Use of Geographic Information Systems for the Planning of Semi-Informal Settlements.

A case study: Hout Bay

by

Bonita Shereen Kleyn

Submitted in fulfillment for the Masters Degree in Applied Science in the Department of Geomatics in the Faculty of Engineering,

University of Cape Town

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ABSTRACT

Incorrect planning of informal settlements have resulted in environmental degradation in the forms of drainage problems, soil erosion, destruction of sensitive vegetation and the related social problems. These types of settlements have to be located in stable environments, as the residents cannot afford expensive solutions to the environmental problems. Meeting the land and housing requirements of the community as well as managing the natural environment is one of the important issues facing South Africa.

Geographic Information Systems (GIS) is one of the technologies that can assist with housing this sector of the community in a sustainable manner. GIS technology is increasingly being used for the inventory, analysis, modelling and management of the natural and built environment. It is important that the analysis and modelling of environmental phenomena be accompanied by reliable data and sensible analytical models that can anticipate the possible results of planning decisions.

This thesis investigates how GIS can be used in the planning process of informal settlements. Tables, maps and models were created to demonstrate how these data sources could be used to assist in the planning process. Three environmental factors namely, slope, soil and drainage were analysed, reclassified, weighted and computed to create the site suitability map. The site suitability map revealed how appropriate the study area, Imizamo Yethu Estate was for the development of the informal settlement. The site suitability map was converted into 3D to show the advantages of using models in planning.

The environmentally sensitive model was created to demonstrate how certain environmental problems currently experienced in the study area, Imizamo Yethu Estate, could be addressed. The site suitability model was used to create a new layout that could have reduced the erosion problems currently experienced in the informal settlement. Windbreaks in the form of fences were added to the environmentally sensitive model to show how mitagatory action could be planned for, in advance, to insulate an area that is exposed to strong winds. The other factors that were investigated are; drainage

infrastructure, aspect and the visual impact of the settlement. This model demonstrates how numerous planning scenarios can be developed by addressing all aspects of the environment.

A methodology for site selection was created that can assist planners, managers and decision makers to facilitate informed decision-making in the planning process of informal settlements. The methodology was divided into three stages, The pre-fieldwork stage, included the desktop data collection process and the planning of the strategy for fieldwork. The second stage is fieldwork. During this stage an environmental assessment would be undertaken. The third stage of the methodology deals with the capture, analyses and the displaying of the data by using GIS.

The use of GIS enables the examination of a range of scenarios and the possible consequences of planning decisions, before expensive and irrevocable mistakes are made. Sustainable development is imperative for our future and GIS provides the tools that can assist in sustainable environmental planning. The maps and models produced in this thesis have demonstrated how GIS can be used to create terrain, slope and site suitability models that can assist in the planning of informal settlements. The methodology created in this thesis can be used for the site selection process of informal settlements. The methodology looks at all aspects of the environment and can therefore be used to promote sustainable development.

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Glossary

Avenue	It is a programming language and development environment, which is part of the software ArcView GIS. Two Avenue scripts are used in the thesis.
Community	In this thesis context, it refers to the residents living in the informal settlement, Imizamo Yethu Estate.
Coverage	The digital form of data for a map, usually devoted to a single theme.
Digitise	The conversion of maps and images into a digital format.
Development	A process that attempts to improve the living conditions of people.
EIA	The effects of a proposed development on the environment is evaluated.
Global Positioning System	A system of satellites that transmits signals used by special receivers on the ground for the precise co-ordinates of a location.
Line coverage	A coverage that represents a single theme, which consist of an ordered set of connected points, for example, roads.
Model	In GIS, a model is a representation of reality or an attempt to display real-world process in a simplified manner.
Polygons	Enclosed areas on coverage bounded by straight lines.

Point coverage	A single theme, which consist of a set of points. Each point has an X and Y coordinate.
Pixels	The smallest resolvable element in an image to contain a data value.
Planning	The activity undertaken to improve and enhance the quality of social and physical environments.
Rills	Micro-channels a few centimeters in depth and width.
Shack	A self-constructed shelter in an informal settlement, which usually consist of plastic, cardboard, wood or corrugated iron.
Stratification	The sampling of soil from one particular or a number of stratums.
Sustainable development	Any development that meets the needs of the present without comprising the ability of the future generations to meet their own needs.

Chapter One
Introduction

1.1.Background

This thesis will demonstrate how Geographic Information Systems (GIS) can be used as a tool to create maps and models that can assist with decision-making and planning for informal settlements.

Informal settlements have become a common feature of South African cities. In 1995 it was estimated that approximately 7,7 million people throughout the country are accommodated in such settlements (Ewing, 1995). This constitutes 20% of the South African population. Informal settlements are the result of the urgent need for shelter by the poor. These shelters are usually constructed from unconventional building materials such as plastic, hardboard and corrugated iron. Housing, upgrading and improvement of living conditions in informal settlements are some of the most complex and pressing problems currently facing South Africa.

The greatest challenge cities presently face, is meeting the land and housing requirements of the community in an environmentally sustainable manner. Sustainability is defined as any development that delivers the basic environmental, social and economic services to the community without threatening the viability of the natural, built and social systems upon which these services depend (International Council for Local Environmental Initiatives, 1995). However, environmental degradation in the form of soil erosion, drainage problems, air and water pollution and the damage and destruction of sensitive vegetation has often been the result of an environmental impact assessment (EIA) not being undertaken during the site identification stages of the development (Gawith, 1996d).

The rapid rate of urbanisation in South Africa has therefore created an urgent demand for information on the suitability of land for housing. Hence, it is important to examine the role science and technology can play in identifying land for housing in an environmentally sustainable manner. One such technology is GIS. According to Bernhardsen (1998) a GIS is not only comprised of hardware and software but include procedures designed to support the capture, analysis, manipulation, storage, management, modelling and display of spatially referenced data, which can be used to solve planning and management problems.

Planning is a method that can be used by the local government to design, manage and monitor all phases of developmental projects to assist with the sustainable development of informal settlements. One key condition for making and measuring progress toward sustainability is that, people whose decisions shape the cause of development gain access to relevant data. Planning and management have always required data as the cornerstone upon which to base decisions. Hence, effective planning can only be achieved through access to "good" geo-spatial data, that is data, which are accurate, relevant and up to date (Mason and Rüther, 1997). This in turn requires that tools be devised for simplifying, quantifying and analysing technical data and for communicating it to various groups of users.

2D and 3D Visualisation can be used as tools to communicate complex spatial concepts to the non-technical population showing different scenarios under a variety of conditions and permitting them to explore the alternatives.

1.2. Problem Statement

The problem is that the biophysical environment was often neglected in the past because of the urgency to provide land to settle communities. Inadequate planning has lead to the sustainability of settlements being threatened by environmental factors such as poor drainage, soil erosion and steep and unstable slopes. This in turn resulted in difficult living conditions for the residents of these settlements.

The causes of the environmental and related social problems in informal settlements can be attributed to the following:

- Limited use of EIAs.
- Decisions based on limited information.
- Minimal public participation.

No specific guidelines have been developed to address environmental issues in identifying land for poor communities. EIAs are not mandatory and therefore offers limited assistance to planners in identifying land for the development of informal settlements. Consequently, decision-makers do not have access to all the relevant information, when making development decisions. New environmental legislation is currently being drafted to protect the environment and thereby promote sustainable development. It is therefore imperative that decision-makers and the public be able to obtain the information they need and to understand the data. Technical information limits public participation, as the residents do not understand the data and can therefore not effectively participate in the discussions or in the decision-making process. Public participation can only be effective when the information and the consequences of decisions are clearly understood.

The study area for this investigation is an informal settlement, Imizamo Yethu Estate in Hout Bay near Cape Town. The informal settlement presents the perfect example, of the problems that can be experienced as a result of insufficient planning. A geo-technical survey was not undertaken during the planning stages of the development of this settlement.

Three problems arose from the failure to investigate the soil and geology.

1. The settlement had pit latrines, which filled up during periods of heavy rain causing flooding. This was a direct result of the soil consisting of clay at the outlet of the pit latrine. Soil containing clay tends to have low infiltration capacities, which can lead to water logging and flooding (Gawith, 1996d). The pit latrines had to be replaced because it presented a potential health risk to the residents of the settlement.

2. The southern part of the settlement was inappropriate for low-cost housing because the area was rocky. The boulders had to be crushed and removed before the development could start.

3. The north-eastern part of the settlement contained a landfill and could not support housing development. This resulted in fewer houses being built than was originally planned.

Additionally, the gridiron layout that was chosen for the informal settlement resulted in steep road gradients, which contributed to the erosion problems in the settlement.

The Hout Bay situation could have been avoided with informed planning. Hence, it is important that the data, the decision-makers are given contain sufficient detail, is accurate and relevant. This data should enable the decision-makers to make informed decisions.

1.3. Aims and Objectives

The aims of the thesis are to:

- Demonstrate how GIS can be used for decision support and planning of informal settlements.
- Develop a methodology that can assist planners with site selection and environmental planning of informal settlements.

The specific objectives that will be met to satisfy the overall aims are:

1. The soil, drainage and slope factors will be studied. The results will be used to create the site suitability map. The site suitability map will be used to assess the appropriateness of the area for low-cost housing.

2. The usefulness of using 3D models instead of 2D displays for environmental planning will be investigated and discussed by using the digital terrain model (DTM), slope and site suitability maps. The definition and uses of a DTM are discussed in Chapter 4, section 4.11.1.

3. The slope and site suitability maps will be draped over the triangular irregular network (TIN) to analyse which areas are unsuitable for development. The definition of a TIN is given in Chapter 4, section 4.11.1. The results from this analysis will be used to create a model that will include environmental concerns that should be addressed during the planning stages of development. The environmental factors that will be addressed when creating the model include; slope, drainage, aspect, microclimate and the visual impact of the site.

4. The methodology that will be developed, based on the case study analysis and previous research done in the area (Gawith, 1996a) can assist in the planning process of informal settlements.

1.4. Contribution of the Study

It is anticipated that the methodology, which will be developed, can be used as guideline, when selecting sites for the development of informal settlements. The methodology is based on the use of GIS to promote informed decision-making by the use of tables, maps and 3D models.

1.5. Synopsis of Chapters

Chapter two reviews previous studies involving GIS and visualisation. Firstly, the perceptions of visualisation are discussed. Secondly, how visualisation has been used for environmental applications. The potential of GIS for informal settlements is discussed.

Chapter three provides the environmental setting for the thesis. The historical background and the location of the settlement, Imizamo Yethu Estate, are provided. The layout of the settlement is described and the problems experienced in the settlement are discussed.

In Chapter four a description of the methodology and procedures used to collect, analyse and display the data are given. The three environmental factors used for the project and the reasons for using these factors are discussed. The fieldwork methods are discussed and the laboratory procedures used to analyse the soil samples are described. The procedures for the creation of the soil, drainage, slope and site suitability maps and 3D models are described.

In Chapter five the results of the fieldwork and laboratory analysis and all the maps produced are presented. The advantages of 3D visualisation are discussed by using the TIN, slope and site suitability models created by using the data collected from the informal settlement, Imizamo Yethu Estate. A description will be given of how GIS was used to create the environmentally sensitive model. The model highlights the potential of using GIS in the planning process of informal settlements. The methodology created to assist with the planning process of informal settlements will be presented and discussed.

The thesis is concluded in Chapter six. The main findings that emerged from the thesis are summarised. The repercussions that an inadequate planning procedure had in the informal settlement, Imizamo Yethu Estate are discussed. The importance of using GIS and visualisation technology for the planning of informal settlements is emphasised. A number of recommendations are provided.

Chapter two
Literature Review

2.1. Introduction

The following literature will reveal how GIS can be used in planning. GIS can perform numerous functions from the collection, storage, management, retrieval and conversion, to the analysis, modelling and displaying of data (Davis, 1996). It is therefore envisioned that GIS and especially 3D visualisation can have an important impact in the planning of informal settlements.

The literature review has been divided into three sections. Visualisation is defined in the first section, followed with, how visualisation is used for environmental applications. The third section deals with the potential use of GIS and 3D visualisation in informal settlements. The literature studied has lead to the strategy that will be used in this thesis to meet the required aims as mentioned in Chapter 1, section 1.3.

2.2. Visualisation in GIS

Visualisation is viewed as a process that transforms data and knowledge into a visual form by exploiting the human perceptual system (Gershon and Eick, 1997 and Haber and McNabb, 1990).

According to Gershon and Eick (1997) the impact of visualisation has resulted in new insights and more efficient decision-making because it links the two most powerful information processing systems, the human mind and the computer. Large volumes of data can now be processed more quickly, understood and hidden patterns can be discovered more effectively thereby improving decision-making. This perception is supported by Simonnett (1993) who agrees that visual representations can assist with problem solving because it provides an efficient structure for expressing the data. The data is therefore easier to understand.

According to the CSIR (1997) 3D visualisation technology is an alternate computerised approach to planning and communication. The impacts of planning proposals can now be presented to the interested parties in a visual format and assessed. Animation can also be used to simulate dynamic environmental processes, for example, the progressive erosion of a riverbank. Smart, Mason and Corrie (1990) argues that 3D visualisation can be used to support proposed developments as the images produced are accurate and realistic. Davidson, Watson and Selman (1996) agree that 3D images are realistic and can therefore provide useful reminders of the development proposals after site visits.

Barry, Crone, Mason and Rüther (1997a) believe that graphic communication can be of great use in engaging community participation in an environment of low literacy rates. The data is in a visual format that makes it easier to understand and therefore the audience can participate effectively. This method can therefore be used to communicate information and ideas that allow people to draw their own conclusions.

2.3. Use of 3D Visualisation for Environmental Applications

Davidson, Watson and Selman (1996) studied the potential contribution of GIS and visualisation to rural environmental planning in the following two case studies.

2.3.1. Environmental and Visual Impact Assessment of Aonch Mor Skiing Development

The Aonach Mor skiing development is situated east of Fort William in the Ben Nevis range, consists of a car park and café at the bottom station, a gondola that goes to the top station where there is a restaurant, a bar and a shop. GIS and 3D visualisation was used to assess the impact of the development on the vegetation, water courses and the visual impact of the base station, infrastructure, the new assess road and the removal of a number of trees. The roads, tracks, footpaths, erosion risk assessment, vegetation, forestry, features of the skiing development and data on contours were digitised.

The soil, vegetation and slope data were captured and analysed to predict areas that would most likely be eroded as a result of the development. The map that was produced showed the vulnerability of certain areas to erosion. This map was used to assess which areas could be used for the development and which areas were unsuitable.

A DTM was created of the area. The DTM was used to assess the visual impact of the development from five different locations. These models were draped with a variety of vector files to provide realistic images of the development. The results of the environmental and visual impact study were presented to the Regional Council and permission was granted for the development.

2.3.2. Tinto Hills Forestry Scheme

A commercial forestry company wanted to plant 740 hectares of forestry in 1986 on the hills of Tinto, which lie to the south-east of Glasgow and rises to a height of 710m. Permission for the development was denied. In 1988 another application was submitted where only 270 hectares would be used. The environmental and visual impacts were the main planning issues with this forestry proposal. The visual impact of the development was assessed by simulating views of the Tinto Hills from panoramic viewpoints along the main road. The competing land uses such as agricultural land, footpaths and archaeological sites were also draped over the DTM to reveal the areas that would not be used for the development. The proposal was approved.

2.4. Assessing the Visual Impact of Development Plans in Vancouver

According to Smart, Mason and Corrie (1990) 3D visualisation can be useful in assessing the impact of forest development on the landscape. 3D visualisation allows the forestry companies to demonstrate the effects of:

- Logging certain areas.
- Avoiding logging areas where environmental degradation can occur.

In Silver Pass, Vancouver, tourism had become increasingly important for the economy of the town. The residents were concerned that logging activities would destroy the natural beauty of the area and therefore have a negative effect on the tourism industry.

A DTM was used to support the proposed forest development in Silver Pass. The 3D displays showed the visual impact of the proposed development. The DTM was created by digitising the contour map of the entire area. Polygons were digitised that represented the areas to be logged and converted into 3D. The coastlines, lakes and islands were digitised and later draped over the DTM. Trees were added to the DTM to add a degree of realism to the model. The DTM was viewed from a number of ground positions within the program to assess the visual impact of the development. The images produced appeared accurate and realistic especially when the trees were added. The 3D model assisted with passing the proposed plan of the development. Prior to viewing the 3D displays the entire development was rejected but after seeing the displays, parts of the development was approved. In the forestry industry, 3D visualisation has the capability to open forbidden areas for logging development.

2.5. Use of GIS for residential development

In 1990, Botany Bay in the US Virgin Islands was used as a demonstration site to show how GIS can be used in resource planning. A database was created from the following data; roads, elevation, geographical points, cultural features and neighbourhood districts. The data were used to derive the following maps, slope, aspect, proximity to coast, watersheds, road and visual exposure to the coastline. The data were used in the demonstration analysis to determine the best location for residential development.

Several maps describing the aesthetic engineering and environmental factors were considered to determine the "best" location for the residential development.

These environmental factors included:

- **Engineering**
- ♦ Slopes – Gentle slopes were preferred because it decreased the site preparation and construction costs.
- ♦ Proximity to the roads – The areas close to existing roads were preferred, as it would decrease the need to build additional roads.

- **Aesthetics**
- ♦ Proximity to the coast – It was a requirement that the development be close to the coast.
- ♦ View of the coast – The second requirement was that the development had a good view of the coastline.

- **Environmental constraints**
- ♦ Steep slopes – This type of slope results in high building costs.
- ♦ Distance from the coast – The distance was limited to 100m from the coastline.

The slope map was created from the elevation data. The slope map was interpreted on a scale of naught to ten. Naught signified the total unsuitability of the area for development, while ten signified the flattest areas, most suitable for development.

The "proximity of roads" map was created from the road map of the entire town and interpreted on a similar scale as the slope map.

The "proximity to the coast" map was interpreted on a scale of naught to ten, with naught being closer than 100m away and 10 being greater than 600m away from the coastline. The slope was considered when creating the "proximity to the coast" map, as development was favoured on gentle slopes.

The visual aesthetics were determined by a procedure, which is analogous to a person standing on the shore and noting all the locations that can be seen. Each inland location was assigned a value equal to the number of times it was seen from different locations along the shore. The locations that had high visual exposure were interpreted as having the "best" views.

Slopes facing in a westerly direction were preferred as this particular orientation allows a greater chance to view the setting sun. Westerly slopes were given a ranking of ten, while north, north-easterly and south were the least preferred slopes and only received a ranking of five.

The environmental constraints to the development were determined by studying the "proximity to the coast" and the slope of the areas. The areas that was less than 100m away from the coastline was given a ranking of naught as it did not meet the requirements for the development. Slopes steeper than 50° were ranked totally unsuitable for the development.

A weighted site suitability map was created with the "view of the coast" being regarded as the most and slope the least, important factor when choosing the site for the residential development. "View of the coast" was ranked ten times, the "proximity of the coast", eight times, road proximity, three times and aspect preference twice as important as the slope of the area.

The composite map was created by using the five separate maps. The sites that were closer than 100m from the coast and slopes that was greater than 50° was eliminated from the site selection process. The suitable areas were found to be localised to three distinct areas. The decision-makers could at this stage decide, which site met most of the requirements for the development of the residential area.

According to Berry (1991) the demonstration has highlighted the capabilities of GIS. GIS has provided significant advances in data management, analysis and presentation of data. This technology can be used to do site selections for all types of developments. Berry (1991) believes that GIS can greatly enhance decision-making capabilities but do not replace the decision-making process in planning.

2.6. Informal Settlements

Very few environmental studies have been reported in the literature for informal settlements. In the past, many of the informal settlements were unplanned. These types of settlements just sprang up wherever there was vacant land. Hence, the sustainability of the environment was not even considered. However, in the past few years, attitudes have changed in favour of environmental protection. The potential of GIS and 3D visualisation can have a positive effect on planning for informal settlements.

