Soils of the Lake Naivasha Area, Kenya

Summary of investigations 1997-2000 by the *International Institute for Aerospace Survey & Earth Sciences* (ITC)

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1. Introduction

Since 1997, students and staff of the Soil Science Division of ITC have carried out Masters of Science research projects in the Lake Naivasha area, Kenya. The results of this research have been published in theses (Ataya, 2000; Atkilt, 2001; Gatahi, 1986; Kamoni, 1988; Kwacha, 1998; Nagelhout, 2001; Ranatunga, 2001; Simfukwe, 2001; Tilaye, 2001) and conference proceedings (Siderius 1977 and 1980). The purpose of the present report is to unify these disparate studies into a common soil information system containing all the knowledge, generated by our research, of the soils of the Lake Naivasha area. This allows interested parties to quickly determine what information has been collected in detailed studies, and also presents a coherent view of the soils in the part of the area that has been studied by ITC.

All soils-related studies of the Naivasha area done by ITC have been reviewed for this report. The locations of each survey areas are shown on an index map, and the maps have been unified into a common map.

1.1. Physical location of studies at ITC

All MSc theses are available in the ITC Library. Datasets from most of the MSc studies led by the Soil Science Division (Ranatunga, 2001; Tilaye, 2001; Atkilt, 2001; Ataya, 2000; Nagelhout, 2001; Simfukwe, 2001) have been collected on CD-ROM and are available on request from technical services in room 4-126. These datasets, as well as those collected by the Water Resources Division are stored in a networked computer, Windows network address as of 01-July-2001 \\Pc5147-03\G-Drive\Naivasha. These have also been collected on CD-ROM and are stored in room 4-126.

1.2. Common coordinate system

All the studies use a common co-ordinate system and geo-reference; therefore, maps could easily be overlaid for further analysis and integration.

ILWIS Co-ordinate system NAIV has the following parameters:

- Minimum X, Y (166,000, 9,889,400),
- Maximum X, Y (221,750, 9,972,350)
- Projection: UTM zone 37, South of the equator
- Datum: Arc 1960
- Datum Area: Mean
- Ellipsoid: Clarke 1880

This is the same datum as shown on the topographic maps that were used as base maps for the digital data sets.

1.3. The geology of the area

The study area is dominated by two types of quaternary deposits, one of which is lacustrine and the other volcanic in origin (Thompson and Dodson, 1963). These have major implications for the distribution and properties of the (mostly young) soils. The oldest rocks found *in situ* in the area are Tertiary. A geological report and map of the area (at 1:100,000 and 1:250,000 scale) is available (Clarke et al., 1990). A sub-map of it is for the study area is shown in Appendix B.

On the basis of surface outcrops, the main products of volcanism within the Olkaria Volcanic Complex (termed the Olkaria Volcanic Group) are alkali rhyolite (comendite) lava and pyroclastic rocks. Trachyte and basalt-hawaiite lava have been minor products, but widespread trachytic pyroclastics to the north-west, west and south-west of the complex are believed to have been erupted from vents within the complex (Clarke et al., 1990).

According to Clarke et al (1990) the Longonot volcano constitute the Longonot Volcanic Group which incorporates seven formations. The major events in its history are:

1. Building of an early shield: Represented by the Longonot Volcanic Formation-poorly exposed pyroclastics and lavas in boreholes.
2. Caldera formation: Represented by the (dominently ignimbritic) Kedong Valley Tuff Formation.
3. Building of a pyroclastic and lava cone: Represented by the Akira (often plinian) pumice Formation. This comprises six members, the early one including surge beds, the-later-ashfalls. Later stages of cone building are dominated by lava-the Longonot trachyte Formation. The Longonot Mixed Lava Formation was erupted on the northern lower flanks at this time also.
4. Formation of a summit crater: Preceded or accompanied by the Longonot Ash Formation.
5. Flank and craterfloor lava eruption: Represented by the Upper Trachyte Member (flanks) and Upper Mixed Lava Member (crater).

Pyroclastics-ashes, agglomerates and tuffs make up a considerable proportion in the area, this covers the whole volcanic plain, Easterly winds during the eruptions caused the heaviest accumulations of ejected ashes, form Longonot volcano, to occur in around the study area and reported that recent pyroclastics are more acid in composition. The ashes are usually inter-bedded with other volcanics (Thompson and Dodson, 1963).

The age of the volcanic activity is between 0.4 and 0.45 Ma (Clarke etal 1990). The most recent eruptions are reported to be 2000 years ago (Thompson and Dodson, 1963)

2. Soil Science Division MSc research

2.1. Field period September 2000

Tilaye's (2001) objective was to develop methodologies to integrate diverse studies into a common database, using modern system design methods. In addition, he investigated user perceptions and needs for soil information. He organised and georeferenced previous works of Kwacha (1998), Kamoni (1988), Getahi (1986) and Siderius (1980). In addition, he scanned and geo-referenced the topographic map of the upper part of Lake Naivasha. Moreover, he developed a relational database system in MS-Access. It is summarised in **Table 1**

Atkilt's (2001) objective was to see if intensive management has altered soil properties to the extent that distinct 'phenoforms' of the same soil genetic 'genoform' can be identified. He also tested the proposed FAO Topsoil Classification to see if it gave useful information for intensive soil management. For this work he developed a relational database in MS-Access , structured to accomodate data of observation points which were not sampled in a standard survey method, for example, sampling at certain depth without deeper horizons. In addition, he produced an orthophoto mosaic; topsoil pH, EC and plot map of Sulmac farm and geopedologic map of his study area. Moreover, he scanned and geo-referenced the topographic map of his study area. It is also summarised in **Table 1**

Nagelhout's (2001) objective was to use and analyse Small Format Aerial Photographs (SFAP) as complementary to conventional aerial photography to assess the current status, and trends in wind erosion. He developed a photo-mosaic using small format aerial photographs of his study area. In addition, he made geopedologic, wind erosion, and landuse map. It is also summarised in **Table 1**

Simfukwe's (2001) objective was to investigate the validity of several concepts of the soil series, using an intensive sampling scheme to, at the same time, elucidate the scale of spatial variability among soil types on the low and mid Longonot volcanic plains. His study site was the Longonot farm of Sulmac Enterprises. He proposed three tentative soil series for this site, based on a geopedological map. He produced a geopedologic map, which is the same as Atkilt (2001). It is also summarised in **Table 1**

Ranatunga's (2001) objective was to evaluate the site suitability for the construction of housing and local roads in terms of soil and site characteristics around Naivasha town. He developed geopedologic map, urban landuse map, and different limitation maps of Naivasha town area for engineering use. It is summarised in **Table 1**

2.2. Earlier Field Seasons

Ataya's (2000) objective was to inventory and analyse the nature, severity, and spatial and temporal distribution of wind erosion in the southern part of the Lake Naivasha catchment. He made a geopedologic map and a wind erosion map both in digital and analogue form.

