LAND SUITABILITY ASSESSMENT FOR HOUSING & LOCAL ROAD CONSTRUCTION

A case study in Naivasha town ship, Kenya.

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Land suitability assessment for housing and local road construction

By

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Abstract

The main goal of the study was to analysis the some land characteristics of the study area and to understand the limitation for housing and local road construction.

This target was achieved by analysing soil engineering properties and site conditions influenced for selected six engineering uses of housing & local roads construction and producing limitation Maps.

These analyses were carried out by using geopedological map (produced through a semi-detailed soil survey), soil engineering test data (both field &laboratory), limitation rating guides & expert judgements and GIS (ILWIS)
.
The resulting Maps of analyses (weighted & unweighted approaches) are qualitative limitation maps showing that alternative locations for housing and roads constructions.

The information provides by this study can be used as a guideline for preliminary site planning for small and medium scale residential development.

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1 Introduction

1.1 Background and problem statement

Urban areas are continuously expanded to serve the needs of growing populations and to improve their living standards. Planned settlement can be defined as habitable living environment for the people. It provides comfortable dwelling unit: dwelling conditions, efficient infrastructure, social-wellbeing, and improve living standards & quality of life for inhabitants in the area. Unfortunately, the reality is often quite different. Haphazard and uncontrolled settlement expansion is the rule. In rapid urbanisation the direct implication of the growth is often more and more dwellings, lands and urban services & facilities are inadequate. As a results of this uncontrolled and therefore unpredictable demand, issues like shortage of housing, insufficient infrastructure and services, unplanned physical development illegal settlements are common in most of the urban centres (Kevin and Hack, 1985).

Especially in developing countries planning of housing and road locations are mainly evaluated based on factors such as socio-economic, political, land use policies and related infrastructure conditions. Most of the occasions soil information are illed considered. Therefore unexpected problems are frequently encountered during the implementation, which are coarsen additional cost and construction failures.

To adequately address these problems, all major factors that influence the process of urban settlement development must be thoroughly analysed and understood.

The process of urban settlement expansion is distinctly influenced the soils and related site conditions.

One major problem that uncontrolled urban settlement expansion leads to the irreversible loss of prime agricultural land often quite unnecessarily.

All this is caused by the fact that (a) specific requirement of the various urban settlement related land uses are insufficiently considered, and that (b) no systematic evaluation procedure is followed to match the various land requirements with soil properties & site and characteristics of the various land units.

Lake Naivasha area has recently become an economic boom area as a consequence of development of flower production, horticulture production, tourism, geo thermal power production and other human activities. There is a continuous increase in population around Lake Naivasha (Becht, 2000).

Over the years the land utilisation types within the town is being changed. (Bemigisha, 1998). The population growth rate was 3.5% and average annual agricultural land per person has been reduced from 1.48 ha. to 0.68 ha between 1979 to 1993 (LNROA, 1993). The effects of this growth rate reflects that the urbanisation trend, speed and expansion of the urban area towards the non-urban locations.

As a result of haphazard development of settlement, a number of problems such as unplanned settlements development in inappropriate locations, loss of irreversible agricultural lands due to expanding urban activities towards good agricultural lands & papyrus swamp, reduction of amount of water and water quality of the lake, & land degradation due to removal of vegetation, incompatible land uses and are distinguished within the area. For example, permanent houses are being built up in drainage valleys, which is causing severe storm water drainage problems and flooding during the rainy season. (Becht, 2000). This way of settlement development will not only increases the cost of construction and maintenance of infrastructure in the area but also greatly affects the environment (see section 6.2.2 for details).

Therefore, by considering the physical problem prevailing in the area, the research intends to look at *problems relating to housing and local roads construction in terms of soils and site conditions.*

1.2 Research objectives

The main aim of this study is to evaluate the site suitability for the construction of housing & local roads in term of soil and site characteristics in the area.

To achieve this goal the following objectives are formulated.

1. To analyse existing settlement patterns in the study area and underlying factors.
2. To outline major physical and construction problems of settlement relating to poor soil and site conditions.
3. To identify specific settlement related land utilisation types (dwelling without basement, septic tank absorption fields, shallow excavations, local roads and streets, soils as sources of road fills and possible sources of gravel and sand.) and their specific requirements in terms of soil and site conditions.
4. To established a set of assessment criteria to evaluate land suitability for land use types as indicated above.
5. To map engineering soil attributes & site characteristics in the area related to housing and local road construction which would be useful for initial settlement planning.
6. To produce alternative development scenarios for housing area and road location selection based on soils and site characteristics.

1.3 Research questions

In order to achieve the research objective, the following questions have to be answered.

1. What are the problems related to settlement development in terms of soil & site conditions of the area?
2. What soil properties and site conditions are to be considered in determining the soil & site limitations for housing and local road constructions?
3. What methods, techniques and tools are to be used for the acquisition of required data?
4. What techniques and tools are to be used to evaluate the soil and site limitations for housing and local road constructions?
5. Which criteria use in determining the limitations for selected land use types?
6. What methods, techniques and tools are to be used to conduct a land evaluation for selected land uses?
7. What development scenarios can be proposed for housing area and road corridor selection?

1.4 Hypothesis

Adverse soil and site conditions provide important physical limitations that need to be considered in adequate housing and local road planning. However contribution of other factors such as socio-economic factors, political, land use policies, and social and economic infrastructure determine to a large extent the decision making on the selection of settlement areas and road corridors.

1.5 Research approach.

Generally, soil information is transferred to the land users through land evaluation or soil interpretation. FAO framework for land evaluation often used to evaluate land for agricultural purposes while USDA soil survey interpretation approach is used for non-agricultural applications. Because of that, in this research USDA approach is used for the evaluation of land for housing and local road construction.

For this research soil and site information gathered mainly from soil survey, field measurements/observations, laboratory soil engineering analyses, image interpretations (aerial photos and TM images), interview with officials of relevant organisations and residents in the area, and available literature.

Using the Geographic Information System (GIS), the soil information are used for limitation analyses for housing & road construction and residential development in the town. Six limitation maps are produced for each selected engineering use related to housing and road construction and those maps are in turn used in the development of alternative scenarios for housing and road development. The limitation map for residential development are produced by crossing the resulted maps together with existing and proposed land used map of the area to identify and locate the areas where the limitation for housing and road constriction are exist. The Integrated Land and Water Information System (ILWIS) soft were package enhances the capability of automated soil information interpretation, map crossing, overlaying and developing alternative scenarios.

2 Literature review

2.1 Key factors to be considered in settlement planning

There are many factors have to be considered in adequate settlement planning (Table 2.1). Among the factors that have to be considered in the urban physical planning, soil & site conditions of the area is one of the important factors. Soil characteristics in the area are a vital factor in decision making for housing and road reservation in urban planning activities. Soil characteristics in the area need to be analysed and evaluated to determine the site suitability (for this development) in terms of drainage and erosion characteristics, cost of soil improvement, infrastructure & building types and nature and type of vegetation that can be sustained. "*Soil information can be use as a checklist in the development of a site or as a framework for preliminary investigations of sites and site planning*" (Caminos and Goethert, 1978).

Table 2.1. Key factors to be considered in settlement planning

Location (physical) suitability, stability and constrains	Infrastructure –availability, adequacy, quality and consistency	Socio-economic factors
Land availability Soil suitability for constructions (roadways, foundations & sewerage). Environmental conditions (natural hazards such as flooding, landslides, erosion etc.) Topography	Distance from city centre and employment. Accessibility and transport facilities Water supply, power, and communication Schools, administrative services, shopping & market places and recreational facilities.	Affordability to pay for housing and services Land values, land ownership, and development costs. Residential density, ethnic group, religious and socio-economic classes Political and commercial factors Housing development policy Existing & proposed development projects

2.2 Relationship between soil properties and settlement planning

2.2.1 Importance of soil information in settlement planning

Soil information provides some of the background information as required for site investigation for development. Soil data can interpret to assess the suitability of the land for road construction. Land available for urban expansion is severely limited, it is important that sites are carefully located.

In most of the developed countries as well as developing countries use of soil information in planning is well established. In the USA, soil information has been used as the physical basis for planning of land urban expansion. *"Soil survey are a source of data about the physical characteristics of land and when suitability interpreted can be of considerable value in both planning and locating site for development"* (Hartnup & Jarvis, 1979).

Many urban areas in the world are being expanded into areas that are less suitable. Problems like encroachment of buildings onto prime agriculture lands may occur as a result of rapid urbanisation. Careful interpretation of soil map can ensure that urban activities are located in suitable place.

According to Hartnup & Jarvis, 1979, *"there is a need for more effective planning procedure for containing urban development, and in locating it in areas least harmful to agriculture and forestry. The soil map is the best single tool for identifying such areas".*

Onthe basis of soil survry information, predictions can be made the range of problems that can be encountered when constructions of houses and related infrastructure on a particular site. Unsuitable soil conditions can create problems in terms of structural failures of buildings, corrosion of pipes, septic tanks failures and cracking & potholing of roads laid on poorly suitable soil (Davidson, 1992).

Results of the soil survey plays an important role in proposed new urban areas in identifying special design, which is necessary to address the specific problems.
The soil survey for urban needs provides very clear cost advantages. A cost-benefit analysis of a soil survey for urban needs done by Klingebie (l966) in the USA estimated as 1 to 100 (Davidson, 1992). Background in encouraging first urban soil survey programme in Virginia were the mistakes made in selection schools and other buildings where extra cost were incurred due to ignorance of soil condition.

According to Bartelli (1992), detailed soil maps can be used to predict some constructional difficulties. He describes which engineering properties can be deduced from soil characteristics as well as how soil survey can assist to locate fill materials for foundation of building or roads. And also he emphases the necessity of detailed site and laboratory investigations (Davidson, 1992).

2.2.2 Application of soil information

Interpretation of soil information for both agricultural and non-agricultural uses is included in the recent publications by United States Department of Agriculture (USDA). These reports include engineering test data, description and interpretation of soil, their suitability as a source of top soil, features that effects their suitability for highway location and cut condition, embankment & building foundations, infiltration systems, dikes & levees, ponds, agricultural drainage, irrigation and waterways. Most of the characteristics important for agriculture can be used for other applications as well. Surface stoniness, slop, depth to bedrock, particle size distribution, flooding and depth to water table are some of them.

2.3 Some of the engineering uses

Urban development involving light structures: Urban development planning involves different kinds of land uses and should be taken in to account the various types of natural constrains on siting. Reservation of areas liable to natural hazards and sources of construction materials such as sand, clay and road gravel is a basic requirement in urban planning.

Dwelling without basement: Soil properties influence the selection of building site significantly. Dwellings without basement are considered as single family houses of three stories or less. The foundation of this type of buildings assumed to be built at a depth of 60cm. Areas containing the best stable soils for housing construction should be zoned for placing of heavier structures, which more expensive foundations are justified on worse soils. Soil conditions affecting these requirements are expansion and shrinkage of active soil during wetting and drying out (Ohamobi, 1993).

Septic tank absorption fields: Septic tank absorption fields are subsurface tile systems or perforated pipe that distribute effluent from a septic tank into the natural soil (Soil Survey Staff, 1999). The importance of using soil survey information for selecting site for septic tank absorption field have been recognised in the develop world. Practicability in the use of soil data in the planning and site selection for these uses have been discussed by (Bouma, 1974 And Olson, 1964). The safe disposal of liquid wastes is one of the major prerequisites for protecting public health and environment. Inadequate facilities to dispose the wastes will results in damaging the public health and environment. In this context, data on soil condition is required for the selection of appropriate site for septic tank absorption fields.

Foundations: The cost component for the foundation of civil engineering construction has major influence to overall cost of the construction. The selection of appropriate and economical foundation type is always based on the geotechnical properties of the ground. The soil properties to be acquired through an exploration of subsoil. the depth of exploration is according to the load that carry the foundation. Some of the soil properties used for engineering applications are USDA texture, Unified classification, AASTHO classification, atterberg limit, shrink-swell potential, permeability, and California bearing ratio (CBR).

Earthworks: Earthworks include construction of earth cuts and fills for highway and railway lines, roads and air fields, canals and stream diversion, or any other projects in which soil is at once the foundation and construction materials. The cut and fill materials must be well compacted. Soil conditions that affecting these requirements is the shear strength of the exposed faces. Low shear strength presents severe problems in clayey soils if they are highly fissured. Road corridors must be located avoiding unstable slopes or areas where rock is present at shallow depth and fill height & cut depth should reduced when route passes through unstable slops.

Local roads and streets: The road structure has four layers. They are surface, base, sub base and sub-grade. The surfacing of the street or road should be strengthen & durable and waterproof to protect the lower layers structured by prevent the entry of water. The base may consist of natural gravel or crushed rock materials. The sub-grade is compressed fill materials not contain active clay or have low shear strength. Soil conditions affecting these requirements are active clay and highly sensitive or compressible soils.

2.4 Some of the soil properties used to rate the soils for engineering uses.

USDA texture: This refers to the USDA's soil texture classification as defined in the soil survey manual. Based on the distribution of the size classes of the mineral particles less than 2mm. Diameter, soil textural classes are defined. Soil texture has a strong influence on the soil behaviour when is used as construction material. It influences some engineering properties such as bearing capacity, compressibility, permeability, swell and compaction (Soil Survey Staff, 1999).

Unified soil classification: In engineering applications this classification is used frequently. It is based on particle size distribution less than 7.5cm and Atterberg limits. The system defined three main classes. These are coarse grained, fine grained and organic soils. The method provides the first step information in any field and laboratory investigation for engineering purposes. It is used to make certain general interpretations relating to probable performance of the soil such as foundation for dwelling with out basements, local roads and streets, road fill and construction material (Soil Survey Staff, 1971).

Atterberg limits: The Atterberg limits (liquid limit, plastic limit plasticity index and leaner shrinkage) provide a means of measuring and describing the consistency of soil in numerical terms. Plasticity index is the range of water content over which the soil exhibits plastic behaviour and it is between upper plastic limit (liquid limit) and the lower plastic limit (Head, 1981). The Atterberg limits are used in the engineering soil classifications (Unified and AASHTO).

Permeability: Soil permeability refers to rate at which saturated soil transmits water. Permeability classes are used in two ways: to characterise a horizon or a soil profile. Permeability on saturated soil is used to determine the quality of soils that enables in to transmit water and air (Head, 1981). Permeability is used to determine the capacity of sub soils (between 60 to 180 cm from the surface) to absorb, filter and distribute effluent from the septic tanks. Falling head method is a one method that used often in engineering applications to determine the Permeability on saturated soils.

California Bearing Ratio (CBR): California Bearing Ratio is a empirical test which was developed in California, USA for estimating the bearing value of highway sub-bases and sub-grades.

There is little difference between British and American standards for test. However there are numerous ways of preparing samples for this test. "*CBR is the ratio of the force required to penetrate a circular piston in to soil in a special container at a rate of 1mm/min. to that required for similar penetration in to a standard sample of compacted crushed rock. The ratio is determined at penetration of 2.5mm and 5mm and higher value is used"* (Head, 1981). The standard forces were based on test on sample of compacted crushed rock and by definition rate to a 100 %. The CBR derived from an add-hoc test and it is not based on theoretical concept. The only calculation necessary is to express the measured force for a certain penetration as percentage of the standard force for the same penetration.

2.5 GIS and RS application in settlement and road planning

Most of the necessary information for urban layout, can be gathered by reading aerial photographs and also detailed information required for urban physical planning such as land use pattern, circulation system, densities, and other natural features, can be read from pattern, texture, tone, shape and shadows.
The use of imageries for engineering purposes and soil & material inventory is well established (Dowling, 1968).
For the data analysis, the use of GIS has been recognised to be effective for decision making in road planning. The computer-based GIS can therefore often be an efficient means of applying land evaluation models to road planning and allocation.

2.6 Land capability /land evaluation techniques and tools

Land evaluation may be concerned with the assessment of land performance when use for specified purposes (FAO, 1983). The process includes interpretation and analysis of climate, soils, land cover types, and other aspects of land in terms of land use requirements.
The better known land evaluation methods are the FAO framework introduced by Food and Agriculture Organisation of United Nations and USDA Soil Survey Interpretation Approach introduced by United States Department of Agriculture (1969).

FAO framework for land evaluation: The FAO framework for land evaluation gives a standard set of principles and concepts on national or regional land evaluation systems. The framework structure is compatible with other systems and also allows for considerable flexibility. It suggests orders, classes and sub classes. Classes are defined as highly suitable (S1), moderately suitable (S2), marginally suitable (s3), currently not suitably (N1), and permanently not suitable (N2).
The FAO system also considers a quantitative and qualitative evaluation and recommends to make a choice between the two systems based on available data. When grouping are based on precise numerical economic terms or physical inputs and outputs quantitative evaluation is used while qualitative evaluation is used the classification which do not meet the requirements are described as qualitative (FAO, 1976).

The Automated Land Evaluation System (ALES): is a tool (a computer program) that can be used to land evaluation according to the FAO framework for land evaluation (FAO, 1976) for both agricultural and non agricultural purposes. The user is free to use his local knowledge in selecting land use requirements for land uses and to determine the diagnostic characteristics form land qualities (Rossiter & Wambeke, 1997).

USDA-SCS Soil Survey Interpretation Approach: Soil information interpretation for site development have been designed to use as a tool for evaluating suitability or limitation for various engineering uses (construction). Limitation ratings are given based on influence of the existing soil properties for that use. Rating guides allow the user to identify and recommend the site selection and to plan the alternatives to minimise the impact on the soil. Rating terms used are limitation and suitability. Limitation can be defined as degree of limitation that restrict the use of a site for specific purpose and suitability defined as degree of soil favourable for given use. The stage of Soil properties influence the building site are site selection, site planning design construction, performance after construction and maintenance (Soil Survey Staff, 1971).

2.7 Definitions

Land: includes all interacting biophysical attributes at the earth' surface. They have a significant influence on actual and potential uses of land by man. Land includes climate, landform or topography, soil hydrology, natural vegetation, plant & animal and relatively permanent changes of land as a result of human activity.

Land Characteristics(LC): is an attribute if land that can be measured or estimated in any operational sense such as remote sensing and natural resources inventory. Land characteristics are used to distinguish land mapping units and as a mean to describe land qualities. Soil drainage classes, % slope, effective soil depth, soil texture, available water capacity are some examples. Land characteristic of a plot of land can be translated into land qualities. Land characteristics may influence several land qualities at the same time and thereby influence in different ways. Unified classification is an example. Unified classification has as effect on the land quality load bearing capacity, compaction, and strength of soil, permeability and workability.

Land Qualities (LQ): is a complex property that can be assessed by different combinations of land characteristics. Land qualities have distinct influence on suitability of land for a specific use. Examples of land qualities are temperature regime, moisture availability, drainage, terrain conditions affecting mechanisation, susceptibility flooding of etc. These land qualities can not be measured or estimated directly but need to be calculated in an indirect manner.

Land Utilisation Type (LUT): is a specific type of land use that is described in terms of diagnostic or key attributes. These may include management characteristics (materials inputs, and technology) as well as socio-economic factors (land tenure, capital intensity, labour intensity, technical knowledge, etc.)

Land Use Requirements (LURs): Land use requirements are the biophysical conditions that are needed for a successful and sustainable use of land. The biophysical conditions can be known as land requirements that can be determined by the data on natural resources that need to collected for a land evaluation study. These land use requirements are used to compare with land qualities and land characteristic of a land unit.

Land suitability and limitation: land suitability/limitation can be defined as the ability or fitness of a given plot of land to satisfy the specific kind of lands use. Limitations are land qualities (complex attributes of land) which badly affect a land utilisation type. For example; the requirements for road construction include high load bearing capacity of sub-grade soils. Presence of weaker soils (soils have low bearing capacity, high compressibility) in sub-grade are limitations.The term “limitation” is used in this research to explain the fitness of land in the area for selected engineering uses. Degree of limitation is explained the degree of fitness.

3 The study area

3.1 Location and extent

The study area is located within the Naivasha municipality, Naivasha Division, Nakuru District of Rift Valley Province in the South-western part of Kenya. It lies between longitude 212663 E to 216878 E and latitude 9917514 N to 9923652 N of Greenwich meridian. The area covered nearly 16 km^2. Administratively area is governed by the Naivasha Division of Nakura district, in the Rift Valley Provision of Kenya (Fig.3.1.)

3.2 Climate

The area has a semi-arid type of climate. The mean monthly temperatures range from 15.9 to 17.8 ^{0} C with the coldest month in July and August. Highest temperature is in January & February. There is a big diurnal variation and a definite cold season as a result of cold air coming from the Nyandarua range.

The Lake Naivasha area receives an average annual rainfall of 627 mm per year. The heights rainfall experienced from March to May and the short rainy season from November to January (Fig. 3.2). Naivasha D.O station at altitude 1900m is located within the town, which is the representative weather station for the study area. The historical rainfall around the lake catchment fluctuates as illustrated in Fig.3.3 (LNROA, 1993).

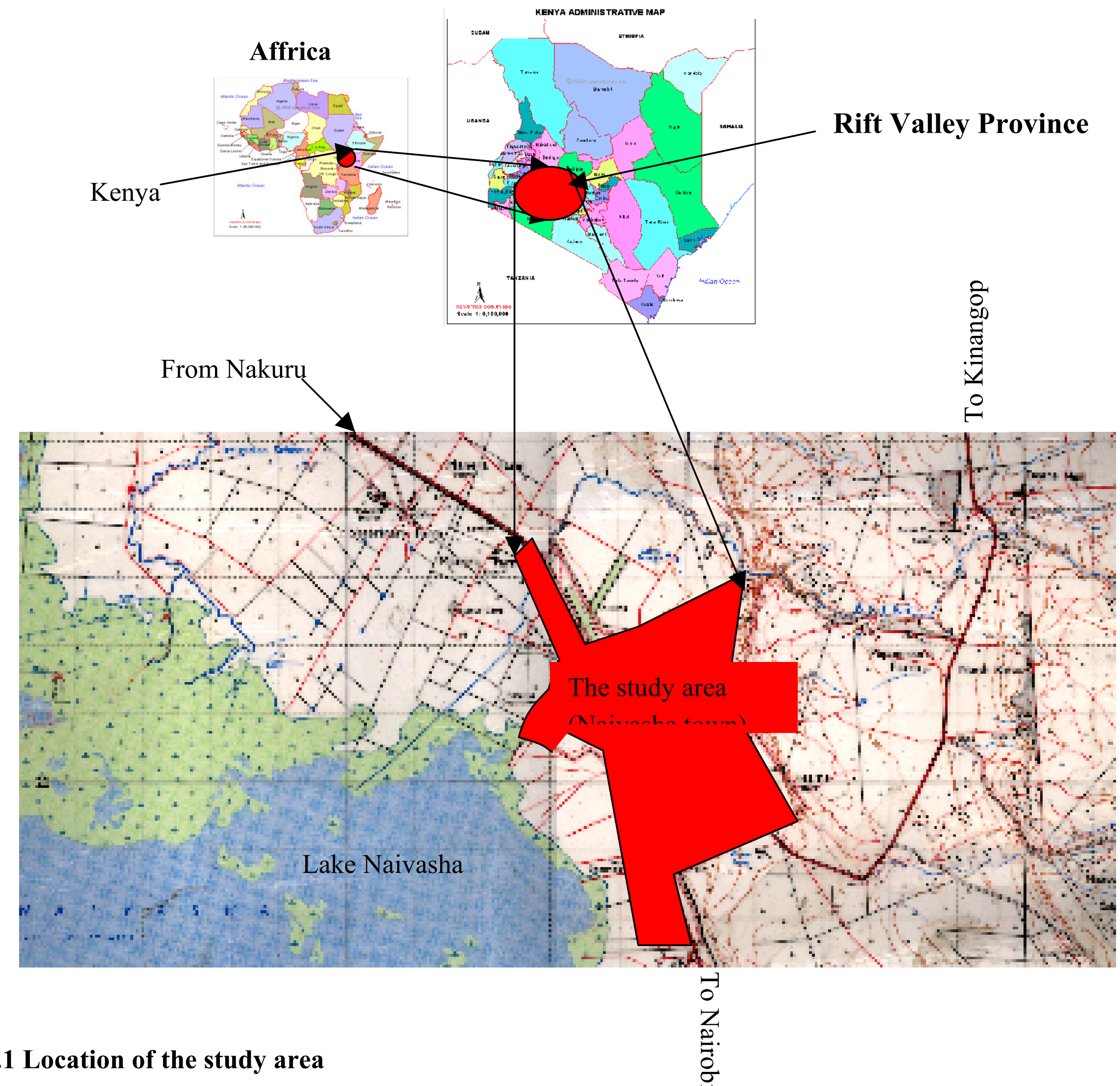


Fig. 3.1 Location of the study area

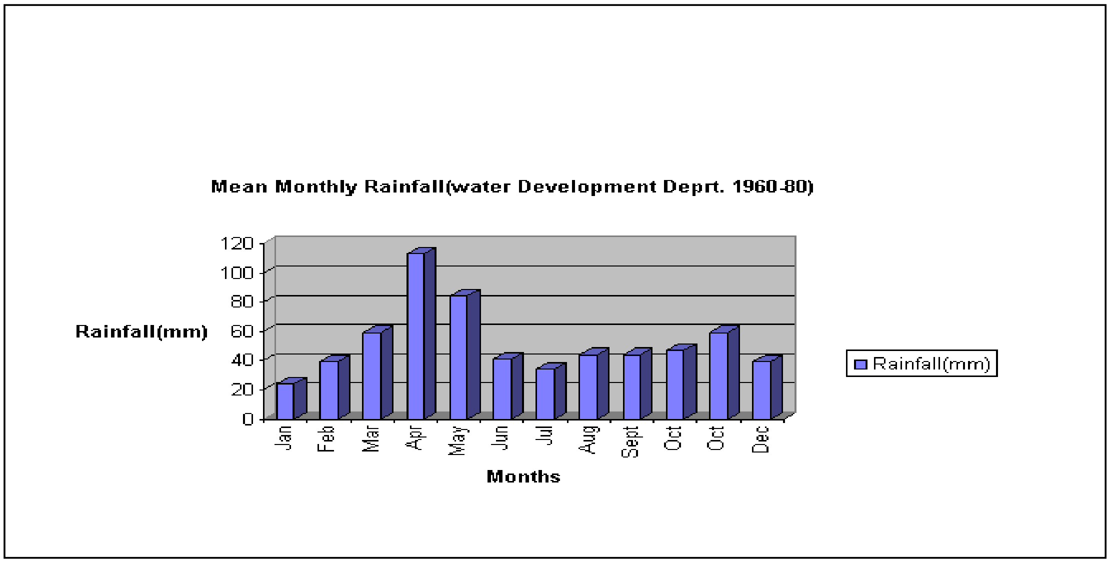


Fig. 3.2 Mean Monthly Rain fall for Naivasha. (Source Ministry of Land reclamation, Regional and water development, Kenya).