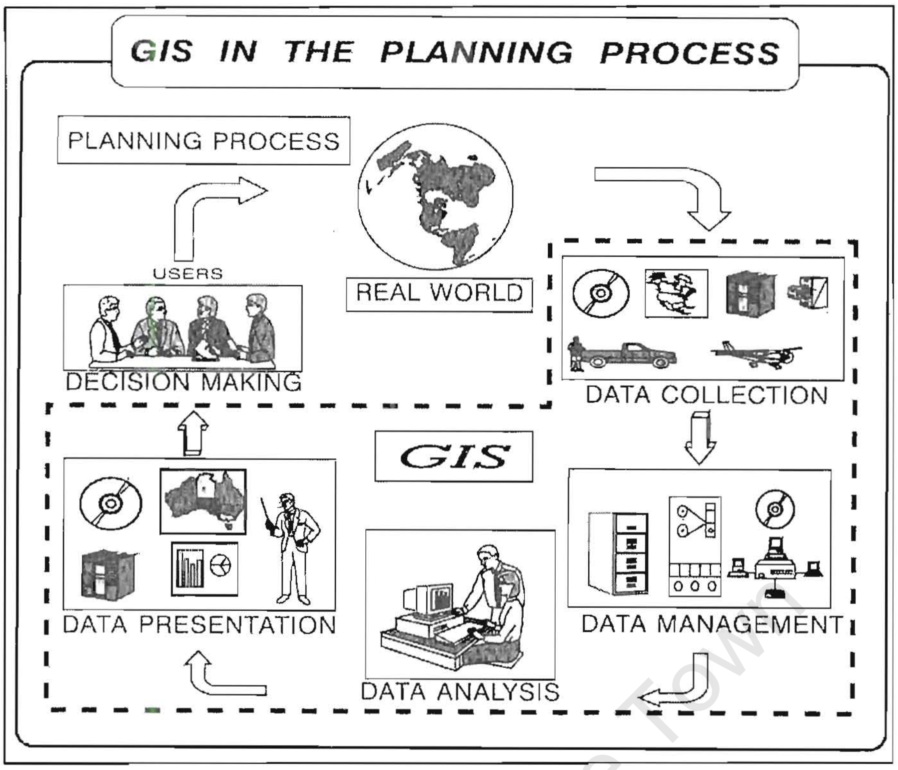


Figure 1. GIS in the planning process.

Figure 1 illustrates how GIS can be used in planning. When a problem occurs in the real world that needs to be addressed, data is required to solve the problem. This data is collected from a number of different sources which, include, CD Roms, tapes, maps, reports, field collection and remote sensing. During the "Data Management" phase the data is prepared for use and stored. The real work begins during the "Data Analysis" phase. GIS is used in this phase to perform the analysis, which eventually produces the results. The data can be presented in a number of forms namely, graphs, tables, maps or models. Decisions can be made based on the results and passed on to the real world for action. GIS has become a major tool for a range of applications from simple queries, environmental assessments to the mapping and modelling of natural hazards.

GIS will be used in this thesis to demonstrate how this technology can be used for the site selection and environmental planning of informal settlements. The literature review has revealed the usefulness of GIS in planning and has been used to create the following strategy that will be employed in this research.

The strategy that will be used to meet the required aims of this thesis are:

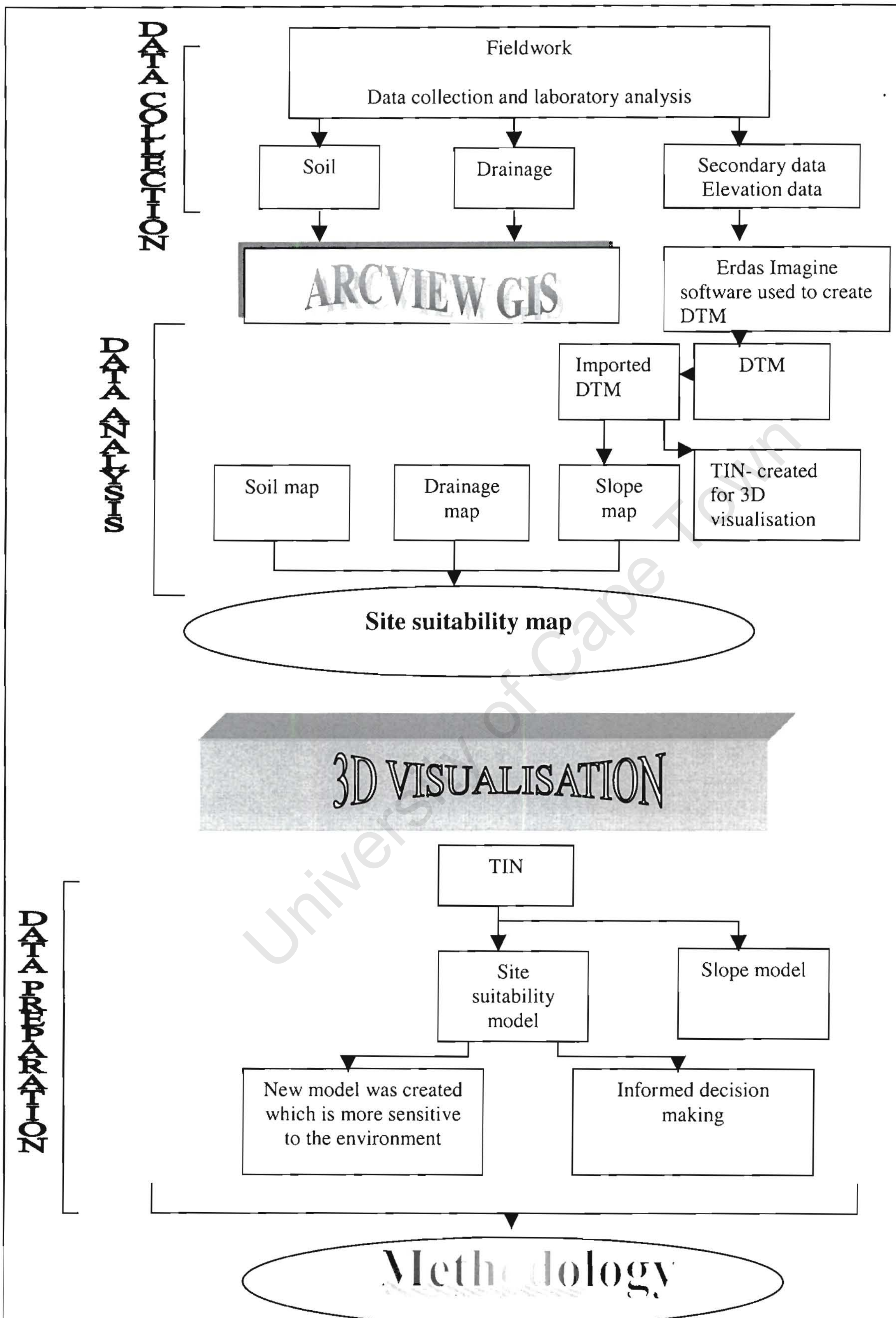


Figure 2. Flowchart of the strategy used for the research.

The methodology used to capture, analyse and present the data will be discussed in detail in Chapter 4.

2.7. Summary of Literature

The main appeal of visualisation is its potential to assist with decisions on real world problems. The literature review has revealed that GIS and visualisation can be used to undertake environmental impact and visual assessments and monitor environmental changes over time. 3D visualisation, modelling and animation make information meaningful and easy to understand because of the "highly communicative visuals". Visualisation can therefore be an ideal tool for planning and to assist with community participation in informal settlements, as visual presentations can decrease the scope for differences of opinion brought on by differences in interpretation (Bishop, 1994).

Chapter Three

Environmental Setting

3.1. Introduction

In this chapter the location and the historical background of the informal settlement, Imizamo Yethu Estate are discussed. The environmental problems relating to the layout, slope, soil, drainage and microclimatic conditions in the settlement will be outlined in this chapter. The informal settlement, Imizamo Yethu Estate was chosen for this investigation because of the environmental and social problems resulting from insufficient planning. The informal settlement will be used as an example, to demonstrate how GIS can be used to address environmental issues and improve planning.

3.2. Study Area

Hout Bay is a coastal residential area situated in the Disa River valley of the Southern Cape Peninsula near Cape Town (see Figure 3). Imizamo Yethu Estate is an informal settlement close to Hout Bay with an area of approximately 22 hectares (see Figures 4 and 5). The settlement is situated on the western slope of Skoorsteenkop.

Most of the buildings in the informal settlement, Imizamo Yethu Estate, are self-constructed except for a few formal buildings such as three community halls, a day-care centre, a church and a municipal building. The shacks are constructed from a variety of materials that include corrugated iron, plastic, wood, tin and asbestos. The shacks are densely built with about two to three meters separating one from the other. Aerial photography taken in 1997 revealed that there were approximately 1044 shacks in the settlement.

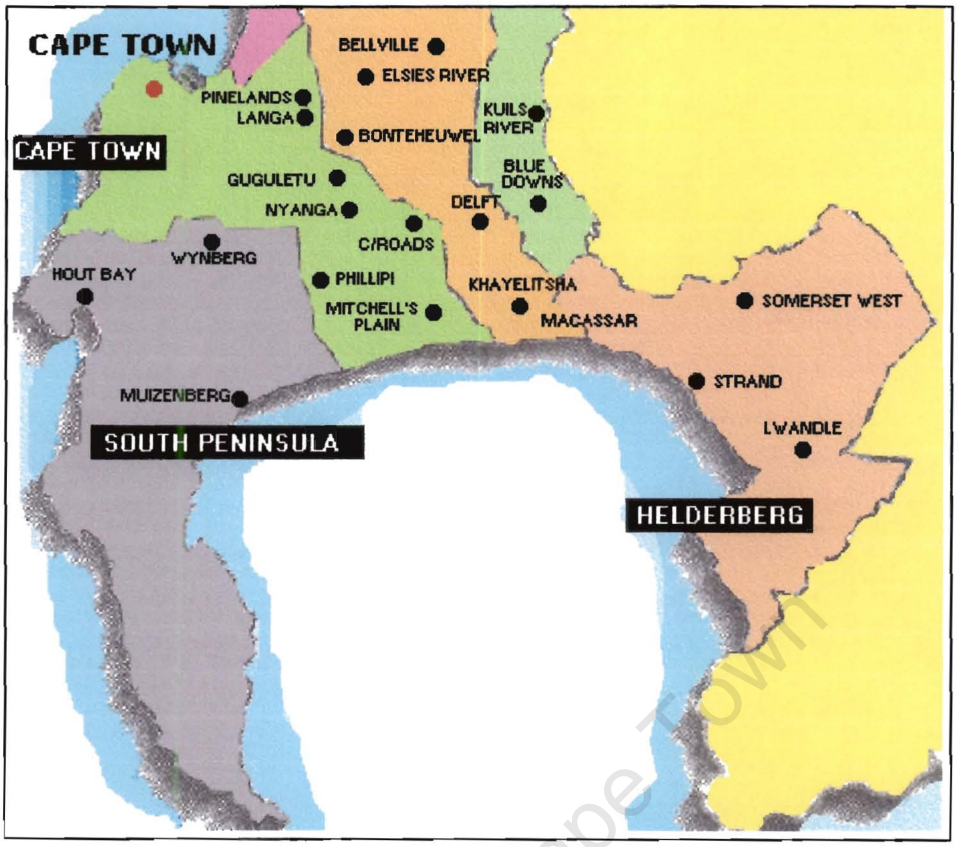


Figure 3. Location map of Hout Bay.

Source: Li (2000)

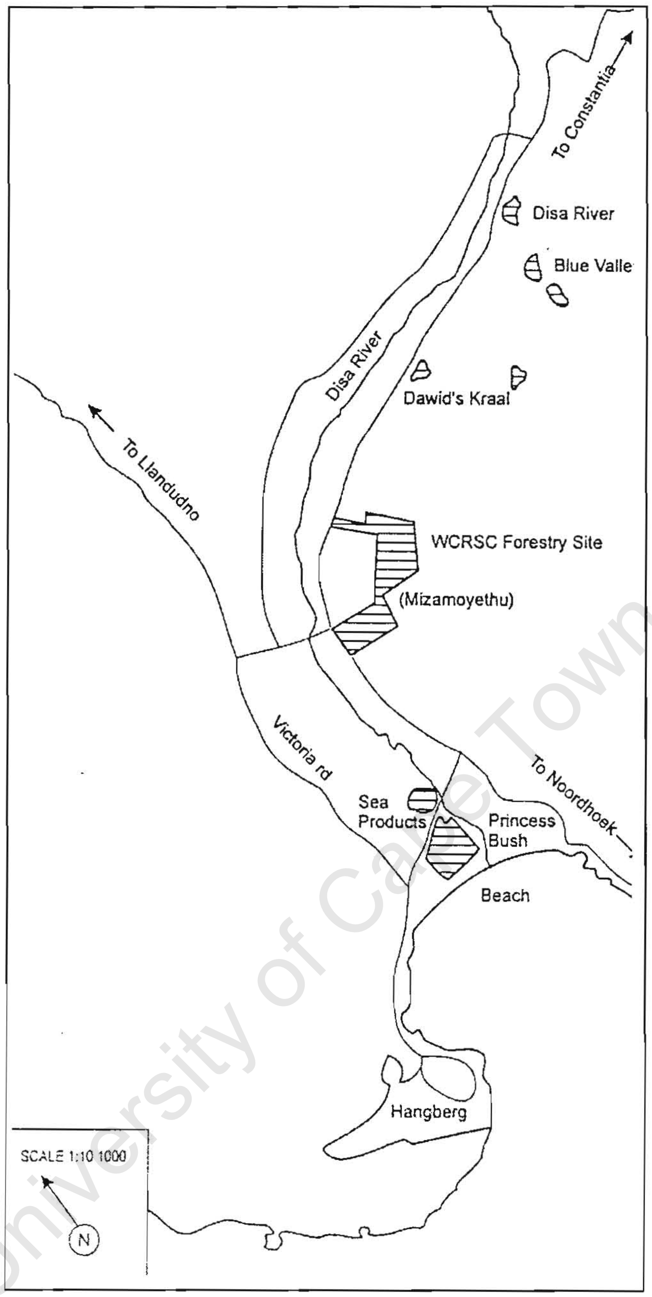


Figure 4. Location map of Imizamo Yethu Estate (Mizamoyethu).

Source: Gawith (1996c)

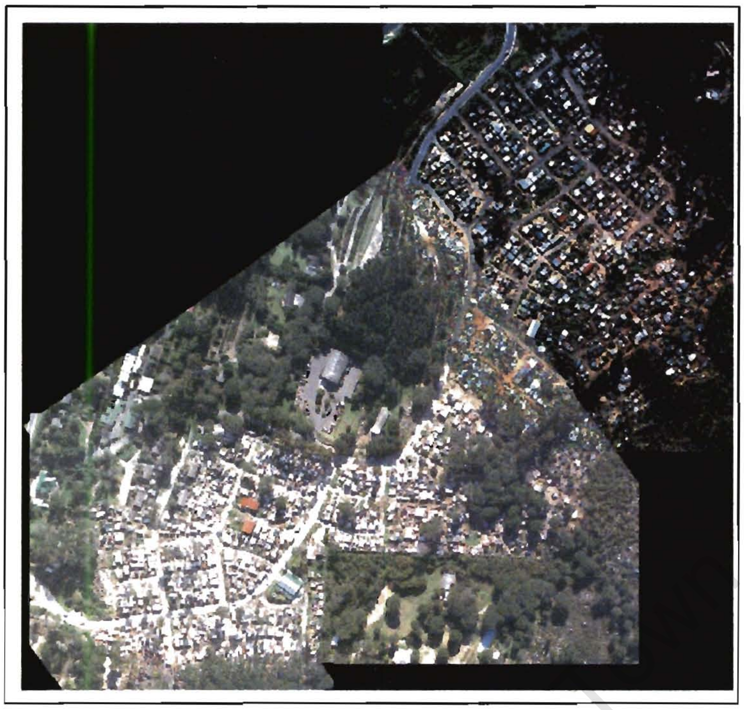


Figure 5. Image of the informal settlement, Imizamo Yethu Estate.

3.3. Historical Background

In the past the economy of the Hout Bay community was based on fishing and small-scale agricultural activities. The farming and fishing industry has become less significant in recent years. In the 1950's many of the farms were sold for residential development. Today, tourism, residential and small-scale commercial centres are the predominant economic activities (Gawith, 1996c).

In 1989, the squatter settlements named Princess Bush and Sea Products developed in the coastal dunes of Hout Bay. According to the legislation, the settlements were illegal. By the middle of the 1990's the two settlements had grown to 1000 shacks. The state decided to allocate land for a permanent settlement for the residents of both communities (Gawith, 1996c). The eventual site was chosen from 33 undeveloped parcels of land around Hout Bay. The parcels of land were assessed by using the following criteria; size, slope, visibility, location, accessibility, current status, ownership and acquisition costs. The urgency to resettle the two communities increased when a fire broke out in Sea Products and the community of Princess Bush was found guilty of illegal squatting. No detailed assessments of the potential sites were undertaken because it was imperative to relocate the two communities. Imizamo Yethu Estate was chosen because the land was state owned and was relatively flat. Relocation could therefore start immediately. The planners felt that the site could be developed and upgraded for a permanent low-income residential area. The site was suitably located in relation to facilities and public transport. The residents were relocated to the new settlement that was named Imizamo Yethu Estate.

3.4. Site Layout and Slope

Most of the informal settlement, Imizamo Yethu Estate has a gridiron layout except along some of the sides where unplanned expansion has taken place. Gawith (1996d) argues that gridiron layouts should be avoided because they do not provide the basis for sustainable development, especially if employed on steep slopes. Steep slopes can generate high development, servicing and maintenance costs and promote erosion. This is one of the reasons why the majority of the settlement now has tarred roads and walkways.

3.5. Soils and Drainage

The soil in the informal settlement generated high maintenance costs. The fundamental problem was that no detailed geo-technical survey was undertaken during the environmental assessment of the area. The problems relating to the drainage, size and the rockiness of the area were discussed in Chapter 1, section 1.2.

3.6. Microclimatic Conditions

The informal settlement is exposed to strong north-westerly and south-easterly winds. The devastating effects of the winds have caused a few shacks in the informal settlement to be rebuilt. The shacks are built from unstable building materials, which makes them vulnerable to the strong winds. The effects of the microclimatic conditions in the informal settlement will be discussed in greater detail in Chapter 5, section 5.8.

3.7. Summary

The environmental factors discussed in this chapter should have been investigated during the planning stages of this development. Omitting to address these environmental factors have resulted in environmental degradation in the forms of drainage and erosion problems as well as increasing the construction costs, as boulders had to be crushed before development could proceed. The strong winds have resulted in the rebuilding of shacks in the informal settlement at a financial cost that the residents cannot afford. Incorrect planning does not only have a negative effect on the environment but ultimately effects the quality of the residents' lives. A thorough biophysical assessment at the outset of planning would have revealed the limited developmental potential of the site. Measures could have been taken to accommodate the limitations of the site or an alternative site could have been considered.

Chapter Four
Methodology – Maps and Models

4.1.Introduction

The procedures used to collect, capture, analyse and display the data will be discussed in this chapter. The three environmental factors, which are investigated in this project, are soils, drainage and slope. These three factors influence the choice and uses of land. The motivations for using these environmental factors are discussed.

The methodology can be divided into four parts,
1. Fieldwork
2. Laboratory analysis
3. Capturing, analysing and displaying of data using ArcView GIS and the extension Spatial Analyst.
4. 3D Visualisation by using 3D Analyst.

The environmental-sensitive model will be created by investigating the environmental problems currently experienced in the settlement. This model will show how GIS can be used to provide different development plans that can assist with decision-making.

4.2. Factors relating to the Bio-Physical Environment

4.2.1. Soils

The soil conditions of a location can have important implications for the development and long-term maintenance costs of land. Soils like clay have low infiltration rates and may impede drainage. When clay soils absorb water it can result in the expansion of the soil when wet and the shrinking of the soil when dry. This process of swelling and shrinking of the soil can cause damage to buildings and foundations (Gawith, 1996c, Ollier and Plain, 1996). Sandy soils on the other hand can be easily eroded by wind and water, which can create difficult building conditions (Gawith, 1996d). In Imizamo Yethu Estate, the pit latrines filled up during periods of heavy rainfall causing flooding. The main reason for the flooding was the type of soil present, a few meters below the soil surface. The purpose of the soil study is therefore to collect information that can help in the proper use of the land. Hence, it will enable more accurate planning and management strategies.