Kwacha's (1998) objective was to study soil vulnerability based at field and laboratory analysis. He produced geopedologic map of his study area in analogue format. This was later re-digitised by Tilaye (2001).

Kamoni's (1988) objective was to evaluate the suitability of the soils for growing irrigated vegetables in the 'Quarantine' farm (National Husbandry Research Station, Naivasha). He produced an analogue soils map of part of this farm.

Gatahi (1986) objective was to survey the soil condition of the Nini Farm Ltd, Naivasha and to determine their suitability for cultivation of some horticultural crops using sprinkler irrigation. He produced soils map of the area in analogue format.

Siderius (1980) surveyed the soil conditions at Kulia Farm (Naivasha) and produced a soils map of this farm. Siderius (1977) also surveyed the soils and environmental conditions of Agricultural Research Stations in Kenya.

The thesis abstracts of the different authors (i.e., all except Siderius) are found in Appendix A.

Table 1. Soil reports including maps of the Naivasha area, Kenya

S.No	Title	Author (S)	Year	Document Type	Observation points for soil mapping	Remark
1	Performance Analysis of Small Format Aerial Photography (SFAP) in Assessing Current Status and Trends in Wind Erosion (Nagelhout, 2001)	A. Nagelhout	2001	MSc. Thesis	9 standard pits	Geopedologic, wind erosion, & landuse change maps both in digital and analogue.
2	Soil Survey to Predict Soil Characteristics Relevant to Land Management (Naivasha, Kenya) (Atkilt, 2001)	Atkilt Girma	2001	MSc. Thesis	2-standard pits, 15minipits, and 12 shovel holes	Geopedologic and topsoil map both in digital and analogue.
3	The Use of Multivariate Classification in the Definition of Soil Series in Lake Naivasha Area (Simfukwe, 2001)	Simfukwe Paul	2001	MSc. Thesis	72-minipits & 2 standard pits (similar to 2 above)	Geopedologic map both in digital and analogue
4	Land Suitability Assessment for Housing and Local Road construction (Ranatunga, 2001)	D.M.B. Ranatunga	2001	MSc. Thesis	4 standard pits, eleven mini pits, and 34 auger holes	Limitation maps for different uses (engineering uses)
5	Building a Soil Information System for Multi-Source Data Integration (A Case Study in Lake Naivasha Area, Kenya). (Tilaye, 2001)	Tilaye Bitew	2001	MSc. Thesis	Has Geo-referenced previous analogue maps (several GPS pts)	Re-digitised maps of S. No. 7, 8,9, and 10
6	Wind Erosion of Volcanic Soils a Reconnaissance Study in the Southern Catchment of Lake Naivasha Region, Kenya (Ataya, 2000)	C.O. Ataya	2000	MSc. Thesis	6 mini-pits (are more or less to a depth similar to standard pits- ~120 cm) and 1 auger hole	Wind erosion map both in digital and analogue
7	Vulnerability of Soils to Change in Agricultural Use Around Lake Naivasha, Kenya (Kwacha, 1998)	C.P.H.J Kwacha	1998	MSc. Thesis	19 mini-pits and 9 auger holes	Geo-pedologic map in analogue form
8	Detailed Soil Survey of a Part of Quarantine Farm National Animal Husbandry Research Station, Naivasha (Nakuru District) (Kamoni, 1988)	P.T. Kamoni	1988	Soil Survey Report	3 standard pits and 30 auger holes	Physiographic units in analogue form (sketch map)
9	Detailed Soil Survey of the Nini Farm, Naivasha, (Nakuru District) (Gatahi, 1986)	M.M. Getahi	1986	Soil Survey Report	6 standard pits and 53 auger holes	Soil map (analogue form, sketch)
10	Soil Conditions at Kulia Farm, Naivasha (Nakuru District) (Siderius, 1980)	W. Siderius	1980	Soil Survey Report	3 standard pits and 30 auger holes	Soil map (analogue form, sketch)
11	Soils and Environmental Conditions of Agricultural Research Stations in Kenya (Siderius and Muchena, 1977)	W. Siderius F.N. Muchena	1977	Report	2 standard pits	No map
12	Explortory Soil Map and Agro-climatic Zone Map of Kenya (1:1,000,000) (Sombroek et al., 1980)	KSS	1980	Soil Map	Survey of the whole country, Kenya	Physiographic units available both in analogue and digital form.

Table 2. Soil information available for the Naivasha area, Kenya without soil maps

S. No.	Title	Author (S)	Year	Document Type	Information related to soil
1	The Fate of Agrochemicals in the Vadose Zone Environment Around Lake Naivasha (De Silva, 1998)	Anil Upendra de Silva	1998	MSc thesis	Soil pesticide leaching simulation
2	Erosion Assessment for Large Basins Using Remote Sensing and GIS (Hamududu, 1998)	Byman H. Hamududu	1998	MSc thesis	Erosion maps by different erosion models
3	Groundwater Contamination Potential of Agriculture around Lake Naivasha (Jolicoeur, 2000)	Jean Louis-Charles Jolicoeur	2000	MSc thesis	No maps but some soil properties are analysed
4	The Wetland Soils Around Lake Naivasha Kenya (Urassa, 1999)	Godson Jesaya Urassa	1999	MSc thesis	Geopedologic map of wetland soils and soil properties are analysed a total of 41 observation points (auger and mini-pit)

