid waste is being dumped without any segregation resulting in to the loss of valuable waste that can be recycled. The site emits foul smell due to decomposing of organic waste. There is no compaction of solid waste at the site (Punjab Urban Planning and Development Authority, 2009a).

When a buffer of 10 km is made around the city of Bathinda city to define its study area, almost entire study area falls within Bathinda district. Only a fractional part of just 0.2 sq km falls in the adjoining Faridkot district which is clipped with district boundary. Among all municipal corporations it is the second largest study area after Amritsar. It covers an area of 955 sq km where suitable sites are to be identified for solid waste management.

d. Patiala

Patiala municipal corporation lies in Patiala district in southeastern Punjab. Its study area lies very close to the state of Haryana in south. Relief of this study area is characterized by absolute flatness. As per figures of Census

2011 the total population of Patiala metropolitan area was 4,46,246 with decadal growth rate of 27.4%.

Everyday around 177 tons of solid waste is generated in the city which is disposed of at a site situated at Sanauri Adda. This site is not lined and waste is disposed of by landfilling technique only. The waste is not segregated by the municipal authorities however rag pickers pick the valuable waste and sell for recycling. In the absence of road rollers the solid waste is not even compacted. Present site is close to a residential colony and emits foul smell due to presence of organic waste (Punjab Urban Planning and Development Authority, 2009c).

When a buffer of 10 km is made around the Patiala city to define its study area, a small part of it falls in the adjoining northern district of Fatehgarh Sahib where it is clipped with district boundary. However maximum part of it remains in Patiala district covering an area of 755 sq km where suitable sites can be identified for solid waste management.

e. SAS Nagar

The municipal corporation of Sahibzada Ajit Singh Nagar or SAS Nagar falls in SAS Nagar district in the eastern Punjab. SAS Nagar is also known as Mohali. This district shares its eastern boundary with the state of Haryana, Himachal Pradesh and union territory of Chandigarh. Shiwalik hills just touch this study area in the north east but does not cover much area. Most part of this study area is plain. As per Census 2011 the total population of Mohali metropolitan area was 1,76,170 growing at a decadal growth rate of 25.9%.

Everyday around 200 tons of solid waste is generated in the city that is dumped in an unscientific way at a site in Industrial Area in Phase VIII B. This site is situated in an area of 8 acres along a drain called Patiali ki Rao (Chauhan, 2018, see also TNN or Times News Network, 2018).

When a buffer of 10 km is made around the city of Mohali or SAS Nagar to define its study area, some of its western part falls in the adjoining districts of Fatehgarh Sahib and Patiala and some of its eastern part falls in union territory of Chandigarh and Haryana state. However maximum part covering 417 sq km remains in SAS Nagar district where suitable sites can be identified for solid waste management.

2.4 Conclusion

There are 167 urban local bodies in Punjab of which 10 are municipal corporations. All these ten municipal corporations are big cities of Punjab that generate a large volume of solid waste everyday. Almost all of these cities are confronting with the problem of site identification for solid waste management. At most locations the site for solid waste management is situated close to the residential areas. Local residents of such areas oppose the solid waste disposal in their neighborhood. Identification of sites for solid waste management for all the municipal corporations in Punjab state can help in solving the issue of locating suitable sites. Making a buffer of 10 km around the city to define the study area for each municipal corporation is a reasonable distance from the outer limit of city because everyday vehicles have to make several trips to carry solid waste from collection points to the disposal site. Also the sites are kept at reasonable distance from the city so that all sites remains at sufficient distance from the residential areas.

Chapter – 3

METHODOLOGY

Designing and executing the methodology meticulously is very important in order to ensure that the right type of variables and sufficient information is selected to obtain best results. It requires a lot of mind mapping as only those variables and methods are to be selected that are not only feasible to be applied but are also capable of providing the desired solutions.

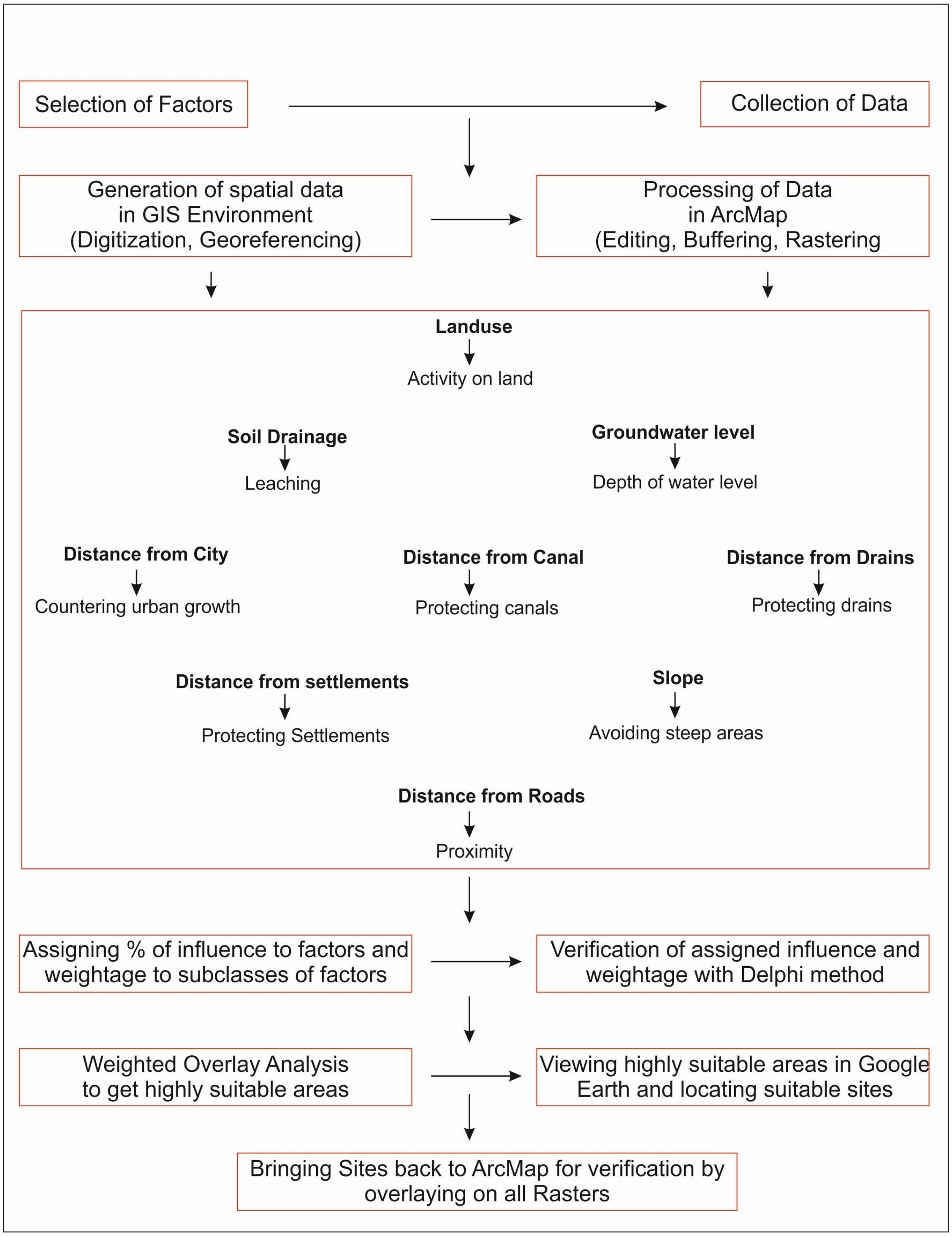
3.1 Selection of Factors

Selection of suitable factors is the most important step before site identification. As a matter of fact, all factors are the components of local environment. To identify such factors is crucial to accomplish this task. Several studies have been consulted to identify the most influencing factors in selection of solid waste management site. A detailed review of studies done on the similar theme was undertaken and suitable factors were selected keeping in mind the characteristics of the study area. The detailed examination of all the studies (Sharma et al., 2015; Sunder et al., 2014; Jaybhaye et al., 2014; Nishanth et al., 2010; Rinsitha et al., 2013; Pradhan and Samanta, 2015; Choudhury and Das, 2012; Dharanikota, 2013) has facilitated the researcher in finalizing the influencing variables that has been discussed in literature review in Chapter 1. In total nine factors or variables are selected for the present study i.e. Landuse landcover, Soil Drainage, Groundwater level, Distance from city, Distance from canals, Distance from drains, Distance from settlements/villages, Slope and Distance from roads.

3.2 Collection and Processing of Spatial Data

The spatial datasets to be used in the present study are the nine variables discussed above in para 3.1. All the selected variables are classified into various subclasses with different levels of significance in selection of waste management site. The difference in significance level of each variable and its subclasses is taken into

Figure 3.1: Flow Chart of Methodology



consideration in the following study for the selection of suitable site. The variables with their subclasses and the procedure followed to convert them into spatial datasets for the site selection is explained below.

a. Landuse Landcover

The term landuse and landcover are often used interchangeably. Landuse refers to the utilization of the land i.e. cultivation, mining, settlement etc. whereas landcover means the surface cover of the land e.g. vegetation, water bodies, soil, settlement etc. (Saymote P.A., 2015). In the present case four prominent features are visible on the satellite imageries of study areas i.e. cultivated land, settlements, industry and forest/plantation. Some other features of landuse landcover category like roads, rivers, canals and drains are being considered as separate variables due to different levels of significance towards site identification process.

All these subclasses of landuse landcover have variable level of significance towards site identification process for solid waste management. For instance, settlements are not preferred areas for site selection as per the government rules. Such site has to be at least 500 meters away from any settlement (Ministry of Urban Development, 2016). The local residents may also object against such site as it has happened in case of Bhagtanwala, Amritsar site in Punjab. It is pertinent to mention here that there is no waste land in the study areas. In the absence of waste land, the vacant cultivated area or fallow land is likely to get attention. The remaining subclasses i.e. industry and plantation are less significant than the cultivated areas and more significant than the settlements. All these subclasses of landuse landcover are delineated and digitized in Google Earth for all the ten municipal corporations of Punjab. Google Earth is a computer program based on satellite imagery. The subclasses are saved as Keyhole Markup Language (KML) files and later brought in ArcGIS as shape files for further analysis. ArcGIS is a Geographic Information System or GIS developed by ESRI or Environmental Systems Research Institute.

b. Soil Drainage

Soil drainage means the movement of water in soil and more specifically in empty pore spaces between the soil particles (Randall et al., 2009). Drainage capacity is different in different types of soil. The data on soil drainage has been procured from the soil map of Punjab which has been prepared and revised jointly by National Bureau of Soil Survey, Landuse Planning and Punjab Remote Sensing Centre, Ludhiana (1:2,000,000). Seven subclasses of soil drainage can be seen in this soil map of Punjab (Table 3.1). This map is geo-referenced and digitized in ArcGIS. Out of seven categories of soil drainage of Punjab only four categories i.e. D4, D5, D6 and D7 are found in the study areas of the present study. All these categories or subclasses of soil drainage have their different bearing on site identification process hence their role need to be recognized. Among D4, D5, D6 and D7 subclasses the D6 and D7 are not suitable because of excessive drainage while D4 and D5 are going to be favorable for solid waste management site. Heavy leaching in excessively drained categories like D6 and D7, besides polluting soil, is likely to pollute the groundwater (Olusina and Shyllon, 2014).

Table 3.1
Soil Drainage Categories in Punjab, (Punjab Remote Sensing Centre, 2003)

S. no.	Soil Drainage Code	Soil Drainage Category
1	D1	Very Poorly Drained
2	D2	Poorly Drained
3	D3	Imperfectly Drained
4	D4	Moderately Well Drained
5	D5	Well Drained
6	D6	Somewhat Excessively Drained
7	D7	Excessively Drained

c. Groundwater Level

Water that is found in the aquifers below the surface of earth is called groundwater. It is found almost everywhere. The level of groundwater changes both temporally as well as spatially (Groundwater Information Booklet, Amritsar Dist, 2013a). For present study it is important to include the variable of groundwater because of its vulnerability of getting polluted from the leachate of solid waste management site (Ministry of Urban Development, 2016). Deeper the level of groundwater, fewer are chances of its getting polluted and vice versa. The data on groundwater level is obtained from the district maps of groundwater prepared by the Central Groundwater Board on the scale of 1:200,000. Four zones have been recognized in the study areas under the purview of present study. These are 0-5 mbgl (meters below ground level), 5-10 mbgl, 10-20 mbgl and more than 20 mbgl. Site for solid waste management will not be preferred in 0-5 mbgl because of greater chances of its getting polluted from the leachate of solid waste. Therefore, as the depth of groundwater increases the preference for the site also increases. The groundwater maps obtained in image format are geo-referenced and digitized in ArcGIS.

d. Distance from City

This variable is directly related with the urban expansion of the concerned city. Ten cities that fall under the purview of this study are growing every year (Census 2011). However, the rate of growth may vary form one city to another. The purpose of including this variable is that the site should remain at an appropriate distance from the city in the next 20-25 years or till the life of solid waste management site (The Gazette of India, 2016). Purpose is that residential areas do not get polluted from the solid waste management site. The boundary of city is digitized in Google Earth and then brought in GIS environment for analysis. Then five buffer zones of 2 km each are made around each city i.e. 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km, using multiple buffer tool in ArcGIS. It is desirable that the site does not get located in 0-2 km zone because here the site can become part of the city in the next few years as a result of urban growth. Therefore, as the distance from city increases, suitability for site identification also increases. Maximum distance of 10 km is taken because beyond that it becomes too far as each vehicle has to make several trips each day to transport solid waste from city to the site.

e. Distance from Canals

Canal is a man made channel of water in which fresh water of rivers flow and is used for irrigation. Purpose of including this variable is that these fresh water channels of water do not get polluted from the proposed sites (Pradhan & Samanta 2015). There are numerous canals in the Punjab state and many of these flow through the study areas. If site is located closer to the canal, the surface runoff can pollute the fresh water of canal (Ministry of Urban Development, 2016). All canals flowing through the study areas, have been digitized in Google Earth and then brought in GIS environment as shape files for analysis. Five buffer zones of 250 m each are made using multiple buffer tool in ArcGIS, on both sides of canals i.e. 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. Efforts are made that site does not get located in the first zone of 0-250 m buffer zone and as the distance from canals increases the suitability for site also increases.

f. Distance from Drains

Most drains of Punjab are natural channels that originate in the Shiwalik hills. These natural channels are also known as Choes. They carry rain or river water and many of these become perennial only during rainy season. Although most of drains remain dry for most part of the year still it is not advisable to locate the solid waste management site in their vicinity (Groundwater Year Book, Punjab and Chandigarh, 2016). Purpose of including drains as a separate variable from canals is that influence of canals is considered more than the drains (Jaybhaye et al., 2014). All drains have been digitized in Google Earth and then brought in GIS environment as shape files for analysis. Like canals, five buffer zones of 250 m each are made on both sides of drains i.e. 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. Efforts are made that site does not get located in the first zone of 0-250 m because drain water may get polluted by surface runoff from the solid waste management site and as the distance increases from drains, the suitability for site also increases.

g. Distance from Settlement/Village

Although there is hardly any areal expansion of villages, it is important to include this variable because 'Solid Waste Management Rules, 2016' do not permit a location of solid waste management site in the proximity of any human settlement. A zone of 500 m around such site is to be declared as a no development zone (Ministry of Urban Development, 2016). Purpose of this rule is to keep the human settlements away from the effect of pollution emanating from solid waste management site. There are numerous settlements falling in the study areas of present study. All these settlements are digitized in Google Earth and then brought in GIS environment for further analysis. Then, a buffer of 500 m is made around all such settlements / villages for least preference so that the proposed site does not get located in the vicinity of these settlements.

h. Slope

The factor of slope cannot be ignored for location of solid waste management site. In the present study, slope does not hold much importance as most of the study areas are flat with a few exceptions in Hoshiarpur and Pathankot study areas. However, as per the solid waste management rule 20 a (The Gazette of India, 2016) the site for solid waste management may be avoided on hill side and in case of hilly areas such site is to be located in the adjoining plain areas within a radius of 25 km. That is why the factor of slope is being considered for the site identification process. Slope is calculated from the Cartosat-I data obtained from official website of Bhuvan – Indian Geo-Platform of ISRO or Indian Space Research Organization. The datasets are brought into GIS environment and slope categories are made using the spatial analyst tool. Five categories of slope are made : 0-10 degrees, 10-20, 20-30, 30-40 and more than 40 degrees. A large majority of area in most of the study areas, falls under 0-10 degrees and such areas are likely to get attention for location of site for solid waste management and steeper areas are avoided for site identification (Sunder Rajan et al., 2014).

i. Distance from Roads

This is the last factor to be considered for site identification for solid waste management. Since only one or two sites are going to manage the solid waste of entire city therefore, these sites must be in close proximity of roads. Another reason for including roads as a variable is that vehicles have to make several rounds on daily basis to transport solid waste from city to the proposed sites. That means areas closer to the roads are preferred against those areas which are far from the roads. All roads passing through study areas are digitized in Google Earth and then brought in GIS environment for analysis. Five buffer zones are made on both sides of roads : 0-100 m, 100-200 m, 200-300 m, 300-400 m and more than 400 m. Site that falls in 0-100 m buffer are preferred and as distance increases, preference for site decreases. It is worth mentioning here that although proximity to roads is preferred but proximity to National highways is avoided. During manual analysis of suitable areas in Google Earth, the areas along highways are avoided so as to satisfy the government rules (Ministry of Urban Development, 2016).

3.3 Assigning Influence and Weights Using Delphi Method

Present study involves a total of nine variables : Landuse landcover, Soil Drainage, Groundwater level, Distance from city, Distance from canals, Distance from drains, Distance from settlements/villages, Slope and Distance from roads. All these variables and their subclasses have already been discussed earlier in this chapter (section 3.1 and 3.2). All these variables and their subclasses influence the process of site identification, but not uniformly i.e. some variables influence more than the other variables. Same is true for the subclasses of these variables. It becomes therefore, imperative to quantify the influence of all the variables and their subclasses. This stage of quantification is crucial for the model (chapter-4) which requires comprehensive inspection and rational approach to complete the task. To quantify all the variables and their subclasses several studies (section 3.1) were perused to unravel this complicated process. An understanding of the local geography also helps in the process of quantification.

Delphi method is used to assign the percent influence to each variable and weights to the subclasses of each variable. Delphi is originally a process to forecast with the help of a group of experts. It is very common in the prediction of markets but is used in other fields as well. It involves anonymous feedbacks from experts on a questionnaire in two or more rounds. After each round the experts may adjust or change their decision by taking cue from the responses of other experts (Parks, 2018). In the present study the experts are selected from different departments whose views are sought on the site identification process. All the experts are provided with a questionnaire to assign the influence in percentage to each variable and also assign the weights on the scale of 1-5 to the subclasses of variables. A total of seven experts are selected for this purpose. Highest percentage of influence is assigned to the most dominant variable and as the influence decreases the percentage also decreases. Similarly, highest value of 5 is assigned to the most dominant subclass of variable and as the influence of subclass decreases the value also decreases. It is worth mentioning here that 'R' or 'Restricted' weight is also assigned to a subclass which is depicted as '0' in the table 3.2. This value is assigned to that subclass which is not to be considered for site identification.

3.3.1 Result of Delphi Method

After the submission of questionnaires by all experts, the percentage of influence assigned to each variable and weights to the subclasses of each variable are grouped together and presented in the form of a table (table 3.2).

3.4 Weighted Overlay Analysis

In all overlay tools weights can be applied to all inputs in order to get a single output by way of combining all layers. All these tools are used for suitability modeling. Approaches may vary in the analysis of overlaying but all are used for multi-criteria problems with common steps. There are four tools of overlaying analysis viz. Fuzzy membership, Fuzzy Overlay, Weighted Sum and Weighted Overlay Analysis (table 3.3).

Table 3.2
Percentage of Influence of Factors and Weightage to Subclasses

S. no.	VARIABLE	PERCENTAGE OF INFLUENCE	SUBCLASSES	SCALE VALUE (1-5)
1	Landuse Landcover	22	Cultivated	5
			Industry	3
			Plantation	2
			Villages	0
2	Soil Drainage	18	D4 (moderately well drained)	5
			D5 (well drained)	4
			D6 (somewhat excessively drained)	3
			D7 (excessively drained)	2
3	Groundwater Level	12	0-5 mbgl	2
			5-10 mbgl	3
			10-20 mbgl	4
			> 20 mbgl	5
4	Distance from City	12	0-2 km	1
			2-4 km	2
			4-6 km	3
			6-8 km	4
			8-10 km	5
5	Distance from Canals	10	0 - 250 m	1
			250-500 m	2
			500-750 m	3
			750-1000 m	4
			> 1000 m	5
6	Distance from Drains	8	0 - 250 m	1
			250-500 m	2
			500-750 m	3
			750-1000 m	4
			> 1000 m	5
7	Distance from Villages / Settlements	8	0 - 500 m	1
			> 500 m	5
8	Slope	7	0-10 degree	5
			10-20 degree	4
			20-30 degree	3
			30-40 degree	2
			40-90 degree	1
9	Distance from Roads	3	0-100 m	5
			100-200 m	4
			200-300 m	3
			300-400 m	2
			> 400 m	1

Table 3.3
Tools of Overlay Analysis with Brief Description (ESRI)

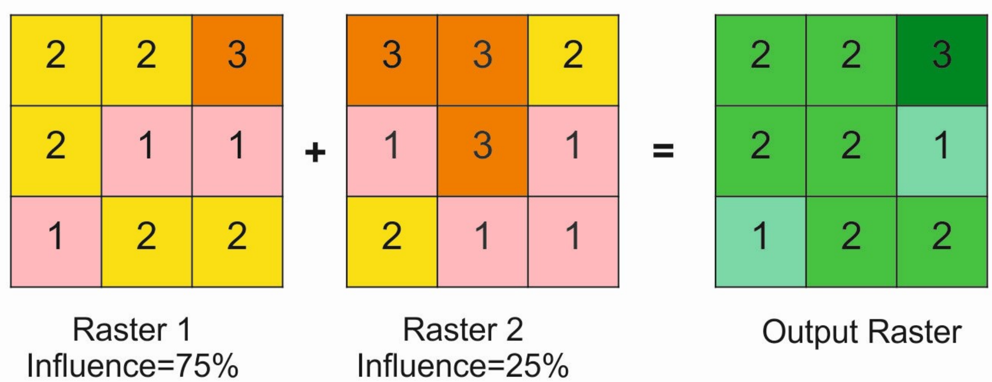
Tool	Description
Fuzzy Membership	It converts the input raster to 0 to 1 scale, that reveals the membership strength in the set.
Fuzzy Overlay	This tool is based on chosen overlay type. It combines the fuzzy membership raster data sets.
Weighted Sum	This tool overlays many raster data sets and multiplies these by their weight and then adds together.
Weighted Overlay	It analyzes many raster data sets by overlaying. It works on a common measurement scale and weighs each variable to its importance.

Weighted Overlay Analysis is the most befitting technique of overlay analysis for solving multi criteria problems (Sharma Monika et al., 2015). This in itself is like a model that works as a group of methodologies in which a common scale of values is applied to dissimilar inputs. In case of site selection, all data or input layers are first converted into raster format. Each raster layer has tens of thousands or even lakhs of cells and each cell is assigned its value. It is very likely that all input layers of variables are in different data ranges or even different numbering system for their subclasses. It therefore, becomes imperative for the subclasses of all layers that each cell is reclassified on a common preference scale e.g. 1-5 wherein 5 is the most favorable and 1 the least favorable. Further this preference is to be on a relative scale i.e. a criterion assigned the scale value of 4 is twice preferred over 2. This preference scale is uniformly applied to all the layers of variables or input data. In every preference scale there is one more value of 'R' which means 'Restricted'. This value is assigned to those cells of subclasses which are not to be considered for the analysis (ESRI). In table 3.2 it is mentioned as 0.

Further, it is not necessary that all input layers or variables have the same influence on site selection. One criterion or variable may be more important than others. So important criterion or variable should get higher percentage of influence and less important should get lower percentage of influence. In weighted overlay analysis it is possible to assign varying percentage of influence to all the variables or input layers (Pradhan et al., 2015).

Hence, two values are assigned in weighted overlay analysis: percentage of influence to each variable or raster layer and weight to the subclasses of each variable or raster layer on a preference scale. Since, there are multiple variables or criteria, they are arranged in layers and overlaid on each other. Now, there are lakhs of cells and each one of these is assigned its value on a common preference scale and each layer has different percentage of influence, it appears very messy. But Weighted Overlay Analysis makes this task easy by computing values of all the layers and their cells and produce the result in a new output raster layer.

Figure 3.2: Calculation of cell values of raster datasets (ESRI)



In the given figure for example, raster layer 1 is assigned the influence of 75% and raster layer 2 is assigned the influence of 25%. The cells of each raster are assigned their values. Now the value of each cell of raster 1 is multiplied by its percentage of influence and then added to the value of same cell in raster 2, which is also calculated in the similar manner. The result is reflected in the output raster layer. In this case, if we take the top left cell, the values look like this :

(2*0.75)=1.5 and (3*0.25)=0.75

Now we add both values i.e. 1.5 + 0.75 = 2.25

Because the output raster layer is integer so the value of 2.25 is rounded to 2.

The weighted overlay analysis has been undertaken in the Spatial Analyst tool of ArcGIS. As per the requirement of tool, all the selected nine variables are converted into raster layers for further processing. As shown in the table 3.2 prepared after Delphi analysis, all variables or raster layers are assigned the percentage of influence and their subclasses are assigned weights on the scale of 1-5 and R or 0. Weighted Overlay Analysis tool for each municipal corporation is applied to generate a new output raster. This newly generated raster categorizes each study area on the basis of suitability on the scale of 0-5. Areas having 5 value are the most suitable areas and as the value decreases the site suitability also decreases on the scale value of 0-5. The highly suitable areas having scale value of 5 are extracted and converted into a Keyhole Markup Language (KML) file which is then saved in a shape file that contains several polygons.

3.5 Selection of Sites and Validation

The objective is to find a site of 50 acres for solid waste management. The polygons with high suitability index may be smaller or larger than 50 acres; therefore it becomes essential to manually locate and authenticate three sites of 50 acres in those polygons that are larger than 50 acres in size. To do this the shape file containing the most suitable areas is converted into a Keyhole Markup Language (KML) file. This KML file alongwith other KML files of all the nine variables are then viewed in Google Earth. This is also a kind of validation step where one can manually corroborate or double check the result of 'Weighted Overlay Analysis'. In this step all layers are viewed above the layer of Google Earth.

After validation, three sites are marked within the suitable areas in Google Earth wherein all the nine variables are once again considered before locating the sites. Here, spatial features outside the study areas are also considered specially when sites are situated closer to the boundary of study areas. That means if site is marked closer to the boundary of study area, then spatial features out side the boundary of study area are also considered because for example a settlement or canal even if it lies outside the study area may be closer to the site situated on the boundary. Features like places of religious, archaeological, military importance are also considered during manual analysis. An airport may be located outside the study area but a distance of 20 km from airport is considered while locating the site for solid waste management. Areas along highways are also avoided while locating the sites (Ministry of Urban Development, 2016). Since the areas with high suitability index are not large but small in size, its not complicated to locate three sites of 50 acres each. These three sites could have been marked even without viewing in Google Earth but steps are repeated in Google Earth to validate the role of all nine variables. This stage is a kind of manual authentication after technical precision and accuracy of machine generated results obtained with weighted overlay analysis.

After sites are located, another validation is done by making a table in which all the nine variables are listed in rows and three sites for each municipal corporation are listed in columns. Then subclasses alongwith weightage are mentioned for each site or column against each row or variable. At this stage it can be noticed whether sites are located in those subclasses which are assigned high scale value on preference scale. Only after this exercise the sites are finalized for solid waste management.

3.6 Conclusion

In the end it may be concluded that methodology is crucial to any study because only carefully selected techniques can lead to the desired goals. Present study is based on remote sensing and GIS technology that makes the spatial analysis with precision and efficiency. Selection of criteria is done after going through several studies and comprehending the local geography. Assigning percentage of influence to all factors and weights to the subclasses on a common scale is vital to this study and Delphi method handles it rationally. The tool of weighted overlay analysis helps to solve this chaotic situation. Validation exercise confirms that site gets located in an appropriate area that satisfies all the variables.

Chapter – 4

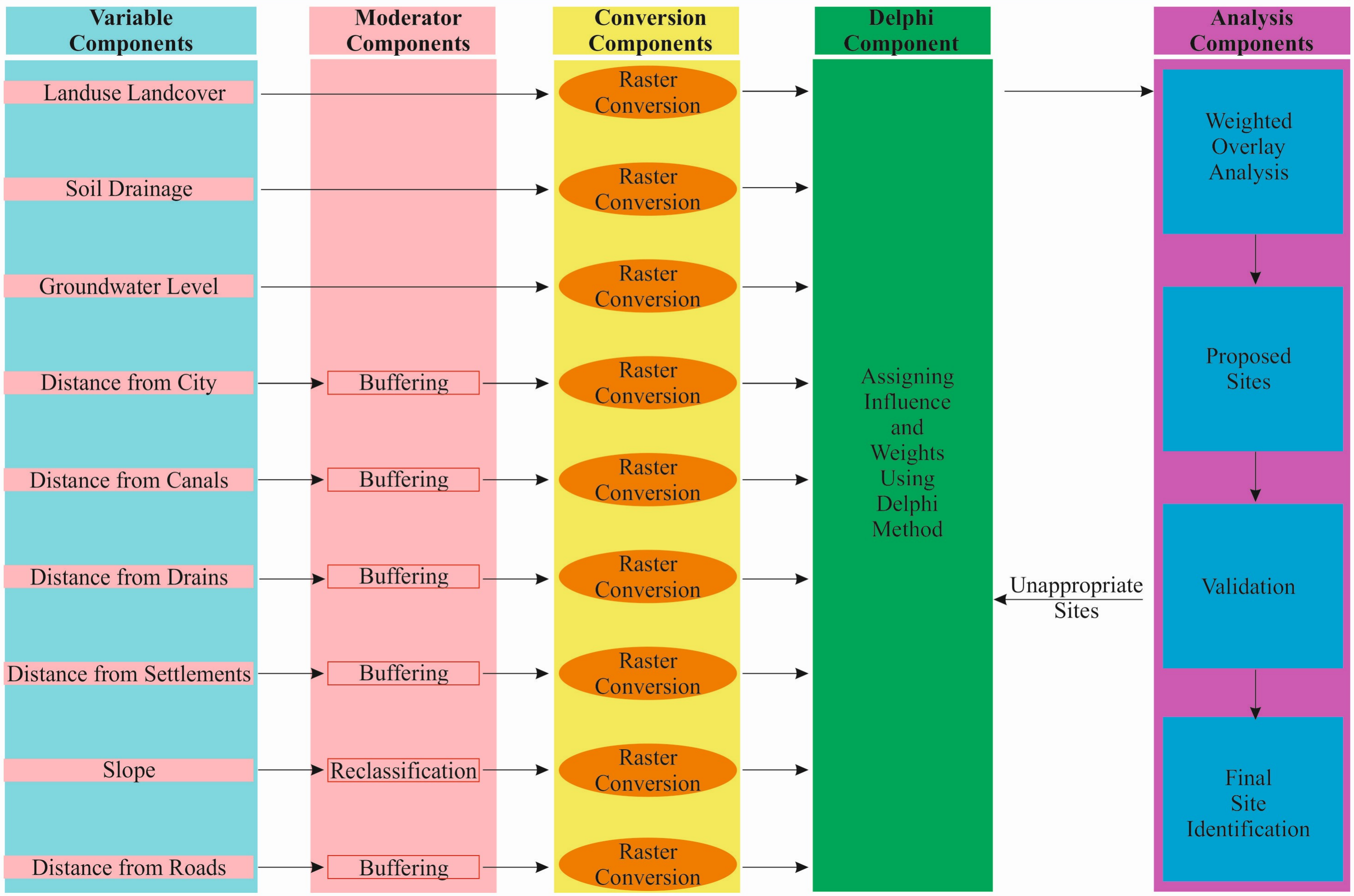
DEEPAK-KALOTA MODEL OF SITE IDENTIFICATION FOR SOLID WASTE MANAGEMENT

Model is a way of systematizing the mechanism through which a strategy can be generalized for application in other spheres or areas. Any model is a set of several variables that may be dependent or independent of each other. An experimental model, as the present case, is a causative expression that illustrates the connectivity of all the variables for the outcome of a phenomenon. From the present study a model is proposed namely "Deepak-Kalota Model of Site Identification for Solid Waste Management". This model besides the ten municipal corporations of Punjab in present study can also be applied in other locations as well where similar conditions prevail specially topography. As regards the copyright of "Deepak-Kalota Model of Site Identification for Solid Waste Management", the researcher has already applied for the registration of copyright under section 45 of the Copyright Act, 1957 to the Registrar of Copyrights, Department of Industrial Policy and Promotion, Ministry of Commerce and Industry, New Delhi vide Diary number 13359/2019-CO/L dated 21-08-2019.

4.1 Components of Deepak-Kalota Model

The present model is a modified version of weighted overlay analysis technique to identify site for solid waste management. However, its uniqueness lies in the selection of variables and assigning influence and weights to variables and their subclasses respectively. The selection of variables and the assigning of influence and weights has been decided on the basis of the characteristics of the study area as well as Delphi method used in social sciences. The present model is designed with a variety of components and moderator components that can be grouped in four categories: Variable components; Editing components; Delphi component and Analysis components. Detailed description of all these components is explained below.

Figure: 4.1 Deepak-Kalota Model of Site Identification For Solid Waste Management



4.1.1 Variable Components

The present study attempts to identify suitable sites for solid waste management for all the ten municipal corporations of Punjab. For this, all the affecting variables and their subclasses are identified that are significant for the selection of solid waste management site. As all factors do not uniformly affect the site identification, the influence of each factor is studied and made a component of the model for site identification. In order to generate relevant information for the purpose of present research the experiment is executed as shown in the flowchart of model (figure 4.1).

a. Landuse Landcover

The variable component of Landuse landcover is the most important variable for site identification as we come to know about the activities on land (Karthiheyan and Yeshoda, 2016). In the present study its four subclasses are cultivated land, settlements, industry and plantation. The model is designed in such a way that inhabited areas are avoided for site identification for solid waste management. Reasons to avoid the settlement areas are public health, public resentment, spoilage of landscape etc. Moreover Solid waste Management rules, 2016 also require to keep at least 500 m distance of landfill site from the habitations (Ministry of Urban Development, 2016).

b. Soil Drainage

The variable component of soil drainage refers to the movement of water within the soil (Randall et al., 2009). Its inclusion is made in the model because of expected soil pollution from the leachate of solid waste which can pollute subsoil and eventually groundwater (Olusina and Shyllon, 2014). Four types of soil drainage are found in the study areas falling under the purview of this study. These types or subclasses of soil drainage are D4 (moderately well drained soil), D5 (well drained), D6 (somewhat excessively drained) and D7 (excessively drained soil). The model is devised in such a way that areas with excessive soil drainage are avoided and areas with lesser soil drainage are preferred to identify site for solid waste management. Here purpose is to protect the subsoil and groundwater.

c. Groundwater level

The variable component of groundwater level is included because leachate from the solid waste management site can pollute this fresh water reserve (Dharanikota, 2013). In the study areas of present study, the groundwater level has four subclasses viz. 0-5 mbgl (meters below ground level), 5-10 mbgl, 10-20 mbgl and >20 mbgl. Considering the expected leaching of pollutants from solid waste the model is framed to avoid areas where groundwater level is minimum and prefer areas with deeper groundwater levels.

d. Distance from City

This variable component is included to maintain sufficient distance of proposed site from the city because all cities are growing every year (Census 2011). This component has five subclasses : 0-2 km from the outer limit of city, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the city. The model handles this component in such a way that areas closer to the city are avoided and areas farther from the city are preferred for site identification. Purpose is that in the next 20-25 years the site should not become part of the city due to urban growth. Period of 20-25 years is considered because the average life of a landfill site is 20-25 years (The Gazette of India, 2016).

e. Distance from Canals

This variable component of model is included so as to protect the canal water from getting polluted due to surface runoff from solid waste management site. Effort is therefore made to keep sufficient distance of proposed site from canals (Pradhan and Samanta, 2015). This variable component has five subclasses: 0-250 m from the canals, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from the canals. The model works out in such a way that areas closer to the canals are least preferred and areas farther from the canals are most preferred for site identification.

f. Distance from Drains

The next variable component of distance from drains is included to protect the drains from getting polluted due to surface runoff from solid waste management site (Karthiheyan and Yeshoda, 2016). This component variable also has five subclasses like canals i.e. 0-250 m from the drains, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from the drains. The model calculates in such a way that areas closer to drains are avoided and areas farther from the drains are preferred for site identification.

g. Distance from Settlements

The next variable component of model is the distance from settlements. Its analysis is vital before site identification for solid waste management (Sunder Rajan et al., 2014). In the present study this variable component has two subclasses of 0-500 m and more than 500 m. The model is framed to avoid the first subclass of 0-500 m and prefer the second subclass of more than 500 m from settlements. Here purpose is to keep the solid waste management site at a sufficient distance from the habitations to avoid public resentment and to satisfy the Solid Waste Management Rules, 2016 (Ministry of Urban Development, 2016).

h. Slope

The variable component of slope is important for site identification to avoid steeper areas (Sunder Rajan et al., 2014). It has five subclasses in the present study: 0-10 degrees, 10-20 degrees, 20-30 degrees, 30-40 degrees and more than 40 degrees. The model analyzes in such a way that relatively flat or plain areas are preferred over areas with steeper slope. Steeper areas are not suitable for solid waste management site because of expected slippage and also to satisfy the Solid Waste Management Rules, 2016 (Ministry of Urban Development, 2016).

i. Distance from Roads

The last variable component of model is distance from roads. It is included for the proximity of proposed site to the roads (Ministry of Urban Development, 2016). This variable is important because vehicles have to make several trips each day to bring solid waste to the site. This variable component has five subclasses: 0-100 m from roads, 100-200 m, 200-300 m, 300-400 m and more than 400 m from the roads. However areas along highways are avoided when suitable areas are analyzed manually in Google Earth. The model is designed in such a way that areas closer to the roads are preferred and areas farther from the roads are avoided for the site.

4.1.2 Editing Components

The second group of components is editing components of the model. The editing components deal with the editing of spatial datasets of variables discussed above and converting all these in raster datasets. The first three variables viz. landuse landcover, soil drainage and groundwater level do not require editing, therefore these three spatial datasets are directly converted into raster datasets. Following variables require editing and is described as under :

1. Distance from city: Five buffer zones are made around the city i.e. 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km.
2. Distance from canals: Five buffer zones are made around the canals i.e. 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m.
3. Distance from Drains: Five buffer zones are made around the drains i.e. 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m.
4. Distance from Settlements: Two buffer zones are made around the settlements i.e. 0-500 m and more than 500 m.
5. Distance from Roads: Five buffer zones are made around the roads i.e. 0-100 m, 100-200 m, 200-300 m, 300-400 m and more than 400 m.
6. The variable of slope requires editing in the form of reclassification, therefore the slope data is reclassified in five subclasses: 0-10 degrees, 10-20 degrees, 20-30 degrees, 30-40 degrees and more than 40 degrees.

After buffering, all spatial datasets are converted into raster datasets to perform weighted overlay analysis. Since slope data is already in raster format, there is no need of its conversion into raster format. This way, all data in raster format is set for further analysis. When spatial data is converted into raster format it takes the shape of matrix of cells or dots and each dot or cell is assigned a value.

4.1.3 Delphi Component

The Delphi method is a process to quantify the influence of variables on site identification. It is done because influence of variables on site identification is not uniform but varies. Some variables are more important than others. It becomes therefore, imperative to quantify the influence of all the variables and their subclasses. This stage of quantification is crucial for the model which requires comprehensive inspection and rational approach to complete this task. Moreover, it is a requirement of 'weighted overlay analysis' to bring all the values to a common scale. Five to eight experts are suggested to be involved in this activity. In the present study, seven experts from different departments are involved (Appendix 12). Being the requirement of weighted overlay analysis, all the nine variables are assigned influence in terms of percentage and subclasses of all the variables are assigned weights on the preference scale of 1-5. Another value of 'R' is also assigned to a subclass which is not to be considered for site identification. Views of all experts are considered and depicted in the form of a table in chapter 3 (table 3.2).

4.1.4 Analysis Components

This is the last group of components of model. In the Analysis Components four distinct components are made.

a. Weighted Overlay Analysis

This is the vital component of model which analyzes all the raster datasets by overlaying. Since all raster datasets are assigned percentage of influence and their subclasses are assigned weights on the scale of 1-5 and 'R' or Restricted, it is all set for the generation of a new raster dataset that categorizes the study area into various zones on the basis of suitability. This new raster dataset alongwith the suitability index from 0-5 is the outcome of weighted overlay analysis wherein 0 is not suitable and as the values increases the suitability also increases. Areas having highest values of 5 are the most suitable areas for site identification. These highly suitable areas are extracted and saved as Keyhole Markup Language (KML) file to view in Google Earth.

b. Proposed Site Identification

This is the ultimate component of model because it provides the desired goal of site where solid waste management can be done. It is done by viewing KML file of highly suitable areas in Google Earth. Here first of all the machine generated results are manually verified and then sites are identified and marked by once again considering all the nine variables within the most suitable areas. At this stage spatial features outside the study areas are also considered specially when sites are located closer to the boundary of study areas. Areas along highways are avoided for site identification. Places of religious, military, archaeological importance are also considered. Airport location is also considered even if it is located outside the study area because distance of 20 km is to be maintained between site and airport. After careful consideration of all the variables within the suitable areas, three sites of 50 acres each are marked for each municipal corporation. Hence 30 sites are identified and proposed for all the ten municipal corporations of Punjab.

c. Validation

This component of model validates the results of site identification. Once sites are identified, these must be validated to ascertain the efficacy of methodology. It is done by making a table wherein all nine variables are listed in rows and three sites of a municipal corporation are listed in columns. Then subclasses alongwith weightage are mentioned for each site or column against each row or variable. It is observed that sites are marked in those subclasses which are assigned high values of 4 or 5. It validates the results of site identification. Only a few exceptions can be seen where value of 3 is found which is because of absence of subclasses with high weightage. At this stage if it is found that sites are not located in areas having high values of preference scale, then the percentage of influence and weights are reassigned and process is repeated from thereon.

d. Finalization of Sites

After successful validation of the proposed sites, three sites for each municipal corporation are ranked on the basis of suitability. That means site 1 having maximum high values in the validation table is ranked the most suitable site followed by sites 2 and 3. In the present study it is observed that only negligible difference is there in the validation stage. That means all three sites are almost equally suitable and it gives choice to the administration when only one site is to be selected. After ranking, the three sites are finalized and proposed for solid waste management. This way by applying this model, the objective of site identification is achieved.

4.2 Applying Model to Evaluate Current Sites

An attempt has been made to apply this model on all those sites that are being used for managing solid waste in all the ten municipal corporations of Punjab. This exercise divulges the veracity of sites in use. On testing this model, all those factors are commented on which current sites fail to catch up.

4.2.1 Applying Model on Current Site of Amritsar MC

Currently solid waste of Amritsar municipal corporation is being managed at Bhagtanwala site. When "Deepak-Kalota Model of Site Identification for Solid Waste Management" is tested on this site, it is observed that this site miserably fails on the variable of 'Distance from City' as this site lies inside the Amritsar city at Bhagtanwala. This site is situated at the southern boundary of the city and is too close to the habitations. Moreover local residents are also opposing against this site (Parshad, S.P., 2015). When site of solid waste management lies close to the residential areas, it poses

Fig: 4.2 Evaluating Current Site of Amritsar MC With Deepak-Kalota Model of Site Identification For Solid Waste Management

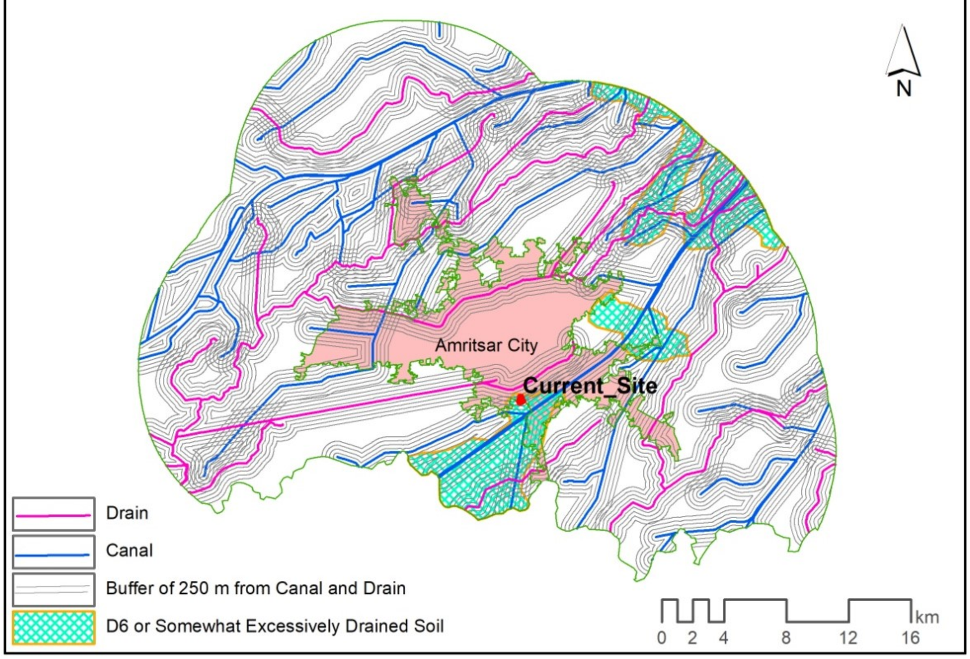
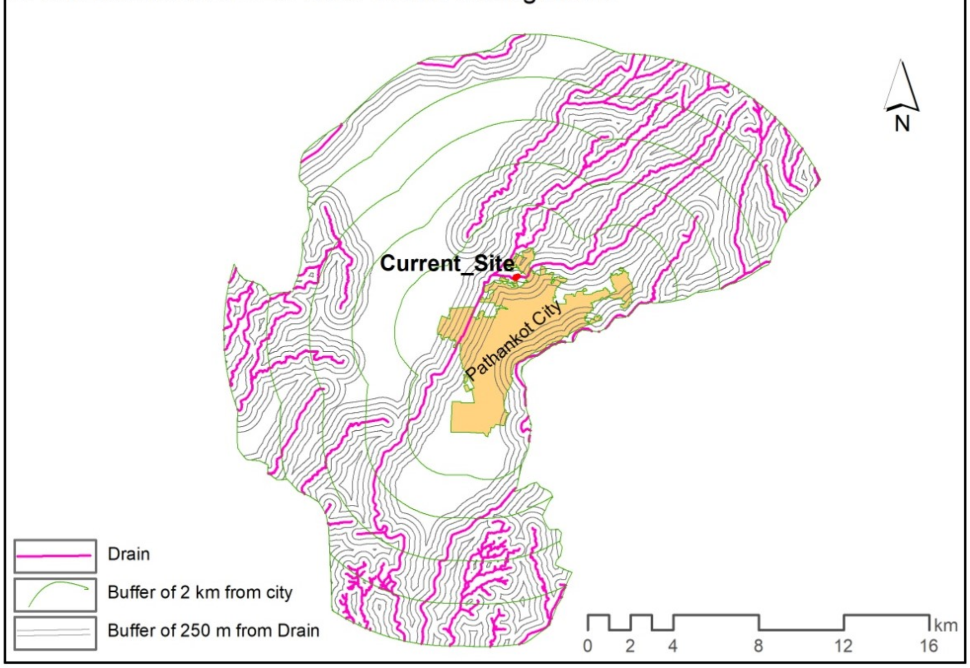


Fig: 4.3 Evaluating Current Site of Pathankot MC With Deepak-Kalota Model of Site Identification For Solid Waste Management



serious health risks to the residents besides polluting the environment. Secondly, this site lies close to the canal in east and is just 500 meters away from it thus posing risk of polluting the fresh water of canal. Thirdly, this site lies almost at a similar distance of 500 m from the drain to the northwest and poses risk of polluting it from the surface runoff during heavy rains. Fourthly, the current site of Bhagtanwala lies in the area where D6 type of soil is found. On the basis of soil drainage this soil is classified as 'somewhat excessively drained soil' (Punjab Remote Sensing Centre, Ludhiana, 2003). Therefore, there are more chances of leachate pollution from the site that may leach down and pollute subsoil and even groundwater (fig: 4.2).