4.2.2. Drainage

Drainage is a function of soil and slope type. Soil containing a high percentage of sand drains readily while clay soils can cause waterlogging. The outcome of the drainage problems can increase the maintenance costs in an area. These biophysical environmental problems can be translated into socio-economic problems. In Imizamo Yethu Estate the canals, which were dug by the residents to improve the drainage conditions resulted in taxi drivers increasing their fares to enter the settlement as the canals caused rills to form in the road.

4.2.3. Slope

Slope measures the steepness of the terrain. A slope map can provide a more detailed look at the relief of the landscape (GeoInformation International, 1997). It is considered an important criterion in evaluating land for low-cost housing because steep slopes promote runoff and erosion (Gawith, 1996c, Dent and Young, 1980). These types of slope increase maintenance costs.

The classification of soil, drainage and slope and their response to environmental management in the forms of drainage infrastructure and the levelling of steep slopes, are required for informed decision-making in rural and urban planning. These factors can also be used for feasibility and design studies in land development projects.

4.3. Methodology used for the environmental study

The following methodology provides an outline of the procedures used to prepare the environmental data for analyses. The methodology will be discussed in detail in the following sections.

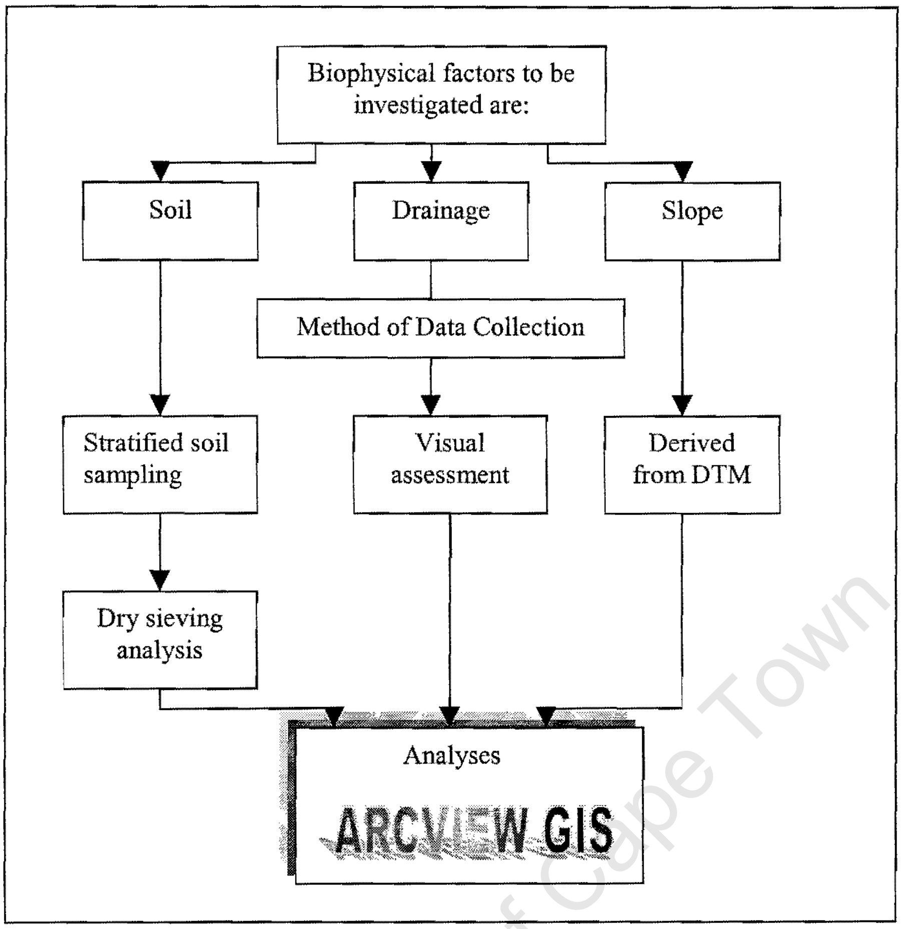


Figure 6. Flowchart of the methodology used for the environmental study.

4.4. Fieldwork

The fieldwork took place in August 1998 and in October 1998 and involved collecting soil samples for laboratory analysis and assessing the drainage of the settlement.

Gawith's (1996d) study in Imizamo Yethu Estate revealed that the soil a few meters below the soil surface consisted of clay. The evidence supporting this was the pit latrines that had to be replaced as a result of filling up and overflowing during periods of heavy rainfall. The days before and during field investigations were marked by periods of heavy rainfall. It was noted that the topsoil did not display the characteristics inherent of clay soils, which feels soapy when rubbed between the fingers and have low infiltration capacities. Firstly, there did not appear to be any serious drainage problems throughout the settlement. The few areas that experienced drainage problems were more a result of the steep slope gradients and soil compaction than from the type of soil. Secondly, upon studying the soil grains more closely the soil particles appeared larger than those found in clay soils.

Soil sampling was done to investigate if the field observations were correct and thereby justify why there did not appear to be any serious drainage problems in the settlement.

4.4.1. Field Equipment

1. A map containing the grid layout was taken into the field as a location guide. Each grid was numbered on the map to assist with the numbering of the soil samples.
2. The differential Global Positioning System (GPS) was used to capture the ground control points by using the Stop and Go Kinematic method, which were subsequently used for the rectification of the Imizamo Yethu Estate images. The GPS was also used to record the co-ordinates where each soil and drainage observation was taken. The Stop and Go method has an accuracy of a few centimetres (Van Sickle, 1996).
3. A shovel was used to dig the holes for soil sampling.
4. Soil sampling and drainage checklists were included to review if soil samples were taken and the drainage conditions assessed at each site.

4.4.2. Stratified Random Soil Sampling

The technique of stratified random sampling was used to collect the soil samples.
Stratified random sampling involves constructing a grid pattern where a random soil sample is taken from each grid. According Carter (1996) stratified random sampling is used to:

1. Make statements about the soil type in each grid.
2. Increase the precision of sampling over the entire area.

In this case study the grid pattern was already in place because of the gridiron layout in the settlement (see Figure 6). However, in some areas two grids were combined because of their size. The study area eventually consisted of 38 grids. One random soil sample was taken from each grid. The average soil sample size was 350g. The depth to which the soil sample was taken was approximately 15cm to 20cm as only the topsoil was being investigated.

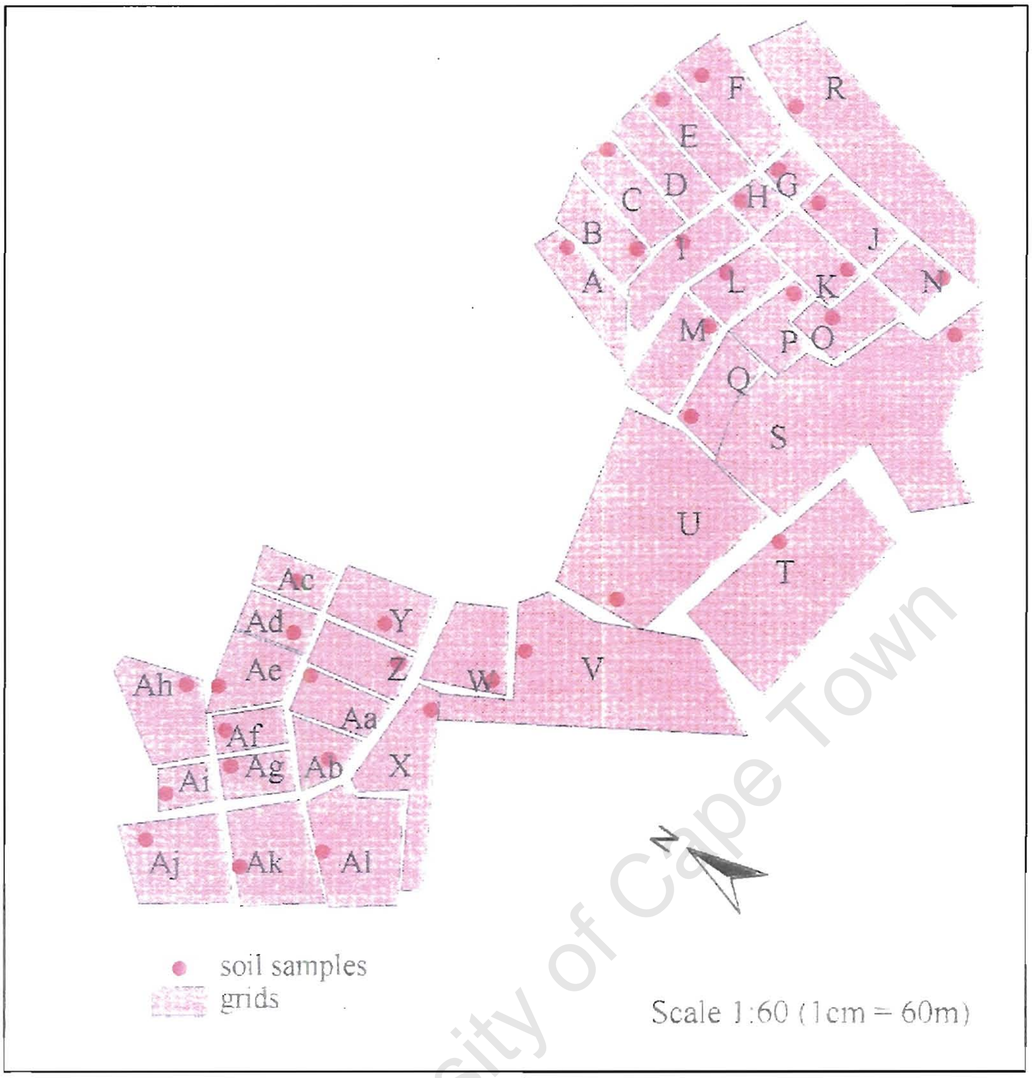


Figure 7. Grid layout of the informal settlement, Imizamo Yethu Estate

4.4.3. Drainage

A visual assessment of the surface drainage of the settlement was undertaken. The drainage was classified into three groups, fair, poor and very poor.

Table 1. Classification criteria used to categorise drainage.

Drainage type	Factors assessed
Fair	Drainage infrastructure present, little signs of erosion and the area appear stable.
Poor	No drainage infrastructure present. Signs of instability (for example, logs or rocks used to stabilise an area.) signs of erosion and puddling.
Very poor	Waterlogged areas, rill formation and roads blocked because of soil being washed down from the slopes above.

4.5. Laboratory Analysis

According to Head (1980) soil consists of a collection of distinct particles of various shapes and sizes. The object of a particle size analysis is to group these particles into separate ranges of sizes. It is possible from this procedure to tell whether the soil consists of predominantly gravel, sand, clay or silt.

Dry sieving is the simplest of all the methods of particle size analysis. The dry sieving procedure can be carried out in soils that have negligible amounts of silt or clay particles. This procedure can be used for sandy and gravelly soils.

4.5.1. Apparatus

1. Five sieves were used to determine the quantity of soil left on each sieve in order to plot the particle size data and classify the soil type. The sizes of the sieves used were 0.063mm, 0.150mm, 0.3mm, 0.425mm and 0.6mm. According to Head (1980) the sieves to be used must be selected to suit the size of the sample and the type of material.

2. A weigh was used to determine the weight of the sample before and after drying. It was also used to weigh the soil left on each of the five sieves.
3. A pestle and mortar was used to loosen the soil grains after it was oven dried.

4.5.2. Procedure – Preparation of sample and sieving analysis

According to the British Standard (Head, 1980) the mass required for sieving depends on the maximum grain size of the soil sample. The table used to determine the size of the soil sample that would be used for dry sieving is given below.

Table 2. Minimum quantities for particle size tests.

The size of material present retained on the sieve (mm)	Minimum mass of sample to be taken for sieving
Pass 2mm or smaller	100g
6.3	200g
10	500g
14	1kg
20	2kg
28	6kg
37.5	15kg
50	35kg
63	50kg
75	70kg

Source: (Head, 1980)

It was deduced from the table that a 200g soil sample was required to do the soil sieving analysis.

The 38 soil samples were ovendried at a temperature of 105^0C overnight. The samples were weighed to determine the dry mass. A mortar and pestle was used to separate soil particles that stuck together due to the drying process.

The dried soil sample was placed in the topmost sieve and shaken long enough for all the particles smaller than each sieve size to pass through.

The soil retained on each sieve was weighed.

The percentage of the soil retained on each sieve was calculated as follows.

The formula used:

$$P\% = \frac{m_{1} - \sum m * 100}{m_{1}}$$

$P\%$ = Percentage passing through each sieve

m_1 = Total initial mass

$\sum m$ = Sum of mass retained on each sieve

Source: (Head, 1980)

Particle distribution curves were drawn in order to classify the soils. The cumulative weight percentage retained on each sieve was plotted on a vertical axis of a graph, with the sieve sizes plotted on a logarithmic scale. The advantage of plotting the particle size data on a graph is that the grading characteristics of a soil can be more easily recognised than from tabulated data. The position of the curve on the graph indicates the fineness or coarseness of the grains. The steepness, flatness and general shape of the curve indicate the distribution of the grain sizes within the soil, for example,

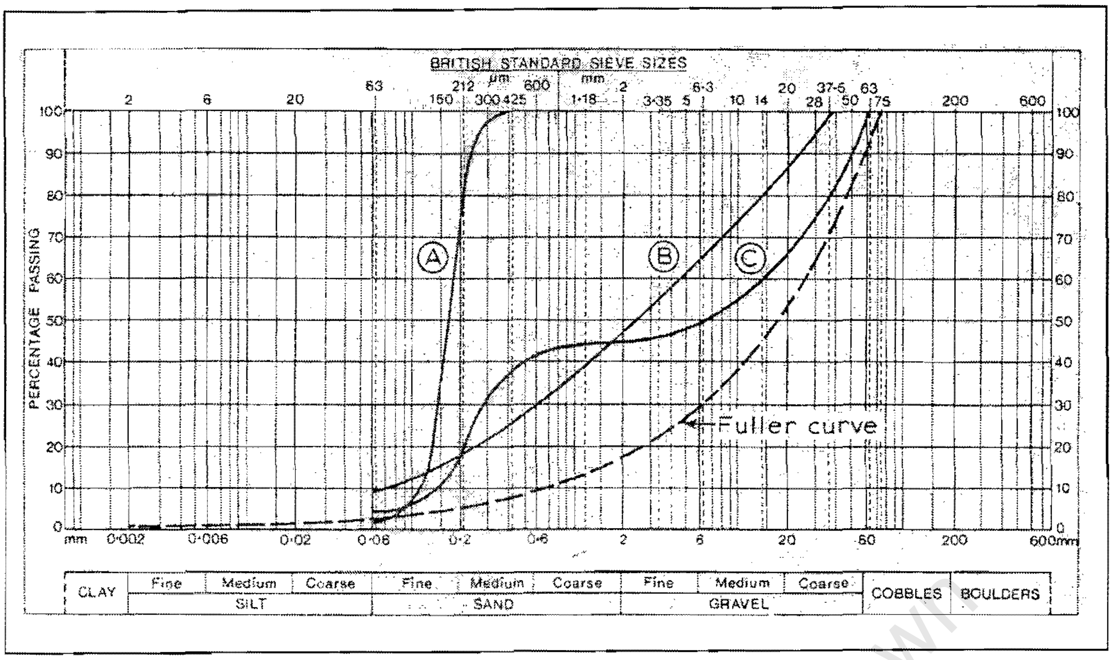


Figure 8. Grading curve

Source: (Head, 1980)

Curve A has a very steep grading curve, as the soil particles are nearly all the same size. Curve A therefore represents uniform sand.

Curve B had a smooth concave upward grading curve. This curve is typical of soils that contain a wide and even distribution of particle sizes. Curve B represents a well graded silty sand and gravel.

Curve C has two distinct sections separated by a horizontal portion. The soil is classified as poorly graded as it is deficient in certain grain sizes. The deficiency usually occurs in coarse sand to fine gravel size particles.

The dash curve shows soil particles of all sizes. These particles are densely packed together with the voids between the larger particles being filled with the smaller particles. These soils range from clay to gravel.

Soils are divided on the basis of particle size into 6 categories as shown in the table below.

Table 3. Classification by particle size.

Particle size (mm)	*Designation*		*Test procedure*
>200		BOULDERS	Measurement of separate pieces
200		COBBLES	
60	Coarse	GRAVEL	Sieve analysis
20	Medium		
6	Fine		
2	Coarse	SAND	
0.6	Medium		
0.2	Fine		
0.06	Coarse	SILT	Sedimentation analysis
0.02	Medium		
0.006	Fine		
0.002 and less		CLAY	

Source: (Head, 1980)

Each heavy horizontal dividing line in the Designation column separates materials of significantly different engineering properties. In practice, most natural soils do not fall within one of these main size ranges, but consist of a mixture of these categories. According to Head (1980) particle size distribution curves provide a means by which soils can be classified and their engineering properties broadly assessed.

4.6. GIS

The software and the procedures used to create the soil; drainage, slope and site suitability maps are described. The methods used to create the DTM and the 3D models of Imizamo Yethu Estate are discussed in the following sections.

4.6.1. Software used:

1. Erdas Imagine V 8.3

This software incorporates the functions of both image processing and GIS. It was used to rectify and create a mosaic of the Hout Bay 1997 images. The images were imported into ArcView GIS for analyses.

Other uses include:

1. Visualisation
2. Image display
3. Terrain analysis
4. Mapping

2. ArcView GIS 3.a.

The software ArcView was used in the thesis to capture, analyse, query and visualise the data. ArcView GIS are accessible on portable desktop computers and are inexpensive. It was used for this research because it is icon-based which makes it easier to use than other software namely, ArcInfo, which require typing in commands. Scripts that were needed were obtained from the Internet and imported into ArcView GIS. Spatial Analyst, an extension of ArcView GIS provided additional analytical capabilities. This software was used to create the soil, drainage and site suitability maps by interpolation.

Spatial analyst allows the user to:

1. Import data from standard formats.
2. Display and reclassify grid data.
3. Create slope, aspect, hill shade and contours from surface maps.
4. Perform queries and algebraic calculations on multiple grid themes simultaneously.

ArcView 3D Analyst is another extension of Arcview GIS. This software was used to create the slope, site suitability and the environmental-sensitive model of the informal settlement, Imizamo Yethu Estate.

3D Analyst can perform the following functions:

1. Create realistic surface models from multiple input sources.
2. Determine height at any location on the surface.
3. Visualise data in 3D.

4.7. Rectification of Images with the use of Erdas Imagine

Raw images acquired from a sensor of a aircraft contain distortions attributable to the altitude of the sensor and the relief of the ground, which can result in a loss of usable data, for example, all the features will not be visible (Dowman, 1999). These distortions have to be corrected before the data can be used in a defined reference system. The rectified mosaic image of Imizamo Yethu Estate that is used in this thesis was created in the Department of Geomatics at the University of Cape Town in 1997. The image was used to capture the shack outlines needed to create the 3D shack features and to digitise the grid pattern needed for soil sampling.

There are two main methods of correction:

1. 2D transformation correction

This method is suitable for images in which there is very low relief distortion. This method was used in this project.

2. 3D correction

This type of correction is used to correct the effects of relief, sensor orientation, and earth rotation and curvature.

4.8. Use of Rubber Sheeting to geometrically correct imagery of the informal settlement, Imizamo Yethu Estate

Rubber sheeting in this investigation is the process of transforming the data from pixel co-ordinates to a co-ordinate system using a 2nd order polynomial. The rubber sheeting procedure is similar to stretching one data layer to fit another. According to Roux (1997) rubber sheeting provides an adequate geometric accuracy for the mapping of informal settlements and no DTM is required as in the case of orthophotos.