Table 3. Maps and photographs of Naivasha area, Kenya

S. No.	Maps and Photos	Year	Scale	No. of copies *	Contact person	Remark	Source of information
1	Aerial photographs (B/W) full coverage of Naivasha lake and surroundings	1967	1:50,000	5	Benno Masselink and J. Duim Jr. R# 4-126	5 working copies + originals + negatives in ITC Lab	(Siderius, 2000)
2	Aerial photographs (B/W) full basin-wide cover of Naivasha-Elementia-Nakuru-Aberdare range Approximate co-ordinates of quadrangle 36E-36.45E & OS-1S	1970	1:50,000	2	Drs. J. Looijen, R# 4-139	2 working copies available + original + Negatives at ITC photolab	(Siderius, 2000)
3	Aerial photos (B/W) cover of lake Naivasha and immediate surroundings	1984	1:12,500	5	Same	5 working copies available + original + Negatives at ITC phtolab	(Siderius, 2000)
4	Aerial photos (B/W) cover of the geothermal plant area (Olkaria comples); southern part of the lake Naivasha	1990/91	1:10,000	1	Same as 1	1 copy only available : they are good quality prints	
5	Topographic maps Series Nyeri sheet SA-37-1 includes all basin 10 (B/W) copies made		1:250,000	1	R # 5-144		(Siderius, 2000)
6	Topographic maps (BKS Surveys Ltd., 1975) Series Y-731 12 sheets (map number with names): 8 available. Is also available in digital form in WREM Data PC-5147 ITC network	1975	1:50,000	5	Same as 1 also R# 144 **	1 original and B/W copies available. 4 missing sheets (119/2, 120/1, 120/3, 134/3)	
7	Geological map (Ledgard, 1988), is also available in digital form WREM Data (computer No. PC-5147)	1888	1:100,000	1	**	In colour, including the report	
8	Rough land use and vegetation map available in digital form can be obtained in WREM data (computer No. PC-5147)						
9	Satellite images of lake + surrounds (from UK) image available fileserver	1989					(Siderius, 2000)
9	Two TM scenes (full coverage Narok-Mara up to north of Naivasha rift valley) row/col 169/30-169/31. Jan. 21, 1995 (7 bands)	1995					(Siderius, 2000)
10	Land sat TM image 2000 (Feb & May) (6bands)	2000			PC-5147		
11	Soil map of Kenya	--	1:1M	1	** and PC-5147	Hard copies** and digital	
12	Water erosion risk assessment in Kenya (SOTER)	1996	1:5M	1	**	Hard copy only available	
13	Tourist map of Naivahsa area		1:			Hard copy (original available)	

* Working copies

** Also can be found in soil Naivasha database

3. The unified soil map

For the purpose of this report, we integrated the various earlier studies into a common geopedological and soil type map. The conceptual approach followed here and in most of the earlier studies is the `geo-pedological' soil-landscape mapping method of Zinck (1988, 1990, 1991).

3.1. Method

The various earlier maps already had a common geo-reference and were available in digital form. They were overlaid visually on the screen to check their degree of geometric and conceptual (thematic) agreement. Where they overlapped or were adjacent, we classified them as one of:

(1) identical,
(2) matching,
(3) conceptually matching but geometrically not matching,
(4) geometrically matching but conceptually not matching, or
(5) completely inconsistent.

Case (2) required only minor geometric and terminology adjustments. The other cases were more difficult, and required expert knowledge of the soil-landscape relations, and in some cases a review of the original sources (photographs, topographic maps, and observations) to resolve.

The major discrepancies are conceptually matching but geometrically not matching, type (4). This means that the various authors agreed on the soilscapes but not on the placement of boundaries. Correction for such types of discrepancies was minimised by using aerial photo mosaic and satellite image as a background. Geometrically matching but conceptually not matching, type (5), were resolved by finding the best category in a unified legend. This avoided an artificial boundary placed only because two mappers worked on adjacent areas. This was essentially re-correlation of the survey using our expert knowledge of the area.

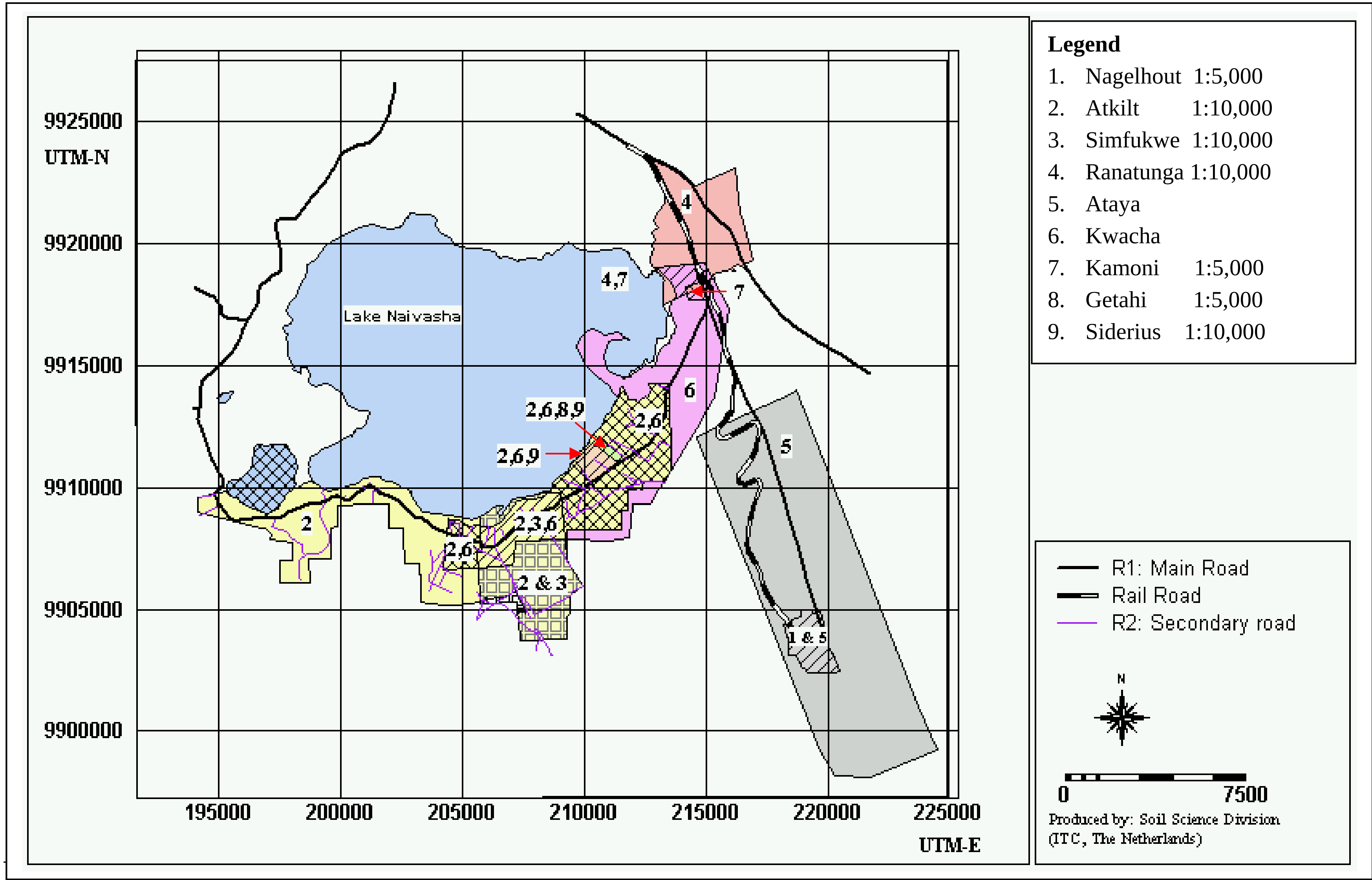
Once the discrepancies had been solved, the various segment maps defining the polygons were glued and adjusted manually. Match lines between surveys were deleted. The polygons were re-labelled, and the maps were polygonized. Each polygon was linked to a legend category.