4.2.2 Applying Model on Current Site of Pathankot MC

Solid waste of Pathankot municipal corporation is managed at a site in Rara village that lies to the northwest of city. On executing "Deepak-Kalota Model of Site Identification for Solid Waste Management" on the current site of Pathankot municipal corporation it is found that this site lies too close to the city. When this site is overlaid on the layer of 'Distance from City' it is observed that this site falls in the first buffer zone of 0-2 km from the city. Being too close to the city it is likely to be surrounded by habitations in the near future and may pose health risks to the local residents. Secondly, it is observed that this site lies too close to a drain called Khadi Nalla. Actually the waste is spread along this drain for about 800 meters. Hence during heavy rains, there is possibility of pollutants from the site being carried by the flowing water to downstream areas (fig: 4.3).

4.2.3 Applying Model on Current Site of Jalandhar MC

The current site of solid waste management of Jalandhar Municipal Corporation is situated at Wariana. When "Deepak-Kalota Model of Site Identification for Solid Waste Management" is tested on Wariana site, it is found that this site failed miserably on the variable of 'Distance from City'. When this site is overlaid on the layer of 'Distance from City' it is observed that it is situated on the periphery of city and is too close to the inhabited area.

Fig: 4.4 Evaluating Current Site of Jalandhar MC With Deepak-Kalota Model of Site Identification For Solid Waste Management

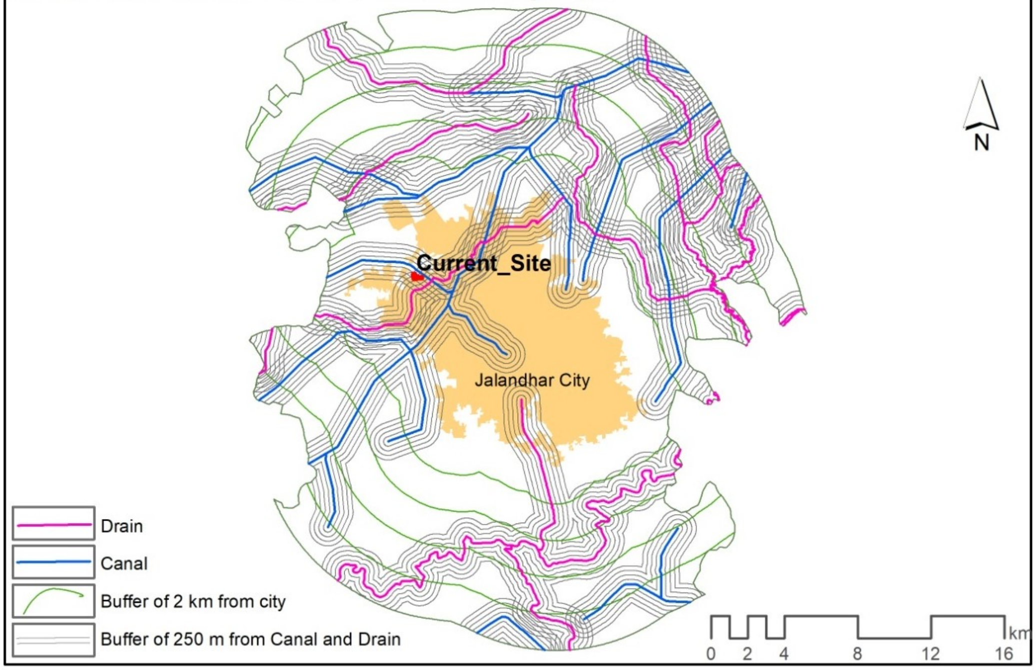
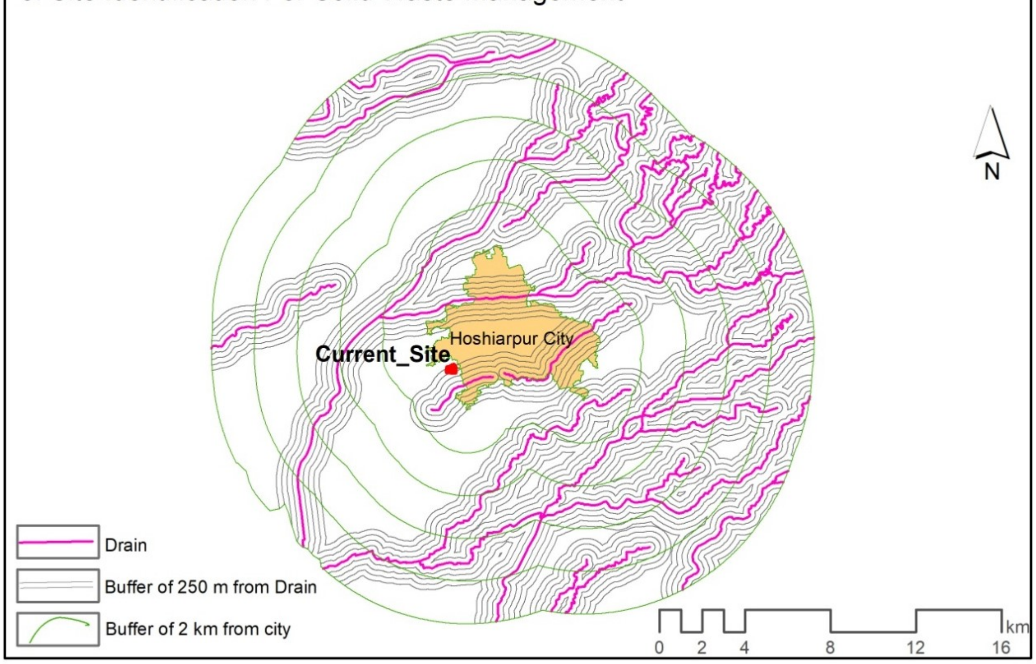


Fig: 4.5 Evaluating Current Site of Hoshiarpur MC With Deepak-Kalota Model of Site Identification For Solid Waste Management



The factor of urban growth was ignored for this site and today this site has become part of the city. The Wariana site is of only 14 acres in size and further expansion is not workable. People in neighbourhood are already protesting against this site. Sanitation and health conditions are deteriorating in the vicinity of site. Diseases like malaria, typhoid, dengue, jaundice have affected almost every household (Kaur H., 2016). Secondly, the site at Wariana lies close to the canal and most part of it lies in 250-500 m buffer zone of canal. Thirdly, this site is also close to the drain as most part of it lies in 500-750 m buffer zone of drain. Surface runoff from this site is capable of polluting both the canal as well as drain (fig: 4.4).

4.2.4 Applying Model on Current Site of Hoshiarpur MC

At present the Hoshiarpur municipal corporation manages its solid waste at Piplanwala site. On testing "Deepak-Kalota Model of Site Identification for Solid Waste Management" on the Piplanwala site it is observed that this site fails on two variables i.e. 'Distance from City' and 'Distance from Drains'. When this site is overlaid on the layer of 'Distance from City' it is noticed that this site falls within the buffer zone of 0-2 km from the city. Although the site is outside the city but lies just adjacent to the city and is close to the residential areas of city. Therefore, such close proximity of site to habitations is capable of posing health risk to the residents. Secondly, there are numerous drains in and around Hoshiarpur city and the factor of 'Distance from Drain' has also been ignored in identifying this site. When this site is overlaid on the layer of drains it is observed that most part of this site falls in 500-1000 m buffer zones of drain. Hence during heavy rains surface runoff from this site can pollute the drain which eventually can pollute the downstream areas (fig: 4.5).

4.2.5 Applying Model on Current Site of Phagwara MC

Currently the Phagwara municipal corporation is managing its solid waste at a site in Hargobindgarh lying to the north of Phagwara city. While applying the model on this site, only one variable is noticed that needs to be

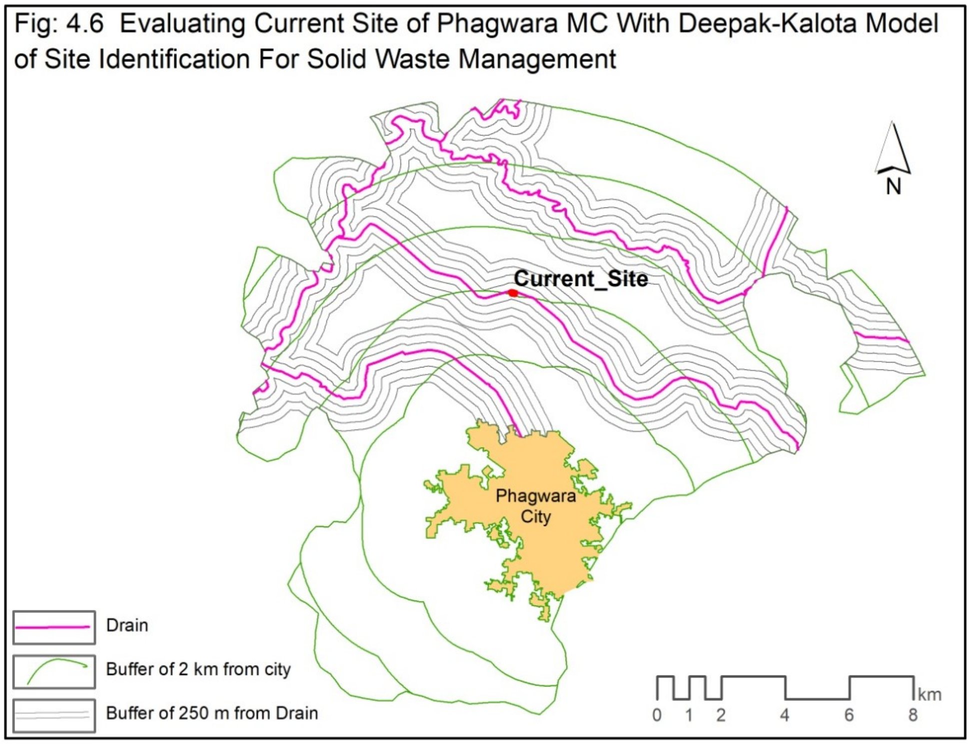


Fig: 4.6 Evaluating Current Site of Phagwara MC With Deepak-Kalota Model of Site Identification For Solid Waste Management
Current_Site
Phagwara City
N
Drain
Buffer of 2 km from city
Buffer of 250 m from Drain
0 1 2 4 6 8
km

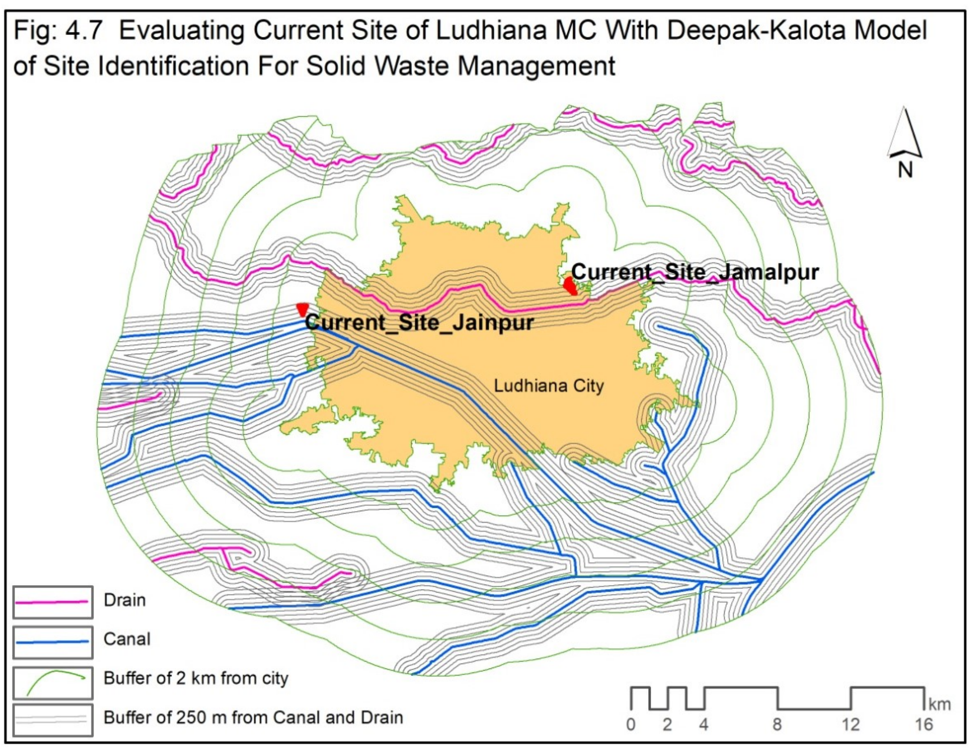


Fig: 4.7 Evaluating Current Site of Ludhiana MC With Deepak-Kalota Model of Site Identification For Solid Waste Management
Current_Site_Jamalpur
Current_Site_Jainpur
Ludhiana City
N
Drain
Canal
Buffer of 2 km from city
Buffer of 250 m from Canal and Drain
0 2 4 8 12 16
km

addressed. When this site is overlaid on the layer of 'Distance from Drains' it is observed that the site lies in the first buffer zone of 0-250 m. That means this site is too close or almost on the bank of drain. During heavy rains, pollution may enter the drain and pollute the downstream areas (fig: 4.6).

4.2.6 Applying Model on Current Site of Ludhiana MC

Among three sites, the Ludhiana municipal corporation is using two sites where solid waste is managed. These are Jamalpur in the east and Jainpur in the west. Third site at Noorpur Bet is purchased exclusively for installing solid waste treatment plant only. The site of Jainpur has reached its saturation level and has been closed for further use, however some dumping of solid waste can still be seen. When "Deepak-Kalota Model of Site Identification for Solid Waste Management" is tested on these sites, three variables are noticed that need to be commented. First of all when these sites are overlaid on the layer of 'Distance from City' it is observed that the site of Jamalpur lies at the outer limit but within the city and is too close to the habitations. It poses serious health risks to the local residents. The other site of Jainpur in the west lies outside the city but within the buffer of 0-2 km. When measured, it is found that the Jainpur site is only a few hundred meters away from the habitations. Hence it is not sufficient distance and there is likelihood of its being surrounded by the settlements in the next few years due to urban growth. Secondly, when these two sites are overlaid on the layer of 'Distance from Drain' it is noticed that the site of Jamalpur lies 500 meters away from the drain and site of Jainpur is much away from drain. Thirdly, when these sites are overlaid on the layer of 'Distance from Canals' it is observed that the site of Jamalpur is away from canal but the Jainpur site is close to canal lying just 250 m from the canal. This is not enough distance to protect the fresh water of canal from getting polluted (fig: 4.7).

4.2.7 Applying Model on Current Site of Moga MC

At present the solid waste of Moga municipal corporation is being managed at a site in Dhalle Ke village to the northwest of city. On testing

Fig: 4.8 Evaluating Current Site of Moga MC With Deepak-Kalota Model of Site Identification For Solid Waste Management

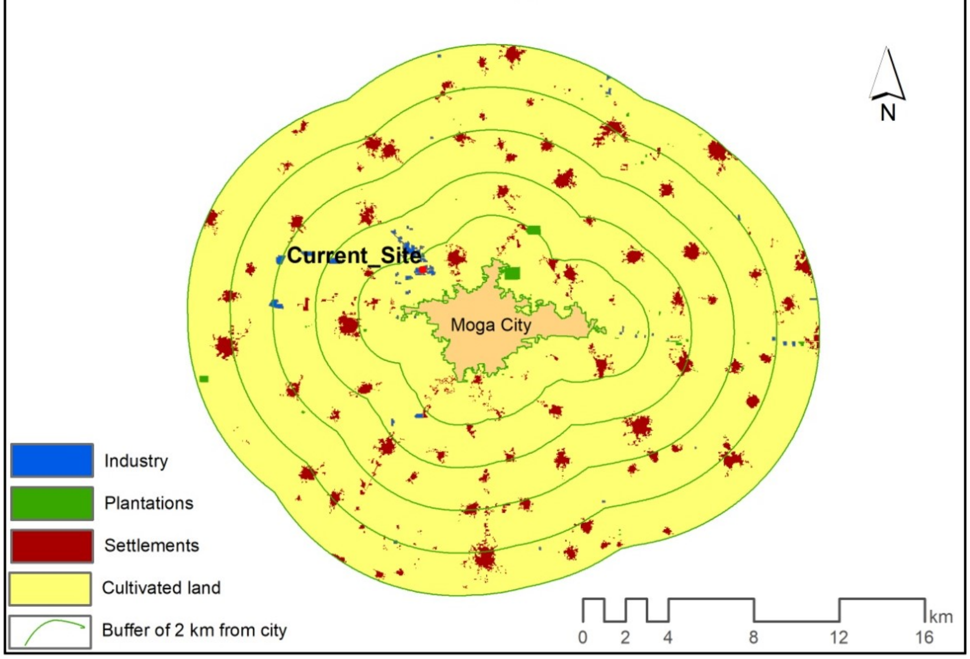
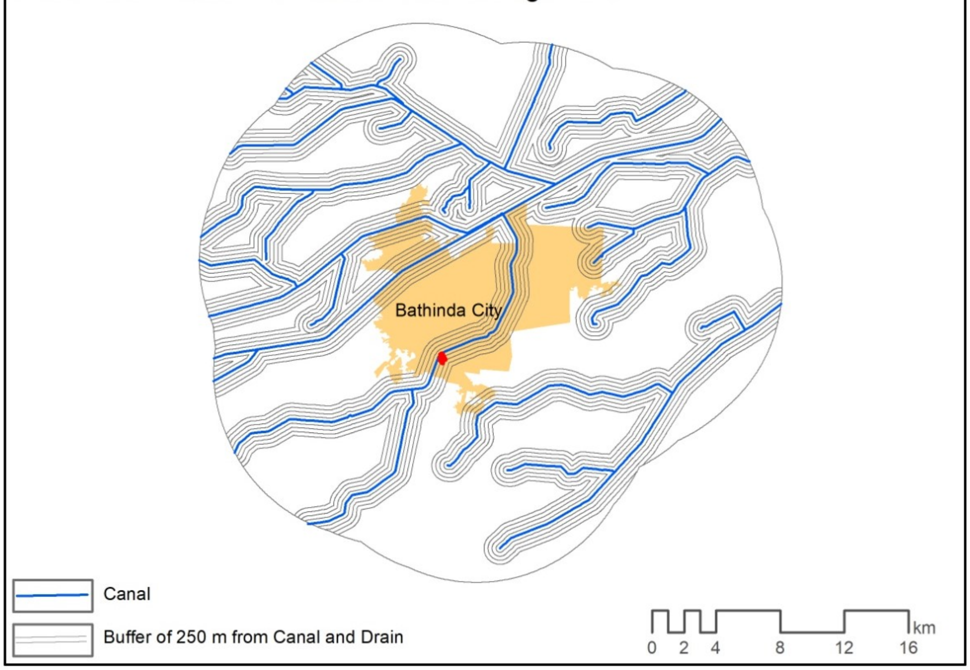


Fig: 4.9 Evaluating Current Site of Bathinda MC With Deepak-Kalota Model of Site Identification For Solid Waste Management



"Deepak-Kalota Model of Site Identification for Solid Waste Management" on the Dhalle Ke site it is observed that this site fails on two variables i.e. 'Distance from City' and 'Landuse Landcover'. When this site is overlaid on the layer of 'Distance from City' it is observed that it lies in the first buffer zone of 0-2 km and is situated roughly 1.5 km away from the city. This distance is not enough when we consider the urban growth and expected long serving period of site of 20-25 years. Secondly, when this site is overlaid on the layer of 'Landuse Landcover' it is noticed that this site is surrounded by industries on all sides. Pollution emanating from site can affect the surroundings (fig: 4.8).

4.2.8 Applying Model on Current Site of Bathinda MC

The solid waste of Bathinda municipal corporation is being managed at a site near Bhai Mati Das Nagar on Mansa Road in south. When "Deepak-Kalota Model of Site Identification for Solid Waste Management" is applied on the present site of Bathinda municipal corporation, it is observed that this site fails on two variables. Firstly, when this site is overlaid on the layer of 'Distance from City' it is found that this site lies within the city and is enclosed by habitations on all sides. The site is separated from surrounding residential areas by 100-300 meters only. This distance is not enough and pose serious health risks to the residents in neighbourhood. Secondly when this site is overlaid on the layer of 'Distance from Drain' it is observed that the most part of site lies within the buffer of 0-250 m. That means the site is situated on the drain itself. During rains, the pollutants from the site can be carried away by drain to the downstream areas (fig: 4.9).

4.2.9 Applying Model on Current Site of Patiala MC

Patiala municipal corporation manages its solid waste at Sanauri Adda site that lies in the southeast. When "Deepak-Kalota Model of Site Identification for Solid Waste Management" is applied on the current site of Patiala municipal corporation, it is observed that this site fails to address two major variables. Firstly when this site is overlaid on the layer of 'Distance

Fig: 4.10 Evaluating Current Site of Patiala MC With Deepak-Kalota Model of Site Identification For Solid Waste Management

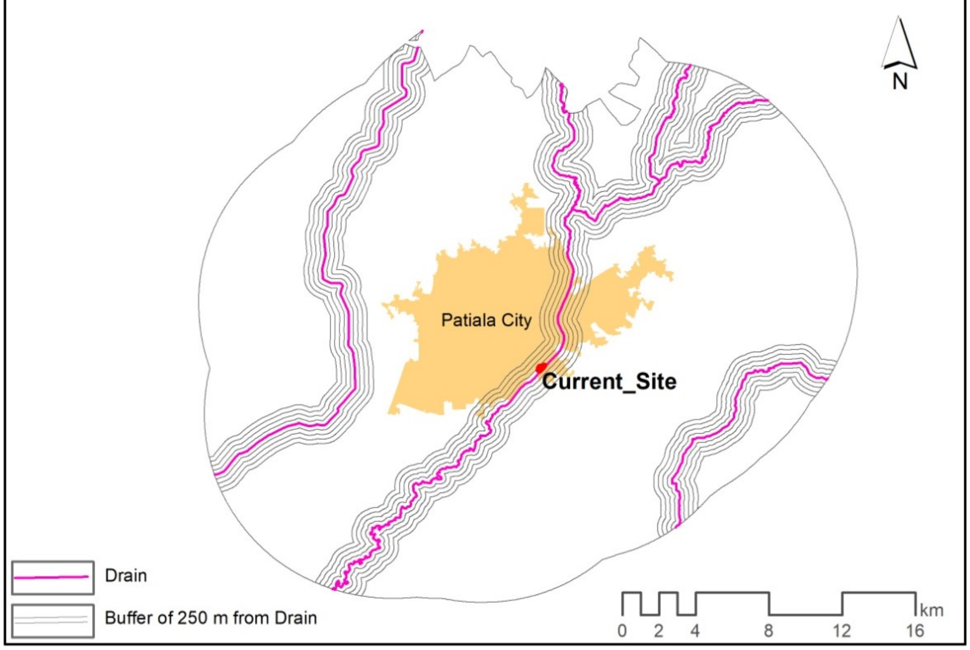
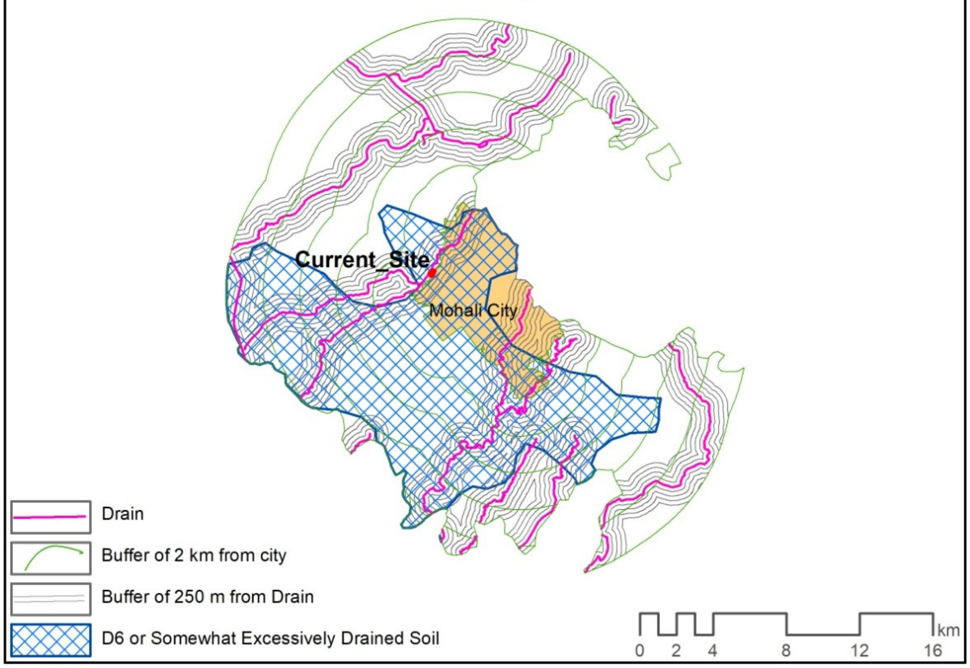


Fig: 4.11 Evaluating Current Site of Mohali MC With Deepak-Kalota Model of Site Identification For Solid Waste Management



from City' it is observed that this site lies on the periphery of city and falls within the city. That means the site is surrounded by habitations at least on three sides. In the west and north the habitations are hardly 100 m away but in the east it is less than 100 m. It means the site poses serious health risks to the people in neighbourhood. Secondly, when this site is overlaid on the layer of 'Distance from Drain' it is noticed that this site is situated on the banks of drain and falls within the buffer of 0-250 m. Therefore, there are chances of pollution entering the drain and affecting the downstream areas (fig: 4.10).

4.2.10 Applying Model on Current Site of Mohali MC

Mohali or SAS Nagar municipal corporation manages its solid waste at a site that falls in Sohana village and lies behind Industrial area. When "Deepak-Kalota Model of Site Identification for Solid Waste Management" is applied on this site it is found that this site does not satisfy two important variables of 'Distance from City' and 'Distance from Drain'. When this site is overlaid on the layer of 'Distance from City' it is observed that it lies just outside the city limit but is very close to the adjoining residential and industrial areas. Thus it poses health risks to the people in neighbourhood. Secondly when this site is overlaid on the layer of 'Distance from Drain' it is observed that this site lies within the buffer of 0-250 m and is almost on the banks of drain. Hence it can pollute this drain and affect the downstream areas. Lastly, when the site is overlaid on the layer of soil drainage it is found that this site is situated in the area where D6 or 'Somewhat Excessively Drained Soil' is found. In this soil, the leaching is high therefore leachate from site can pollute subsoil and even groundwater. (fig: 4.11).

4.3 Suggestions

From the description of the above mentioned scenarios of all the municipal corporations of Punjab, it is apparent that each site fails on one or the other variable. It looks like that all the factors were not considered at the time of site identification. It is therefore suggested that in future sites for solid waste management must be identified by considering all those variables that are capable of affecting the environment in the neighbourhood of site or a model may be applied that includes all such variables and analyzes the variables with the help of remote sensing and GIS technology for precise and accurate results. The nine variables viz. landuse landcover, soil drainage, groundwater level, distance from city, distance from canals, distance from drains, distance from settlements, slope, distance from roads are vital for site identification. "Deepak-Kalota Model of Site Identification for Solid Waste Management" considers all these nine variables and identifies site with the help of remote sensing and GIS techniques.

4.4 Conclusion

It may be submitted in the end that "Deepak-Kalota Model of Site Identification for Solid Waste Management" is designed with a variety of components. It takes into account all the variables that affect the site identification process, their editing and conversion into raster format. It is followed by Delphi component that judiciously assigns importance and weights to all the variables and their subclasses. Finally the analysis part of the model converts the complexity into clarity and presents the results in the form of suitable site that can be used for solid waste management. When this model is tested on the present sites, the shortcomings are detected easily.

Chapter-5

SITE IDENTIFICATION FOR MUNICIPAL CORPORATIONS OF MAJHA AND DOABA AREAS

Majha and Doaba areas constitute the northern half of Punjab state in which five municipal corporations are situated. These are Amritsar and Pathankot of Majha area and Jalandhar, Hoshiarpur, Phagwara of Doaba area. This chapter deals with the site identification for solid waste management based on "Deepak-Kalota Model of Site Identification for Solid Waste Management" for these five municipal corporations.

5.1 SITE IDENTIFICATION FOR AMRITSAR MC

The study area of Amritsar municipal corporation covers a total area of 960 sq km. The southern boundary of study area is clipped by the district boundary because the 10 km buffer around the city of Amritsar which is marked to define the study area extends into the district of Taran Tarn in south (fig 5.1).

5.1.1 Analysis of Variables

As per "Deepak-Kalota Model of Site Identification for Solid Waste Management" a total of nine variables are considered for Amritsar MC. The same are described below.

(a) Landuse landcover

Four major subclasses that appear in the satellite imagery are cultivated land, settlements, industry and plantations. Out of 960 sq km of total study area, the cultivated land accounts for 848 sq km (table 5.1). The cultivated land is found all across the study area and is the largest of all subclasses (fig 5.2). When the subclass of industry is analyzed, it is found that there are 65 industrial locations in this study area covering an area of only 1.33 sq km. The

Table 5.1
Area under subclasses of each variable in Amritsar study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	5.75
		Villages/Settlements	56.19
		Industry	1.33
		Cultivated	848
2	Soil Drainage		
		D4-Moderately well drained	39
		D5-Well drained	834
		D6- Somewhat excessively drained	87
3	Groundwater Level		
		<15 mbgl	241
		15-20 mbgl	205
		>20 mbgl	514
4	Distance from City		
		0-2 km	248
		2-4 km	190
		4-6 km	179
		6-8 km	167
		8-10 km	176
5	Distance from Canals		
		0-250 m	171
		250-500 m	152
		500-750 m	134
		750-1000 m	113
		>1000 m	390
6	Distance from Drains		
		0-250 m	123
		250-500 m	115
		500-750 m	104
		750-1000 m	97
		>1000 m	521
7	Distance from Villages/Settlements		
		0-500 m	516
		>500 m	444
8	Slope		
		0-10 degrees	886.20
		10-20 degrees	70.36
		20-30 degrees	3.30
		30-40 degrees	0.13
		>40 degrees	0.01
9	Distance from Roads		
		0-100 m	342
		100-200 m	247
		200-300 m	159
		300-400 m	96
		>400 m	116

industrial locations are found in all parts of study area except in the west which is close to the international border. For the subclass of plantations it is found that there are 133 locations covering an area of 5.75 sq km. The plantation locations are almost uniformly distributed in all parts of the study area except sparse locations in the west. For the subclass of settlements it is noticed that there are 346 number of settlements that cover an area of 56.19 sq km. The locations of settlements are almost uniform all across the study area without any exception. Two settlements are conspicuous by their larger size. These are towns of Jandiala in the southeast and Majitha in the northeast.

(b) Soil Drainage

On the basis of soil drainage there are seven categories in Punjab but in this study area only three categories or subclasses are found i.e. D4, D5 and D6. The subclass of D4 or 'moderately well drained' soil is found in a single patch in the extreme east of the study area and covers an area of 39 sq km. Next subclass of D5 or 'well drained' soil is seen in all parts of study area and covers the maximum area of 834 sq km. Next subclass of D6 or 'somewhat excessively drained' soil is found in several patches in the eastern half of study area covering 87 sq km of area (fig 5.3).

(c) Groundwater Level

On the basis of groundwater level three levels are found in this study area which are <15 mbgl, 15-20 mbgl and >20 mbgl. Minimum levels are found in the western part of study area which go on increasing towards east. Subclass of < 15 mbgl which is found in the west covers an area of 241 sq km. The subclass of 15-20 mbgl is seen in the mid-western parts and covers 205 sq km of area. The subclass of >20 mbgl is seen in middle and eastern half of study area. It is the most widespread subclass and covers the maximum area of 514 sq km (fig 5.4).

(d) Distance from City

On the basis of distance from the outer limit of city, five zones or

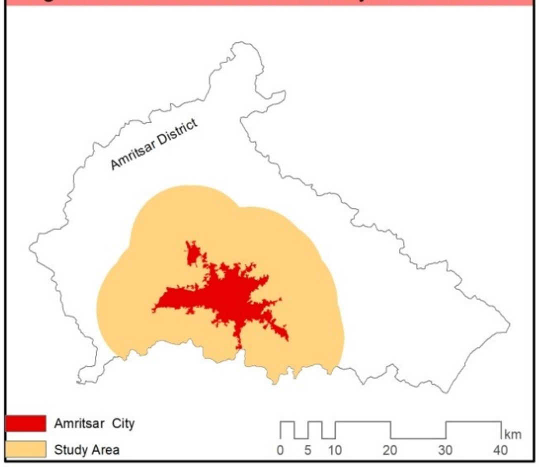


Fig 5.1: Location of Amritsar Study Area in District

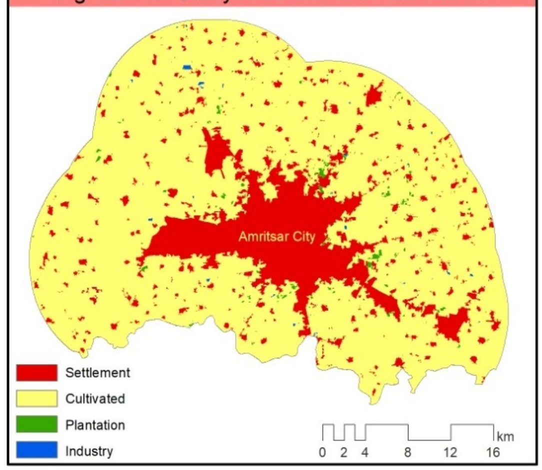


Fig 5.2: Asr Study Area-Landuse Landcover

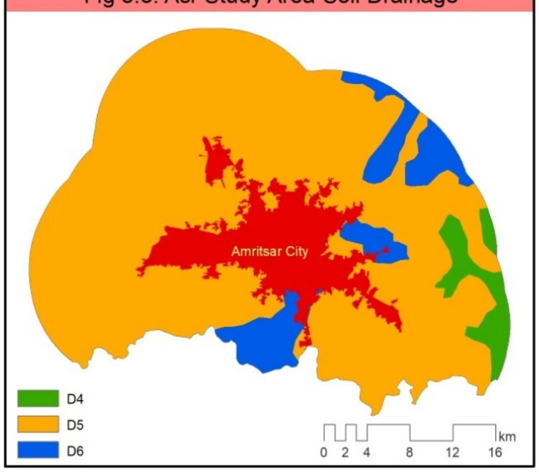


Fig 5.3: Asr Study Area-Soil Drainage

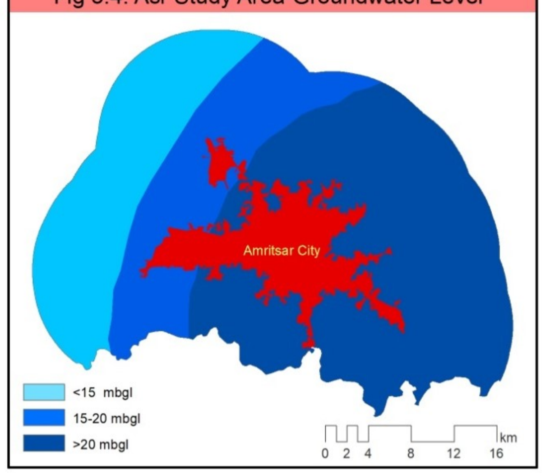


Fig 5.4: Asr Study Area-Groundwater Level

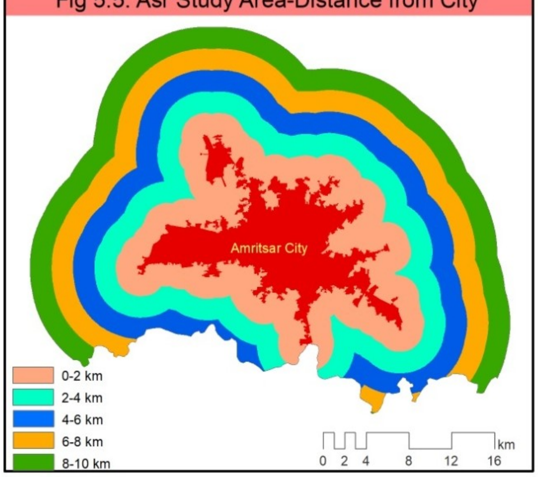


Fig 5.5: Asr Study Area-Distance from City

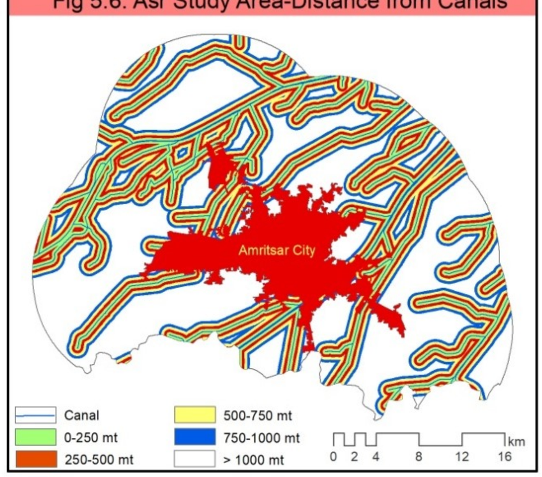


Fig 5.6: Asr Study Area-Distance from Canals

Fig 5.7: Asr Study Area-Distance from Drains

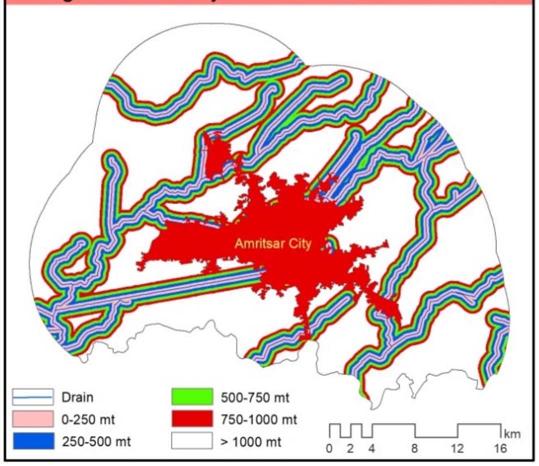


Fig 5.8: Asr Study Area-Distance from Settlements

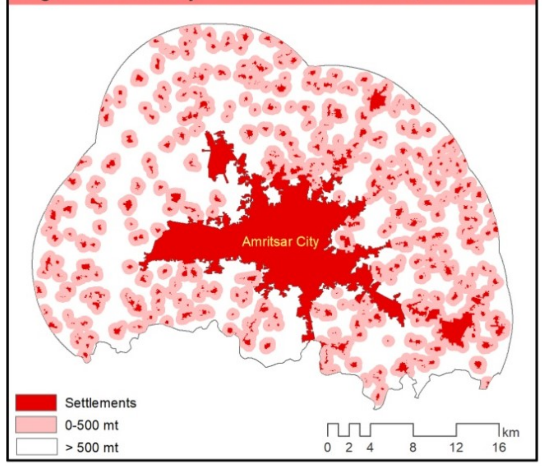


Fig. 5.9: Asr Study Area-Slope

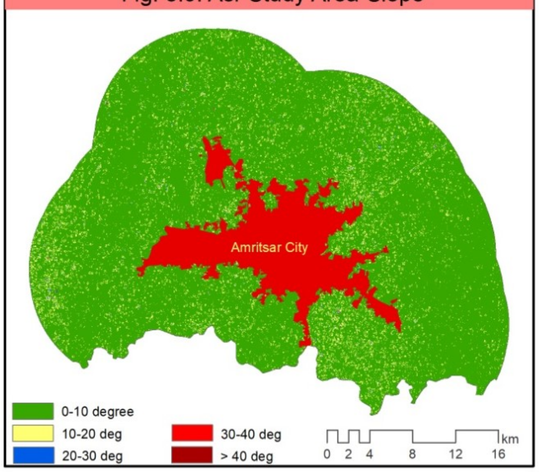


Fig 5.10: Asr Study Area-Distance from Roads

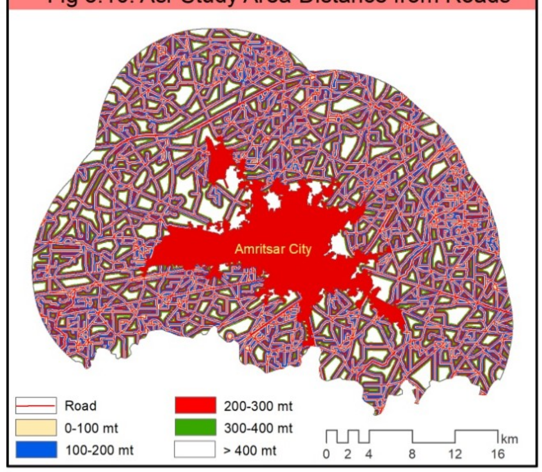


Fig 5.11: Asr Study Area-Suitable Areas

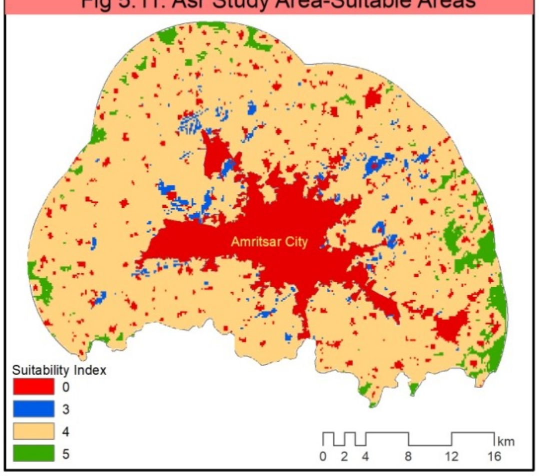
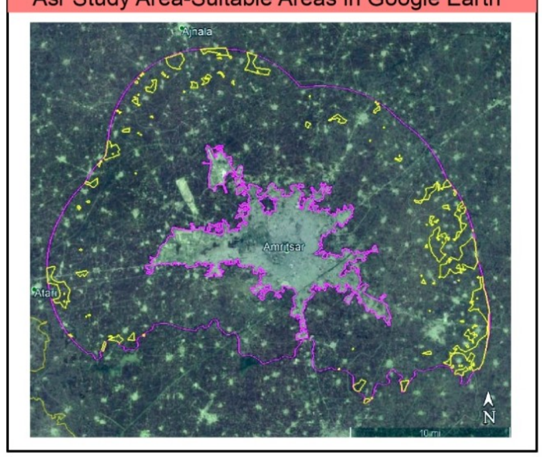


Fig 5.12:
Asr Study Area-Suitable Areas in Google Earth



subclasses are made around the city. These are 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km. First subclass of 0-2 km occupies an area of 248 sq km, 2-4 km subclass covers 190 sq km, 4-6 km subclass covers 179 sq km, 6-8 km subclass covers 167 and 8-10 km subclass covers an area of 176 sq km. All five subclasses are not visible in the south because these have been clipped with the district boundary. That's why the area of outer zones is less than the inner zones (fig 5.5).

(e) Distance from Canals

There are numerous canals which are almost uniformly distributed all across the study area. With regard to distance from canals five buffer zones or subclasses are made on both sides of canals. These are 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. Buffer zone or subclass of 0-250 m has an area of 171 sq km, 250-500 m has 152 sq km, 500-750 m has 134 sq km, 750-1000 m has an area of 113 sq km and subclass of more than 1000 m covers maximum area of 390 sq km (fig 5.6).

(f) Distance from Drains

There are numerous drains and these are almost uniformly distributed in this study area. Like canals, five buffer zones or subclasses are made on both sides of all the drains. These are 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. Buffer zone or subclass of 0-250 m has an area of 123 sq km, subclass of 250-500 m has 115 sq km, subclass of 500-750 m has 104 sq km, subclass of 750-1000 m has an area of 96 sq km and subclass of more than 1000 m covers maximum area of 521 sq km (fig 5.7).

(g) Distance from Settlements

As already mentioned in para 5.1.1 (a) there are 346 number of settlements in this study area. In order to avoid the site in the immediate vicinity of these settlements the factor of distance from settlements is calculated and two buffer zones or subclasses are made around all settlements. These are 0-500 m and more than 500 m. The subclass of 0-500 m covers an area of 516 sq km and the second subclass of more than 500 m covers an area of 444 sq km (fig 5.8).

(h) Slope

To analyze slope the entire study area is divided into five subclasses: 0-10 degrees, 10-20, 20-30, 30-40 and more than 40 degrees. While analyzing the variable of slope it is found that out of 960 sq km of study area a very large portion of 886.20 sq km of area falls in 0-10 degrees of slope distantly followed by the category of 10-20 degrees of slope that covers 70.36 sq km of area. The subclass of 20-30 degrees of slope covers only 3.30 sq km of area. Next two subclasses cover negligible area i.e. 0.13 sq km of area in 30-40 degrees of slope and 0.01 sq km of area in more than 40 degrees of slope (fig 5.9).

(i) Distance from Roads

With regard to distance from roads, it is noted that the present study area has sufficient density of roads. For site identification, proximity to roads is preferred therefore five buffer zones or subclasses are marked on both sides of all the roads. These subclasses are 0-100 m, 100-200 m, 200-300 m, 300-400 m and more than 400 m. Maximum area of 342 sq km lies in the first subclass of 0-100 m followed by 247 sq km in 100-200 m, 159 sq km in 200-300 m, 96 sq km in 300-400 m and 116 sq km in more than 400 m subclass (fig 5.10).

5.1.2 Weighted Overlay Analysis for Amritsar MC

After processing, all feature classes are converted into raster format and assigned percentage of influence to all the variables and weightage to the subclasses of the variables on the basis of model already described in chapter 4. In ArcGIS when the tool of 'weighted overlay analysis' is run for the study area of Amritsar, a new raster is generated that categorizes the entire study area into four suitability zones along with the suitability index i.e. 0, 3, 4 and 5 (fig 5.11). The areas with highest suitability index of 5 cover only 4.4% of the study area. This suitable area is then extracted and converted into Keyhole Markup Language (KML) file so that the same can be viewed in Google Earth (fig 5.12). In Google Earth first of all the machine generated results are manually verified. Then three sites of 50 acres each are marked within the suitable areas by once again considering all the nine variables.

5.1.3 Validation for Amritsar MC

After marking the sites, these are validated by overlaying on layers of all the nine variables (table 5.2). When sites are overlaid on landuse landcover layer it is observed that all three sites are in the subclass of cultivated land that is assigned highest weightage of 5. On the layer of soil drainage it is discovered that all three sites are located on D5 subclass or well drained soil that is assigned the weightage of 4.