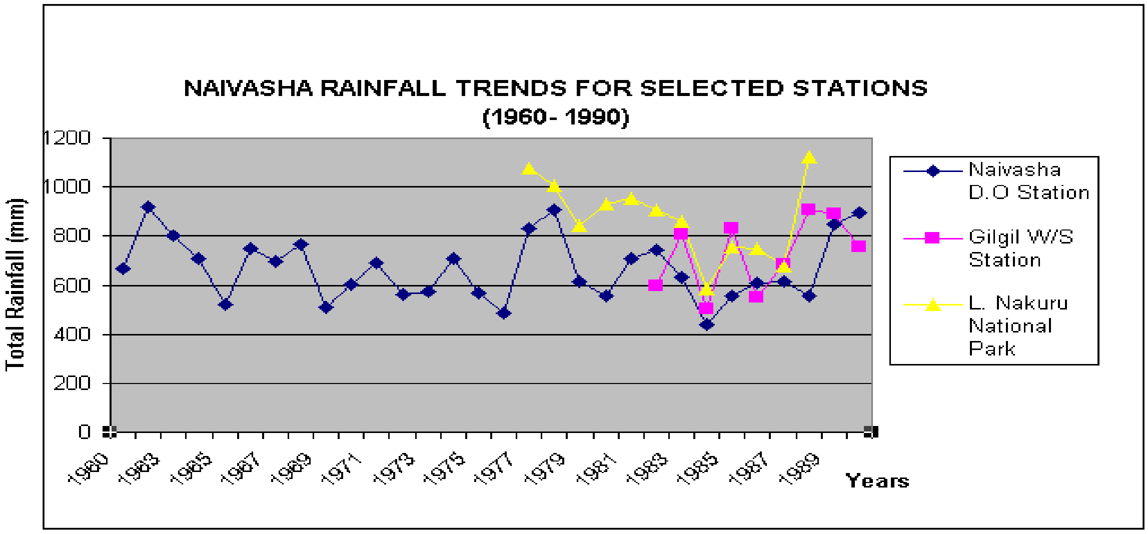


Fig. 3.3 Naivasha Rainfall trends (1960–1990). (Source: Ministry of Land Reclamation and Water development).

3.3 Geology

The study area is falling within the Longonot Volcano group, which incorporate seven geological formations. They are formed of (often perekaline), trachyte, pyroclastic rocks and lava flows, but some cases, there is evidence of the mixing of magmas of alkali basalt and trachyte compositions (Fig. 3.3.1). The major events in history are:

- Longonot volcanic formation (poorly exposed pyroclastics and lava).
- Kedong Valley tuff formation

- Building of pyroclastic and lava cone (represented by the Akira pumice formation)
- Lava- Longonot trachyte formation
- Formation of a summit crater (accomplished bythe Longonot Ash formation) (Clarke et al., 1990)).
- As per the geological map of the area (Clarke et al., 1988), parent materials can be grouped as follows:

• Lacustrine sediments : this is covers the whole mapping units in lacustrine plain,

• Limuru trachyte, Karati and ol Mogogo basalt, Kinanhop tuff, Alluvial deposits, Eburru Pumice (pentallerite and trachyte pumice and Volcano ash fall deposits, Longonot Volcano Akira pumice and Kedong valley tuff (trachyte ignimbrites and associated falls), occupies the Lower plateau

• Longonot Volcano Akira Pumice Weathered Volcanic lava flows, Alluvial deposits, Kedong valley tuff (trachyte ignimbrites and associated fall deposits).covers the higher plateau

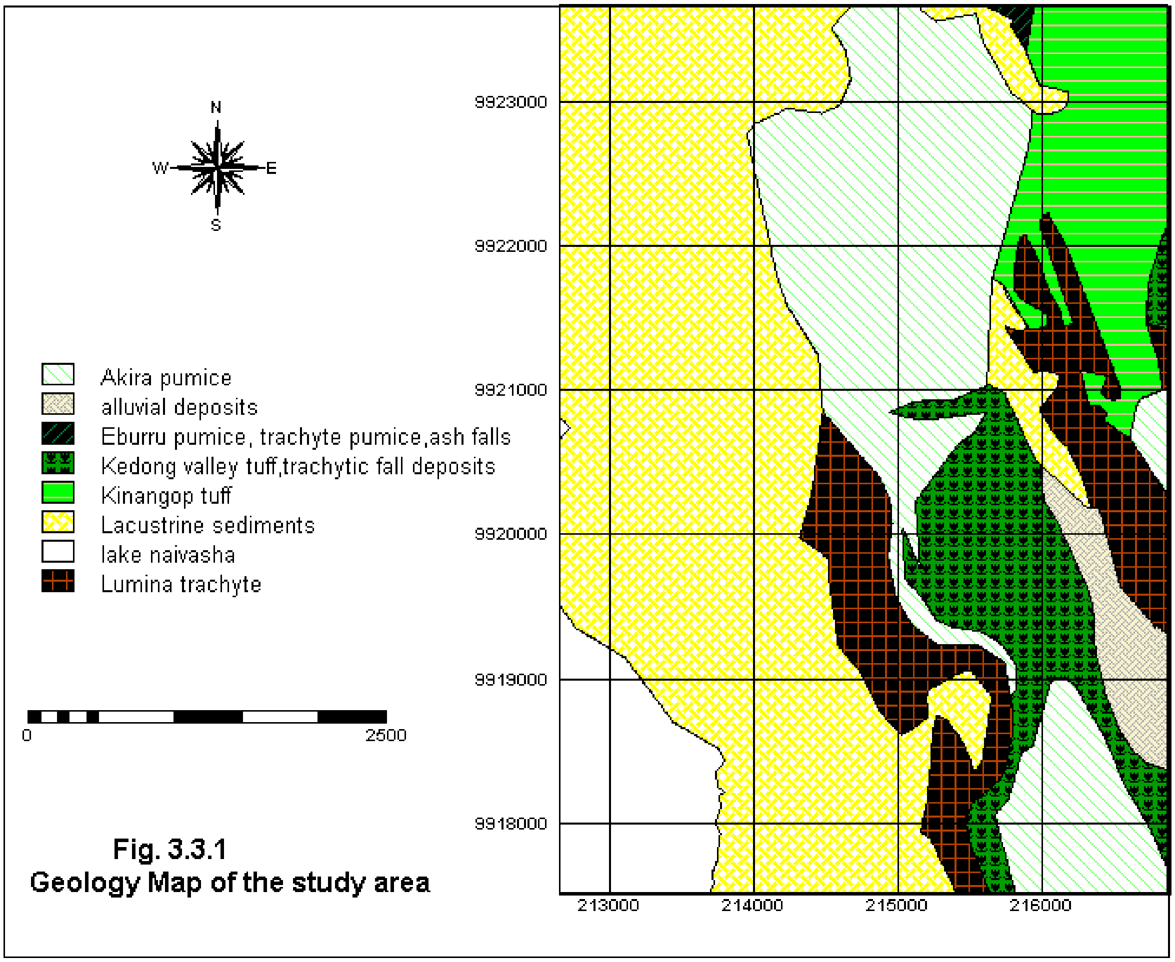


Fig. 3.3.1
Geology Map of the study area

Source: Based on *Geological Map of Longonot Volcano*, the Greater Olkaria and Eburru Volcanic complexes, and Adjacent Areas (Clarke et al., 1990).

3.4 Geomorphology

Four main landscapes have been identified according to the geopedologic approach (Zink, 1988/89): volcanic plateau, volcanic complex, volcanic plain and lacustrine plain. The lacustrine plain is around the lake and it extends between an altitude of approximately 1850 to 1920m. above mean sea level. Volcanic plain has resulted from the lava flow from Longonot and wind deposition of pyroclastic materials (Thompson et al., 1958).

The study area consists of two types of landscape: plateau and plain. The shape of topography of lacustrine plain is flat to almost flat and 80% of land in high and low Plateau is almost flat to undulating while rest is steeply deep desiccated escarpment. The altitude ranges from1880m to 2098m above mean sea level. Higher plateau area located eastern part of the main road to Nairobi and lacustrine plain located west to the Nairobi main road bordering to the Lake Naivasha(Fig 6.2 and table 6.3).

3.5 Soils in general

The soils of the area are derived mainly from weathered volcanic and basement rock system: Limuru trachyte, Karati and ol Mogogo basalt, Kinanhop tuff, Alluvial deposits, Volcano ash fall deposits, Akira pumice and Kedong valley tuff (Clarke et al., 1990).). The soils in the study area can be grouped in to two: soils developed on the lacustrine plain and those developed on the volcanic plateau. Soils developed in the lacustrine plain are imperfectly drained to poorly drained, very deep, dark greyish brown to dark brown, firm to very firm, slightly to moderately calcareous, slightly to moderately saline, moderately to strongly sodic, silt loam to clay. Soils developed on the volcanic plain are excessively drained to well drained, moderately deep to deep, dark greyish to olivegrey, stratified, calcareous, loos find sand to very friable find sandy loam or silt (Andic-Cambisols, Duric-Andosols and Calcaric Fluvisols, sodic phase) See section 6.1.2 in chapter 6 for details.

3.6 Land use and population

The area was formally occupied by pastoralists (Maasai tribe) from 18th Century and grazing and watering their livestock on the lake (Kwacha, 1998). After migration of settlers (white) considerable land use changes occurred due to beef & diary farming, irrigated agriculture, horticulture and flower production. However landless people migrated from other parts of the country and settled down on the southern part of the lake where the pastoral activities were occurred. The new setters started to grow commercial agricultural crops (been, maize) clearing the vegetation cover around the settlements.

3.7 Commercial and domestic power & water supply

Lake Naivasha is a source of domestic water supply to Naivasha and Nakuru towns and adjacent areas. The urban growth has numerous indirect effects on the swamp through demand for water, which has led to a need for diversion of rivers and direct extraction. The Malawi river almost contributes 95% of the input to the lake (Gaudet, 1979).

Geothermal power is the main source of energy used by the area, which is one of the main environmentally friendly sources of power. The geothermal power plant (Olkaria Geothermal Power) is located to the south of the lake, which is a source of employment for local inhabitants.

3.8 Urbanisation and tourism development

There are three small town ships (Longonot, Suswa, Marula) along the Nairobi main road and other several residential neighbourhoods centres within the large agricultural farms. Main problem perceived by the residence, especially near to the lake is Lake Water pollution, encroachment on the lake, use of dangerous chemicals and settlements encroach to the agricultural lands. Unplanned & inadequate housing and related services for residents in the area that engaged in agriculture & horticulture and other economic activities are the main problems.

Lake Naivasha area has recently become an economic boom area as a consequence of development of flower production, horticulture production, tourism, geo thermal power production and other human activities. In the flower production sector employs more than 20,000 directly and many other indirectly. The area counts some 80,000 tourist days per year (Becht, 2000). There is a continues increase in population around the lake Naivasha.

Over the years the land utilisation types within the town is being changed. The percentage change per year of the urban land use, between 1967-1984 and 1984-1995 was 5.8% and 3.2 % respectively (Bemigisha, 1998). The population growth rate was 3.5% and average annual agricultural land per person has been reduced from 1.48 ha. to 0.68 ha between 1979 to 1993 (LNROA, 1993). The effects of this growth rate reflects that the urbanisation trend, speed and expansion of the urban area towards the non-urban locations.

Consequently, the neighbourhood centres around the lake are spring up and expanding very rapidly to cater the demand by local inhabitants as well as migrants for housing and related services commercial centres as well as recreational facilities.

Tourism is most important foreign exchange earner in Kenya as well as Naivasha. The Lake Naivasha wetlands are one of the best bird watching camp in the country the area is reputable for sports fishing especially the historic Black bass fish (Gaudet, 1980). There are two National parks in the neighbourhood: Longonot and Hills Gate that are reputable. The impact of tourism on the papyrus area is one subject that could interest investigation.

4 Materials and methods

4.1 Materials used

The materials used for the study summarised as follows:

- Topographic map of Naivasha at scale of 1:50,000 (1975),
- Exploratory Soil Map & agro-climatic zone map of Kenya (semi-detailed) at the scale of 1:1,000,000 (1980).
- Geological map of Longonot volcano at the scale of 1:100,000 (1988),
- Aerial photographs at the scale of 1:50,000 (1972) and 1:12,500 (1984),
- TM sensors/Jan.1995 and (TM) image May, 2000,
- Urban Land use 2000, Naivasha Town,
- Meteorological data of Naivasha catchment,
- Socio-economic data, land use, population density, housing density, urban layout, circulation sys tem, etc (Naivasha Municipal Council),
- Computer software such as ILWIS, Microsoft excel etc.
- Field test/measurement (GPS (Garmin), Hand Penetrometer, Slope meter, Altimeter pH meter etc.), soil sampling and digging tools.

4.2 Methodological approach

4.2.1 Pre-field work

The following activities were carried out during this stage (Fig.4.1).

1. Gathering of information and data required for this research work from the previous research works and deferent institutions & government organisations in Kenya as well as at ITC.
2. Determination of study area, data collection & analysis of factors influencing settlement development and identification of research problem.
3. Preparation of inventory on soil properties and environmental condition to determine the suitability of the area for selected engineering uses.
4. Interpretation of aerial photographs (using geo-pedologic approach) in order to produce:
   - General photo interpretation map of the area for soil survey purpose,
   - Map of present land use and settlement pattern & existing road network.
   - Selection of sample area and observation points based on the general photo interpretation map.

4.2.2 Field work

1. Collection of relevant secondary data
1. Soil survey
3 Soil mechanical tests (field & laboratory)
   A. Engineering soil classification (unified) (mixed samples))
   - Particle size distribution
   - Atterberg limits determination tests

   B Relative compaction capacity test to estimate compaction capacity and strength of sub-grade soils using:
   - Compaction test /lab dry density (proctor method)
   - Field bulk density test (sand replacement method)

   C CBR Test (AASHTO T99) for estimating the bearing value of roadway sub-bases and sub-grades.

   D Permeability test on saturated soil (falling head method) to determine the quality of soil that enables it to transmit water & air and Water movement of soil

   E Hydrometer analysis for determining texture
4 Field tests and observations
5 Interviews

4.2.3 Post field work (data compilation & analysis)

1. Preparation of semi-detailed geo-pedologic map
   - Correction of delineated boundaries of photo interpretation map and incorporation of soil information in to the legend.
   - Produce a geo-pedologic map based on the field and laboratory information. Interpretation of engineering and environmental data collected from field and laboratory testing for each mapping unit.
2. Digitising geo pedologic map.
3. Processing /compilation of data on soil properties & site conditions (land qualities) of geo pedologic map units.
4. Adaptation of evaluation criteria (tables from USDA-SCS rating guides). These tables are modified to suit the conditions in the area.
5. Matching the land qualities of the area with the criteria tables to evaluate the each mapping unit and to identify the severity levels for each use.
6. Incorporate the resulted matching tables in ILWIS (Fig. 4.2)to produce:
   - Attribute maps (limitation maps) for each property and each engineering use,
   - Severity limits maps for housing and road construction and residential development.

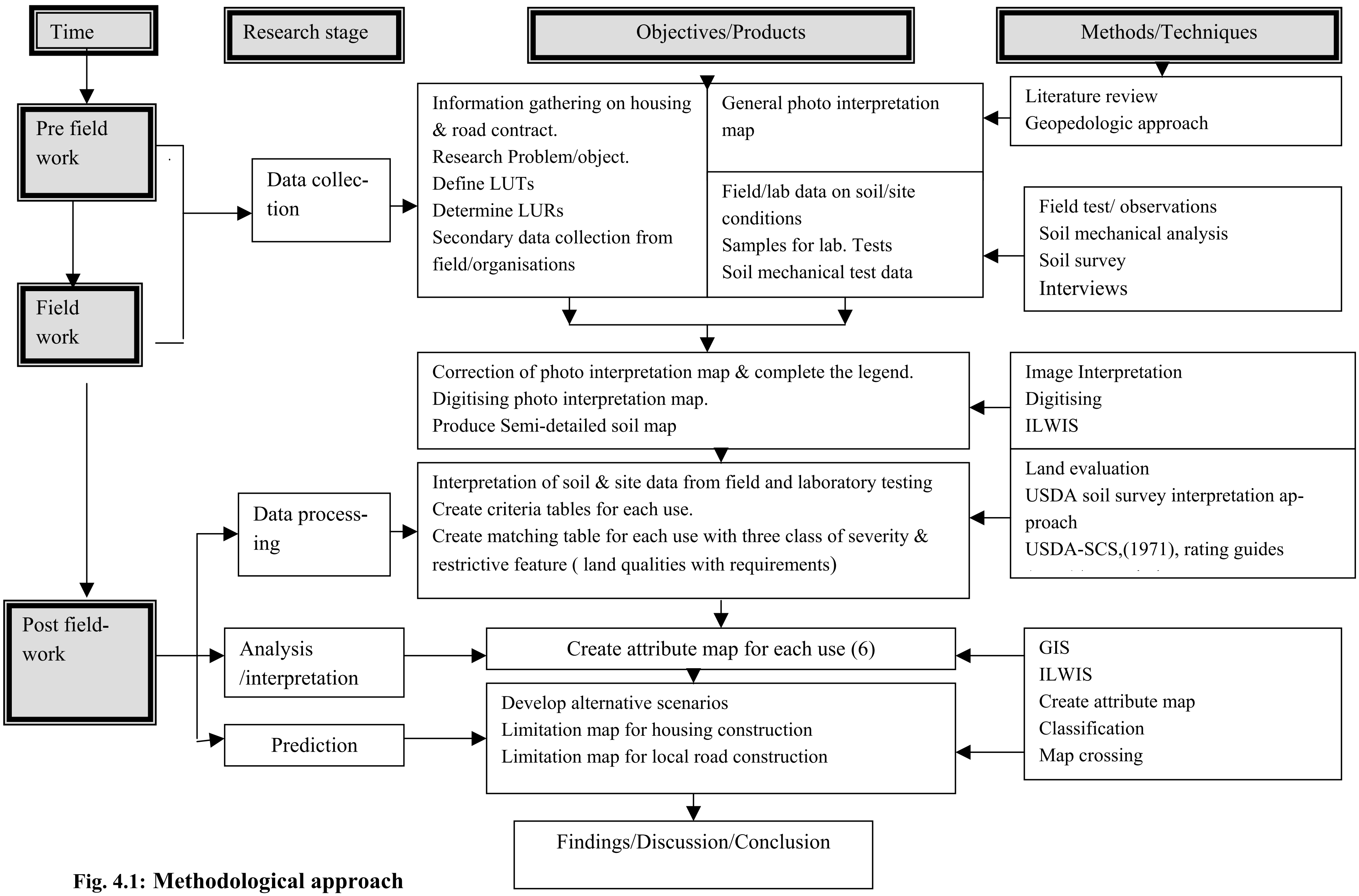


Fig. 4.1: Methodological approach

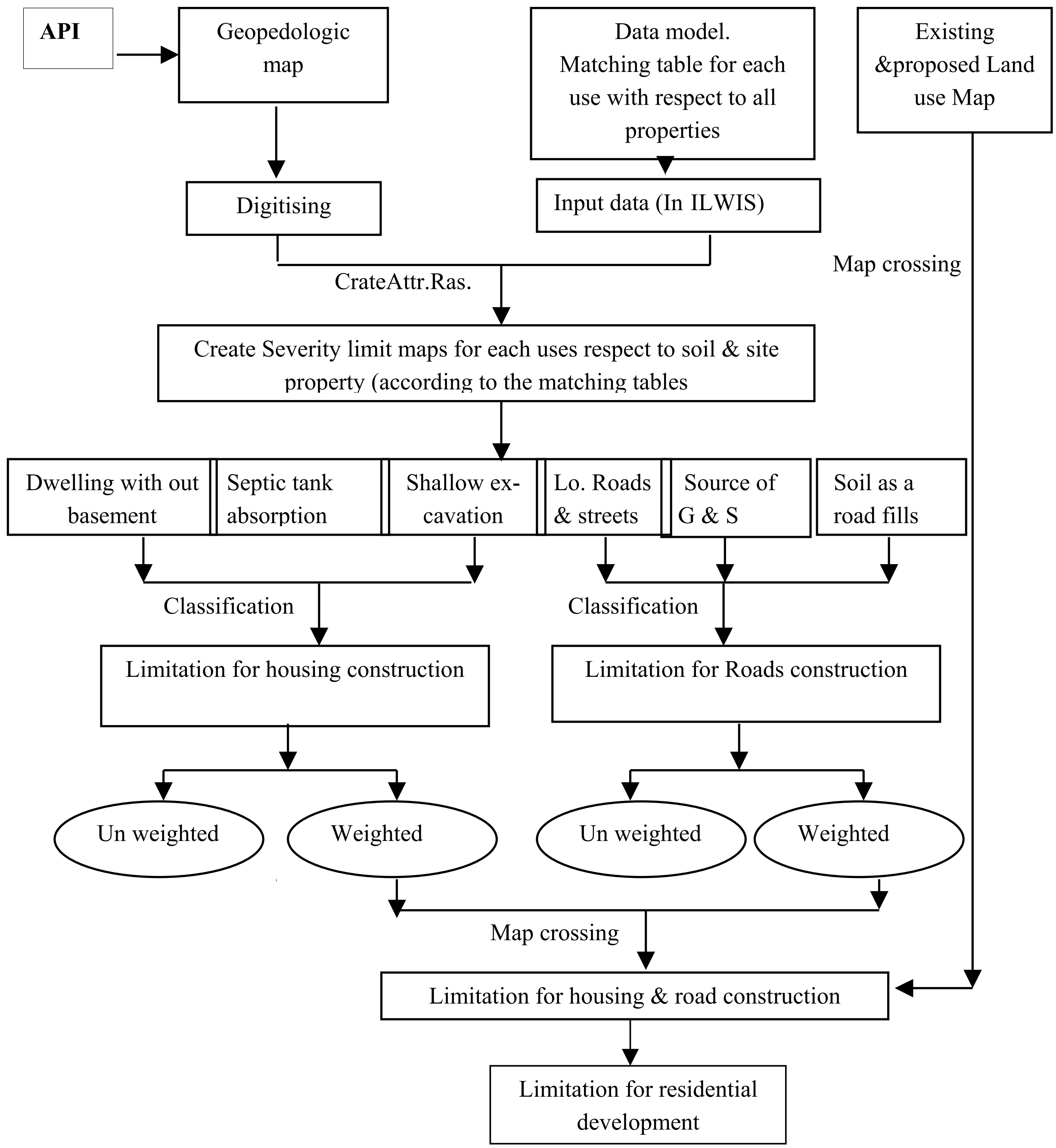


Fig. 4.2 Schematic representation of GIS Application

4.3 Methods and techniques

4.3.1 Identification of housing & road -related land utilisation types

This section describes consideration of use of soil information for the selected engineering uses. Soil properties and site characteristics influenced their specific requirements, land qualities and ratings for each use. Each rating table (Table 1 to 6 in Annex IV) includes properties influenced, criteria based & degree of limitations and restrictive features of each property.

A Dwelling without basement

In this study, soil survey interpretation is made in the analysis for the selection of suitable areas for housing. Out of engineering uses involved in selecting areas for housing locations, dwelling without basement is the prime use. Dwelling without basement is considered as single family houses of which have two stories or less and the foundation at a depth of 60 cm from the surface. This land utilisation type (LUT) requires site conditions with good physical strength. Consequently the affecting land qualities are strength of soil, compaction capacity, shrink-swell potential, load bearing capacity and ease excavation.

B Septic tank absorption fields

The Septic tank absorption fields may vary, in this research an absorption field with subsurface tile system or pipe system overlaid by gravel in the specific size of trench is considered. The depth centre-line of tile system is assumed to be 60 cm from the surface. The type of septic tank is selected by considering the human waste disposal system used in the study area.

Ability of the soil to absorb and filter the effluent is the land qualities required. Permeability is the main soils property influences the land qualities, which was estimated by permeability test on saturated soils.

Depth to bedrock, depth to water table, surface stoniness greatly influences the instillation & maintenance of system and process of distribution of effluent. Steep slope, may cause lateral seepage and surfacing of effluent in the down slope areas.

The ratings are based on the ability to absorb and filter effluent form the septic tank. Since the centre-line of the tile or pipe system assumed to be at a depth of 60 cm, soils between 60 to 180 cm are considered as the effective soil depth in the rating (Table 2 in Annex IV).

C Shallow excavations

The LUT ‘Shallow excavations’ are considered as excavations or digging done to a maximum depth of 150-to180 cm from the surface. This use selected as a supportive activities such as laying sewers, telephone, pipe lines, power lines, building foundations, excavation for road bases etc. in housing and road development sites. They are used from the beginning to completion of constructions. The land qualities and characteristics required are: good workability, gentle slope, absence of large stones and rock out, no flooding hazards and ease excavation. The ratings are based on soil properties influence the land qualities (Table 3 in annex IV).

D Local road and streets

In this study, a width of 15 meter or less, labour intensive, low technologies used and road suitable for all weather conditions are considered. These type of roads (C, D &E class roads) are generally maintained by local authority. In general, roads consist of road surface (street pavement), base, sub-base and sub-grade (underlying soil materials). Properties of the sub base and sub-grade soil materials are influencing the constriction potential of roads.
For the ratings, properties effecting on the ease excavation, soil strength, compaction capacity and traffic load bearing capacity are considered (Table 4 in Annex IV). The traffic load carrying capacity and swell of sub base and sub-grade soil materials were estimated by California Bearing Ratio (CBR) test on compacted soils. Soil strength and ease excavation were determined by Unified classification (includes, liquid limit test plastic limit test, linear shrinkage and plastic index) whereas compaction capacity of sub base and sub-grade soil materials was determined by relative compaction test including field bulk density (sand replacement method) and lab dry density (Proctor method).

E Possible sources of gravel and sand

Gravel and sand materials are used in large quantity for many kind of housing and road constructions. they are heavy, bulky and expensive to transport. These materials determined the type and cost of construction. Therefore, nearest locations of gravel and sand deposits were considered as possible sources. In this study, only availability of gravel and sand within economically viable distance is considered. Suitability for specific uses was not evaluated.
The ratings are based on probability for finding the materials in suitable quantities ease excavation and layer thickness. The properties used to estimate the probable sources of gravel and sand are grain size distribution, layer thickness, and amount of stones in the soil materials. For the determination of grain-size distribution Unified classification was used (Table 5 in Annex IV.) presence of small stones, too clayey, and excess fines are considered as most limiting factors.
<u>Note:</u> Soils in the area have little or no sand or gravel in the uppermost150 cm or 180 cm. From the visual observation made in deep cuts and interviews with Resident Engineer, Naivasha road maintenance unit, Ministry of public works, and knowledge of local geology of Town Engineer, Naivasha Municipality, some soils are underlying by gravel deposits, specially soils in the volcanic plain (upper plateau and lower plateau) areas. These deposits easily can be used, as they are located fringes of the town, very few urban activities and devoted for open spaces. Therefore in the rating table, soils are rated as “severe” limitations, but footnote have been used to call attention to the user that gravel deposits are under soils.