Different authors working in different places have named the same unit differently. We selected the best name in a new unified legend. Thus the legend here is not exactly the same as in any of the previous studies. It is shown in Table 4. An overview of the soil taxonomic classes found in each map unit is shown in Table 5.

3.2. The unified map

Figure 2 shows the unified map. The legend is described in section 3.3

Figure 1. The locations of the different soil surveys made in the Naivasha area[1]



[1] Excluding the exploratory soil map of whole Kenya (Sombroek 1980)

Figure 2. The unified geopedologic map of the area (for the full legend description see **Table 4**)

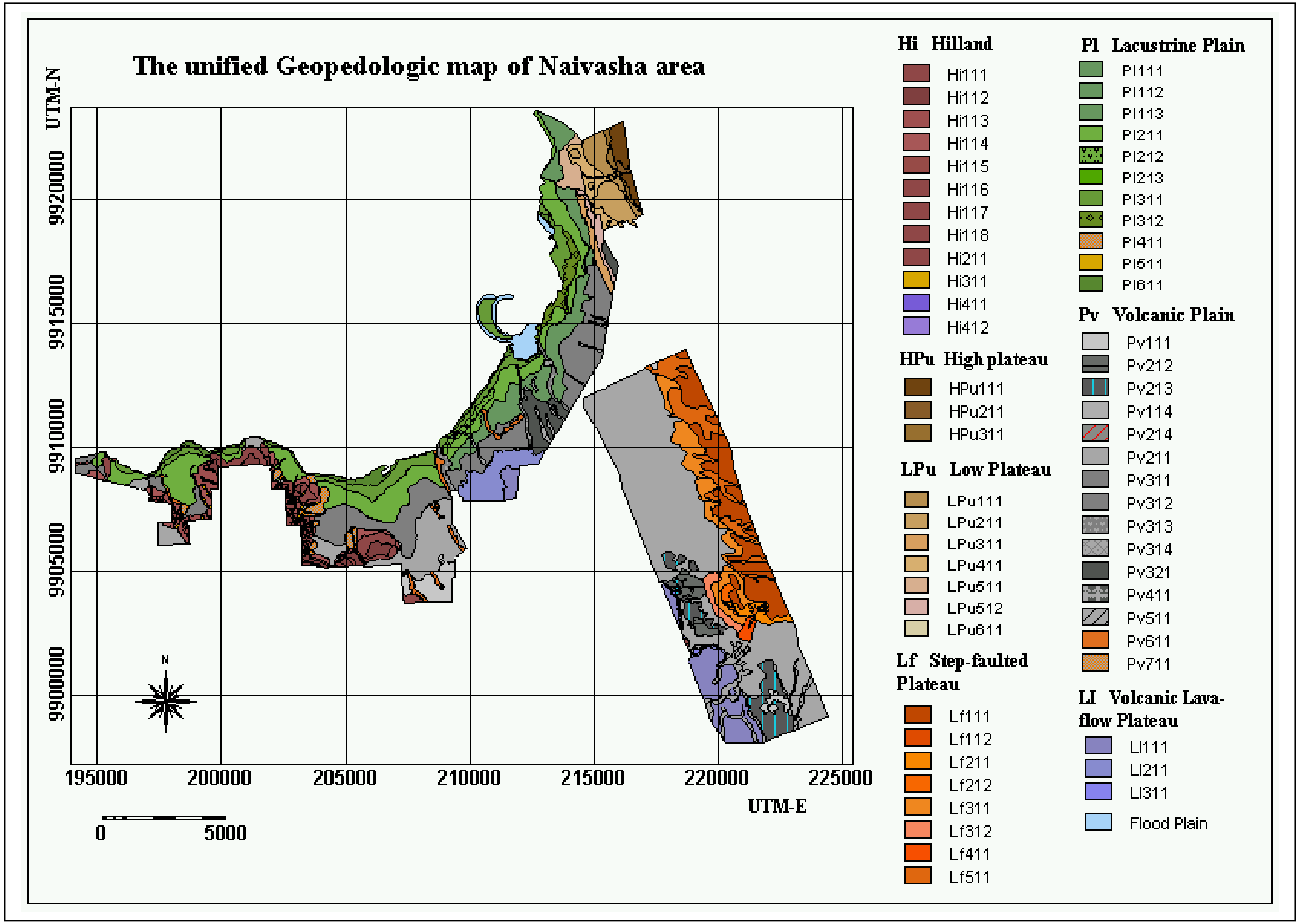


Table 4. The geopedologic map legend

Landscape	Relief	Lithology	Code	Landform
High Plateau	Mesa	Longonot volcano Akira pumice weathered volcanic lava flows	HPu111	?
	Vale	Alluvial deposits, Kedong valley tuff (trachyte ignimbrites and associated fall deposits)	HPu211	Bottom side complex
	Escarpment	Limuru trachyte, Karati and ol Mogogo basalt, Kinanhop tuff	HPu311	Scarp
Hilland	High Hills	Olkaria Comendite; lavaflows and In some parts covered with Longonot Ash	Hi111	Slope facet complex
			Hi112	Summit/sholder complex
			Hi113	Backslope/footslope complex
			Hi114	Foot slope
			Hi115	Scarp
			Hi116	Talus
			Hi117	Dissected Summit
			Hi118	Backslope
	Low Hills	Same as above	Hi211	Slope facet complex
	Vale	alluvium	Hi311	Bottom side complex
	Obsidian Ridge	Lower Longonot (Mixed basalt/trachyte lava flows)	Hi411	Summit
			Hi412	Riser
Lacustrine Plain	High Lacustrine Plain	Lacustrine sediments	Pl111	Tread/riser complex
			Pl112	Tread
			Pl113	Riser
	Mid Lacustrine Plain	Lacustrine sediments	Pl211	Tread/riser complex
			Pl212	Tread
			Pl213	Riser
	Low Lacustrine Plain	Lacustrine sediments	Pl311	Tread/riser complex (nearly level)
			Pl312	Tread/riser complex (Undulating)
	Fan	Alluvium/colluvium	Pl411	Distal/proximal complex
	Swale	Alluvium/colluvium	Pl511	Bottom side complex
	Reperian	Lacustrine sediments	Pl611	Undefferentiated
Low Plateau	High Glacis	Unconsolidated pyroclastic, alluvial deposits & Akira pumice	LPu111	Backslope
	Mesa	Alluvial deposits, Longonot Volcano Akira pumice, Kedong valley tuff (trachyt e ignimbrites and associated fall deposits).	LPu211	Almost flat
	Escarpment	Limuru trachyte, Karati and ol Mogogo basalt, Kinanhop tuff.	LPu311	
	Mid glacis	Alluvial deposits, Longonot Volcano, Akira pumice, Kedong valley tuff (trachyte ignimbrites and associated fall deposits).	LPu411	Sloping riser
	Low glacis	Same as above	LPu511	footslope
		Alluvial deposits, Eburru Pumice (pentallerite and trachyte pumice and Volcano ash fall deposits	LPu512	Sloping riser
	Vale	Same as low plateau mesa	LPu611	Bottom side complex
Step-faulted Plateau	Vale (incision1)	Kidong valley tuff, trachyte, ingimbrites	Lf511	Bottom side complex
	Mesa (non-dissected)	Limuru trachyte (Tl) & Longonot Ash	Lf111	Summit
	Mesa	Limuru trachyte (Tl)	Lf112	Summit-sholder complex
	Escarpment	Same as above	Lf211	Steep, dissected