Table 5.2
Sites for Amritsar MC falling under subclasses of each variable alongwith weightage

S. no.	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D5 (4)	D5 (4)	D5 (4), D4 (5)
3	Groundwater level	<15 mbgl (4)	>20 mbgl (5)	>20 mbgl (5)
4	Distance from City	8-10 km (5)	6-8 km (4), 4-6 km (3)	8-10 km (5), 6-8 km (4)
5	Distance from Canal	>1000 m (5)	>1000 m (5)	>1000 m(5), 750-1000 m(4)
6	Distance from Drain	>1000 m(5)	>1000 m(5)	>1000 m(5)
7	Distance from Village	>500 m(5)	>500 m(5)	>500 m(5)
8	Slope	0-10 degrees (5), 10-20 degrees (4)	0-10 degrees (5), 10-20 degrees (4)	0-10 degrees (5), 10-20 degrees (4)
9	Distance from Roads	0-100 m(5)	0-100 m(5)	0-100 m(5)

However some parts of site 3 lie in the subclass of D4 whose weightage is 5. On the layer of groundwater it is noticed that site 1 is in the subclass of <15 mbgl which is assigned the weight of 4 and site 2 and 3 are in the subclass of >20 mbgl that is assigned the weight of 5. Further on the layer of distance from city it is found that site 1 lies in the farthest zone of 8-10 km from city that is assigned the weight of 5 while site 2 is mostly located in the 6-8 km zone that is assigned the weight of 4 however very small part of it lies in 4-6 km subclass having weight of 3. Site 3 lies mostly in subclass of 8-10 km from city which is assigned weight of 5 with very small part in 6-8 km subclass having weightage of 4. Then on the layer of distance from canals it is noticed that all three sites are located in the subclass of more than 1000 m away from canal that is assigned the weight of 5 however a tiny part of site 3 falls in 750-1000 m subclass with weightage of 4. Then on the layer of distance from drains it is found that all three sites are located in the subclass of maximum distance from drains i.e. 1000 m which is assigned the weight of 5. By overlaying sites on the layer of distance from settlements or villages it is discovered that all three sites are located in the subclass of > 500 m from settlements that is assigned the maximum weight of 5. On the layer of slope it is noted all three sites are located in the subclass of 0-10 degrees that is assigned the maximum weightage of 5 except very tiny patches of sites that fall in the subclass of 10-20 degrees which is assigned the weightage of 4. When sites are overlaid on the last layer of distance of roads it is found that all three sites are located right on the road or in the subclass of 0-100 m from road that is assigned the maximum weight of 5. Hence it is proved that the results of weighted overlay analysis for site identification for solid waste management of Amritsar municipal corporation are authentic and judicious because only those areas are selected by this tool that are assigned high values on preference scale. Manual authentication is also performed when results are viewed in Google Earth while marking the sites. After validation the proposed three sites are finalized for solid waste management of Amritsar municipal corporation.

5.1.4 Final Sites

After validation, it is observed that all three sites successfully satisfy all the nine variables mentioned in the "Deepak-Kalota Model of Site Identification for Solid Waste Management". These three sites are hence finalized for solid waste management of Amritsar municipal corporation. Site 1 lies in the extreme southwest near Kaunke village; site 2 lies in the extreme southeast near the district boundary with Taran Tarn district near Pakhoke village and site 3 lies in the east near Khalehra village. Site 1 is the most preferred site followed by site 2 and site 3 (fig App 1.1).

5.2 SITE IDENTIFICATION FOR PATHANKOT MC

The study area of Pathankot lies in the foothill zone of Shiwaliks and shares its borders with two states of India: Himachal Pradesh to the east and Jammu and Kashmir to the northwest. To the south it shares its boundary with the district Gurdaspur. On all three sides the boundary of study area is clipped with state and district boundary leaving behind 418 sq km of area for site identification (fig 5.13).

5.2.1 Analysis of Variables

Analysis of nine variables for the study area of Pathankot municipal corporation is given below.

(a) Landuse landcover

When the variable of landuse landcover is analyzed it is noticed in the map that the subclass of cultivated area spreads all across the study area and predominates over 311 sq km (table 5.3). The plantation / forest subclass is found in 911 locations covering 48.13 sq km of area and can be seen all across the study area and is more predominant in the northeastern part where Shiwalik hills are situated. The subclass of settlements or villages found in 521 locations spreading over 24.06 sq km of area and can be seen in all parts of the study area except northeastern hilly area where settlements are not as dense as in the adjoining plain areas. A large settlement, town of Sujanpur can be seen in the west which is surrounded by two canals ie. Beas Link and UBDC (Upper Bari Doab canal). Industries are very limited and this subclass is found only at 36 locations covering only 0.73 sq km. Number of industries in the hilly areas of northeast is negligible (fig 5.14).

(b) Soil Drainage

While analyzing the variable of soil drainage it is observed that only

Table 5.3
Area under subclasses of each variable in Pathankot study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	48.13
		Villages/Settlements	24.06
		Industry	0.73
		Cultivated	311
2	Soil		
		D5-Well Drained	365
		D6- Somewhat excessively drained	2
		D7- Excessively drained	51
3	Groundwater Level		
		0-5 mbgl	119
		5-10 mgl	205
		>10 mbgl	94
4	Distance from City		
		0-2 km	65
		2-4 km	71
		4-6 km	89
		6-8 km	100
		8-10 km	93
5	Distance from Canals		
		0-250 m	47
		250-500 m	39
		500-750 m	31
		750-1000 m	25
		>1000 m	276
6	Distance from Drains		
		0-250 m	118
		250-500 m	83
		500-750 m	59
		750-1000 m	42
		>1000 m	116
7	Distance from Villages/Settlements		
		0-500 m	324
		>500 m	94
8	Slope		
		0-10 degrees	391.15
		10-20 degrees	19.87
		20-30 degrees	6.29
		30-40 degrees	0.35
		>40 degrees	0.34
9	Distance from Roads		
		0-100 m	196
		100-200 m	109
		200-300 m	54
		300-400 m	26
		>400 m	34

three subclasses are found in this study area i.e. D5, D6 and D7. The D5 subclass or well drained soil is seen in most parts of the study area covering maximum area of 365 sq km. The D6 subclass or somewhat excessively drained soil is seen in a single patch in the extreme west that occupies only 2 sq km of area. The D7 subclass or excessively drained soil is found in several patches in northeast foothill zone and southern parts of study area covering 51 sq km of area (fig 5.15).

(c) Groundwater Level

As regards the variable of groundwater level only three subclasses are noticed in this study area. Three patches of 0-5 mbgl (meters below ground level) subclass are found in north, middle and southern parts of study area which cover 119 sq km of area. The subclass of 5-10 mbgl is seen in most parts of the study area and covers maximum area of 205 sq km. Third subclass of >10 mbgl found in two patches in north and southeastern parts of study area covering 94 sq km of area (fig 5.16).

(d) Distance from City

To analyze the variable of distance from city the study area is divided into five zones or subclasses viz. 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the outer limit of the city. The subclass of 0-2 km from the city covers 65 sq km of area; subclass of 2-4 km from city covers 71 sq km; subclass of 4-6 km from city covers 89 sq km; subclass of 6-8 km from city covers 100 sq km and the last subclass of 8-10 km from the city covers 93 sq km of area (fig 5.17).

(e) Distance from Canals

Canals flow mainly in the western parts of this study area. UBDC (Upper Bari Doab canal) and Beas Link are two major canals of this study area. To analyze the variable of distance from canals the study area is divided into five zones or subclasses viz. 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. The first subclass of 0-250 m away from canals

Fig 5.13: Location of Pathankot Study Area in District

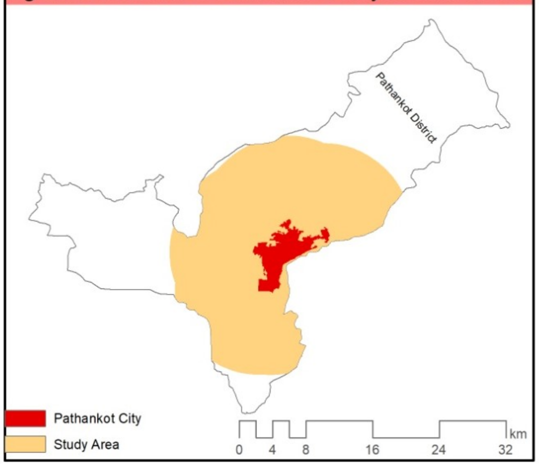


Fig 5.14: Pkt Study Area-Landuse Landcover

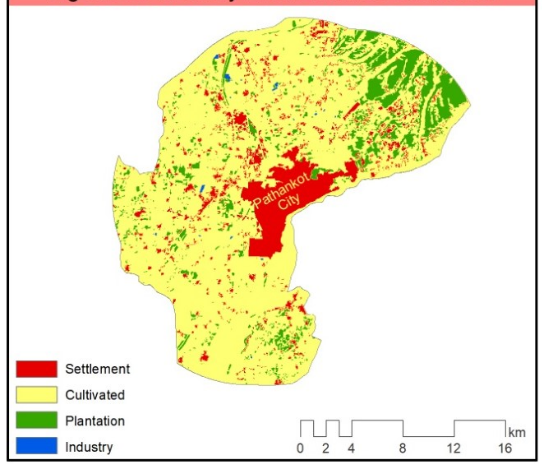


Fig 5.15: Pkt Study Area-Soil Drainage

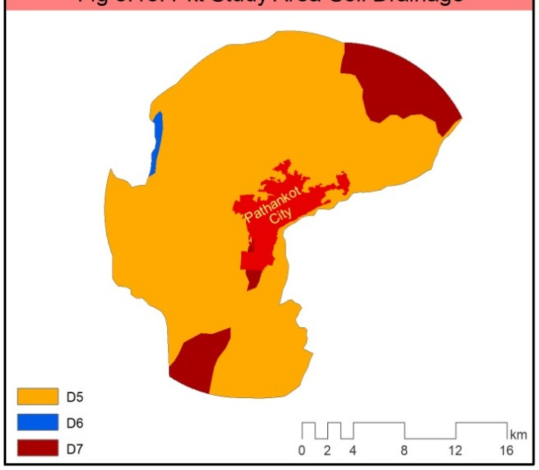


Fig 5.16: Pkt Study Area-Groundwater Level

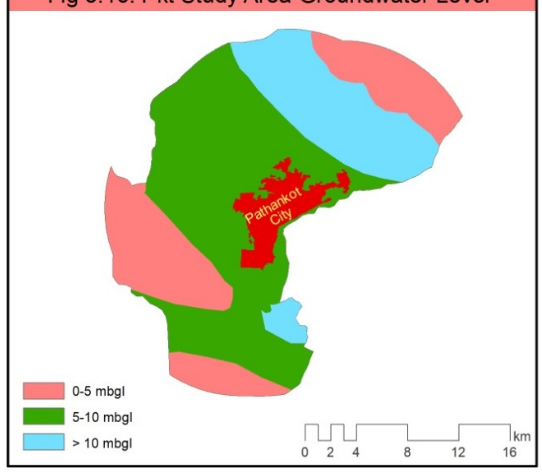


Fig 5.17: Pkt Study Area-Distance from City

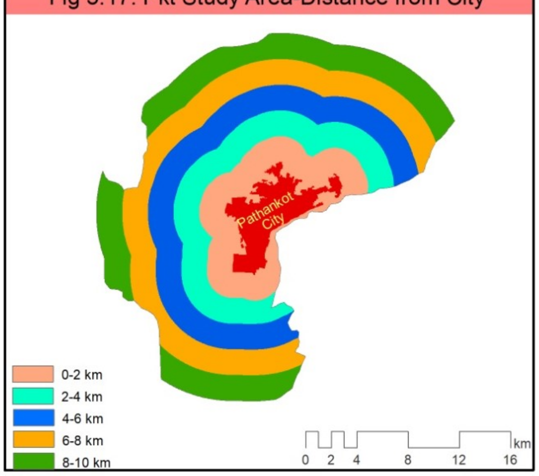


Fig 5.18: Pkt Study Area-Distance from Canals

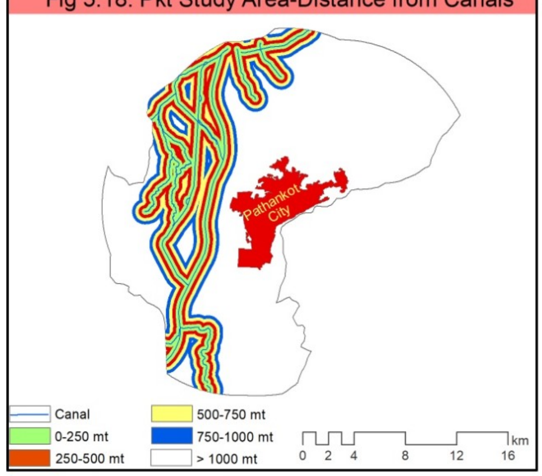


Fig 5.19: Pkt Study Area-Distance from Drains

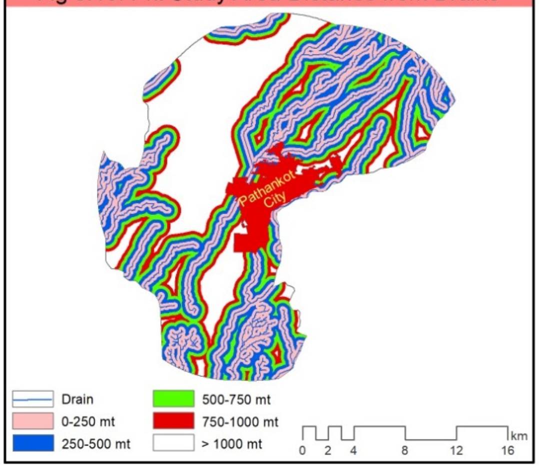


Fig 5.20: Pkt Study Area-Distance from Settlements

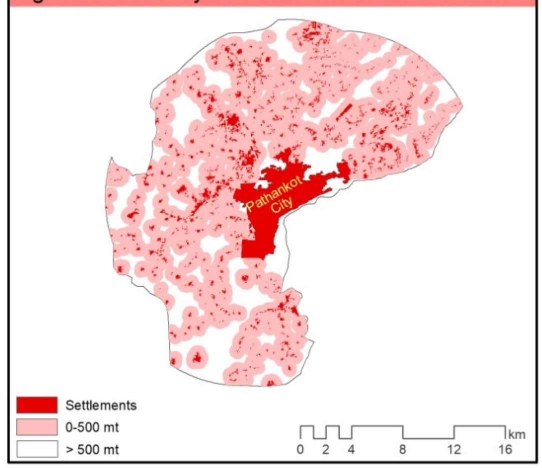


Fig. 5.21: Pkt Study Area-Slope

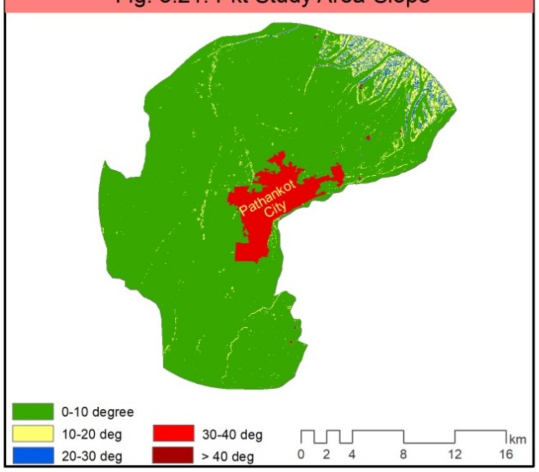


Fig 5.22: Pkt Study Area-Distance from Roads

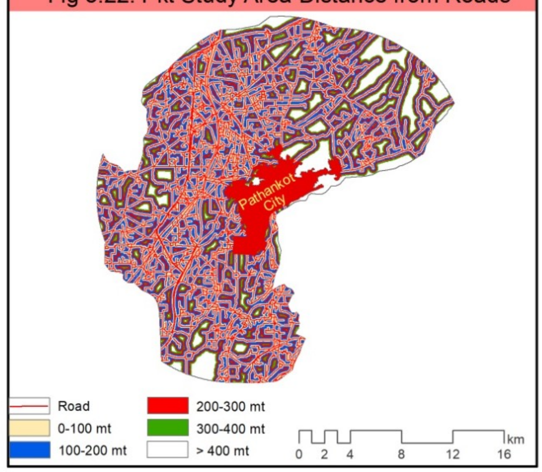


Fig 5.23: Pkt Study Area-Suitable Areas

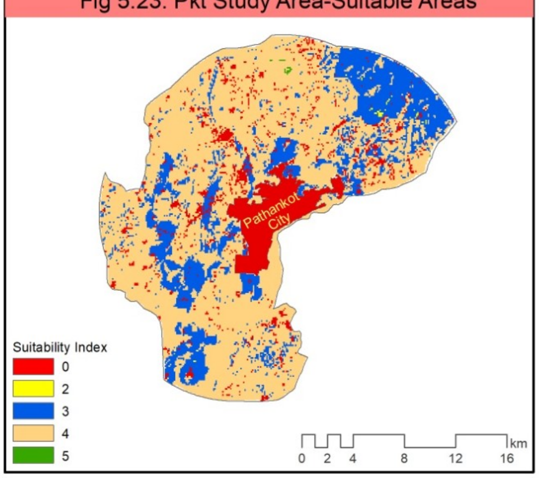
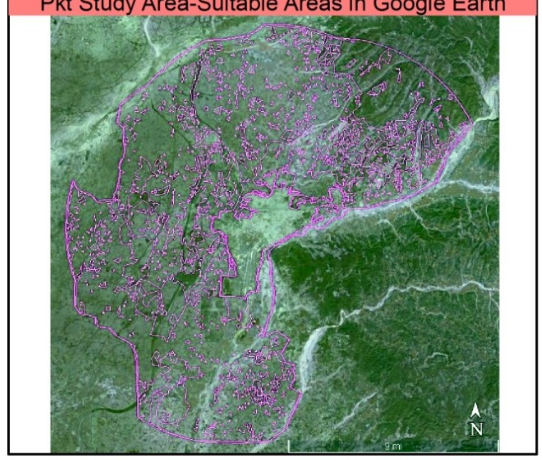


Fig 5.24:
Pkt Study Area-Suitable Areas in Google Earth



covers 47 sq km of area; 250-500 m subclass covers 39 sq km; 500-750 m subclass covers 31 sq km; 750-1000 m subclass covers the minimum 25 sq km and last subclass of >1000 m covers an area of 276 sq km (fig 5.18).

(f) Distance from Drains

Numerous drains flow in this study area. River Ravi flows along the northwestern boundary of this study area. Chakki river which is a tributary of River Beas flows along the eastern boundary of this study area. To analyze the variable of distance from drains the entire study area is divided into five subclasses viz. 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. The first subclass of 0-250 m away from drains covers 118 sq km of area; 250-500 m subclass covers 83 sq km; 500-750 m subclass covers 59 sq km; 750-1000 m subclass covers the 42 sq km and the last subclass of >1000 m from drains covers the area of 116 sq km (fig 5.19).

(g) Distance from Settlements

As already mentioned in para 5.2.1 (a) there are 521 locations of settlements in this study area. To analyze the variable of distance from villages/settlements only two subclasses are made in the study area viz. 0-500 m and > 500 m away from the settlements. The first subclass of 0-500 m from the settlement covers an area of 324 sq km and subclass of >500 m from the settlement covers 94 sq km of area (fig 5.20).

(h) Slope

To analyze the variable of slope the study area is categorized in five subclasses. Out of 418 sq km of study area the first subclass of 0-10 degrees of slope predominates over 391.15 sq km of area. It means that most parts of this study are plain or have less than 10 degrees of slope. The next subclass of 10-20 degrees of slope covers 19.87 sq km; 20-30 degrees covers 6.29 sq km; 30-40 degrees covers 0.35 sq km and > 40 degrees covers just 0.34 sq km of area (fig 5.21).

(i) Distance from Roads

Lastly, when the variable of distance from roads is analyzed for the proximity of sites to roads, the study area is divided into five subclasses viz. 0-100 m, 100-200 m, 200-300 m, 300-400 m and > 400 m from the roads. The first subclass of 0-100 m away from roads spreads over maximum area of 196 sq km followed by 100-200 m subclass covering 109 sq km; 200-300 m subclass covering 54 sq km; 300-400 m subclass covering 26 sq km and >400 m subclass covering 34 sq km of area(fig 5.22).

5.2.2 Weighted Overlay Analysis

After the conversion of all feature classes into raster datasets, percentage of influence to each variable and weightage to the subclasses of each variable are assigned on the basis of model described in chapter 4. When 'weighted overlay analysis' tool is run in ArcGIS, a new raster is generated that categorizes this study area into five suitability zones alongwith suitability index which are 0,2,3,4 and 5 (fig 5.23). In this case there is limited area of 0.3 sq km with highest suitability of 5 which is not enough to locate all three sites. Therefore, areas with suitability index of 4 need to be considered. Hence areas with suitability index of 4 and 5 are converted in Keyhole Markup Language (KML) file alongwith the KML files of all other variables to view in Google Earth (fig 5.24). Here, first of all the machine generated results are manually verified and then three sites are marked within suitable areas by once again considering all the nine variables.

5.2.3 Validation

In this step the results are tested by overlaying the sites for Pathankot municipal corporation on the layers of all nine variables. The same are depicted in table 5.4 also. First of all sites are overlaid on the layer of landuse landcover and it is found that all three sites are located in the subclass of cultivated area that is assigned the highest weightage of 5. Then on the layer of soil drainage it is discovered that all three sites are located in the subclass of

D5 or well drained soil that is assigned the weightage of 4 which is the highest value in this study area. Next, on the layer of groundwater level it is noticed that site 1 is located in the subclass of >10 mbgl which is assigned the weightage of 4, the highest weightage in this study area. Site 2 and 3 are located in the subclass of 5-10 mbgl of groundwater level which is assigned the weightage of 3. Then the sites are overlaid on the layer of distance from

Table 5.4
Sites for Pathankot MC falling under subclasses of each variable alongwith weightage

S. no.	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D5 (4)	D5 (4)	D5 (4)
3	Groundwater level	>10 mbgl (3)	5-10 mbgl (3)	5-10 mbgl (3)
4	Distance from City	6-8 km (4)	6-8 km (4)	6-8 km (4)
5	Distance from Canal	>1000 m(5)	>1000 m(5), 750-1000 m (4)	>1000 m(5)
6	Distance from Drain	>1000 m(5)	>1000 m(5)	>1000 m(5)
7	Distance from Village	>500 m(5)	>500 m(5)	>500 m(5)
8	Slope	0-10 degrees (5)	0-10 degrees (5)	0-10 degrees (5)
9	Distance from Roads	0-100 m(5)	0-100 m(5)	0-100 m(5)

city and noted that all three sites are located in the subclass of 6-8 km from the city which is assigned the weightage of 4. Next, on the layer of distance from canals it is found that all three sites are located in the subclass of > 1000 m which is assigned the weightage of 5. However some portion of site 2 falls in the category of 750-1000 m subclass which is assigned the weightage of 4. Then on the layer of distance from drains it is noticed that all three sites are located in the subclass of > 1000 m from drains which is assigned the highest weightage of 5. Next, when sites are overlaid on the layer of distance from villages or settlements it is discovered that all three sites are located in the subclass of >500 m from settlements which is assigned the highest weightage of 5. Then the sites are overlaid on the layer of slope and it is found that all three sites fall in the subclass of 0-10 degrees of slope which is assigned the highest weightage of 5. Lastly, all three sites are overlaid on the layer of distance from roads and noticed that all three sites are located right on the road or in the subclass of 0-100 m which is assigned the highest weightage of 5. Hence it is proved that the results of weighted overlay analysis for site identification for solid waste management of Pathankot municipal corporation are authentic and judicious because only those areas are selected by this tool that are assigned the high values on the preference scale. After validation, all three sites are finalized for managing solid waste of Pathankot municipal corporation.

5.2.4 Final Sites

After validating the results, it is discerned that all the three sites successfully satisfy all the nine variables mentioned in the "Deepak-Kalota Model of Site Identification for Solid Waste Management". These three sites are therefore finalized for solid waste management of Pathankot municipal corporation. Site 1 of 50 acres lies in north near Kamwal and Rajpura villages; Site 2 of 45 acres in northwest near Tharyal village and Site 3 again of 50 acres in the west near Bhool Chack village (fig App 2.1). Site 1 is the most preferred site followed by site 2 and site 3.

5.3 SITE IDENTIFICATION FOR JALANDHAR MC

The Jalandhar Municipal Corporation lies in the Doaba region of Punjab. This region lies between rivers Beas and Sutlej. The study area of Jalandhar municipal corporation shares its boundary with district Kapurthala on the west and Phagwara on the east which is also a part of Kapurthala district. On both sides the study area is clipped by the district boundary. After clipping, the study area of Jalandhar municipal corporation extends over 641 sq km (fig 5.25).

5.3.1 Analysis of Variables

The model of site identification is applied on the study area of Jalandhar MC to analyze all the nine variables which are described below.

(a) Landuse landcover

When the variable of landuse landcover is analyzed it is observed that

Table 5.5
Area under subclasses of each variable in Jalandhar study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	7.06
		Villages/Settlements	34.52
		Industry	0.53
		Cultivated	572
2	Soil		
		D4-Moderately well drained	11
		D5-Well drained	494
		D7- Excessively drained	136
3	Groundwater Level		
		<15 mbgl	64
		15-20 mbgl	366
		>20 mbgl	211
4	Distance from City		
		0-2 km	141
		2-4 km	118
		4-6 km	128
		6-8 km	132
		8-10 km	122
5	Distance from Canals		
		0-250 m	64
		250-500 m	62
		500-750 m	59
		750-1000 m	55
		>1000 m	401
6	Distance from Drains		
		0-250 m	73
		250-500 m	66
		500-750 m	61
		750-1000 m	56
		>1000 m	385
7	Distance from Villages/Settlements		
		0-500 m	349
		>500 m	292
8	Slope		
		0-10 degrees	639.28
		10-20 degrees	1.70
		20-30 degrees	0.02
		30-40 degrees	0
		>40 degrees	0
9	Distance from Roads		
		0-100 m	214
		100-200 m	158
		200-300 m	108
		300-400 m	67
		>400 m	94

out of 641 sq km of study area, the subclass of cultivated land covers 572 sq km which is the maximum of all subclasses in landuse landcover (table: 5.5). For the next subclass of settlements it is noticed that there are 285 number of settlements found in all parts of the study area covering an area of 34.52 sq km. Among these settlements, a bigger settlement can be seen in the northern part which is the town of Kartarpur. For the next subclass of plantation it is noted that there are 318 locations covering an area of 7.06 sq km and are more predominant in the southern part of study area. For the last subclass of industry, there are only 32 industrial locations covering an area of 0.53 sq km and are very limited in the southern part (fig 5.26).

(b) Soil Drainage

On the basis of soil drainage it is noticed that only three subclasses of soil drainage are found in this study area i.e. D4. D5 and D7. The subclass of D4 or moderately well drained soil is found in a single patch in the east that covers an area of 11 sq km. The next subclass of D5 or well drained soil is seen in most parts of the study area except west and covers the maximum area of 494 sq km. The next subclass of D7 or excessively drained soil is found in a single large patch all along the western boundary of study area that covers 136 sq km of area (fig 5.27).

(c) Groundwater Level

On the basis of groundwater level, a total of three levels are found in this study area which are < 15 mbgl (meters below ground level), 15-20 mbgl and >20 mbgl. Subclass of <15 mbgl is found in three patches in north, south and west that collectively cover an area of 64 sq km. Next subclass of 15-20 mbgl is found in most parts of study area and covers maximum area of 366 sq km. The subclass of >20 mbgl is found in central and southeastern part of study area that covers an area of 211 sq km (fig 5.28).

(d) Distance from City

To analyze the variable of distance from city the study area is divided

Fig 5.25: Location of Jalandhar Study Area in District

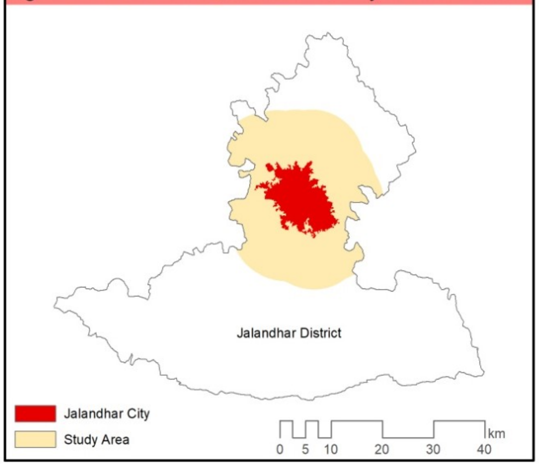


Fig 5.26: Jal Study Area-Landuse Landcover

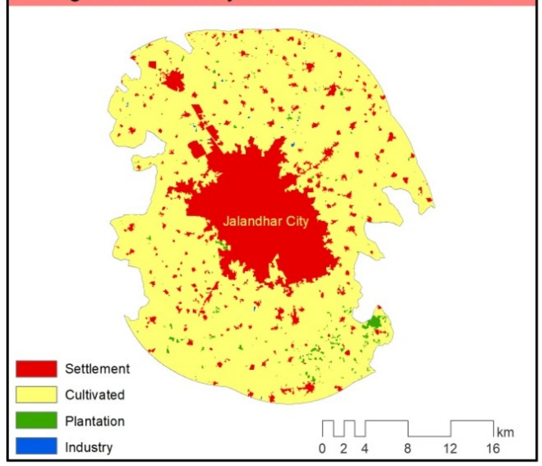


Fig 5.27: Jal Study Area-Soil Drainage

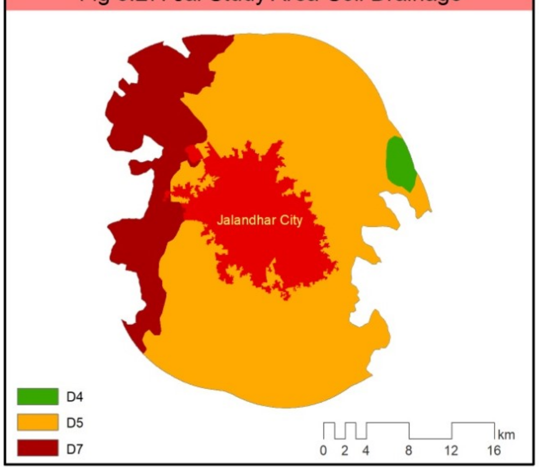


Fig 5.28: Jal Study Area-Groundwater Level

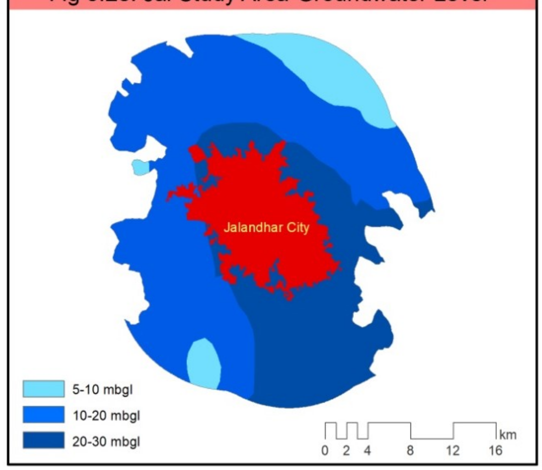


Fig 5.29: Jal Study Area-Distance from City

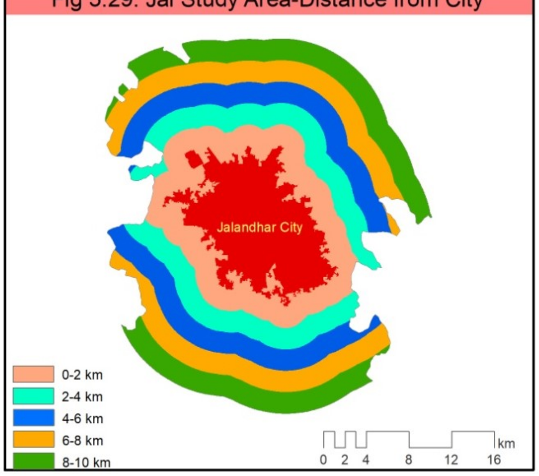


Fig 5.30: Jal Study Area-Distance from Canals

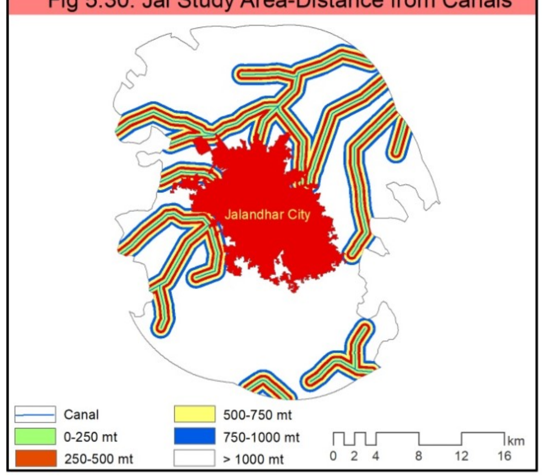


Fig 5.31: Jal Study Area-Distance from Drains

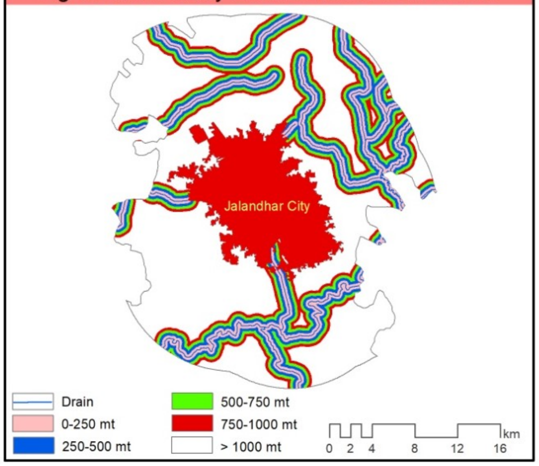


Fig 5.32: Jal Study Area-Distance from Settlements

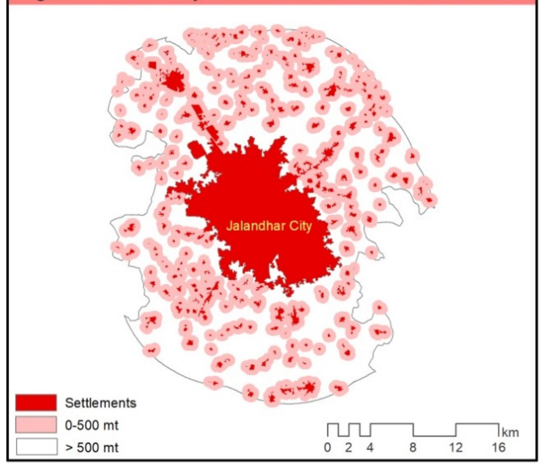


Fig. 5.33: Jal Study Area-Slope

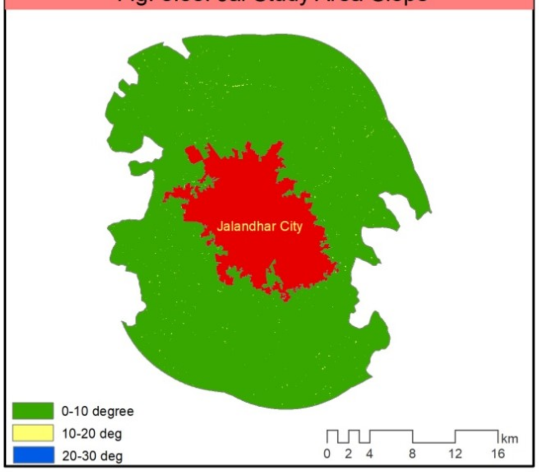


Fig 5.34: Jal Study Area-Distance from Roads

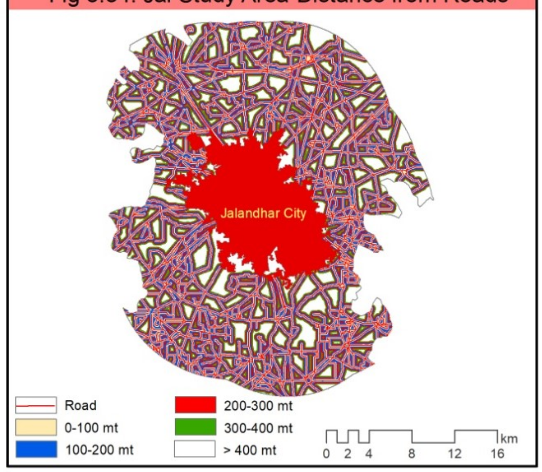


Fig 5.35: Jal Study Area-Suitable Areas

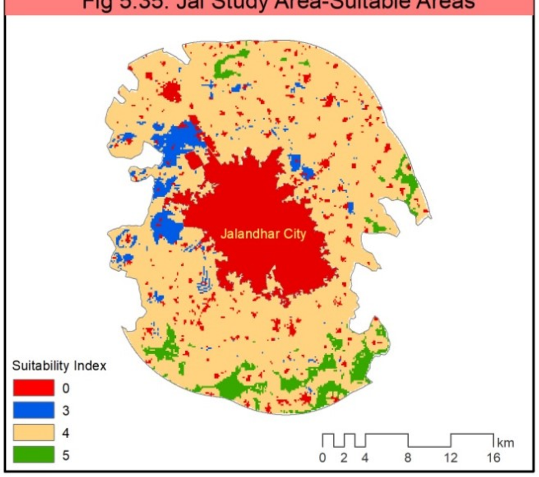
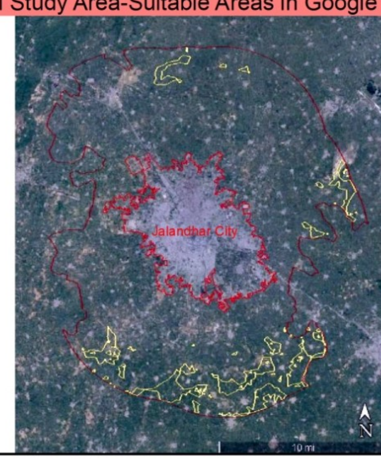


Fig 5.36:
Jal Study Area-Suitable Areas in Google Earth



into five zones or subclasses: 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the city. The zone or subclass of 0-2 km from city occupies an area of 141 sq km which is highest of all subclasses, 2-4 km subclass covers 118 sq km, 4-6 km subclass covers 128 sq km, 6-8 km subclass covers 132 and 8-10 km subclass covers 122 sq km of area (fig 5.29).

(e) Distance from Canals

There are numerous canals in this study area which distribute from Jalandhar and Nawanshahr branches of canal originating from Sutlej river near Ropar. In order to protect fresh water of canals the variable of distance from canals is analyzed. For this, the entire study area is divided into five zones or subclasses: 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. The first zone or subclass of 0-250 m has an area of 64 sq km, 250-500 m subclass has 62 sq km, 500-750 m subclass has 59 sq km, 750-1000 m subclass has an area of 55 sq km and subclass of more than 1000 m from the canals covers maximum area of 401 sq km (fig 5.30).

(f) Distance from Drains

There are several drains in this study area and the most important white bein drain flows in the southern part of the study area. On the basis of distance from drains also the study area of Jalandhar municipal corporation is divided into five zones or subclasses: 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. It is noticed that the zone or subclass of 0-250 m has an area of 73 sq km, 250-500 m subclass has 66 sq km, 500-750 m subclass has 61 sq km, 750-1000 m subclass has an area of 56 sq km and subclass of more than 1000 m covers maximum area of 385 sq km (fig 5.31).

(g) Distance from Settlements

As already described in para 5.3.1 (a) the Jalandhar municipal corporation has 285 number of settlements. This variable is analyzed to protect the habitable areas from the expected pollution emanating from proposed site. Moreover the rules also state that any site of solid waste management must be at least 500 meters away from the residential areas (Ministry of Urban Development, 2016). To analyze this variable, the study area is divided into two subclasses: 0-500 m and > 500 m from the settlements. It is found that the zone of 0-500 m covers an area of 349 sq km and the second subclass of more than 500 m covers an area of 292 sq km (fig 5.32).

(h) Slope

To analyze slope, when model for site identification is applied on this study area, it is noticed that only three categories of slope are there in this study area which are : 0-10 degrees, 10-20 and 20-30 degrees. It is found that 639.28 sq km of area falls in 0-10 degrees of slope, 1.70 sq km of area falls in 10-20 degrees and negligible 0.02 sq km of area in 20-30 degrees of slope. Hence this study area is characterized by flatness or has less than 10 degrees of slope (fig 5.33).

(i) Distance from Roads

To analyze the proximity of proposed site to the roads the study area is divided into five zones or subclasses with regard to distance from roads. It is also noted that this study area has sufficient density of roads. Maximum area of 214 sq km lies in the first subclass of 0-100 m followed by 158 sq km in 100-200 m subclass, 108 sq km in 200-300 m subclass, 67 sq km in 300-400 m subclass and 94 sq km in more than 400 m subclass (fig 5.34).

5.3.2 Weighted Overlay Analysis

After processing, all data or feature classes are converted into raster format and assigned percentage of influence to all the variables and weightage to the subclasses of variables on the basis of model already discussed in chapter 4. In ArcGIS when the tool of weighted overlay analysis is run for the study area of Jalandhar municipal corporation, a new raster is generated that categorizes the study area in four categories on the basis of suitability index i.e. 0, 3, 4 and 5 (fig 5.35). The areas with highest suitability index of 5 cover only 6.08 % of the study area. This suitable area is then extracted and converted into Keyhole Markup Language (KML) file so that the same can be viewed in Google Earth (fig 5.36). In Google Earth first of all the machine generated results are verified manually. Here all nine variables are once again kept in mind while locating three sites of 50 acres each within suitable areas.

5.3.3 Validation

After locating three sites, the same are validated by overlaying on layers of all the nine variables. When sites are overlaid on landuse landcover layer it is observed that all three sites are on the cultivated land that is assigned highest weightage of 5 (table: 5.6). On the layer of soil drainage it is found that all three sites are located on D5 subclass or well drained soil that is assigned the weightage of 4. On the layer of groundwater it is noticed that

Table 5.6
Sites for Jalandhar MC falling under subclasses of each variable alongwith weightage

S. no.	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D5 (4)	D5 (4)	D5 (4)
3	Groundwater level	15-20 mbgl (4)	15-20 mbgl (4)	>20 mbgl (5)
4	Distance from City	6-8 km (4)	8-10 km (5)	6-8 km (4)
5	Distance from Canal	>1000 m(5)	>1000 m(5)	>1000 m(5)
6	Distance from Drain	>1000 m(5)	>1000 m(5)	>1000 m(5)
7	Distance from Village	>500 m(5)	>500 m(5)	>500 m(5)
8	Slope	0-10 degrees (5)	0-10 degrees (5)	0-10 degrees (5)
9	Distance from Roads	0-100 m(5)	0-100 m(5)	0-100 m(5)

all three sites are located in the subclass of 15-20 mbgl which is assigned the weight of 4. Then on the layer of distance from city it is noted that site 1 and site 3 lie in the subclass of 6-8 km from city that is assigned the weight of 4 while site 2 is located in the farthest subclass of 8-10 km zone that is assigned the weight of 5. Then on the layer of distance from canals it is noticed that all three layers are located in the subclass of more than 1000 m away from canal that is assigned the weightage of 5. Then on the layer of distance from drains it is found that all three sites are located in the subclass of maximum distance from drains i.e. 1000 m which is assigned the weight of 5. When sites are overlaid on the layer of distance from settlements or villages and it is noticed that all three sites are located in the subclass of > 500 m from settlements that is assigned the maximum weight of 5. On the layer of slope it is noted all three sites are located in the subclass of 0-10 degrees that is assigned the maximum weightage of 5. When sites are overlaid on the last layer of distance of roads it is found that all three sites are located right on the road or in the first zone of 0-100 m from road that is assigned the maximum weight of 5. Hence it is proved that the results of weighted overlay analysis for site identification for solid waste management of Jalandhar municipal corporation are authentic and judicious because only those areas are selected by this tool that are assigned the high values on the preference scale. Manual authentication is also performed and after validation, all three sites are finalized for managing solid waste of Jalandhar municipal corporation.

5.3.4 Final Sites

After validating the results, it is noticed that all the three sites successfully satisfy all the nine variables mentioned in the "Deepak-Kalota Model of Site Identification for Solid Waste Management". These three sites are therefore finalized for solid waste management of Jalandhar municipal corporation. Site 1 is selected in the southwest part of study area near Kang Sabhu and Singh villages; site 2 is selected in the southern part near Chak Khurd village and site 3 is selected in the south near Kangniwal village. Site 1 is the most preferred site followed by site 2 and site 3 (fig App 3.1).

5.4 SITE IDENTIFICATION FOR HOSHIARPUR MC

The study area of Hoshiarpur municipal corporation lies in the foothill zone of Shiwaliks in Doaba region of Punjab. The hills of Shiwaliks cover some portion of this study area in the northeast. The study area of Hoshiarpur municipal corporation shares its boundary with Jalandhar district in the southwest where it is clipped with the district boundary (fig 5.37). After clipping a total area of 576 sq km remains to identify suitable sites for solid waste management.

5.4.1 Analysis of Variables

To apply the model for site identification, all nine variables are analyzed for the study area of Hoshiarpur MC and are described below.

(a) Landuse landcover

While analyzing the variable of landuse landcover it is observed that the subclass of cultivated area exists in all parts of the study area except in the northeast where forests dominate. Among all subclasses of landuse landcover the cultivated area predominates covering 385 sq km of area (table 5.7). The plantation/forest area can be seen all across the study area. There are 3889 locations of plantations or forest which occupy an area of 133.58 sq km. The plantation or forest cover is more predominant in the northeastern portion where Shiwaliks are situated. Next subclass of settlements spreads over 21.58 sq km. In total 306 number of settlements can be seen all across the study area except northeastern hilly area where settlements are limited due to rugged terrain and forests. Two large sized settlements can be seen in this study area. First is Chak Gujran village in the southwest and the second is Chohal village that lies in the piedmont area in northeast. The subclass of industries can be seen at 109 locations covering only 1.03 sq km of area and is well distributed all across the study area except northeastern hilly area (fig 5.38).

(b) Soil Drainage

In terms of soil drainage only three subclasses are found in this study area i.e. D4, D5 and D7. The D4 subclass or moderately well drained soil is found in two patches in south and southwest covering an area of 95 sq km. D5 subclass of well drained soil is seen in most parts of the study area and covers the maximum area of 431 sq km. The D7 or excessively drained soil is found only in northeast and occupies only 50 sq km of area (fig 5.39).