F Soils as a source of road fill

Road fills is defined as soil materials that is excavated from their original position and is used in road embankments elsewhere. Road fill is soil materials used for making embankments for roads which are save as the sub-grade or foundation for the road. Soil materials good for road fill must be also good for sub-grade. The quality of the soil materials and the distance from the development site has been considered as main concerns to the engineers.
Fill materials having no volume changes, reasonable distance from the development site, no slips owning to shear failure and ability to stand with erosion on the side slope of road embankment are considered to determine the quality of fill materials.
The ratings are based on properties effecting the qualities of materials are engineering soil classification (Unified), shrink-swell, soil drainage, layer thickness, depth to bed rock, rock fragment in the

soils and flooding (Table 6 in Annex IV). The strength characteristic of soils was estimated from Unified classification whereas compaction capacity was inferred from relative compaction test.

In this research, the evaluation of the soil as road fill is limited to low embankments, which are generally less than 180 cm in height and less excavating in design than high embankments. Consideration for the ratings is given for the whole soils from the surface to a depth of 180 cm based on assumption that soil layers will be mixed in loading, unloading and spreading.

4.3.2 Engineering soil attributes & site characteristics as relevant to housing and local road construction

A Soil engineering properties

To assess the soil suitability for the selected engineering uses, mainly influencing soil properties are considered. They are determined from the laboratory analyses and field test & observations.

The significant and the techniques applied to determine or estimate these properties are discussed in this section. In the determination of the properties, topsoil is usually assumed to be removed in the implementation of selected engineering works. Therefore, in most cases soils in the B-horizon are considered.

B Soil engineering classification (Unified)

Importance: Unified classification system is used to identify the first step information in any field and laboratory investigation for engineering purposes. It is used to make certain general interpretation relating to probable performance of soil such as foundation for housing, local roads and streets, road fills and constriction materials. Science, this property was used in ration table of dwelling, road and streets, road fills and source of gravel & sand.

Classes: soils are grouped in to three major soil groups. They are highly organic soil, (soils having certain organic characteristics), course grained (50% or less passing through No.200 (0.074mm sieve) and fine grained (more than 50% passing through No.200 sieve). These three groups are further subdivided in to a total of 17 groups (see Annex II-A & B). Limitation rating classes are based on strength of soil materials. Bearing capacity, compressibility, shrink-swell, Atterberge limits are properties that affect strength of soil. Therefore, soils have high strength (well and poorly graded gravel and sand, silty gravel, clayey gravel , silty sand) are classified as none to slight, soils have moderate strength (silt and clay with PI > 15)and soils have low strength (silt and clay PI < 15 and organic clay)severe.

C USDA texture

Importance: The texture classes were used to determine the influence for the engineering soil properties such as bearing capacity, compressibility, swell and compaction. Since soil texture has a strong influence on the soil behaviour when it is use as a construction materials.

Classes: Soils are classified according to the particle size less than 2mm diameter. The texture classes includes sand silt and clay soils. USDA texture was infrared from particle size distribution using hydrometer analysis. Basis of the limitation ratings is same as Unified classification.

D California Bearing Ratio (CBR)

Importance: CBR was used to estimate the vehicle traffic load bearing value of roadway sub base and sub-grade soils. And also it was used to estimate the strength of sub-grade soils and road fill materials (See Annex II.C for. detailed test procedure).
Classes: In this study, limitation classes are based on design standards used for road constructions in Naivasha by Road Maintenance Unit, Ministry of public works, Kenya. In their design standards, sub-grade soils having CBR value less than 7% are recommended to be filled with other road fill materials, which have CBR value > 7%. Over the sub-grade materials, a sub base having CBR value grater than 7% is recommended. Therefore in the rating table degree of limitation are assigned as “severe” limitation when soil have CBR value less than 7%, CBR between 7- 14% moderate and grater than 14% none to slight.

E Permeability

Importance: Permeability on saturated soil is used to determine the quality of soils that enables in to transmit water and air. By considering the importance of soil permeability in selecting of site for septic tank absorption fields, permeability of sub soils (between 60 to 180 cm from the surface) was tested to determine the capacity of sub soils to filter and distribute effluent from the septic tanks. Falling head method was used to determine the Permeability on saturated soils (see Annex II-D for detailed test procedure).
Classes: In the study, permeability of soil horizons between 60 to 180 cm is considered. To rate the permeability, the rating s given in USDA –SCS are used. Seven classes given in USDA –SCS was categorised in to three classes: low (<1.52 cm/hr), moderate (1.52 – 5.08cm/hr) and high (> 5.08 cm/hr). These ratings are based on ability of soils to absorb and filter effluents form septic tanks.

F Relative compaction

Importance: Compressibility of sub-grade soil is highly influenced in road construction. The main properties that influenced the degree of compaction of soils is field bulk density. The test was carried out to determine the degree of compaction of soil of the area as a main property influencing the local road & street and dwelling without basement.
Classes: limitation classes of relative compaction are based on compressibility of soils. The standards used by Naivasha road maintain unit, Ministry of public works, Kenya for road way planning, design and construction in Naivasha are applied.. According to their standards, soils have relative compaction < 92% is recommended as poor compatibility. Relative compaction between 92 to 98 is moderate and > 98% is recommended as perfect. Therefore degree of limitation in the rating table is shown, soil has relative compaction less than 92% is severe,92 to 98% moderate and more than 98% none to slight limitations. See Annex ii E for detailed test procedure.

G Shrink- swell potential

Importance: shrink-swell potential of the soil is a important property which is often used to determine the strength of soil materials. Building foundation, roads and other structures may be severely damaged by the shrinking and swelling of soils. It is the susceptibility of volume changes due to loss or gain in moisture content (Annex II. F for detailed test procedure). Therefore shrink-swell potential of the soils in the area is considered as an important factor in dwelling without basement, local road and streets and road fills.

Classes: Although, five classes have been developed to express shrink-swell behaviour of soils by USDA-SCS, in my study three classes were used. The rating classes are based on degree of Coefficient Of Leaner Extendibility (COLE).

The COLE value less than 3% recommended as low, between 3 to 6% moderate and more than 6% as high. In the rating table, soil has low shrink-swell (COLE <3), rated as none to slight, moderate class (COLE 3 to 6) rated as moderate and soil has high shrink-swell (COLE >6) rated as severe limitations.

4.3.3 Collection of relevant secondary data

The main objective of the field work included to collect the data on (a) problems of settlements & local road construction due to unsuitable soil & environment conditions in residential neighbourhoods, (b) socio-economic conditions,(c)and relevant physical, chemical & geological properties of soil and site conditions prevailing in the area.

The fieldwork was carried out during a period of 4 weeks from early September to early October 2000.The following activities were carried out during the fieldwork.

Information on physical and socio-economic condition, town development plan, zoning plain and problems of housing & road construction due to unstable soil were collected from Naivasha Municipality and Ministry of Urban Development.

Available data on soil mechanical properties such as engineering classification of soil, compaction capacity depth to bedrock in the area were collected from Road Maintenance Unit, Ministry of Public Works, Naivasha, Kenya.

4.3.4 Soil survey

General field reconnaissance was carried out in order to study the geomorphology, geology, land use/land cover, accessibility and also to correct the photo interpretation map.

The objective of the soil survey was to evaluate the land for semi-detailed site planning at municipal or District level. Intensity level of the survey (according to the USDA Soil Survey Manual) is medium, semi-detailed, or survey order is 4th order as per the NRCS order. Minimum delineation (MLA = 0.4cm2) is 4.5 ha. (Fig. 5.3) And inspection density is 2 per km2. Therefore the soil map publication scale will be approximately 1:33000.

Soil survey was carried out including soil pit digging and profile descriptions, sampling & soil classification according to the World Reference Base (FAO, 1998).

The representative sample area was selected at the eastern part of the study area to cut across all possible mapping units delineated in the photo interpretation map. A number of auger holes was made within the sample area to get the general idea of soil occurring in the area and to locate the observa-

tion points. Four full pits about 1.8m deep and eleven mini pits of about 60cm deep were dug in each of the mapping unit and profile descriptions were made. Thirty-four auger holes were made in and out side the sample area in each mapping unit for checking and extrapolation purpose (Fig. 5.1).
Mixed samples from all horizons of selected pits (8 pits) were collected for soil physical and geotechnical analysis in Kenya (Nairobi and Naivasha) and 34 soil samples also were collected from selected pits for laboratory tests in The Netherlands.

4.3.5 Soil mechanical tests (field & laboratory)

The following soil mechanical analyses were performed in Engineering Soil Laboratory, Material Branch, Road Maintenance Unit, and Ministry of Public Works, Naivasha, Kenya The detailed description of test procedures are discussed in Annex II).

A. Engineering soil classification (unified) (mixed samples))
Test procedure: Using data from laboratory analysis on grain size distribution and atterberg limits, Unified classification was performed according to the plasticity chart & Unified Classification Chart 3 adapted from the Military Standard-Unified Soil Classification System for roads, airfields, and foundations. mil.-std-619B, 1968 (see Annex II-A).

- **Particle size distribution**

Dry tests were carried out (sieve analysis based on particle size less than 2cm) to determine the grain size of which the soil consists and mass percent of the grains (see Annex II). In the potion of soil between 750mm and 0.074mm.

- **Atterberg limits determination tests**

Atterberg limits determination was carried out for the measuring and estimating the consistency of soil materials in numerical terms. Standard test method (multipoint test using a wet preparation procedure) was carried out for determining liquid limit, plastic limit Shrinkage limit and plastic index (see Annex II-B for details).

B. **Relative compaction test** to estimate compaction capacity and strength of sub-grade soils using:
   B.1 Compaction test /lab dry density (proctor method)
   B.2 Field bulk density test (sand replacement method)

C. **CBR Test (AASHTO T99)** for estimating the bearing value of roadway sub-bases and sub-grades.
D. **Permeability test on saturated soil** (falling head method) to determine the quality of soil that enables it to transmit water & air and Water movement of soil
E. Hydrometer analysis for determining texture

4.3.6 Field tests and observations

The attributes such as depth to bed rock, depth to water table, depth to cemented pan, soil resistance (hand penetrometer), texture, pH, soil drainage classes, slope (slope meter), elevation (altimeter), surface stoniness, flooding, percentage of rock fragments, layer thickness and land use land cover data were observed and/or measured in the field.

4.3.7 Interviews

In addition, interviews (informal) were conducted with the sanitary and health officials of municipality on standards and system used in waste disposal and related problems, interviews with town engineer, Munici
pality regarding town development plan, zoning regulations and issues related to housing and road construction.

5 Data analysis, results and discussion

This chapter provides an overview of findings in the field as well as form secondary data search. The sections describe the followings:
Section 5.1 brings out results of the geopedological analysis of the area.
Section 5.2 presents Analysing existing land use & settlement pattern and major construction problems of housing & local roads. And section 5.3 shows the limitation or suitability analyses for each engineering uses, housing & local road construction and residential development.

5.1 Soils and landscape

5.1.1 Geopedological analysis

Three major landscapes have been identified in the study area: High Step-faulted Plateau (HPu), Low Step-faulted Plateau (LPu) and Lacustrine Plain (Pl). The High Step-faulted Plateau (13 %) comprises the higher parts of the study area with altitudes ranging between 2,040m to 2,098m above m.s.l. It includes the high dissected and undulating Karati plateau in the eastern part of the study area as well as vale, mesa and escarpment.
The Low Step-faulted Plateau (48 %) occupies the intermediate central part of the study area including high glacis, mesa, escarpment, mid glacis, low glacis, vale, of with altitudes ranging between 1,909m to 2,040m above m.s.l.
The flat Lacustrine Plain (39 %) occupies the lower western part of the area including higher part, intermediate part, lower part, and bottom of with altitudes ranging between 1,888m to1, 909 m above m.s.l.
A cross-section showing the different landscapes in the study area is presented in Fig. 5.2. Geopedological map and legend are shown in Fig 5.3 and Table 5.1, respectively. They are discussed below in more detail.

HPu - HIGH PLATEAU
High Plateau consist of three relief units: Mesa, Vale and Escarpment, which in town comprise three land form units. These are Volcanic plain (HPu 111),Colluvium-Alluvium Complex (deep slope) (Hpu 211) and Scarp (Hpu 311).

Mesa
HPu 111
The main soils in the volcanic plain are ferralsols. These soils are some what well drained, comparative to shallow. Very dark brown to brown silty loam to silty clay loam. . In the sub-surface horizons have common medium rounded weathered rock fragments (phonolite). The pH is ranging from 5.o to 5.5 and the horizon transitions are clear & wavy in topsoil clear and smooth in the sub soil.

Vale
HPu 211 - Colluvium-Alluvium Complex (deep slope)

The dominant soil in the area is Skeletic Calcisols, which is developed on pyroclastic deposits. The soils are well drained, shallow, very dark brown to dark yellowish brown, clay loam to sandy loam texture. The sub-surface C-horizon is continuous platy iron-manganese cemented pan. The pH value is increasing from surface to sub surface horizons (5.0 to 7.5).

Escarpment

HPu 311 - Scarp

More than 90% of the area consists of Yamic Lithic Leptosols. These soils are very shallow to shallow, well-drained, very dark greyish brown and dark olive grey, silt clay loam to sandy loam soils. 15 – 40% of the surface covered by hard bedrock (phonolite and basalt). Weathered sub-rounded Stones are found in sub surface B-horizons. The transitions are gradual and smooth and pH is 6.5.

LPu - LOW PLATEAU

Low plateau is divided in to six relief levels: high glacis, Mesa, escarpment mid glicis, low glacies, and Vale. They consist of six land form units: back slope (LPu 111), almost flat land (LPu 211), scarp (LPu 311), sloping riser (Lpu411), foot slope (Lpu511), sloping riser (Lpu512) and bottom dry river course (Lpu611).

High Glacis

LPu 111- Back slope

In this landform the dominant soil is Arrenic Andosols. These soils are very deep, well drained, dark yellowish brown to brown. The sub surface B-horizon is white in colour. Sandy loam and coarse sand texture, few fine rounded rock fragments in sub-surface B horizons, non calcareous; clear and smooth boundary; pH ranges from 6.0 to9.0; resistance 4.25kg/cm2. The B-horizon at the depth of 60 –80cm is largely constructed from cemented nodules (carbonates-silica cementation) and strongly calcareous.

Mesa

LPu 211- Almost flat land

This map unit is dominated by Skeletic Petric Calcisols. These soils are very deep, somewhat well drained. Soils colours are brown to Very dark brown, brownish Yellow, very pale brown and Light yellowish brown. Fine sandy loam none to strong calcareous, clear and smooth boundary. pH is increasing from the surface to underlying horizons (5.0 to 9.0) and soil resistance 4.25kg/cm2. Broken nodular iron magnesium Concretion found in the sub surface B-horizons. Mixed coarse loose light greyish or white colour thick sand and gravel layer (pumice) is exists at the depth of 110 cm.

Escarpment

LPu 311- Scarp

Main soil is Umbric Lithic Leptosols. These soils are very shallow to shallow, well-drained, very dark greyish brown and dark olive grey, silt clay loam to sandy loam soils. 20 – 40% of the surface covered by hard bed rock (trachyte and basalt). Weathered sub-rounded stones are found in sub surface B-horizons. The transitions are diffuse and broken and pH is 5.5.

Mid Glacis

LPu 411- Sloping riser

Pre-dominant soil in the area is Arenic Andosols. I t has moderately deep, well-drained sandy loamy soils. The soil colours are Dark brown to brown, dark yellowish brown, Light brownish grey and Yellow. Accumu
lation of few rounded medium gravel rock fragments can be seen in sub-surface B-horizons. These soils are slightly sticky and slightly plastic and pH is varying from 5.5 to 7.5.

Low Glacis

LPu 511- Foot slope

The soil developed in the foot slope is found as Ferrelic Andosols. These are some what excessively well drained, very deep, Very dark brown to yellowish brown, sub-angular blocky structure, sandy loam to sandy clay loam soils. Transitions are abrupt and smooth in the sub soils. There are few fine gravel rock fragments in the surface A-horizon. The pH is gradually increasing (5.to 7.5) form topsoils to sub soils.

LPu 512- Sloping riser

The predominant soils in this unit are Mollic Andosols. The soils are shallow, well-drained, clay loam to loam very dark greyish brown to grey. Strong medium sub angular blocky structure; Slightly hard to hard consistence when dry; sticky and plastics; non-calcareous; clear and smooth boundary; pH 5.0.to 6.0. Few rounded weathered stones rock fragments found in B-horizon at the depth of 60 cm that is underlying by the
hard bedrock.

Vale

Bottom Dry River course (LPu 611)

The main soil of this unit is Ochric Fluvisols. The soils are very deep, excessively well drained, Dark brown to brown to pale brown Pale yellow, abrupt textural changes (coarse sand sandy loam loamy sand silt) from surface –horizon to sub surface B-horizons. The Bw3- horizon contains fragment of unweathered coarse gravel sub-rounded pumice. The pH is more than 8.0.

Pl - LACUSTRINE PLAIN

Lacustrine Plain is sub divided in to three relief levels: high terrace, middle terrace, and low terrace. High terrace and middle terrace consist of two landform units: high plain (Pl 111) & middle plain (Pl 211) and low terrace sub divided in to two landform levels: lower plain (Pl 311) and flood plain (Pl312).

High terrace

Pl 111 –higher part (almost flat)

Andic Cambisols is the main soil in the high plain. These silos are well-drained, very deep, very dark greyish brown to olive grey, silt clay to loamy soils. They have weak common sub-angular blocky structure, hard consistence when dry, slightly sticky and plastics, channels (elongate voids of faunal floral origin) fine and few/very fine and medium porosity; strong calcareous, and clear and smooth boundary. pH is vary from 5.5 to 8.5. These soils are developed on weathering of pyroclastic deposits association with volcanic ash the soils consists more than 10% clay, low bulk density. Andic B-horizon started within 33cm from the surface. These soils have high bearing capacity and high permeability.

Middle terrace

Pl 211 – intermediate part (flat)

The main soil in the mapping unit is Duric Andosols. The soils are Very dark greyish brown to olive brown, very deep, moderately well drained. The surface A-horizon consists of silt clay and sub- surface B-horizons have sandy clay loam to sandy loam.

The pH is gradually increasing from surface A-horizon to underlying B-horizons (5.5 to 8.5). The soils are developed on weathering of lacustrine deposits association with volcanic ash. The soils consist of more than 10% clay, low bulk density. Andic B-horizon started within 20cm from the surface. These soils have high bearing capacity and high permeability.

3. Low terrace

Pl 311 –lower part (almost flat)

The dominant soil in the unit is Ochric Glaysols. These soils are very deep, excessively drained, Very dark brown when moist and greyish brown when dry, sandy clay loam, moderate common sub-angular blocky structure; hard when dry, firm when moist, slightly sticky and slightly plastic when wet; non-calcareous and abrupt and wavy boundary. The pH is 7.5. The soils consist of high clay content, low bulk density. These soils have high bearing capacity and high permeability.

Pl 312 –bottom(Flat & liable to flooding)

The main Soil is Calcaric Fluvisols. The soils are imperfectly drained, extremely deep, olive grey to dark grey, sandy loam to loam soils. They have an A-C horizon sequence with irregular decrease of % carbon with depth and are stratified. The horizons transitions are clear and smooth becoming an abrupt and wavy in the sub soils. The soils in C-horizon are slightly to strong calcareous. The soils have low bulk density and extremely high permeability. pH is 8- 10.

5.1.2 Data presentation

The table 5.2 shows that the data collected form field tests & observations and laboratory analysis on soils and environmental conditions of the area .The geopedologic map unit on the column and soil and site properties on the raw are represented. These data are used in the matching process of evaluation. The analytical data table is prepared from the mechanical analyses performed in the soil-engineering laboratory, Ministry of Public works, Naivasha, Kenya (Table 5.3).

Table 5.1. Legend for Geopedologic Map (Naivasha Town)

Landscape	Relief	Lithology	Land form	Map Unit Code	Main Soils	Slope %	Area (ha)
High Plateau	Mesa	Longonot Volcano Akira Pumice Weathered Volcanic lava flows.		HPu 111	Ferrasols	0.5 –1 (nearly level)	135
	Vale	Alluvial deposits, Kedong valley tuff (trachyte ignimbrites and associated fall deposits).	Colluvium-alluvium complex (Steep slope)	HPu 211	Cambic Yamic Leptosols	10-30 (strong sloping	17
	Escarpment	Limuru trachyte, Karati and ol Mogogo basalt, Kinanhop tuff	Scarp (rise ridge)	HPu 311	Yamic Lithic Leptosols	> 60 (very steep)	56
Low Plateau	High glacis	Unconsolidated pyroclastic and alluvial deposits & Akira pumice	Back slope	LPu 111	SkeleticArenic Andosols	5 –10 sloping	176
	Mesa	Alluvial deposits, Longonot Volcano Akira pumice, Kedong valley tuff (trachyt e ignimbrites and associated fall deposits).	A most flat land	LPu 211	Calciols,Skeletic Calcisols	0.5-1 (nearly level)	200
	Escarpment	Limuru trachyte, Karati and ol Mogogo basalt, Kinanhop tuff.	Scarp (rise ridge)	LPu 311	Umbric Lithic Leptosols	15-50 (moderately steep)	45
	mid glacis	Alluvial deposits, Longonot Volcano Akira pumice, Kedong valley tuff (trachyte ignimbrites and associated fall deposits).	Sloping riser	LPu 411	ArenicAndosols	2-5 (gently sloping	164
	Low glacis	Alluvial deposits, Longonot Volcano Akira pumice, Kedong valley tuff (trachyt e ignimbrites and associated fall deposits).	Foot slope	LPu 511	Ferric Anthrosols	5-14 sloping	130
		Alluvial deposits, Eburru Pumice (pentallerite and trachyte pumice and Volcano ash fall deposits	Sloping riser	LPu 512	Mollic Andosols	5-10 sloping	54
	vale	Alluvial deposits, Kedong valley tuff (trachyte ignimbrites and associated fall deposits) and Longonot Volcano Akira pumice.	Bottom dry river course	LPu 611	Ochric Fluvisols	5-15 sloping	4.5
Lacustrine plain	High terrace	Unconsolidated volcanic ash and Lacustrine sediments	Higher part (almost flat)	Pl111	Mollic Andic Cambisols	0.5-2 (nearly level)	345
	mid terrace	Lacustrine sediments	Intermediate part (flat)	Pl 211	Duric Andosols	0 –0.2 (flat)	195
	Low terrace	Lacustrine sediments	Lower part (almost flat)	Pl 311	Ochric Glaysols	0 -1 (level)	55
			Bottom (flat & liable to flooding	Pl 312	Calcaric Fluvisols	0-0.2 (flat)	33

Table 5.2. Engineering properties and site conditions of soil map units

Map unit Properties	Unit	Hpu111	HPu211	HPu311	LPu111	LPu211	LPu311	LPu411	LPu511	LPu512	LPu 611	Pl 111	Pl211	Pl311	Pl312
Permeability	cm/hr	4	-	-	44	16	-	-	-	3	-	4	2	66	-
Shrink-swell	Class, %	High 7	High 8	-	Low < 3	Moder 6	-	-	-	High 9		High 8	High 8	High 7	High 7
CBR	%	5	-	-	9	9	-	-	-	3	-	4	9	11	-
Engineering. Soil classification (Unified)	Class	CL	CL	CL	SM-SC	CL	CL	SM-SC	CL	CL	SM	CL	CL	CL	SM-SC
AASHO GI	Index	A-7	A-6	A-7	A-2-4	A-6	A-6	A-2-4	A-6	A-7	A-4	A-7	A-6	A-7	A-4
PI	Index	20	-	-	-	15	-	-	-	17	-	20	20	14	-
Relative compac-tion	%	102			76	81		-	-	82		77	84.11	96	
Texture USDA	class	L	SiL	SiCL	SL	CL,L	SCL	SL	SL,SCL	C	SL,	CL	SCL	SL	FSL
Soil drainage	class	Sw.w.dr	we.dr	We.dr	We.dr	Sw.we.d r	We.dr	We.dr	Sw.ex.we. dr	We.dr	Ex.we.dr	We.dr	We.dr	Ex.dr	Im.dr
Depth to bed rock	cm	51	58	<20	>180	>180	<25	>180	>180	>180	52	>180	>180	>180	>180
Depth to water table	cm	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150	>150	120	60
Stoniness frac-tion>7.5 cm	%	2-15	40-80	>80	None	None	>80	0 - 2	None	5-15	5-15	None	None	None	None
Slope	%	0.5 -1	10-30	>60	5-10	0.5-1.0	15-50	2-5	5-14	5-10	5-15	0.5-2.0	0 –0. 2	0 - 1	0 – 0.2
Layer thickness	cm	51	58	<20	>150	>150	<25	>150	>150	>150	52	>150	>150	>150	>150
Flooding	class	None	Rare	none	None	None	None	None	none	none	Rare	rare	common	common	common
PH		5-5.5	5-7.5	6.5	6-9	5-9	5.5	5.5-7.5	5-7.5	5-6	8	5.5-8.5	5.5-8.5	7.5	8-10
Soil resistance	Kg/cm^3	3.25	-	-	4.5	4.5	-	>5				3.25	4.25	2.75	

Table 5.3. Soil engineering tests data

Profile No	Map unit	Physical properties									Geotechnical properties										
		Grain size % passing (sieve analysis)					Texture (hydrometer analysis)				Plasticity				Compaction (Lab density)		Field density		Relative compaction	CBR 4DAY SOAK	Permeability
		20 mm	2.0 mm	0.425 mm	0.075 mm	Unified Class.	Sand %	Silt %	Clay %	texture	LL %	PL %	PI %	LS %	MDD kg/m^3	OMC %	D kg/m^3	MC %	%	%	cm/hr
MP1	Pl311	100	98	76	56	CL	63	28	9	SL	44	30	14	7	1,245	36.1	1,190	18.4	96	11	66
FP1	Pl211	100	99	96	94	CL	49	25	26	SCL	48	28	20	8	1,321	30.1	1,112	32.9	84	9	3
MP2	Pl111	100	100	95	80	CL	28	32	40	CL	48	28	20	8	1,245	29.2	968	28.5	78	4	4
MP5	LPu512	100	100	96	71	CL	5	35	60	C	34	17	17	8	1,370	25.6	1,125	20.1	82	3	3
MP6	Lpu211	100	99	83	58	CL	30	43	27	CL	39	23	16	8	1,295	26.0	1,097	22.0	85	4	16
FP2	LPu211	100	96	80	64	CL	50	32	18	L	39	24	15	6	1,296	25.6	1,045	18.5	81	9	-
MP7	LPu111	100	99	87	46	CL	55	28	17	SL	NON PLASTIC				1,300	24.8	982	6.3	76	9	44
MP10	HPu111	100	96	81	84	CL	38	38	24	L	43	23	20	9	1,300	26.8	1,329	22.7	102	5	4

CL (Unified) : clay
SL : sandy loam
SCL : sandy clay loam
CL : clay loam
C : clay
L : loam

LL : liquid limit
PL : plastic limit
PI : plasticity index
LS : leaner shrinkage
MDD : maximum dry density
OMC : optimum moisture content