			Lf212	steep, not dissected
	Glacis	Same as above	Lf311	Upper part
			Lf312	Lower part
	Alluvial fan	Same as above	Lf411	Distal-proximal complex
Volcanic lava-flow plateau	Mesa	Longonot ash (Lp8) & Obsidian	Ll111	?
	Scarp	Lower Longonot trachyte (Lt2): lava flows and pyroclasitc cones	Ll211	?
	Glacis	Same as above	Ll311	?
Volcanic Plain	High Volcanic Plain	Longonot ash, Akira Pumice	Pv111	Tread/riser complex
	High Volcanic Plain (slopi	Same as above	Pv114	
	Mid Volcanic Plain	Same as above	Pv212	With very low dunes (0.3-2m)
			Pv213	With low dunes (2-4m)
	Mid Volcanic Plain (slopin	Same as above	Pv214	Medium hummocks
	Mid Volcanic Plain	Same as above	Pv211	Tread/riser complex
	Low Volcanic Plain	Volcanic ash, Akira pumice	Pv311	Tread/riser complex
			Pv312	Tread
			Pv313	Riser
			Pv314	Talus
		lava flow	Pv321	Tread/riser complex
	Ridge	Longonot mixed basalt/ Trachyte lava flows	Pv411	Slope facet complex
	Vale	Alluvium	Pv511	Bottom side complex
	Swale	Alluvium	Pv611	Bottom side complex
	Fan	Alluvium	Pv711	Distal/proximal complex

Table 5. Soil types as classified by different authors around lake Naivasha

	USDA Soil Taxonomy 8^{th} Edition	**World Reference Base for Soil Classification**
HPu111	?	Ferrasols (?)
HPu211	?	Cambic Yamic Leptosols (?)
HPu311	?	Haplic Phaeozems
Lf312	?	Areni-Vitric Andosols (Dystric)
LPu111	?	Arenic Andosols (?)
LPu211	?	Leptic Phaeozems; Pachi-Vitric Phaeozems
LPu311	?	Umbric Lithic Leptosols
LPu411	?	Arenic Andosols (?)
LPu511	?	Ferralic Andosols (?)
LPu512	?	Leptic Phaeozems
Pl111	Typic Calciustepts (Coarse-loamy,mixed,isothermic);Typic Haplustalfs	Orthicalcic Calcisol; Hypersodi-Calcaric Flu-visols; Calcic Cambisol; Calcic Cambisol (Sodic Phase); Chromic Cambisol; Eutric Cambisol
Pl113	Typic Haplustalfs	Haplic Luvisols
Pl211	Typic Calciustepts;Aridic Ustipsamments (Ashy,Glassy,Isothermic	Eutric Cambisol; Areni-Vitric Andosols; Pa-chi-Sodic Phaeozems; Calcic Cambisols; Chromic Cambisols
Pl212	Typic Ustipsamments (Sandy,mixed,isothermic);Typic Calciustepts	Arenic Fluvisols; Eutric Cambisols; Eutric Fluvisols
Pl213	Typic Calciustepts	Eutric Cambisols
Pl311	Typic Ustorthents;Vitric Haplustepts (Ashy-pumicious,mixed,isothermic)	Eutric Cambisol;Sodi-fluvic Cambisol (Skeletic, Eutric);Molli-Gleyic Fluvisols (So-dic);Calcaric Fluvisols
Pl312	Typic Calciustepts	Eutric Cambisols; Gleyic Cambisol
Pl611	Typic Udipsamments (Sandy,mixed,isothermic)	Fluvic Cambisols
Pv111	Aridic Ustipsamments (Ashy,glassy,isothermic); Vitrandic Ustorthents	Tephric Arenosol
Pv212	?	Areni-Vitric Andosols (Dystric)
Pv213	Vitrandic Ustipsamments (?)	Areni-Vitric Andosols (Dystric)
Pv211	Aridic Ustipsamments (Ashy,glassy,isothermic); Vitrandic Ustorthents; Vitrandic Ustipsamments	Areni-Vitric Andosols (Eutric); Tephric Are-nosols; Areni-Vitric Andosols (Dystric)
Pv311	Aridic Ustipsamments (Ashy,glassy,isothermic)	Areni-vitric Andosols
Pv312	Andic Haplustepts	Haplic Andosols
Pv611	Aridic Ustipsamments (Ashy,glassy,isothermic)	Areni-Vitric Andosols (Dystric)