(c) Groundwater Level

While analyzing the variable of groundwater level it is observed that this study area has four subclasses viz. 2-5 mbgl (meters below ground level)

Table 5.7
Area under subclasses of each variable in Hoshiarpur study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	133.58
		Villages/Settlements	21.58
		Industry	1.03
		Cultivated	385
2	Soil		
		D4- Moderately Well Drained	95
		D5-Well Drained	431
		D7- Excessively drained	50
3	Groundwater Level		
		0-5 mbgl	75
		5-10 mgl	259
		10-20 mbgl	235
		>20 mbgl	7
4	Distance from City		
		0-2 km	71
		2-4 km	89
		4-6 km	115
		6-8 km	139
		8-10 km	162
5	Distance from Canals		
		0-250 m	14
		250-500 m	14
		500-750 m	14
		750-1000 m	14
		>1000 m	519
6	Distance from Drains		
		0-250 m	131
		250-500 m	108
		500-750 m	82
		750-1000 m	60
		>1000 m	195
7	Distance from Villages/Settlements		
		0-500 m	330
		>500 m	246
8	Slope		
		0-10 degrees	527.46
		10-20 degrees	37.87
		20-30 degrees	9.58
		30-40 degrees	1.12
		>40 degrees	0.009
9	Distance from Roads		
		0-100 m	259
		100-200 m	149
		200-300 m	72
		300-400 m	33
		>400 m	63

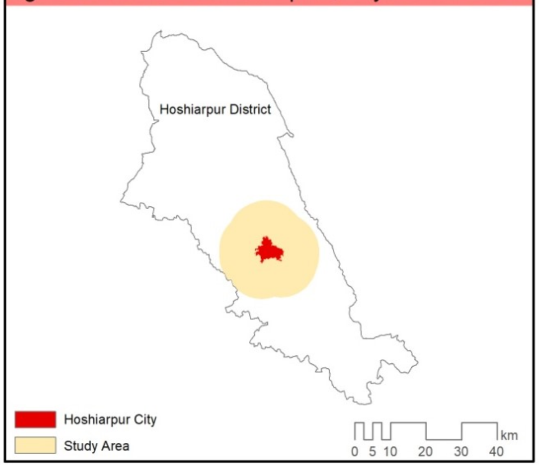


Fig 5.37: Location of Hoshiarpur Study Area in District

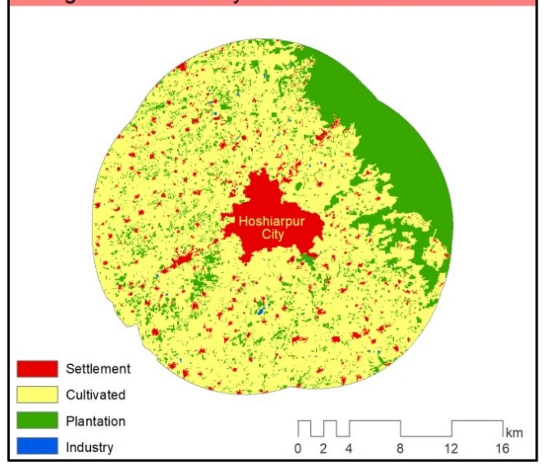


Fig 5.38: Hsh Study Area-Landuse Landcover

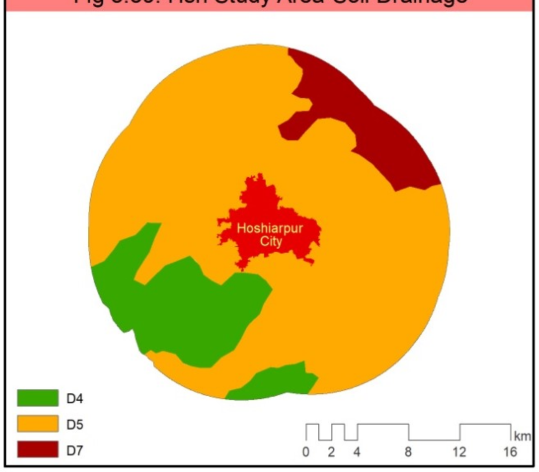


Fig 5.39: Hsh Study Area-Soil Drainage

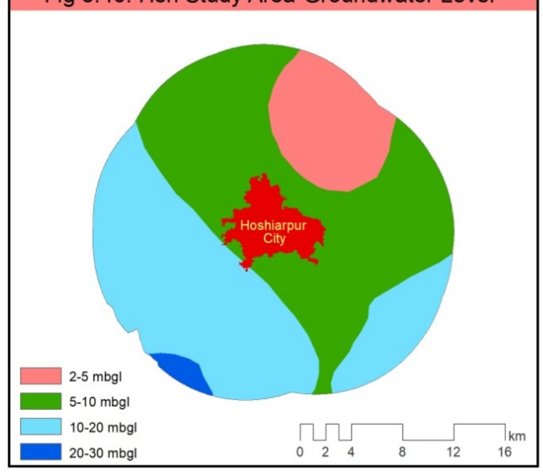


Fig 5.40: Hsh Study Area-Groundwater Level

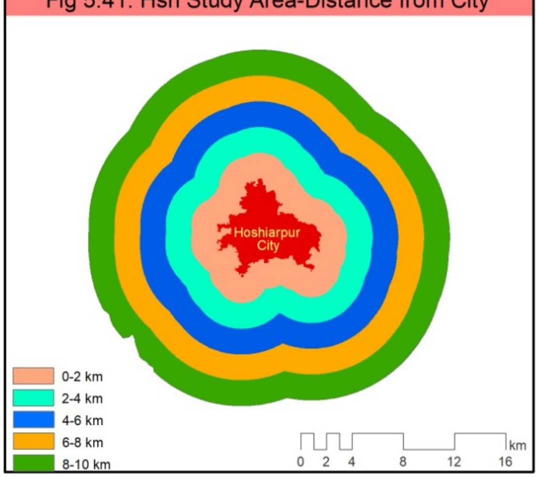


Fig 5.41: Hsh Study Area-Distance from City

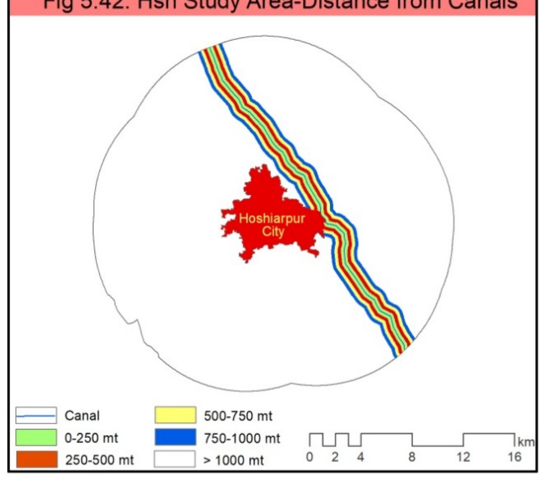


Fig 5.42: Hsh Study Area-Distance from Canals

Fig 5.43: Hsh Study Area-Distance from Drains

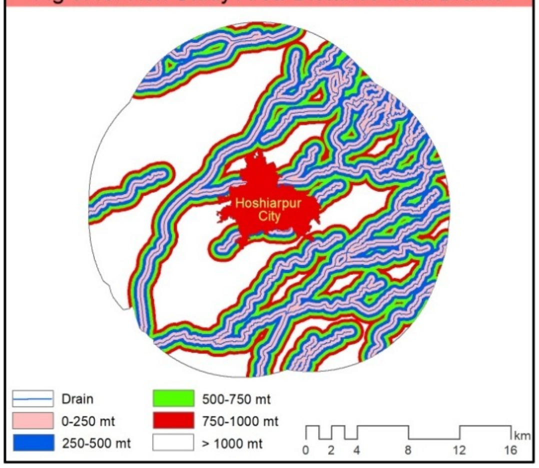


Fig 5.44: Hsh Study Area-Distance from Settlements

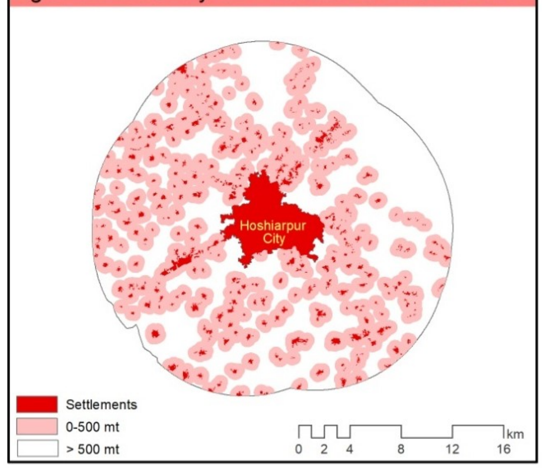


Fig. 5.45: Hsh Study Area-Slope

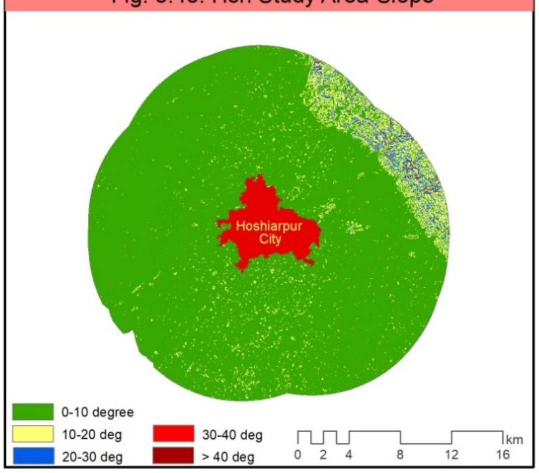


Fig 5.46: Hsh Study Area-Distance from Roads

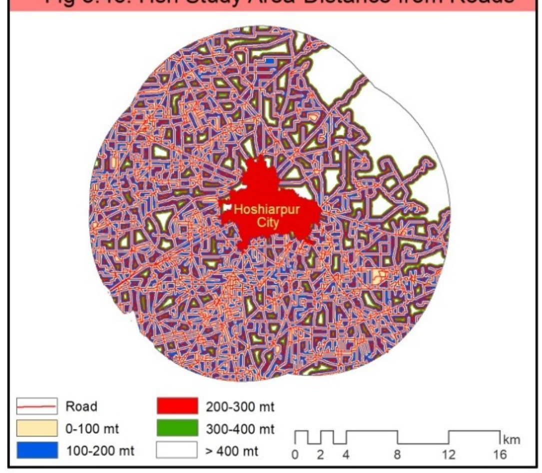


Fig 5.47: Hsh Study Area-Suitable Areas

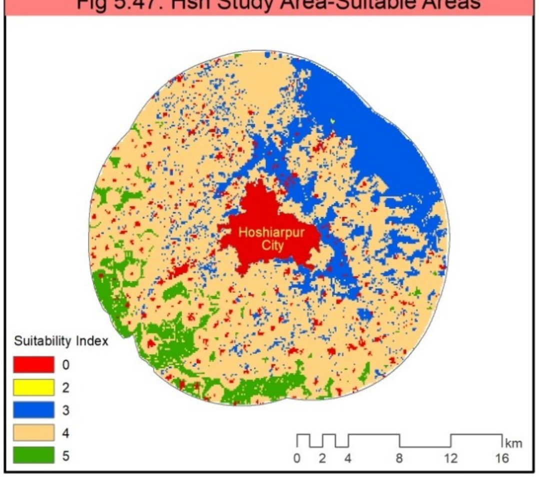
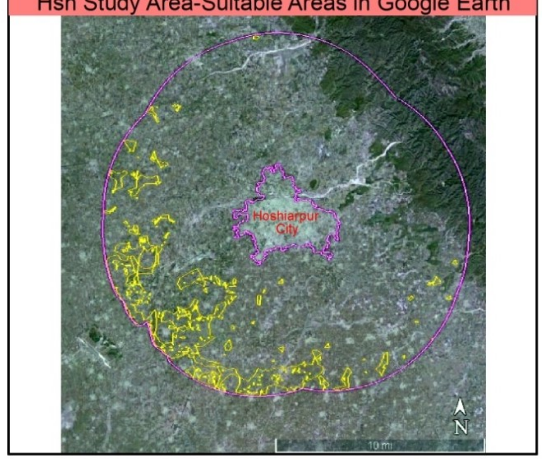


Fig 5.48:
Hsh Study Area-Suitable Areas in Google Earth



5-10 mbgl, 10-20 mbgl and 20-30 mbgl. The 2-5 mbgl subclass is found only in the northeastern part of the study area and covers 75 sq km of area. The 5-10 mbgl category is seen in most parts of northeastern half of study area and some parts in southeast covering 259 sq km which is maximum area among all subclasses of groundwater level. Third subclass of 10-20 mbgl covers most parts in southwestern half of study area in 235 sq km of area. The subclass of >20 or 20-30 mbgl covers only 7 sq km of area in the southwest (fig 5.40).

(d) Distance from City

To analyze the variable of distance from city the study area is divided into five zones or subclasses: 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the outer limit of the city. The closest zone or subclass of 0-2 km from the city covers 71 sq km of area; subclass of 2-4 km from city covers 89 sq km; subclass of 4-6 km from city covers 115 sq km; subclass of 6-8 km from city covers 139 sq km and the farthest subclass of 8-10 km from the city covers the maximum area of 162 sq km (fig 5.41).

(e) Distance from Canals

There is only one canal in this study area. To analyze the variable of distance from canal the entire study area is divided into five zones or subclasses: 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from canal. The first zone or subclass which is of 0-250 m away from canal covers 14 sq km of area; 250-500 m subclass covers 14 sq km; 500-750 m subclass covers 14 sq km; 750-1000 m subclass covers the 14 sq km and the last subclass of > 1000 m covers the maximum area of 519 sq km (fig 5.42).

(f) Distance from Drains

There are numerous drains in this study area. To analyze the variable of distance from drains the entire study area is divided into five zones or subclasses: 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. The first zone or subclass of 0-250 m away from drains covers 131 sq km of area; 250-500 m subclass covers 108 sq km; 500-750 m subclass covers 82 sq km; 750-1000 m subclass covers the 60 sq km and the last subclass of

>1000 m covers the maximum area of 195 sq km (fig 5.43).

(g) Distance from Settlements

As already mentioned in para 5.4.1 (a) there are 306 number of settlements in this study area which are found in all parts of study are except northeastern hilly region. To analyze the variable of distance from settlements two zones are made in the study area i.e. 0-500 m and > 500 m. The first zone of 0-500 m cover 330 sq km and second zone of > 500 m from settlements covers 246 sq km of area (fig 5.44).

(h) Slope

To analyze the variable of slope the study area is categorized in five subclasses : 0-10 degrees, 10-20 degrees, 20-30 degrees, 30-40 degrees and more than 40 degrees. Out of 576 sq km of study area the first subclass of 0-10 degrees of slope predominates over 527.46 sq km of area followed by 10-20 degrees in 37.87 sq km; 20-30 degrees in 9.58 sq km; 30-40 degrees in 1.12 sq km and > 40 degrees in just 0.009 sq km of area. This study area is more or less flat except the northeastern hilly area (fig 5.45).

(i) Distance from Roads

Lastly, to analyze the proximity of proposed sites to the road, the study area is divided into five zones or subclasses 0-100 m, 100-200 m, 200-300 m, 300-400 m and more than 400 m. The first zone or subclass of 0-100 m away from roads spreads over maximum area of 259 sq km followed by 100-200 m subclass covering 149 sq km; 200-300 m subclass covering 72 sq km; 300-400 m subclass covering 33 sq km and > 400 m subclass covering 63 sq km of area. The study area has sufficient density of roads except in the northeastern hilly area (fig 5.46).

5.4.2 Weighted Overlay Analysis

After analysis and conversion of data into raster datasets, percentage of influence to each variable and weightage to the subclasses of each variable are assigned on the basis of model mentioned in chapter 4. Then the tool of 'weighted overlay analysis' is run in ArcGIS which generates a new raster dataset that categorizes this study area in five suitability zones alongwith suitability index i.e. 0,2,3,4 and 5 (fig 5.47). Since 5 the highest suitability, these areas constituting 7.67% of the study area are extracted and converted into Keyhole Markup Language (KML) file alongwith the KML files of all other variables to view in Google Earth (fig 5.48). Here the machine generated results are first of all manually verified. It is also a kind of manual authentication of the machine generated results. Then three sites of 50 acres each are located within the suitable areas. While locating three sites in Google Earth, all nine variables are once again considered for the best possible results.

5.4.3 Validation

After locating the sites for the study area of Hoshiarpur municipal corporation the results are validated by overlaying the sites on the layers of all nine variables. The same are depicted in the table 5.8 also. First of all sites are overlaid on the layer of landuse landcover and it is found that all three sites are located in the subclass of cultivated area that is assigned the highest weightage of 5. Then on the layer of soil drainage it is discovered that all three sites are located in the subclass of D4 or moderately well drained soil that is assigned the highest weightage of 5. Then, on the layer of groundwater level it is noted that all three sites are located in the subclass of 10-20 mbgl which is assigned the weightage of 4. Next, the sites are overlaid on the layer of distance from city and noted that Site 1 is located in the subclass of 6-8 km which is assigned the weightage of 4; site 2 is located in the subclass of 8-10 km which is assigned the highest weightage of 5 and site 3 is located in the subclass of 4-6 km which is assigned the weightage of 3. Next, on the layer of distance from canal it is found that all three sites are located in the subclass of > 1000 m which is assigned the weightage of 5. Next, on the layer of distance from drains it is noticed that all three sites are located in the subclass of > 1000 m from drains which is assigned the highest weightage of 5. Next, when sites are overlaid on the layer of distance from villages or settlements, it is found that

Table 5.8
Sites for Hoshiarpur MC falling under subclasses of each variable alongwith weightage

S. no	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D4 (5)	D4 (5)	D4 (5)
3	Groundwater level	10-20 mbgl (4)	10-20 mbgl (4)	10-20 mbgl (4)
4	Distance from City	6-8 km (4)	8-10 km (5)	4-6 km (3)
5	Distance from Canal	>1000 m(5)	>1000 m(5)	>1000 m(5)
6	Distance from Drain	>1000 m(5)	>1000 m(5)	>1000 m(5)
7	Distance from Village	>500 m(5)	>500 m(5)	>500 m(5)
8	Slope	0-10 degrees (5)	0-10 degrees (5)	0-10 degrees (5)
9	Distance from Roads	0-100 m(5)	0-100 m(5)	0-100 m(5)

all three sites are located in the subclass of >500 m from settlements which is assigned the highest weightage of 5. Then the sites are overlaid on the layer of slope and it is found that all three sites fall in the subclass of 0-10 degrees of slope which is assigned the highest weightage of 5. Lastly, all three sites are overlaid on the layer of distance from roads and noticed that all three sites are located right on the road or in the subclass of 0-100 m which is assigned the highest weightage of 5. Hence it is proved that the results of weighted overlay analysis for site identification for solid waste management of Hoshiarpur MC are authentic and judicious because only those areas are selected by this tool that are assigned the high values on the preference scale. After validation, all three sites are finalized to manage the solid waste of Hoshiarpur MC.

5.4.4 Final Sites

After validating the results, it is observed that all the three sites successfully satisfy all the nine variables mentioned in the "Deepak-Kalota Model of Site Identification for Solid Waste Management". These three sites are therefore finalized for solid waste management of Hoshiarpur municipal corporation. Site 1 lies in southwest near Arjam village; Site 2 lies in west near Badala Mahi village and Site 3 in west near Gagnuli village (fig App 4.1). Site 1 is the most preferred site followed by site 2 and 3.

5.5 SITE IDENTIFICATION FOR PHAGWARA MC

The study area of Phagwara municipal corporation lies in Doaba region of Punjab. It shares its boundary with three districts i.e. Jalandhar in the west and south, Nawanshahr in east and Hoshiarpur in the northeast. On all three sides its boundary is clipped with the district boundaries (fig 5.49). After clipping a total of 217 sq km area remains that is available for site identification for solid waste management. It therefore, becomes the smallest of all the ten study areas.

5.5.1 Analysis of Variables

To apply the model of site identification, all the nine variables are analyzed for the study area of Phagwara municipal corporation. Their description is given below.

(a) Landuse Landcover

While analyzing the variable of landuse landcover, it is noted that out of 217 sq km of study area, the subclass of cultivated area occupies maximum area of 205.89 sq km and it can be seen in all parts of study area (table 5.9). The subclass of plantation/forest is well distributed throughout the study area which is found in 172 locations covering 5.10 sq km of area. The next subclass of settlements or villages numbering 93 cover 11.86 sq km of area and can be seen in all parts of the study area. To the north a bigger sized settlement Bhulla Rai can be seen adjoining Phagwara city. Subclass of industries is very limited and can be seen at just 15 locations and most of these can be seen only north of Phagwara city covering only 0.22 sq km of area (fig 5.50).

(b) Soil Drainage

While analyzing the variable of soil drainage it is observed that only two subclasses of soil drainage are found in this study area i.e. D4 and D5. The D4 or moderately well drained soil is found in two patches in northern part of study area covering 73 sq km of area while D5 or well drained soil covers an area of 144 sq km spreading all across the study area (fig 5.51).

Table 5.9
Area under subclasses of each variable in Phagwara study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	5.10
		Villages/Settlements	11.86
		Industry	0.22
		Cultivated	205.89
2	Soil		
		D4-Moderately Well Drained	73
		D5-Well Drained	144
3	Groundwater Level		
		10-20 mbgl	86
		>20 mbgl	131
4	Distance from City		
		0-2 km	48
		2-4 km	48
		4-6 km	47
		6-8 km	36
		8-10 km	38
5	Distance from Canals		
		0-250 m	15
		250-500 m	16
		500-750 m	16
		750-1000 m	17
		>1000 m	153
6	Distance from Drains		
		0-250 m	31
		250-500 m	28
		500-750 m	25
		750-1000 m	22
		>1000 m	111
7	Distance from Villages/Settlements		
		0-500 m	139
		>500 m	78
8	Slope		
		0-10 degrees	172.63
		10-20 degrees	38.77
		20-30 degrees	4.63
		30-40 degrees	0.81
		>40 degrees	0.16
9	Distance from Roads		
		0-100 m	90
		100-200 m	60
		200-300 m	34
		300-400 m	17
		>400 m	16

Fig 5.49: Location of Phagwara Study Area in District

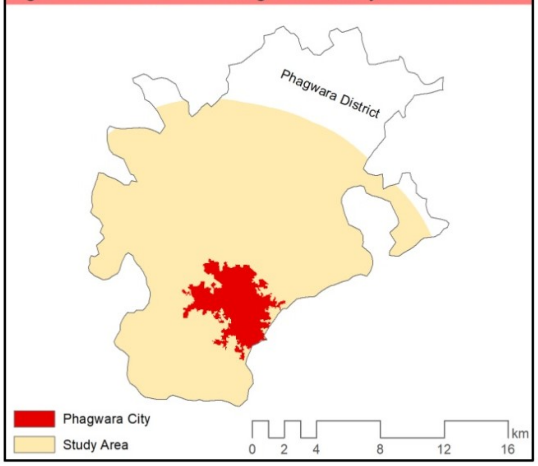


Fig 5.50: Phg Study Area-Landuse Landcover

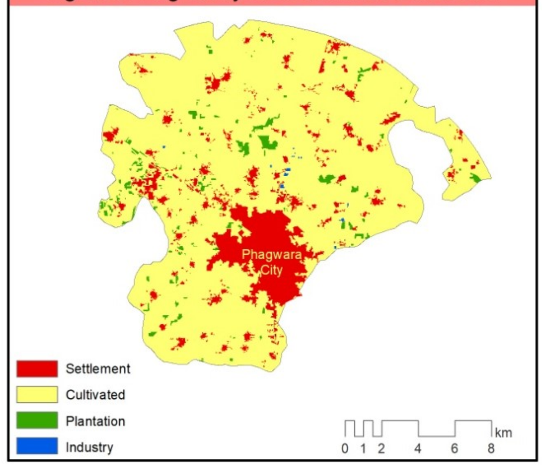


Fig 5.51: Phg Study Area-Soil Drainage

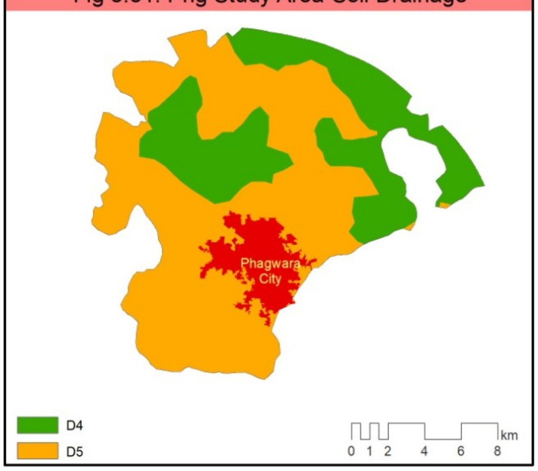


Fig 5.52: Phg Study Area-Groundwater Level

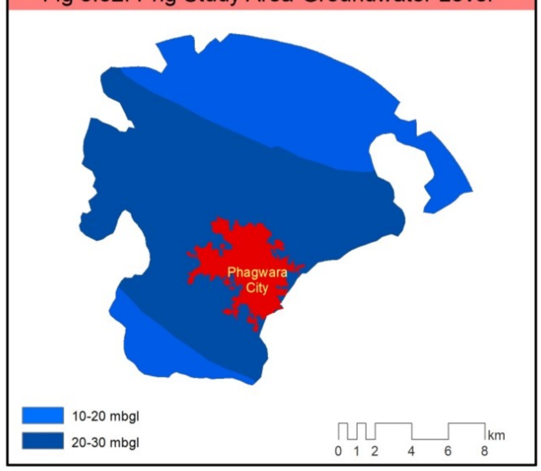


Fig 5.53: Phg Study Area-Distance from City

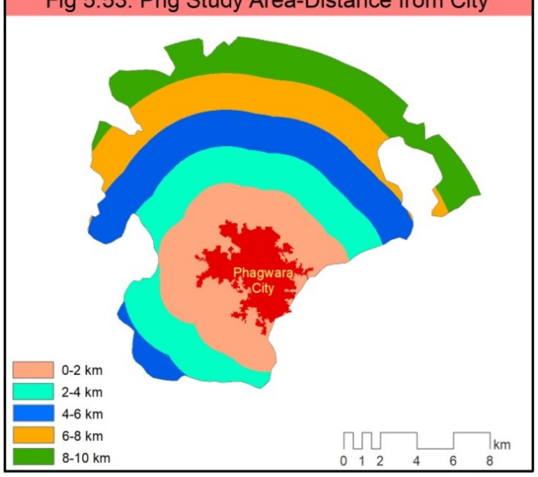


Fig 5.54: Phg Study Area-Distance from Canals

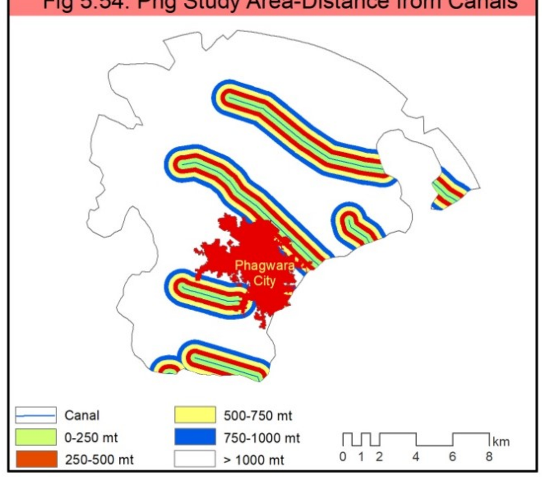


Fig 5.55: Phg Study Area-Distance from Drains

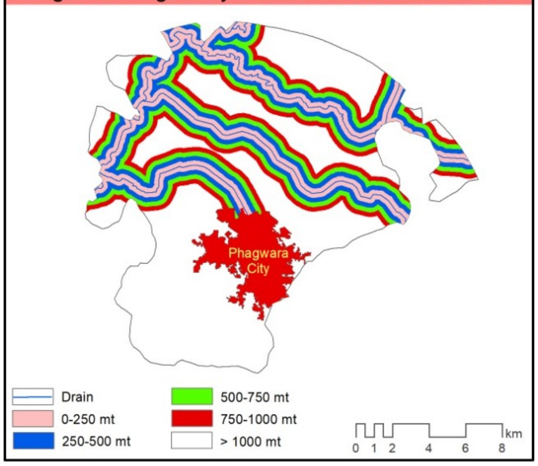


Fig 5.56: Phg Study Area-Distance from Settlements

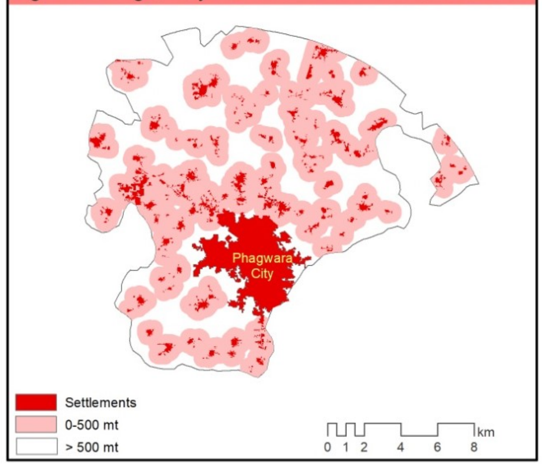


Fig. 5.57: Phg Study Area-Slope

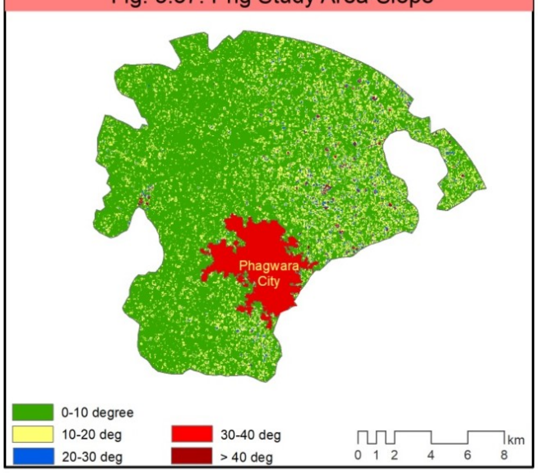


Fig 5.58: Phg Study Area-Distance from Roads

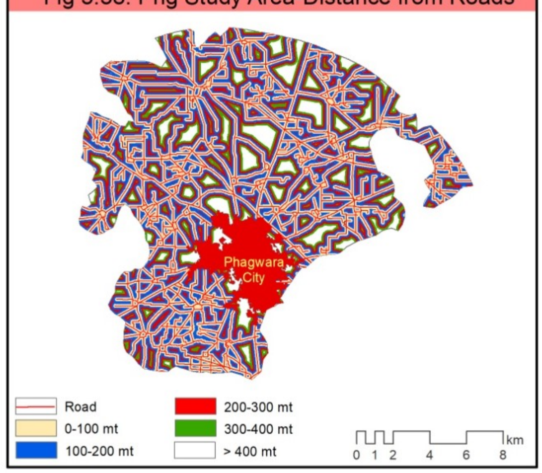


Fig 5.59: Phg Study Area-Suitable Areas

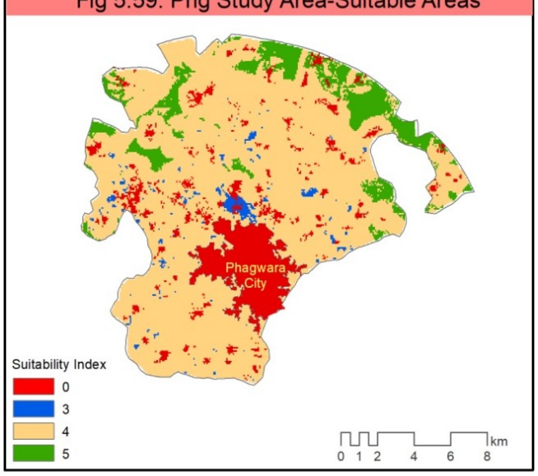
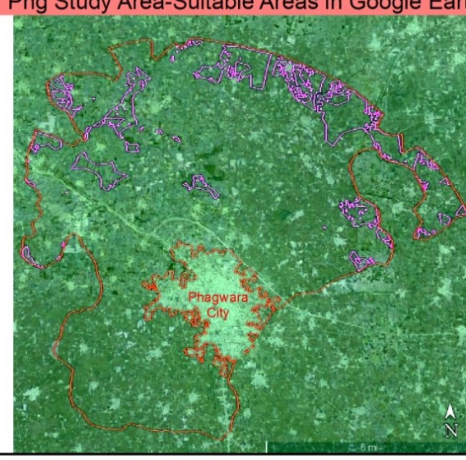


Fig 5.60:
Phg Study Area-Suitable Areas in Google Earth



(c) Groundwater Level

While analyzing the variable of groundwater level it is observed that only two subclasses of groundwater level are found in this study area i.e. 10-20 mbgl (meters below ground level) and >20 mbgl. The 10-20 mbgl subclass is found in two patches; one in the extreme north and the other in the extreme south covering 86 sq km of area in total. The subclass of >20 mbgl is found in a large single patch covering most of the study area in 131 sq km (fig 5.52).

(d) Distance from City

In order to analyze the variable of distance from city the entire study area is divided into five zones or subclasses. These are 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the outer limit of the city. The subclass of 0-2 km from the city covers 48 sq km of area; subclass of 2-4 km from city also covers 48 sq km; subclass of 4-6 km from city covers 47 sq km; subclass of 6-8 km from city covers 36 sq km and the last subclass of 8-10 km from the city covers 38 sq km of area (fig 5.53).

(e) Distance from Canals

Canals are found almost in all parts of the study area. To analyze the variable of distance from canals the study areas is divided into five zones or subclasses which are 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. The first subclass which is of 0-250 m away from canals covers 15 sq km of area; 250-500 m subclass covers 16 sq km; 500-750 m subclass covers 16 sq km; 750-1000 m subclass covers 17 sq km and the last subclass of >1000 m covers the maximum area of 153 sq km (fig 5.54).

(f) Distance from Drains

Drains are found only in the northern half of the study area. To analyze the variable of distance from drains the entire study area is divided into five zones or subclasses viz. 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m. The first zone or subclass of 0-250 m away from drains covers 31 sq km of area; 250-500 m subclass covers 28 sq km; 500-750 m subclass covers 25 sq km; 750-1000 m subclass covers the 22 sq km and the last subclass of > 1000 m covers the maximum area of 111 sq km (fig 5.55).

(g) Distance from Settlements

As already mentioned in para 5.5.1 (a) the total number of settlements is 93 and are seen in all parts of the study area. In order to analyze the variable of distance from settlements the study area is divided into two parts: 0-500 m and more than 500 m. The first subclass of 0-500 m cover 139 sq km and second subclass of > 500 m covers 78 sq km of area (fig 5.56).

(h) Slope

To analyze the variable of slope the study area is categorized in five subclasses: 0-10 degrees, 10-20 degrees, 20-30 degrees, 30-40 degrees and more than 40 degrees.. The first subclass of 0-10 degrees of slope predominates over maximum area of 172.63 sq km out of 217 sq km of study area. The next subclass of 10-20 degrees covers 38.77 sq km followed by 20-30 degrees in 4.63 sq km; 30-40 degrees in 0.81 sq km and > 40 degrees of slope in just 0.16 sq km of area. It clearly shows that the this study area is almost plain (fig 5.57).

(i) Distance from Roads

Lastly, in order to analyze the proximity of proposed sites to roads the entire study area is divided into five zones or subclasses: 0-100 m, 100-200 m, 200-300 m, 300-400 m and more than 400 m. The first subclass of 0-100 m away from roads covers maximum area of 90 sq km followed by 100-200 m subclass covering 60 sq km; 200-300 m subclass covering 34 sq km; 300-400 m subclass covering 17 sq km and > 400 m subclass covering 16 sq km of area. The present study area has sufficient density of roads (fig 5.58).

5.5.2 Weighted Overlay Analysis

After analysis, all feature classes are converted into raster datasets and assigned percentage of influence to each variable and weightage to the subclasses of each variable on the basis of model already mentioned in chapter 4. When the tool of 'weighted overlay analysis' is run in ArcGIS, a new raster dataset is generated which categorizes the entire study area into four suitability zones alongwith suitability index i.e. 0,3,4 and 5 (fig 5.59). Areas with highest suitability of 5 that constitute 10.48% of study area are extracted and converted into Keyhole Markup Language (KML) file alongwith the KML files of all other variables to view in Google Earth (fig 5.60). Here first of all the machine generated results are manually validated and then three sites of 50 acres each are marked within suitable areas. While marking three sites in Google Earth all nine variables are once again considered before marking these sites. After marking the sites, these are validated to check the efficacy of weighted overlay analysis.

5.5.3 Validation

Finally the results of site identification are tested by overlaying the sites for Phagwara municipal corporation on the layers of all nine variables which are also depicted in the table 5.10. First of all sites are overlaid on the layer of landuse landcover and it is found the all three sites are located in the subclass of cultivated area that is assigned the highest weightage of 5. Then on the layer of soil drainage it is discovered that all three sites are located in the subclass of D4 or moderately well drained soil that is assigned the highest weightage of 5 however some parts of site 2 fall in the category of D5 or well drained soil that is assigned the weightage of 4. Next, on the layer of groundwater level it is noticed that site 1 is located in the subclass of >20 mbgl which is assigned the highest weightage of 5. Site 2 and site 3 are located in the subclass of 10-20 mbgl of groundwater level which is assigned the weightage of 4. Then the sites are overlaid on the layer of distance from city and noted that site 1 is located in the subclass of 4-6 km from city that is assigned the weightage of 3 while site 2 and site 3 are located in the subclass of 8-10 km that is assigned the highest weightage of 5. Next, on the layer of distance from canals it is found that all three sites are located in the subclass of

Table 5.10
Sites for Phagwara MC falling under subclasses of each variable alongwith weightage

S. no.	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D4 (5)	D4 (5), D5(4)	D4 (5)
3	Groundwater level	>20 mbgl (5)	10-20 mbgl (4)	10-20 mbgl (4)
4	Distance from City	4-6 km (3)	8-10 km (5)	8-10 km (5)
5	Distance from Canal	>1000 m(5)	>1000 m(5)	>1000 m(5)
6	Distance from Drain	>1000 m(5)	>1000 m(5)	>1000 m(5)
7	Distance from Village	>500 m(5)	>500 m(5)	>500 m(5)
8	Slope	0-10 deg (5), 0-20 deg (4)	0-10 degrees (5), 0-20 degrees (4)	0-10 degrees (5), 0-20 degrees (4)
9	Distance from Roads	0-100 m(5)	0-100 m(5)	0-100 m(5)

> 1000 m which is assigned the weightage of 5. Then on the layer of distance from drains it is noticed that all three sites are located in the subclass of > 1000 m from drains which is assigned the highest weightage of 5. Next, when sites are overlaid on the layer of distance from villages or settlements it is discovered that all three sites are located in the subclass of >500 m from settlements which is assigned the highest weightage of 5. Then the sites are overlaid on the layer of slope and it is found that all three sites fall in the subclass of 0-10 degrees of slope which is assigned the highest weightage of 5. However some tiny pockets of all sites have slope of 10-20 and 20-30 having weightage of 4 and 3 respectively and site 3 has some dots having slope of 30-40 and > 40 degrees having weightage of 2 and 1 but these areas are too small or negligible. Lastly, all three sites are overlaid on the layer of distance from roads and noticed that all three sites are located right on the road or in the subclass of 0-100 m which is assigned the highest weightage of 5. Hence it is proved that the results of weighted overlay analysis for site identification for solid waste management of Phagwara municipal corporation are authentic and judicious because only those areas are selected by this tool that are assigned the high values on the preference scale. After validation all three sites are finalized for solid waste management in Phagwara municipal corporation.

5.5.4 Final Sites

After validating the results, it is noted that all the three sites successfully satisfy all the nine variables mentioned in the "Deepak-Kalota Model of Site Identification for Solid Waste Management". These three sites are therefore finalized for solid waste management of Phagwara municipal corporation. Site 1 lies in west near Chaheru village; Site 2 in north near Rampur Sunra village and Site 3 in northeast near Sahni village (fig App 5.1). Site 1 is the most preferred site followed by site 2 and site 3.

5.6 CONCLUSION

In total five municipal corporations of Majha and Doaba area are analyzed in this chapter namely: Amritsar, Pathankot, Jalandhar, Hoshiarpur and Phagwara. Three sites for solid waste management have been identified for each municipal corporation. For Amritsar municipal Corporation Site 1 lies in the southwest near Kaunke village; Site 2 in the southeast near Pakhoke village and Site 3 in the east near Khalehra village. For Pathankot municipal Corporation Site 1 lies in north near Kamwal and Rajpura villages; Site 2 in northwest near Tharyal village and Site 3 in west near Bhool Chack village. For Jalandhar municipal Corporation Site 1 is in southwest near Kang Sabhu and Singh villages; Site 2 is in the southern part near Chak Khurd village and Site 3 is in the south near Kangniwal village. For Hoshiarpur municipal Corporation Site 1 lies on southwest near Arjam village; Site 2 lies in west near Badala Mahi village and Site 3 in west near Gagnuli village. For Phagwara municipal Corporation Site 1 lies in west near Chaheru village; Site 2 in north near Rampur Sunra village and Site 3 in northeast near Sahni village. Hence in total fifteen sites are identified in this chapter with the help of weighted overlay analysis. The model that has already been discussed in chapter four is implemented with the help of weighted overlay analysis which judiciously considers all the nine variables that affect the site identification. The results are also verified manually in Google Earth to test the efficacy of model.

Chapter-6

SITE IDENTIFICATION FOR MUNICIPAL CORPORATIONS OF MALWA AREA

Malwa area lies in the southern part of Punjab and is separated from Majha and Doaba areas by river Sutlej. This area is famous for cotton cultivation (Department of Rural Development and Panchayats, Punjab). Comprising of 14 districts, this region has five municipal corporations namely : Ludhiana, Moga, Bathinda, Patiala and SAS Nagar or Mohali. This chapter deals with the site identification for solid waste management for these five municipal corporations using "Deepak-Kalota Model of Site Identification for Solid Waste Management".

6.1 SITE IDENTIFICATION FOR LUDHIANA MC

The study area of Ludhiana municipal corporation lies almost in the middle of Punjab state. Its northern boundary is shared by district Jalandhar and Nawanshahr. Therefore its northern boundary is clipped with the district boundary (fig: 6.1). River Sutlej flows along its northern boundary. This study area covers an area of 865 sq km.

6.1.1 Analysis of Variables

As per "Deepak-Kalota Model of Site Identification for Solid Waste Management" the first step is to analyze all the nine variables that affect the site identification process in Ludhiana municipal corporation.

(a) Landuse Landcover

First of all the variable of landuse landcover is analyzed and it is observed that among all the subclasses cultivated land covers the maximum area of 759 sq km and it is seen in all parts of the study area (table 6.1). Next, the subclass of settlements is analyzed and it is noticed that 277 number of settlements cover 53 sq km of area. In the southeast two bigger settlements

Table 6.1
Area under subclasses of each variable in Ludhiana study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	28
		Villages/Settlements	53
		Industry	4
		Cultivated	759
2	Soil		
		D4-Moderately well drained	99
		D5-Well drained	595
		D7- Excessively drained	171
3	Groundwater Level		
		5-10 mbgl	4
		10-20 mbgl	402
		20-30 mbgl	459
4	Distance from City		
		0-2 km	184
		2-4 km	166
		4-6 km	167
		6-8 km	172
		8-10 km	176
5	Distance from Canals		
		0-250 mt	89
		250-500 mt	81
		500-750 mt	72
		750-1000 mt	61
		>1000 mt	562
6	Distance from Drains		
		0-250 mt	45
		250-500 mt	42
		500-750 mt	40
		750-1000 mt	39
		>1000 mt	699
7	Distance from Villages/Settlements		
		0-500 mt	485
		>500 mt	380
8	Slope		
		0-10 degrees	832.86
		10-20 degrees	30.93
		20-30 degrees	1.1
		30-40 degrees	0.04
		>40 degrees	0.003
9	Distance from Roads		
		0-100 mt	364
		100-200 mt	238
		200-300 mt	131
		300-400 mt	65
		>400 mt	67

can be seen which are Sahnewal and Doraha towns. Another town of Mullanpur Dakha is seen in the southwest. Next subclass of industries is found at 244 locations covering an area of 4 sq km and can be seen in all parts of the study area. Next subclass of plantations is seen at 558 locations that cover 28 sq km of area. The settlements are almost uniformly distributed except in the north along the banks of river Sutlej where these are fewer in number. On the contrary the plantations are more predominant in the north than other parts of the study area (fig: 6.2).

(b) Soil Drainage

While analyzing the second variable of soil drainage it is noted that only three kinds of soil are found in this study area. These are D4 or moderately well drained, D5 or well drained and D7 or excessively drained. The subclass of D4 can be seen in the western and northern parts covering 99 sq km of area. The D7 subclass is seen in the north and northeast parts of the study area covering 171 sq km of area. The D5 subclass is seen all across the study area covering maximum area of 595 sq km (fig: 6.3).

(c) Groundwater Level

While analyzing the third variable of groundwater level, three levels are found in this study area viz. 5-10 mbgl (meters below ground level), 10-20 mbgl and > 20 mbgl. First subclass of 5-10 mbgl covers only 4 sq km of area and found in the extreme east. The second subclass of 10-20 mbgl is found in most parts of the study area covering 402 sq km of area and the last subclass of >20 mbgl covers the maximum area of 459 sq km and can be seen in most parts of this study area except southern and eastern borders (fig: 6.4).