D : density
MC : moisture content

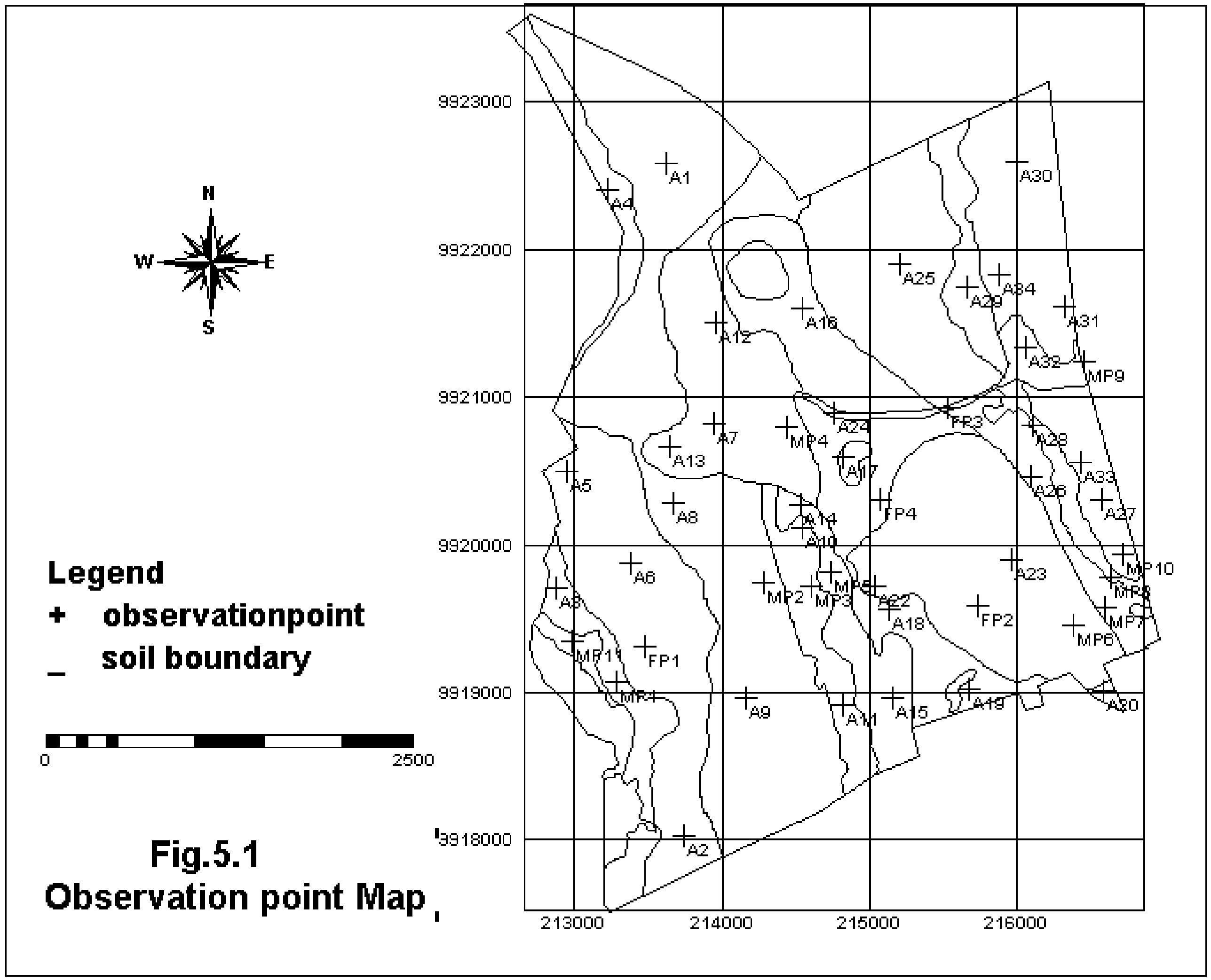


Fig.5.1
Observation point Map

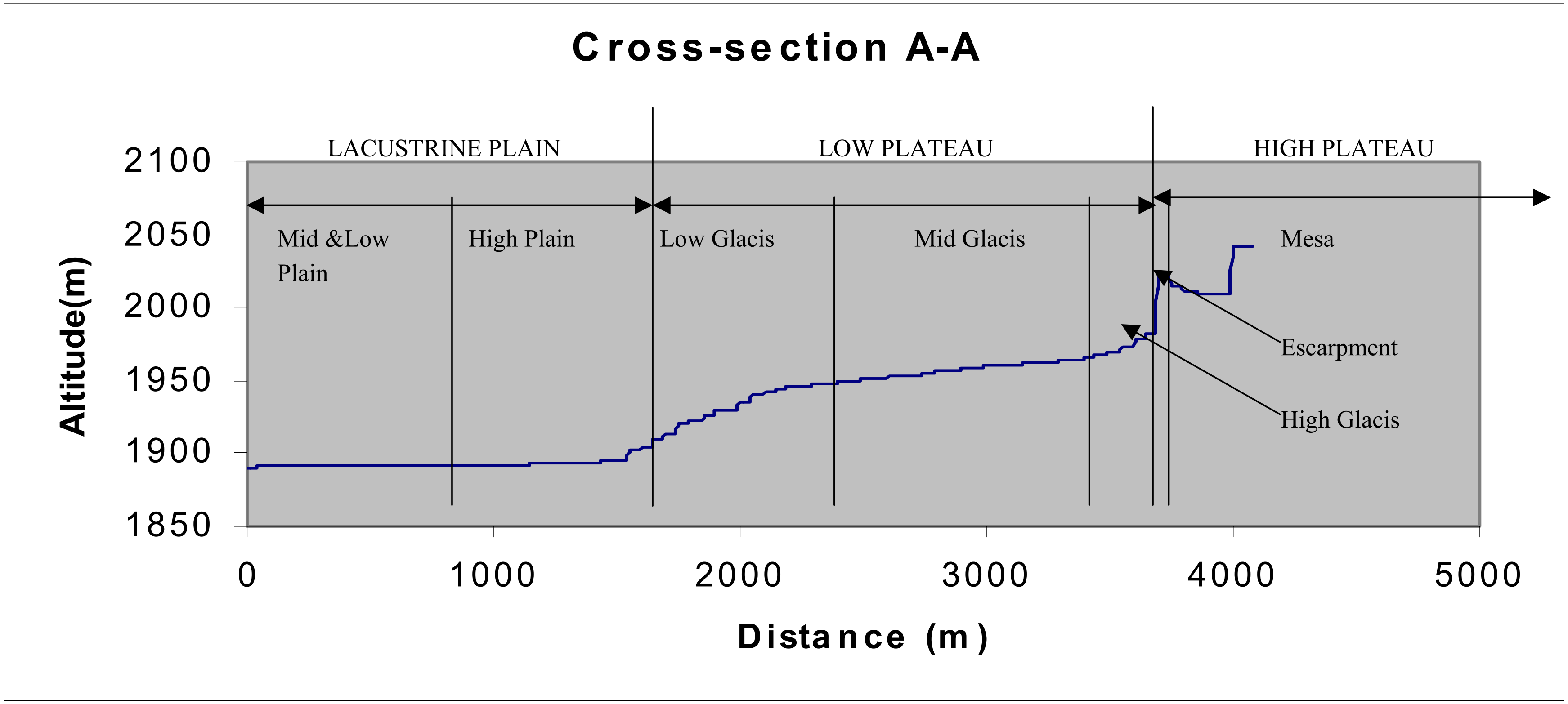


Fig. 5.2. Cross- section of the study area

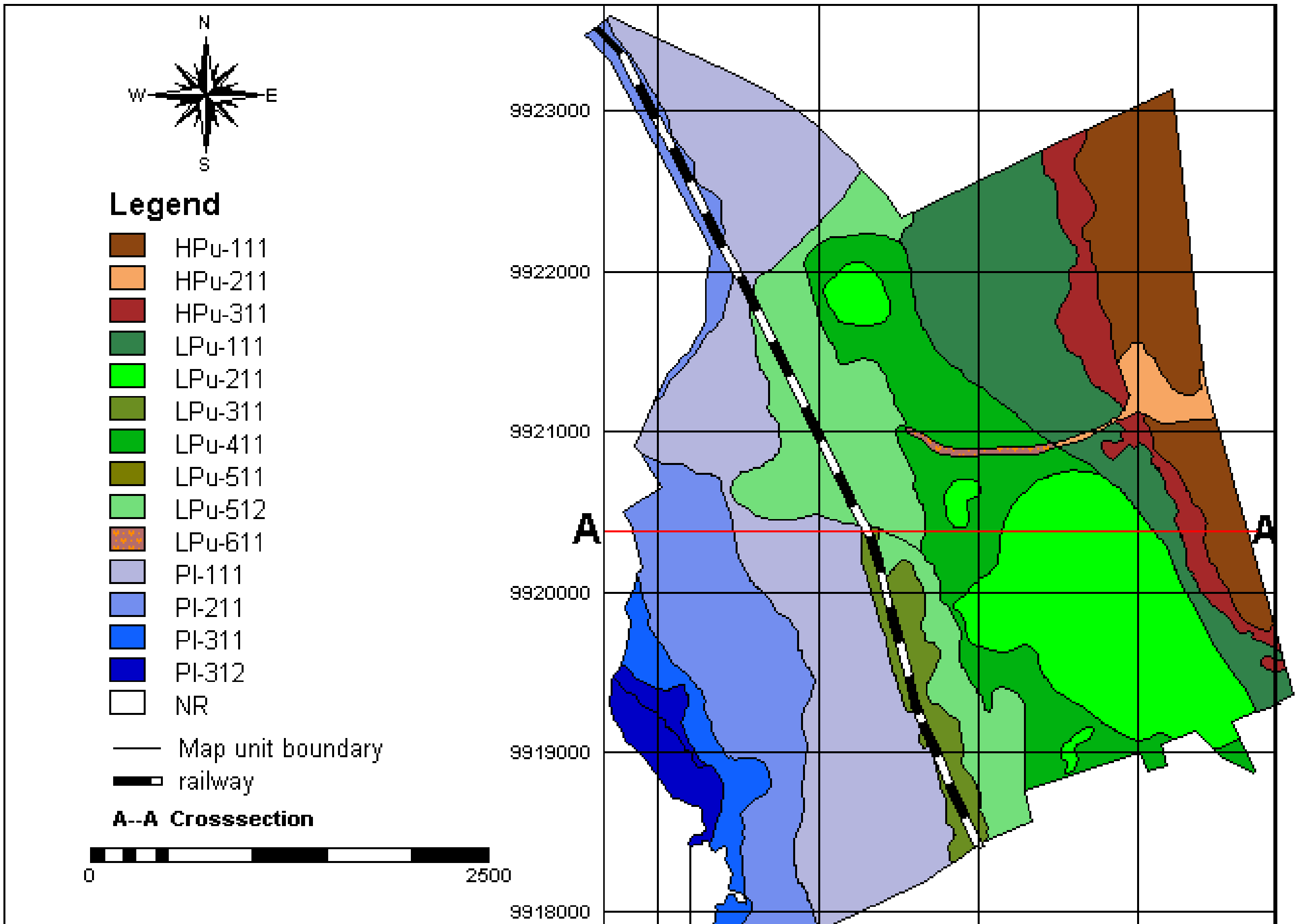


Fig.5.3
Geopedological Map of the study area

5.2 Analysis of existing land use & settlement pattern and major construction problems of housing & local roads

5.2.1 Analysis of existing settlement patterns in the study area

The area was formally occupied by pastoralists of the Maasai tribe from 18th century and grazing and watering their livestock on the Lake Naivasha (Kwacha, 1998). After migration of European considerable land use changes occurred due to beef & diary farming, irrigated agriculture, horticulture including flower production. However, landless people migrated from other parts of the country and settled down on the southern part of the lake where the pastoral activities were occurred. The new setters started to grow commercial agricultural crops (been, maize) clearing the vegetation cover around the settlements. The urban land use classification has 12 distinct categories (Table 5.4 & Fig.5.4).

Table 5.4 Urban land use – 2000, Naivasha town

Urban land use,	Area (Ha)
Residential high & low (which includes low, medium and high income classes)	231
Industrial (light and heavy)	67
Educational (primary and secondary schools plus other learning institutions)	84
Recreational (Open spaces and public gardens)	100
Public purpose (Municipal offices, administration offices, police station among others	284
Commercial (mainly CBD, market and retail activities)	54
Public utilities (Sewage treatment plant, solid waste dump site)	8
Transport (Railway station, petrol service stations, major highways)	226
Agricultural (Green houses and farming activities)	230
Future development (land reserved for residential development)	190
Reservation (road & railway)	19
Roads	139
Total land area	1639

Source: Based on Mbathi 2001.

The population density map (Fig.5.5) illustrates the population densities within Naivasha Town. *"Areas with highest population density are of residential land use specifically low income residential. These are located in the south west of the town and within a distance of 500 metres from the Lake Naivasha. The density here is greater than 130 persons per hectare. Areas with the lowest density are located in the Southeastern part of the town. These are inhabited by residents of higher status / income. Average plot sizes are 0.2 Hectares compared to the low-income areas with average plot sizes of 0.03 hectares (KBS, 1997)*" Mbathi 2001)).

"Three different human waste disposal methods are distinct in Naivasha town (Fig.5.6). These are municipal sewer, underground septic tanks, and pit latrines. The municipal sewer system covers approximately 400 ha (30%) of the town while septic tanks and pit latrines cover approximately 320 ha each. This implies that about 66% of the town relay's on septic tanks and pit latrines. The municipal sewer system covers the northern part of the town where density is not high. Low income (high density) surveyed areas mainly use pit latrines. Septic tanks are mostly used within the low density or high-income areas of the town"(Mbathi, 2001)

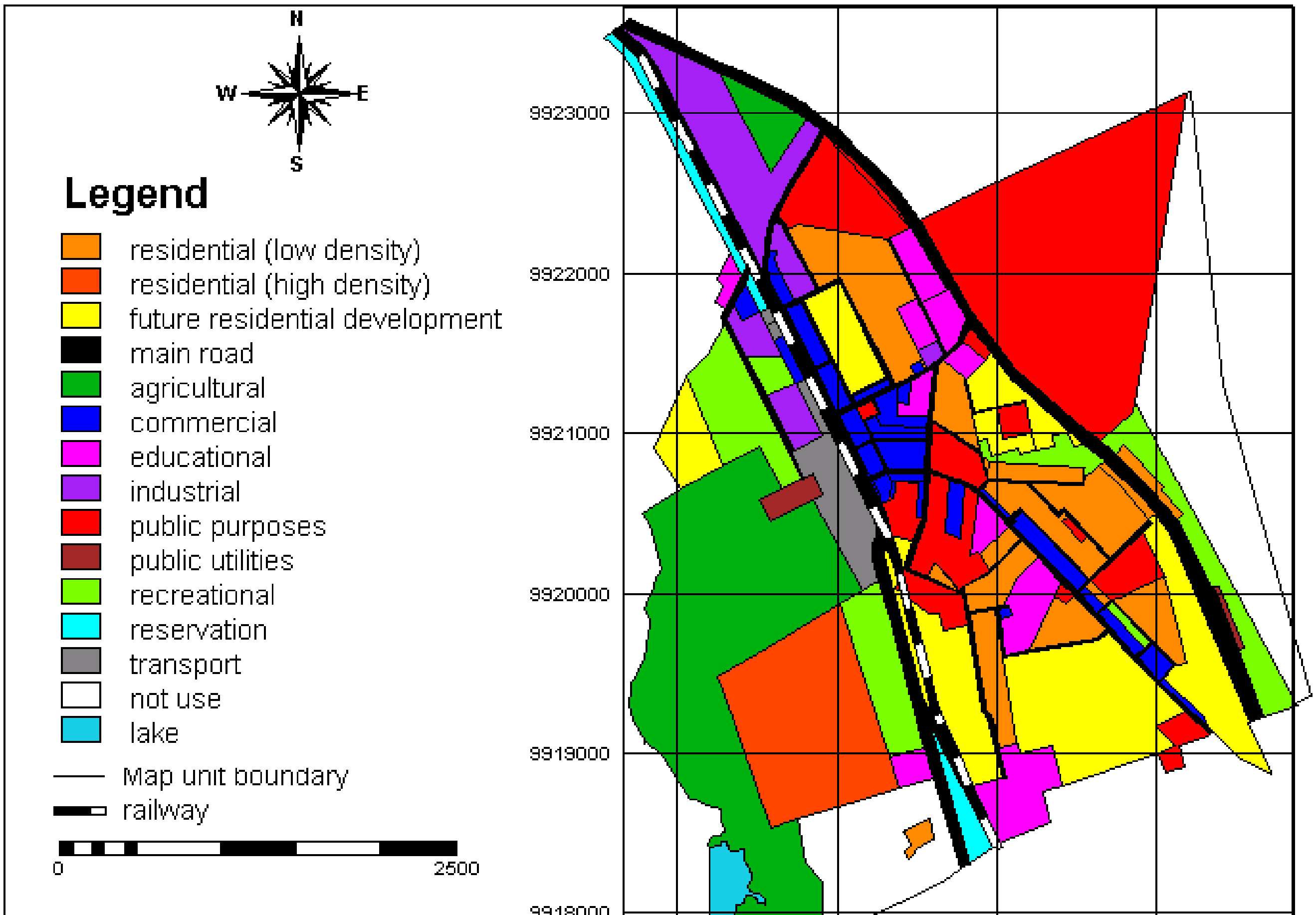


Fig.5.4
Urban land use Naivasha town -2000

Source: Based on Mbathi, 2001

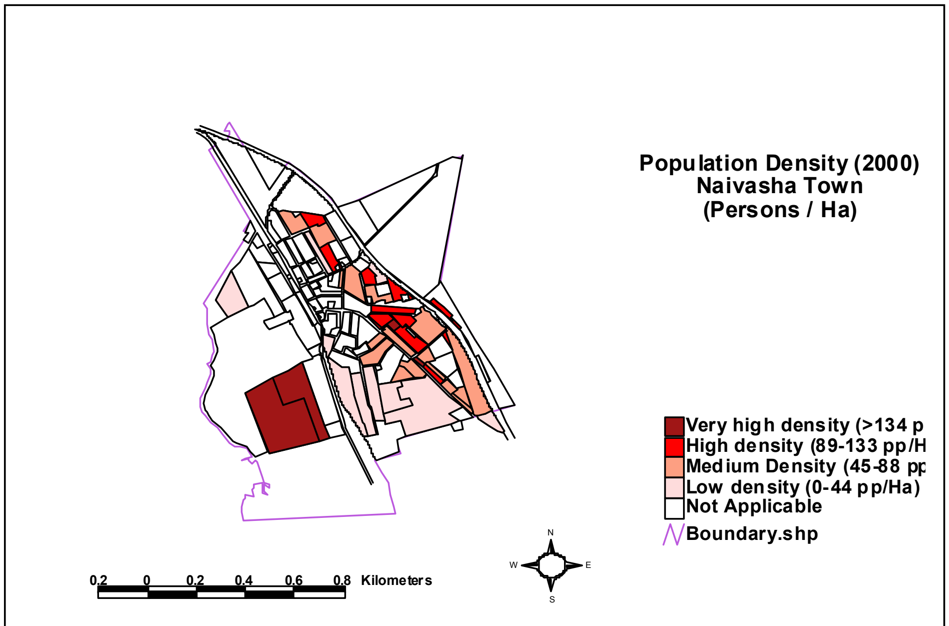
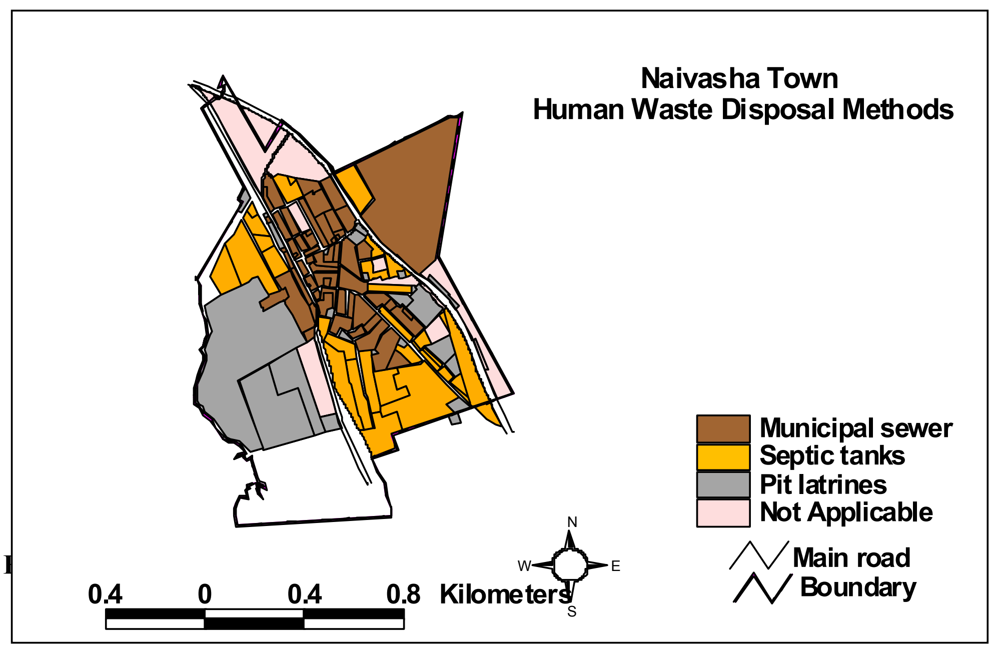


Fig.5.5 Population density –2000 (Source: Mbatia, 2001)



5.2.2 Major physical & construction problems of settlement relating to poor soil and site conditions

The main physical and construction problems prevailing in the area are as follows;

- Unplanned settlements development in inappropriate locations,
- Loss of irreversible agricultural lands due to expanding urban activities towards good agricultural lands & papyrus swamp, (For example, permanent houses are being built up in drainage valleys, which is causing severe storm water drainage problems and flooding during the rainy season(Becht, 2000)).
- Reduction of amount of water and water quality of the lake,
- Land degradation due to removal of vegetation.

This way of settlement development will not only increases the cost of construction and maintenance of infrastructure in the area but also greatly affects the environment.

According to the town engineer, Naivasha municipality and Environmental Impact Assessment (EIA) report of Lake Naivasha Riparian owners association, soils of the study area are clay soils which have high shrinking & swelling properties and high plasticity index. These soils are not good for housing (dwelling without basement) and road construction. Very few good soils are occurred in back slope of lower plateau.

In the study area, hard stones such as gravel and granite/basalt/trachyte conventionally used as construction materials for housing and roads. These materials are not available within economically viable distance. Although some rocks are available in the vicinity, there are many restrictions to use them.

According to the town engineer, Naivasha Municipality, most of the houses which had been constructed with out basements and unpaved roads in the lacustrine plain get damaged during the rainy season.

Approximately, 100 ha. (6%) of total land of the study area is belongs to large escarpments which have 60- 90 % been covered by hard rocks. These lands creates severe limitations for housing and local road construction because of very deep slope and rockiness. On the other hand lands in the flood plain (approximately 33 ha.) which are often liable to floods due to low elevation and flat terrain create structural failures of constructions (Photo 1 in Annex III). These lands are located within a range of 1 to 4 km from the CBD which can be considered as very valuable lands in the core zone which could not be used for urban development.

5.3 Suitability or limitation analysis

5.3.1 Assessment criteria

1n this research considers the engineering uses: dwelling without basement, septic tank absorption fields, shallow excavation, local road & streets, sources of gravel and sand, soils as a source of road fills. Specific property influence for these uses inferred from laboratory tests and field measurements & observations. Soil mechanical analysis was performed on mixed and disturbed sample from all hori zons. Some of the uses are selected preliminary infrastructure that should be requires during the establishment of housing scheme and others are selected based on need of construction materials.

The soil properties and site characteristics effecting selected uses are considered as prime factors in all cases. The rating tables, based on USDA – SCS rating guides for interpreting engineering uses of soil (Soil Survey Staff, 1971), National Soil Survey Handbook soil interpretation rating guides for building site development part 620.05 & 620.06 (Soil Survey Staff, 1999.) and other expert judgements were used. Some of the rating tables were modified according to the environmental condition of the area and standards/methods used in housing and road construction fields in the area. The rating tables include three severity classes: none to slight (NS) moderate (MO) and severe (SE). The limitation rating assess the degree of limitation that restricts the use of a site for a specific use.

Limitation class:

- *None to Slight* is given to soils that have properties favourable for the use. This degree of limitation is small & can be overcome easily and low maintenance can be expected.
- *Moderate* is given to soils that have properties moderately favourable for the use. This degree of limitation can be overcome or modified by special planning, design, or maintenance. Somewhat less desirable performance than soils rated slight can be expected.
- *Severe* is given to soils that have one or more properties unfavourable for the use. This degree of limitation generally requires major soil reclamation, special design, or intensive maintenance. However, some of the soils can be improved by reducing or removing the soil.

5.3.2 Limitation analysis for engineering uses

A Introduction

Limitation analyses for selected six engineering uses was carried out using matching procedure (matching and qualities (LQs) with land use requirements (LURs). The rating tables (Table 1 to 6 in Annex IV) & interpretation criteria for engineering uses and data in Table 5.2 and 5.3 were used for this purpose.

The results of the limitation assessment are shown for each engineering use. The interpretation tables (Table 1 to 6 in Annex V) show the limiting factors and severity limits per mapping units. Overall severity limit for map unit is assessed based on maximum limitation factor (MLF). Three terms are used to classify degree of limitation: none to slight (NS), moderate (MO) and severe (SE). The maps showing limitation for selected engineering uses are presented in Fig. 5.7 to 5.12.