3.3. Description of the geopedologic map units

There are seven major landscape units in the Naivasha area: (1) lacustrine plain, (2) volcanic plain, (3) hilland, (4) high plateau, (5) low plateau, (6) step-faulted plateau & (7) volcanic lava-flow plateau.

3.3.1. The lacustrine plain (code PL)

It occurs around the lake and ranges between an altitude of approximately 1880-1910 m.a.s.l. It is not easy to put sharp boundary between the lacustrine and the volcanic plain. By looking at the surface or during aerial photo interpretation, one may put the boundary line possibly in a horizontal range (uncertainty) of 50-200m's.

The lake level changes and the different episodes of the volcanic ash eruptions complicated the boundary between the two landscape units. For example, the maximum height the lake has reached was 1940 m.a.s.l. (Clarke et al., 1990). This reworked the volcanic materials found under it. After some years, the lake level has lowered and it was followed by another Longonot volcanic eruptions. The eruption covered the lacustrine reworked and/or deposited materials.

Though the lacustrine plain doesn't have sharp boundaries with the volcanic plain, its surface features and topography to some degree can identify it. Generally, it has straight, flat, gently sloping topography and the soils are less sandy than the next higher plain.

This landscape unit has three major relief types, namely the high, mid and low lacustrine plain. They are modified terraces or relief types of high water lines. That is to say, the riser and tread units cannot be separated. The tread tapers out to the lower lacustrine landform unit. It is probably smoothened by the wave and lake water level fluctuations. In fact, at a few places, the tread and riser can still be separated. Similar to the boundary between the volcanic and lacustrine plain, the relief units don't have sharp boundaries between them. But, they could be separated by grey tone, vegetation and texture, probably corresponding to ground water levels reflected in vegetation types.

Generally the soils of the lacustrine plain are moderately well drained to well drained, very deep, dark brown (10YR3/3, dry) to olive brown (2.5Y4/3, dry), silty-clay to clay-loam. The major lacustrine landform units are described in detail below.

A. Map unit PL111 (high lacustrine plain)

This unit is the upper portion of the lacustrine plain (see Figure 2) it extends more or less parallel with the other lacustrine units. It has gently undulating topography (2-5% slope), more or less straight, well drained to moderately well drained, mostly dominated by diatomites, very deep soils, light olive brown (2.5Y 5/3, dry) to white (2.5Y 8/1, dry), loamy sand to loam, and weak to very weak subangular blocky structure. At some places volcanic ashes and glasses are observable.

The dominant soil types according to FAO (1998) and FAO-UNESCO (1997) are Orthicalcic Calcisols, Hypersodi-Calcaric Fluvisols (at a few places), Calcic Cambisol, Chromic Cambisol; and Eutric Cambisol. The representative profiles for this unit are Am14 (in Kijabe farm) and 5AB (in Aberdare estates). Most profiles have free carbonates, some are sodium-enriched.

B. Map unit PL211 (mid lacustrine plain)

This unit lies more or less in the middle portion of the lacustrine plain (see Figure 2) it extends more or less parallel with the other lacustrine units. It has almost flat to gently undulating topography (1-4% slope), straight, with scattered acacia trees, very deep soils, very dark olive brown (2.5Y 3/2, dry) to olive brown (2.5Y 4/3, dry), loamy sand to loam, and weak to very weak subangular blocky structure. Thin volcanic ash covers around Sulmac farm are observable.

The dominant soil types according to FAO (1998) and FAO-UNESCO (1997) are Eutric Cambisols, Areni-Vitric Andosols, Pachi-Sodic Phaeozems, Calcic Cambisols, and Chromic Cambisols.

C. Map unit PL311 (low lacustrine plain)

This map unit is located adjacent to the riparian zone (see Figure 2). It has almost flat to gently undulating topography (1-3% slope), straight, moderately well drained, very deep, with few acacia trees and grasses, dark brown (10YR3/3 dry) to olive brown (2.5Y4/3 dry), loam to sandy loam, none to common fresh pumice gravels, weak to very weak subangular blocky structure. The representative profile for this unit is P2.

The dominant soil types according to FAO (1998) and FAO-UNESCO (1997) are Eutric Cambisosl, Sodi-fluvic Cambisols (Skeletic, Eutric), Molli-Gleyic Fluvisols (Sodic), and Calcaric Fluvisols. These soils are Sodic and should be managed with care.

D. Map unit Pl611 (Riparian zone)

This map unit is the lower part of the lacustrine plain. It is the youngest in terms of soil development. It has flat to almost flat topography (0-1%), imperfectly drained, very deep, olive grey to dark grey, sandy loam to loam soils. The horizon transitions are clear and smooth, becoming abrupt and wavy in the subsoil and common pumice gravels. The land is mainly a riparian area dominated by papyrus vegetation.

The soils are mainly Fluvic Cambisols (sodic) and Calcaric Fluvisols (sodic).

3.3.2. The volcanic plain (code Pv)

The volcanic plain has also three different relief or moulding types, namely the low, mid and high volcanic plain. It is underlain by layers of different episodes of volcanic materials erupted from Longonot and Olkaria complex, the most recent 200 years ago (Thompson and Dodson, 1963). This unit, for example around the Longonot branch of Sulmac farm, shows hummocky surfaces that are sander than the lacustrine plain. They are most probably transported and shaped by wind, i.e. low sand dunes. Moreover, on some places fresh lava flows are evident on the surface.