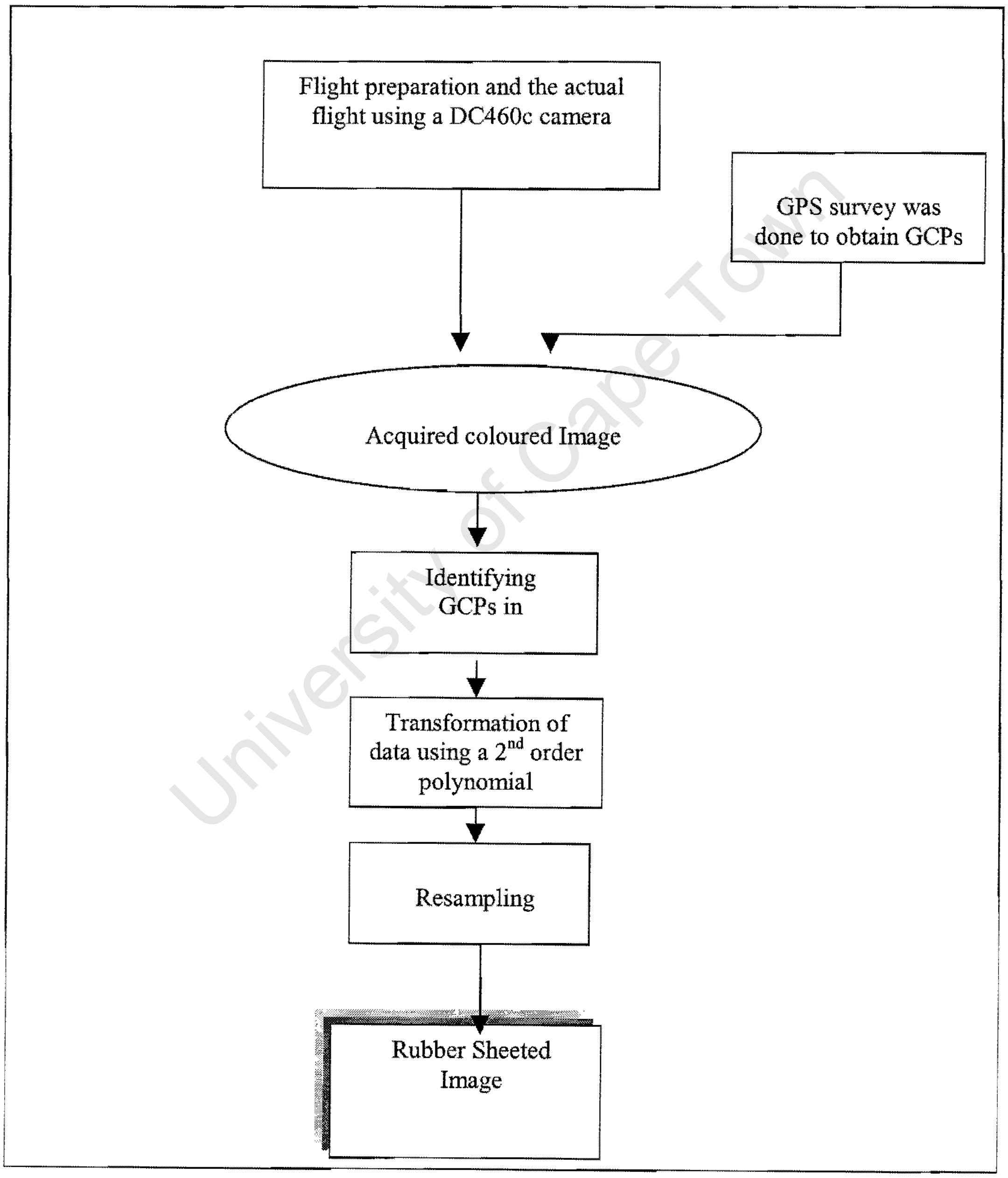


Figure 9. Flowchart of the rubber sheeting process.

4.8.1. Acquisition of Hout Bay Images

The three images acquired to make the 1997 Hout Bay mosaic image were obtained by using a DCS 460c camera, while flying over the informal settlement, Imizamo Yethu Estate.

4.8.2. Ground Control Points

Ground control points (GCP) are used to set up the position and orientation of each image in space, relative to the ground.

Two types of GCPs were used in this project:

1. Signalised points
2. Natural points

Signalised points are usually targets drawn on flat surfaces. The signalised points in the settlement were crosses marked in the roads. The natural points used in this project were the shack corners.

The requirements that have to meet when choosing GCPs are the following,

1. The grid size of the pixels must be taken into account for digital imagery. The targets have to extend over five pixels in order to be recognisable and measurable (Roux, 1997).
2. The GCPs must be locatable at high precision.
3. Occlusion has to be avoided because GCPs can be masked by trees or buildings, making the points undefinable in the images.

4.8.3. Capture of GCPs

A total of 43 GCPs were captured in the settlement.

Three Ashtech receivers were used to do the STOP and GO kinematic survey of the ground points. According to Van Sickle (1996) a relative accuracy of the centimetre level can be achieved by using the STOP and GO survey.

1. Two receivers were set up within a radius of five kilometres of the informal settlement, Imizamo Yethu Estate. The third receiver was used as a rover receiver. The rover receiver was used to collect enough data to determine the receiver's relative position. The master

receiver was used to track the satellites. The ground points were surveyed with the Rover receiver for one to two minutes.

2. The data was downloaded from the receiver and processed using Ashtech's Prism software. The Ashtech's Prism software is used to calculate point co-ordinates from data collected. The data were transformed into geographical co-ordinates because the software required that the position of the points had to be in a WGS84 geographical co-ordinate system. The heights were transformed from orthometric to ellipsoidal, as this is the height system used in South Africa. The co-ordinates were subsequently transformed into the Gauss Conform System with a central meridian of 19° on the Cape Datum as this system conforms to the South African co-ordinate system (Appendix A).

4.8.4. Rubber sheeting process

The three images of Imizamo Yethu Estate were imported into the image processing software Erdas Imagine to be rectified.

The rectification of data can be done by applying a transformation and resampling the data to produce a rectified image, which gives a best fit to the GCPs. Firstly, the GCPs were identified in the image by matching the source co-ordinates (pixel co-ordinates) with the reference co-ordinates (GCPs). The reference co-ordinates must be accurate in order to calculate an accurate transformation of the source co-ordinates. The three images in Imizamo Yethu Estate were rubber sheeted using a 2nd order polynomial. 2nd order distortions can be caused by pitch and roll, sub-satellite track curvature and scan lines convergence because of earth rotation and map projection (Dowman, 1999). A minimum of six GCPs were required to determine the transformation parameters. In this study 25 GCPs were used.

The minimum number of GCPs that must be used to determine the transformation parameters can be calculated by using the following formula.

$$\frac{(t+1)(t+2)}{2}$$

t = Order of transformation

Source: (Erdas Image, 1995)

The transformation was applied to the image. Resampling is required to change the pixel positions and assign them into the desired grid pattern. However, the transformed pixels still have to fit within the original grid pattern. The images were resampled with a pixel size of 0,25m using the bilinear interpolation method. This method enables the data file values of the rubber sheeted pixel, which is based upon the distances between the retransformed co-ordinate location and the four closest pixels in the original image. A linear interpolation between the different pixels was done to produce the new values.

The three rectified images were edge matched to create the mosaic of the informal settlement, Imizamo Yethu Estate (see Figure 10).

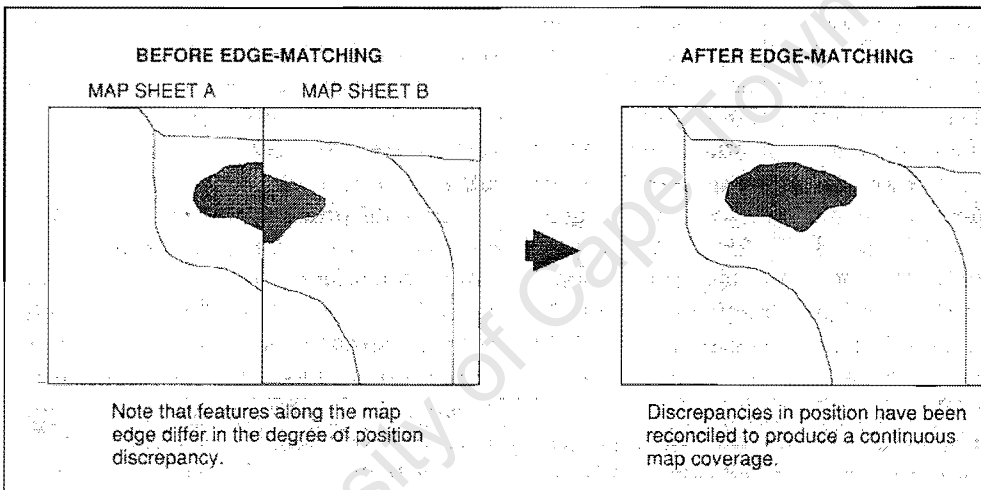


Figure 10. Edge matching.

Source: (Arnoff, 1993a)

The same principle (see Figure 10) was applied to create the mosaic image of Imizamo Yethu Estate. In this case, it was necessary to combine the three images because the study area spanned several image files. The image of Imizamo Yethu Estate was exported to ArcView for analyses.

4.9. ArcView GIS – Spatial Analyst

4.9.1. Soil and Drainage Maps

The soil and drainage surfaces were created by interpolation with the software Spatial Analyst. Each soil and drainage type were assigned a colour to distinguish between the different classes. Interpolation is a procedure of predicting unknown values using the known values at surrounding locations (see Figure 11).

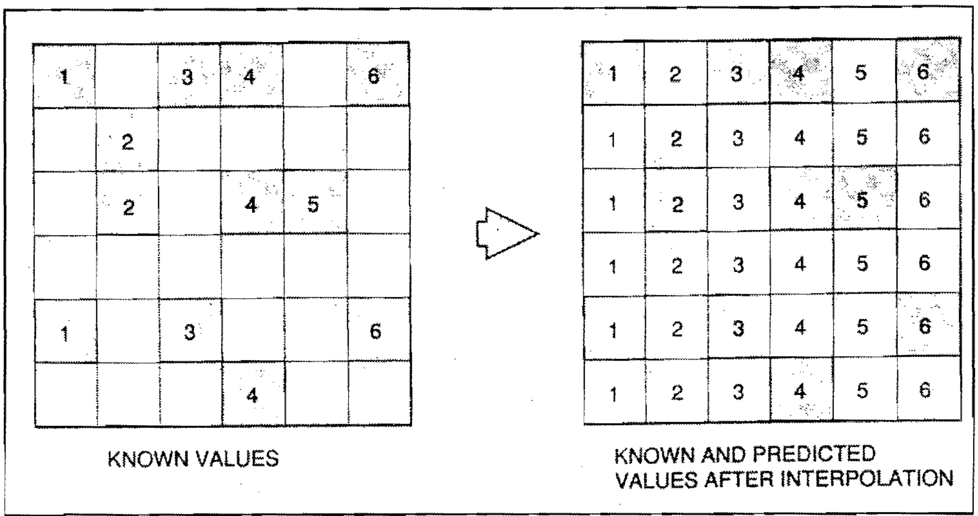


Figure 11. Interpolation

Source: (Arnoff, 1993c)

Interpolators create a continuous surface from sample points. Some interpolation methods available to create grided surfaces are Kriging, Inverse Distance Weighted, Spline and Trend. Kriging was used to interpolate the soil and drainage surfaces. Kriging is often used in the fields of Soil Science, Ecology, Geology, Geochemistry and in the Mining industry. The main strength of Kriging lies in its ability to predict spatial distribution of uncertainty and the statistical quality of its predictions, for example, unbiasedness (Mitas and Mitasova, 1999). Another advantage of Kriging is that it can be used to quantify the interpolated errors.

According to Arnoff (1993c) the quality of the results obtained by interpolation depends on the accuracy, the number and distribution of the known points as well as on how accurately the mathematical function models the phenomenon. The greater the number of input points and the denser their distribution the more reliable the results. The type of interpolator can effect the results therefore it is essential to choose the correct interpolator for the specific type of application.

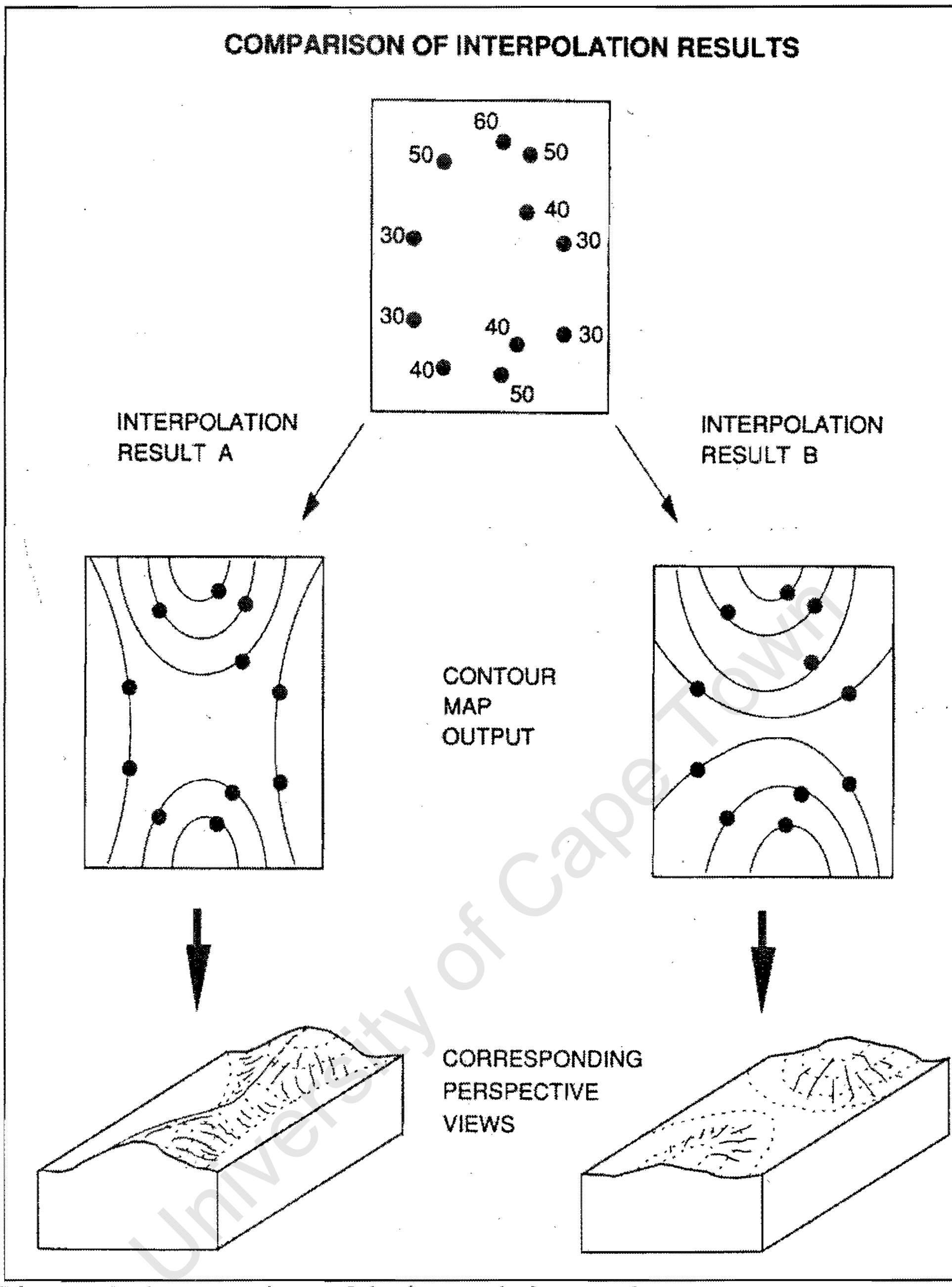


Figure 12. A comparison of the interpolation results.

Source: (Arnoff, 1993c)

Figure 12 shows how a single set of data can produce two different patterns of contours and therefore different terrain models.

4.9.2. Slope Map

The slope of the area was derived from the DTM. The slope was divided into three classes according to Young's slope classification (1976). Flat slopes are regarded as the "best" areas for any type of development as it reduces the construction costs and limits soil erosion.

Table 4. Slope classification

Slope Classification	Degree of steepness (Degrees)	Limitations
Flat to moderately steep	1-10°	No problems for constructional purposes.
Moderately steep to very steep	10-30°	Practical limitations for constructional purposes. The soil erosion hazard is considerable.
Very steep to vertical	30-90°	Not practical for constructional purposes.

4.10. Site Suitability Map

The soil, drainage and slope maps were used to create the site suitability map. A site suitability map shows areas that range from suitable to unsuitable for any type of development. The purpose of the site suitability map for this research is to determine the appropriateness of the study area, Imizamo Yethu Estate for the development of the informal settlement. The site suitability map was used to create the 3D- suitability model to show the advantages of using 3D models for planning.

The procedure involved the following steps:

1. The soil, drainage and slope grids were reclassified according to their suitability. Values were assigned for each environmental factor on a scale of naught to three, with three being the most suitable and naught being totally unsuitable for development.

Table 5.1. Reclassification of soil factors

Soil	Assigned values	Weight
Soil type A	3	1
Soil type B	2	1
Soil type C	1	1

According to Selby (1995) "Soil type" A displays a lower permeability and a higher strength which makes this type of soil more stable than "Soil type B". These attributes make "Soil type A" more suitable for construction. This is the reason why it received an assigned value of three and "Soil type B" an assigned value of two. "Soil type C" received an assigned value of one because it was the least suitable as it was more vulnerable to erosion than the other two types of soil.

Table 5.2. Reclassification of drainage factors

Drainage	Assigned values	Weight
Fair	3	1
Poor	2	1
Very poor	1	1

Table 5.3. Reclassification of slope factors

Slope	Assigned values	Weight
0-10°	3	2
10-30°	1	2
30-75°	0	2

The slope greater than 30° were assigned a value of naught as it is entirely unsuitable for any form of development. The slope between 10°-30° was assigned a value of one instead of two because these slopes contribute to erosion problems.

2. The next step involved assigning weights indicating the relative importance of each factor in determining the suitability of the land for the informal settlement. Since "good" slope was regarded as a more critical factor than "good" soil or drainage, a weighting factor of two was applied to the slope layer.

3. The final step was to compute the sum of the weighted factor scores of each grid cell. The higher scores indicated cells considered more suitable for the development of informal settlements.

The resultant map showed the areas ranging from the most suitable to the least suitable for development. Any area can be deemed unsuitable for development if 60% of the land is classified as undesirable. It is not financially or environmentally feasible to develop these types of areas.

4.11. 3D Visualisation

3D Analyst was used to create the 3D-terrain model of the informal settlement Imizamo Yehtu Estate accompanied with roads and buildings. The slope and site suitability maps were draped over the TIN to create the 3D models. The 2D themes that include the DTM, soil and the site suitability maps were compared to the 3D models to show the effectiveness of using 3D visualisation in planning.

4.11.1. DTM

A Digital elevation model (DEM) is an ordered array of point measurements of elevation distributed over the land surface (Arnoff, 1993b). The grid of points is referenced to a geographic co-ordinate system that defines the horizontal position of the data. A DEM is produced when the elevation data is obtained by measuring the top of objects such as trees and houses. On the other hand, a DTM is created when the elevation is measured from the actual ground surface.

DTMs can be used for the:

1. Storage of elevation data.
2. 3D displays of landforms for landscape planning.
3. Computation of slope and aspect maps.

The DTM of the informal settlement, Imizamo Yethu Estate was used to create the slope map of the area and to create a TIN. A TIN is a vector–based data model that is used to represent terrain data. A TIN represents a terrain surface accurately as a set of interconnected triangular facets. The DTM was converted into a TIN by using the 3D Analyst interface tools. The slope and site suitability maps were draped over the TIN to create the 3D-slope and suitability models.

The DTM of the Imizamo Yethu Estate site was generated with an Adam Topocart stereo plotter at the Department of Geomatics, University of Cape Town. The DTM was imported into ArcView for analyses.