B Results and discussion

a) Dwelling without basement

The result of matching table (Table 1 in Annex V) shows that foot slope (LPu111) mesa (Lpu211) in the high Glacis which are covered by 23. % of total land area have moderate limitation for housing constriction the whole land in the lacustrine plain and higher and escarpments in the lower plateau shows severe limitation for this use (Fig. 5.7). High shrinking and

swelling, shallow depth of bed rock, steep slope, presence of large stones, low strength of soil poor drainage and susceptibility to flooding are the major restrictive features.
Areas, that classified as moderate, have no limitation with respect to the properties influence for this use except Unified classification. Therefore these lands could be used for residential activities with some improvement of soil at a little cost.

b) Septic tank absorption field

Limitation assessment for septic tank absorption field (Table 2 in Annex V) shows somewhat deferent results as dwelling with out basement. The lands in mesa (LPu211) and back slope (LPu111) in the lower plateau, which have favourable environmental condition for residential activities, shows no or slight limitation for the constriction and maintenance of septic tank absorption fields. This area covered by approximately 20% of total land in the town. Although the dry vale (HPu211) and Mesa in the higher plateau and sloping riser (LPu411) of mid glacis, foot slope & sloping riser of low glacis in the lower plateau and high & mid plain in the lacustrine plain shows moderate limitations, only one property caused the map units make moderate limitation for this use.
The sloping land in the lower plateau, which have moderate limitations for dwelling with out basement also have moderate limitation for septic tank absorption fields due to steep slope.
Escarpments, higher & lower part of Lacustrine plain, have severe limitation for construction, maintenance and performance of septic tank absorption fields due to steep slope, poor drainage, flooding, wetness, poor filter, absorption and distribution of effluent form the septic tanks (Fig.5.8).

c) Shallow excavation

Severity limit map (Fig.5.9) shows that 34 % out of total land in the town have severe limitation for shallow excavation. This is due to shallow depth to rock, steep slope, presence of large rock out crops, flooding are restricting the ease excavation.
Although, whole lands in the lacustrine plain and mesa in the lower plateau have only two severe limitations, which are less important and rarely influenced. For example, lands in the lacustrine plain have only flooding as a restrictive feature, which may occur once in ten years. All other important factors cause no limitations (Table 3 in Annex V).
The high residential areas (LPu111, LPu211), where excavation works required being no limitations show favourable conditions (NS).

d) Local roads and streets

The attribute map (Fig.5.10) for local roads and streets also shows the almost same results as source of gravel & sand. Except dry vale, whole other areas reflect severe limitation for the construction, maintenance and performance of roads. The main reason of this situation is that unfavourable condition of highly influenced properties such as soil strength and shrink-swell for road construction.

The limitation factors are shrinking and swelling of soil, low strength, low bulk density, high compressibility, shallow depth to rock, steep slope, large stones, wetness and flooding (Table 4 in Annex V).

e) Possible sources of gravel and sand

This is the limitation map (Fig.5.11) which has only one limitation class: severe. Low strength of the soil is strongly effected for this situation. According to the Unified classification soils in the area are clayey soils (more than 50% passes through No 200 (0.075mm). These soils classified as fine grained in the unified classification chart. Unified classification is the main property influenced for possible source of gravel and sand. The restrictive features are too clayey for sand, small stones and excess fine. But there are some possible gravel deposit underlying the soils of foot slope (LPu111) and mesa in the lower plateau. Although, the whole area shows the severe limitation for this use, still some lands in the area could be used as sources of gravel (Table 6 in Annex V).

f) Soils as source of road fills

The limitation Table 5 in Annex V for road fill reveals those three classes of severity. Soils in the back slope of high glacis in the lower plateau (LPu111) have no or slight limitation for sources of road fill (Fig.5.12). These soils can easily be used for road construction works as road fills materials because, large part of this unit is devoted for forest plantation and no building area.

Soils in the almost flat lands (LPu211) of mesa in the lower plateau have moderate limitations for this use due to low strength and high shrinking and swelling behaviour of soil. Except these two restrictive features, all other factor influenced for road fills give no limitation.

Except above mentioned two mapping units, soils in all other lands have severe limitation for this use. Low strength of soil, steep slope, high shrinking and swelling behaviour, shallow depth to rock, large stone, thin layer, low compaction and low bearing capacity are strongly effected for this situation.

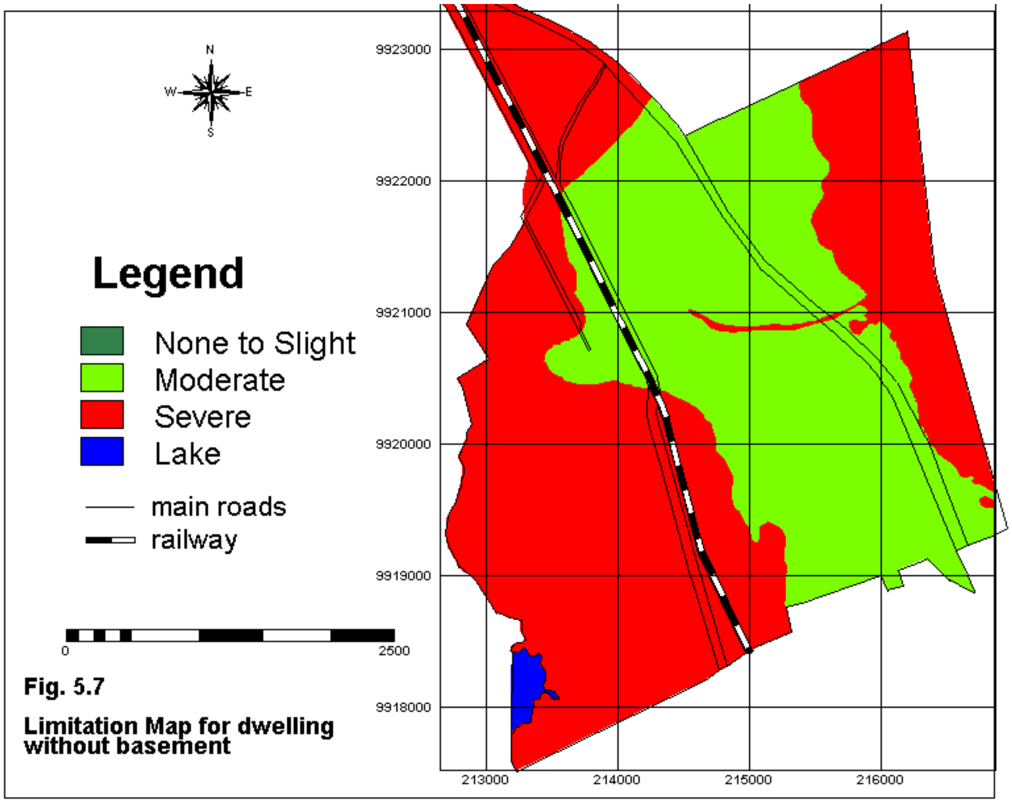


Fig. 5.7

Limitation Map for dwelling without basement

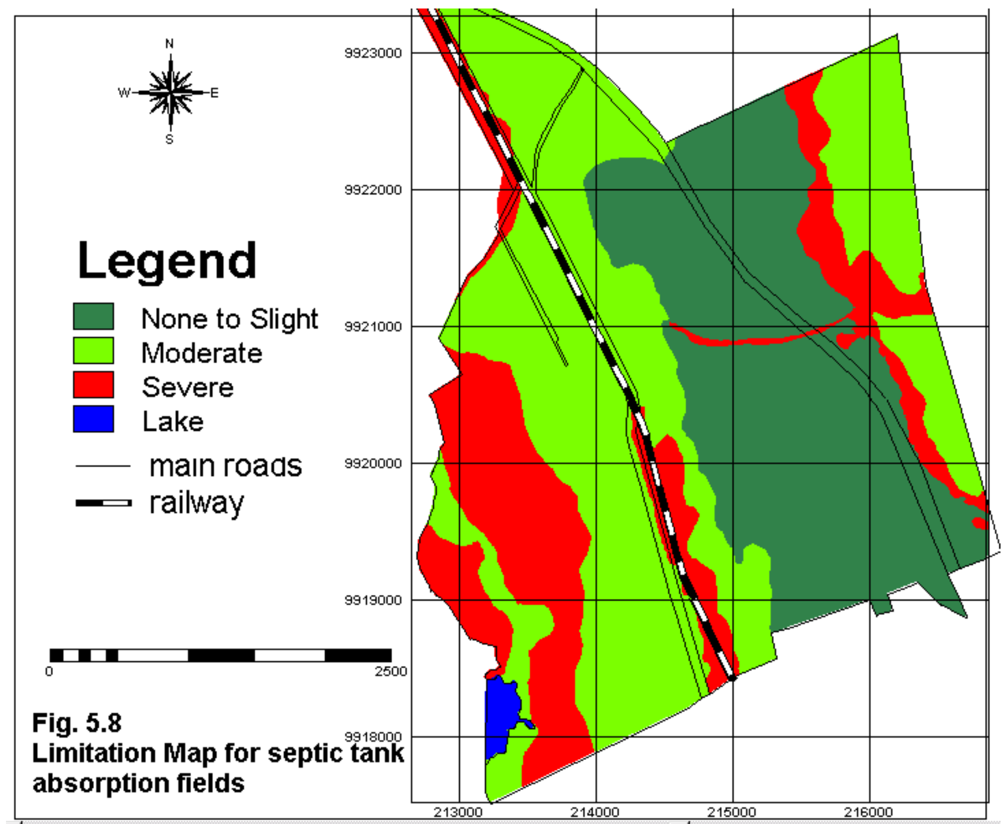


Fig. 5.8
Limitation Map for septic tank absorption fields

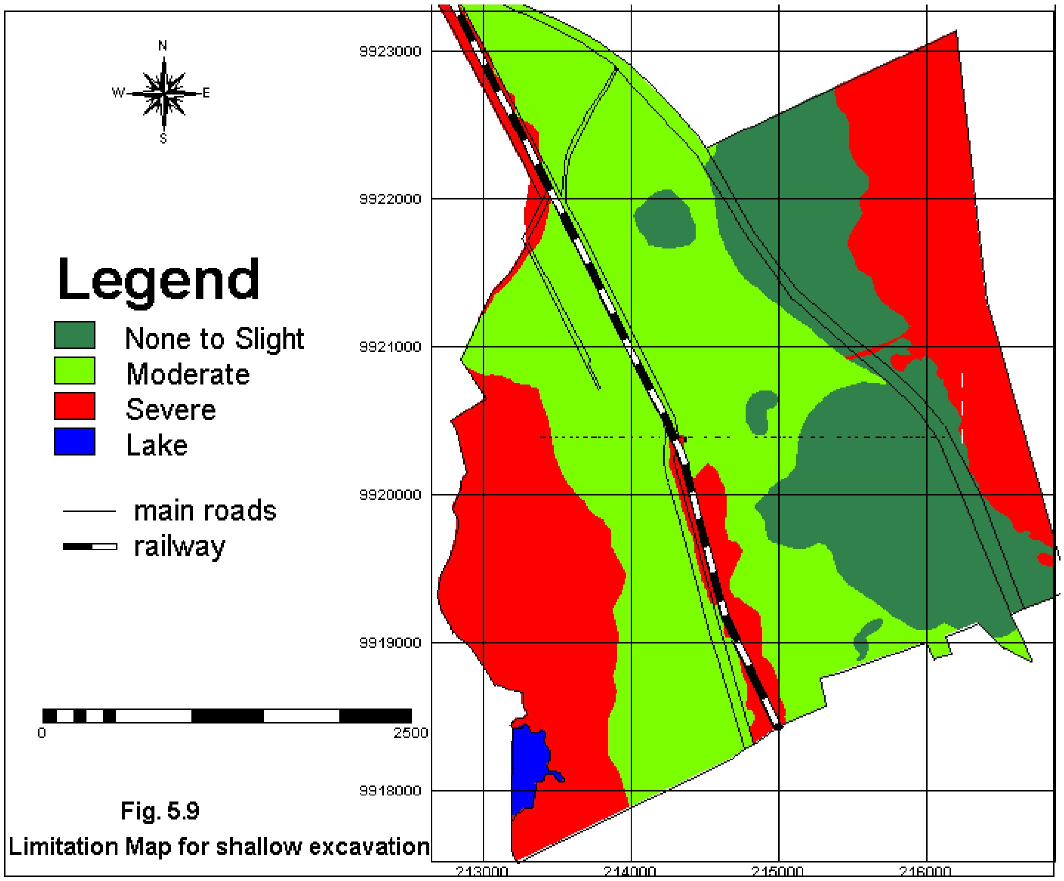


Fig. 5.9
Limitation Map for shallow excavation

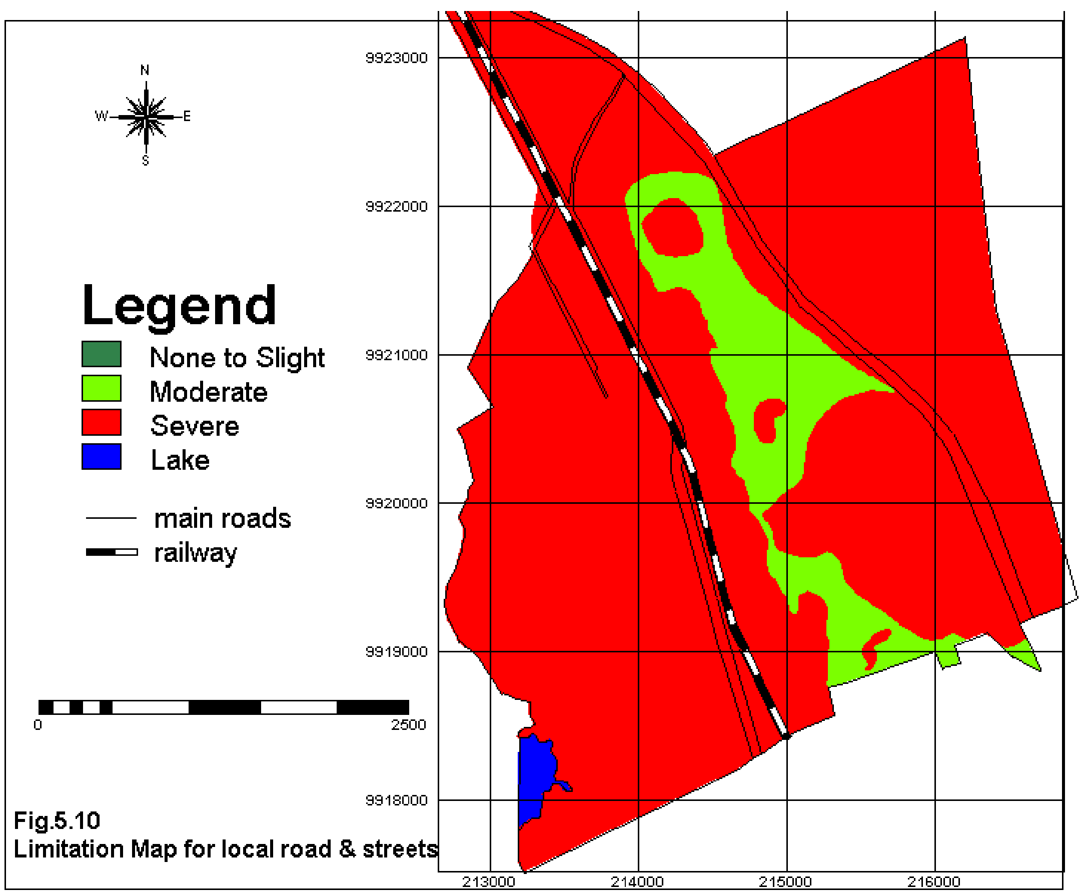


Fig.5.10
Limitation Map for local road & streets

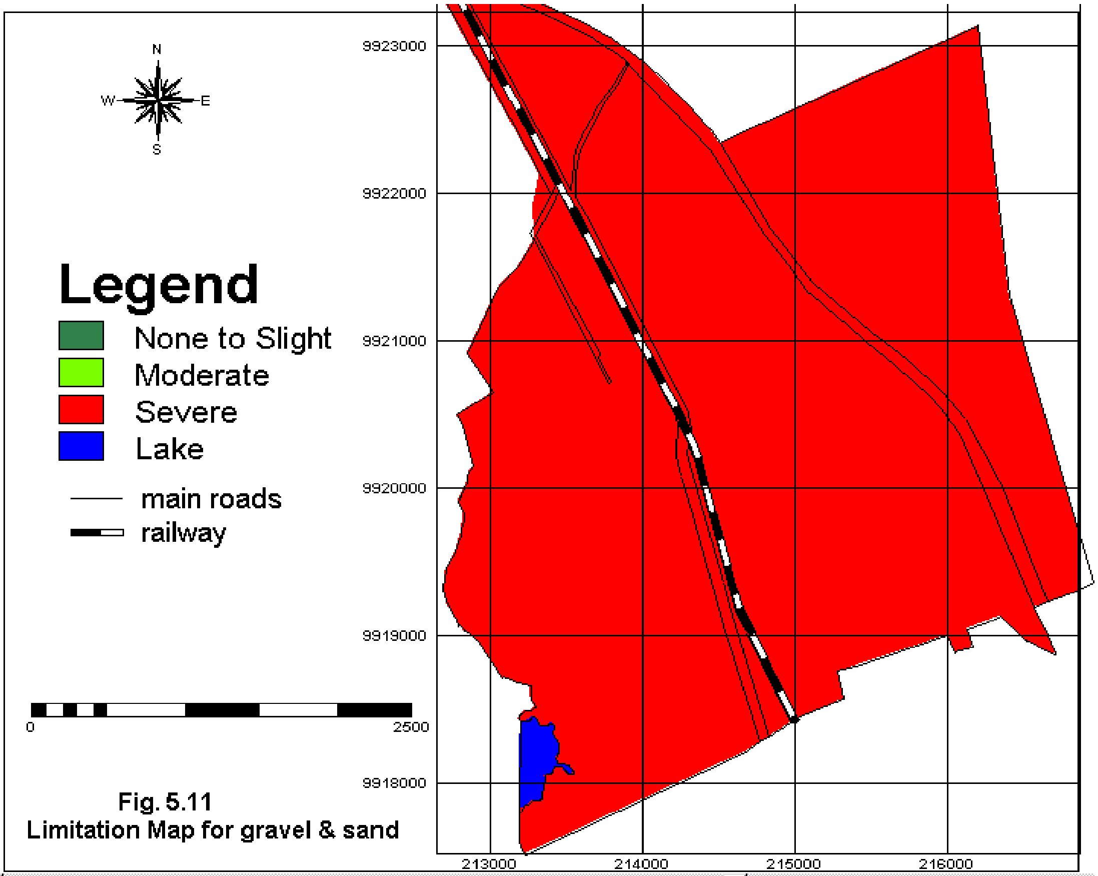


Fig. 5.11
Limitation Map for gravel & sand

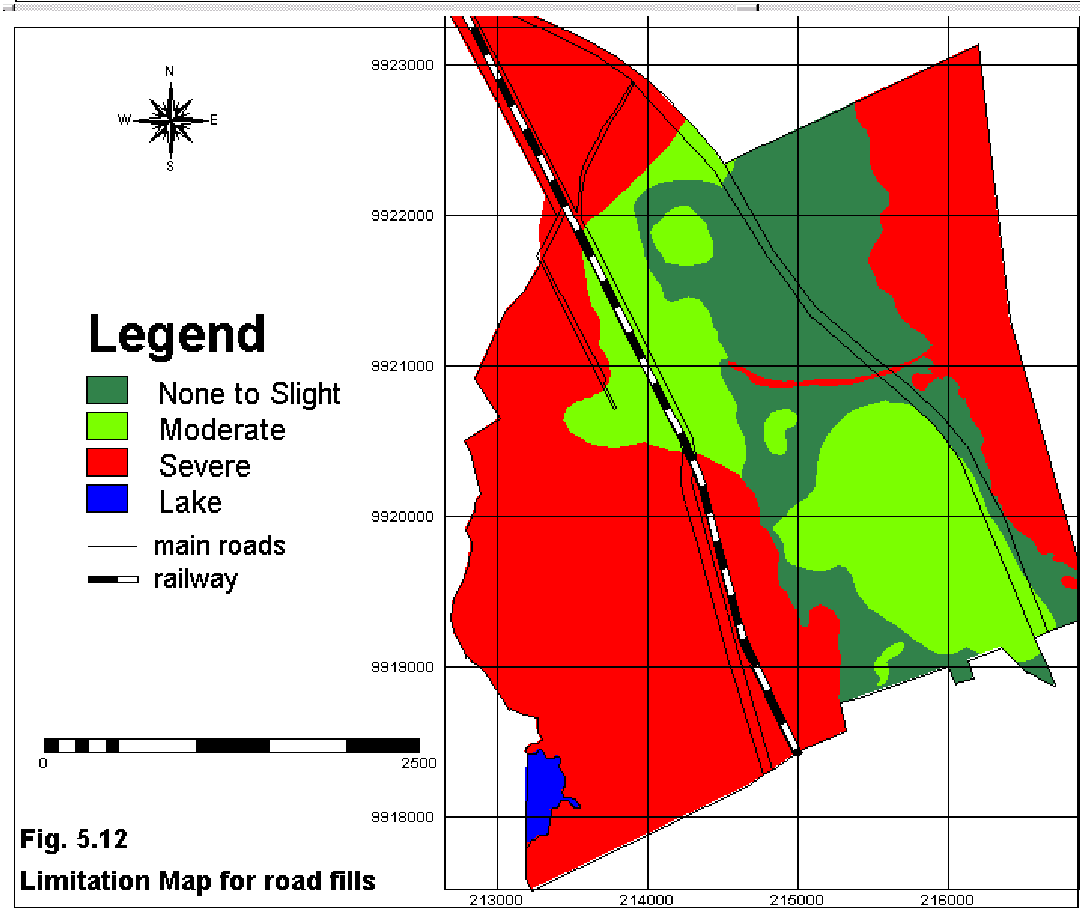


Fig. 5.12
Limitation Map for road fills

5.3.3 Limitation analysis for housing construction

A Introduction

Site planning for housing construction usually involves socio-economic, political, infrastructure and land & environmental factors. But, in this research evaluate the influence of some soil properties and site conditions.
The attribute maps (Fig.5.7, 5.8 and 5.9) produced to show the limitation for the selected engineering works, are used for the limitation or suitability analysis for housing construction. Overlaying the attribute maps performed the model and two approaches were executed: unweighted approaches and weighted approaches.

B Unweighted approach

a) Approach

The objective of the analysis is to answer the question such as which area has none, moderate and severe limitation and for housing construction. This approach is a simple overlaying of attribute. In this approach each attribute is given equal importance to decide on the final limitation of deferent mapping units. Attribute maps of severity limits for selected three uses: dwelling with out basement, septic tank absorption fields, and shallow excavation is involved in the overlay operation. Based on limitation tables of these three uses, a new table (Table 5.5) was prepared. The resulted rating table was incorporated in ILWIS and using "Mapcalc" the overlay operation was executed to produce a final limitation map for housing construction.

b) Assumptions

Each attribute is as important as the others for the selection of housing locations. Most limiting factor is assigned to each map unit controls its final limitation for a particular use. There is no any kind of weighting and order of overlaying.

c) Procedure

A new table (Table 5.5) was created in ILWIS combining the overall severity limit columns of attribute tables of three uses, reclassify the three selected attributes and create a new column. Using ILWIS operation "Mapcalc" a new map of limitation for housing construction (Fig. 5.13) was generated.
The function used is:
Mapcalc>ulh: =WULH. ULH[solniv].
Where;
ulh = new Map of unweighted limitation classification
WULH = limitation table
ULH = unweighted limitation column *solniv* = soil map of Naivasha town

Table 5.5 Limitations for housing construction (weighted & uneweighted overlay)

MAP UNIT	DWB	SAF	SHA	ULH	WLH
Almost flat land	Moderate	None to Slight	None to Slight	Moderate	Moderate
back slope	Moderate	None to Slight	None to Slight	Moderate	Moderate
Colluvium-alluvium complex	Severe	Severe	Severe	Severe	Severe
dry river course	Severe	Severe	Moderate	Severe	Severe
Bottom liable to flooding	Severe	Severe	Severe	Severe	Severe
foot slope	Moderate	Moderate	Moderate	Moderate	Moderate
higher part	Severe	Moderate	Moderate	Severe	Severe
LAKE	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
lower part	Severe	Moderate	Severe	Severe	Severe
low scarp	Severe	Severe	Severe	Severe	Severe
Intermediate part	Severe	Severe	Severe	Severe	Severe
scarp	Severe	Severe	Severe	Severe	Severe
sloping riser M	Moderate	None to Slight	Moderate	Moderate	Moderate
sloping riser	Severe	Moderate	Moderate	Severe	Severe
Undulating land	Severe	Moderate	Severe	Severe	Severe

DWB : dwelling with out basement
SAF : septic tank absorption fields
SHA : shallow excavation
ULH : unweighted limitation for housing
WLH : weighted limitation for housing

C Weighted approach

a) Approach

Weighted approach is a discriminative overlaying operation of three-selected attribute maps: dwelling without basement (DWB), septic tank absorption field (SAF) and shallow excavation (SHA).

b) Assumptions

1. The most limiting factors are assigned to the soil map unit.
2. Some attributes are more important than others for housing construction.
3. Dwelling with out basement is the most dominant factors for housing development in the area.
4. Septic tank absorption fields are the medium in order. Because, it is assumed that individual septic tank are used in the area, which are not connected to sewerage system.

5. Shallow excavation is the lower in order, because soils in most of the areas are fine grained and loose materials. Although some areas have shallow bedrock, the top layer of rocks can be excavated with simple equipment. Therefore excavation is not a problem.
6. Sources of gravel and sand and road fills are not a big problem in the area because; they are available in the closed proximity to the housing development site. Therefore, these attributes are not considered in this analysis.

c) Weighting criteria

For the three attribute maps, weightings are assigned by considering their importance for housing construction. Therefore dwelling with out basement is given high weight, septic tank absorption fields given medium weight and shallow excavation is assigned lower weight. The criteria implemented for the analysis is shown in table 5.6.

Table 5.6. Limitation weighting criteria matrix (housing)

Class/attribute	DWB	SAF	SHA
None to slight (NS)	11	3	2
Moderate (MO)	5	2	1
Severe (SE)	0	0	0

According to the Table 5.6, weights were assigned to each use. Then added weights of each use. Finally, the added weights reclassified in to limitation classes. As per the weights in the table, maximum weight for class NS of dwelling without basement can be 16 and minimum can be 11. For moderate class, maximum can be 10 and minimum should be 5. Class severe should be between 0 to 5. Therefore, weights between 0 to 5, classified as severe (SE) limitation, 6 to 10 is moderate (MO) and 11 to 16 is none to slight (NS)(See Table 5.5).

d) Procedure

Based on the weighting criteria matrix (table 5.6), reclassify the three selected attributes and a new column called "WLH" (weighted limitation for housing) was created in the table 5.5. And using ILWIS operation called "Mapcalc" the map of weighted limitation for housing development is created to produce weighted limitation map for housing construction (Fig. 5.13)

The function used is:

Mapcalc>wlh: =WULH. WLH[solniv].
Where
wlh = new Map of weighted limitation for housing construction
WULH = limitation table
WLH = weighted limitation column *solniv* = soil map of Naivasha town

D Results and discussion

The outcome of both weighted and unweighted overlay operations does not show any difference. Hence the results have been merged together onto as one map (Fig.5.13.). There is no any land in the area, which has no limitation for the selected engineering uses. Map unit back slope, sloping riser and almost flat land in the lower plateau, and foot slope in lower glacis and whole land in the lacustrine plain have moderate limitations for housing constructions. The limitations map of dwelling without basement has been strongly affected for this situation. Although the septic tank absorption field and shallow excavation have no limitation, dwelling without basement has moderate limitation in back slope and almost flat land in the lower plateau. All other mapping units including lacustrine plain in the area have severe limitation for these engineering uses. Most limiting factors effecting for the construction limitations are steep slope, susceptibility to flooding, low strength of soils low bearing capacity, high shrinking and swelling behaviour of soils in the area.