Generally the soils of the volcanic plain are well drained to somewhat excessively drained, very deep, with non calcareous to moderately calcareous topsoils, mostly dominated by volcanic ashes and glasses. The contents of the volcanic glasses and ashes decrease as one goes form the high volcanic plain to the low lacustrine plain. The volcanic glasses are mainly obsidian.

When these soils are put under cultivation, they turn into a powdery masses which later impedes proper infiltration. Therefore, appropriate tillage implements that do not excessively pulverise the soil should be used. Unmanaged or natural volcanic soils often have compacted surface layers, perhaps because of grazing animals.

A. Map unit Pv111 (high volcanic plain)

This unit is the upper portion of the volcanic plain. It is characterized by slightly hummocky, more or less stable sand dunes, ashy, with large amounts of volcanic glasses. The land use mainly includes wild life and livestock grazing with scattered bushes. In addition, this unit has little human influence as compared to the lacustrine & mid and low volcanic plain, mainly because of lack of irrigation water.

It has a very deep regolith with alternating volcanic ash layers erupted from nearby volcanoes, which is later modified by the action of wind. Probably due to trampling of wild animals, the topsoil is very compact, beyond CBR (California Bearing Ratio) 14. The topsoil colour is dominantly light olive brown (2.5Y 5/3, dry) The soil immediately loses moisture and changes its colour from grey (2.5Y 5/2, moist) to light brownish grey (2.5Y 6/2, dry) upon exposure to the sunlight. The soils in this unit are less developed than the other volcanic plain soils.

The soils are mainly Tephric Arenosols and Areni-Vitric Andosols. The representative profile for this unit is Am1.

B. Map unit Pv211 (mid volcanic plain)

This unit is located in the middle portion of the volcanic plain (see **Figure 2**). It has more or less similar topography like the high volcanic plain. The hummocky surfaces are sand dunes, probably shaped by wind action. The volcanic glass content decreases as one goes form the high volcanic plain to the lower lacustrine plain. The representative profile for this unit is P1.

It has very deep soil, well drained to somewhat excessively drained, gently sloping (2-4% slope), at depth thin compacted layer is evident on some places, for example in P1; this is probably caused by silt illuviation under irrigation. The soils are Areni-Vitric Andosols (Eutric), Tephric Arenosols and Areni-Vitric Andosols (Dystric).

C. Map unit Pv311 (low volcanic plain)

This unit has more or less straight topography with no hummocky surfaces, well drained to moderately well drained, gently sloping (1-3% slope), very deep, alternating volcanic ash layers. Most part of this unit is under cultivation.

These soils are less Sodic than the lacustrine plain soils. The major soil types of this unit are: Areni-vitric Andosols.

3.3.3. Hilland

The hilland landscape units are mainly lava flows from the Olkaria volcanic complex. They have very shallow soils and ashes intermingled with the volcanic rocks. The soils of these areas are probably Leptosols. They are mostly kept as a nature reserve. This landscape unit has several landform units; however because of its small importance for agriculture it is not treated extensively here.

3.3.4. High Plateau (code HPu)

The High plateau consists of three relief units: mesa, vale and escarpment.

The soils of the mesa *(HPu111)* are mainly Ferralsols, somewhat well drained, relatively shallow, very dark brown to brown silty loam to silty clay loam. Mostly the sub-surface soil horizons have common medium rounded weathered rock fragments (Phonolite).

The soils of the vale (*HPu211*) are Skeletic Calcisols that have developed on pyroclastic deposits. The soils are well-drained, shallow, very dark brown to dark yellowish brown, clay loam to sandy loam. The soil pH values increase from the topsoil down to the subsoil for example 5-7.5.

More than 90% of the escarpment (*HPu311*) soils are classified as Haplic Phaeozems. These soils are very shallow to shallow, well-drained, very dark greyish brown and dark olive grey, silty clay loam to sandy loam soil. Approximately, 15-40% of the surface is covered by hard rock, phonolite and basalt. Weathered sub-rounded stones are found in the B-horizon.

3.3.5. Low Plateau (code LPu)

The low plateau is divided in to six relief levels: high glacis, mesa, escarpment, mid glacis, low glacis and vale.

The dominant soil of the high glacis *(LPu111)* is Arenic Andosols. Generally, it has very deep, well drained, sandy loam to coarse sand, with few rounded rock fragments in B-horizon, mostly non calcareous but at depth (60-80cm) it shows cementation probably by carbonates and silica because of this it is calcareous, dark yellowish brown to brown soil, pH ranges form 6 to 9. The sub-surface B-horizon is white in colour.

The mesa (*LPu211*) of the low plateau is dominated by Leptic Phaeozems and Pachi-Vitric Phaeozems soils. The soil is very deep, somewhat well drained, very dark brown to light yellowish brown, fine sandy loam, none to strongly calcareous, soil pH increasing with depth from approximately 5 to 9.

The escarpment (*LPu311*) soil is classified as Umbric Lithic Leptosols. They are very shallow to shallow, well-drained, very dark greyish brown and dark olive grey, silty clay loam to sandy loam soils. 20-40% of the surface is covered by hard rock (trachyte and basalt) Weathered sub-rounded stones are found in the sub surface B-horizon.

The mid glacis (*LPu411*) soil is mainly Arenic Andosols. It has moderately deep, well-drained sandy loam soils, dark brown to light yellowish brown, slightly sticky and slightly plastic. Accumulation of some rounded medium gravel in the B-horizon can be seen. The soil pH mostly varies from 5.5-7.5.

The soils of the low glacis foot slope (*LPu511*) are classified as Haplic Andosols. The soil is somewhat excessively drained, very deep, very dark brown to yellowish brown, sub-angular blocky, sandy loam to clay loam soils. Transitions are abrupt and smooth in the sub soils. Few, fine gravel are found on the surface horizon.

The soil of the riser of the low plateau (*LPu512*) is classified as Mollic Andosols. The soils are shallow, well-drained, clay loam to loam, very dark greyish brown to grey, strong medium subangular blocky structure, non-calcareous, pH ranging form 5-6. Few rounded weathered stones were found in the B-horizon at approximately 60cm from the soil surface.