4.11.2. Shack Polygons

The rectified 1997 Imizamo Yethu Estate image was loaded into ArcView. A shapefile containing the polygons of the shacks were created by digitising the outlines of the shacks from the image. The polygon-shack shapefile was added to the 3D scene and was subsequently draped over the TIN surface. The height of the buildings on the TIN surface was determined by using the following formula.

$$Height\ of\ buildings\ on\ TIN = [\,height\ of\ shacks\ (m) * extruded\ heights\,]$$

$height\ of\ shacks$ = 1 meter

$extruded\ height$ = 2 (the extruded height was chosen to be 2 to make the shacks visible in 3D above the TIN surface).

4.11.3. Road Network

The lines representing the road network in the informal settlement were digitised from the 1997 Imizamo Yethu Estate rectified image. The road shapefile was added to the 3D scene and converted to a 3D shapefile. The height information required to convert the 2D-line features into 3D was selected from the TIN. The roads were raised from the TIN surface by two units with the "Offset height" option in ArcView to increase the visibility of the roads on the TIN.

4.11.4. Slope and Suitability Maps

The slope and site suitability maps were draped over the TIN using the interface tools to create the 3D models.

4.12. Environmentally sensitive model

The model was created by addressing the environmental problems currently experienced in the settlement. The new model provides a layout and additional features that takes into account the sensitivities of the environment. Different models provide decision-makers with a set of alternatives enabling them to choose the model that can cause the least environmental degradation. The model was used to investigate the following:

- Layout – The current layout promotes erosion.
- Drainage infrastructure – The drainage problems in the settlement can to some extent be attributed to the lack of drainage infrastructure.
- Microclimatic conditions – The strong winds have caused damage to the buildings in the informal settlement.
- Visual impact of the settlement – The settlement is not an aesthetically pleasing site from the main and mountain roads.
- Aspect – This factor is not a problem but it can be useful to build the shacks in a direction where they can receive maximum sunlight in informal settlements.

These factors will be discussed in greater detail in the Chapter 5, section 5.8.

4.12.1. Use of the Site Suitability Map to create the New Layout

The site suitability map was draped over the TIN to inspect the suitability of the area for development. The unsuitable areas were eliminated from the layout. A grid layout was constructed with each grid containing shacks. The shack polygons were digitised in ArcView. The 2D-shack shapefile was added to the 3D scene and extruded from the TIN to create the 3D buildings. The new layout was on flatter land and therefore could have reduced the erosion problems currently experienced in the informal settlement.

4.12.2 Road Network

Lines representing the road network were digitised throughout the new settlement. The road shapefile was added to the 3D scene and converted to a 3D shapefile. The height information required to convert the 2D-line features to 3D was obtained from the TIN surface. The roads were distinguished from the TIN surface by using the "offset height" option. The roads were raised by one unit from the TIN surface.

4.12.3. Planting Trees

A point coverage was created to specify the locations where the trees would be planted on the TIN. The information that was required to create the trees were the:

- Height of the trees (in meters)
- Height to the first branch (in meters)
- Width of the tree (in centimetres)

The trees were placed on the TIN surface by compiling and running an Avenue script for planting trees (Appendix B). The trees were planted on the TIN to reduce the negative visual impact of the informal settlement. The trees were planted in the front and on both sides of the informal settlement.

4.12.4. 3D Fences

Lines representing a fence shapefile were digitised on the eastern, south-eastern and north-western boundaries of the settlement. The 2D-fence shapefile was added to the 3D scene. The information required to create the fences were a:

- Line coverage
- TIN

The 2D-fence shapefile was converted into 3D fences by compiling and running an Avenue script for creating 3D fences (Appendix C). The fences were used as windbreaks to reduce the effects of the strong winds.

4.12.5. Drainage Infrastructure

Lines representing the drainage infrastructure were digitised. The resultant 2D-drainage shapefile was added to the 3D scene and converted into a 3D shapefile. The drainage network was raised by one unit from the TIN's surface.

4.13. Summary

The procedures used to capture, analyse and present the data in the form of maps and models using ArcView GIS were discussed. Firstly, the fieldwork and the analyses of the soil samples were discussed. The slope data was obtained from the DTM. 2D maps were created from the data by using the software Spatial Analyst, which is an extension of ArcView GIS. The soil and site suitability maps were used to create the 3D models. The environmentally sensitive model was created by looking at a variety of different environmental factors. This model reveals how GIS can be used to develop alternate models, allowing the planners and decision-makers to see the effects of different planning strategies.

Chapter Five
Results and Discussion

5.1. Introduction

The soil, drainage and slope results will be presented and discussed in this chapter. Maps done in ArcView and photographs taken at the site, Imizamo Yethu Estate, will be used to support the results. The soil, drainage and slope factors were investigated to assess the suitability of the area for development. These three factors were used to create the site suitability map for subsequent draping over the TIN to show how 3D models can assist with planning. The environmentally sensitive model presented in this chapter will show how environmental problems can be addressed by using 3D models. The knowledge gained from the literature studied and the results from this research have resulted in the methodology that will be presented. It is envisioned that this methodology can be used as a guide in the site selection process of informal settlements.

5.2. Soil Analysis

The results from the laboratory analysis revealed that all the soil in the settlement consisted of a very high percentage of sand (Appendix D). The sand was classified into 3 groups, medium and fine sand, a mixture of coarse, medium and fine sand and coarse sand. The quantities of clay and silt were so small that it was ignored.

The table below reveals that the 71% of the 38 soil samples taken in the settlement consist of medium and fine-grained sand, while 21% consist of the mixture of all three soil types and 7% consists of coarse sand.

Table 6. The percentages of the soil types in the settlement.

Soil Classification	Percentage
Medium + fine sand	71%
Coarse + medium + fine sand	21%
Coarse sand	7%

5.2.1. Soil Map

The soil map shows the different types of soil in the settlement.

Figure 13. Soil map of Imizamo Yethu Estate.

In the eastern and north-eastern part of the informal settlement, Imizamo Yethu Estate fine and medium-grained sand is the dominant soil type. In the western part of the settlement small areas contains coarse-grain sand, while the south-western part contains a mixture of the three types of soil.

5.3. Drainage Analysis

The data in table 8 shows the drainage conditions in the settlement (Appendix E). The data in table 8 reveal that the drainage conditions in 79% of the settlement are fair while 16% is poor and only 5% are very poor. Fair drainage conditions are dominant in the settlement.

Table 7. Percentages of the type of drainage in the settlement.

Drainage Type	Percentage
Fair	79%
Poor	16%
Very Poor	5%

5.3.1. Drainage Map

The drainage map shows the drainage conditions in the settlement.

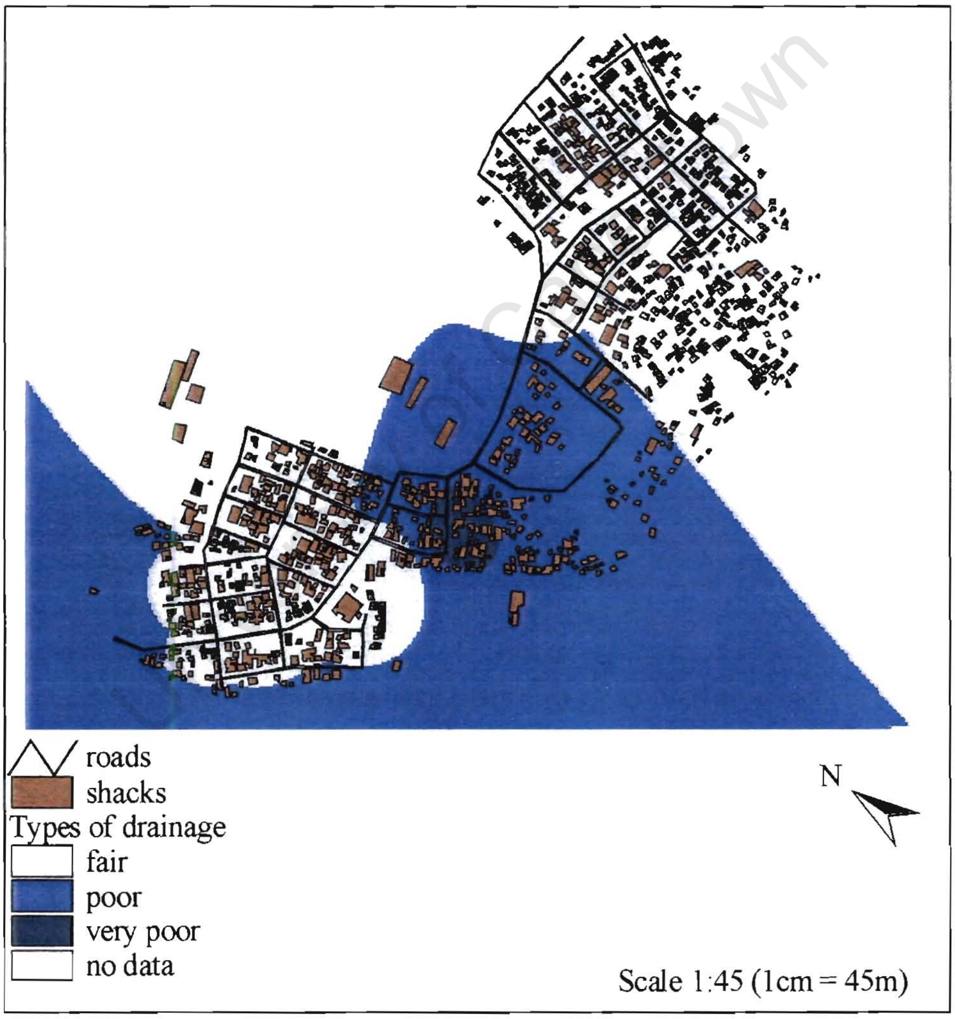


Figure 14. Drainage conditions in the settlement.

The settlement does not experience any serious drainage problems, as fair drainage conditions are dominant. Only a few areas display poor drainage conditions and only one small area exhibits very poor drainage conditions.

5.4. Slope Map

The slope map shows the steepness of the terrain throughout the settlement.

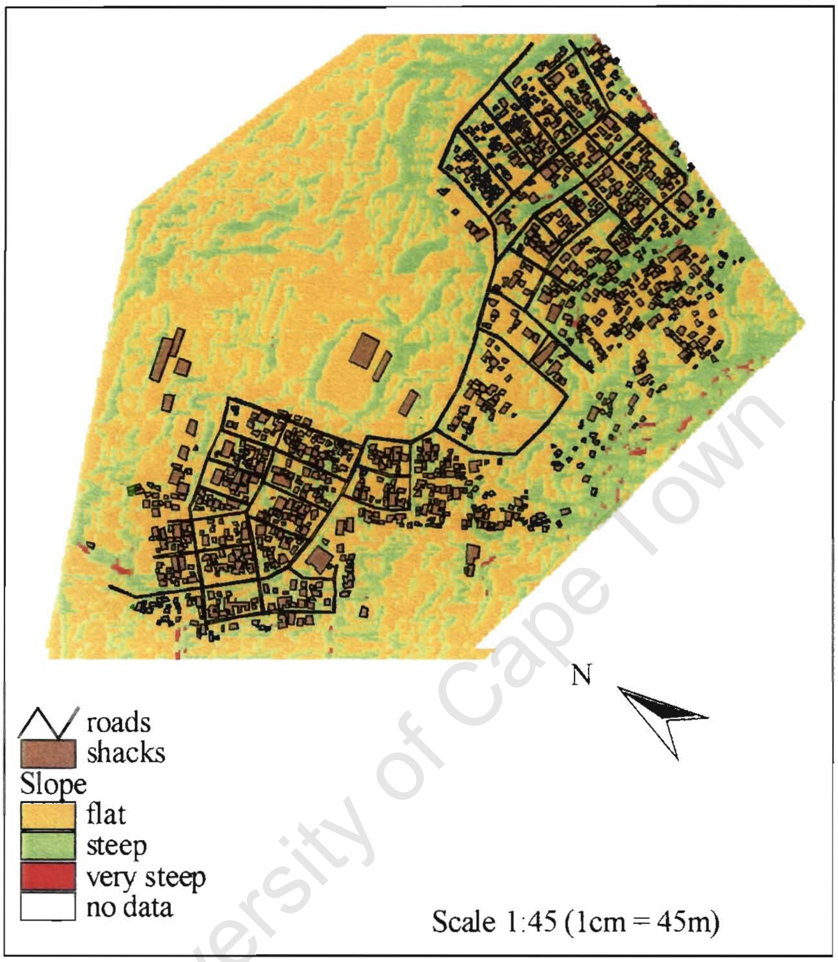


Figure 15. Slope map of Imizamo Yethu Estate.

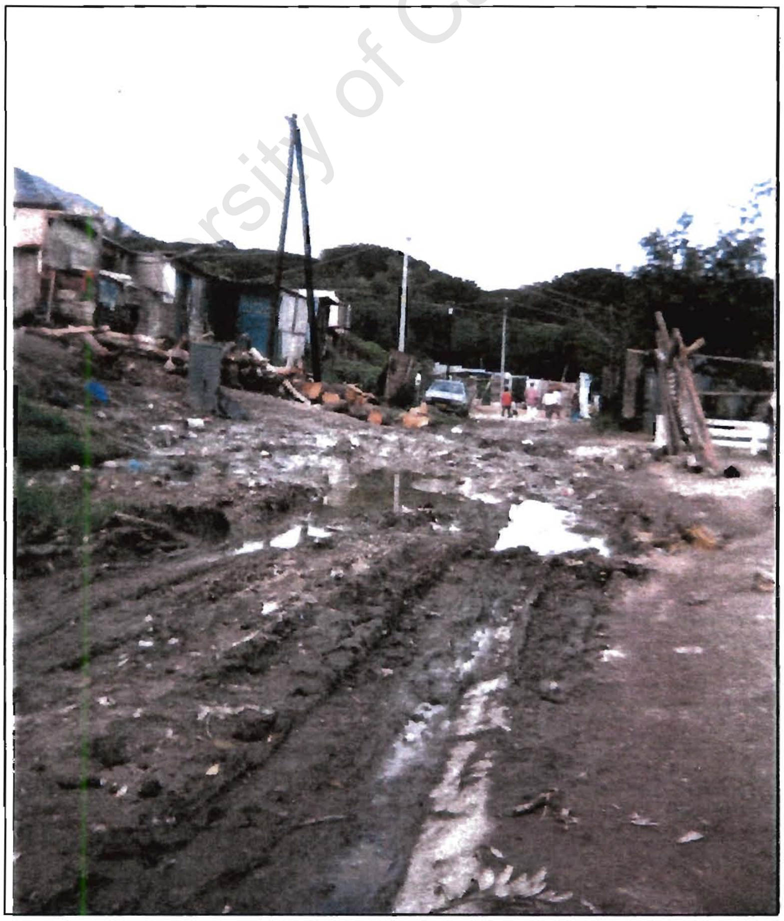
The majority of the site is relatively flat. However, there is a portion of the settlement that has steep and very steep slopes.

5.5. Discussion of Soil, Drainage and Slope Conditions

The drainage conditions of any area are dependent on the soil type and gradient. According to Ellis and Mellor (1995) sandy soils have the tendency to be extremely well drained and aerated. In this type of soil the aggregation is poor, which makes it susceptible to wind and water erosion, particularly if it is dominated by fine sand which contains little organic matter (Gawith, 1996d).

This is the case in the Imizamo Yethu Estate where the soil in the settlement consists of a very high percentage of sand. Selby (1995) states that the behaviour of a soil is dependent on the dominant soil type. In the informal settlement, Imizamo Yethu Estate 99% of the topsoil consists of sand therefore it can be deduced that the site is vulnerable to water and wind erosion. Soils that contain a high percentage of sand drains water easily therefore these areas do not usually display any serious drainage problems. The soil analysis therefore correlates with the drainage study, which shows fair drainage conditions are dominant in the settlement.

The poor and very poor drainage conditions were primarily a result of the steep slopes and to a certain extent, the lack of drainage infrastructure than the soil type in the settlement. Once the infiltration capacity of the soil is reached the excess water and fine-grain material are washed down the steep slopes. The soil material and excess water accumulates at the base of the slopes or washes onto the roads resulting in puddling and waterlogging. The accumulation of sand and water is the main reason why a few of the roads in the settlement are nearly unusable in winter (see Photographs 1 and 2). The bad roads have resulted in taxi drivers charging extra fares to bring residents into the settlement during winter.



Photograph 1. The accumulation of water in a road in winter.

Photograph 2. The same road in summer.

The lack of drainage infrastructure results in drainage problems on the flat as well as steep areas in the informal settlement. The water washes down from the higher lying areas and accumulates around the shacks in the flatter areas. The wet conditions create a difficult living environment for the residents, as the accumulation of water around the shacks is a health risk. The residents in the settlement have resorted to digging canals between their homes to divert the water (see Photograph 3). Grass has been planted and logs placed on the ground to try and minimise erosion and stabilise the soil (see Photograph 4).

Photograph 3. The canals dug by the residents to divert the water away from their homes.

Photograph 4. The grass and logs used to minimise erosion.

Additional drainage infrastructure throughout the settlement can reduce the negative effects of the gradient and compacted soil. The majority of the water will be directed into the canals thereby decreasing the quantity of water that eventually reaches the lower lying areas.

Table 8. Steepness of the terrain versus the costs

Slope angle	Practical limitations
0-10°	The practical limitations for construction are slight and the construction and maintenance costs are low.
10-30°	The practical limitations for both construction and agriculture become considerable. The erosion hazard increase as the slope increases. The building costs for this type of development will be much greater than for flat land.
>30°	Expensive techniques will have to be used to flatten the area and prepare it for development. It is not feasible to choose these sites for informal settlements, as the development of steep areas are not cost effective.

Most of the areas in the settlement today, are flat with slope gradients ranging from 0° to 10°. These gradients can be attributed to the use of cut and fill techniques (Gawith, 1996d). However, there are still areas that have steep slopes that contribute to the drainage and erosion problems in the informal settlement.

5.6. Site Suitability Map

The site suitability map shows the composite map of the reclassified soil, slope and drainage maps. The site suitability map shows the appropriateness of the site for the informal settlement.

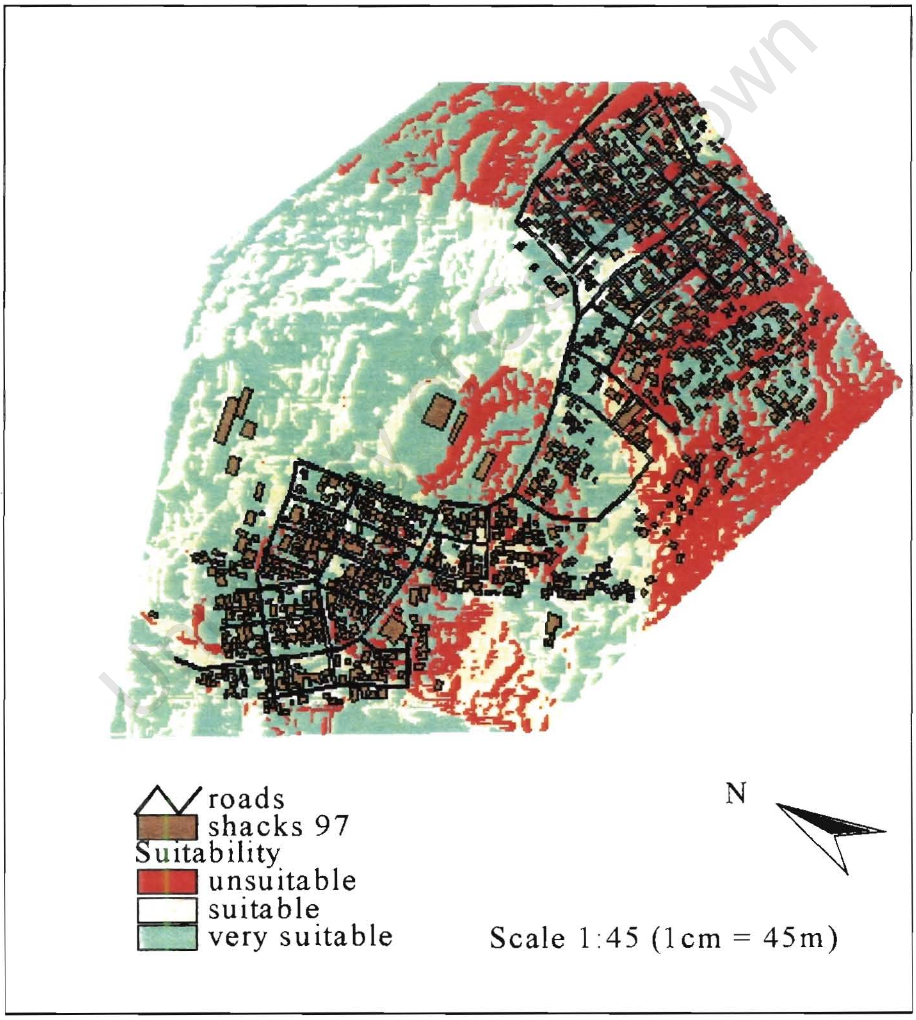


Figure 16. Site suitability map of Imizamo Yethu Estate.