(d) Distance from City

To analyze the variable of distance from city the entire study area is divided in five zones or subclasses : 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the outer limit of the city. It is noticed that maximum area of 184 sq km falls in the first subclass of 0-2 km from city; 166 sq km in the subclass of

Fig 6.1: Location of Ludhiana Study Area in District

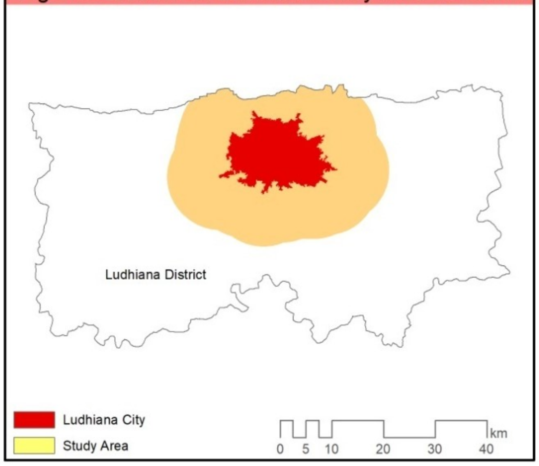


Fig 6.2: Ldh Study Area-Landuse Landcover

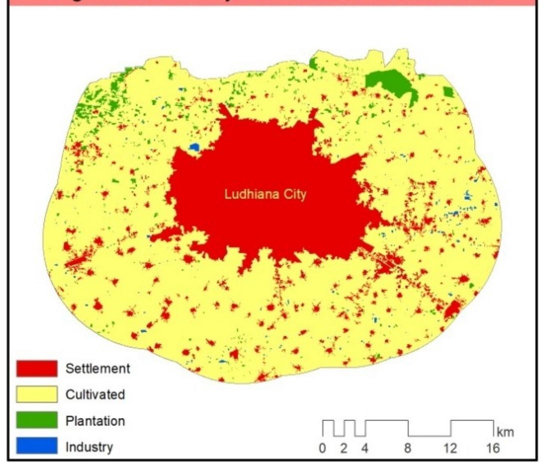


Fig 6.3: Ldh Study Area-Soil Drainage

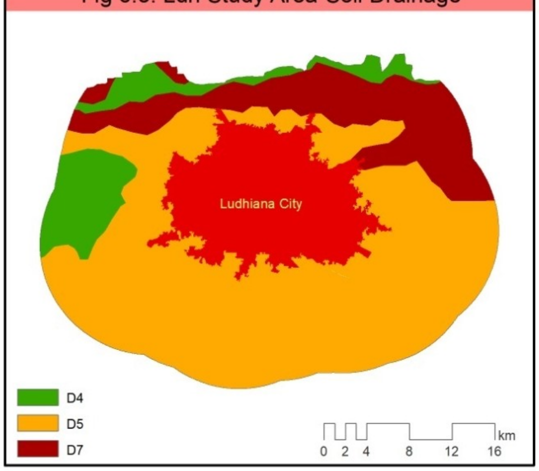


Fig 6.4: Ldh Study Area-Groundwater Level

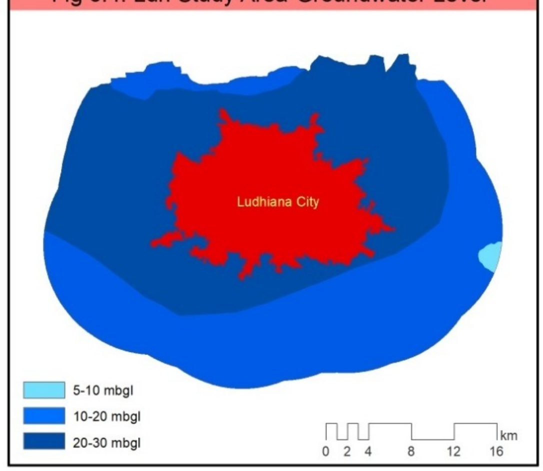


Fig 6.5: Ldh Study Area-Distance from City

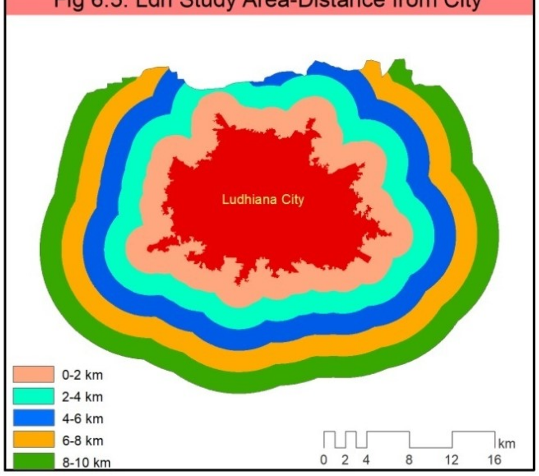


Fig 6.6: Ldh Study Area-Distance from Canals

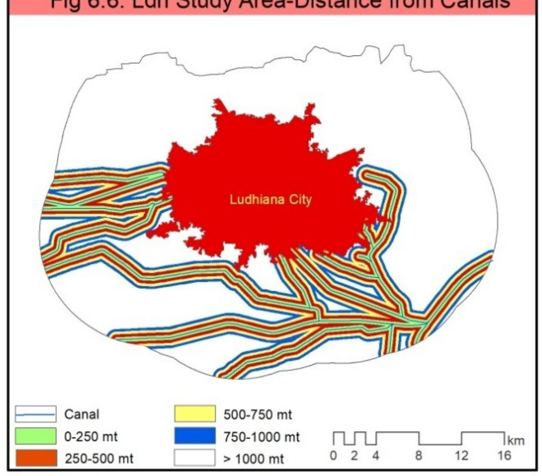


Fig 6.7: Ldh Study Area-Distance from Drains

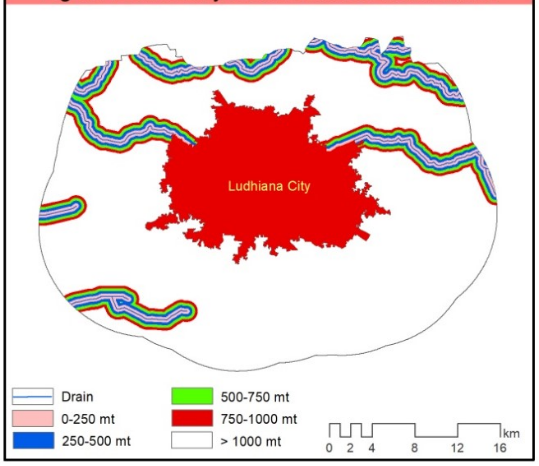


Fig 6.8: Ldh Study Area-Distance from Settlements

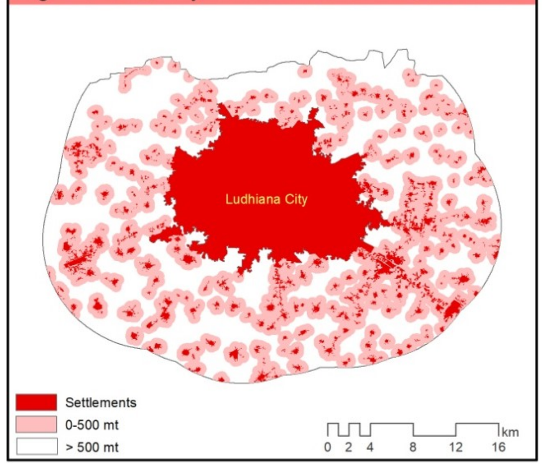


Fig. 6.9: Ldh Study Area-Slope

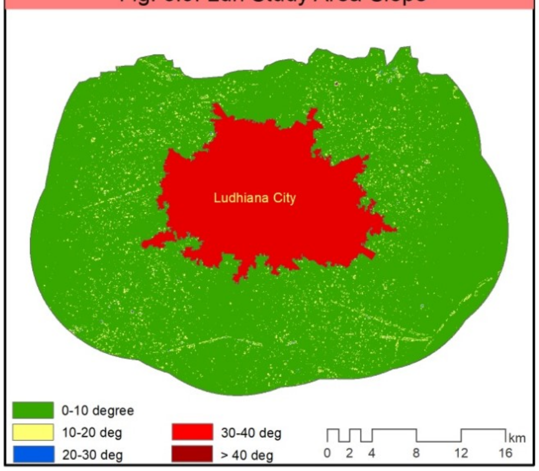


Fig 6.10: Ldh Study Area-Distance from Roads

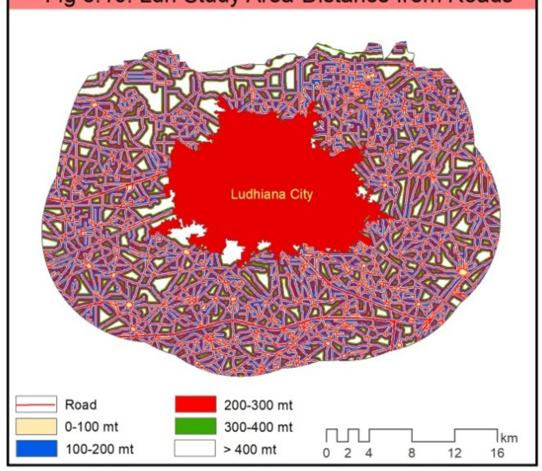


Fig 6.11: Ldh Study Area-Suitable Areas

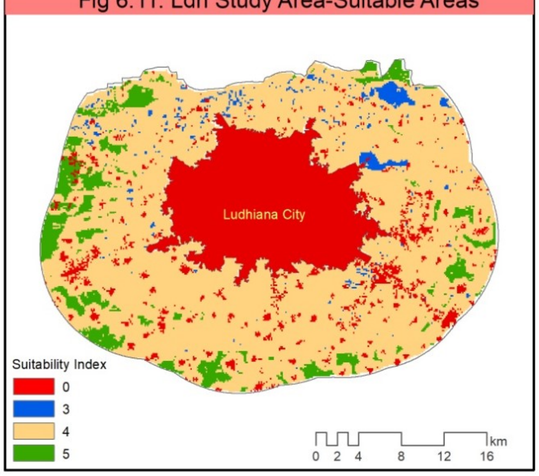
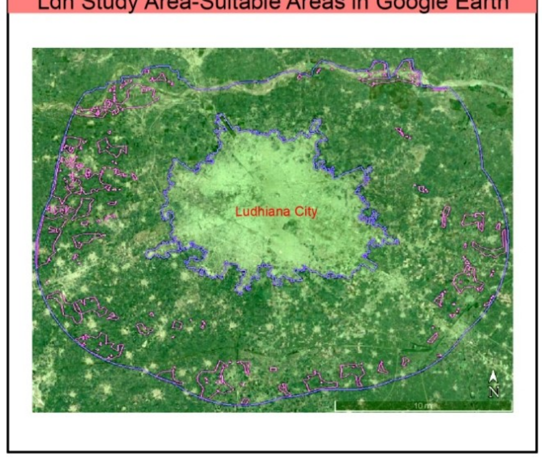


Fig 6.12:
Ldh Study Area-Suitable Areas in Google Earth



2-4 km; 167 sq km in the subclass of 4-6 km; 172 sq km in the subclass of 6-8 km and 176 sq km in the farthest subclass of 8-10 km from the city (fig: 6.5).

(e) Distance from Canals

To analyze the next variable of distance from canals the study area is divided into five zones or subclasses: 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from the canals. Canals can be seen all across the study area except in the north. It is noted that 89 sq km of area falls in the first subclass of 0-250 m from canals; 81 sq km of area falls in the second subclass of 250-500 m from canals; 72 sq km of area falls in the subclass of 500-750 m from canals; 61 sq km falls in the subclass of 750-1000 m from canals and maximum area of 562 sq km falls in the last subclass of more than 1000 m from the canals (fig: 6.6).

(f) Distance from Drains

To analyze the the next variable of distance from drains the study area is divided into five zones or subclasses: 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from the drains. It is noted that drains flow in all parts of the study area except southeastern part. The first subclass of 0-250 m from drains covers 45 sq km of area; second subclass of 250-500 m from drains covers 42 sq km of area; third subclass of 500-750 m from drains covers 40 sq km of area; fourth subclass of 750-1000 m from drains covers 39 sq km of area and the last subclass of more than 1000 m from drains covers maximum area of 699 sq km (fig: 6.7).

(g) Distance from Settlements

As already mentioned in para 6.1.1 (a) there are 277 number of settlements in this study area. To analyze the variable of distance from settlements the study area is divided into two zones or subclasses: 0-500 m and > 500 m from the settlements. It is noted that the first subclass of 0-500 m from settlements covers 485 sq km of area and the subclass of more than 500 m from settlements covers 380 sq km of area (fig: 6.8).

(h) Slope

While analyzing the variable of slope five subclasses are made of study area i.e. 0-10 degrees, 10-20 degrees, 20-30 degrees, 30-40 degrees and more than 40 degrees. Among these five subclasses of slope the maximum area of 832.86 sq km is covered in the first category of 0-10 degrees of slope indicating the flatness of area while the next subclass of 10-20 degrees of slope covers 30.93 sq km of area; 20-30 degrees of slope covers only 1.1 sq km of area; 30-40 degrees of slope covers just 0.04 sq km of area and the last category of more than 40 degrees of slope covers fractional or 0.003 sq km of area (fig: 6.9).

(i) Distance from Roads

To analyze the proximity of proposed sites to the roads the last variable of distance from roads is analyzed. To do this the study area is divided into five subclasses: 0-100 m, 100-200 m, 200-300 m, 300-400 m and more than 400 m from the roads. It is noticed that among all five subclasses the first subclass of 0-100 m from roads covers 364 sq km of area; subclass of 100-200 m from roads cover 238 sq km; subclass of 200-300 m from roads cover 131 sq km; subclass of 300-400 m cover 65 sq km and subclass of more than 400 m from roads cover 67 sq km of area. It is also observed that there is enough density of roads in this study area (fig: 6.10).

6.1.2 Weighted Overlay Analysis

Applying the tool of Weighted Overlay Analysis is the uttermost step in site identification process. This tool can be applied only on raster datasets therefore, all data is converted into raster format and each variable and its subclasses are assigned percentage of influence and weightage respectively on the basis of model already discussed in chapter 4. When the tool of Weighted Overlay Analysis is run for this study area, a new raster dataset is generated that categorizes the study area into various suitability zones alongwith suitability index. In this case only four categories of suitability are generated in the raster dataset i.e. 0, 3, 4 and 5 (fig: 6.11). The most suitable areas are those that have weightage of 5 which account for 8.65% of the total study area. These highly suitable areas are extracted and converted into Keyhole Markup Language (KML) file to view in Google Earth alongwith KML files of all other variables (fig: 6.12). In Google Earth first of all the machine generated results are manually verified and then three sites for solid waste management are marked within suitable areas. When sites are marked in Google Earth, all the nine variables are once again considered. For this study area, three sites of 50 acres each are marked, two in the eastern and one in the southern part of the study area.

6.1.3 Validation

The last step of site identification is the validation. After locating three sites these are overlaid on the layers of all the nine variables that are considered for this study. First of all the sites are overlaid on the layer of landuse landcover and found that all three sites are situated in the subclass of cultivated land which is assigned the weightage of 5 (table 6.2). Secondly, these sites are overlaid on the layer of soil drainage and it is noticed that all three sites are situated in the subclass of D5 or well drained soil that is assigned the weightage of 4. Next the sites are overlaid on the layer of groundwater level and found that all three sites are situated in the subclass of

Table 6.2
Sites for Ludhiana MC falling under subclasses of each variable alongwith weightage

S. no.	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D5 (4)	D5 (4)	D5 (4)
3	Groundwater level	10-20 mbgl (4)	10-20 mbgl (4)	10-20 mbgl (4)
4	Distance from City	6-8 km (4)	6-8 km (4)	8-10 km (5)
5	Distance from Canal	>1000 m (5)	>1000 m (5)	>1000 m (5)
6	Distance from Drain	>1000 m (5)	>1000 m (5)	>1000 m (5)
7	Distance from Village	>500 m (5)	>500 m (5)	>500 m (5)
8	Slope	0-10 degrees (5)	0-10 degrees (5)	0-10 degrees (5)
9	Distance from Roads	0-100 m (5)	0-100 m (5)	0-100 m (5)

10-20 mbgl that is assigned the weightage of 4. Next the sites are overlaid on the layer of distance from city and found that site 1 and site 2 are situated in the zone of 6-8 km from the city which is assigned the weightage of 4 and site 3 lies in the zone of 8-10 km from city that is assigned the weightage of 5. Next the sites are overlaid on the layer of distance from canals and it is noticed that all three sites are situated in the subclass of more than 1000 m from the canals that is assigned the weightage of 5. Then all sites are overlaid on the layer of distance from drains and it is found that all three sites are situated in the subclass of more than 1000 m from the drains that is assigned the weightage of 5. Next all sites are overlaid on the layer of distance from settlements or villages and it is found all three sites are situated in the zone of more than 500 m from the settlements that is assigned the weightage of 5. Then all sites are overlaid on the layer of slope and it is noted that all three sites are located in the subclass of 0-10 degrees of slope that is assigned the weightage of 5 however a few dots of 10-20 degrees of slope are found in site 3 which are negligible. Lastly, all sites are overlaid on the layer of distance from roads and it is noticed that all three sites are situated right on the road or in the zone of 0-100 m from road that is assigned the weightage of 5. In the end it can be concluded that all three sites are situated in the most suitable areas identified by weighted overlay analysis which satisfies all the criteria. Further the results of this tool are manually validated in Google Earth while locating the sites.

6.1.4 Final Sites

After the validation of results, it is observed that all the three sites successfully satisfy all the nine variables mentioned in the “Deepak-Kalota Model of Site Identification for Solid Waste Management”. These three sites are hence finalized for solid waste management of Ludhiana municipal corporation. The most preferred site or site 1 is located in the east near Rampur village, site 2 is located in the east near Bhagpur village and site 3 is in the south near Bhutta village (fig App 6.1). Site 1 is the most preferred site followed by site 2 and site 3.

6.2 SITE IDENTIFICATION FOR MOGA MC

The study area for Moga municipal corporation lies in mid-western part of Punjab and northern part of Malwa region. This study area does not share its boundary with any district hence its boundary is not clipped with the district boundary (fig: 6.13). The study area for Moga municipal corporation spreads over 558 sq km.

6.2.1 Analysis of Variables

Like other study areas, nine variables for this study area are analyzed to apply the model of site identification. The description of these nine variables is given below.

(a) Landuse Landcover

The first variable of landuse landcover has four subclasses. The first subclass of cultivated land covers 499.66 sq km out of 558 sq km of total study area. It is the maximum of all subclasses in landuse landcover (table: 6.3). Analyzing second subclass of settlements it is noted that there are 139 number of settlements which are almost uniformly distributed in the study area and cover an area of 25.37 sq km. Two bigger settlements can be noticed which are Daroli Bhai village in the extreme west and another is Charik village in the extreme south. Regarding third subclass of plantations it is noted that there are 61 locations of plantations which are more predominant in northern than southern parts of study area and cover an area of 1.3 sq km. As regards industries there are 36 industrial locations that can be seen in all parts of study area covering an area of 0.96 sq km (fig: 6.14).

(b) Soil Drainage

While analyzing the second variable of soil drainage it is noted that only two subclasses are found in this study area i.e. D4 and D5. The subclass of D4 or moderately well drained soil is found only in southwestern part and covers an area of 26 sq km while D5 or well drained soil subclass spreads all across the study area covering an area of 532 sq km (fig: 6.15).

Table 6.3
Area under subclasses of each variable in Moga study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	1.3
		Villages/Settlements	25.37
		Industry	0.96
		Cultivated	499.66
2	Soil		
		D4-Moderately well drained	26
		D5-Well drained	532
3	Groundwater Level		
		10-20 mbgl	223
		20-30 mbgl	335
4	Distance from City		
		0-2 km	67
		2-4 km	86
		4-6 km	110
		6-8 km	135
		8-10 km	160
5	Distance from Canals		
		0-250 mt	98
		250-500 mt	93
		500-750 mt	84
		750-1000 mt	75
		>1000 mt	208
6	Distance from Drains		
		0-250 mt	44
		250-500 mt	42
		500-750 mt	36
		750-1000 mt	29
		>1000 mt	407
7	Distance from Villages/Settlements		
		0-500 mt	254
		>500 mt	304
8	Slope		
		0-10 degrees	557
		10-20 degrees	0.93
		>20 degrees	0.007
9	Distance from Roads		
		0-100 mt	235
		100-200 mt	162
		200-300 mt	91
		300-400 mt	42
		>400 mt	28

Fig 6.13: Location of Moga Study Area in District

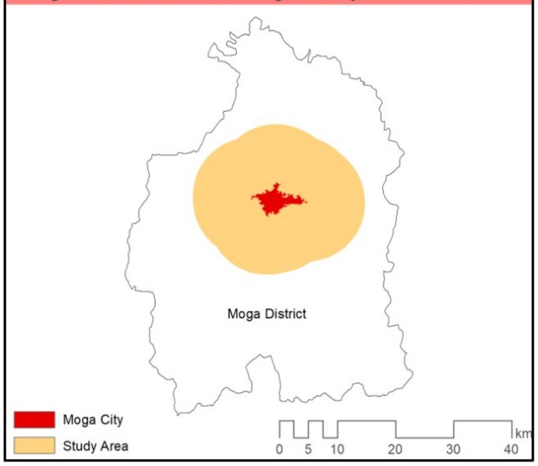


Fig 6.14: Moga Study Area-Landuse Landcover

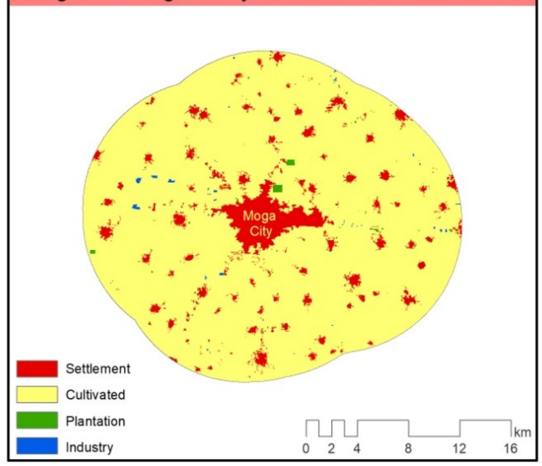


Fig 6.15: Moga Study Area-Soil Drainage

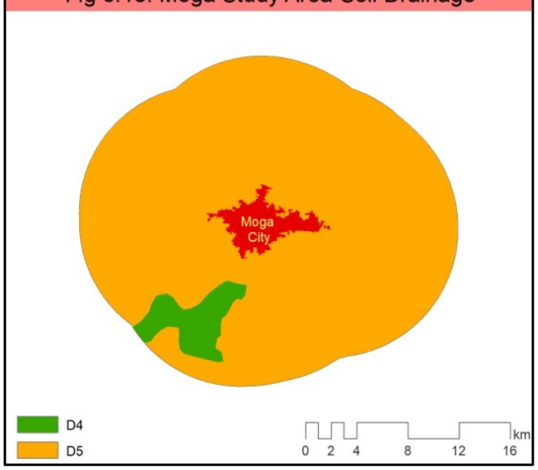


Fig 6.16: Moga Study Area-Groundwater Level

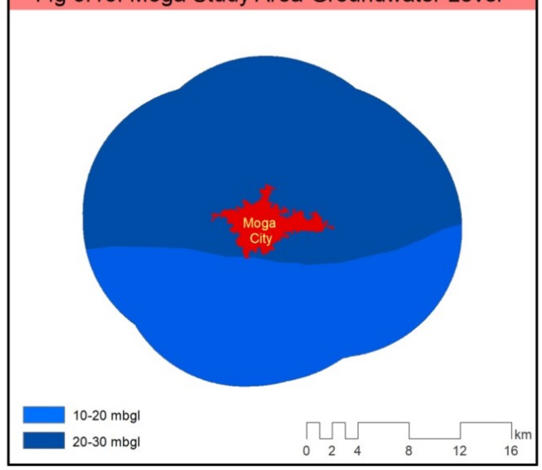


Fig 6.17: Moga Study Area-Distance from City

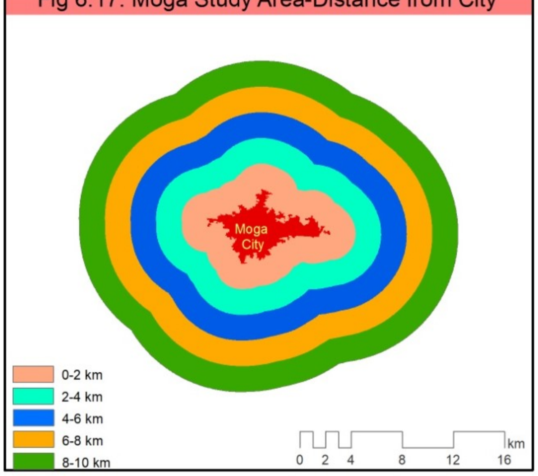
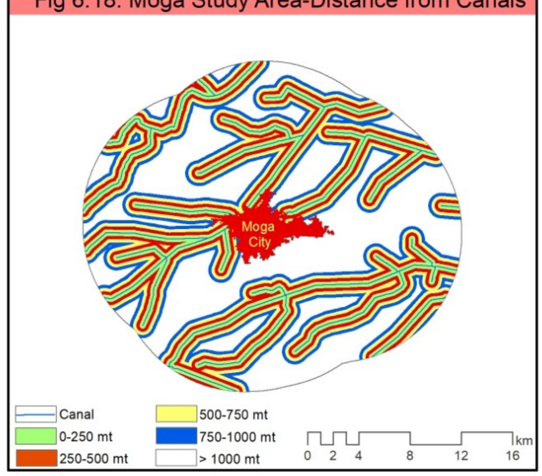


Fig 6.18: Moga Study Area-Distance from Canals



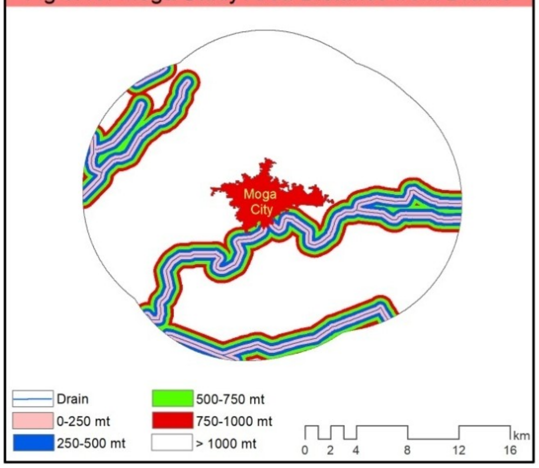


Fig 6.19: Moga Study Area-Distance from Drains

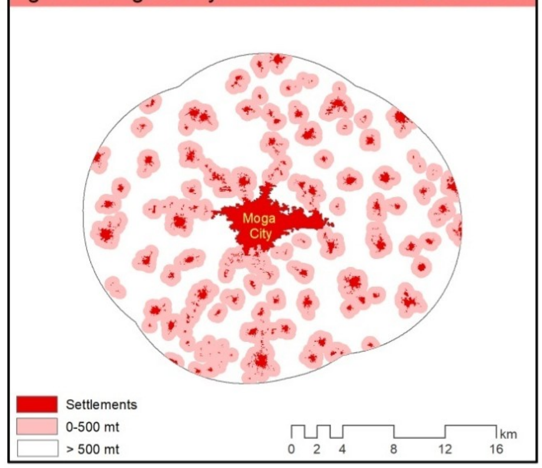


Fig 6.20: Moga Study Area-Distance from Settlements

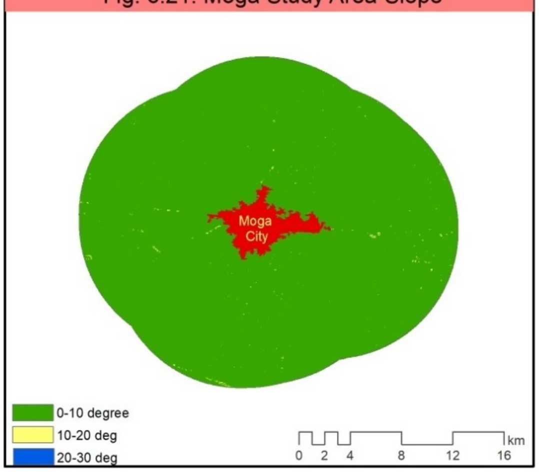


Fig. 6.21: Moga Study Area-Slope

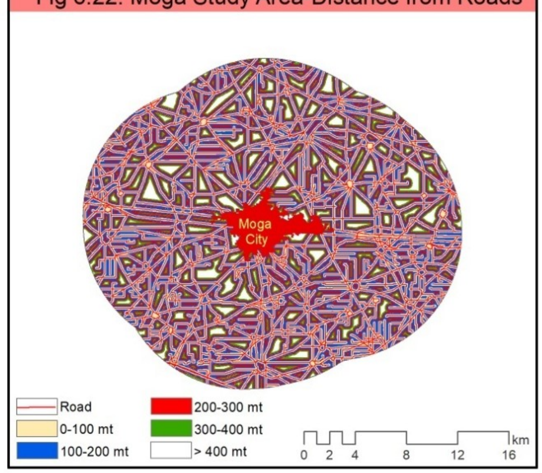


Fig 6.22: Moga Study Area-Distance from Roads

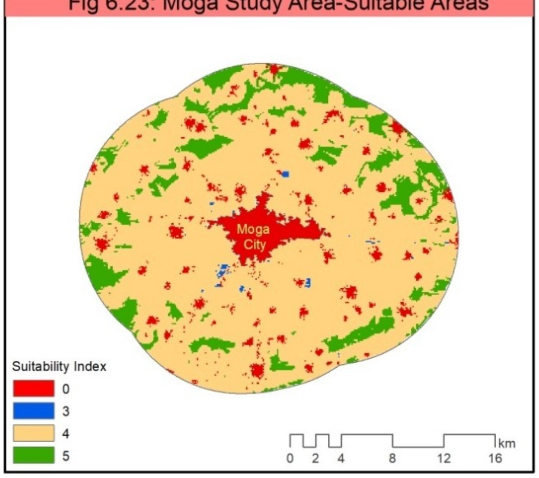


Fig 6.23: Moga Study Area-Suitable Areas

Fig 6.24:
Moga Study Area-Suitable Areas in Google Earth

(c) Groundwater Level

While analyzing the variable of groundwater level, only two subclasses are found in this study area which are 10-20 mbgl (meters below ground level) and 20-30 mbgl. Subclass of 10-20 mbgl roughly covers the southern half of study area covering an area of 223 sq km while subclass of 20-30 mbgl covers northern half of study area and central parts covering an area of 335 sq km (fig: 6.16).

(d) Distance from City

To analyze the variable of distance from city the study area is divided into five zones or subclasses: 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the outer limit of the city. The subclass of 0-2 km from city occupies an area of 67 sq km, 2-4 km subclass covers 86 sq km, 4-6 km subclass covers 110 sq km, 6-8 km subclass covers 135 and 8-10 km subclass covers an area of 160 sq km (fig: 6.17).

(e) Distance from Canals

Numerous canals can be seen in this study area which are almost uniformly distributed. To analyze the variable of distance from canals the entire study are is divided into five zones or subclasses: 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from the canals. It is found that the subclass of 0-250 m has an area of 98 sq km, 250-500 m has 93 sq km, 500-750 m has 84 sq km, 750-1000 m has an area of 75 sq km and subclass of more than 1000 m covers maximum area of 208 sq km (fig: 6.18).

(f) Distance from Drains

Drains can be seen in the southern half and western part of study area. To analyze the variable of distance from drains the study are is divided into five zones or subclasses : 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from the drains. It is noticed that the subclass of 0-250 m has an area of 44 sq km, 250-500 m has 42 sq km, 500-750 m has 36 sq km, 750-1000 m has an area of 29 sq and subclass of more than 1000 m from drains covers maximum area of 407 sq km (fig: 6.19).

(g) Distance from Settlements

As already mentioned in para 6.2.1 (a) there are 139 number of settlements in this study area which are almost uniformly distributed. To analyze the variable of distance from settlements the entire study area is divided into two subclasses: 0-500 m and > 500 m. It is noticed that the subclass of 0-500 m covers an area of 254 sq km and the second subclass of more than 500 m covers an area of 304 sq km (fig: 6.20).

(h) Slope

When model for site identification is applied to analyze slope, it is noticed that only three subclasses of slope are found in this study area which are : 0-10 degrees, 10-20 and 20-30 degrees. It is found that 557 sq km of area falls in 0-10 degrees of slope, 0.93 sq km of area falls in 10-20 degrees and negligible 0.007 sq km of area in 20-30 degrees of slope. Hence this study area is characterized by absolute flatness (fig: 6.21).

(i) Distance from Roads

In order to analyze proximity of proposed sites to roads this study area is divided into five subclasses: 0-100 m, 100-200 m, 200-300 m, 300-400 m and more than 400 m from roads. With regard to distance from roads, it is noted that this study area has sufficient density of roads. Maximum area of 235 sq km lies in the first subclass of 0-100 m followed by 162 sq km in 100-200 mt, 91 sq km in 200-300 mt, 42 sq km in 300-400 m and 28 sq km in more than 400 m zone (fig: 6.22).

6.2.2 Weighted Overlay Analysis

In order to apply the tool of Weighted Overlay Analysis all data are converted into raster format and assigned percentage of influence to all the factors and weightage to the subclasses of factors on the basis of model already prepared and discussed in chapter 4. In ArcGIS when the tool of weighted overlay analysis is run for the study area of Moga municipal corporation, a new raster is generated that categorizes the study area in four zones of suitability alongwith suitability index i.e. 0, 3, 4 and 5 (fig: 6.23). The areas with highest suitability index of 5 cover only 12.82 % of the study area. This suitable area is extracted and converted into Keyhole Markup Language (KML) file so that the same can be viewed in Google Earth (fig: 6.24). Similarly, all other variables are also brought in Google Earth where the machine generated results are validated manually. Then three suitable locations are marked within the suitable areas in Google Earth and all nine variables are once again kept in mind while locating three sites of 50 acres each.

6.2.3 Validation

After locating three sites, the same are validated by overlaying on layers of all the nine variables. When sites are overlaid on landuse landcover layer it is observed that all three sites are on the cultivated land that is assigned highest weightage of 5 (table: 6.4). On the layer of soil drainage it is found that all three sites are located on D5 category or well drained soil that is assigned the weightage of 4. On the layer of groundwater it is noticed that site 1 is located in the subclass of 10-20 mbgl that is assigned the weightage of 4 and site 2 and site 3 are located in the subclass of 20-30 mbgl which is assigned the weight of 5. Then on the layer of distance from city it is noted that site 1 lies in the subclass of 8-10 km km from city that is assigned the weight of 5 while site 2 is located in the zone of 6-8 km subclass that is assigned the weight of 4 and site 3 is located in the zone of 4-6 km that is assigned the weightage of 3. Then on the layer of distance from canals it is noticed that all three layers are located in the zone of more than 1000 m away from canal that is assigned the weightage of 5. Then on the layer of distance from drains it is found that all three sites are located in the zone of maximum distance from drains i.e. 1000 m which is assigned the weight of 5. When sites are overlaid on the layer of distance from settlements or villages it is noticed

Table 6.4
Sites for Moga MC falling under subclasses of each variable alongwith weightage.

S. no.	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D5 (4)	D5 (4)	D5 (4)
3	Groundwater level	10-20 mbgl (4)	20-30 mbgl (5)	20-30 mbgl (5)
4	Distance from City	8-10 km (5)	6-8 km (4)	4-6 km (3)
5	Distance from Canal	>1000 m (5)	>1000 m (5)	>1000 m (5)
6	Distance from Drain	>1000 m (5)	>1000 m (5)	>1000 m (5)
7	Distance from Village	>500 m (5)	>500 m (5)	>500 m (5)
8	Slope	0-10 degrees (5)	0-10 degrees (5)	0-10 degrees (5)
9	Distance from Roads	0-100 m (5)	0-100 m (5)	0-100 m (5)

that all three sites are located in the subclass of > 500 m from settlements that is assigned the maximum weight of 5. On the layer of slope it is noted all three sites are located in the subclass of 0-10 degrees that is assigned the maximum weightage of 5. When sites are overlaid on the last layer of distance of roads it is found that all three sites are located right on the road or in the first subclass of 0-100 m from road that is assigned the maximum weight of 5. Hence it is proved that the results of weighted overlay analysis for site identification for solid waste management of Moga municipal corporation are authentic and judicious because only those areas are selected by this tool that are assigned the highest values on the preference scale. Manual authentication is also performed when the results are viewed in Google Earth while locating the sites. After validation, the sites are finalized for Moga municipal corporation.

6.2.4 Final Sites

After the process of validation, it is noticed that all the three sites successfully satisfy all the nine variables mentioned in the "Deepak-Kalota Model of Site Identification for Solid Waste Management". These three sites are therefore finalized for the solid waste management of Moga municipal corporation. Site 1 is the most preferred site followed by site 2 and site 3. Site 1 lies in the western part of study area near Dadahoor village; site 2 lies in the eastern part near Kokri hera village and site 3 lies in the north near Khosa

Randhir village (fig App 7.1). Site 1 is the most preferred site followed by site 2 and site 3.

6.3 SITE IDENTIFICATION FOR BATHINDA MC

The study area of Bathinda municipal corporation lies in the southwestern Punjab. For most part this study area does not share its boundary with the surrounding districts except for a tiny portion in north where the boundary of Faridkot district intersects it (fig: 6.25). This study area covers 846 sq km of area that is to be analyzed for site identification.

6.3.1 Analysis of Variables

All the nine variables are analyzed for this study area in order to apply the model of site identification. Description of these is given below.

(a) Landuse Landcover

While analyzing the variable of landuse landcover it is noted that among all four subclasses the subclass of cultivated area occupies maximum area of 760.91 sq km out of 846 sq km of total area (table 6.5). The cultivated area can be seen in all parts of the study area. The second subclass of plantation is seen all across the study area at 61 locations covering 2.11 sq km of area. The third subclass of settlements or villages numbering 191 occupy 38.14 sq km of area and can be seen in all parts of the study area. Two large sized settlements can be seen in the study area namely Goniana in the north and Bhucho mandi in the east. Industries are limited, uniformly distributed and can be seen at 26 locations which cover only 1.96 sq km of area. (fig: 6.26).

(b) Soil Drainage

While analyzing the variable of soil drainage only two cat subclasses are found in this study area i.e. D5 and D7. The D5 subclass or well drained soil is seen in most parts of study area and cover 776 sq km of area. The D7 subclass or excessively drained soil is seen in four patches two in northern and two in the eastern parts of study area covering an area of 70 sq km in total (fig: 6.27).

Table 6.5
Area under subclasses of each variable in Bathinda study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	2.11
		Villages/Settlements	38.14
		Industry	1.96
		Cultivated	760.91
2	Soil		
		D5-Well Drained	776
		D7-Excessively Drained	70
3	Groundwater Level		
		0-5 mbgl	111
		5-10 mbgl	386
		10-20 mbgl	349
4	Distance from City		
		0-2 km	142
		2-4 km	143
		4-6 km	163
		6-8 km	187
		8-10 km	211
5	Distance from Canals		
		0-250 mt	129
		250-500 mt	122
		500-750 mt	111
		750-1000 mt	99
		>1000 mt	385
6	Distance from Drains		
		0-250 mt	8
		250-500 mt	8
		500-750 mt	8
		750-1000 mt	9
		>1000 mt	813
7	Distance from Villages/Settlements		
		0-500 mt	369
		>500 mt	477
8	Slope		
		0-10 degrees	843.13
		10-20 degrees	2.85
		20-30 degrees	0.03
9	Distance from Roads		
		0-100 mt	362
		100-200 mt	244
		200-300 mt	133
		300-400 mt	59
		>400 mt	48

Fig 6.25: Location of Bathinda Study Area in District

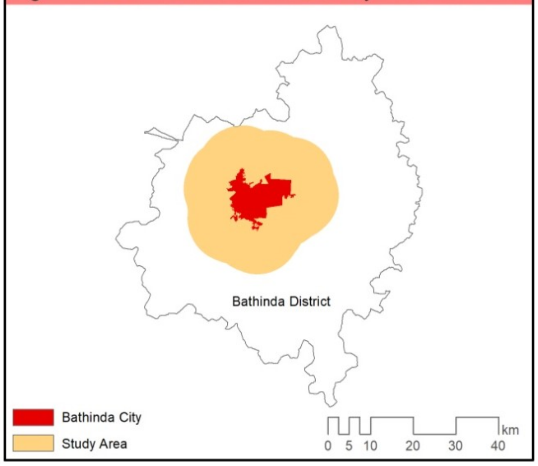


Fig 6.26: Btd Study Area-Landuse Landcover

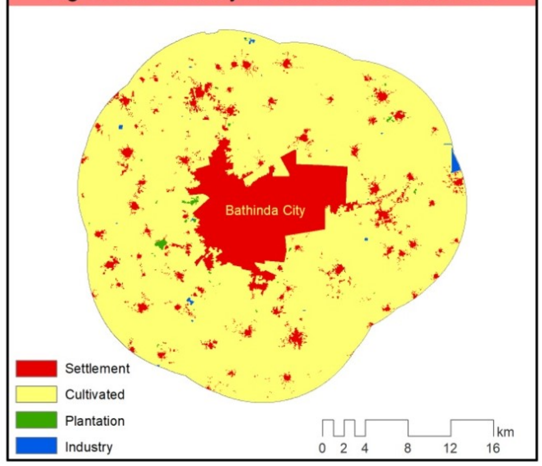


Fig 6.27: Btd Study Area-Soil Drainage

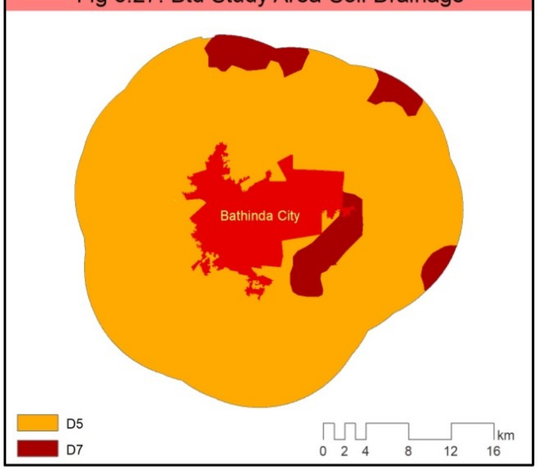


Fig 6.28: Btd Study Area-Groundwater Level

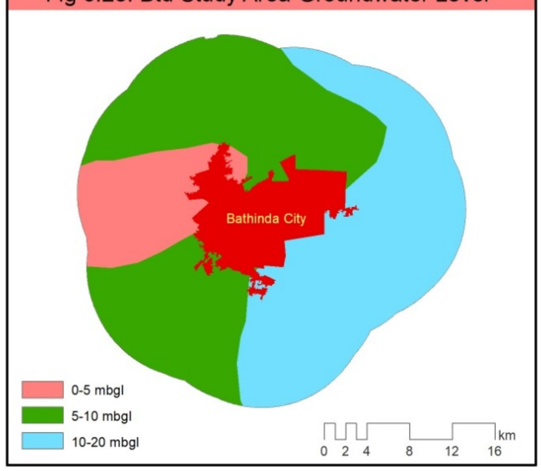


Fig 6.29: Btd Study Area-Distance from City

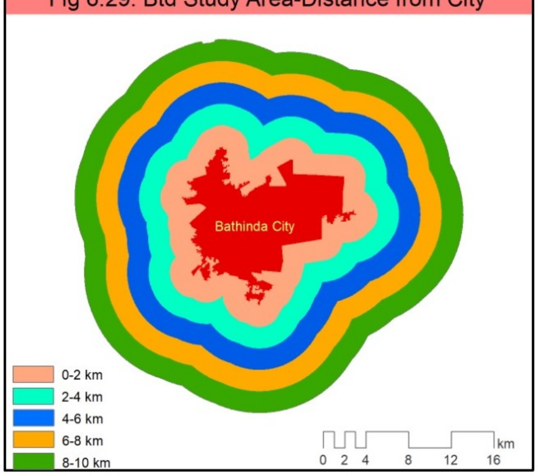


Fig 6.30: Btd Study Area-Distance from Canals

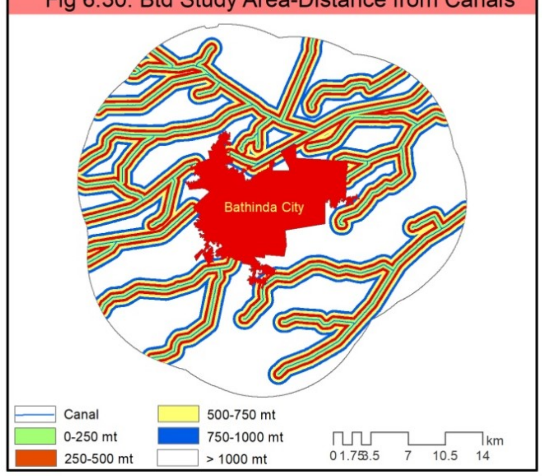


Fig 6.31: Btd Study Area-Distance from Drains

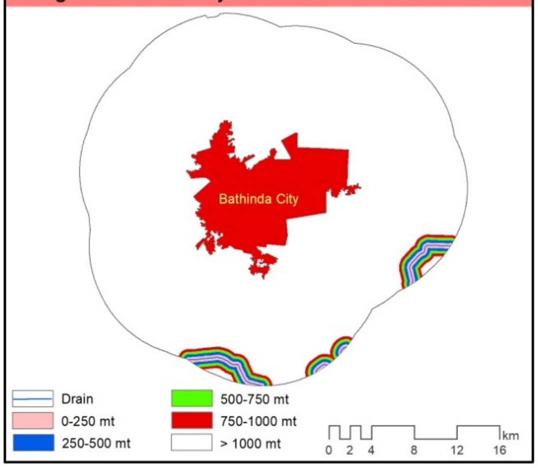


Fig 6.32: Btd Study Area-Distance from Settlements

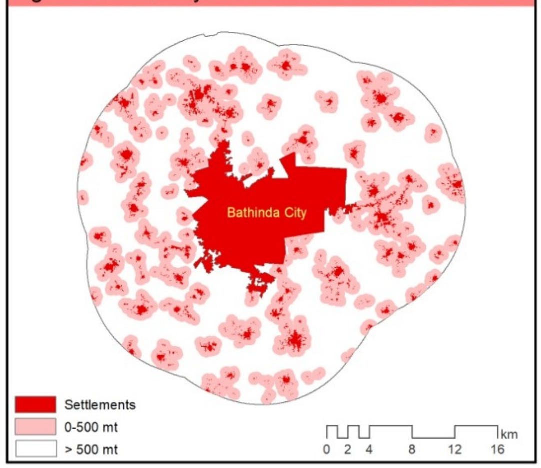


Fig. 6.33: Btd Study Area-Slope

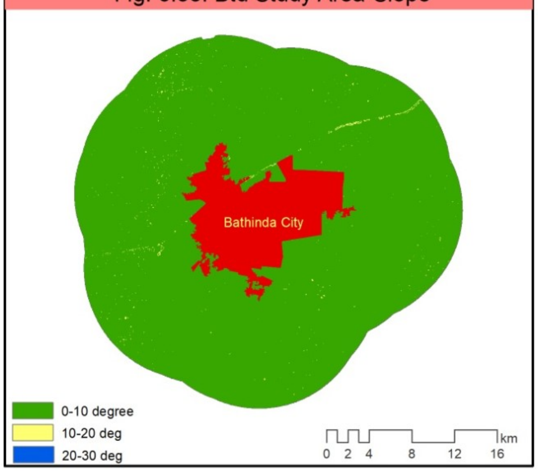


Fig 6.34: Btd Study Area-Distance from Roads

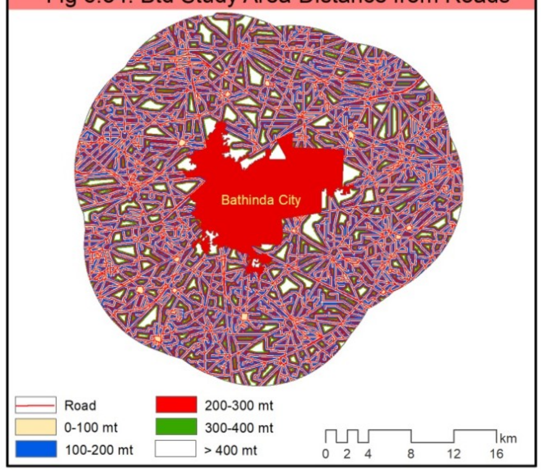


Fig 6.35: Btd Study Area-Suitable Areas

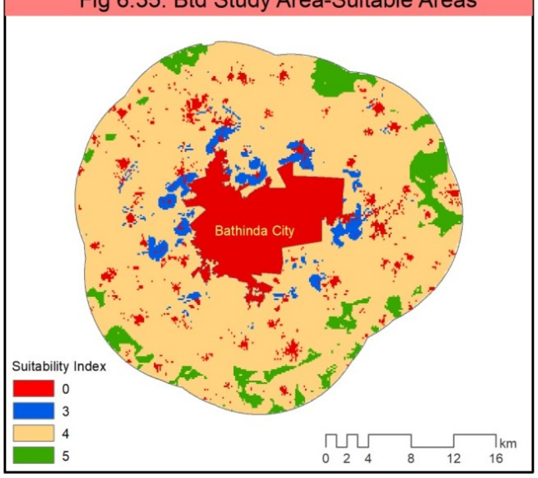
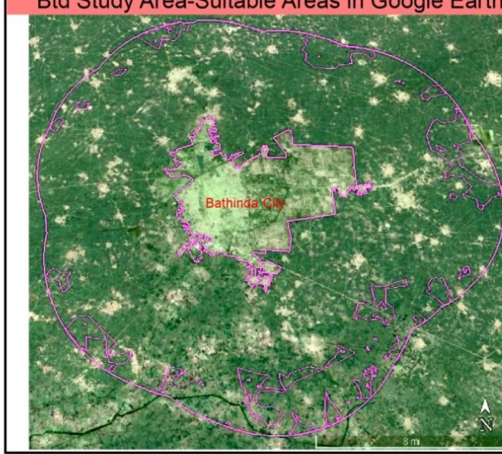


Fig 6.36:
Btd Study Area-Suitable Areas in Google Earth



(c) Groundwater Level

While analyzing the variable of groundwater level, three subclass are found in this study area: 0-5 mbgl (meters below ground level), 5-10 mbgl and 10-20 mbgl. The 0-5 mbgl subclass covers 111 sq km of area which is limited to western parts only while 5-10 mbgl subclass is seen over a large area in western half of study area covering 386 sq km. The last subclass of 10-20 mbgl is predominant in eastern parts of study area covering 349 sq km of area (fig: 6.28).

(d) Distance from City

To analyze the variable of distance from city the study area is divided into five zones or subclasses : 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the outer limit of the city. The subclass of 0-2 km from the city covers 142 sq km of area; subclass of 2-4 km from city covers 143 sq km; subclass of 4-6 km from city covers 163 sq km; subclass of 6-8 km from city covers 187 sq km and the last subclass of 8-10 km from the city covers 211 sq km of area (fig: 6.29).

(e) Distance from Drains

There are numerous canals in this study area. To analyze the variable of distance from canals the entire study area is divided into five subclasses: 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from the canals. The first subclass which is of 0-250 m away from canals covers 129 sq km of area; 250-500 m subclass covers 122 sq km; 500-750 m subclass covers 111 sq km; 750-1000 m subclass covers 99 sq km and the last subclass of >1000 m covers the maximum area of 385 sq km. Canals can be seen in all parts of the study area (fig: 6.30).

(f) Distance from Drains

Only one drain can be seen in the southeastern part of this study area. In order to analyze the variable of distance from drains the entire study area is divided into five zones or subclasses: 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from the drain. The first subclass which is of 0-250 m away from drain covers 8 sq km of area; 250-500 m subclass also covers 8 sq km; 500-750 m subclass also covers 8 sq km; 750-1000 m subclass covers the 9 sq km and the last subclass of >1000 m covers the maximum area of 813 sq km (fig: 6.31).

(g) Distance from Settlements

As already mentioned in para 6.3.1 (a) 191 number of settlements are found in this study area which are almost uniformly distributed. In order to analyze the variable of distance from settlements the study area is divided into two subclasses: 0-500 m and > 500 m from the settlements. The first subclass of 0-500 m cover 369 sq km and second subclass of > 500 m covers 477 sq km of area (fig: 6.32).

(h) Slope

The variable of slope is analyzed by dividing the study area into slope zones or subclasses. On the basis of slope this study area has only three categories: 0-10 degrees, 10-20 and 20-30 degrees. The first subclass of 0-10 degrees of slope predominates over maximum area of 843.13 sq km followed by 10-20 degrees which is seen in tiny patches all across the study area and covers 2.85 sq km of area. The last subclass of 20-30 degrees is seen in negligible 0.03 sq km of area (fig: 6.33).

(i) Distance from Roads

Lastly, in order to analyze the proximity of proposed sites to roads the study area is divided into five zones or subclasses: 0-100 m, 100-200 m, 200-300 m, 300-400 m and more than 400 m from roads. The first subclass of 0-100 m away from roads spreads over maximum area of 362 sq km followed by 100-200 m subclass covering 244 sq km; 200-300 m subclass 133 sq km; 300-400 m subclass 59 sq km and > 400 m subclass covering 48 sq km of area. This study area has sufficient density of roads (fig: 6.34).