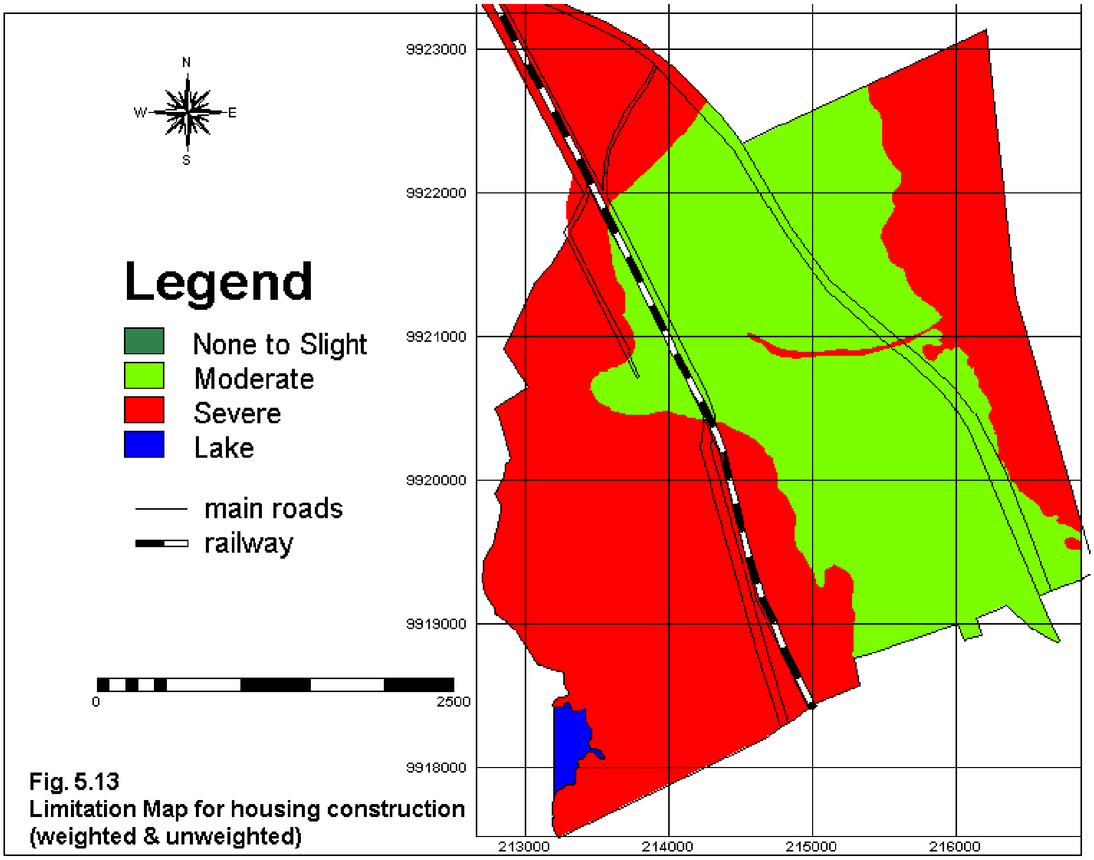


Fig. 5.13
Limitation Map for housing construction (weighted & unweighted)

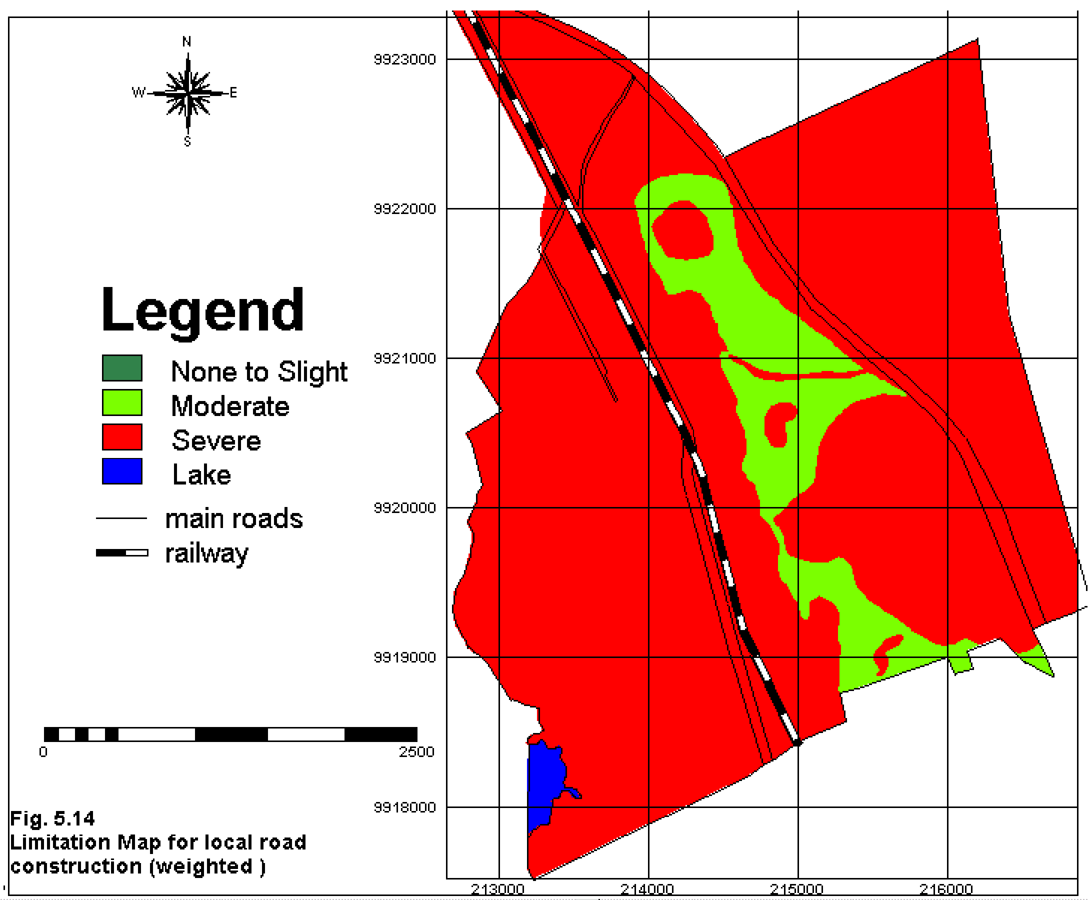


Fig. 5.14
Limitation Map for local road construction (weighted)

5.3.4 Limitation analysis for local road constructions

A Introduction

The main idea of this limitation analysis is to evaluate the influence of some soil properties and site conditions for local road construction. Limitation attribute maps: local roads & streets, shallow excavation, possible sources of gravel & sand and soil as a source of road fills are selected for this analysis by considering the relationship with road construction. Approaches and procedures for this analysis are similar as analyses for housing construction.

B Unweighted approach

a) Approach

The approach is same as unweighted approoach of limitation analysis for housing construction

b) Assumptions

Assumptions are similar as unweighted analysis for housing construction.

c) Procedure

The function used to produce the Map of unweighted limitation for road construction is:
Mapcalc>ulr: = WULR. ULR[solniv].
Where
ulr = map of unweighted limitation classification for roads
WULR = limitation table
ULR = unweighted limitation column
solniv = soil map of Naivasha town

C Weighted approach

a) Approach

Weighted approach is a discriminative overlaying operation of four-selected attribute maps: local road &streets (LRS), shallow excavation (SHA), sources of gravel & sand (GS) and soil as a sources of road fill (RF).

b) Assumptions

1. The most limiting factors are assigned to the soil map unit.
2. Some attributes are more important than others for road construction.
3. Local road & streets is the most dominant engineering use for road construction.
4. Shallow excavation is the medium in order. Because more excavation works are required due to unfavourable terrain conditions (e.g. steep slope and rock out crop in plateau).
5. Sources of gravel and sand and road fills are not a big problem in the area because; they are available in the closed proximity to the construction site (gravel deposits are available underlying the soils in back slope area which have not yet been tapped). Therefore, these attributes are the lower in order.

c) Weighting criteria

For the four attribute maps, weightings are assigned by considering their importance for road construction. Therefore local road & street (LRS) is given high weight, shallow excavation (SHA) given medium weight and sources of gravel & sand (GS) and road fill (RF) are assigned lower weight. The criteria implemented for the analysis is shown in table 5.8.

Table 5. 7. Limitation for road construction (weighted & unweighted overlay)

	LRS	SHA	SG	RF	ULR	WLR
almost flat land	Severe	None to Slight	Severe	Moderate	Severe	Severe
back slope	Severe	None to Slight	Severe	None to Slight	Severe	Severe
colluvium-alluvium complex	Severe	Severe	Severe	Severe	Severe	Severe
dry river course	Moderate	Moderate	Severe	Severe	Severe	**Severe**
bottom liable to flooding	Severe	Severe	Severe	Severe	Severe	Severe
foot slope	Severe	Moderate	Severe	Moderate	Severe	Severe
higher part	Severe	Moderate	Severe	Severe	Severe	Severe
LAKE	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant	Not Relevant
lower part	Severe	Severe	Severe	Severe	Severe	Severe
low scarp	Severe	Severe	Severe	Severe	Severe	Severe
Intermediate part	Severe	Severe	Severe	Severe	Severe	Severe
scarp	Severe	Severe	Severe	Severe	Severe	Severe
sloping riser M	**Moderate**	Moderate	Severe	**None to Slight**	Severe	**Moderate**
sloping riser	Severe	Moderate	Severe	Severe	Severe	Severe
undulating land	Severe	Severe	Severe	Severe	Severe	Severe

LRS : local roads & streets
SHA : shallow excavation
ULR : unweighted limitation for roads
WLH : weighted limitation for roads
SG : source of gravel &sand
RF : soils as a road fills

Table 5.8. Limitation weighting criteria matrix (roads)

Class/attribute	LRS	SHA	RF	GS
None to slight (NS)	12	3	2	2
Moderate (MO)	5	2	1	1
Severe (SE)	0	0	0	0

According to the table 5.8,weights were assigned to each use and each mapping unit. Then added weights of each use. Finally, based on the weighting criteria, the added weights reclassified in to limitation classes. Weights between 0 to 7, classified as severe (SE) limitation, 8 to 13 is moderate (MO) and 14 to 19 is none to slight (NS). Based on the weighting criteria matrix, a new column called "WLR" (weighted limitation for roads) was created in the Table 5.7 to produce weighted limitation map for road construction (Fig. 5.14).

a) Procedure

The function used is:

Mapcalc>wlr: =WULR. WLR[solniv].

Where;

wlr = new Map of weighted limitation for road construction

WULR = limitation table

WLR = weighted limitation column *solniv* = soil map of Naivasha town

D Results and discussion

The unweighted limitation map shows that total lands in the area have severe limitation for road construction. The attributes: local roads and streets and gravel and sand strongly effected to make the map unit severe limitation. As most of the soils in the area are fine grained and clayey soils, they have properties such as low strength, high shrinkage, poor load bearing capacity, low compaction which are strongly effected to make the map unit severe limitation. Additional cost would be involved to correct the restrictive features that effected.

The weighted limitation map (Fig.5.14) shows map unit slopping riser in the lower Plateau shows moderate limitation. These lands can be used for road construction with special design and some additional cost. But all other mapping unit require major soil improvements or reclamation and special design or intensive maintenance due to the effect of unfavourable soil properties

5.3.5 Limitation analysis for existing & proposed urban residential land use

A Introduction

Main objectives of this analysis are;

1. To identify and classify existing housing and local road land uses located on moderate and severe limitation areas.
2. To identify non-urban/ non-residential, moderate or no limitation areas available for future development.

This analysis was executed by using limitation for housing construction (Fig.5.13), limitation for road construction (Fig. 5.14), urban land use (Fig. 5.4). In this analysis land use type residential, transport and road are considered. Existing housing areas and road network are classified in to which are located on zones that none to slight moderate and severe limitation for construction. Limitations are based on soils and site characteristics in the area.

B Procedure

Using *MapCross,* a new table showing limitation for construction for both housing and roads is produced.

The function used is:

MapCross(wlh.mpr,wlr.mpr, wlhr.tbt)

Where *wlhr* = new map created

wlh = final weighted limitation map for housing construction
wlr = final weighted limitation map for road construction
wlhr.tbt = related cross table

Once the cross map (limitation for housing and roads) created, using the same function a new map showing the combination of existing land uses and limitation zones for constructions is produced. The function used is as follows:

MapCross(laduse.mpr,wlhr.mpr,lluse.tbt)

Then a new column (lrd) is created using new domain (resi) in the cross table (lluse) to produce a map showing limitation for residential development. The function to create the new map is given as:

lrd: lluse.mpr.lluse.tbt.lrd.

where: *lrd* = new map showing limitation for residential development
lluse.mpr = crossed map(land use, limitation for housing and limitation for roads)
lluse.tbt = cross table *lrd* = new column used to create new map.

C Results and discussion

High-density residential areas in the Lacustrine Plain are located on the severe limitation zone for housing construction (Fig.5.15). It is clear that most of the physical problems related to housing construction are due to unfavourable soil and site condition in these residential neighbourhoods.

Low-density residential areas of back slope (LPu111), sloping riser (LPu4111), almost flat land (LPu211), in the lower Plateau are falling within the moderate limitation zone for residential development. The low-density residential neighbourhoods located in lower escarpment (LPu311) and lower glacis (LPu512) have severe limitation for construction. There is no any kind of residential area within the town, which have no limitation for housing construction

Total land extent of residential (high and low-density) use within the town is about 231 ha. Out of total 56% is located within severe limitation areas for residential development. Total lands used for high-density residential activities are located within the severe limitation zone for housing construction.

The total land extent covers by the road net work of the town is approximately 140 ha. 70% out of total is local roads & streets (Photo 2 in Annex III). Both categories of roads are falling within the area of severe limitation for road construction.

According to the town development plan of the city, land has not been devoted for residential development in the Lacustrine Plain. The reasons are unfavourable physical conditions such as susceptibility to flooding prevailing in the area. The results of this study also reveals that, the lands in the Lacustrine Plain have severe limitation for residential development due to low strength of soils, wetness and high shrinking and swelling of soils etc. The lands reserved for future residential development, especially in the higher part of the lower Plateau are falling within the moderate limitation zone for residential development. The reserved land for future development located adjacent to the Central Business District (CBD) have severe limitation for residential development (Fig.5.15).

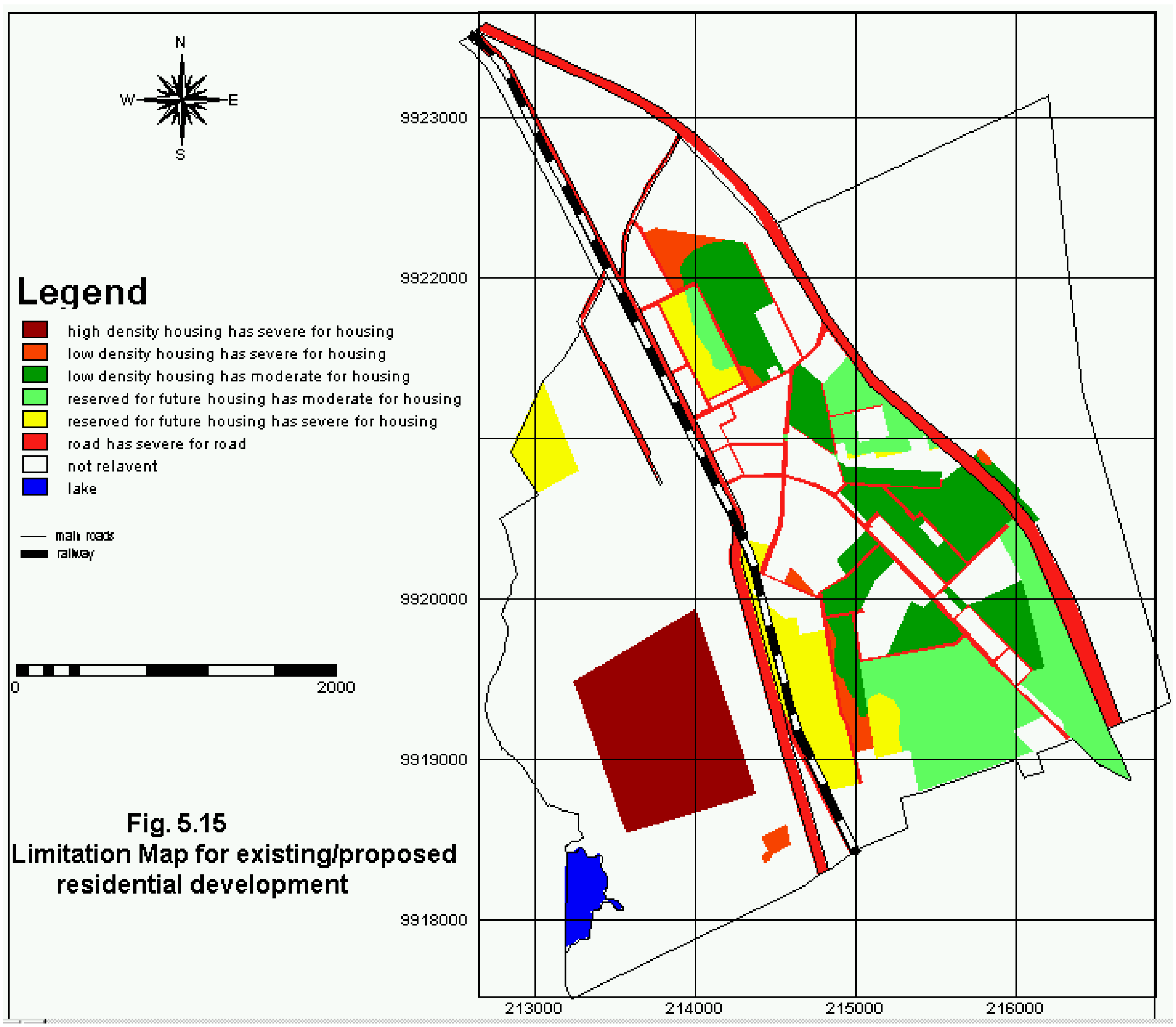


Fig. 5.15
Limitation Map for existing/proposed residential development

6 Conclusions and recommendations

6.1 Conclusion

6.1.1 Physical and construction problems in the area

Problem of housing development in inappropriate locations due to rapid urbanisation growth has been created most of the physical and socio-economic problems in the Naivasha town.
Problems related to housing and local roads construction due to unsuitable soil conditions (too clayey, low strength, low bearing capacity low compaction capacity, high shrink-swell of the soil) and site conditions (steep slope, rockiness, flooding hazards) are the main issues. Problems such as sewerage system failures due to high water table and poor filter (low permeability), structural fallers in engineering works due to poor soil conditions and high maintain cost of roads.

6.1.2 Settlement related Land Utilisation Types (LUTs) and their requirements

As settlement related LUTs dwelling without basement, septic tank absorption fields, shallow excavation, local road & streets, sources of gravel and sand, soils as a source of road fills were identified. Dwelling without basement, septic tank absorption fields, shallow excavation were selected as basic uses in housing construction and they were used in suitability assessment through limitation analysis. The LUTs Local road & streets, shallow excavation, sources of gravel and sand, soils as a source of road fills were selected as important uses in roads construction and they were used in suitability assessment through limitation analysis for road construction. Local road & streets and were considered as preliminary infrastructure that should be requires during the establishment of housing scheme and others are selected based on need of construction materials.
The required land qualities of these LUTs are construction potential including soil strength & settlement under load, ease excavation, vehicle traffic load carrying capacity, capacity of soil to filter & distribute effluent from septic tank, the materials in suitable quantities and economically viable distance and layer thickness. Soil properties and site conditions effecting the land qualities are Unified classification (particle size distribution & Atterberg limits), shrink –swell, California Bearing Ratio (CBR), relative compaction (lab dry density &field bulk density), soil resistance, permeability, pH, depth to bed rock, depth to water table slope, rockiness surface stones, flooding.

6.1.3 Assessment criteria

The rating tables (Table 1 to 6 in Annex IV) based on USDA – SCS rating guides (Soil Survey Staff, 1971) and (Soil Survey Staff., 1999) and other expert judgements. Some of the rating tables were modified according to the environmental condition of the area and standards and methods used in housing and road construction fields in the Naivasha area.

The rating tables include three severity classes: none to slight (NS) moderate (MO) and severe (SE), soil properties and site condition influence the particular use and restrictive feature for limitation. The rating criteria for selected Land Utilisation Types (LUTs) based on affected Land Qualities.

6.1.4 Method and techniques

Specific soil property and site conditions influence for these uses were inferred from laboratory tests and field measurements & observations. A semi-detailed Soil survey was carried out using free survey method including profile descriptions.

By considering importance placed on Unified engineering soil classification (particle size distribution and Atterberg limits), CBR, relative compaction and permeability for interpretation of soil for housing and road construction, the soil mechanical analyses were performed on mixed and disturbed sample from all horizons of selected pits.

The application of GIS (ILWIS) and Remote Sensing considerably enhanced the integration of spatial data with non-spatial data for producing limitation maps.

6.1.5 Limitation Maps for selected LUTs

Matching the criteria rating tables and land qualities, six attribute Maps were produce for each engineering use. Attribute map (Fig. 5.7) for dwelling without basement shows two classes: moderate in lower Plateau and severe for all other mapping units. The map of septic tank absorption fields (Fig. 5.8) reveals that no limitation in higher glacis, moderate in high Plateau and low glacis. The higher & lower part of Lacustrine Plain and scarps shows severe limitations. The limitation map for shallow excavations (Fig 5.9) shows similar results (except map unit of high Plateau) as limitation map for septic tank absorption fields. The map for local roads (Fig. 5.10) shows two limitation classes: moderate in the Mese and severe in all other mapping units. The limitation maps for gravel and sand (Fig. 5.11) shows severe limitations in whole lands in the study area while map for road fills (Fig. 5.12) shows three limitations: none to slight in high glacis, moderate in mesa and severe in all other mapping units.

These resulted limitation maps are capable to identify the problem areas, indicate the nature of the problem and explain the potential use of the land qualitatively for the selected engineering uses.

6.1.6 Land suitability assessment for housing and local road construction

The suitability assessment for both housing and local roads construction was carried out through alternative limitation analysis (weighted and unwighted approaches). The approach is simple matching, based on expert judgement. The resulted limitations map (Fig.5.13) of both weighed and unweighted for housing construction do not show any difference. The reason is that, the most important attribute is dominated in both weighed and unweighted analysis. The limitation map shows two classes: moderate in higher part of the lower Plateau and severe limitations in all other mapping units.

The resulted limitations map (Fig.5.14) of weighed approach for local road construction shows significant difference than unweighted limitation map. As per the unweighted limitation map whole mapping units in the area have severe limitations for road construction while weighted limitation map (Fig.5.14) shows moderately favourable lands in mid glacis of lower Plateau and severe limitation in all other areas.

It is realised that, the weighted limitation map can be effectively used for housing and road construction because, appropriate decision can be made from this approach than unweighted approach. And also weighted approach shows better capability to explain the practical aspects, which are useful for planning, and decision making.

6.1.7 Suitability assessment for residential development

The objective was to identify the existing roads and housing areas, which are located in severe or moderate limitations zones. This analysis was executed by using limitation map (Fig. 5.13) for housing construction, limitation map (Fig.5.14) for road construction and existing and proposed land use map (Fig.5.4).

The resulted crossed map (Fig.5.15) reveals that, high density residential areas in the Lacusreine Plain have severe limitations for housing construction. It can be assumed that most of the physical problems related to housing construction in this residential neighbourhood due to unfavourable soils and site conditions. It also can be seen from the resulting map that most existing roads are located severe limitation zones for road construction. It is therefore clear that the existing road network need to be developed either by special design with intensive maintenance or by major soil reclamation (reducing or removing the soils). The result of this analysis could be used as a guide for land use planning. And also this information may help the planners and decision makers to identify the problematic residential areas, to understand the coarse and effects of the problems and locate the suitable areas for future development to overcome the existing land use conflicts.

6.2 Recommendations

1. Since the information provides in this research could be used as a framework for preliminary investigations in planning and development of a land for residential purposes, further on site detailed investigations are recommended before the implementation of development work.
2. It is recommended that the results of limitation analyses could used to predict on range of problems such as construction difficulties, which can be encountered in the construction of housing and local roads.
3. The limitation analysis could be used in proposed urban areas for identifying special design which is necessary to address the specific problems related to housing and local roads construction and to minimise the initial cost of land development.
4. The modelling approach is not applicable for high technologies used large-scale construction fields (high rise building and high ways construction) which constructions are based on beyond the soil layer.
5. It is recommended therefore that to use the information for low technologies used, labour intensive small scale construction fields (two or less story housing with single family and local road & streets) where the constructions are based on soils.

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Annexes

Annex I Soil profile descriptions & analytical data

Soil profile description- 01

a) General site information	
Observation ID	R/MP/01
Soil Map Unit	Pl 311
Date of observation	21/09/2000
Location	350m. East of the Lake Naivasha and 1.25 km West of old Nairobi main road UTM zone 37 , latitude (X) : 0213142 E, longitude (Y): 9919069 N
Authors	Ranatunga, D.M.B. and Hennemann, G.R
Elevation	1,891 m
Landscape	Lacustrine plain (Pl)
Relief	Low terrace
Landform	Lower plain (slightly slopping)
Slope gradient	0.1 to 0.5%
Land use	Small-scale irrigated horticulture
Vegetation	No natural vegetation
Climatic conditions	Annual average rainfall: 627mm mean temperatures 16.0 to18.3^{0}C.
Flooding	Rare (less than once in 10 years)
b) General soil information	
Higher Category Soil classification (WRB)	Ochric Glaysols
Diagnostic horizons	
Parent material	Lacustrine deposits
Drainage class	well drained, never saturated, very high permeability.
Moisture condition of soil	slightly moist
Depth to water table	At 3 m depth
Depth to bed rock	More than 3 m
Effective soil depth	Very deep
Surface stoniness	Nil
Erosion	Nil
Human influence	Removal of Papyrus vegetation ('marula'), ploughing, digging of drainage

	ditches, and grazing.
c) Profile description	
Ap 0 - 25 cm	Very dark brown (10YR 3/2) when moist and greyish brown (2.5Y5/3) when dry; sandy clay loam; moderate common sub-angular blocky structure; hard when dry, firm when moist; slightly sticky and slightly plastic when wet; few fine roots; non-calcareous; abrupt and wavy boundary; pH 7.5.
Bw1 25 – 31 cm	Brown (10YR 4/3) when moist and white (10YR 8/1) when dry, sandy clay loam; weak medium sub-angular blocky structure; slightly hard when dry, firm when moist; slightly sticky and plastic when wet; few fine roots; non- calcare-ous; abrupt and wavy boundary; pH 8.0.
Bw2 31 – 50 cm	Very dark brown (10YR 3/2) when moist and pale brown (10YR 6/3) when dry, sandy clay loam; weak medium angular blocky structure; slightly hard when dry, firm when moist; slightly sticky and plastic when wet; non calcareous; clear and wavy boundary; pH 8.0.
Bw3 50 –60+cm	Very dark brown (10YR 3/2) when moist and greyish brown (2.5Y 5/3) when dry, sandy clay loam; weak medium angular blocky structure; hard when dry, firm when moist; slightly sticky and plastic when wet; non calcareous; ; clear and smooth boundary; pH 7.5.