1. The "least suitable areas" appear in the eastern and western part of the settlement. These areas have steep slopes ranging from 30-75°, which contribute to the poor drainage conditions. These areas are not feasible for construction because the land has to be flattened as the steep slopes promote erosion and drainage problems. Developing these types of areas would result in high construction and maintenance costs.

2. The "suitable areas" have a combination of good and poor environmental factors. The good environmental factors outweigh the bad and therefore meet some of the requirements for the construction of low cost housing. "Suitable areas" are therefore not ideal but it could be used for construction by implementing mitigatory measures. Most of the areas have slopes ranging from 10-30° but flat land with slopes ranging from 0-10° is present. The drainage conditions in these areas ranges from poor to fair.

3. The "most suitable areas" appear in the western and south-western side of the settlement. In these areas the land is relatively flat with fair drainage conditions. The most suitable areas consist principally of flat land with fair drainage. These areas would be ideal for the construction of low cost housing because the construction and maintenance costs will not be very high. The flat land will reduce the soil's vulnerability to erosion and reduce the effect of the drainage conditions in winter.

Today, the large portion of the land in Imizamo Yethu Estate is suitable for the informal settlement. However, the important point to remember is that the area was made suitable by cut and fill methods. The construction of informal settlements can only be feasible if the costs involved to develop the areas are kept relatively low.

5.7. 3D Visualisation

5.7.1. Models

The 3D models are presented and the advantages of 3D visualisation are discussed. The reasons for creating the environmentally sensitive model of Imizamo Yethu Estate will be discussed in the following sections. The methodology that was developed as a result from this research and the literature studied will be presented.

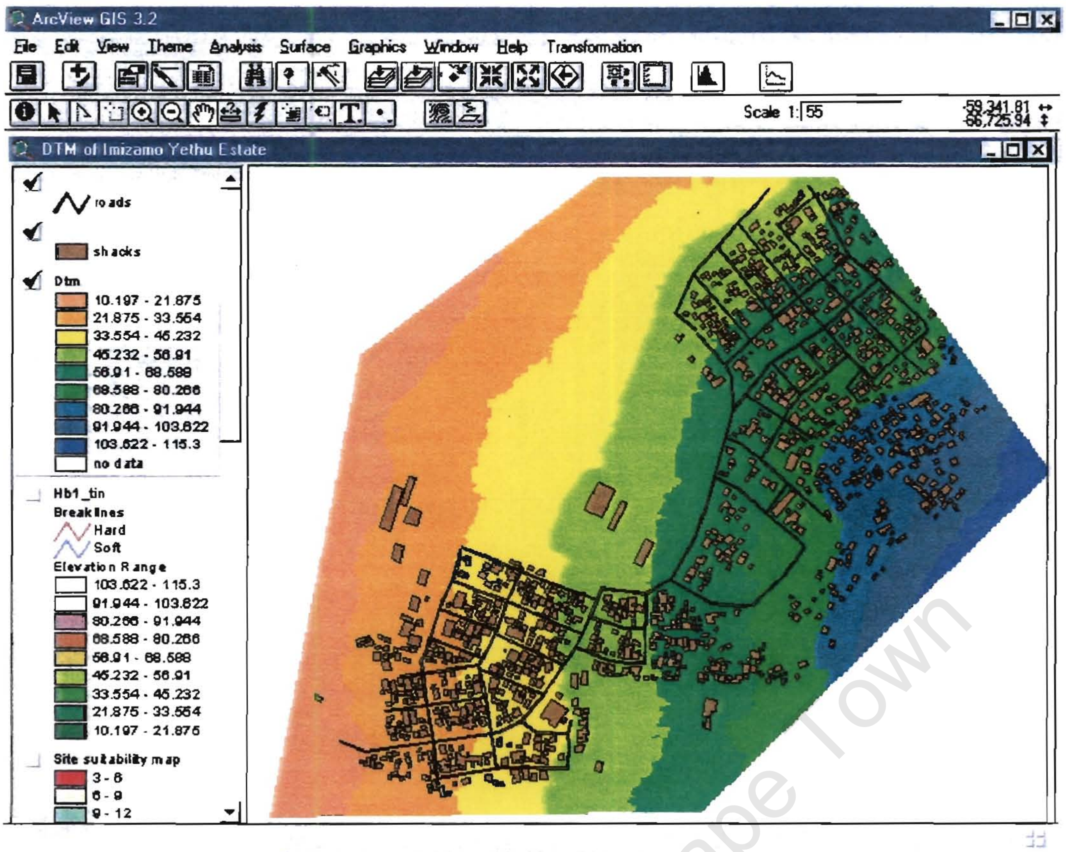


Figure 17a. DTM map of Imizamo Yethu Estate

Figure 17b. TIN of Imizamo Yethu Estate

Figure 17a and 17b shows the DTM in 2D and 3D respectively. The 2D map appears flat, while the TIN gives the viewer an idea of how the terrain appears in reality.

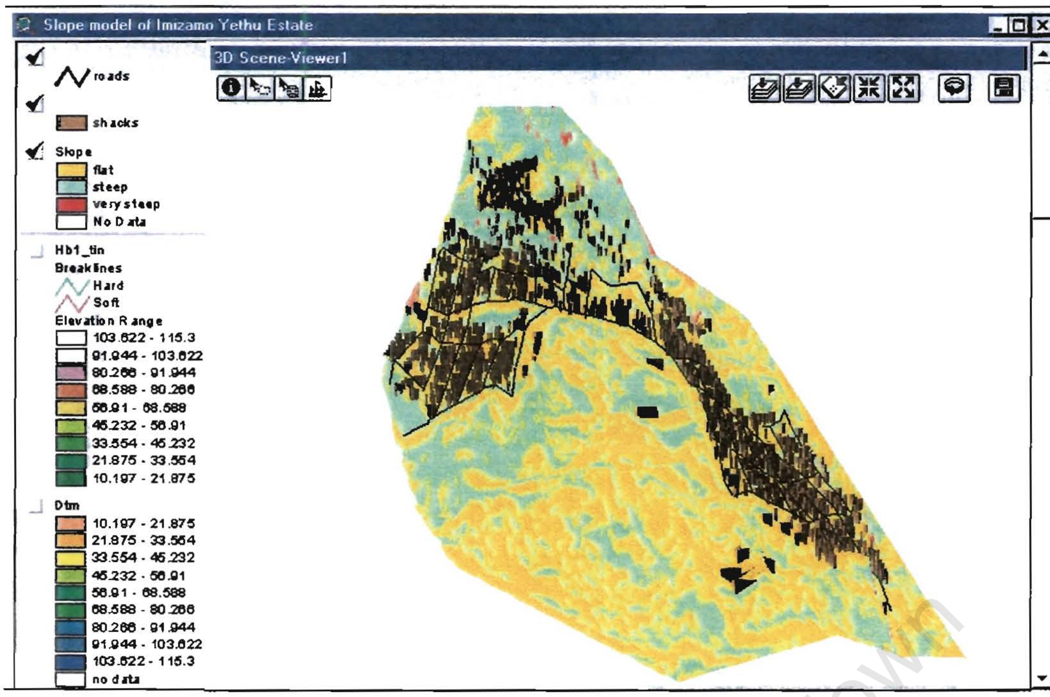


Figure 18. Slope model.

In figure 18 the slope model shows the suitability of the area with respect to the steepness of the terrain. The slope map was draped over the TIN to create the 3D-slope model.

Figure 19. Overhead view of the site suitability model.

Figure 19 shows the site suitability map draped over the TIN. This type of model would have been of great help to the planners, as it would have directed the development away from the unsuitable areas.

2D and 3D models can effectively be used to:

1. Illustrate the landscape before development.
2. Monitor the progress of development.

The advantage of 3D visualisation lies in the way we see and understand the information. According to Swanson (1996) it is estimated that 50% of the brains neurons are involved when viewing 2D displays. It is believed that additional neurons are stimulated through 3D displays thereby involving a larger portion of the brain in the problem solving process. Thus information becomes more meaningful and easier to understand. Hence, decision making becomes straightforward.

2D displays are presented as a flat surface. The mind first has to build a conceptual model of the relief, for example, 2D contour maps, before any analysis can be initiated (see Figure 20a). However, 3D displays stimulate spatial reality allowing the viewer to quickly recognise and understand the spatial context (see Figure 20b). Cities and informal settlements are composed of 3D structures and objects, for example, buildings, terrain and vegetation. 3D models provide physically accurate and informative perspectives of the terrain (see Figures 18 and 19). 2D models suffer a loss of information and consequently are limited in the type of analyses they can perform.

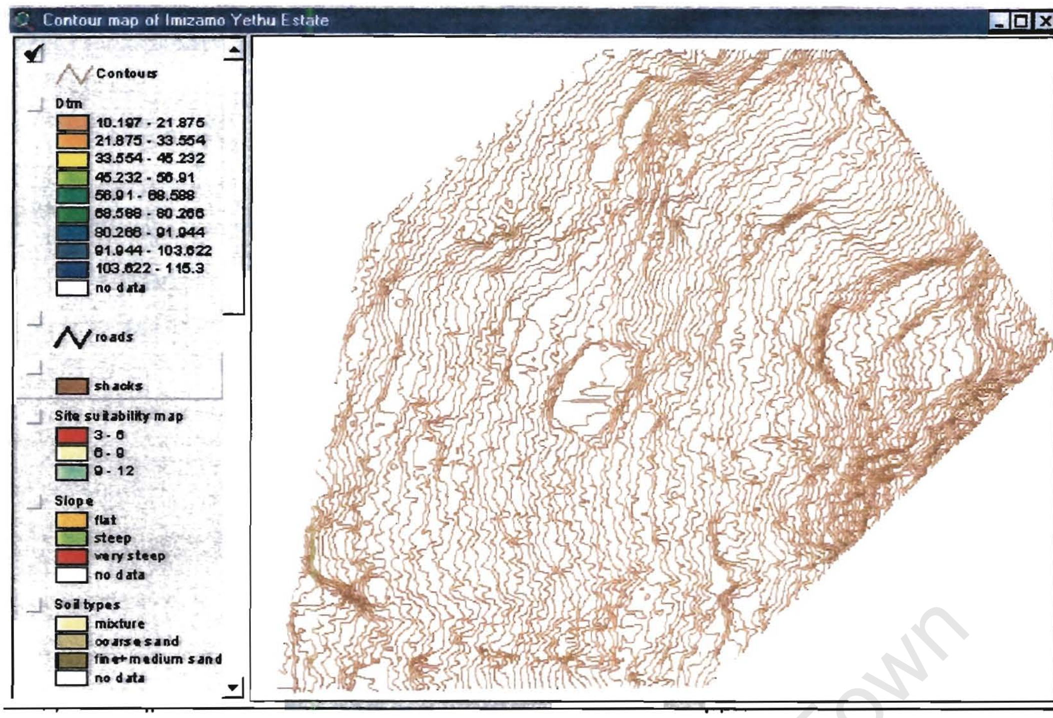


Figure 20a. Contour map.

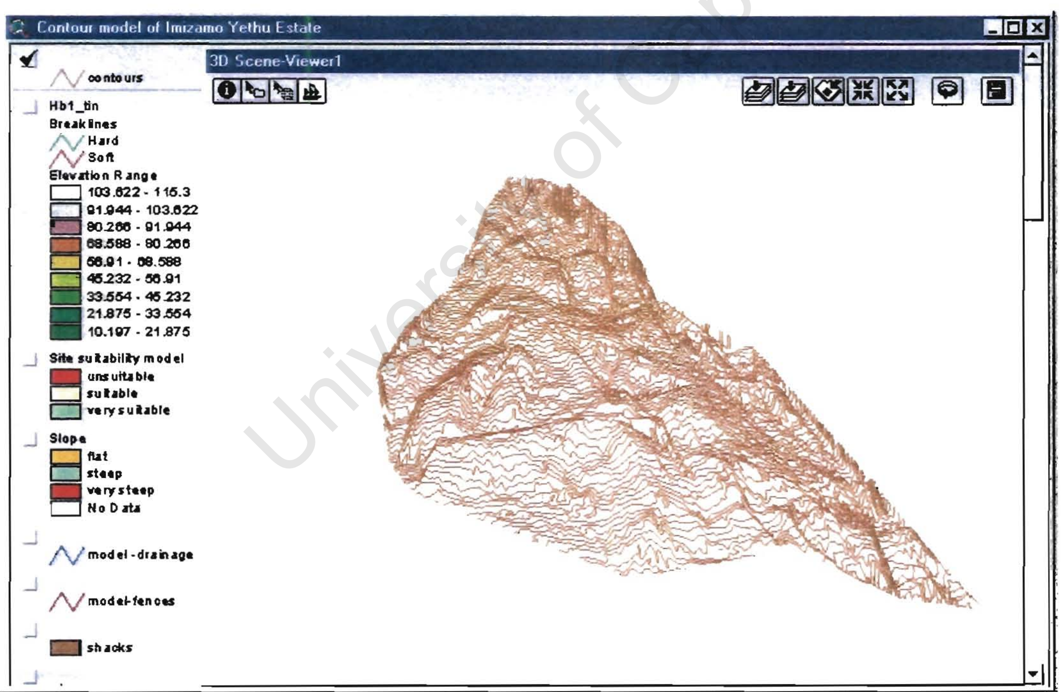


Figure 20b. Contour model.

In figures 18 and 19 the models could have assisted planners during the planning stages of development by revealing which areas in the settlement were unsuitable for development. The model could have resulted in a design, which could have reduced the drainage problems related to the steep slopes.

The 3D model shows that the areas in the east and the south-western parts of Imizamo Yethu Estate are unsuitable for the informal settlement. When comparing the figures 18 and 19 the most unsuitable areas correspond to the steep areas in the settlement. Hence, it can be deduced that the gradient plays a very important role in the suitability of the area. The erosion and drainage problems could have been reduced if the settlement was moved down to the west where the land is flatter. This move would have reduced erosion and with the assistance of additional drainage infrastructure could have improved the drainage conditions in winter when the area experiences heavy rainfall. Alternate scenarios could have been developed to provide the planners and decision-makers with a number of options that could have resulted in informed decision- making.

3D visualisation can prove to be a very persuasive tool in the hand of planners and urban designers as more brain neurons are used, the consequences of development decisions becomes easier to comprehend. 3D visualisation therefore has the potential to promote community participation in informal settlements where a portion of the community is illiterate or semi-illiterate. 3D visualisation can help the community see the impact of planning proposals whether it involves site selection, managing the settlement's relocation to a low-cost housing site or the impact of a road development. This will allow the residents to visualise the future and allows them to draw their own conclusions. This method of communication reduces the need to discuss technical information that the residents do not understand. 3D visualisation can reduce the level of ignorance of the consequences of certain planning proposals and can facilitate informed decision making.

'Driving', 'flying' and 'walking' over or through models are only possible if the data are presented in 3D. 3D scenes can be exported to an exchange format for 3D data called Virtual Reality Modelling Language (VRML). VRML allows the user to create simulations, for example, the progressive erosion of a riverbank. Simulations allow the user to "drive", "fly" and "walk" over a proposed development and allows them to make decisions based on second hand experience. Simulations can therefore be used to demonstrate the effects that a planning decision can have on the physical environment. According to Rowe (1997), depending on the level of hardware and the complexity of the data, the user can move through the data at up to 30 frames per second. 2D map views serve as a sort of navigational device for viewing position locations in models.

5.8. Environmentally sensitive model of Imizamo Yethu Estate

The model was created to demonstrate how the insights gained from the site suitability model and from problems reported from previous research (Gawith, 1996a) can be used to create a model that takes into account the unsuitability of the environment. This model demonstrates the potential of GIS to create models that can address all aspects of the environment and demonstrates how mitigatory action can be planned in advance to minimise environmental degradation and the costs involved to correct mistakes.

The important factors that were considered when creating the model was:

1. The Steepness of the Terrain

Flat land is considered ideal for any type of development but in this instance the flat area available was not feasible. The size of the site would have been reduced dramatically by only including areas that were completely flat. The areas having slopes that ranged between 10-30° were therefore included in the model but only if these areas displayed no significant drainage problems. The areas having very steep slopes were excluded from the layout, as these areas were totally unsuitable (see Figure 21b).

2. Aspect

Aspect information can be used to assist with the layout plans during the planning stages of development. This information can be used to place houses in positions where they will receive maximum sunlight. This is of benefit to the residents in informal settlements without access to electricity. North and west facing slopes receive more solar radiation and can help reduce space heating (see Figure 21b).

3. Surface Runoff

Drainage infrastructure was planned for the entire settlement. The drainage canals were organised in a grid pattern to decrease the accumulation of water in the lower lying areas and around the shacks. The drainage infrastructure was added to the model to decrease the erosion problems in the settlement (see Figure 21c).

4. Microclimatic Conditions

The negative micro-climatic conditions have created a difficult living environment for the residents as the site is exposed to the strong north-westerly and south-easterly winds. The shacks in the settlement are vulnerable to damage caused by the wind as some of the shacks are constructed from plastic and hardwood; both not very stable building materials. According to Gawith (1996d) one particular shack had to be rebuilt twice in a few months as the result of the strong winds. The residents cannot afford to rebuild their homes every few months. It is just too costly.

The micro-climatic conditions of the site and the effect it would have on the residents had to be investigated at the planning stages of the development. Mitigatory action could have been planned during this stage. Windbreaks in the form of fences were added to the model. These were placed along the eastern, south-eastern and north-western boundaries thereby protecting the settlement and reducing the effects of the strong south-easterly and north-westerly winds. Windbreaks are one of the solutions that could have been used to minimise the negative effects of the strong winds (see Figure 21c).

5. Visual Impact

The informal settlement Imizamo Yethu Estate is not an aesthetically pleasing sight from the main road. Trees were added to the model not only to enhance the natural environment but also to reduce the visual impact of the settlement (see Figure 21d).

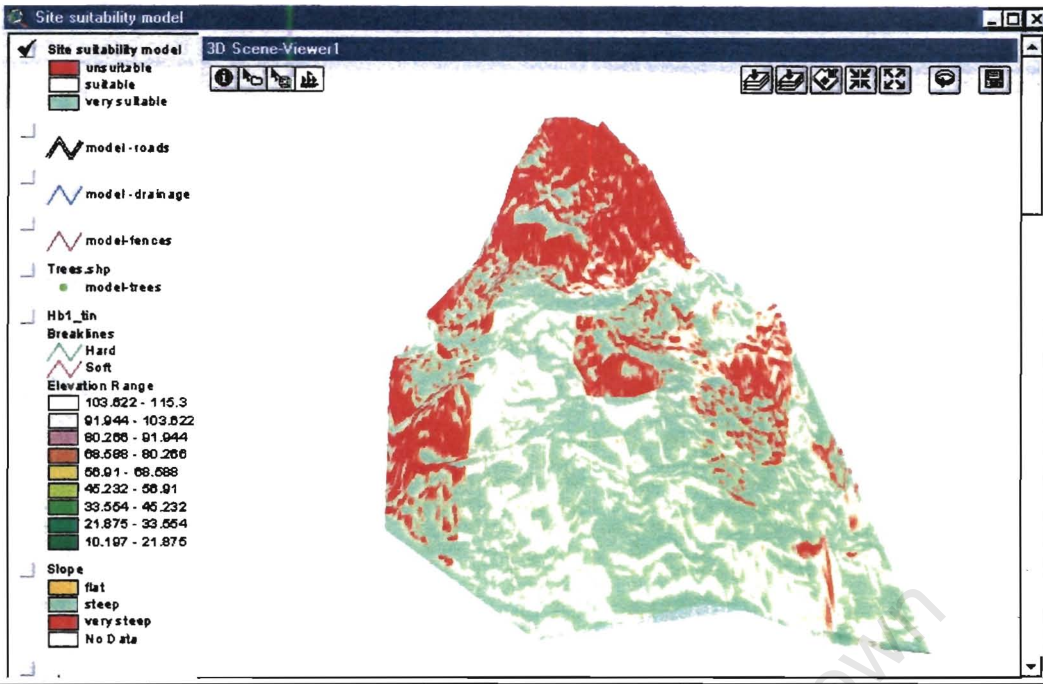


Figure 21a. The area before development.