6.3.2 Weighted Overlay Analysis

After analysis, all feature classes are converted into raster datasets and is followed by assigning percentage of influence to each variable and weightage to the subclasses of each variable on the basis of model described in chapter 4. When weighted overlay analysis is applied for this study area, a new raster dataset is generated that categorizes the entire study area in four suitability zones alongwith suitability index i.e. 0, 3, 4 and 5 (fig: 6.35). Areas with highest suitability are extracted and converted into Keyhole Markup Language (KML) file alongwith the KML files of all other variables to view in Google Earth (fig: 6.36). Here the machine generated results are manually validated before locating three sites in the most suitable areas. In Google Earth all nine variables are once again considered before locating three sites.

6.3.3 Validation

In the end, the results of site identification are tested by overlaying the sites for Bathinda municipal corporation on the layers of all nine variables which are also depicted in the table 6.6. First of all sites are overlaid on the layer of landuse landcover and it is found the all three sites are located in the subclass of cultivated area that is assigned the highest weightage of 5. Then on the layer of soil drainage it is discovered that all three sites are located in the subclass of D5 or well drained soil that is assigned the weightage of 4. Next, on the layer of groundwater level it is noticed that site 1 and site 2 are located in the subclass of 10-20 mbgl which is assigned the weightage of 4 while site 3 is located in the subclass of 5-10 mbgl of groundwater level which is assigned the weightage of 3. Then the sites are overlaid on the layer of distance from city and noted that site 1 and site 2 are located in the subclass of 6-8 km from city that is assigned the weightage of 4 while site 3 is located in the subclass of 8-10 km that is assigned the highest weightage of 5. Next, on the layer of distance from canals it is found that all three sites are located in the subclass of > 1000 m which is assigned the weightage of 5. Then on the layer of distance from drain it is noticed that all three sites are located in the

Table 6.6
Sites for Bathinda MC falling under subclasses of each variable alongwith weightage

S. no.	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D5 (4)	D5 (4)	D5 (4)
3	Groundwater level	10-20 mbgl (4)	10-20 mbgl (4)	5-10 mbgl (3)
4	Distance from City	6-8 km (4)	6-8 km (4)	8-10 km (5)
5	Distance from Canal	>1000 m (5)	>1000 m (5)	>1000 m (5)
6	Distance from Drain	>1000 m (5)	>1000 m (5)	>1000 m (5)
7	Distance from Village	>500 m (5)	>500 m (5)	>500 m (5)
8	Slope	0-10 degrees (5)	0-10 degrees (5)	0-10 degrees (5)
9	Distance from Roads	0-100 m (5)	0-100 m (5)	0-100 m (5)

subclass of >1000 m from drain which is assigned the highest weightage of 5. Next, when sites are overlaid on the layer of distance from villages or settlements it is discovered that all three sites are located inthe subclass of >500 m from settlements which is assigned the highest weightage of 5. Then the sites are overlaid on the layer of slope and it is found that all three sites fall in the subclass of 0-10 degrees of slope which is assigned the highest weightage of 5. Lastly, all three sites are overlaid on the layer of distance from roads and noticed that all three sites are located right on the road or in the subclass of 0-100 m which is assigned the highest weightage of 5. Hence it is proved that the results of weighted overlay analysis for site identification for solid waste management of Bathinda municipal corporation are authentic and judicious because only those areas are selected by this tool that are assigned highest values on the preference scale. Manual authentication is also performed and after validation all the three sites are finalized for solid waste management of Bathinda municipal corporation.

6.3.4 Final Sites

After validation, it is noticed that all the three sites successfully satisfy all the nine variables mentioned in the "Deepak-Kalota Model of Site Identification for Solid Waste Management". These three sites are therefore finalized for the solid waste management of Bathinda municipal corporation.

The Site 1 is of 50 acres and lies in north near Dhelwa village; site 2 is of 50 acres in northeast near Lehra Bega village and site 3 of 50 acres lies in southwest near Jai Singh wala village (fig App 8.1). Site 1 is the most preferred site followed by site 2 and site 3.

6.4 SITE IDENTIFICATION FOR PATIALA MC

The study area of Patiala municipal corporation lies in the southeastern part of Punjab state. This study areas shares its boundary only in the north with the district of Fatehgarh Sahib where it has been clipped with the district boundary (fig: 6.37). The study area for Patiala municipal corporation covers a total area of 755 sq km.

6.4.1 Analysis of Variables

To apply model, all the nine variables are analyzed for Patiala MC. Description of all the nine variables is given below.

(a) Landuse Landcover

First of all the variable of landuse landcover is analyzed and it is noticed that among all the subclasses the subclass of cultivated land accounts for 675.28 sq km out of 755 sq km of total area of study area and is the largest of all subclasses (table 6.7). The next subclass of settlements is almost uniformly distributed at 316 locations in the study area and covers an area of 25.55 sq km. To the southeast of Patiala city a bigger settlement can be seen which is town of Sanaur. The third subclass of plantation is almost uniformly distributed all across the study area and seen at 182 locations covering an area of 14.31 sq km. The subclass of industry is almost uniformly distributed in the study area at 63 locations covering an area of 1.38 sq km (fig 6.38).

(b) Soil Drainage

On the basis of soil drainage only three categories or subclasses are found in this study area: D4, D5 and D6. The category of D4 or moderately well drained soil is found in four patches in north and southeast that cover an area of 22 sq km. The next subclass of D5 or well drained soil is seen in most

Table 6.7
Area under subclasses of each variable in Patiala study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	14.31
		Villages/Settlements	25.55
		Industry	1.38
		Cultivated	675.28
2	Soil		
		D4-Moderately Well Drained	22
		D5-Well Drained	689
		D6-Excessively Drained	44
3	Groundwater Level		
		5-10 mbgl	8
		10-20 mbgl	219
		20-30 mbgl	528
4	Distance from City		
		0-2 km	129
		2-4 km	134
		4-6 km	152
		6-8 km	162
		8-10 km	178
5	Distance from Canals		
		0-250 mt	125
		250-500 mt	113
		500-750 mt	104
		750-1000 mt	94
		>1000 mt	319
6	Distance from Drains		
		0-250 mt	52
		250-500 mt	48
		500-750 mt	46
		750-1000 mt	44
		>1000 mt	565
7	Distance from Villages/Settlements		
		0-500 mt	424
		>500 mt	331
8	Slope		
		0-10 degrees	752.7
		10-20 degrees	2.12
		20-30 degrees	0.10
		30-40 degrees	0.05
		>40 degrees	0.007
9	Distance from Roads		
		0-100 mt	296
		100-200 mt	207
		200-300 mt	127
		300-400 mt	66
		>400 mt	59

Fig 6.37: Location of Patiala Study Area in District

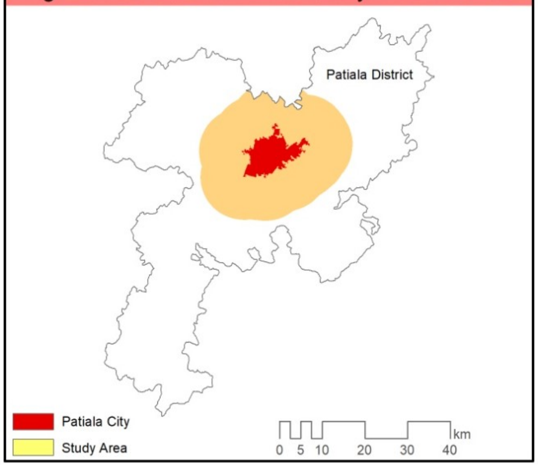


Fig 6.38: Pat Study Area-Landuse Landcover

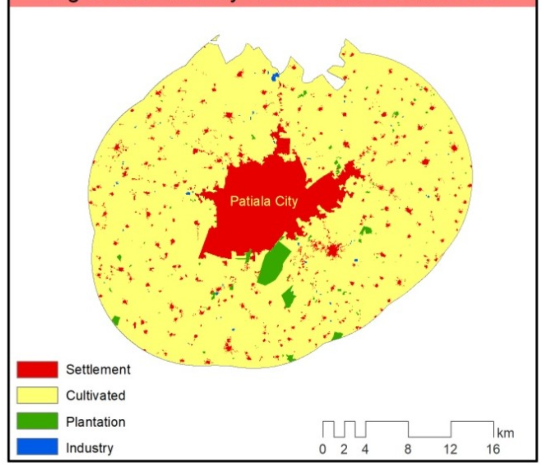


Fig 6.39: Pat Study Area-Soil Drainage

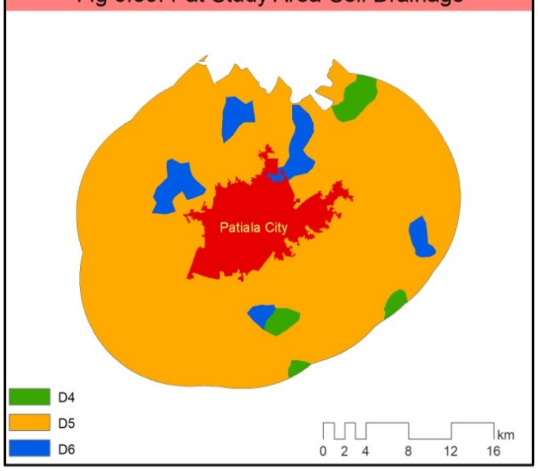


Fig 6.40: Pat Study Area-Groundwater Level

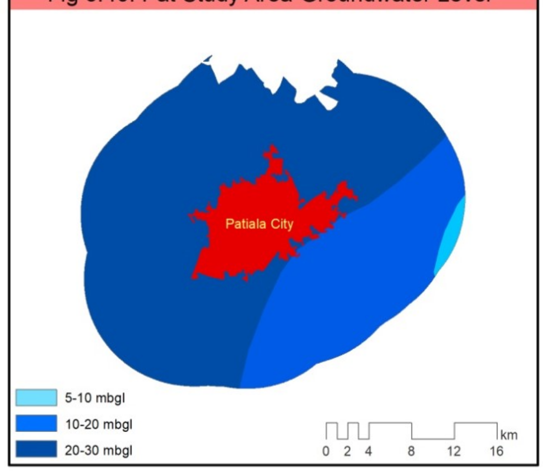


Fig 6.41: Pat Study Area-Distance from City

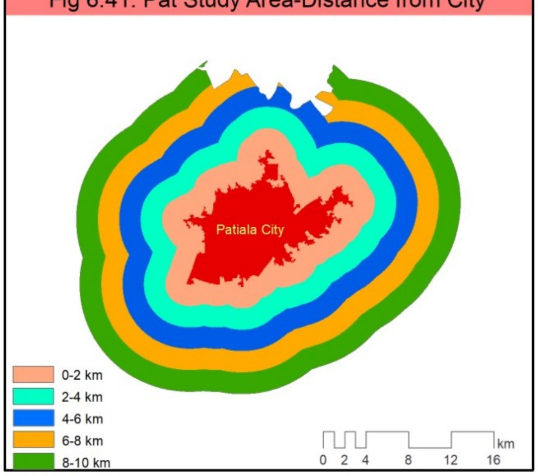


Fig 6.42: Pat Study Area-Distance from Canals

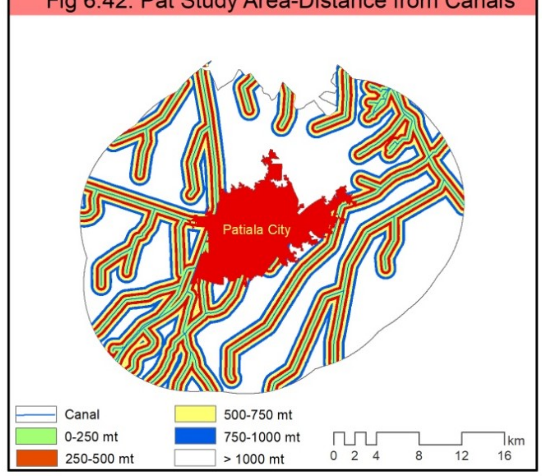


Fig 6.43: Pat Study Area-Distance from Drains

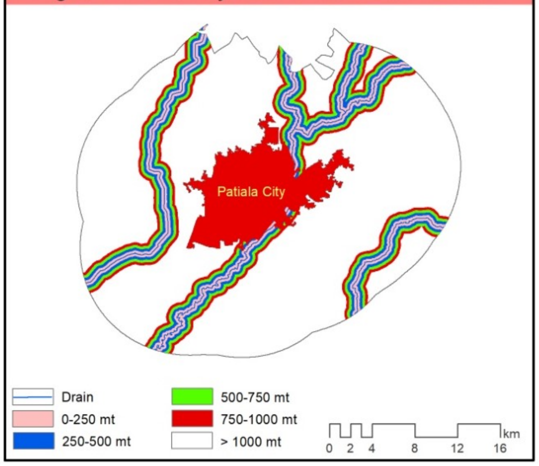


Fig 6.44: Pat Study Area-Distance from Settlements

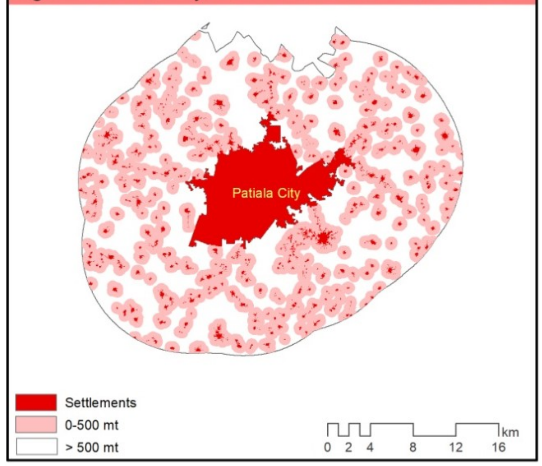


Fig. 6.45: Pat Study Area-Slope

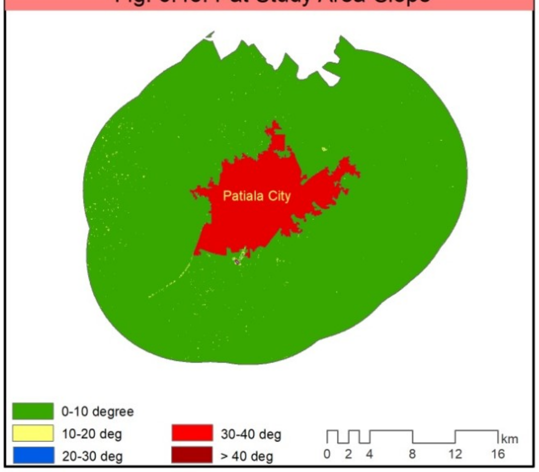


Fig 6.46: Pat Study Area-Distance from Roads

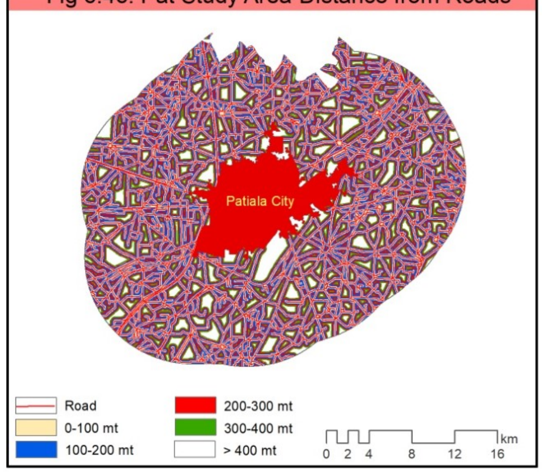


Fig 6.47: Pat Study Area-Suitable Areas

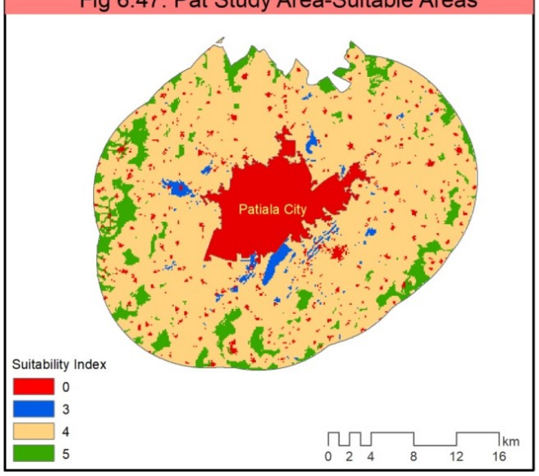
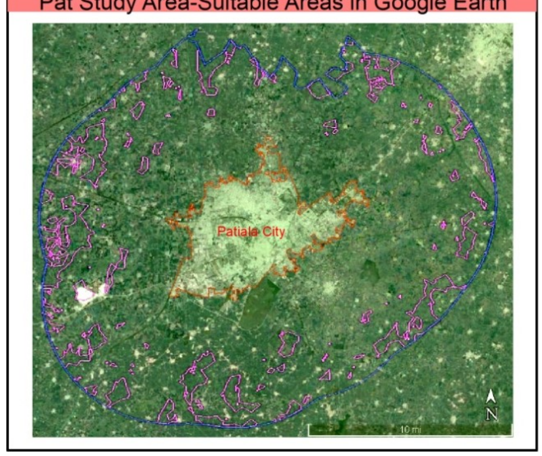


Fig 6.48:
Pat Study Area-Suitable Areas in Google Earth



parts of the study area covering maximum area of 689 sq km. Next category of D6 or somewhat excessively drained soil covers 44 sq km of area in five patches three in north, one in east and one in southeast (fig 6.39).

(c) Groundwater Level

While analyzing the variable of groundwater level it is noted that only three levels are found in this study area which are 5-10 mbgl (meters below ground level), 10-20 mbgl and 20-30 mbgl. Minimum levels are found in the eastern part of study area and towards west the levels go on increasing. Subclass of 5-10 mbgl is found in eastern part in a single patch which covers an area of only 8 sq km. The next subclass of 10-20 mbgl which is found in eastern part covering 219 sq km of area. The third subclass of 20-30 mbgl covers entire western half and northeastern part of study area in an area of 528 sq km (fig 6.40).

(d) Distance from City

To analyze the variable of distance from city the study area is divided into five zones which are 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the outer limit of the city. First zone or subclass of 0-2 km from the city occupies an area of 129 sq km, 2-4 km subclass covers 134 sq km, 4-6 km subclass covers 152 sq km, 6-8 km subclass covers 162 and 8-10 km subclass covers an area of 178 sq km (fig 6.41).

(e) Distance from Canals

There are numerous canals in this study area and most of these are branches of Patiala branch of Bhakhra canal. To analyze the variable of distance from canals, five buffer zones or subclasses are made on both sides of canals. These are 0-250 mt, 250-500 mt, 500-750 mt, 750-1000 m and more than 1000 mt. Buffer zone of 0-250 m has an area of 125 sq km, 250-500 m has 113 sq km, 500-750 m has 104 sq km, 750-1000 m has an area of 94 sq km and zone of more than 1000 m covers maximum area of 319 sq km (fig 6.42).

(f) Distance from Drains

Like canals, five buffer zones or subclasses on both sides of all the drains are also made for the analysis of variable of distance from drains. These buffer zones are 0-250 mt, 250-500 mt, 500-750 mt, 750-1000 m and more than 1000 mt. Buffer zone of 0-250 m has an area of 52 sq km, 250-500 m has 48 sq km, 500-750 m has 46 sq km, 750-1000 m has an area of 44 sq km and zone of more than 1000 m covers maximum area of 565 sq km (fig 6.43).

(g) Distance from Settlements

Next, the variable of distance from settlements is analyzed. As already mentioned in para 6.4.1 (a) there are 316 number of settlements in this study area. In order to avoid the site in immediate vicinity of these settlements two subclasses are made around all settlements or villages. These are 0-500 m and more than 500 mt. The subclass of 0-500 m covers an area of 424 sq km and the subclass of more than 500 m covers an area of 331 sq km (fig 6.44).

(h) Slope

To analyze the variable of slope of the entire study area is divided into five subclasses: 0-10 degrees, 10-20 degrees, 20-30 degrees, 30-40 degrees and more than 40 degrees. While analyzing the layer of slope it is found that 752.7 sq km of area out of 755 sq km of total area falls in 0-10 degrees of slope. It is followed by 2.12 sq km of area falling in 10-20 degrees of slope, 0.10 sq km of area in 20-30 degrees of slope, 0.05 sq km of area in 30-40 degrees of slope and negligible 0.007 sq km of area in more than 40 degrees of slope. This study area is characterized by absolute flatness (fig 6.45).

(i) Distance from Roads

With regard to the variable of distance from roads, it is noted that the present study area has sufficient density of roads. To analyze proximity of sites to the roads five buffer zones or subclasses are marked on both sides of all the roads. These subclasses are 0-100 mt, 100-200 mt, 200-300 mt, 300-

400 m and more than 400 mt. Maximum area of 296 sq km lies in the first subclass of 0-100 m followed by 207 sq km in 100-200 mt, 127 sq km in 200-300 mt, 66 sq km in 300-400 m and 59 sq km in > 400 m subclass (fig 6.46).

6.4.2 Weighted Overlay Analysis

For weighted overlay analysis, all data are converted into raster format and assigned percentage of influence to all the variables and weightage to the subclasses of variables on the basis of model already prepared and discussed in chapter 4. In ArcGIS when the tool of weighted overlay analysis is run for the study area of Patiala, a new raster is generated that categorizes the entire study area in four suitability zones alongwith suitability index i.e. 0, 3, 4 and 5 (fig 6.47). The areas with highest suitability index of 5 cover only 10.63% of the study area. This suitable area is extracted and converted into Keyhole Markup Language (KML) file alongwith KML files of all other variables so that the same can be viewed in Google Earth (fig 6.48). In Google Earth the machine generated results are verified manually before locating three sites of 50 acres each within suitable areas.

6.4.3 Validation

After locating three sites, these are validated by overlaying on layers of all the nine variables. When sites are overlaid on landuse landcover layer it is observed that all three sites are on the cultivated land that is assigned highest weightage of 5. On the layer of soil drainage it is discovered that all three sites are located on D5 category or well drained soil that is assigned the weightage of 4 (table 6.8). On the layer of groundwater it is noticed that site 1 and site 3 are located in the subclass of 20-30 mbgl which is assigned the maximum weight of 5 and site 2 is in the subclass of 10-20 mbgl that is assigned the weightage of 4. Further, on the layer of distance from city it is found that site 1 lies in the subclass of 6-8 km from city that is assigned the weight of 4 while site 2 and 3 are located in the 8-10 km subclass that is assigned the maximum weightage of 5 however some part of site 2 lies in 6-8 km subclass having weightage of 4. Then on the layer of distance from canals it is noticed that all three sites are located in the subclass of more than 1000 m from canal that is assigned the weightage of 5. Then on the layer of distance from drains it is found that all three sites are located in the subclass of more than 1000 m from drains which is assigned the weight of 5. By overlaying sites on the layer of distance from settlements or villages it is discovered that all three sites are located in the subclass of > 500 m from settlements that is assigned the maximum weight of 5. On the layer of slope it is noted that all three sites are

Table 6.8
Sites for Patiala MC falling under subclasses of each variable alongwith weightage

S. no.	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D5 (4)	D5 (4)	D5 (4)
3	Groundwater level	20-30 mbgl (5)	10-20 mbgl (4)	20-30 mbgl (5)
4	Distance from City	6-8 km (4)	8-10 km (5), 6-8 km (4)	8-10 km (5)
5	Distance from Canal	>1000 m (5)	>1000 m (5)	>1000 m (5)
6	Distance from Drain	>1000 m (5)	>1000 m (5)	>1000 m (5)
7	Distance from Village	>500 m (5)	>500 m (5)	>500 m (5)
8	Slope	0-10 degrees (5)	0-10 degrees (5)	0-10 degrees (5)
9	Distance from Roads	0-100 m (5)	0-100 m (5)	0-100 m (5)

located in the subclass of 0-10 degrees that is assigned the maximum weightage of 5 except very tiny patches of site 1 and 3 fall in the category of 10-20 degrees category having weightage of 4. When sites are overlaid on the last layer of distance from roads it is found that all three sites are located right on the road or in the subclass of 0-100 m from road that is assigned the maximum weight of 5. Hence it is proved that the results of weighted overlay analysis for site identification for solid waste management of Patiala municipal corporation are authentic and judicious because only those areas are selected by this tool that are assigned the highest values on the preference scale. Manual authentication is also performed and sites are finalized for Patiala municipal corporation after the validation process.

6.4.4 Final Sites

After validation, it is observed that all the three sites successfully satisfy all the nine variables mentioned in the "Deepak-Kalota Model of Site Identification for Solid Waste Management". These three sites are therefore finalized for the solid waste management of Patiala municipal corporation. The Site 1 is marked in the extreme west near Kheri Musalmani village; site 2 is marked in the extreme east near Rasulpur and Rurki village and site 3 in the northwest near Mandour village. Site 1 is the most preferred site followed by site 2 and site 3 (fig App 9.1).

6.5 SITE IDENTIFICATION FOR SAS NAGAR / MOHALI MC

The study area of SAS Nagar or Mohali municipal corporation lies adjacent to Shiwalik hills in the southeastern part of Punjab state. It shares its boundary with the union territory of Chandigarh in the east; district Fatehgarh Sahib to the west and district Patiala to the south. On all three sides the boundary of this study area is clipped (fig: 6.49). After clipping a total area of 420 sq km remains for analysis.

6.5.1 Analysis of Variables

To apply the model for site identification all nine variables need to be analyzed for their role in site identification process. For the SAS Nagar or Mohali municipal corporation the analysis of variables is described below.

(a) Landuse Landcover

While analyzing the variable of landuse landcover, it is noticed that subclass of cultivated land covers the maximum area of 314.14 sq km out of 420 sq km of total study area (table 6.9). The cultivated area can be seen in all parts of the study area. Next, the subclass of settlements is analyzed and it is noticed that these cover 74.06 sq km of area at 180 locations. Two settlements of bigger size are noticeable and these are Kharar town in the northwest and Zirakpur town in the southeast. Next, the subclass of plantations can be seen at 491 locations covering 9.91 sq km of area. The plantations are more dense in the western half of study area. Lastly, the subclass of industries are found at 27 locations covering 0.47 sq km of area. The industries are almost uniformly distributed all across the study area (fig: 6.50).

Table 6.9
Area under subclasses of each variable in Mohali study area

S. no.	Variable	Subclass	Area in sq km
1	Landuse landcover		
		Plantation	9.91
		Villages/Settlements	74.06
		Industry	0.47
		Cultivated	314.14
2	Soil		
		D4-Moderately Well Drained	22
		D5-Well Drained	242
		D6-Somewhat Excessively Drained	156
3	Groundwater Level		
		5-10 mbgl	320
		10-20 mbgl	79
		20-30 mbgl	21
4	Distance from City		
		0-2 km	55
		2-4 km	71
		4-6 km	92
		6-8 km	100
		8-10 km	102
5	Distance from Canals		
		0-250 mt	6
		250-500 mt	5
		500-750 mt	5
		750-1000 mt	5
		>1000 mt	399
6	Distance from Drains		
		0-250 mt	66
		250-500 mt	57
		500-750 mt	52
		750-1000 mt	47
		>1000 mt	198
7	Distance from Villages/Settlements		
		0-500 mt	326
		>500 mt	94
8	Slope		
		0-10 degrees	418.07
		10-20 degrees	1.9
		20-30 degrees	0.03
9	Distance from Roads		
		0-100 mt	176
		100-200 mt	114
		200-300 mt	62
		300-400 mt	32
		>400 mt	36

Fig 6.49: Location of Mohali Study Area in District

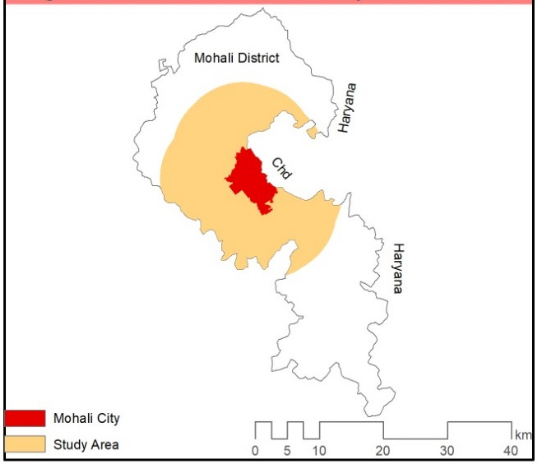


Fig 6.50: Moh Study Area-Landuse Landcover

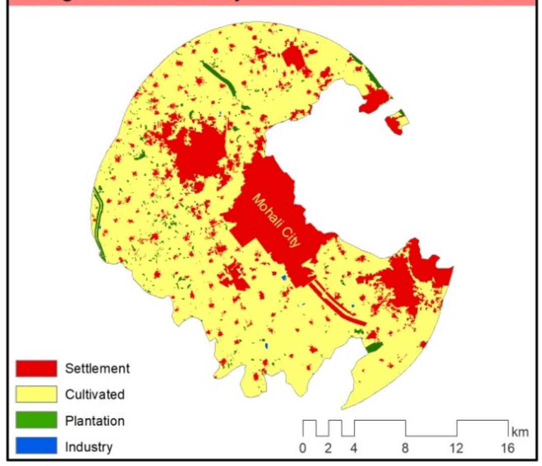


Fig 6.51: Moh Study Area-Soil Drainage

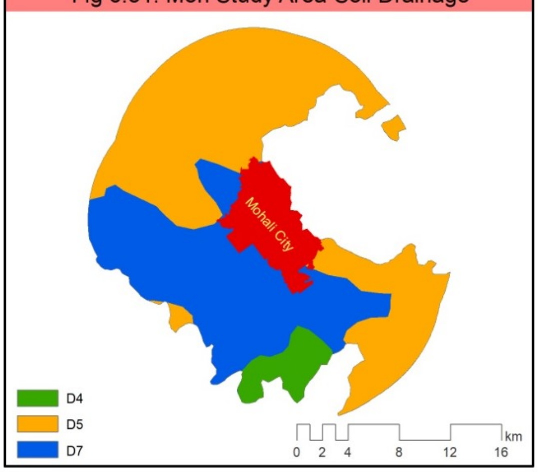


Fig 6.52: Moh Study Area-Groundwater Level

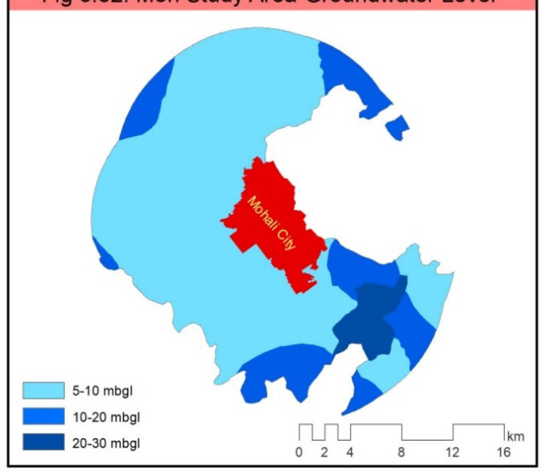


Fig 6.53: Moh Study Area-Distance from City

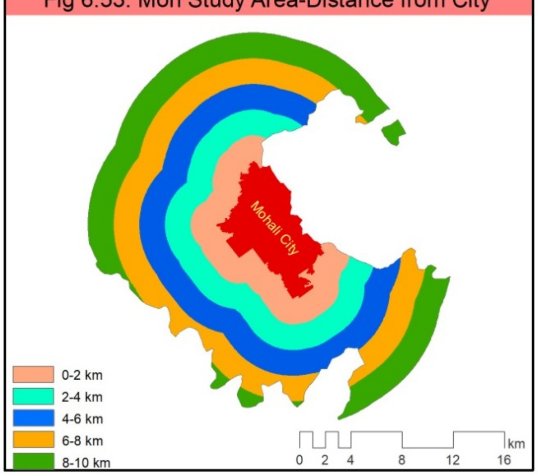


Fig 6.54: Moh Study Area-Distance from Canals

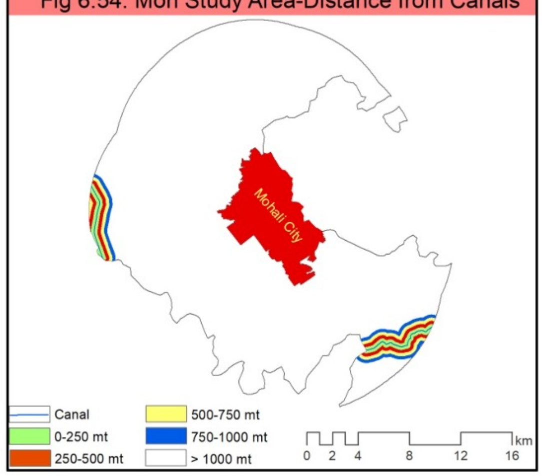


Fig 6.55: Moh Study Area-Distance from Drains

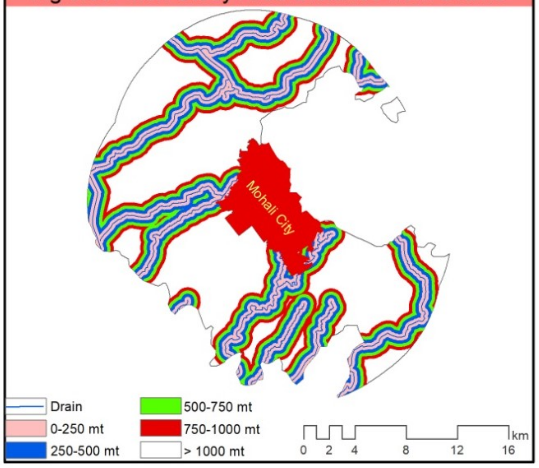


Fig 6.56: Moh Study Area-Distance from Settlements

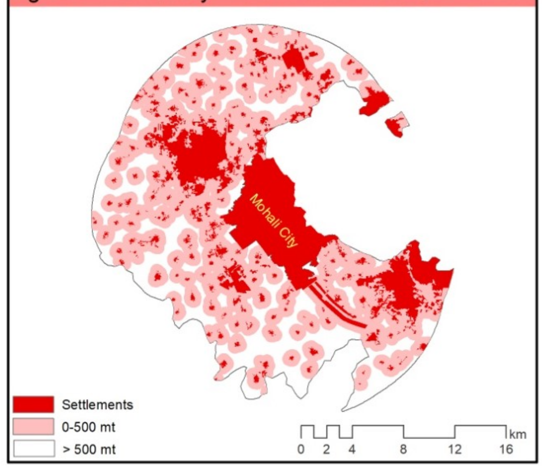


Fig. 6.57: Moh Study Area-Slope

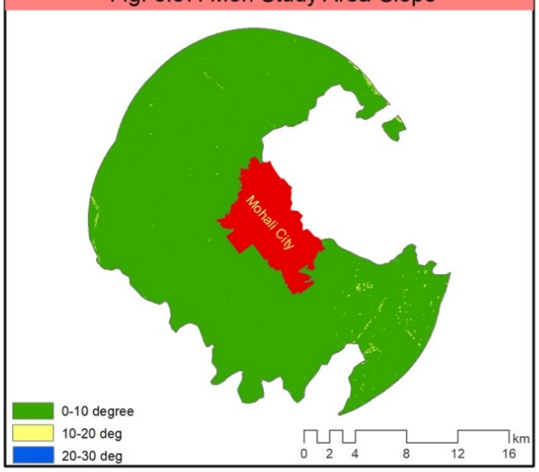


Fig 6.58: Moh Study Area-Distance from Roads

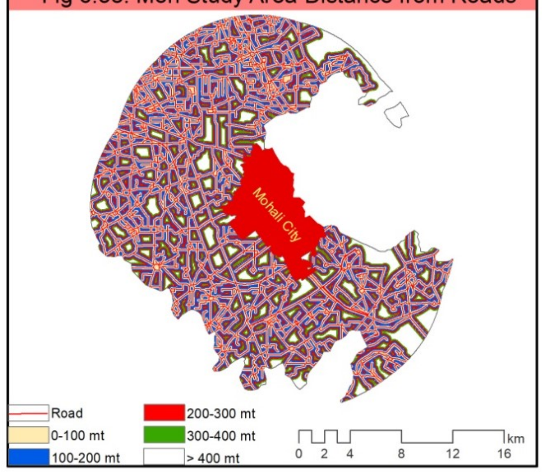


Fig 6.59: Moh Study Area-Suitable Areas

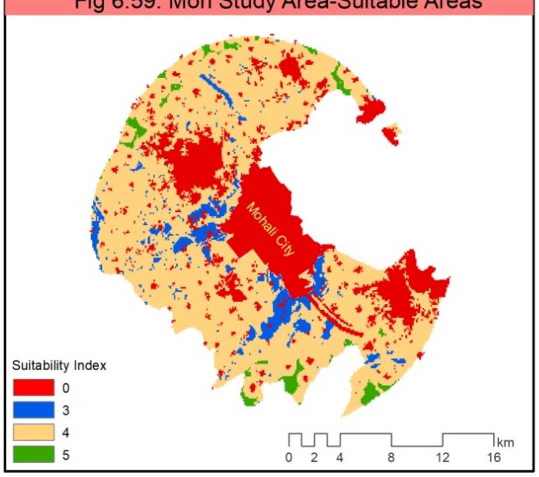
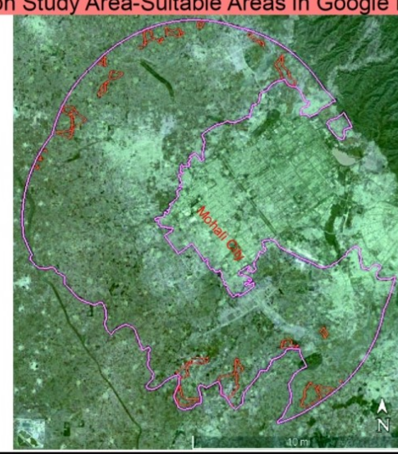


Fig 6.60:
Moh Study Area-Suitable Areas in Google Earth



(b) Soil Drainage

While analyzing the variable of soil drainage it is observed that only three kinds of soil are found in this study area. These are D4 or moderately well drained, D5 or well drained and D6 or somewhat excessively drained. Subclass of D4 can be seen in south covering 22 sq km of area; D5 subclass covers most parts of the study area in 242 sq km of area and D6 subclass is seen in middle and western parts covering 156 sq km of area (fig: 6.51).

(c) Groundwater Level

While analyzing the third variable of groundwater level, three levels are found in this study area: 5-10 mbgl (meters below ground level), 10-20 mbgl and 20-30 mbgl. First subclass of 5-10 mbgl covers maximum area in 320 sq km and found in almost all parts of the study area. The second subclass of 10-20 mbgl is found in seven patches in different parts of the study area covering 79 sq km of area. The last subclass of 20-30 mbgl is seen only in south covering an area of 21 sq km (fig: 6.52).

(d) Distance from City

To analyze the variable of distance from city the study area is divided into five distance zones or subclasses: 0-2 km, 2-4 km, 4-6 km, 6-8 km and 8-10 km from the outer limit of the city. While analyzing it is noticed that an area of 55 sq km falls in the first subclass of 0-2 km from city; 71 sq km of area falls in the subclass of 2-4 km; 92 sq km in the subclass of 4-6 km; 100 sq km in the subclass of 6-8 km and 102 sq km of area falls in the farthest subclass of 8-10 km from the city (fig: 6.53).

(e) Distance from Canals

For the next variable of distance from canals it is noted that canals are limited to the southern part only. To analyze the variable of distance from canals the study area is divided into five categories or subclasses: 0-250 mt, 250-500 mt, 500-750 mt, 750-1000 m and more than 1000 m from canals. It is noticed that an area of 6 sq km falls in the first subclass of 0-250 m from canals; 5 sq km of area in the second subclass of 250-500 m from the canals; 5 sq km of area in the subclass of 500-750 m from the canals; again 5 sq km in the subclass of 750-1000 m from the canals and maximum area of 399 sq km falls in the last subclass of more than 1000 m from the canals (fig: 6.54).

(f) Distance from Drains

There are numerous drains in this study area. To analyze the variable of distance from drains the study area is divided into five categories or subclasses: 0-250 mt, 250-500 mt, 500-750 mt, 750-1000 m and more than 1000 m from drains. While analyzing it is noted that the first subclass of 0-250 m from drains covers 66 sq km of area; second subclass of 250-500 m from drains covers 57 sq km of area; third subclass of 500-750 m from drains covers 52 sq km of area; fourth subclass of 750-1000 m from drains covers 47 sq km of area and the last subclass of more than 1000 m from drains covers maximum area of 198 sq km (fig: 6.55).

(g) Distance from Settlements

As already mentioned in para 6.5.1 (a) there are 180 number of locations and are found in all parts of the study area. To analyze the variable of distance from settlements the study area is divided into two subclasses: 0-500 m and >500 m. While analyzing it is noted that the first subclass of 0-500 m from settlements covers 326 sq km of area and the subclass of more than 500 m from settlements covers 94 sq km of area (fig: 6.56).

(h) Slope

To analyze the variable of slope five subclasses are made with regard to slope in degrees but in this study area only three subclasses are found. These are: 0-10 degrees, 10-20 degrees and 20-30 degrees. While analyzing it is noted that the maximum area of 418.07 sq km is covered in the first subclass of 0-10 degrees of slope indicating the flatness of area. The next subclass of 10-20 degrees of slope covers 1.9 sq km of area and 20-30 degrees of slope covers only 0.03 sq km of area (fig: 6.57).

(i) Distance from Roads

To analyze the proximity of proposed sites to the roads the entire study area is divided in five subclasses or distance zones. These are: 0-100 m from roads, 100-200 mt, 200-300 mt, 300-400 m and more than 400 m from the roads. The first subclass of 0-100 m from roads covers 176 sq km of area; subclass of 100-200 m from roads cover 114 sq km; 200-300 m from roads cover 62 sq km; 300-400 m from roads cover 32 sq km and the last or farthest subclass of >1000 m from roads cover 36 sq km of area. There is enough density of roads in this study area (fig: 6.58).

6.5.2 Weighted Overlay Analysis

After analyzing, all data are converted into raster format. Then each variable and its subclasses are assigned percentage of influences and weightage respectively on the basis of model already discussed in chapter 4. When the tool of Weighted Overlay Analysis is run for this study area, a new raster dataset is generated that categorizes the study area into four suitability zones alongwith suitability index i.e. 0, 3, 4 and 5 (fig: 6.59). The most suitable areas have weightage of 5 and account for 2.95% of the total study area. These highly suitable areas are extracted and converted into Keyhole Markup Language (KML) file to view in Google Earth alongwith KML files of all other variables (fig: 6.60). Here the machine generated results of Weighted Overlay Analysis are manually verified and then three sites are marked in the highly suitable areas by once again considering all the nine variables. For this study area three sites of 50 acres each are marked, two in the southern and one in the northwestern part of the study area.

6.5.3 Validation

Site identification process is not complete without validation. After locating the sites these are overlaid on the layers of all the nine variables. First of all the sites are overlaid on the layer of landuse landcover and found that all three sites are situated in the subclass of cultivated land which is assigned the

Table 6.10
Sites for Mohali MC falling under subclasses of each variable alongwith weightage

S. no.	Factor	Location of Site 1 in subclasses and weightage	Location of Site 2 in subclasses and weightage	Location of Site 3 in subclasses and weightage
1	Landuse	Cultivated (5)	Cultivated (5)	Cultivated (5)
2	Soil Drainage	D5 (4)	D4 (5)	D5 (4)
3	Groundwater level	10-20 mbgl (4), 5-10 mbgl (3)	10-20 mbgl (4)	10-20 mbgl (4)
4	Distance from City	8-10 km (5)	6-8 km (4)	8-10 km (5)
5	Distance from Canal	>1000 m (5)	>1000 m (5)	>1000 m (5)
6	Distance from Drain	>1000 m (5)	>1000 m (5)	>1000 m (5)
7	Distance from Village	>500 m (5)	>500 m (5)	>500 m (5)
8	Slope	0-10 degrees (5)	0-10 degrees (5)	0-10 degrees (5)
9	Distance from Roads	0-100 m (5)	0-100 m (5)	0-100 m (5)

weightage of 5 (table 5.10). Secondly, these sites are overlaid on the layer of soil drainage and it is noticed that site 1 and site 3 are situated in the subclass of D5 or well drained soil that is assigned the weightage of 4 while site 2 lies in the subclass of D4 or moderately well drained soil that is assigned the weightage of 5. Next the sites are overlaid on the layer of groundwater level and found that all three sites are situated in the subclass of 10-20 mbgl that is assigned the weightage of 4 however some parts of site 1 also lie in the subclass of 5-10 mbgl that is assigned the weightage of 3. Next the sites are overlaid on the layer of distance from city and found that site 1 and site 3 are situated in the subclass of 8-10 km from the city which is assigned the weightage of 5 and site 2 lies in the subclass of 6-8 km from city that is assigned the weightage of 4. Next the sites are overlaid on the layer of distance from canals and it is noticed that all three sites are situated in the subclass of more than 1000 m from the canals that is assigned the weightage of 5. Then all sites are overlaid on the layer of distance from drains and it is found that all three sites are situated in the subclass of more than 1000 m from the drains that is assigned the weightage of 5. Next all sites are overlaid on the layer of distance from settlements and it is found that all three sites are situated in the subclass of more than 500 m from the settlements that is assigned the weightage of 5. Then all sites are overlaid on the layer of slope and it is observed that all three sites are located in the zone of 0-10 degrees of slope that is assigned the weightage of 5 however one pixel or tiny area of site 1 has 10-20 degrees of slope having weightage of 4 but that is negligible. Lastly, all sites are overlaid on the layer of distance from roads and it is noticed that all three sites are situated right on the road or in the zone of 0-100 m from road that is assigned the weightage of 5. In the end it can be concluded that all three sites are situated in the most suitable areas identified by weighted overlay analysis which satisfies all the criteria. Further the results of this tool are also manually validated in Google Earth while locating the sites. After validation all the three sites are finalized for solid waste management of Mohali municipal corporation.

6.5.4 Final Sites

After validation, it is observed that all the three sites successfully satisfy all the nine variables mentioned in the "Deepak-Kalota Model of Site Identification for Solid Waste Management". These three sites are therefore finalized for the solid waste management of Mohali municipal corporation. The most preferred site or site 1 lies in south near Bahora village, site 2 in south near Sekhan Majra village and site 3 is in northwest near Rurkee Pukhta village (fig App 10.1). Site 1 is the most preferred site followed by site 2 and site 3.

6.6 CONCLUSION

In this chapter five municipal corporations of Malwa area are analyzed namely: Ludhiana, Moga, Bathinda, Patiala and SAS Nagar or Mohali. Three sites of 50 acres each for solid waste management are identified for each municipal corporation by using "Deepak-Kalota Model of Site Identification for Solid Waste Management". In Ludhiana municipal corporation Site 1 is located in the east near Rampur village, Site 2 is located in the east near Bhagpur village and Site 3 is in the south near Bhutta village. In Moga municipal corporation Site 1 lies in the western part near Dadahoor village; Site 2 lies in the eastern part near Kokri hera village and Site 3 in the north near Khosa Randhir village. In Bathinda municipal corporation Site

1 lies in north near Dhelwa village; Site 2 is in northeast near Lehra Bega village and Site 3 lies in southwest near Jai Singh wala village. In Patiala municipal corporation Site 1 lies in the west near Kheri Musalmani village; Site 2 is in the east near Rasulpur and Rurki village and Site 3 in the northwest near Mandour village. In SAS Nagar or Mohali municipal corporation Site 1 lies in south near Bahora village, Site 2 in south near Sekhan Majra village and Site 3 is in northwest near Rurkee Pukhta village. Hence in total fifteen sites are identified in this chapter with the help of weighted overlay analysis. The tool of weighted overlay analysis requires specific inputs which are provided by the model. The model that has already been discussed in chapter 4 plays a vital role by considering all the nine variables judiciously and helps in site identification. The machine generated results are also verified manually in Google Earth to test the efficacy of model.