Soil profile description- 02

a) General site information	
Observation ID	R/FP/01
Soil Map Unit ID	PL211
Date of observation	9/09/2000
Location	km. East of the lake Naivasha and 750m West of old Nairobi main road UTM zone 37, (latitude(X):0213478E longitude(Y): 9919306N
Authors	Ranatunga, D.M.B. and Hennemann, G.R.
Elevation	1896m.
Landscape	Lacustrine plain
Relief	Mid terrace
Landform	Middle plain (slightly slopping)
Slope gradient	0-1% (nearly level)
Land use	Nature protection (forest)
Vegetation	Woodlands
Climatic condition	Annual average rainfall :627mm., mean Temperatures :16.0 to 18.3^{0}C.
Flooding	Rare (less than once in 10 years)
b) General soil information	
Higher Category Soil classification (WRB)	Duri-Andosols
Diagnostic horizons	Alca-duri-Andosols
Parent material	Lacustrine deposits and volcanic ash.
Drainage class	Moderately well drained.
Moisture condition of soil	Dry to 50cm and moist below
Depth to water table	At 6 m depth
Depth to bed rock	Deeper than 2m.
Effective soil depth	Very deep
Surface stoniness	Nil

Erosion	Nil
Human influence	Grazing, firewood collection
c) Profile description	
O 0 - 2cm	Black (10YR 2/1) ;undecomposed and partlyComposed Organic such as leaves, needles; abrupt and smooth boundary; pH 6.0.
Ah 2 – 20 cm	Greyish brown (10YR5/2) when dry; humic organic matter; silt clay loam; Strong Common to medium sub-angular blocky structure; very hard consistence when dry and firm when moist; sticky and plastics; iron concretion; common medium to coarse roots; non calcareous; abrupt and clear boundary; pH 8.5.
Bw1 20 – 41 cm	Very dark Greyish brown (10YR 3/2) when moist; sandy Clay loam; weak Medium to fine sub-angular blocky structure; friable Consistence when moist; slightly sticky and slightly Plastics; very few medium roots (occasionally larger (coarse) roots) none calcareous; clear and smooth boundary; pH 9.0.
Bw2 41 –85cm	Very dark greyish brown (10YR 3/2) when moist and greyish brown (2.5Y 5/2) /yellowish brown (10YR5/8) when dry; sandy Clay loam; weak Medium to fine sub-angular blocky structure; friable consistence when moist; slightly sticky and none plastics; very few medium roots (occasionally larger (coarse) roots) non calcareous; diffuse and smooth boundary; pH 9.0.
Bw3 85 –150+cm	Very dark greyish brown (10YR 3/2) when moist and greyish brown (2.5Y 5/2) /yellowish brown (10YR5/8) when dry; sandy Clay loam; very weak Medium to fine sub-angular blocky structure; friable consistence when moist; slightly sticky and non plastics; few fine to medium, distinct clear, red colour(2.5YR4/8) mottles (possibly weathering pumice fragments). very few medium roots (occasionally larger (coarse) roots) non calcareous; diffuse and smooth boundary; pH 9.0.

Note : weathering of mainly form pyroclastic deposits association with volcanic materials, high pH more than 10% clay, low bulk density (.9dm^2)volcanic glass less than 10%, andic horizon started within 25cm from the surface. And this soil has good bearing capacity, low infiltration, when rains pounding may occur.

Soil profile description- 03

a) General site information	
Observation ID	R/MP/02
Soil Map Unit ID	PL111
Date of observation	21/09/2000
Location	1.65km. East of the lake Naivasha and 100m West of old Nairobi main road, UTM zone 37, (latitude(X):0214285E, longitude(Y): 9919742N
Authors	Ranatunga, D.M.B. and Hennemann, G.R.
Elevation	1909m
Landscape	Lacustrine plain
Relief	High terrace
Landform	Upper plain
Slope gradient	1-2% (very gently sloping)

Land use	Nature protection (forest)
Vegetation	Woodlands
Climatic condition	Annual average rainfall: 627mm. Mean Temperatures: 16.0 to 18.3^0 C.
Flooding	Rare (less than once in 10 years)
b) General soil information	
Higher Category Soil classification (WRB)	Mollic-Andic-Cambisols
Diagnostic horizons	Mollic, Andic and cabmic
Parent material	Volcanic ash over lacustrine deposits
Drainage class	Well drained.
Moisture condition of soil	Moist
Depth to water table	At 8 m depth
Depth to bed rock	Deeper than 2m.
Effective soil depth	Very deep
Surface stoniness	Nil
Erosion	Nil
Human influence	Gracing, firewood collection
c) Profile description	
O 0 - 2cm	Black (10YR 2/1) ;undecomposed and partly Composed Organic materials such as leaves, needles; abrupt and clear boundary; pH 6.0.
Ah 2 – 15 cm	Very dark greyish brown (10YR 3/2) when moist and Greyish brown (2.5Y 5/2) when dry humid organic matter; sandy clay loam; Strong medium to fine sub-angular blocky structure; hard consistence when dry and firm when moist; slightly sticky and plastics; fine and very few porosity few and fine roots; non calcareous; clear and smooth boundary pH 5.5.
Bw1 15 – 33 cm	Very dark grey (2.5Y3/1) when moist and Dark greyish brown (10YR 4/2)when dry; loamy; moderate common sub-angular blocky structure; slightly hard consistence when dry; slightly sticky and plastics; channels (elongate voids of faunal floral origin) fine and few porosity. few fine roots(occasionally larger (coarse)roots); slight calcareous; clear and smooth boundary; pH 7.0.
Bw2 33 –67+cm	Olive brown (2.5Y4/3) when moist and olive yellow (2.5Y 6/6) when dry; loamy; weak common sub-angular blocky structure; hard consistence when dry; slightly sticky and plastics; channels (elongate voids of faunal floral origin) fine and few/very fine and medium porosity; very few medium roots (occasionally larger (coarse) roots) strong calcareous; clear and smooth boundary; pH 8.5.

Note: weathering of mainly pyroclastic deposits association with volcanic materials, high pH more than 10% clay, low bulk density (.9dm^2)vocanic glass less than 10%, andic horizon tarted within 33cm from the surface. And this soil has good bearing capacity, low infiltration, when rains pounding may occur

Soil profile description- 04

a) General site information	
Observation ID	MP/05
Soil Map Unit ID	LPU411
Date of observation	22/09/2000
Location	375m East of old Nairobi main road UTM Zone37, (latitude(X):0214737E, longitude(Y): 9919817N
Authors	Ranatunga, D.M.B. and Hennemann, G.R.
Elevation	1960m
Landscape	Low plateau
Relief	Low glacis
Landform	Back slope (gently slopping)
Slope gradient	5%
Land use	Residential
Vegetation	No vegetation
Climatic condition	Annual average rainfall :627mm., mean temperatures 16.0 to 18.3^{0}C.
Flooding	Rare (less than once in 10 years)
b) General soil information	
Higher Category Soil classification (WRB)	Mollic-Andosols
Diagnostic horizons	Mollic, andic
Parent material	Alluvial deposits, Longonot Volcano Akira pumice, Kedong valley tuff (trachyte ignimbrites and associated fall deposits).
Drainage class	Moderately well drained
Moisture condition of soil	Dry
Depth to water table	20 to 25m.
Depth to bed rock	1.2m
Effective soil depth	Moderately deep (50 to 100cm)
Surface stoniness	Common (5 –15% and stones (6 to20cm)
Erosion	Rill erosion and moderate (clear evidence of Removal of surface horizon
Human influence	Building, borrow pits, surface compaction and clearing,
c) Profile description	
Ap 0 - 27 cm	very dark greyish brown (10YR 3/2) when moist and dark brown to brown 10YR 4/3)when dry; Clay loam; moderate very common/medium sub angular blocky structure; slightly hard to hard firm consistence when dry; slightly sticky and plastics; non calcareous; ; clear and smooth boundary; pH 5.5
Bw1 27 – 32cm	very dark grey(7.5YR3/1) when moist and greyish brown when dry (10YR5/2); clay loam; weak medium sub angular blocky structure; Slightly hard consistence when dry; sticky and plastics; fine to very few/very fine to medium channels porosity; very fine to fine roots; non calcareous; clear and smooth boundary; pH 6.0.
Bw2 32 – 60 cm	Very dark grey (7.5YR 3/1) when moist and very dark brown (10YR2/2) when dry; Clay; strong medium angular blocky Structure; hard consistence when dry; very sticky and very Plastics; fine many/very fine very few channels porosity; very Fine very few roots; few rounded stones weathered rock (basalt) Fragments; non-calcareous; abrupt and smooth boundary; pH 6.0.

ACR60+cm	Hard bed rock (basalt) underlying the soil. The bed rock is Weathered which can be dug with a spade.

Soil profile description- 05

a) General site information	
Observation ID	R/MP/10
Soil Map Unit ID	HPu111
Date of observation	22/09/2000
Location	650m East of New Nairobi main road ,UTM Zone 37,(latitude(X):0217252E, longitude(Y): 9919352N
Authors	Ranatunga, D.M.B. and Hennemann, G.R.
Elevation	2040m
Landscape	High plateau
Relief	Mesa
Landform	Nearly flat land
Slope gradient	1.0%
Land use	Grassing rainfed agriculture
Vegetation	No vegetation
Climatic condition	16.0 to 18.3^{0} C.
b) General soil information	
Higher Category Soil classification WRB)	Frrasols
Diagnostic horizons	
Parent material	Longonot Volcano Akira Pumice Weathered Volcanic lava flows.
Drainage class	Moderately well drained
Moisture condition soil	Dry
Depth to water table	Deeper than 200m..
Depth to bed rock	3m
Effective soil depth	Moderately deep (50 to 100cm)
Surface stoniness	Common (5 –15% and stones (6 to20cm)
Erosion	Rill erosion and moderate (clear evidence of removal of surface horizon)
Human influence	Grazing building, borrow pits, and clearing
c) Profile description	
Ah 0 - 12 cm	Very dark brown (10YR 2/2) when moist and dark brown to brown 10YR 4/3)when dry; silty loam; moderate fine sub angular blocky structure; hard when dry; non tricky and non plastics; very fine to fine roots; clear and wavy boundary; pH 5.0

Bt1 12 – 21cm	Brown(10YR4/3) when moist and yellowish brown(10YR5/4) when dry; silty clay loam; weak medium sub-angular blocky structure; hard consistence when dry; non-sticky and non-plastics; fine common channels; common medium rounded weathered rock fragments(phonolite): very fine to fine roots; non calcareous; clear and smooth boundary; pH 5.0.
Bt2 21 – 38 cm	Very dark brown (7.5YR 3/3) when moist and dark brown (10YR3/3) when dry; silty Clay; strong very common angular blocky structure; hard consistence when dry; slightly sticky and slightly plastics; abrupt and smooth boundary; pH 4.5.
Bt3 38 – 51 cm	Very dark grey (10YR3/1) when moist and very dark greyish brown (10YR3/2) when dry; Clay; strong medium angular blocky structure; hard Consistence when dry; sticky and plastics; gradual and broken boundary; pH 5.5.
Bm 51 - 60+cm	Grey(7.5YR5/1) when moist and reddish yellow (7.5YR6/6); when dry; very strong medium Sub angular blocky structure; hard consistency when dry; continuous massive structured iron-manganese cemented pan (pyroclastic rock). pH 5.0.

Note : iron-magnesium concretion , low pH, and acidity in Bm horizon due to heavy rain and dry condition. This weathering process allows accumulating of clay.

Soil profile description- 06

a) General site information	
Observation ID	R/MP/06
Soil Map Unit ID	LPU211
Date of observation	24/09/2000
Location	200m west of New Nairobi main road UTM Zone 37(latitude(X):0216355E, longitude(Y): 9919967N
Authors	Ranatunga, D.M.B. and Hennemann, G.R.
Elevation	2040m.
Landscape	Low plateau
Relief	Mesa
Landform	Nearly level
Slope gradient	Less than 1.0%
Land use	Residential
Vegetation	No vegetation
Climatic condition	Annual average rainfall :627mm., mean temperatures 16.0 to 18.3^{0}C.
Flooding	Rare (less than once in 10 years)
b) General soil information	
Higher Category Soil classification (WRB)	Skeletic-Calcisols
Diagnostic horizons	Skeletic, Calcic petrocalcic
Parent material	Alluvial deposits, Longonot Volcano Akira pumice, Kedong valley tuff (trachyt e ignimbrites and associated fall deposits).

Drainage class	Well drained
Moisture condition of soil	Dry
Depth to water table	Deeper than 25m
Depth to bed rock	10m
Effective soil depth	Very deep
Surface stoniness	Nil
Erosion	Nil
Human influence	Building, borrow pits, surface compaction and clearing,
c) Profile description	
Ap 0 - 20 cm	Black (7.5YR 2.5/1) when moist and brown (10YR 4/3) when dry; Clay loam; moderate fine sub-angular blocky structure; soft when dry and firm when moist; slightly sticky and slightly plastics; initial(controlled by the fabric or arraignment of the soil particles) fine few porosity; few fine roots; non-calcareous; abrupt and smooth boundary; pH 5.0; soil resistance 4.5kg/cm2.
Bw1 20 – 36cm	Very dark brown (10YR2/2) when moist and dark yellowish Brown(10YR4/4) when dry; sandy clay loam; weak very fine sub angular blocky structure; loose consistence when dry; slightly sticky and slightly plastics; initial(controlled by the fabric or arraignment of the soil particles) fine fewporosity few fine roots; non calcareous; abrupt and smooth boundary; pH6.5;soil resistance 3.25 kg/cm2.
Bw2 36– 61cm	Black (5YR 2.5/1) when moist and black (7.5YR 2.5/1) when dry; Clay; strong fine angular blocky structure; strong consistence when dry; non sticky and non plastics; ;initial(controlled by the fabric or arraignment of the soil particles) fine few porosity; non calcareous; abrupt and smooth boundary; pH 7.5.soil resistance 4.5 kg/cm2.
Bm 61+cm	Dark reddish brown (5YR3/2); when moist; strong brown (7.5 YR5/6) when dry; very strong structure; hard consistency when dry; continuous platy structured iron-manganese cemented pan(pyroclastic rock); abrupt smooth boundary;.

Soil profile description- 07

a) General site information	
Observation ID	R/FP/02
Soil Map Unit ID	LPU211
Date of observation	25/09/2000
Location	750m west of New Nairobi main road (latitude UTM Zone 37(X):0215731E, longitude(Y): 9919585N
Authors	Ranatunga, D.M.B. and Hennemann, G.R.
Elevation	1995m.
Landscape	Low plateau
Relief	High glacis
Landform	Foot slope (very gently slopping)

Slope gradient	Less than 1-2%
Land use	Residential
Vegetation	Nil
Climatic condition	Annual average rainfall :627mm., mean temperatures 16.0 to 18.3^{0}C.
Flooding	Rare (less than once in 10 years)
b) General soil information	
Higher Category Soil classification (WRB)	Petric-Calcisols
Diagnostic horizons	Andic, Duric, Alcalic
Parent material	Alluvial deposits, Longonot Volcano Akira pumice, Kedong valley tuff (trachyt e ignimbrites and associated fall deposits).
Drainage class	Well drained
Moisture condition of soil	Dry
Depth to water table	Deeper than 25m.
Depth to bed rock	3m
Effective soil depth	Very deep
Surface stoniness	Nil
Erosion	Nil
Human influence	Building, borrow pits, surface compaction and clearing,
c) Profile description	
Ap 0 - 31 cm	Black (7.5YR 2.5/1) when moist and brown (10YR 4/3) when dry; fine sandy loam; moderate fine sub angular Blocky structure; slightly hard when dry and firm when moist; slightly sticky and slightly plastics; vesicles (discontinuous voids chambers) fine few medium porosity; very few very fine roots; non calcareous; clear and smooth boundary pH 5.0; soil resistance 4.25kg/cm2.
Bw1 31– 47cm	Very dark brown (10YR2/2) when moist and brown (10YR53) when dry; Fine sandy loam; weak very fine sub-angular blocky structure; slightly hard consistence when dry; slightly sticky and slightly plastics vesicles (discontinuous voids chambers) fine common medium porosity; very few very fine roots; non calcareous; abrupt wavy boundary; pH 5.5;soil resistance 3.25 kg/cm2.
Bw2 47– 75cm	Black (10YR 2/1) when moist and black (7.5YR 2/1) when dry; fine sandy loam; moderate medium angular blocky structure; Loose consistence when dry; broken nodular iron magnesium Concretion (the layer is concentration with cemented Irregular shape nodules); slightly sticky and none plastics; Channels (elongated voids of faunal or origin) fine common medium porosity; non calcareous; Clear smooth boundary; pH 8.0; soil resistance 4.5 kg/cm2.
Bm 75 -110cm	Dark yellowish brown (10YR 4/4) when moist and brownish Yellow (10YR 6/6) when dry; fine loamy coarse sand; strong coarse sub-angular blocky structure; hard consistence when dry; non sticky and non plastics; Channels (elongated voids of Faunal or floral origin) fine few medium porosity; Continuous weakly cemented Nodular (the layer is largely constructed from cemented nodules) carbonates-silica cementation; strong calcareous; Clear and smooth Boundary; pH 9.0; soil resistance >4.5 kg/cm2

E 110 -140cm	Light yellowish brown (10YR 6/4) when moist and very pale brown (10YR 8/2) when dry; coarse sand; many coarse sub-rounded rock fragments; weakly cemented Nodular (the layer is largely constructed from cemented nodules) carbonates-silica cementation; strong calcareous; abrupt and smooth Boundary; pH 9.0. Note; mixed coarse loose sand and gravel light Greyish or white colour thick layer (pumice).
Ck 140 – 155+	Dark yellowish brown (10YR 3/4) when moist and yellowish brown (7.5YR 2/1) when dry; Fine sandy loam; moderate medium angular blocky structure; Loose consistence when dry; slightly sticky and non-plastics; common medium gravel and sub rounded rock fragment; non-calcareous; clear and smooth boundary; pH 8.0.;soil resistance >4.5kg/cm2.

.

Soil profile description- 08

a) General site information	
Observation ID	R/MP/07
Soil Map Unit ID	LPu111
Date of observation	25/09/2000
Location	60m East of New Nairobi main road ,UTM Zone 37 (latitude(X):0216414E, longitude(Y): 9919218N
Authors	Ranatunga, D.M.B. and Hennemann, G.R.
Elevation	2025m.
Landscape	Low plateau
Relief	High glacis
Landform	Back slope
Slope gradient	9%
Land use	Nature park
Vegetation	Forest (woodlands)
Climatic condition	Annual average rainfall :627mm., mean temperatures 16.0 to 18.3^{0}C.
Flooding	Rare (less than once in 10 years)
b) General soil information	
Higher Category Soil classification (WRB)	Arenic-Andosols
Diagnostic horizons	Andic, skeletic, Arenic
Parent material	Unconsolidated pyroclastic and alluvial deposits & Akira pumice
Drainage class	Well drained
Moisture condition of soil	Slightly moist
Depth to water table	Deeper than 25m.
Depth to bed rock	10m
Effective soil depth	Very deep

Surface stoniness	Very few
Erosion	Rill erosion
Human influence	Borrow pits, garbage disposal and clearing,
c) Profile description	
Ap 0 - 22 cm	Dark brown (10YR3/3) when moist and dark yellowish brown (10YR4/4) when dry; sandy loam; moderate fine sub angular blocky structure; soft when dry and firm when moist; slightly sticky and slightly plastics; few finerounded rock fragments; vesicles(discontinuous voids chambers) fine few low porosity; few fine roots; non calcareous; clear and smooth boundary; pH 6.0; soil resistance 4.25kg/cm2.
Bw1 22 – 60cm	Dusky red(2.5YR3/2) when moist and brown (10YR4/3) when dry; sandy loam; moderate fine sub angular blocky structure; loose consistence when dry; few fine rounded rock fragment non sticky and non plastics; vesicles(discontinuous voids chambers) fine few low porosity; few fine roots; non calcareous; clear and smooth boundary; pH 5.0;soil resistance 2.25 kg/cm2
Bw2 60 to 80cm	Light yellowish brown (10YR 6/4) when moist and White (10YR 82) when dry; coarse sand; many coarse sub-rounded rock fragments; weakly cemented Nodular (the layer is largely constructed from cemented nodules) carbonates-silica cementation; strong calcareous; abrupt and smooth Boundary; pH 9.0. Note; mixed coarse loose sand and gravel light Greyish or white colour thick layer (pumice).

Annex II - A. Unified classification chart

B. Atterberg limits test

B.1. Liquid limit test

The test was performed in the laboratory on disturbed soil samples.

Preparation of test specimen: A specimen of 150 to 200 g was prepared with soil materials passing the 425micron (No.40) sieve by mixing thoroughly with distilled water. Then specimen was placed in liquid limit device for measurement. Pushing a cone in to the specimen performed the test.

Calculations: The results of cone penetration-MC relationship were plotted on a graph and the best straight line was drawn through three or more plotted points. The value of the MC (mass of moisture/mass of dry soil *100) corresponding to the intersection of the line with the cone penetration at 20mm was taken as the LL of the soil.

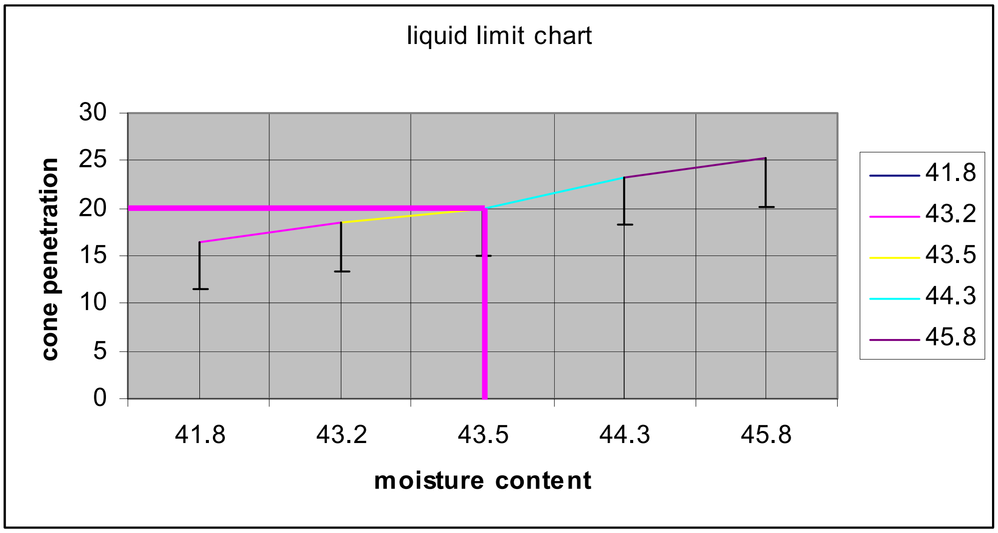


Fig.A.1 Example :Liquid Limit of soil in mapping unit Pl113

B.2. Plasticity limit test

Preparation of test specimen: A 20g portion of soil from the material prepared for the LL test was taken and reduced the water content of the soil to a consistency at which it can be rolled without sticking to the hands by spreading and mixing continuous on glass plate.

Procedure: From the specimen, 1.5 to 2.0g was taken and rolled between palm or fingers until the diameter reaches 3.2mm. When the diameter become3.2mm thread was broken in to several pieces about 3 to 9mm in length. Then threads were placed in a container and covered immediately. The same operation was repeated until the container has at least 6g of soil. The same operations were repeated to make another container holding 6g of Soil. After that the water content, in percent of the soil in the containers was determined.

Calculations: The average of the two water contents was computed and it was taken as plastic limit. These test results were used to calculate the plasticity index (LL-PL=PI) and used to study the swelling potential.

B. 3. Plasticity index

Plasticity index is the difference between liquid limit and plastic limit.
Calculation : PI = LL – PL

C. CBR- Test

Test procedure: The test was performed in the laboratory on disturbed soil samples. Soil materials were remoulded in CBR mould under a static load at required moisture content according to the standard proctor test. The mould was soaked in water for 4 days to bring the soil to the worst stage of strength. After 4 days, the specimen was taken out from the water bath and was drained. Then specimen was fixed in CBR machine for measurement. The test was performed by pushing a standard plunger at constant rate in to the soil at a fixed rate (7.5mm) of penetration and the force required to maintain that rate was measured at each 25mm intervals. From the resulting load penetration relationship the CBR value was derived for the soil in the condition at which it was tested. The highest value was accepted as CBR.
Calculations: Example CBR on soil in mapping unit PL113

CBR = measured force/ standard force x 100%
Or
CBR = measured force x CBR factor

- CBR at 2.5mm on top = 26 x 0.196 = 5.1
- CBR at 2.5mm on bottom = 47 x 0.196 = 9.2
- CBR at 5.0mm on top = 37 x 0.130 = 4.8
- CBR at 5.0mm on bottom = 67 x 0.130 = 8.7

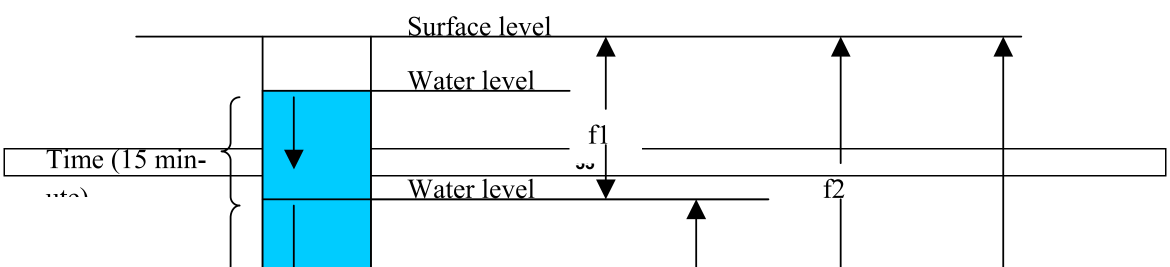
Highest value was taken as CBR, that is 9.2

D. Permeability test by Falling Head method

Test procedure: A hole was dug (75mm diameter * 1.8m) and saturated with water up to the maximum saturation level. Then using the falling head instrument travel time of water was measured at 15s, 30s 60s, 120s 300s 600s 900s 1800s, 3600s, 7200s, 14880s and recorded (Fig.A.1).
Calculations:

K = dh2/4(h1)2 * 1/t

Where;
K = permeability cohificient, t = time (in seconds).
d = diameter of hole,
h1 = (D - f1) length of water at the time of start measuring,
D = Datum (length between hole bottom and the datum),
f1 = length between head of h1 and the datum,
h2 = deference between (D- f2) length of water level after # time,
f2 = length between head of h2 and the datum,



D =1.8m

Fig. A.2: Schematic diagram of Permeability test (Falling Head method)

E. Relative Compaction test

Test procedure: Estimation of relative compaction of soil includes lab dry density test and field density test.