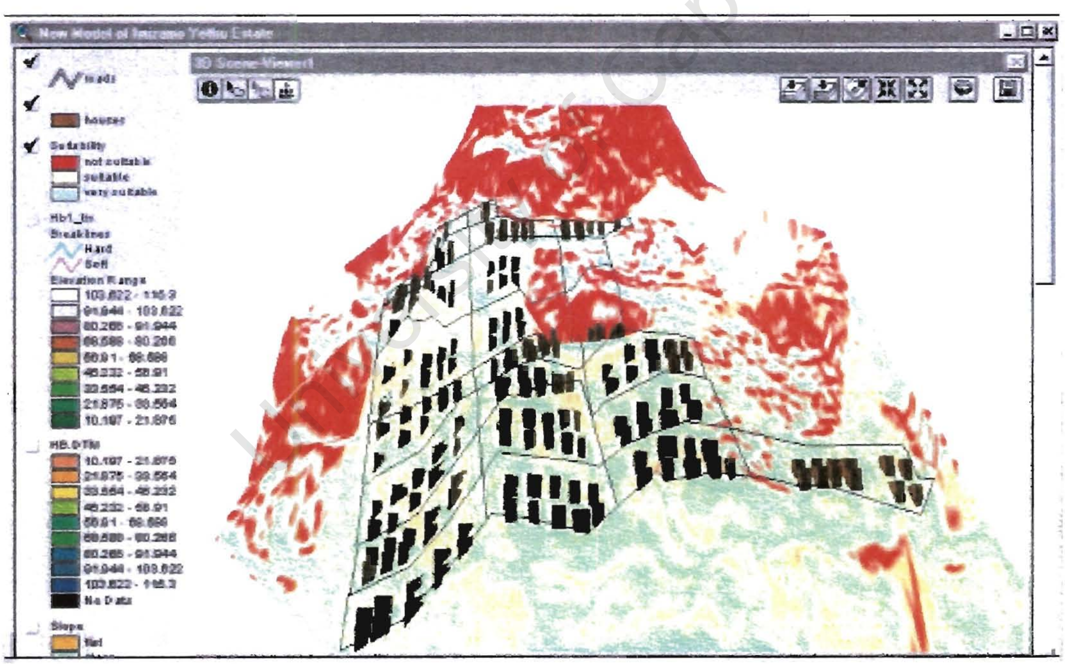


Figure 21b. New layout with the houses and road network.

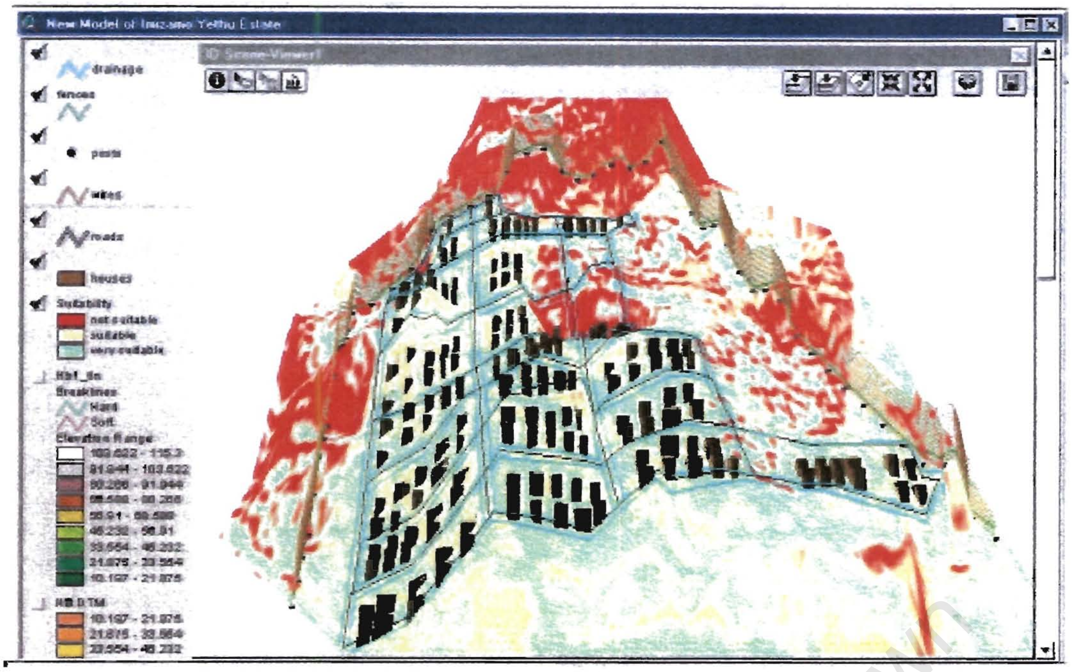


Figure 21c. The drainage infrastructure and the 3D fences added to the model.

Figure 21d. Completed environmental-sensitive model containing the houses, roads, drainage infrastructure, fences and trees.

Figure 21 show models of the settlement if it was moved further to the west. Most of the effects of the steep slopes are avoided because the settlement is on flatter land. The model shows the trees, which enhance the environment. The windbreaks were placed to block the strong south-easterly and north-westerly winds. The houses were built facing towards the west to obtain the maximum sunlight. Providing different models gives the decision-makers a number of options from which to choose the best possible model. The model that the planners and decision-makers decide to use should address all the relevant environmental factors pertaining to the site as it can effect the sustainability of the environment and the quality of the residents lives.

5.9. A Methodology for Planners

The insights gained from the environmental study, the 2D maps and 3D models as well as the environmental problems reported from a previous study (Gawith, 1996a) have contributed to the development of the following methodology. It is envisioned that this methodology can assist planners in the planning process of informal settlements in the future (see Figure 22).

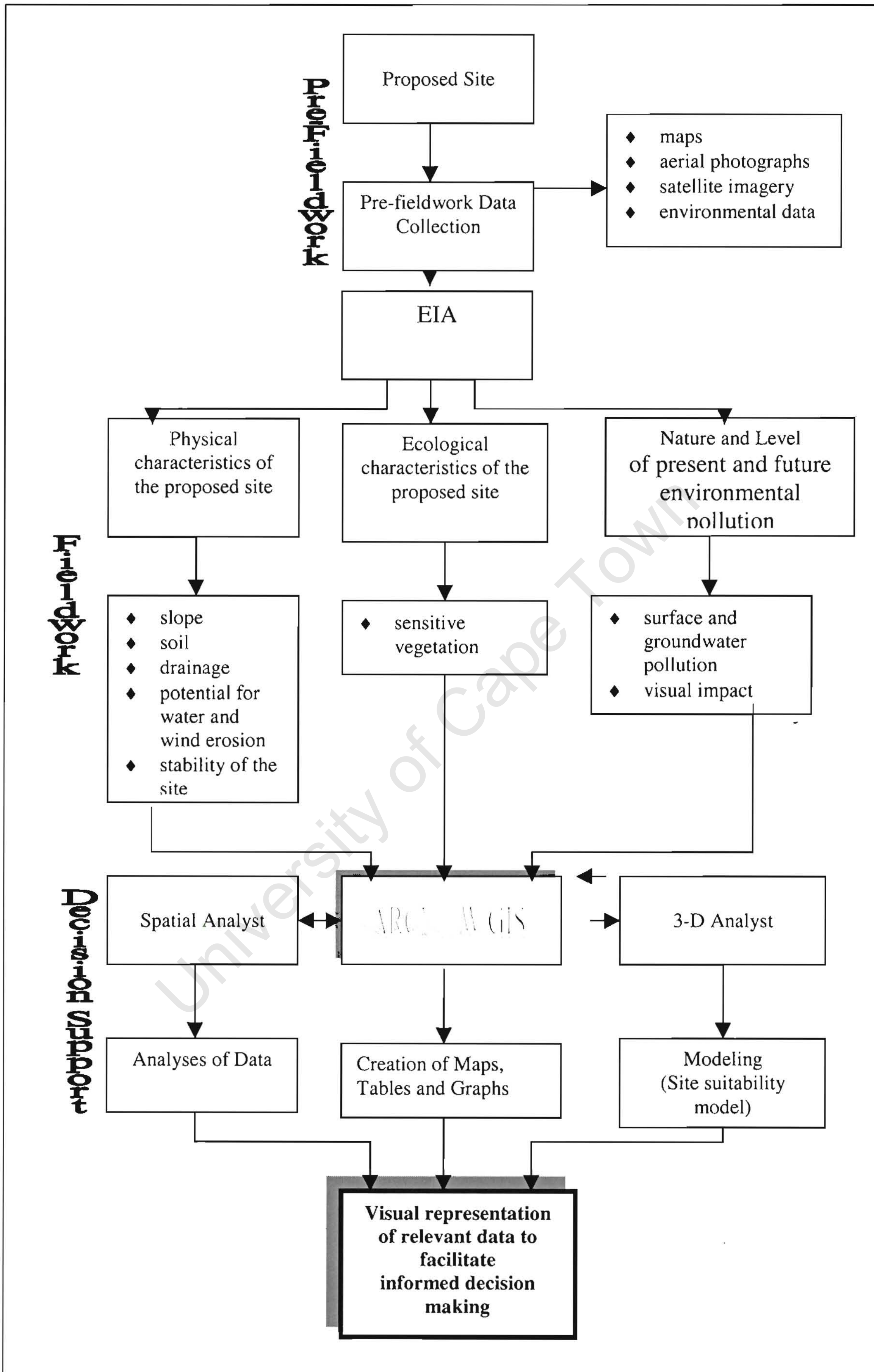


Figure 22. Methodology that can be used by planners to assist in the planning process of informal settlements.

The methodology developed below can be divide into three distinct stages,

- Pre-fieldwork
- Fieldwork
- Decision support

The methodology can be applied once a possible site for the development of an informal settlement has been located. The first stage consists of the desk-based collection process. All the relevant data (maps, photographs, satellite imagery and reports of environmental studies) can be used to provide the baseline information for the area. This information can assist with planning, the initial strategy for fieldwork. It should be noted that the strategy could be altered in the field to accommodate for unexpected environmental phenomena.

The second stage involves the field-based data collection and laboratory analyses of soil and water samples if necessary. It is imperative to investigate if the proposed development can have a significant impact on the physical environment. Furthermore, it should be investigated if the environmental characteristics of the site could place significant constraints on the proposed development. The environmental factors named in the methodology can be changed depending on which factors are regarded as being relevant for the particular area.

The third and final stage of the proposed methodology involves the use of ArcView GIS to capture, analyse, visualise and store the data. The software ArcView GIS was used for this methodology because it is relatively inexpensive, accessible and easy to use as it is icon-based. However, any other software that has the same basic functions as ArcView GIS can be used. The data from the environmental assessment can be captured in ArcView GIS. Spatial Analyst can be used for the analyses of the data and to generate surfaces. Spatial Analyst include a set of spatial interpolation functions that allow the generation of surfaces by using point data, for example, GPS points can be used to interpolate an elevation surface. Consequently, a slope map can be derived from the elevation surface. Spatial Analyst allow the user to ask questions that can span multiple data types, for example, which areas in the proposed settlement have slopes $>10^0$, "good" drainage and soil, and contain no endangered plant species? Spatial Analyst can provide the users with the support they need to make informed decisions. 3D Analyst can be used to create 3D models. The site suitability model can assist with the site selection process and the planning of the layout of the site. The site suitability model can be used to show the appropriateness of the area for the development of the informal settlement. Based on the model it can be decided if it will be feasible to develop the area or to reject the site and investigate alternative locations. Alternate layouts and predictive models can be created to highlight problems that may occur as a result of certain planning decisions. Mitigatory measures can therefore be planned in advance. 3D models can facilitate informed decision-making as the visual representation of the data makes the information more significant and easier to understand. The advantages of 3D visualisation are discussed in Chapter 5 section 5.7. The visual representation of the data can therefore be presented in the form of graphs, tables, maps and 3D models providing the planners, managers and decision-makers with all the relevant data to assist with planning and public participation.

5.10. Summary

The results have revealed that GIS can be used to communicate information in the form of tables, maps and models. The soil, drainage, slope and site suitability maps and models can be used to assist in the planning process for site selection of informal settlements. The site suitability model can be used as a guide to either encourage development or eliminate sites that are not suitable for the development of informal settlements. GIS can be used to create alternate models where different environmental factors can be investigated allowing planners and decision-makers to review all there options before making decisions that ultimately effect not only, the quality of the residents lives but the sustainability of the physical environment. 3D models can be used in addition to 2D maps; tables and graphs to provide all the relevant data to facilitate informed decision-making.

Chapter Six
Conclusion

6.1. Introduction

The thesis will be concluded in this chapter. The main points of the thesis will be summarised and the importance of planning will be discussed in the following sections. The usefulness of using GIS for planning in the informal settlement, Imizamo Yethu Estate will be discussed. Lastly, a few recommendations will be provided.

6.2. Summary of the main points to come from this thesis

1. The study of the surface soils in the settlement revealed that the area consisted of a high percentage of sand. This result was consistent with the fair drainage conditions found in the majority of the settlement.

2. The site suitability map and the 3D models created from the soil, drainage and slope data revealed, that the gradient played a greater role in the drainage and erosion problems in the settlement than the soil type (see Figure 15 and 16). The areas in the east and the south-western part of the settlement were classified as unsuitable for low-cost housing as a result of the steep slopes. In Chapter 5, section 5.5., a detailed discussion on the soil, slope and drainage conditions in the settlement are given.

3. 3D visualisation can be of great use in assessing the impact of any development proposal and thus assist in planning, as it provides the following,

a. 3D models provide a realistic image of the terrain compared to a 2D display, which appear as a flat surface. In Chapter 5, section 5.7.1., the advantages of 3D visualisation in planning are discussed.

b. Decision-making becomes easier as the data becomes more meaningful. A greater number of brain neurons are activated when viewing 3D images thereby involving a larger portion of the brain in the problem solving process (Swanson, 1996).

4. 2D and 3D visualisation can be used to:

a. Show pre and post development situations (see Figures 21a, b, c and d).

b. Show the suitability of the area for development either in 2D or in 3D. During the planning stages of any development the layout of the settlement can be created from the site suitability map or model to produce a site which has taken into account the appropriateness of the environment.

c. Develop alternate models that provide decision-makers with a number of different options, which can assist with decision-making.

5. The construction and maintenance costs to develop the Imizamo Yethu Estate site were high because of the environmental constraints of the site. Informed decision-making at the planning stages of development could have revealed the limited developmental potential of the site. It is important that planners and decision-makers obtain all the relevant data and understand the consequences of their decisions.

6.3. The Importance of Planning

An important objective of planning should be to choose a site that is suitable for the type of development. In the case where the site is totally unsuitable an alternative site should be investigated. The residents of informal settlements do not have the financial resources to pay for expensive solutions to the environmental problems. In the case of Imizamo Yethu Estate during the planning phase no geo-technical survey was undertaken. This oversight resulted in drainage problems, soil erosion and high maintenance costs. These problems highlight the importance of carrying out an environmental assessment during the planning phases of any development. The environmental assessment can assist in choosing a site that is appropriate for a particular type of development. Mitigatory action can be planned in advance therefore eliminating the need for corrective work as the problems arise.

6.4. GIS and 3D Visualisation

The mapping functionality and the analytical capabilities of ArcView GIS and it's application to real world problems was demonstrated in this thesis. Spatial Analyst, an extension of ArcView GIS, was used to create the soil, drainage and slope maps, which were employed to create the site suitability map and model. The site suitability map formed the basis of the research as it was used not only to assess the suitability of the area for development but also to create an alternate model, namely the environmentally sensitive model. The site suitability model of Imizamo Yethu Estate revealed that a significant portion of the land on which the informal settlement is situated was unsuitable for low cost housing. The main reason was the steep slopes. The site suitability model could have revealed the limited developmental potential of the site during the planning stages of the development or directed construction away from environmentally sensitive areas. The environmentally sensitive model of Imizamo Yethu Estate demonstrated how ArcView GIS could be used to plan the layout of informal settlements taking into account the sensitivities of the environment. Environmental factors such as aspect, drainage, roads, slope as well as the visual impact of the settlement can be planned in advance to enhance the physical environment. The construction and maintenance costs of any informal settlement site should be kept relatively low in order to make the development of low cost housing feasible. In the case of Imizamo Yethu Estate an alternative site could have decreased the construction and maintenance costs and, if not possible, mitigatory measures could have been implemented to reduce maintenance costs in the long run.

ArcView GIS has the tools to assist with the planning of informal settlements as it can be used to capture, analyse, query, visualise and present data, which can assist with decision making. Spatial Analyst and 3D Analyst, both extensions of ArcView GIS have demonstrated the analytical and visualisation power of GIS for the interpolation of surfaces through querying data across multiple data layers and the visualisation of data in 2D and 3D. Based on the problems encountered in Imizamo Yethu Estate it can be concluded that land has to be allocated on the basis of suitability rather than availability. Incorrect development decisions can have direct economic (construction and maintenance costs) and physical (soil erosion and quality of residents' lives) repercussions as was highlighted in the informal settlement, Imizamo Yethu Estate.

6.5. Concluding Remarks

The aims of the thesis as mentioned in Chapter 1, section 1.3., have been met. The thesis has demonstrated how GIS can be used to create 2D maps and 3D models to assist in planning and help facilitate informed decision-making. A methodology was created that is envisioned to assist planners with the site selection process of informal settlements. GIS and especially 3D visualisation have the potential to promote public participation, as the information is in a visual format, which improves human understanding. GIS technology is a feasible tool that can be employed as a guide for the sustainable planning of informal settlements.

6.6. Recommendations

1. The housing shortage in South Africa has resulted in the government attempting to alleviate the problem by providing land for informal settlement development. However, informal settlements should be located in stable environments as the residents live in rudimentary shelters with only the basic services, which make them vulnerable to the hostile characteristics of the environment. It is therefore imperative to develop environmental planning guidelines to assist in the identification of sites for the development of informal settlements. There were no clear guidelines to assist with the site selection during the site identification and planning stages of Imizamo Yethu Estate. GIS and visualisation technology cannot provide the guidelines to assist with site selections but it can provide the additional tools and support to assist with planning and decision-making.

2. Environmental impact assessments (EIA) should be made compulsory for any type of development in order to protect the environment and to ensure a good quality of live for the residents. GIS can be used to capture the data assembled from the EIA and to create maps and models that can improve planning.

3. The 3D images of Imizamo Yethu created with 3D Analyst can be imported to VRML to create simulations that increase the interactivity between computer and human. Simulations and animations add realism to a scene. Simulations allow users to "drive", "walk" and "fly" over a proposed development.

4. The feasibility of the methodology created, for the site selection of informal settlements should be tested in the field.

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Appendices

Appendix A

This Appendix contains the WGS84 and Gauss Conform co-ordinates. These points were used for the rectification of the 1997 mosaic image of Imizamo Yethu Estate.