SUMMARY & CONCLUSIONS

Solid waste management has been catching the eye of planners because of continuously deteriorating condition specially in the bigger cities. In the present century the volume of solid waste has increased speedily not only because of growing population but also because of growing per capita generation of solid waste due to changing lifestyle of people. It also appears that in the coming times the solid waste is likely to grow even more. One prediction suggests that the solid waste generation in India is likely to grow from 62 million tons to 165 million tons in 2031 and 436 million tons in 2050 (Ministry of Environment….., 2016b). There are numerous ways to manage the solid waste but landfill is the most common method being adopted by the urban local bodies. In Punjab, out of 4544.35 tons per day (TPD) generation of solid waste 3278.6 tons per day (TPD) is managed by means of landfill (Punjab Pollution Control Board, 2017). This technique is not environment friendly and is capable of polluting the surroundings. Situation may worsen when it is situated in the neighbourhood of a settlement. All urban local bodies are using some site for solid waste management. In most cases it is observed that these sites are close to the settlements. It happens because all factors were not considered at the time of site selection.

Present study attempts to identify suitable sites for solid waste management for the municipal corporations of Punjab. When current scenario is analyzed for the state of Punjab it is noticed that the solid waste management is a neglected sector. Of all the 167 urban local bodies in the state of Punjab, only 7 are complying with the 10 points of common action plan prepared by Punjab government and the remaining are either not implementing or partially implementing (Punjab Pollution Control Board, 2017). The present study focuses on the ten municipal corporations of Punjab namely Amritsar, Pathankot, Jalandhar, Phagwara, Hoshiarpur, Ludhiana, Moga, Bathinda, Patiala and SAS Nagar or Mohali. All of these are big and growing cities of Punjab and their solid waste generation is also growing. Looking at the current scenario of solid waste management in these ten municipal corporations of Punjab it is noted that the sites being used for solid waste management have reached their saturation level and also pose environmental pollution threats.

The ten municipal corporations of Punjab are studied by dividing into three categories i.e. municipal corporations of Majha, Doaba and Malwa area. Amritsar and Pathankot municipal corporations fall the Majha area; Jalandhar, Phagwara and Hoshiarpur municipal corporations fall in Doaba area while Ludhiana, Moga, Bathinda, Patiala and SAS Nagar or Mohali municipal corporations fall in the Malwa area of Punjab.

Study areas for all municipal corporations are defined by making a 10 km buffer around the cities. In other words the boundary of the study area begins from the outer limit of the city and extends upto 10 km. Wherever the boundary of study area crosses the district boundary it is clipped by the district boundary. It generates sufficient area for identification of suitable site for solid waste management.

A total of nine variables are identified that are capable of affecting the site identification process. These variables are landuse landcover, soil drainage, groundwater level, distance from city, distance from canals, distance from drains, distance from settlements or villages, slope and distance from roads. Data for most of these variables is obtained from satellite imageries. Soil drainage data is obtained by digitizing the map prepared and revised jointly by National Bureau of Soil Survey, Landuse Planning and Punjab Remote Sensing Centre, Ludhiana. Data on groundwater level is obtained from the district maps of groundwater prepared by the Central Groundwater Board. Data on slope is obtained in the form of Digital Elevation Models (DEM). This is Cartosat-I data downloaded from official website of Bhuvan – Indian Geo-Platform of ISRO (Indian Space Research Organization).

An experimental model namely "Deepak-Kalota Model of Site Identification for Solid Waste Management" is prepared to identify suitable site for solid waste management. This model uses the above mentioned nine variables. Since all variables do not affect the site identification process equally therefore all variables and their subclasses are quantified. This is done by assigning percentage of influence to each variable and weightage to the subclasses of each variable. The weightage to the subclasses is assigned on scale of 1-5. Delphi method is used for the purpose of quantification by involving academicians, planners, scientists and administrators.

Each variable has its subclasses. The variables are assigned percentage of importance and their subclasses are assigned weightage on the scale of 1-5. Maximum influence of 22 percentage is assigned to the variable of landuse landcover. Its four subclasses are considered viz. cultivated land, plantation, industry and settlement. Among these the cultivated land is assigned maximum weightage because in the absence of waste land it is the only option available for site identification. Next, the variable of soil drainage is assigned 18 percentage of influence and its subclasses are D4 or moderately well drained soil, D5 or well drained soil, D6 or somewhat excessively drained soil and D7 or excessively drained soil. Because excessively drained soil can pollute the subsoil and groundwater therefore it is not preferred subclass for site identification. Subclass of D4 is assigned high weightage because of minimum leaching hence preferred for site identification. Next, the variable of groundwater level is assigned 12 percentage of influence. It has several subclasses but the subclass of > 20 mbgl (meters below groundwater level) is assigned maximum weightage because deeper level of groundwater has minimum chances of getting polluted from the leachate. On the other hand shallow levels with lower weightage are prone to pollution from leachate. Next, the variable of distance from city is assigned 12 percentage of influence and its subclasses of 0-2, 2-4, 4-6, 6-8 and 8-10 km from city are considered. Here the weightage to subclasses is assigned keeping in mind the expected growth of city in the coming years. So zone of 0-2 km is assigned minimum weightage because this area being in the immediate vicinity of city is more vulnerable of getting urbanized in coming years. On the other hand zone of 8-10 km from city being farthest is assigned maximum weightage because this zone has least chances of getting urbanized in the coming years due to growth of city. Next, the variable of distance from canals is assigned 10 percentage of influence and its five subclasses are considered viz. 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from canals. This variable is analyzed to save canals from getting polluted from the proposed site of solid waste management. Therefore, farther zone of > 1000 m is assigned maximum weightage so that the canals remain protected from the surface runoff or pollution emanating from the site. Next, the variable of distance from drains is assigned 8 percentage of influence and its five subclasses are identified viz. 0-250 m, 250-500 m, 500-750 m, 750-1000 m and more than 1000 m from drains. Here also farthest zone of >1000 m is assigned maximum weightage so that the pollution from surface runoff cannot reach drains. Next, the variable of distance from settlements or villages is assigned 8 percentage of influence and its two subclasses are considered viz. 0-500 m and >500 m from the settlement. In this case the >500 m subclass is assigned maximum weightage and 0-500 m is assigned minimum weightage so that site remains away from the settlement. It also satisfies the rules of solid waste management. Next, the variable of slope is assigned 7 percentage of influence and its five subclasses are considered: 0-10 degrees of slope, 10-20 degrees, 20-30 degrees, 30-40 degrees and >40 degrees of slope. In this case area of 0-10 degrees of slope is preferred and assigned maximum weightage. On the other hand steeper areas are assigned minimum weightage for the fear of frequent surface runoff and landslides. However there are fewer areas of steep slope in the study areas. Lastly, the variable of distance from roads is analyzed for the proximity of roads to the proposed site. This variable is assigned 3 percentage of influence because there is already enough density of roads in all study areas. Its five subclasses are considered viz. 0-100 m, 100-200 m, 200-300 m, 300-400 m and >400 m of distance from roads. Here 0-100 m subclass is assigned maximum weightage for its proximity to the proposed site.

After making the model, all data is analyzed in ArcGIS and is followed by converting the data in raster format. It is followed by the crucial step of weighted overlay analysis that calculates the values assigned to variables and their subclasses to generate a new raster that divides the entire study area in various zones on the basis of suitability index ranging from 0-5. Areas that are assigned 5 are the most suitable areas for site identification for solid waste management. These suitable areas are viewed in Google Earth where the machine generated results are manually validated. Here three sites are identified and marked in the suitable areas by once again considering all the nine variables manually. This process is repeated for all the ten municipal corporations thereby locating three sites for each municipal corporation and 30 sites in total for all the municipal corporations of Punjab.

After locating the sites, these are validated by overlaying on the layers of all the nine variables in GIS environment. A table is made for each municipal corporation wherein location of site in each subclass is indicated alongwith the weightage given to that subclass. This table clearly reveals that the site is located in that subclass where all or most of the subclasses have high weightage on the scale of 1-5. After successful validation the sites are finalized for solid waste management.

For Amritsar municipal Corporation Site 1 lies in the southwest near Kaunke village; Site 2 in the southeast near Pakhoke village and Site 3 in the east near Khalehra village. For Pathankot municipal Corporation Site 1 lies in north near Kamwal and Rajpura villages; Site 2 in northwest near Tharyal village and Site 3 in west near Bhool Chack village. For Jalandhar municipal Corporation Site 1 is in southwest near Kang Sabhu and Singh villages; Site 2 is in the southern part near Chak Khurd village and Site 3 is in the south near Kangniwal village. For Hoshiarpur municipal Corporation Site 1 lies on southwest near Arjam village; Site 2 lies in west near Badala Mahi village and Site 3 in west near Gagnuli village. For Phagwara municipal Corporation Site 1 lies in west near Chaheru village; Site 2 in north near Rampur Sunra village and Site 3 in northeast near Sahni village. In Ludhiana municipal corporation Site 1 is located in the east near Rampur village, Site 2 is located in the east near Bhagpur village and Site 3 is in the south near Bhutta village. In Moga municipal corporation Site 1 lies in the western part near Dadahoor village; Site 2 lies in the eastern part near Kokri hera village and Site 3 in the north near Khosa Randhir village. In Bathinda municipal corporation Site 1 lies in north near Dhelwa village; Site 2 is in northeast near Lehra Bega village and Site 3 lies in southwest near Jai Singh wala village. In Patiala municipal corporation Site 1 lies in the west near Kheri Musalmani village; Site 2 is in the east near Rasulpur and Rurki village and Site 3 in the northwest near Mandour village. In SAS Nagar or Mohali municipal corporation Site 1 lies in south near Bahora village, Site 2 in south near Sekhan Majra village and Site 3 is in northwest near Rurkee Pukhta village.

It may be submitted that the present work has successfully located the sites for all the municipal corporations of Punjab to manage solid waste. Current scenario of all the municipal corporations confirms the necessity to have suitable site for solid waste management. Latest advancements in the fields of GIS and Remote Sensing led to the development of efficient tools to analyze the variables. Preparation of model is made possible only because of these widgets. "Deepak-Kalota Model of Site Identification for Solid Waste Management" is made of several components. When this model is applied to evaluate the current sites of all the municipal corporation of Punjab, it is observed that most sites failed on one or the other variable. Had a model like "Deepak-Kalota Model of Site Identification for Solid Waste Management" applied, the scene at these sites would have been different. All the objectives laid down for the present study are thus achieved.

In the end it is proposed that the present study can be helpful in identifying suitable sites for solid waste management in other locations as well. "Deepak-Kalota Model of Site Identification for Solid Waste Management" can be applied in all those areas where similar conditions prevail specially relief. The present study can also be utilized to identify a suitable site for Nuclear Power Plant in the state of Punjab. It may be mentioned here that the Government of India is exploring new sites in the state of Punjab to set up nuclear power plant. Besides Punjab, the government is also looking sites in the adjoining states of Haryana and Uttarakhand to set up nuclear power plants (Tribune news Service, 2019, June, 26). This study can also be used for comparison of operational waste management sites and the sites identified using "Deepak-Kalota Model of Site Identification for Solid Waste Management". In this way the shortcoming of the operational sites can be evaluated and proper action can be taken.

Communications are underway with the 'Punjab Pollution Control Board' and the 'Ministry of Local Government, Punjab' to utilize this research work in Site Identification process for Solid Waste Management in Punjab. A positive reply has already been received from the Hon'ble Minister Sh. Brahm Mohindra, Minister Local Government, Punjab in this regard. He has agreed to share the inputs from researcher with the concerned department and a meeting in this regard has been ordered to be fixed.

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APPENDIX - 1

Sites of Amritsar MC overlaid on layers of each variable

Fig: App 1.1 Sites in Suitable Areas on Google Earth

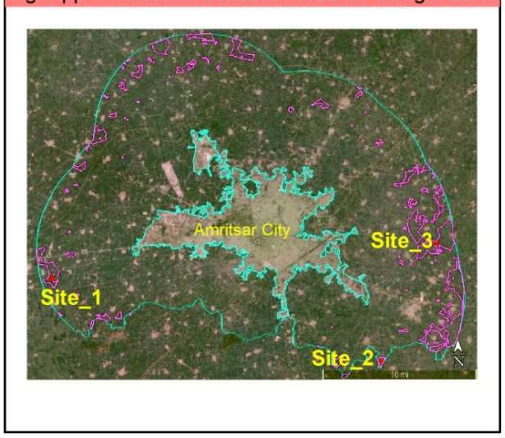


Fig: App 1.2 Sites on Landuse Landcover

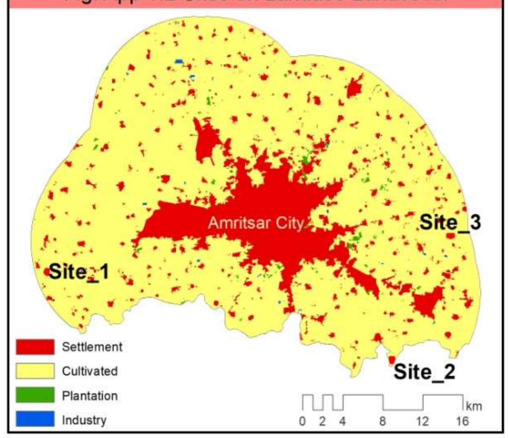


Fig: App 1.3 Sites on Soil Drainage

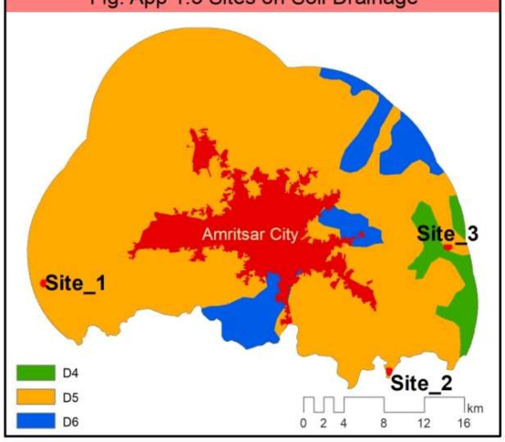


Fig: App 1.4 Sites on Groundwater Level

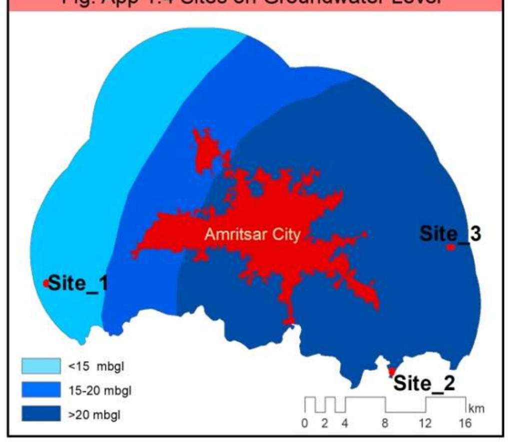


Fig: App 1.5 Sites on Distance From City

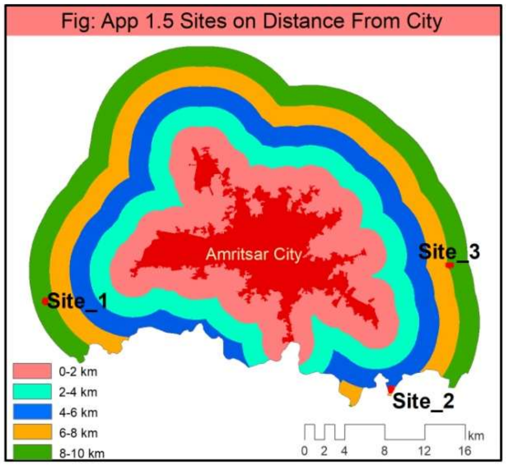


Fig: App 1.6 Sites on Distance from Canals

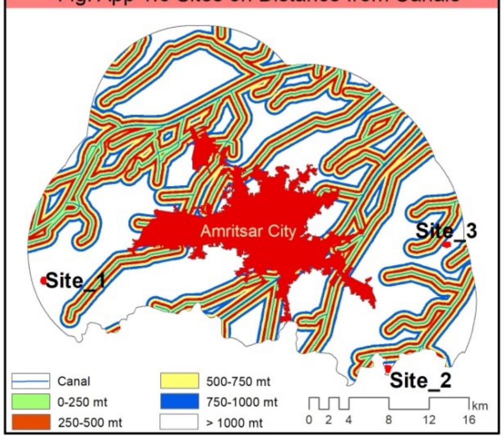


Fig: App 1.7 Sites on Distance from Drains

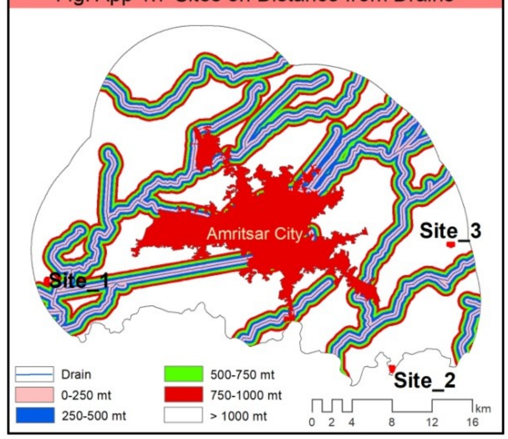


Fig: App 1.8 Sites on Distance from Settlements

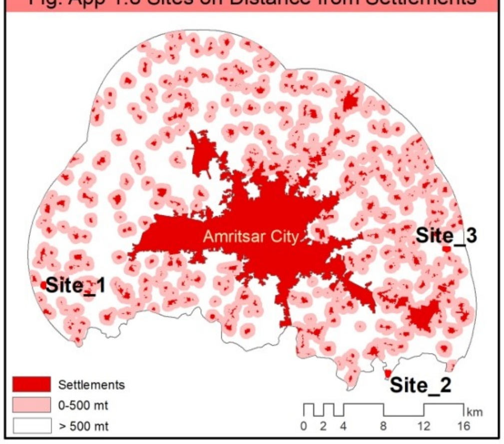


Fig: App 1.9 Sites on Slope

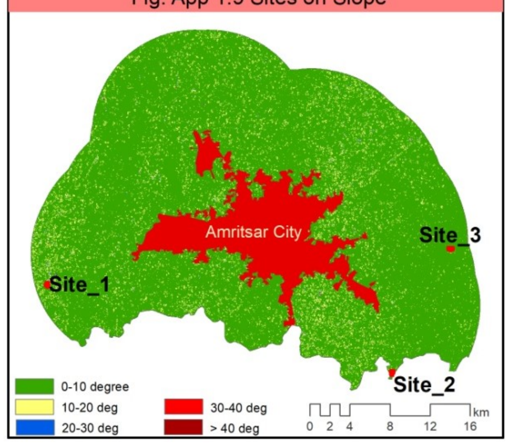
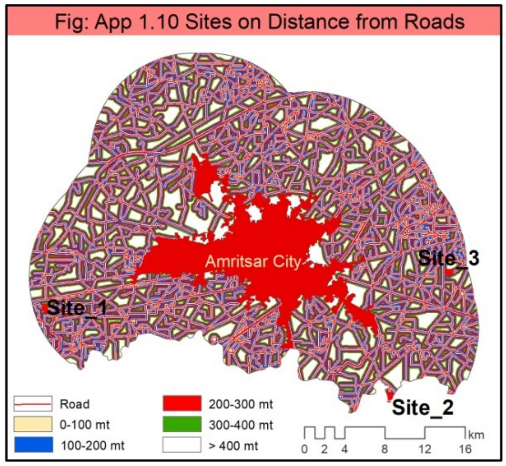


Fig: App 1.10 Sites on Distance from Roads



APPENDIX - 2

Sites of Pathankot MC overlaid on layers of each variable

Fig: App 2.1 Sites in Suitable Areas on Google Earth

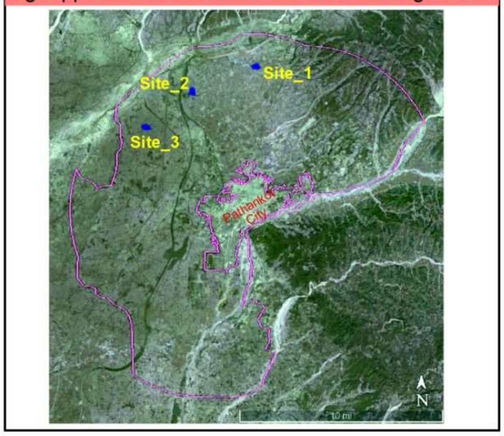


Fig: App 2.2 Sites on Landuse Landcover

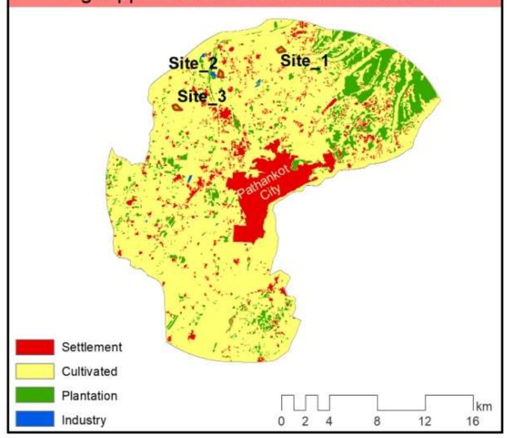


Fig: App 2.3 Sites on Soil Drainage

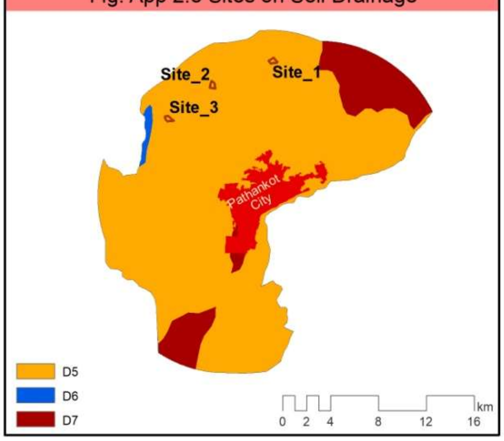


Fig: App 2.4 Sites on Groundwater Level

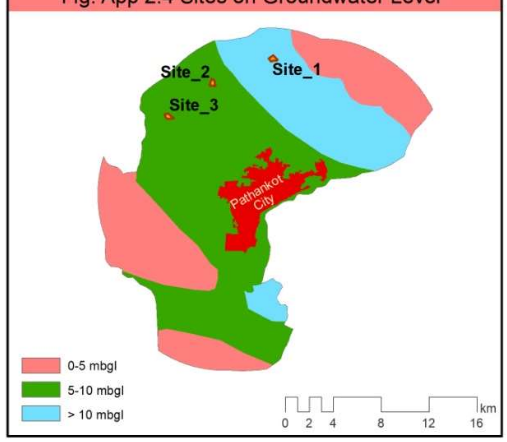
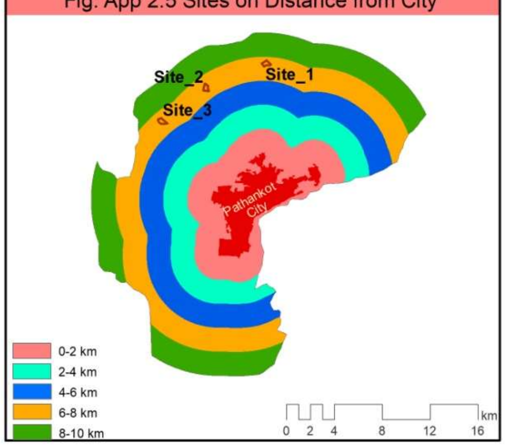


Fig: App 2.5 Sites on Distance from City



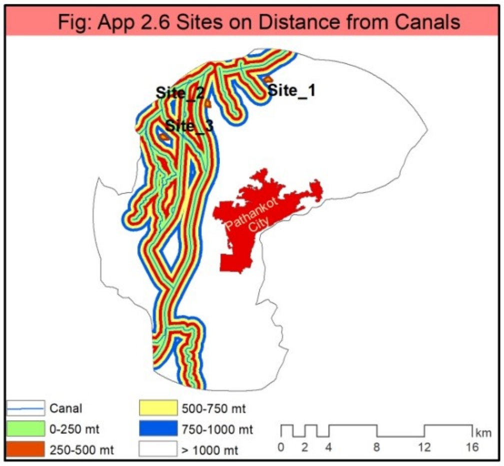


Fig: App 2.6 Sites on Distance from Canals
Site_2
Site_1
Site_3
Pathankot City
Canal
0-250 mt
250-500 mt
500-750 mt
750-1000 mt
> 1000 mt
0 2 4 8 12 16
km

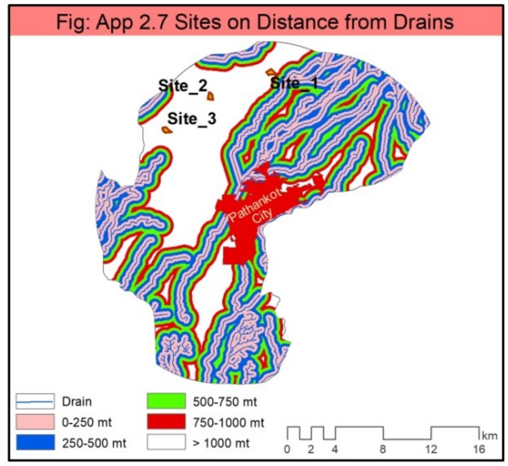


Fig: App 2.7 Sites on Distance from Drains
Site_2
Site_1
Site_3
Pathankot City
Drain
0-250 mt
250-500 mt
500-750 mt
750-1000 mt
> 1000 mt
0 2 4 8 12 16
km

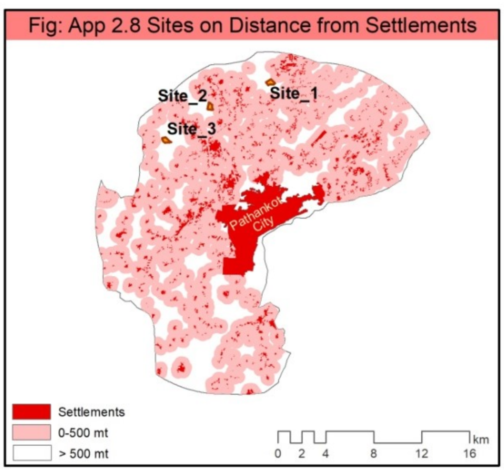


Fig: App 2.8 Sites on Distance from Settlements
Site_2
Site_1
Site_3
Pathankot City
Settlements
0-500 mt
> 500 mt
0 2 4 8 12 16
km

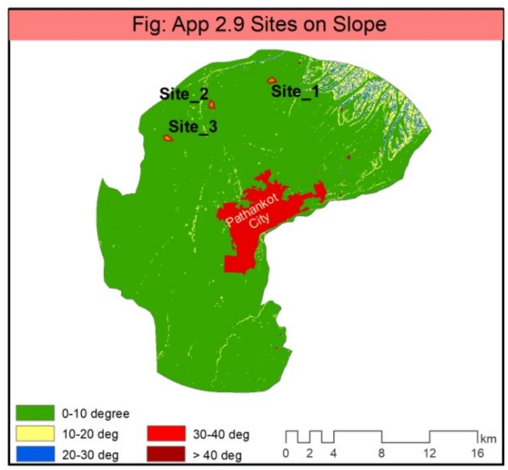


Fig: App 2.9 Sites on Slope
Site_2
Site_1
Site_3
Pathankot City
0-10 degree
10-20 deg
20-30 deg
30-40 deg
> 40 deg
0 2 4 8 12 16
km

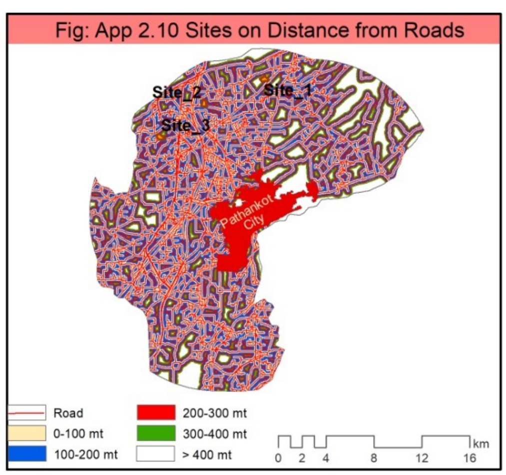


Fig: App 2.10 Sites on Distance from Roads
Site_2
Site_1
Site_3
Pathankot City
Road
0-100 mt
100-200 mt
200-300 mt
300-400 mt
> 400 mt
0 2 4 8 12 16
km

APPENDIX - 3

Sites of Jalandhar MC overlaid on layers of each variable

Fig: App 3.1 Sites in Suitable Areas on Google Earth

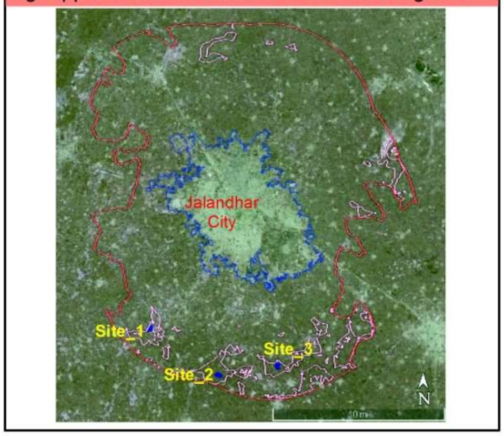


Fig: App 3.2 Sites on Landuse Landcover

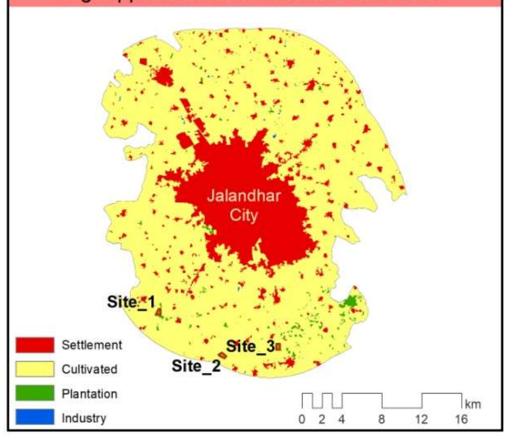


Fig: App 3.3 Sites on Soil Drainage

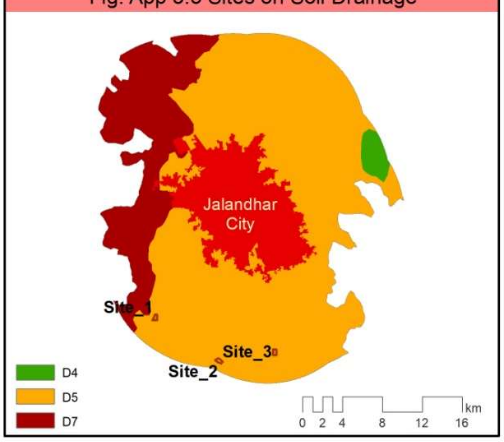


Fig: App 3.4 Sites on Groundwater Level

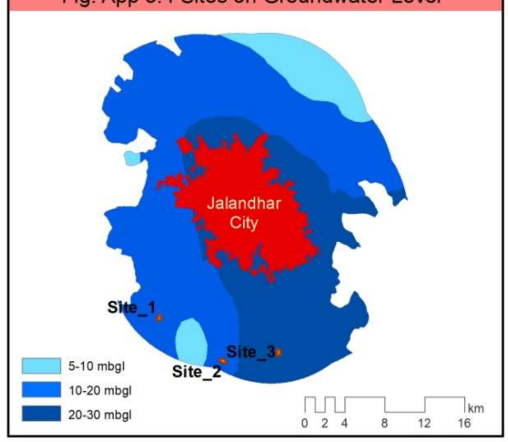


Fig: App 3.5 Sites on Distance from City

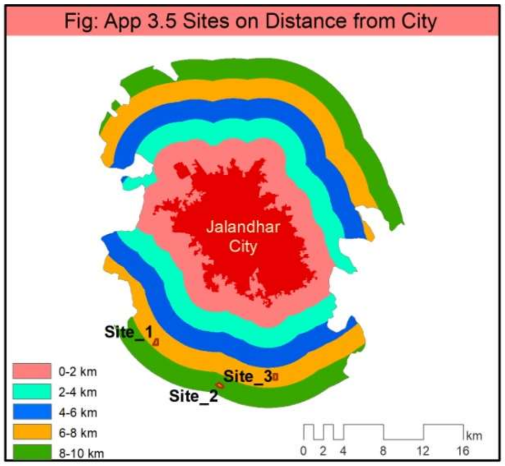


Fig: App 3.6 Sites on Distance from Canals

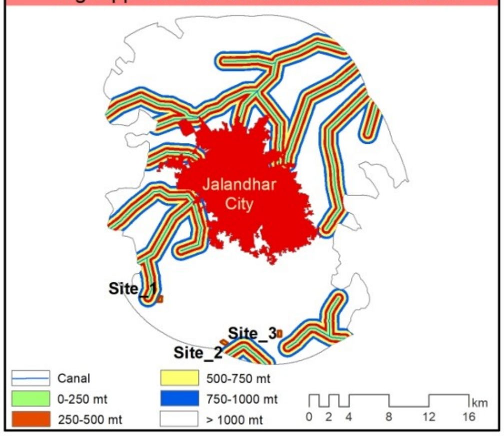


Fig: App 3.7 Sites on Distance from Drains

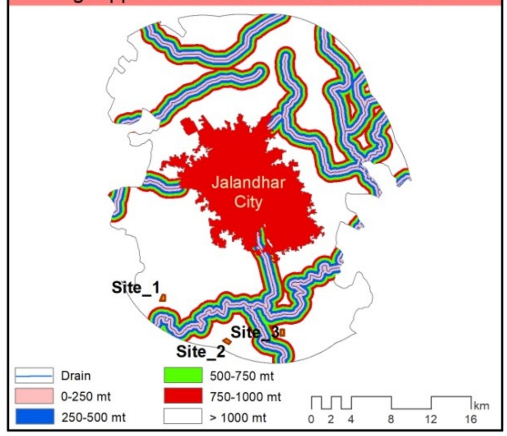


Fig: App 3.8 Sites on Distance from Settlements

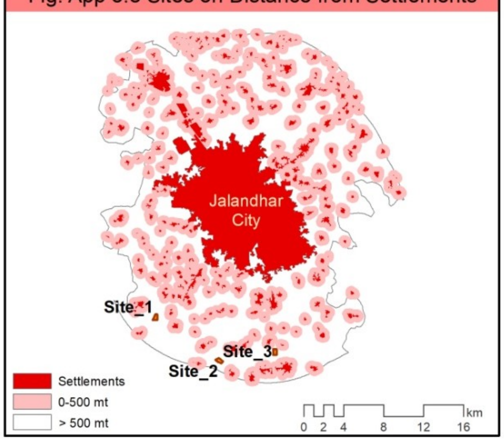


Fig: App 3.9 Sites on Slope

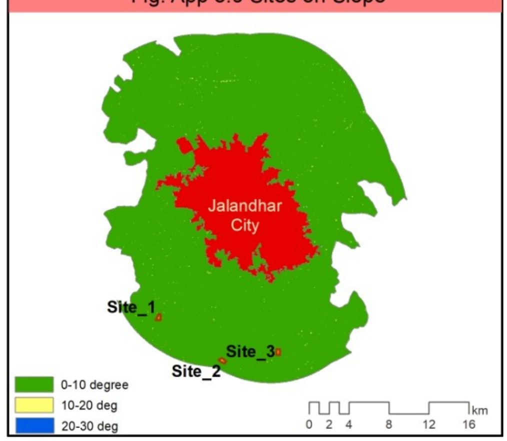
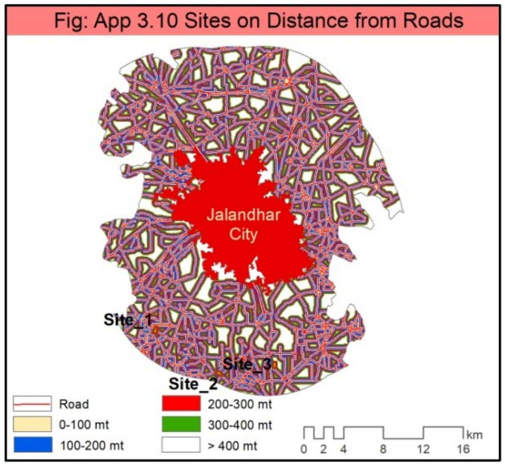


Fig: App 3.10 Sites on Distance from Roads



APPENDIX - 4

Sites of Hoshiarpur MC overlaid on layers of each variable

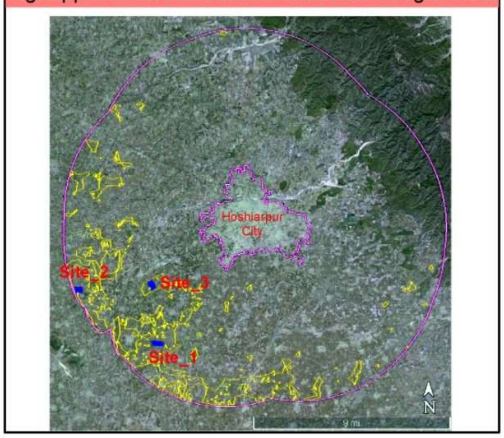


Fig: App 4.1 Sites in Suitable Areas on Google Earth

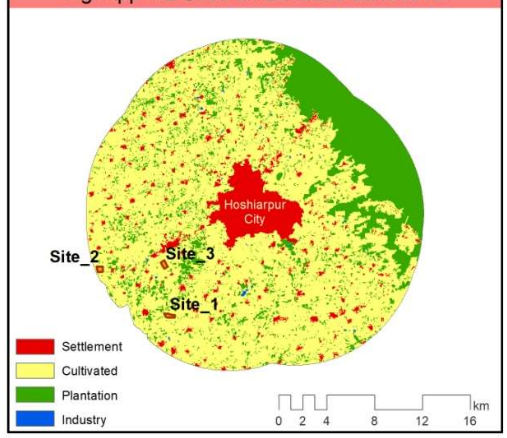


Fig: App 4.2 Sites on Landuse Landcover

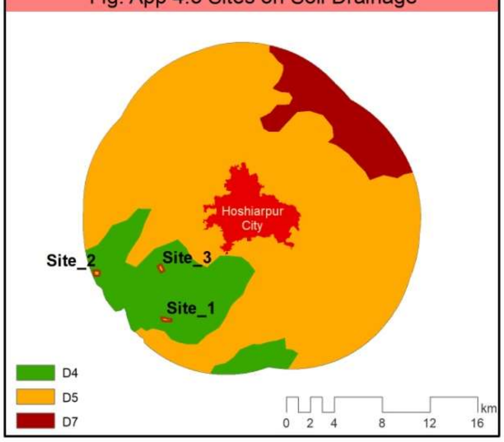


Fig: App 4.3 Sites on Soil Drainage

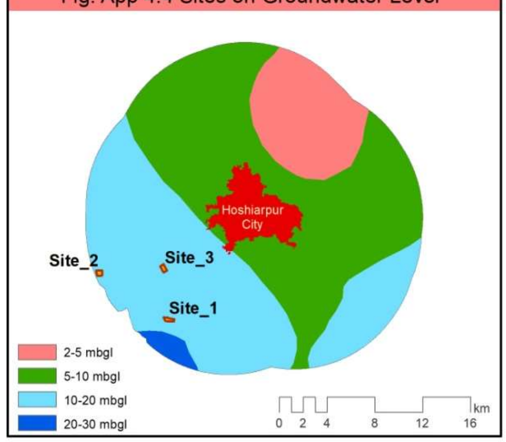


Fig: App 4.4 Sites on Groundwater Level

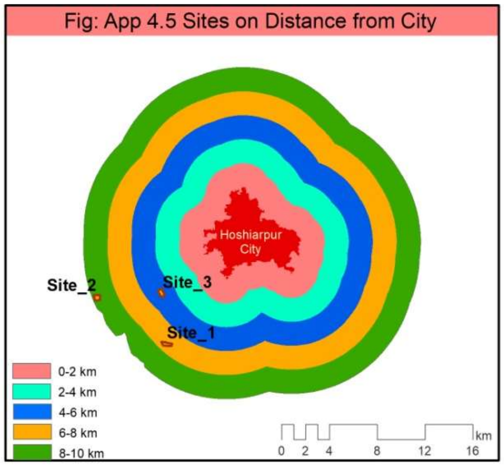


Fig: App 4.5 Sites on Distance from City

Fig: App 4.6 Sites on Distance from Canals

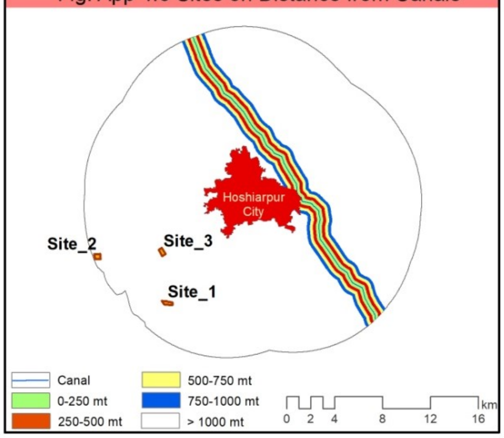


Fig: App 4.7 Sites on Distance from Drains

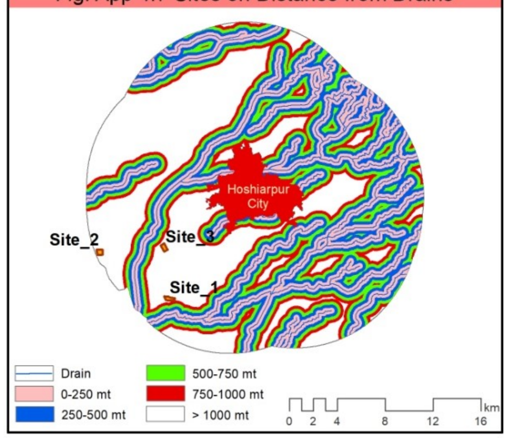


Fig: App 4.8 Sites on Distance from Settlements

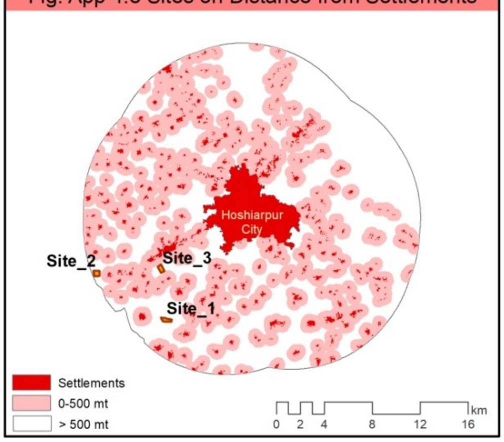


Fig: App 4.9 Sites on Slope

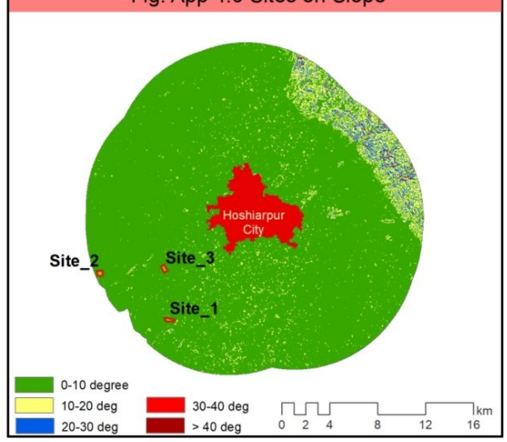
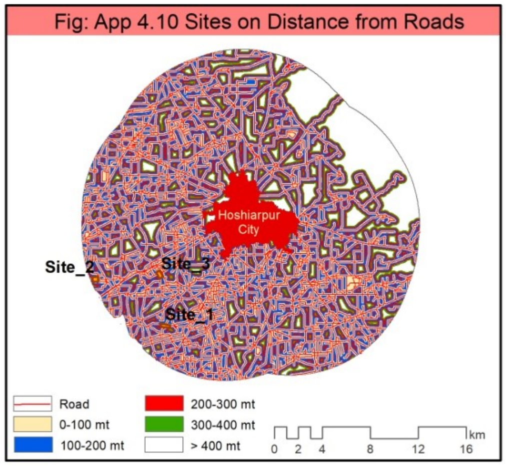


Fig: App 4.10 Sites on Distance from Roads



APPENDIX - 5

Sites of Phagwara MC overlaid on layers of each variable

Fig: App 5.1 Sites in Suitable Areas on Google Earth

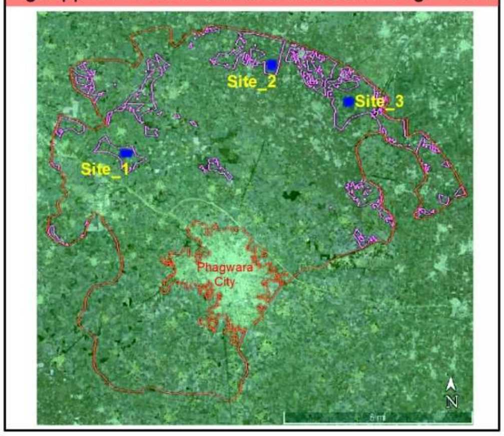


Fig: App 5.2 Sites on Landuse Landcover

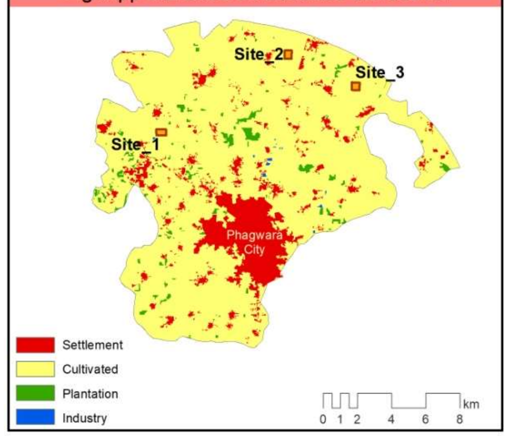


Fig: App 5.3 Sites on Soil Drainage

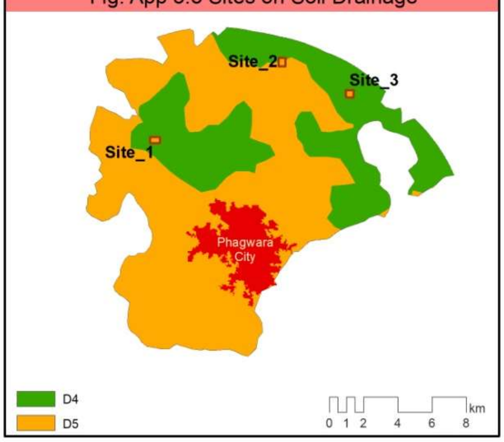


Fig: App 5.4 Sites on Groundwater Level

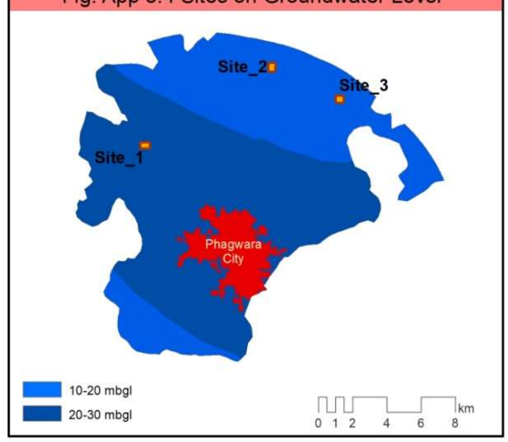


Fig: App 5.5 Sites on Distance from City

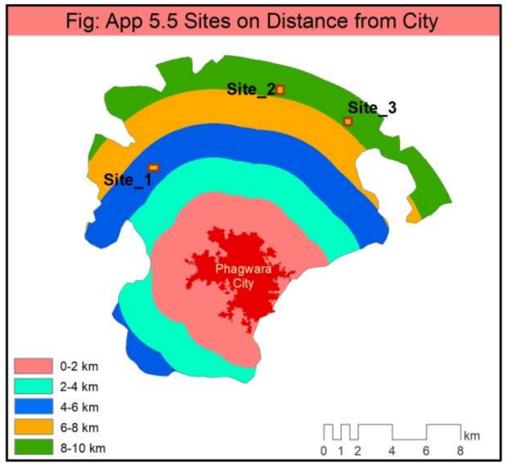


Fig: App 5.6 Sites on Distance from Canals

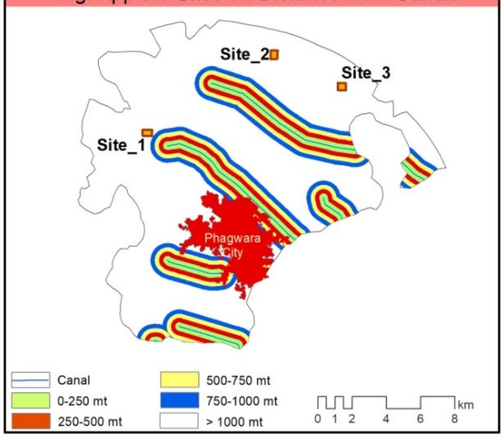


Fig: App 5.7 Sites on Distance from Drains

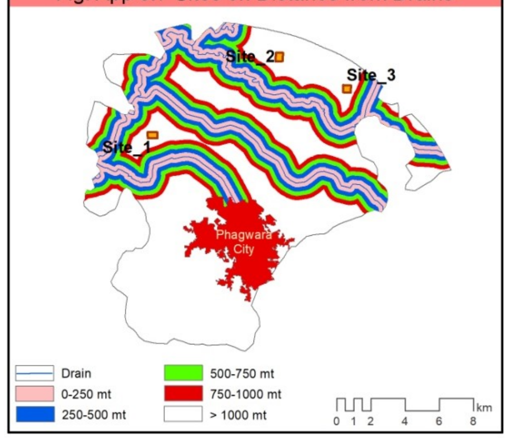


Fig: App 5.8 Sites on Distance from Settlements

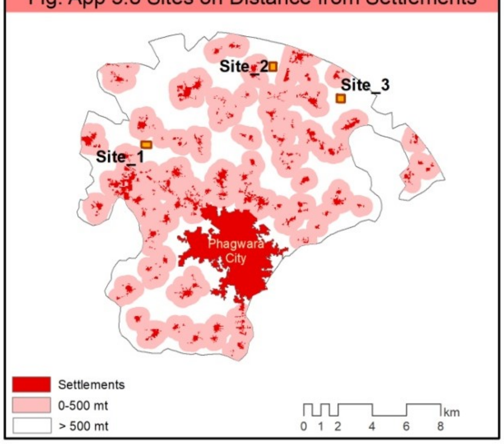


Fig: App 5.9 Sites on Slope

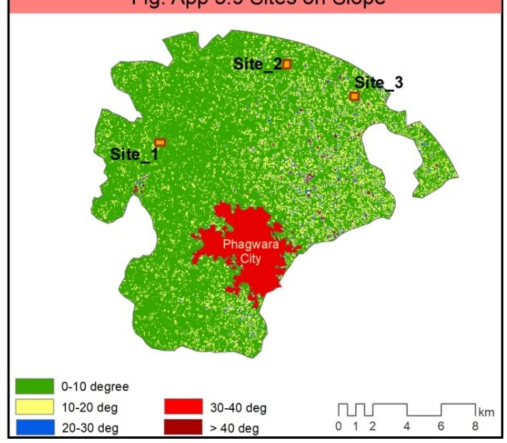
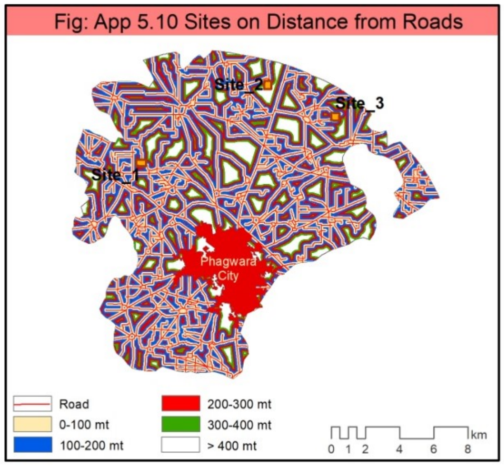