The compaction test /lab dry density analysis was carried out according to the Proctor method (AASHTO T99) and

Sand replacement method was used to take samples for Field bulk density test.

Uses: foundation, roads airfields embankment etc.

a). Compaction tests (lab dry density analysis) Proctor method.

Test procedure: Add water 150mls.to the soils & mixed well, put in to the mould little by little while hammering. Once the mould is filled with compacted soil, it is weighted. Then reduce the mould weight and get the specimen weight. At the same time note the moisture content. Then remove the soil from the mould & add 50mls of water and repeat the same. Like wise perform the test about 7-8 times. Finally, using the test data to calculate the dry density (DD = dry mass/volume of mould and dry mass = weight of wet soil – moisture content) & moisture content and make a graph to get the maximum dry density of soil (Fig.A.3).

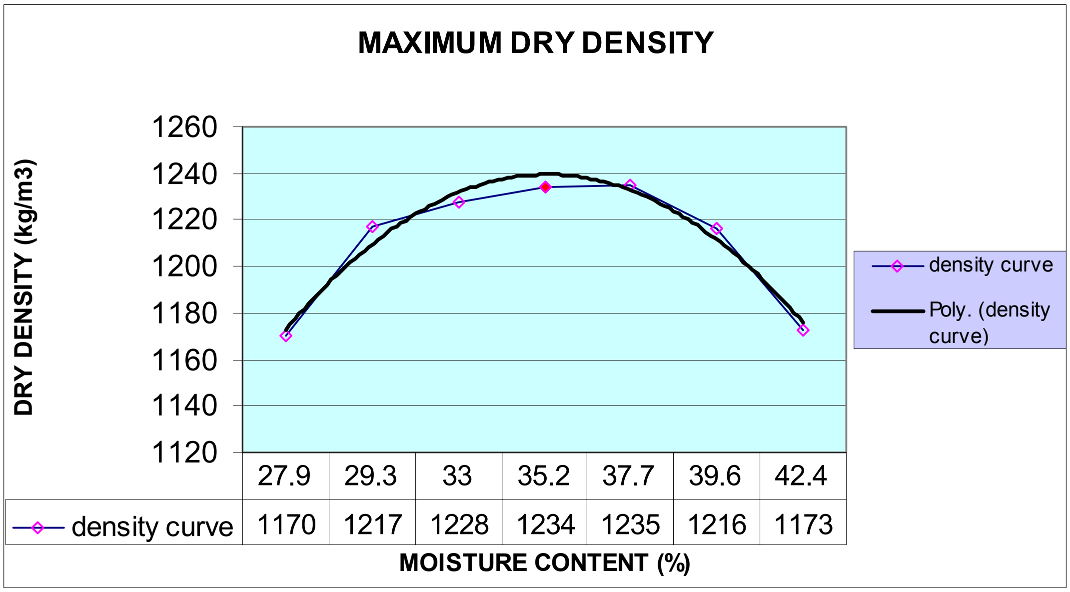


Fig. A.3. Example: Maximum dry density of soil in mapping unit Pl 113

b). Field Bulk Density (Sand replacement method).

Instruments & materials used cone cylinder (150mm diameter), cone plate, standard sand (3kg).

Test procedure: place the cone cylinder in the pit at the depth of 60 cm., fill the sand in to cone, loose the screw to release sand in to surface. Once stopped sand replacement remove the cone and sand on the surface put in to sample bag, which is going to be measured in the lab. Then dig a hole with a dimension of 150mm. Diameter x 150 mm. The volume of this hole & the sand replaced to the surface is equal.

c). Relative compaction:

Calculations: maximum field dry density/lab dry density x100

Example . Relative compaction of soil in mapping unit PL113

Field dry density	kg/m3	1190
Maximum dry density	kg/m3	1245

1190/1245 x 100 = **95.58%**

F. Shrink- swell potential

Test procedure: The test was performed in the laboratory on disturbed soil samples. The soils were crushed at 425 micron, add water, Steered well and put in to the shrinkage mould. The specimen was dry in oven and measured the shrinkage limit.

Calculations: For the determination of shrink-swell behaviour of soils quantitative method which is called COLE (coefficient of leaner extendibility) was applied

COLE is defined as

Lm – Ld/Ld/Ld * 100

Where: Lm = length of moist sample, Ld = length of dry sample

Annex III - Photographs

Photo 1. Physical problems in residential neighbourhood on Naivaha town

Photo 2. Nature of local road and streets in the area

Photo 3. Profile description (observation -MP-5)

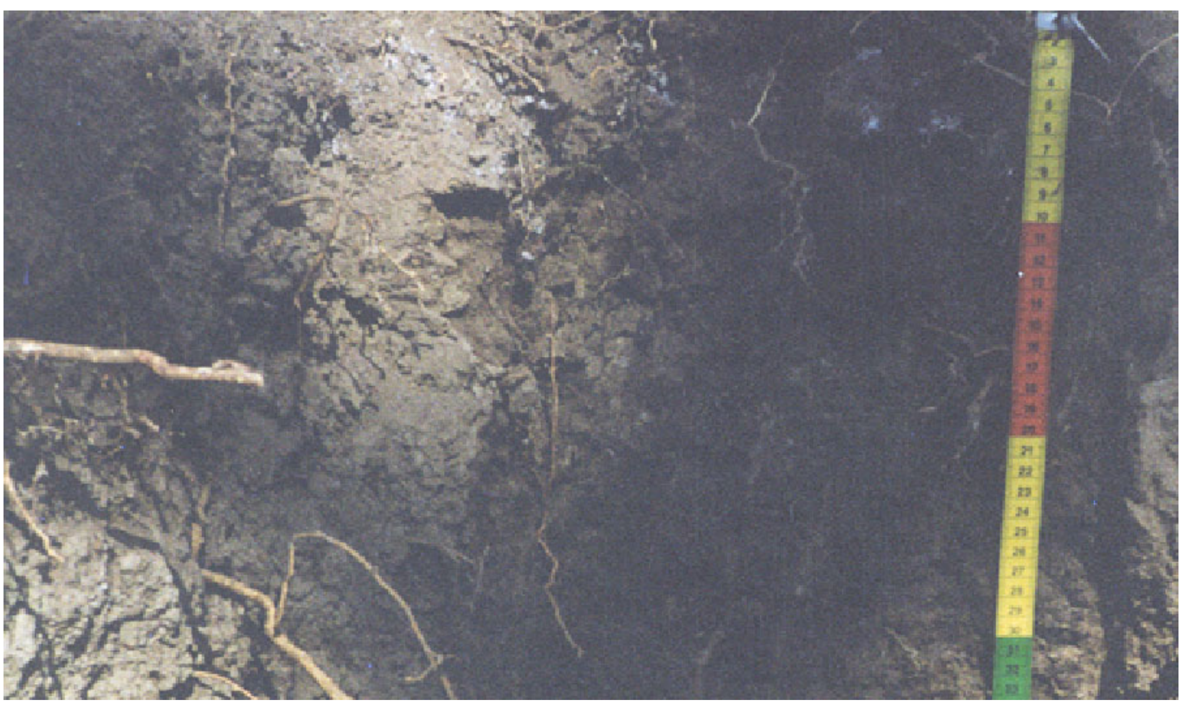


Photo 4. Profile No MP 02 (higher plain of lacustrine plain)

Photo 5. Taking samples for compaction test –sand replacement method(observation point MP-07

Photo 6. CBR Test on compact soil samples (Soil Engineering Laboratory, Road Maintains Unit, Ministry of Public Works, Naivasha, Kenya

Annex IV - Rating tables

Table 1 Soil and site limitation ratings for dwelling without basement.

Property effecting use	Degree of limitation (based on capacity of support load)			Restrictive Feature
	slight	moderate	Severe	
Soil drainage	Excessively drained, somewhat excessively drained well drained, moderately well drained	Somewhat poorly drained	Poorly drained, very poorly drained	Poorly drained
Depth to water table (cm)	Bellow a depth of 75	Bellow a depth of 50	Above a depth of 50	Wetness
Flooding	none	-	Rare	Flooding
Slope (%)	0-10	10 – 20	> 20	Lope
Shrink-swell (%)	< 3 (Low)	3 –6 (Moderate)	> 6 (High)	Shrink-swell
Unified Soil Group	GW,GP,,SW,SP,GM,GC, SM,SC,CL With PI<15	ML,CL, SM with PI > 15	CH, MH, OL,OH	Favourably/excess humus (low strength)
Stoniness (%)	< 25	25-50	50	large stones
Depth to bed rock (cm)	>100	50-100	50	Depth to rock

GW : well graded gravel
GP : poorly graded gravel
SW : well graded sand
SP : poorly graded sand
GM : silty gravel
GC : clayey gravel
SM : silty sand
CL : clay
CH : fat clay
MH : elastic silt
OL : organic clay
OH : organic silt
ML : silt

Source: Based on Guide for Interpreting Engineering Uses of Soils (Soil Survey Staff, 1971).

Table 2 Soil and site limitation ratings for septic tank absorption field.

Property effecting use	Degree of limitation(based on capacity of absorption effluents)			Restrictive Feature (MLF)
	slight	Moderate	Severe	
Permeability (cm/hr) (60 to 180 cm depth)	> 5.08 (high)	1.52 – 5.08 (moderate)	< 1.52 (low)	Poor filter
Soil drainage (Class)	Excessively drained, somewhat excessively drained well drained, moderately well drained	Somewhat poorly drained	poorly drained, very poorly drained	Poor drainage
Depth to water table (cm)	>180	120-180	< 120	Wetness
Flooding (Class)	none	Rare	Occasional or frequent	Flooding
Slope %	0- 8	8 –15	> 15	Slope
Stoniness %	< 25	25-50	50	large stones
Depth to bed rock (cm)	>180	150-180	< 150	Depth to rock

Source: Based on Guide for Interpreting Engineering Uses of Soils (Soil Survey Staff, 1971).

Table 3 Soil and site limitation ratings for shallow excavations.

Property effecting use	Degree of limitation (based on ease of excavation)			Restrictive Feature (MLF)
	Slight	moderate	Severe	
Texture (USDA) depth to be excavated	FSL, SL, L, SiL, SiCL, SCL	Si, CL, SC, all gravely types.	C, SiC, S organic soils; all very gravely types	Too clayey, too sandy
Soil drainage	Excessively drained, somewhat excessively drained well drained, moderately well drained	moderately well drained	Somewhat poorly drained, poorly drained, very poorly drained	Poor drainage
Depth to water table (cm)	>150	75-150	< 75	Wetness
Flooding	none	rare	Occasional or frequent	Flooding
Slope %	0- 8	8 -15	> 15	Slope
Stoniness %	< 5	5- 25	> 25	large stones
Depth to bed rock	> 180	120-180	< 120	Depth to rock
Soil reaction			< 3.6	Too acid

FSL	: fine sand loam	SiL	: silt loam	Si	: silt
SL	: sandy loam	SiCL	: silt clay loam	CL	: clay
L	: loam	SCL	: sandy clay loam	SC	: sandy clay

Source: Based on Guide for Interpreting Engineering Uses of Soils (Soil Survey Staff, 1971).

Table 4 Soil and site limitation ratings for local roads and streets.

Property effecting use	Degree of limitation (based on ease of excavation)			Restrictive Feature (MLF)
	slight	moderate	severe	
Sub-grade soil classification (Unified)	GW, GP, SW, SP, GM, GC, SM, SC	CL with PI < 15	CL with PI >.= 15	Low strength
AASHTO GI	< 5	5 - 8	> 8	Low strength
Relative compaction %	< 92	92 - 98	> 98	high compressibility Low bulk density
CBR	> 14	14 - 7	< 7	Low strength
Soil drainage	Excessively drained, somewhat excessively drained well drained, moderately well drained	Somewhat poorly drained	poorly drained & very poorly drained	Poor drainage
Shrink-swell %	<3 (Low)	3 –6 (Moderate)	> 6 (high)	Shrink-swell
Depth to water table (cm)	> 75	30 - 75	< 30	Wetness ponding
Flooding	none	rare	common	Flooding
Slope %	0- 8	8 -15	> 15	Slope
Stoniness %	< 25	25 - 50	> 50	large stones
Depth to bed rock (cm)	50 -100	< 50	-	Depth to rock

GW : well graded gravel	GM : silty gravel	CH : fat clay	ML : silt
GP : poorly graded gravel	GC : clayey gravel	MH : elastic silt	
SW : well graded sand	SM : silty sand	OL : organic clay	
SP : poorly graded sand	CL : clay	OH : organic silt	

Table 5 Soil and site limitation ratings for soils as possible sources of gravel and sand.

Property effecting use	Degree of limitation (based on Possibility of finding in suitable quantity)			Restrictive Feature (MLF)
	Slight	moderate	Severe	
Engineering soil classification (Unified) (for sand)	GW, GP,	GP- GM, GW- GM	All other groups	Too gravely for sands
Unified (for gravel)	SW, SP	SW –SM SP –SM	All other groups	Too sandy for gravel
Layer thickness (cm)	> 90	< 90	-	Thin layer
Stoniness (%)	< 50	< 50	-	large stones

GW: well graded gravel GM: silty gravel CH: fat clay ML : silt
GP: poorly graded gravel GC: clayey gravel MH: elastic silt
SW: well graded sand SM: silty sand OL: organic clay
SP: poorly graded sand CL: clay OH: organic silt
Source: Based on Guide for Interpreting Engineering Uses of Soils (Soil Survey Staff, 1971).

Table 6 Soil & site limitation ratings for soils as sources of road fill.

Property effecting use	Degree of limitation (based on ease of excavation)			Restrictive Feature (MLF)
	slight	moderate	severe	
Engineering soil classification (Unified) (Class)	GW, GP, SW, SP, GC, SM, SC	ML, CL with PI < 15	CL with PI > 15, CH, MH, OL, OH	Low strength
Soil drainage (class)	Excessively drained, somewhat excessively drained well drained, moderately well drained	Somewhat poorly drained	poorly drained & very poorly drained	Poor drainage
Shrink-swell(% /class)	Low (COLE <3)	Moderate (COLE 3 – 6)	High(COLE >6)	Shrink-swell
Layer thickness (cm)	> 150	150 - 75	< 75	Thin layer
Flooding (class)	none	rare	common	Flooding
Slope (%)	0 -15	15 -25	>25	Slope
Stoniness (%)	< 25	25 - 50	> 50	large stones
Depth to bed rock (cm)	> 150	100 -150	< 100	Depth to rock

GW: well graded gravel GM: silty gravel CH: fat clay ML: silt
GP: poorly graded gravel GC: clayey gravel MH: elastic silt
SW: well graded sand SM: silty sand OL: organic clay
SP: poorly graded sand CL: clay OH : organic silt

Source: Based on Guide for Interpreting Engineering Uses of Soils (Soil Survey Staff, 1971).

Annex V - interpretation tables

Table 1 Interpretation of soil & site properties for dwelling with out basement

Map unit	HPu111		Hpu211		HPu311		LPu111		LPu211		LPu311		LPu411		LPu511		LPu512		LPu 611		Pl 111		Pl211		Pl311		Pl312	
Class/factor Properties	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF
Depth to bed rock	MO	DR	MO	DR	SE	DR	NS		NS		SE	DR	NS		NS		NS		MO	DR	NS		NS		NS		NS	
Soil drainage	NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		SE	PD
Depth to water table	NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		MO	WT
Flooding	NS		SE	FL	NS		NS		NS		NS		NS		NS		NS		SE	FL	SE	FL	SE	FL	SE	FL	SE	FL
Slope	NS		SE	SL	SE	SL	NS		NS		SE	SL	NS		MO	SL	NS		MO	SL	NS		NS		NS		NS	
Shrink-swell	SE	SS	SE	SS	-		NS		MO	SS	-						SE	SS			SE	SS	SE SS		SE SS		SE	SS
Eng. soil classi-fication (Unified)	NS		NS		MO	LST	MO	LST	NS		MO	LST	MO	LST	MO	LST	MO	LST	MO	LST	MO	LST	MO	LST	NS		MO	LST
Stoniness frac-tion >7.5	NS		SE	LS	SE	LS	NS		NS		SE	LS	NS		NS		NS		NS		NS		NS		NS		NS	
severity limit & Maximum limitation fac-tors	**SE**	**SS** **DR**	**SE**	**FL** **SL** **SS** **DR** **LS**	**SE**	**DR** **SL** **LST** **LS**	**MO**	**LST**	**MO**	**SS**	**SE**	**DR** **SL** **LST** **LS**	**MO**	**LST**	**MO**	**SL** **LST**	**SE**	**SS** **LST**	**SE**	**FL** **SL** **DR** **LST**	**SE**	**FL** **SS** **LST**	**SE**	**FL** **SS** **LST**	**SE**	**FL** **SS**	**SE**	**PD** **WT** **FL** **SS** **LST**

Key to severity limits

DR : depth to rock
NS : none to slight
MO : moderate
SE : severe

limitation factors

LF : Limitation Factor
SL : slope
LS : large stone
LST : low strength (Favourably/excess humus)

C : Limitation Class
SS : shrink-swell
FL : flooding
PD : poorly drained

Table 2 Interpretation of soil & site properties for septic tank absorption fields

Map unit Class/factor Properties	HPu111		Hpu211		HPu311		LPu111		LPu211		LPu311		LPu411		LPu511		LPu512		LPu 611		Pl 111		Pl211		Pl311		Pl312	
	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF	C	LF
Permeability (60 -180 cm depth)	MO	PF	-		-		NS		NS		-		-		-		MO	PF	-		MO	PF	MO	PF	NS		-	
Depth to bed rock	SE	DR	SE	DR	SE	DR	NS		NS		SE	DR	NS		NS		NS		SE	DR	NS		NS		NS		NS	
Soil drainage	NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		SE	PD
Depth to water table	NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		MO	WT	SE	WT
Flooding	NS		MO	FL	NS		NS		NS		NS		NS		NS		NS		MO	FL	MO	FL	SE	FL	SE	FL	SE	FL
Slope	NS		SE	SL	SE	SL	NS		NS		SE	SL	NS		MO	SL	NS		MO	SL	NS		NS		NS		NS	
Stoniness fraction >7.5Cm	NS		SE	LS	SE	LS	NS		NS		SE	LS	NS		NS		NS		NS		NS		NS		NS		NS	
severity limit & Maximum limitation factors (MLF	**SE**	**PF DR**	**SE**	**DR PF SL LS**	**SE**	**DR SL LS**	**NS**		**NS**		**SE**	**DR SL LS**	**NS**	**PF**	**MO**	**SL**	**MO**	**PF**	**SE**	**DR FL SL**	**MO**	**FL**	**SE**	**FL PF**	**SE**	**WT FL**	**SE**	**PD WT FL**

Key to severity limits

DR : depth to rock
NS : none to slight
MO : moderate
SE : severe

limitation factors

PD : poorly drained
SL : slope
LS : large stone
WT : wetness
FL : flooding

C : limitation class
LF : limitation factor
PF : poor filter

Table 3 Interpretation of soil & site properties for shallow excavations

Map unit Class/factor	HPu111		HPu211		HPu311		LPu111		LPu211		LPu311		LPu411		LPu511		LPu512		LPu 611		Pl 111		Pl211		Pl311		Pl312	
Properties	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**	**C**	**LF**
Texture USDA	MO	TC	NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		MO	TC	MO	TC
Soil drainage	NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		SE	PD
Depth to water table	NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		MO	DR	SE	DR
Flooding	NS		M O	FL	NS		NS		NS		NS		NS		NS		NS		M O	FL	MO	FL	SE	FL	SE	FL	SE	FL
Slope	NS		SE	SL	SE	SL	NS		NS		SE	SL	MO	SL	M O	SL	NS	SL	M O	SL	NS		NS		NS		NS	
Stoniness fraction>7.5Cm	MO	SS	SE	SS	SE	SS	NS		NS		SE	SS	NS		NS		M O	SS	M O	SS	NS		NS		NS		NS	
Depth to bed rock	SE	DR	SE	D R	SE	DR	NS		NS		SE	DR	NS		NS		NS		SE	DR	NS		NS		NS		NS	
pH	NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS		NS	
Severity limit And Maximum limitation factors (MLF	**SE**	DR TC	**SE** FL	SL SS DR	**SE**	SL SS DR	**NS**		**NS**		**SE**	SL SS DR	**M O**	SL	**M O**	SL	**M O**	SS	**SE**	FL SL DR SS	**M O**	FL	**SE** FL		**SE**	FL DR TC	**SE**	PD DR FL

Key to severity limits
DR : depth to rock
NS : none to slight
MO : moderate
SE : severe

limitation factors
LF : limitation factor
SL : slope
LS : large stone
WT : wetness

C : limitation class
FL : flooding
PD : poorly drained

Table 4 Interpretation of soil & site properties for local roads and streets

Map unit Class/factor Properties	HPu111 C LF	HPu211 C LF	HPu311 C LF	LPu111 C LF	LPu211 C LF	LPu311 C LF	LPu411 C LF	LPu511 C LF	LPu512 C LF	LPu 611 C LF	Pl 111 C LF	Pl211 C LF	Pl311 C LF	Pl312 C LF
Engineering soil classification (Unified)	SE LST	SE LST	SE LST	MO LST	SE LST	SE LST	NS	SE LST	SE LST	NS	SE LST	SE LST	SE LST	NS
CBR	SE LB	-	-	MO LB	MO LB	-	-	-	SE LB	-	SE LB	SE LB	MO LB	-
Relative compactio	NS			SE LC	SE LC	-	-	-	SE LC		SE LC	MO LC	NS	
Soil drainage	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	SE PD
Depth water table	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	MO WT
Flooding	NS	MO FL	NS	NS	NS	NS	NS	NS	NS	MO FL	MO FL	SE FL	SE FL	SE FL
Shrink-swell	SE SS	SE SS	-	NS	MO SS	-	-	-	SE SS	-	SE SS	SE SS	SE SS	SE SS
Slope	NS	SE SL	SE SL	MO SL	NS	SE SL	MO SL	MO SL	NS	NS	NS	NS	NS	NS
Stoniness frar-tion>7.5 cm	NS	SE LS	SE LS	NS	NS	SE LS	NS	NS	NS	NS	NS	NS	NS	NS
Depth to bed rock	MO DR	MO DR	SE DR	NS	NS	SE DR	NS	NS	NS	MO DR	NS	NS	NS	NS
Severity limit & Maximum limitation factors (MLF)	**SE** SS LST LB	**SE** LST FL DR SS LS SL	**SE** LST SL LS DR	**SE** LST LB SL	**SE** LST SS LC LB	**SE** LST SL LS DR	**MO** SL	**SE** ST SS SL	**SE** LST LB SS LC	**MO** FL DR	**SE** LST LB FL SS	**SE** LST FL LB SS LC	**SE** LST FL SS LB	**SE** PD FL WT SS

Key to severity limits

DR : depth to rock

NS : none to slight
MO : moderate
SE : severe
C : limitation class

limitation factors

SS : shrink-swell
SL : slope
LS : large stone
WT : wetness
LF : limitation factor

LC : low compaction capacity
LB : low bearing capacity/bulk density/low strength
LST : low strength
PD : poorly drained
FL : flooding

Table 5 Interpretation of soil & site properties for soils as sources of road fill.

Map unit Class/factor Properties	HPu111 C LF	HPu211 C LF	HPu311 C LF	LPu111 C LF	LPu211 C LF	LPu311 C LF	LPu411 C LF	LPu511 C LF	LPu512 C LF	LPu 611 C LF	Pl 111 C LF	Pl211 C LF	Pl311 C LF	Pl312 C LF
Eng. soil classi. (Unified)	MO LST	MO LST	MO LST	NS	MO LST	MO LST	NS	MO LST	MO LST	NS	MO LST	MO LST	MO LST	NS
Soil drainage	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	SE PD
Shrink-swell	SE SS	SE SS	-	NS	MO SS	-			SE SS	-	SE SS	SE SS	SE SS	SE SS
Layer thickness	SE TL	SE TL	SE TL	NS	NS	SE TL	NS	NS	NS	SE TL	NS	NS	NS	NS
Flooding	NS	MO FL	NS	NS	NS	NS	NS	NS	NS	MO FL	MO FL	SE FL	SE FL	SE FL
Slope	NS	SE SL	SE SL	NS	NS	SE SL	NS	NS	NS	NS	NS	NS	NS	NS
Stoniness fraction>7.5 Cm	NS	SE LS	SE LS	NS	NS	SE LS	NS	NS	NS	NS	NS	NS	NS	NS
Depth to rock	SE DR	SE DR	SE DR	NS	NS	SE DR	NS	NS	NS	SE DR	NS	NS	NS	NS
Severity limit & Maximum limitation factors (MLF	**SE** LST SS TL DR	**SE** SS ST TL FL, SL LS, DR	**SE** TL SL LS DR LST	NS	**MO** LST SS	**SE** LST TL SL LS DR	**NS**	**MO** **LST**	**SE** SS LST	**SE** TL FL DR	**SE** SS FL ST	**SE** LST SS FL	**SE** LST SS FL	**SE** PD SS FL

Key to severity limits

NS : none to slight
MO : moderate
SE : severe

limitation factors

SS : shrink-swell
SL : slope
LS : large stone
PD : poorly drained
FL : flooding

C : limitation class
LF : limitation factor
LD : low bulk density, low strength
LST : low strength
DR : depth to rock
TL : thin layer

Table 6 Interpretation of soil & site properties for possible sources of gravel and sand.

Map unit Class/factor Properties	HPu111 C LF	HPu211 C LF	HPu311 C LF	LPu111 C LF	LPu211 C LF	LPu311 C LF	LPu411 C LF	LPu511 C LF	LPu512 C LF	LPu 611 C LF	Pl 111 C LF	Pl211 C LF	Pl311 C LF	Pl312 C LF
Unified classification for sands	SE TC EF	SE TC SST	SE LS TC	SE TC	SE TC SST	SE TC LS	SE TC	SE TC	SE EF	SE SST	SE TC	SE TC EF	SE EF	SE EF
Unified Classification for gravel	SE TC EF	SE TC EF	SE LS TC	SE TC	SE EF	SE TC LS	SE TC	SE EF	SE EF	SE SST	SE TC	SE TC	SE EF	SE EF
Layer thickness	SE TL	SE TL	SE TL	NS	NS	SE TL	NS	NS	NS	SE TL	NS	NS	NS	NS
Severity limit for the unit & Maximum limitation factors MLF)	**SE** TC EF *	**SE** TC SST EF *	**SE** TC LS TL	**SE** TC *	**SE** TC SST EF	**SE** TC LS TL	**SE** TC	**SE** TC EF	**SE** EF	**SE** SST TL *	**SE** TC	**SE** TC EF	**SE** EF	**SE** EF

Key to severity limit
NS : none to slight
MO : moderate
SE : severe

limitation factors
TC : too clayey for sand
SST : small stones
EF : excess fines
LS : large stone

C : limitation class
LF : limitation factor

*** Soils are underlying by gravel deposits**