XForm for Windows version 3.1
Source Datum: WGS84
Source Co-ordinate System: Geographical Source Height Type:
Ellipsoidal Transformation Parameters:
DX: 139.422 DY: 114.702 DZ: 300.909
RX: 0.0000 RY: 0.0000 RZ: 0.0000 DK: 0.0000000
Target Datum: Cape (South African)
Target Co-ordinate System: Gauss Conform (Central meridian: 19 degrees)
Target Height Type: Orthometric

SOURCE CO-ORDINATES

Name	Latitude	Longitude	Height
M1	-34 1 34.8845	18 21 40.7496	81.508
M2	-34 1 33.1810	18 21 41.6311	79.289
M3	-34 1 31.5788	18 21 43.3946	77.832
M4	-34 1 29.9274	18 21 44.8195	73.894
M5	-34 1 30.1324	18 21 48.1400	87.699
M6	-34 1 32.9754	18 21 46.7378	87.598
M7	-34 1 34.8510	18 21 45.2167	91.279
M8	-34 1 36.4424	18 21 43.1790	91.003
M9	-34 1 35.8148	18 21 46.2621	98.185
mio	-34 1 34.3553	18 21 48.3670	95.449
Mil	-34 1 33.9777	18 21 50.0817	99.641
M12	-34 1 35.1220	18 21 52.6280	108.638
M13	-34 1 36.1260	18 21 50.5620	105.635
M14	-34 1 37.3002	18 21 48.2353	106.630
M15	-34 1 36.7595	18 21 47.4490	102.754
M16	-34 1 38.6394	18 21 45.3943	101.009
M17	-34 1 39.1278	18 21 43.5549	96.392
M18	-34 1 40.1782	18 21 45.2366	100.590
M19	-34 1 41.7230	18 21 47.1540	109.192
M20	-34 1 40.4863	18 21 47.0517	112.813
M21	-34 1 39.3451	18 21 48.3398	114.899
M22	-34 1 37.9457	18 21 50.7170	117.804
M23	-34 1 38.6354	18 21 52.5976	122.645
M24	-34 1 39.9953	18 21 51.2350	123.940
M25	-34 1 40.7957	18 21 52.6401	126.636
M26	-34 1 42.5860	18 21 50.2411	123.357
M27	-34 1 43.1165	18 21 48.0714	113.185
M28	-34 1 45.1569	18 21 46.5378	108.055
M29	-34 1 47.0443	18 21 46.1786	107.824
M30	-34 1 47.2658	18 21 44.5378	101.757
M31	-34 1 43.8267	18 21 41.6825	94.586
M32	-34 1 41.8884	18 21 43.1555	96.818
M33	-34 1 45.3896	18 21 38.5847	85.473
M34	-34 1 46.5206	18 21 36.2967	78-541
M35	-34 1 46.6608	18 21 38.7223	85.157
M36	-34 1 47.9684	18 21 33.2547	68.537
M37	-34 1 45.3821	18 21 33.8356	71.485
M38	-34 1 43.9156	18 21 34.1771	71.953

TARGET CO-ORDINATES

Name	y	x	Height
ml	58923.834	3766468.857	50.986
M2	58901.546	3766416.226	48.768
M3	58856.611	3766366.576	47.311
M4	58820.371	3766315.464	43.374
M5	58735.142	3766321.250	57.179
M6	58770.571	3766409.075	57.078
M7	58809.236	3766467.110	60.758
M8	58861.208	3766516.471	60.481
M9	58782.231	3766496.641	67.664
mio	58728.508	3766451.333	64.929
Mil	58684.591	3766439.425	69.121
M12	58619.046	3766474.279	78.118
M13	58671.857	3766505.544	75.115
M14	58731.324	3766542.095	76.109
M15	58751.600	3766525.560	72.233
M16	58803.953	3766583.813	70.487
M17	58851.049	3766599.156	65.870
M18	58807.704	3766631.253	70.068
M19	58758.217	3766678.546	78.670
M20	58761.079	3766640.457	82.291
M21	58728.252	3766605.088	84.378
M22	58667.533	3766561.589	87.284
M23	58619.154	3766582.541	92.125
M24	58653.851	3766624.660	93.419
M25	58617.651	3766649.099	96.115
M26	58678.854	3766704.646	92.836
M27	58734.415	3766721.338	82.663
M28	58773.367	3766784.453	77.533
M29	58782.220	3766842.666	77.301
M30	58824.271	3766849.753	71.234
M31	58898.182	3766744.241	64.063
M32	58860.765	3766684.281	66.296
M33	58977.354	3766792.895	54.949
M34	59035.833	3766828.111	48.017
M35	58973.579	3766832.042	54.633
M36	59113.594	3766873.209	38.012
M37	59099.190	3766793.425	40.960
M38	59090.712	3766748.183	41.429

SOURCE CO-ORDINATES

Name	Latitude	Longitude	Height
M12A	-34 1 35.1103	18 21 52.6443	111.136
M25A	-34 1 40.7896	18 21 52.6518	126.658
M28A	-34 1 45.1564	18 21 46.5121	108.311
M29A	-34 1 47.0535	18 21 46.2106	111.332
M31A	-34 1 43.8557	18 21 41.6897	94.643
M39	-34 1 50.0878	18 21 28.9851	55.857
M40	-34 1 51.1704	18 21 30.9761	63.175
M41	-34 1 50.6670	IS 21 33.7865	71.115
M42	-34 1 49.9910	18 21 35.5533	75.938
M43	-34 1 49.1289	18 21 31.4356	63.158
M44	-34 1 48.6244	18 21 29.1536	58.359
M45	-34 1 46.7335	18 21 29.9179	60.928

Appendix B

This Appendix contains the Avenue script for the generation of 3D-fences. The fences were used as windbreaks for the environmental-sensitive model to demonstrate how mitagatory action can be planned in advance.

Generation of 3D Fences

```
Name: 3Dfence.ave
Author:  Timothy J Fox
Date:  Nov 3, 98

 Description:  generates a 3d fence from a polyline.  Allows the user to

 select: fence height, post interval and number of wires/boards. The script
 is run from the 3D Scene document.  The script adds two themes to a 3D
scene,
 a post theme (pointZ) and a wire theme (polylineZ).  The post theme can
then
 be extruded to the desired height by setting its 3D Properties (under the
 theme menu in the 3D Scene document.


 Requires:  An active 3D Scene, and a view containing both a polyline theme
and a TIN.


' Get the Viewer & setup lists '
''''''''''''''''''''''''''''''''
theViewer = av.getActivedoc
theViewList = {}
theThmList = {}
theSThmList = {}
thePostList = {}
theLabels = {"Fence Height ","Post Interval (use the same X,Y units as
view)","number of wires (boards)",}
theDefaults = {"4","25","3"}
idField = field.make ("ID",#FIELD_SHORT, 5, 0)
theCount = 0
'''''''''''''''
' choose View '
'''''''''''''''
docList = av.getProject.GetDocs
if (docList.count = 0 ) then
msgbox.info ("You must have a View document" + nl + "in the project.",
"Quitting")
  return nil
end
for each theDoc in docList
  If (theDoc.getGUI = "View") then
     theViewList.add (theDoc)
  end
end
theView = msgbox.list (theViewList, "Select view that contains the" + nl +
"needed themes (a Polyline and TIN)", "Select View")
If (theView = nil) then
  return nil
end
```

```
''''''''''''''''''''''''''''''''''''''''''''''
' Check for Polyline & tin, set their lists '
''''''''''''''''''''''''''''''''''''''''''''''
theTempList = theView.getThemes
for each thm in theTempList
  If (thm.getClass.getClassName = "FTheme") then
    theFtab = thm.getFtab
    If (theFtab.getShapeClass.getClassName = "Polyline") then
      theThmList.add (thm)
    end
  end
end

if (theThmList.count = 0 ) then
  msgbox.info ("You must have a polyline theme" + nl + "in the
sceene.","Quitting")
  return nil
end
for each thm in theTempList
  If (thm.getClass.getClassName = "STheme") then
      theSThmList.add (thm)
  end
end
if (theSThmList.count = 0 ) then
  msgbox.info ("You must have a TIN in the sceene.","Quitting")
  return nil
end
''''''''''''''''''''''''''
' Select polyline & TIN '
''''''''''''''''''''''''''
theTheme = msgbox.list (theThmList,"Select a Fence Line", "Select
Polyline")
If (theTheme = nil) then
  return nil
end
theSTheme = msgbox.list (theSThmList,"Select Surface to Dig Post Holes",
"Select Surface")
If (theSTheme = nil) then
  return nil
end
theFTab = theTheme.getFTab
theShape = theFTab.FindField ("Shape")
theTotal = theFTab.GetNumRecords
theSurface = theStheme.getSurface
''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Get fence info, set vars (makes life easier for me) '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''
fenceInfo = MsgBox.MultiInput ("Fill in all of the fields:", "Fence Info",
thelabels, thedefaults)
If (fenceInfo.count < 3) then
  msgbox.info ("You Need to provide values of all fields.","Quitting")
  return nil
end
FHieght = fenceInfo.Get (0).asNumber
FInterval = fenceInfo.Get (1).asNumber
FWires = fenceInfo.Get (2).asNumber.truncate
If (FWires < 0) then
  FWires = 0
end
theWSpace = FHieght / (FWires + 1)
''''''''''''''''''''''''
```

```
' Post locations x,y,z '
''''''''''''''''''''''''
thePostFN = fileName.getTmpDir.makeTmp ("post","shp")
PostFTab = FTab.makeNew (thePostFN, PointZ)
postShape = postFTab.findField ("Shape")
PostFTab.SetEditable(true)
PostFTab.AddFields({idField})
theID = postFTab.findField ("ID")
for each rec in theFTab
  thePostlist = theFTab.returnValue(theShape,rec).ReturnDensified
(FInterval).asMultipoint.asList
  theTotal = thePostList.count
  for each pnt in thePostList
    thePointZ = pointZ.make (pnt.getX,pnt.getY,theSurface.elevation (pnt))
    theRec = postFTab.AddRecord
    PostFTab.setValue (PostShape,theRec,thePointZ)
    PostFTab.setValue (theID,theRec,0)
    av.SetStatus((theCount / theTotal) * 100)
    theCount = theCount + 1
  end
end
PostFTab.SetEditable(false)
thePostTheme = FTheme.Make (PostFTab)
theViewer.getDisplay.getScene.addTheme (thePostTheme)
'''''''''''''''
' check wires '
'''''''''''''''
if (FWires = 0) then
  return nil
end
'''''''''''''
' the wires '
'''''''''''''
theWireFN = fileName.getTmpDir.makeTmp ("wire","shp")
wireFTab = FTab.makeNew (theWireFN,polyLineZ)
wireShape = wireFTab.findField ("Shape")
wireFTab.SetEditable(true)
wireFTab.AddFields({idField})
theID = wireFTab.findField ("ID")
if (wireFTab.IsEditable) then
  for each rec in theFTab
    theline = theFTab.returnValue(theShape,rec)
    for each w in 1..FWires
        theLineZ = theSurface.interpolateZ(theline).Zoffset (theWSpace * w)
        theRec = wireFTab.AddRecord
        wireFTab.setValue (wireShape,theRec,theLineZ)
        wireFTab.setValue (theID,theRec,0)
    end
    av.SetStatus((theCount / theTotal) * 100)
    theCount = theCount + 1
  end
end
wireFTab.SetEditable(false)
theWireTheme = FTheme.Make (WireFTab)
theViewer.getDisplay.getScene.addTheme (theWireTheme)
msgbox.info ("Set the extrusion property of the 'Post'" + nl + "theme to
the desired height (3D Properties)", "Done")
return nil
```

Appendix C

This Appendix contains the Avenue script that was used to generate the trees for the environmental-sensitive model.

Tree Generation

```
'Avenue Script tree.generate by Christopher Legg
'EU Forest Inventory and Monitoring Project
'Jakarta Indonesia 28th May 1998

'This script generates three-dimensional representations of
'trees and displays them on a three-dimensional surface
' The script is based on the ESRI Tree Planting sample script
'The script requires two active documents in a 3-d view
'the first document is a point file of tree locations, with
'data on tree height("Ht"), height to first branch("Hfl"), and diameter
'("Dia") of the tree. Heigths in meters and diameter in centimetres.
'The second active document is a grid of surface elevations.

'The click property of the button generates a tree-shaped
'cursor. Clicking this cursor in the 3-D view initiates the
'tree-generation process.

'Limitations in terms of number of trees per 3-D view are not
'yet known. The script performs well with about 150 trees, but
'crashed after six hours when attempting about 2000 trees.
'For large data sets, a single tree species, or a group of species,
'should be selected prior to generating 3-D trees.

'As currently set up, the script generates four morphologic/colour
'classes of trees, based on their classification as "future trees"
'or "mature/emergent trees" using height/diameter and height/height 1st
branch
'ratios. These classifications could be easily changed as required

'Find the active themes and required fields (no error checking yet)

theViewer = av.GetActiveDoc
theTheme = theViewer.GetActiveThemes.Get(0)
gridTheme = theViewer.GetActiveThemes.Get(1)
gridsur = gridTheme.GetGrid
theFtab = theTheme.GetFtab
theField = theftab.FindField("Shape")
heightField = theFtab.FindField("Ht")
branchField = theFtab.FindField("Hfl")
diamfield = theFtab.FindField("Dia")
xtree = 0
ytree = 0
ztree = 0
```

```
'Loop through the database of selected trees

for each rec in theFtab
  location2 = theFTab.ReturnValue(theField, rec) 'get x,y position of tree
  treeHeight = theFtab.ReturnValue(heightField, rec)
  hfbranch = theFtab.ReturnValue(branchField, rec)
  diam = theFtab.ReturnValue(diamfield, rec)
  xtree = location2.GetX
  ytree = location2.GetY
  ztree = gridsur.PointValue(location2, prj.MakeNull) 'get Z value for tree
from surface grid
  location = pointZ.Make(xtree, ytree, ztree)'Make a 3-D point for base of
tree
 '    Create tree graphic

  Thick = (treeHeight/8)'Set drawing width for trunk. This is in "Points",
but could be related to Dia

 If (treeHeight > diam) then '"future tree" class 1
  crown = 5
  branchInt = 0.4
  RedVal = 0
  BlueVal = 0
  BrSlope = 7
  LeafSize = 7
 ElseIf (hfBranch < (treeHeight / 2)) then  'future tree class 2
  crown = 5
  branchInt = 0.4
  RedVal = 0
  BlueVal = 100
  BrSlope = 7
  LeafSize = 7
 ElseIf (hfBranch > (treeHeight / 2)) then  'Mature/emergent class 1
  crown = 3
  branchInt = 0.5
  RedVal = 100
  BlueVal = 0
  BrSlope = 10
  LeafSize = 10
Else                'mature/emergent class 2
  crown = 3
  branchInt = 0.5
  RedVal = 0
  BlueVal = 0
  BrSlope = 10
  LeafSize = 10
end
  '
  'set parameters for generating 3-D representation

  span = treeHeight/(crown)

  bottom = location.Clone
  top    = location.Clone.ZOffset(treeHeight)

  minX = bottom.getx - span
```

```
  maxX = bottom.getx + span
  minY = bottom.gety - span
  maxY = bottom.gety + span
  minZ = top.getz - (treeHeight - hfbranch)
  maxZ = top.getz + (treeHeight/10)
  centerX = location.getx
  centerY = location.gety

  brownColor = Color.Make
  brownColor.SetRgbList({151,96,4})

  gra = theViewer.GetDisplay.GetScene.GetGraphics
  tree = GraphicGroup.Make

  '
  '     Make thick brown trunk
  '
  trunk = LineZ.Make(location, top)
  treeTrunk = GraphicShape.Make(trunk)

  treeTrunk.GetSymbol.SetColor(brownColor)
  treeTrunk.GetSymbol.SetWidth(Thick)
  tree.Add(treeTrunk)

  '
  '     Make random green leaves and brown branches
  '
  for each i in 1..(treeHeight) by (branchInt)
    leaf = PointZ.Make(Number.MakeRandom(minX,maxX),
                       Number.MakeRandom(minY,maxY),
                       Number.MakeRandom(minZ,maxZ))
    treeLeaf = GraphicShape.Make(leaf)
    aColor = Color.Make
    aColor.SetRgbList({(RedVal),Number.MakeRandom(100,255),(BlueVal)})

    treeLeaf.GetSymbol.SetColor(aColor)
    treeLeaf.GetSymbol.SetSize(LeafSize)
    tree.Add(treeLeaf)

    centerZ = leaf.getz - (treeHeight/(BrSlope))
    branchStart = PointZ.Make(centerX,centerY,centerZ)

    branch = LineZ.Make(branchStart, leaf)
    treeBranch = GraphicShape.Make(branch)
    treeBranch.GetSymbol.SetColor(brownColor)
    treeBranch.GetSymbol.SetWidth(1)
    tree.Add(treeBranch)
  end

  gra.AddBatch(tree)
  gra.EndBatch
end
```

Appendix D

This Appendix contains the results of the soil analysis. The soil samples were taken in the field and analysed by using the Dry sieving method. The soil samples contained a high percentage of sand.

Shape	X_co_ord	Y_co_ord	Grid_id	Soil_type
point	-58892	-66929	A	coarse sand
point	-58850	-66486	B	mixture
point	-58866	-66405	C	fine+medium sand
point	-58811	-66429	D	mixture
point	-58838	-66367	E	fine+medium sand
point	-58806	-66353	F	fine+medium sand
point	-58743	-66424	G	mixture
point	-58772	-66450	H	fine+medium sand
point	-58817	-66480	I	mixture
point	-58715	-66450	J	fine+medium sand
point	-58689	-66500	K	fine+medium sand
point	-58785	-66504	L	mixture
point	-58800	-66548	M	mixture
point	-58612	-66504	N	fine+medium sand
point	-58702	-66537	O	fine+medium sand
point	-58726	-66518	P	fine+medium sand
point	-58813	-66615	Q	fine+medium sand
point	-58730	-66375	R	mixture
point	-58609	-66528	S	fine+medium sand
point	-58745	-66710	T	fine+medium sand
point	-58871	-66759	U	coarse sand
point	-58937	-66797	V	coarse sand
point	-58956	-66822	W	fine+medium sand
point	-59014	-66842	X	fine+medium sand
point	-59045	-66779	Y	fine+medium sand
point	-59035	-66803	Z	fine+medium sand
point	-59117	-66744	Aa	mixture
point	-59094	-66885	Ab	fine+medium sand
point	-59121	-66744	Ac	coarse sand
point	-59122	-66786	Ad	fine+medium sand
point	-59183	-66827	Ae	fine+medium sand
point	-59176	-66863	Af	coarse sand
point	-59173	-66888	Ag	coarse sand
point	-59202	-66825	Ah	mixture
point	-59223	-66908	Ai	coarse sand
point	-59233	-66944	Aj	fine+medium sand
point	-59166	-66961	Ak	coarse sand
point	-59097	-66567	Al	coarse sand

Appendix E

This Appendix contains the drainage data collected during the fieldwork done in Imizamo Yethu Estate.

Shape	X_co_ord	Y_co_ord	Grid_id	Drainage_conditions	Percentage
point	-58892	-66929	A	poor	35
point	-58850	-66486	B	fair	50
point	-58866	-66405	C	fair	50
point	-58811	-66429	D	fair	50
point	-58838	-66367	E	fair	50
point	-58806	-66353	F	poor	35
point	-58743	-66424	G	fair	50
point	-58772	-66450	H	fair	50
point	-58817	-66480	I	fair	50
point	-58715	-66450	J	fair	50
point	-58689	-66500	K	fair	50
point	-58785	-66504	L	fair	50
point	-58800	-66548	M	fair	50
point	-58612	-66504	N	fair	50
point	-58702	-66537	O	poor	35
point	-58726	-66518	P	fair	50
point	-58813	-66615	Q	poor	35
point	-58730	-66375	R	fair	50
point	-58609	-66528	S	fair	50
point	-58745	-66710	T	poor	35
point	-58871	-66759	U	poor	35
point	-58937	-66797	V	very poor	20
point	-58956	-66822	W	very poor	20
point	-59014	-66842	X	fair	50
point	-59045	-66779	Y	poor	35
point	-59035	-66803	Z	poor	35
point	-59117	-66744	Aa	fair	50
point	-59094	-66885	Ab	poor	35
point	-59121	-66744	Ac	fair	50
point	-59122	-86786	Ad	fair	50
point	-59183	-66827	Ae	fair	50
point	-59176	-66863	Af	fair	50
point	-59173	-66888	Ag	fair	50
point	-59202	-66825	Ah	poor	35
point	-59223	-66908	Ai	poor	35
point	-59233	-66944	Aj	poor	35
point	-59166	-66961	Ak	poor	35
point	-59097	-66567	Al	poor	35