Fig: App 5.10 Sites on Distance from Roads



APPENDIX - 6

Sites of Ludhiana MC overlaid on layers of each variable

Fig: App 6.1 Sites in Suitable Areas on Google Earth

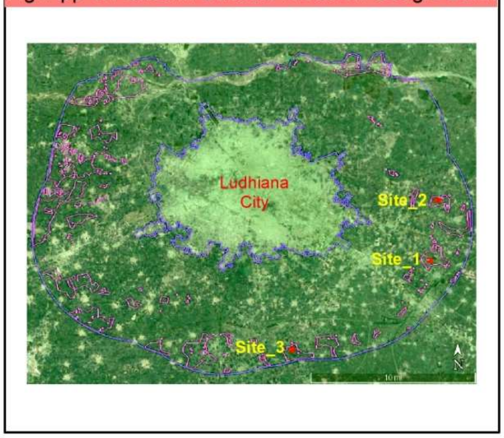


Fig: App 6.2 Sites on Landuse Landcover

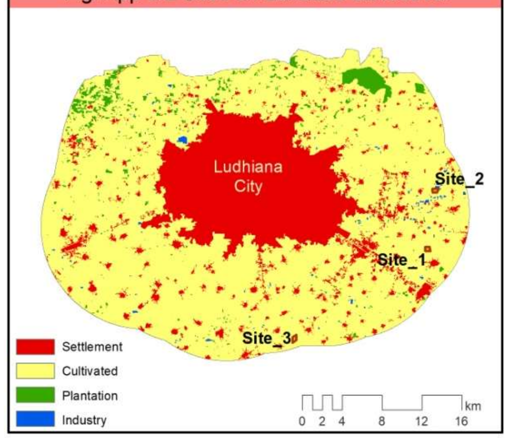


Fig: App 6.3 Sites on Soil Drainage

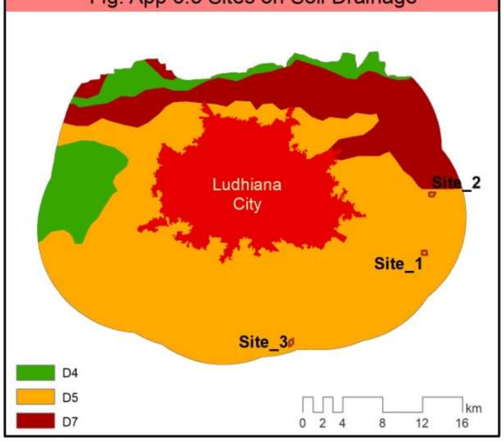


Fig: App 6.4 Sites on Groundwater Level

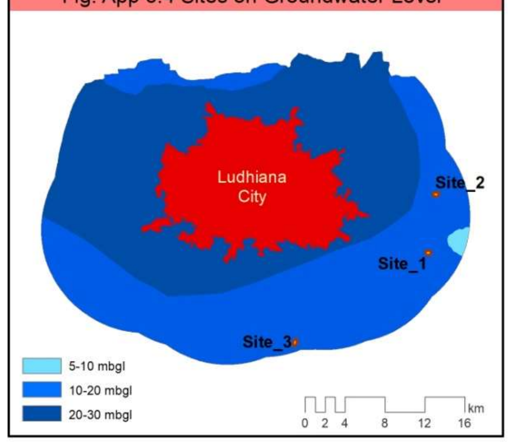
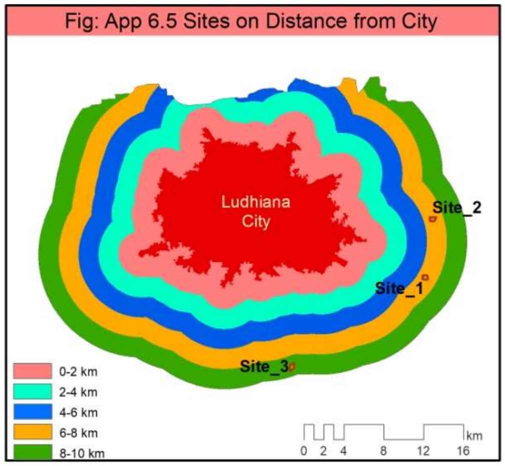


Fig: App 6.5 Sites on Distance from City



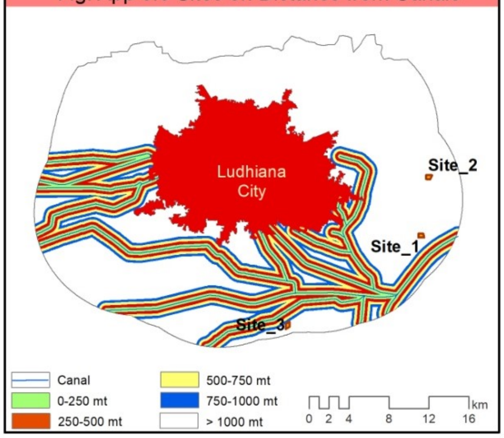


Fig: App 6.6 Sites on Distance from Canals

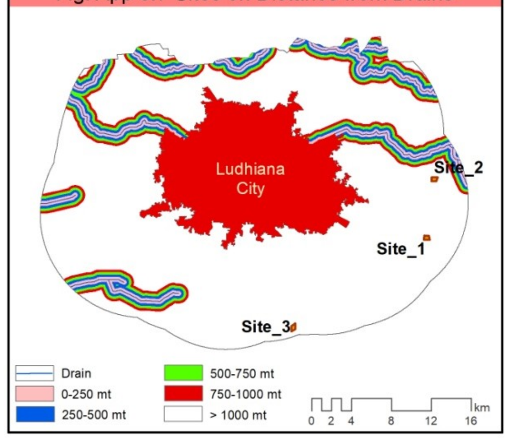


Fig: App 6.7 Sites on Distance from Drains

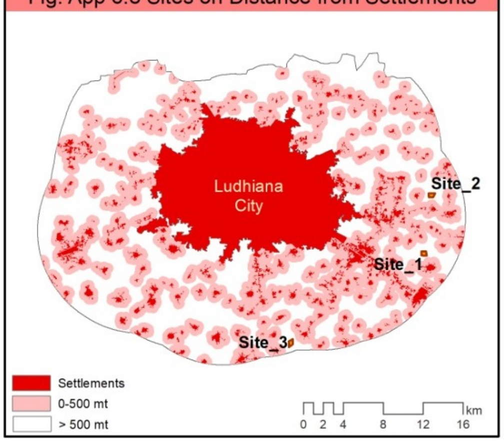


Fig: App 6.8 Sites on Distance from Settlements

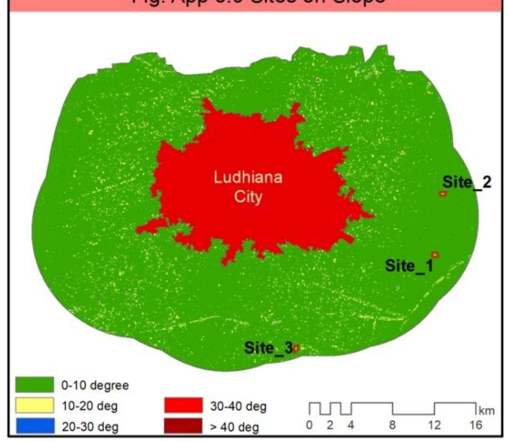


Fig: App 6.9 Sites on Slope

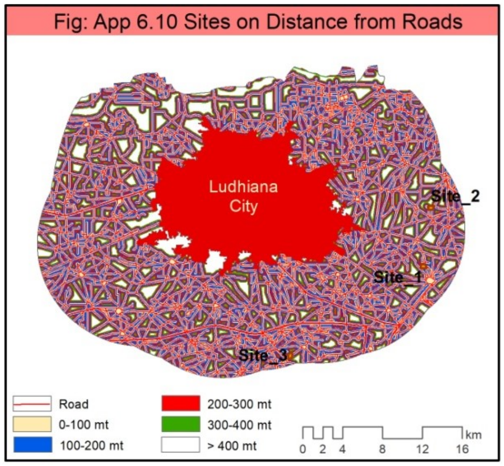


Fig: App 6.10 Sites on Distance from Roads

APPENDIX - 7

Sites of Moga MC overlaid on layers of each variable

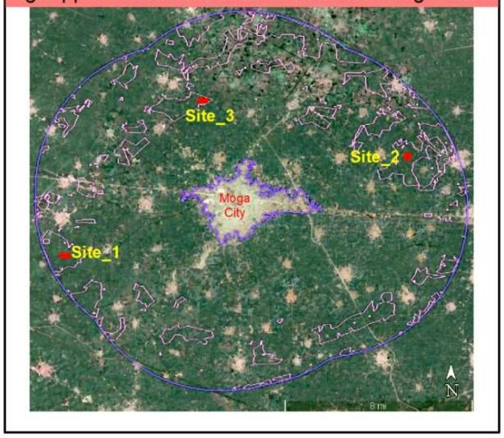


Fig: App 7.1 Sites in Suitable Areas on Google Earth

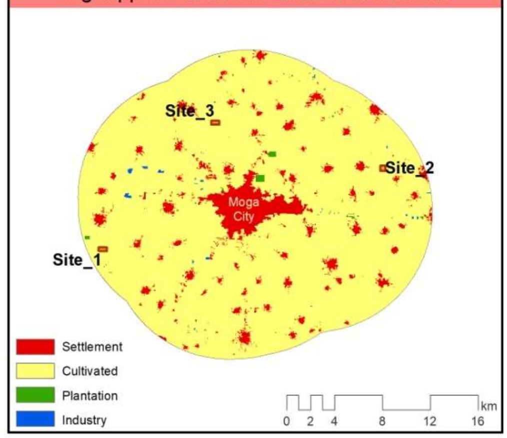


Fig: App 7.2 Sites on Landuse Landcover

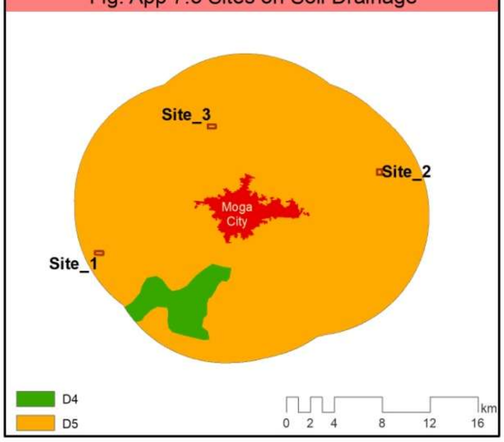


Fig: App 7.3 Sites on Soil Drainage

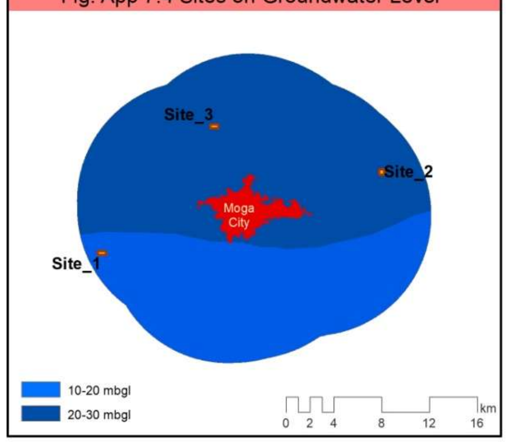


Fig: App 7.4 Sites on Groundwater Level

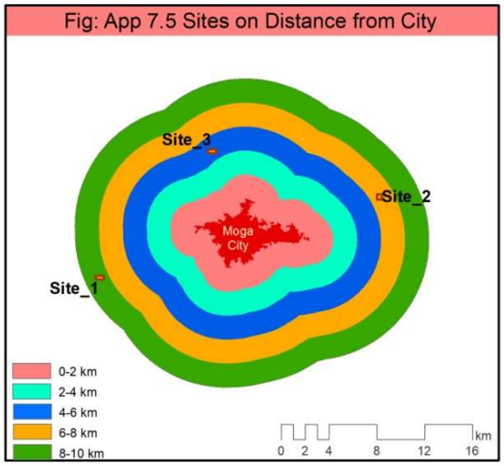


Fig: App 7.5 Sites on Distance from City

Fig: App 7.6 Sites on Distance from Canals

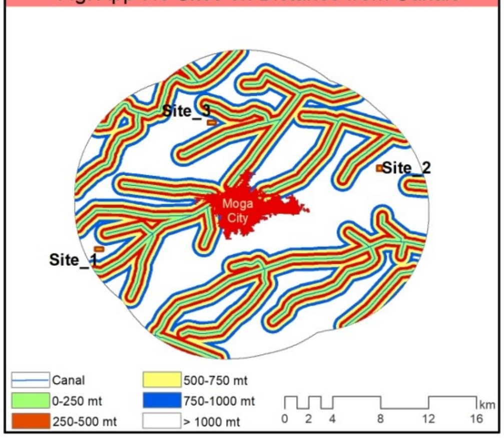


Fig: App 7.7 Sites on Distance from Drains

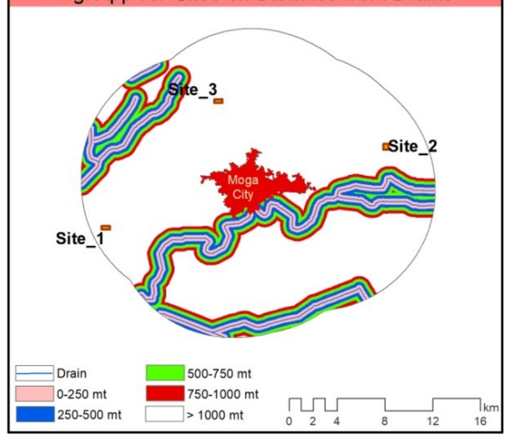


Fig: App 7.8 Sites on Distance from Settlements

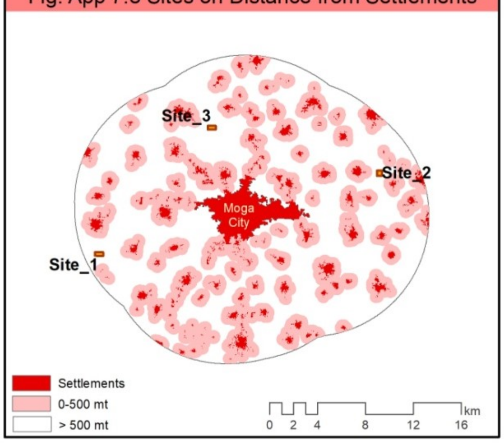


Fig: App 7.9 Sites on Slope

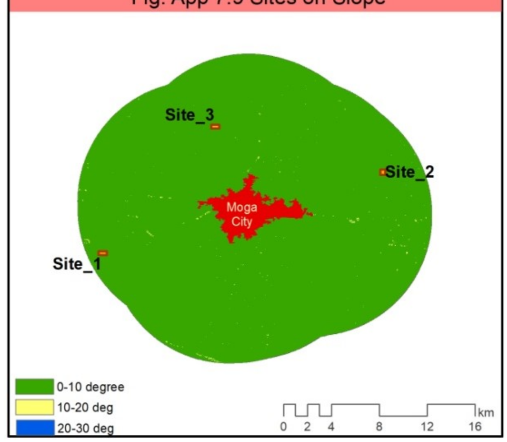
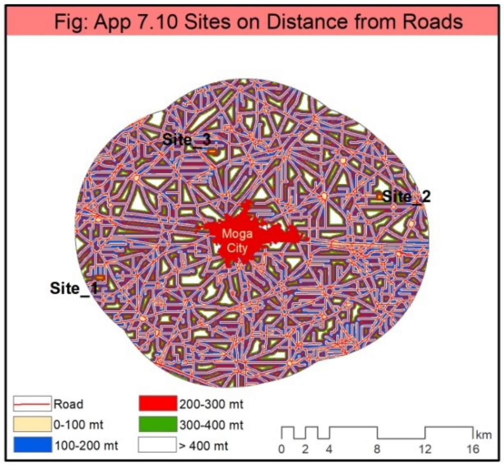


Fig: App 7.10 Sites on Distance from Roads



APPENDIX - 8

Sites of Bathinda MC overlaid on layers of each variable

Fig: App 8.1 Sites on Google Earth

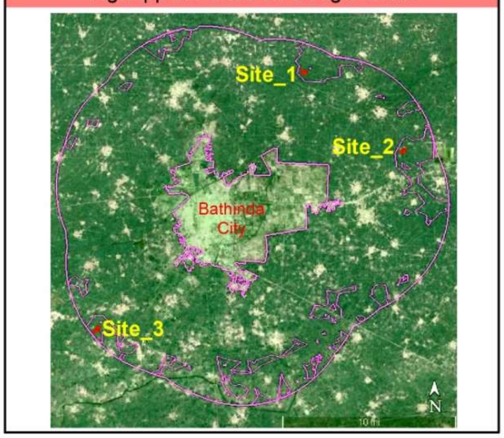


Fig: App 8.2 Sites on Landuse Landcover

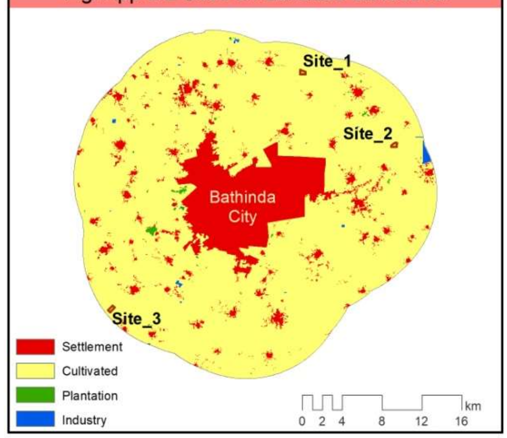


Fig: App 8.3 Sites on Soil Drainage

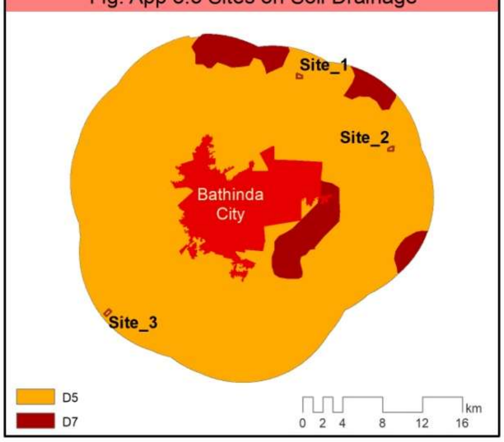


Fig: App 8.4 Sites on Groundwater Level

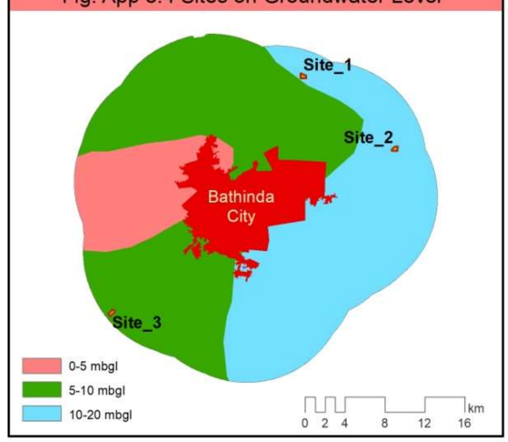


Fig: App 8.5 Sites on Distance from City

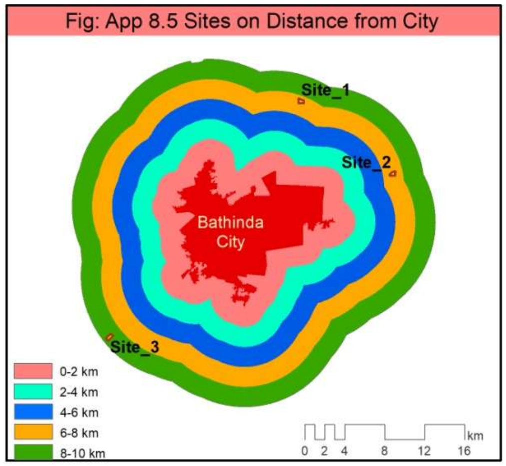


Fig: App 8.6 Sites on Distance from Canals

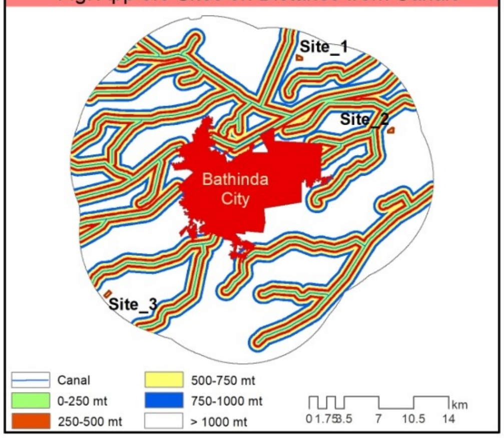


Fig: App 8.7 Sites on Distance from Drains

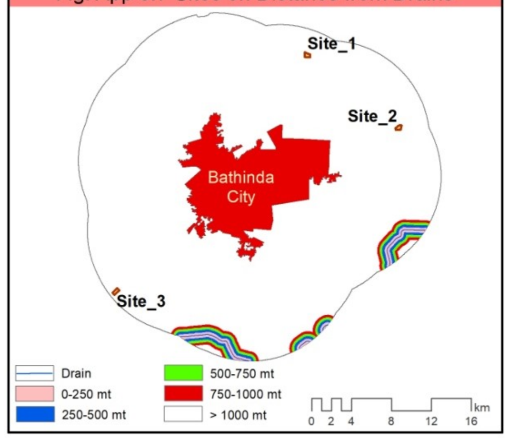


Fig: App 8.8 Sites on Distance from Settlements

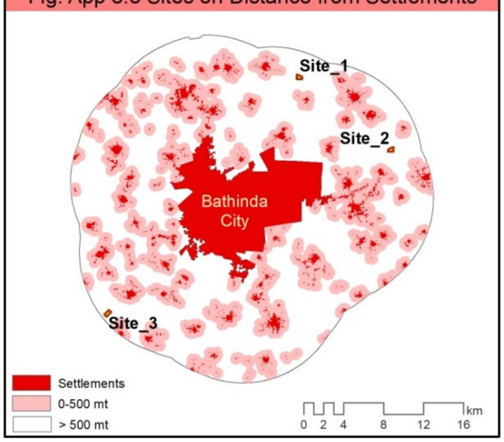


Fig: App 8.9 Sites on Slope

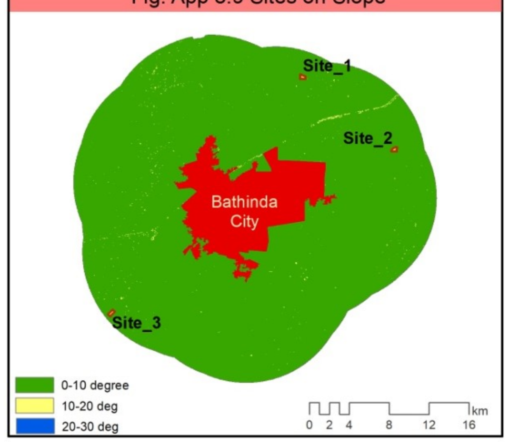
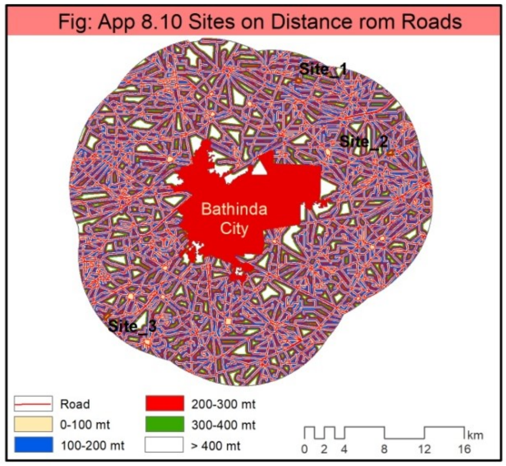


Fig: App 8.10 Sites on Distance rom Roads



APPENDIX - 9

Sites of Patiala MC overlaid on layers of each variable

Fig: App 9.1 Sites in Suitable Areas on Google Earth

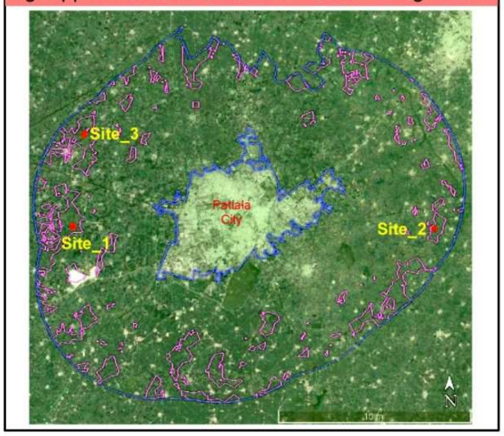


Fig: App 9.2 Sites on Landuse Landcover

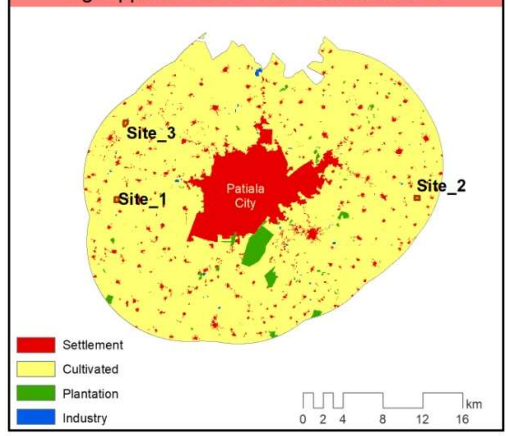


Fig: App 9.3 Sites on Soil Drainage

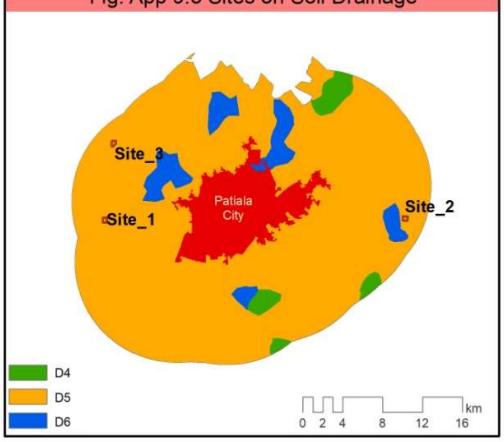


Fig: App 9.4 Sites on Groundwater Level

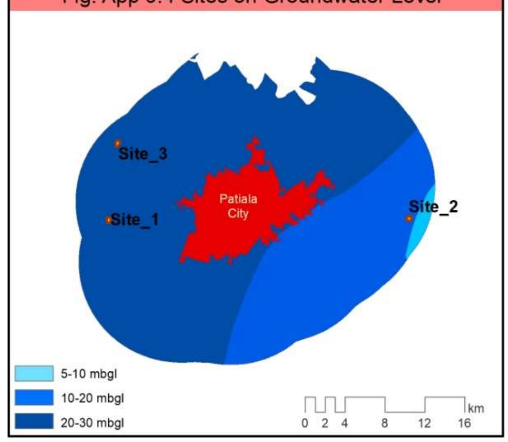


Fig: App 9.5 Sites on Distance from City

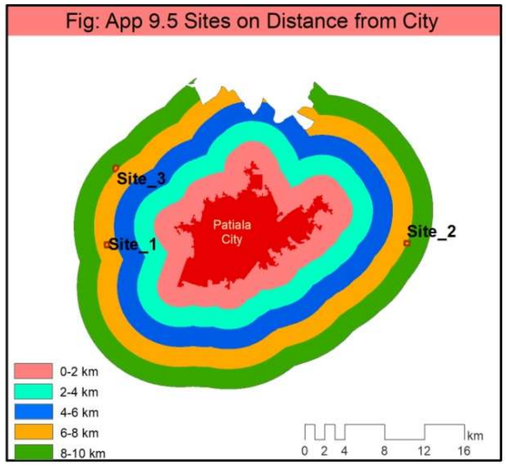


Fig: App 9.6 Sites on Distance from Canals

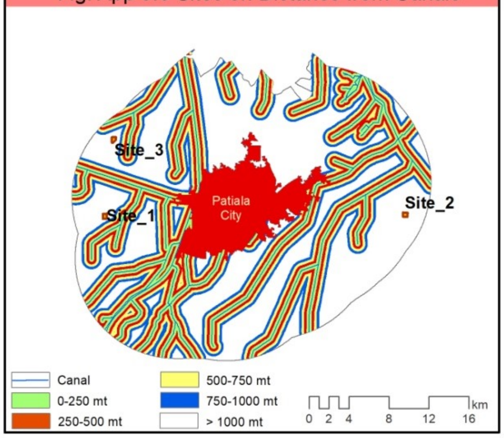


Fig: App 9.7 Sites on Distance from Drains

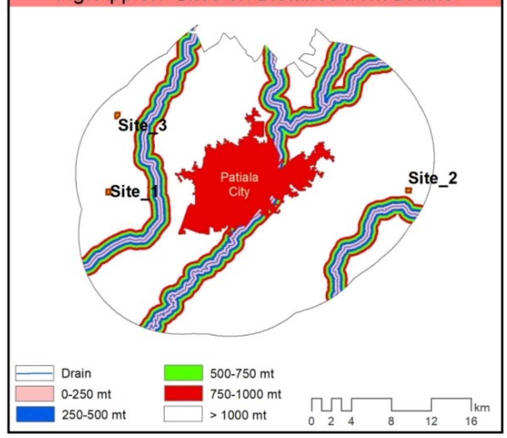


Fig: App 9.8 Sites on Distance from Settlements

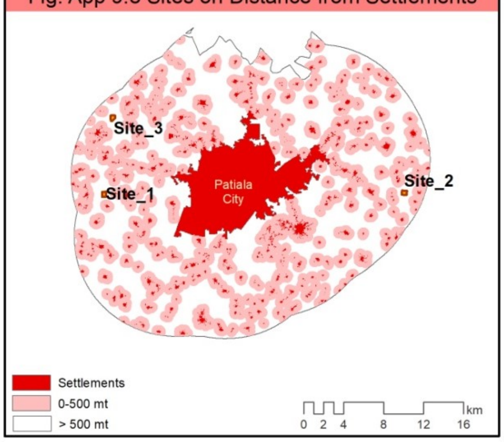


Fig: App 9.9 Sites on Slope

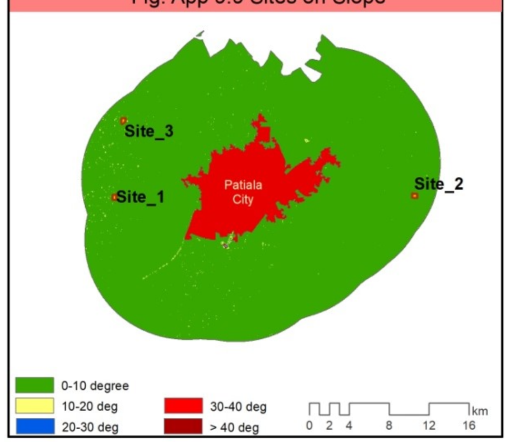
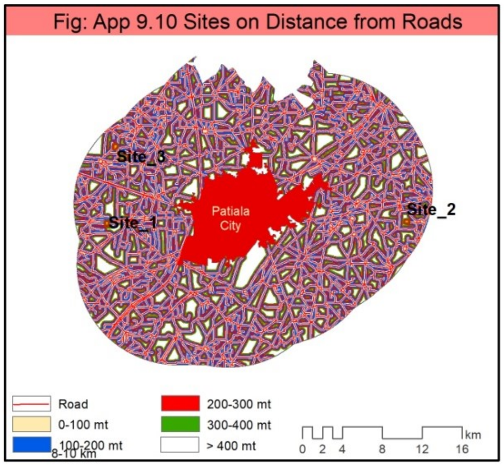


Fig: App 9.10 Sites on Distance from Roads



APPENDIX - 10

Sites of Mohali MC overlaid on layers of each variable

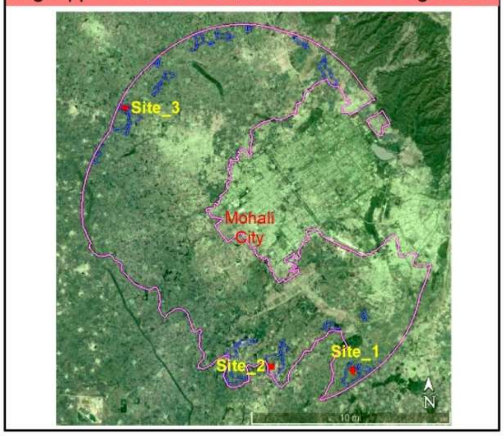


Fig: App 10.1 Sites in Suitable Areas on Google Earth

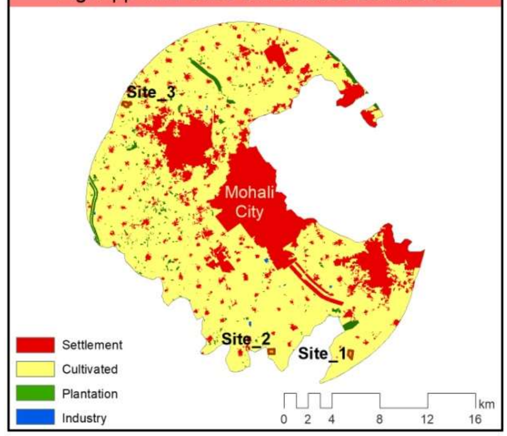


Fig: App 10.2 Sites on Landuse Landcover

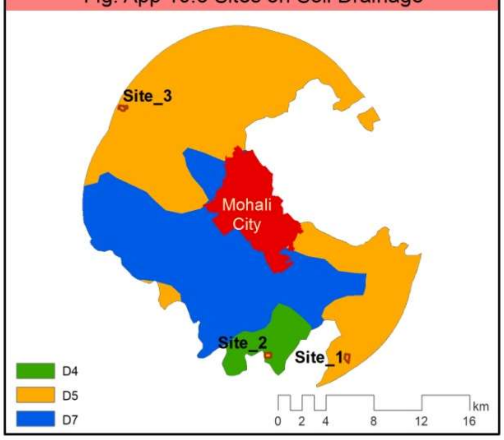


Fig: App 10.3 Sites on Soil Drainage

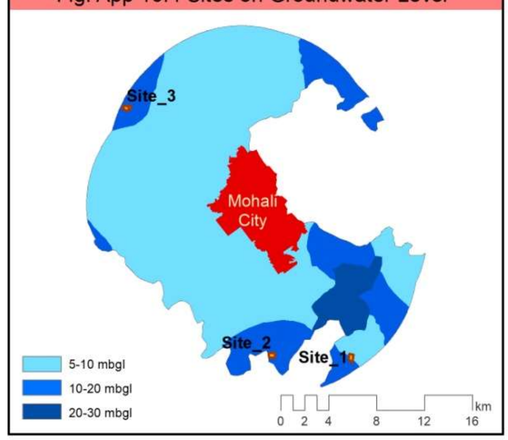


Fig: App 10.4 Sites on Groundwater Level

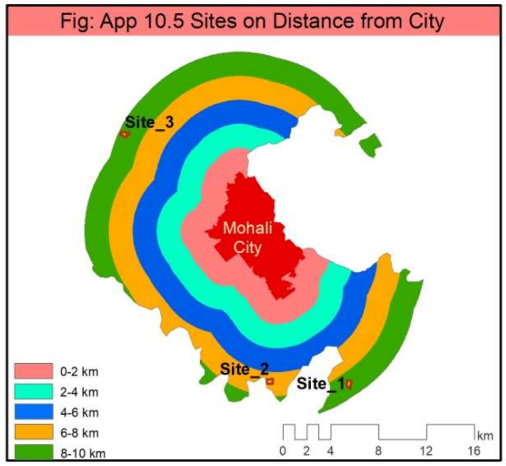


Fig: App 10.5 Sites on Distance from City

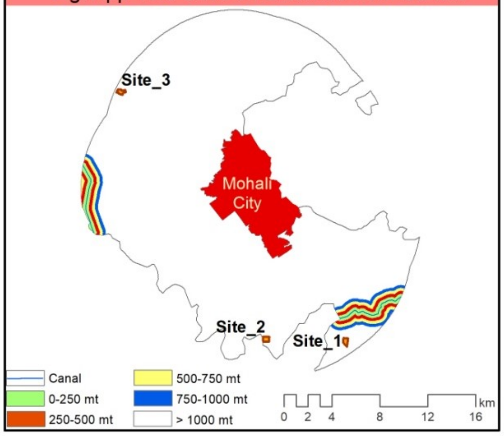


Fig: App 10.6 Sites on Distance from Canals

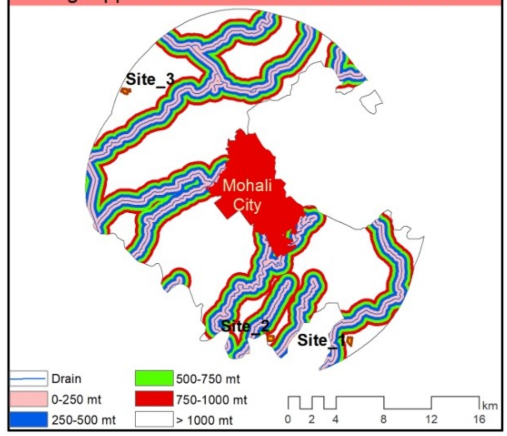


Fig: App 10.7 Sites on Distance from Drains

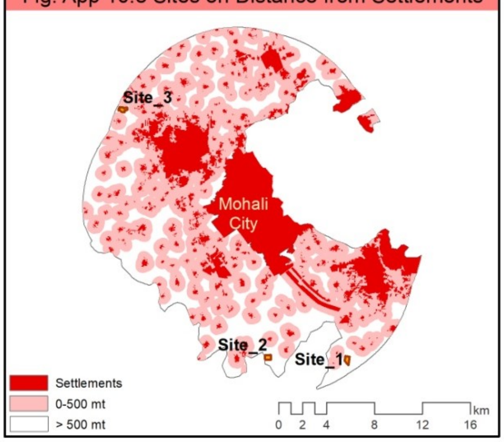


Fig: App 10.8 Sites on Distance from Settlements

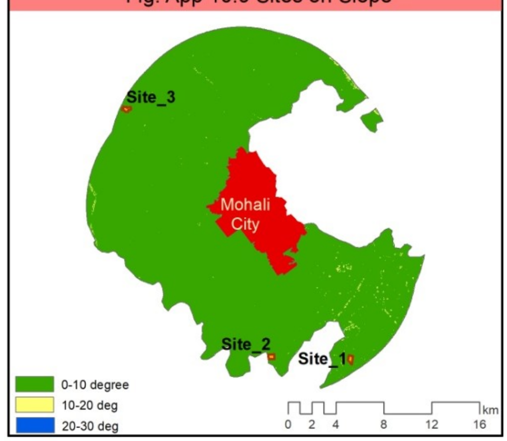


Fig: App 10.9 Sites on Slope

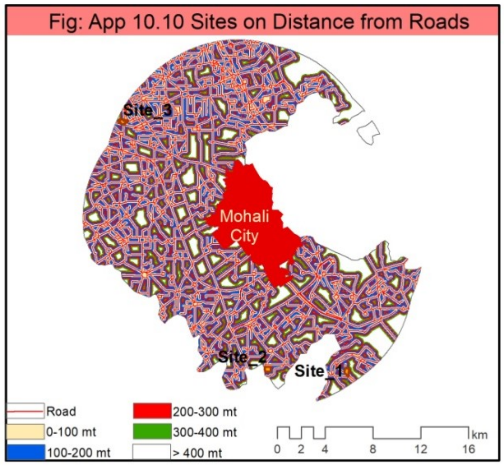


Fig: App 10.10 Sites on Distance from Roads

APPENDIX - 11

Python Code of Weighted Overlay Analysis.

The following code in python scripting language runs when tool of 'weighted overlay analysis' is applied:

```
arcpy.gp.

WeightedOverlay_sa("(

'landuse' 22 'LANDUSE' ('Industry' 3; 'Settlement' Restricted; 'Cultivated' 5; 'Plantation'
2;NODATA NODATA);

'soil_dr' 18 'SOIL_DR' ('D5' 4; 'D6' 3; 'D4' 5;NODATA NODATA);

'gr_water' 12 'GW_LEVEL' ('>20' 5; '<15' 4; 15-20 4;NODATA NODATA);

'city_dis' 12 'VALUE' (2 1; 4 2; 6 3; 8 4; 10 5;NODATA NODATA);

'canal_dis' 10 'VALUE' (250 1; 500 2; 750 3; 1000 4; 10000 5;NODATA NODATA);

'drain_dis' 8 'VALUE' (250 1; 500 2; 750 3; 1000 4; 10000 5;NODATA NODATA);

'sett_dis' 8 'VALUE' (500 1; 7000 5;NODATA NODATA);

'slope' 7 'VALUE' (10 5; 20 4; 30 3; 40 2; 44 1;NODATA NODATA);

'road_dis' 3 'VALUE' (100 5; 200 4; 300 3; 400 2; 5000 1;NODATA NODATA));

1 5 1",

"C:/Users/kanwa/Documents/PhD/MC/Amritsar/WOL/wol_Asr")
```

APPENDIX - 12

Persons contacted for assigning influence and weightage.

Following persons were contacted for assigning percentage of influence to all variables and weightage to the subclasses of variables using Delphi method.

s. no.	Name	Metier
1	Mrs. Sarojini Sharda Gautam	Former Commissioner, Municipal Corp, Jalandhar
2	Prof. Gopal Johri	Associate Prof, School of Planning & Architecture, GNDU, Asr
3	Dr. RK Setia	Scientist, Punjab Remote Sensing Centre, PAU, Ldh
4	Sh. Harpinder Singh	Scientist, Punjab Remote Sensing Centre, PAU, Ldh
5	Sh. Sashikant Sahoo	Scientist, Punjab Remote Sensing Centre, PAU, Ldh
6	Mrs. Reenu Sharma	Scientist, Punjab Remote Sensing Centre, PAU, Ldh
7	Mrs. Surinder Kaur	Senior Deputy Mayor, Municipal Corp, Jalandhar

APPENDIX - 13

Copyright of Site Identification Model.

'Deepak-Kalota Model of Site Identification for Solid Waste Management' has been applied for registration of Copyright to the Registrar of Copyrights, New Delhi on 21-08-2019 vide Diary No: 13359/2019-CO/L. The Acknowledge Slip is given below.

Copyright Office
Government of India

Acknowledgement Slip
(Date: 21/08/2019)

Diary Number: **13359/2019-CO/L**	Form Received: **Online**
Copyright Reg. of: **Literary/ Dramatic**	Titled: **Deepak-Kalota Model of Site Identification for Solid Waste Management**

Communication Address

Name	Address	Phone Number
Deepak Kanwar	353, Mota Singh Nagar, Jalandhar City-144001	6283840353

Financial Details

Payment ID	Amount	Bank Name	Payment Mode	Payment Date
204318	500	HdfcCYBER	CC	21/08/2019

* For future communication please mention this DIARY No.

INSTRUCTIONS

For the purpose of processing the application, following documents are mandatory to send by post along with the acknowledgement slip(Office Copy).

1. 2 Copies of work
2. DD/IPO of Rs.(as applicable) per work favouring Registrar Copyright Office payable at New Delhi (Not applicable for online payment)
3. Authorization from author/publisher
4. If the work is being used on goods or capable of being used on the goods
5. If the application is being field through attorney, a specific power of attorney in original duly signed by the applicant and accepted by the attorney
6. Search Certificate from Trade Mark Office(TM-60) (Only in case of Artistic work).
7. Applicant must take a print out of the application, sign it and send along with the other documents.

Kindly send the above documents within 30 Days from the date of online submission on the following address given by herewith: .

Office of the Registrar of Copyrights
Copyright Office, Department of Industrial Policy & Promotion
Ministry of Commerce and Industry
Boudhik Sampada Bhawan,
Plot No. 32, Sector 14, Dwarka,
New Delhi-110075
Email Address: copyright@nic.in
Telephone No.: 011-28032496, 08929474194

LIST OF PUBLICATIONS

1. Kanwar, Deepak and Kalota, Dheera, (2019). Identification of Suitable Areas for Solid Waste Management with the help of Remote Sensing and GIS technology - A case study of Ludhiana, Punjab. International Journal of Engineering Development and Research. ISSN: 2321-9939. (Accepted For Publication).
2. Kanwar, Deepak, (2019). Remote Sensing and GIS based Site Identification for Solid Waste Management of Amritsar Municipal Corporation, Punjab, India. Re-envisioning Remote Sensing Applications: Perspectives from Developing Countries. Taylor & Francis. (Accepted For Publication).