The vale (*LPu611*) is classified as Ochric Fluvisols. They are very deep, excessively well-drained, dark brown to brown pale yellow. Abrupt textural changes, for example, from coarse sand to sandy loam to loamy sand and to silt, from surface to sub-surface B-horizons. The soil pH is more than 8.

3.3.6. Step-faulted plateau (code *Lf*)

It forms the lowest part of the sequence of step-faulted plateau's of which the Kinangop plateau represents the highest level. Soils are moderately deep (around 90cm), and relatively coarse textured with rock fragments as compared to the volcanic plain. The sub-horizons consist of depositions of lapilli and are strongly calcareous. These lapilli depositions are generally quite thick, up to at least three meters. Slopes vary between sloping (5-10%) and moderately steep (15-30%), with some dissected parts in the steep areas. The terrain of the mesa is flat. The soils are deeper and there are more agricultural activities than the volcanic pain.

3.3.7. Volcanic lava-flow plateau (code *Ll*)

It covers the lower section of old lava flows from Mt. Longonot volcano. The extent of this unit is around 120ha. The plateau lies only a 20-30m higher than the volcanic plain, divided by a very steep scarp, the front of a volcanic lava flow. The soils are probably shallow and less fertile.

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Appendix A: Thesis Abstracts

Ataya (2000)

This reconnaissance study has been undertaken to make an inventory (nature, intensity, extent and trends) of wind erosion in the southern catchment of the Lake Naivasha region, Kenya.
An attempt has been made to analyse the land cover changes and how they have influenced wind erosion. Also it tries to answer questions such as where, why and how is wind erosion occurring and what relationship is there between the soils, land cover changes and human activities.

The area experiences irregular inter-annual rain. Main rain season is between March to May and short rain season is from November to January. The average annual rainfall is about 600mm/year. The average monthly mean temperatures is around 18˚C. The winds are generally calm in the morning while in the afternoons they can attain a speed of 11-15km/h. They are strongest in the months of August to October when they can attain a speed of 21km/h. The direction is from the south-east and north-west depending on the season. Extremely strong winds have been reported to occur through the window between the Longonot and Kijabe Hill.

The study area has 3 types of landscape. Kinangop plateau in the east, the Longonot and its associated lava flow fields to west and the volcanic plain that is flanked by the 2 in the middle.
The study reveals that the wind erosion is largely confined to the volcanic plain landscape (map unit Pl) with the worst affected areas to south followed by the central part. The wind erosion features encountered occur in form of distinct elongated features in form of long east-west running strips following the prevailing wind direction.

Atkilt (2001)

It is generally known that management practices such as tillage, fertilisation, insecticides, herbicides applications, etc. may result in changes in the physical and chemical properties of the soil. For example, soil compaction, problems of soil aeration, decline in soil fertility and the effect on soil ecosystem. The results of the different types of management are called “phenoforms” whereas the genetically defined soil types are “genoforms”.

The purpose of this study was to distinguish and characterise the different phenoforms formed by different types of management in the area of lake Naivasha, Kenya. Genoforms were defined by standard soil survey and classification systems and phenoforms by statistical analysis and classification methods such as the FAO proposed topsoil characterisation (1998) including USDA (1998) and World Reference Base (1998).

Twenty-nine observation points with a total of 74 horizons were sampled. Eleven of them were paired (managed vs unmanaged). The observation points that were made in pairs were chosen based on site observation, close to each other, with the same genoform and differing only in management practices. Soil properties including infiltration (I), bulk density (Bd), soil structure, organic mater content, coarse fragments, pH, EC, and penetration resistance (r) were determined. Results and conclusions were made using statistical methods and by inference from principles of soil science.

The main soil types of the area are Areni-Vitric Andosols (Eutri) and Sodi-Fluvic Cambisols (Skeletic, Eutric). There is significant difference between managed and unmanaged in two properties: in soil infiltration rate during the first 8 minutes and r of the 2^{nd} horizon. Though not significantly different, suggestive results in soil pH and Bd were found. These both increased with depth. Soils in the volcanic plain have significantly higher Bd and significantly lower pH than those in the lacustrine plain. Organic mater content increases due to management in the volcanic plain soils and decreases in the lacustrine plain. Soil structure cannot be a diagnostic criterion in these gravely sandy soils, derived from volcanic ash, due to its weak development.

The proposed FAO topsoil classification highlights most of the soil properties useful for management, for example the low nutrient retention, natric, and altaric properties of these soils. On the other hand, production limitations such as excessively drained properties, problems of nematodes, some toxicities, potic nature, and soil capping were not recognised and could be added to improve the usefulness of the classification system.

Kwacha (1998)

This study is concerned with vulnerability of soils due to change in landuse around the shore of lake Naivasha (Kenya). The soils have been developed on the Lacustrine sediments and volcanic deposits.

An attempt has been made to investigate soil chemical properties in and between sample areas, and also in different landuse, by comparing with existing data of the same area. Some samples were collected form a natural forest (control area), where there is no current observable human influences, for the purpose of comparing soil properties with the cultivated area. Three sample areas were selected which cover different landuse.

Most soils of the study area are moderately well drained to well drained, moderately deep very deep, but also shallow soils are found mainly over the raised ridges in the volcanic plain. The top soil varies from a very dark brown to yellowish brown, which is silty clay to sandy loam, the topsoil pH varies from 4.7 to 8.3 while pH at depth of 50cm varies from 6.6-9.4 and pH at the depth of 120cm varies from 7.3 to 10.6.

In general soils has a high Phosphorus, Calcium and Magnesium content, Nitrogen and Carbon levels are low while Potassium content is very high. Following the USDA Soil classification system the soils belong to three orders Alfisols, Inceptisols and Entisols. Crop production in the area are mainly flower and horticultural crops which depends on abstraction of water from lake Naivasha. Soil cultivation and in combination with other soil management practices has modified some soil properties; topsoil properties being more modified then the subsoil ones. The investigation of soil properties show that C, Ca, EC, Mn, Na and P are liable to change in the study area.

Nagelhout (2001)

This study is directed to assess the current status and trend in wind erosion in the Lake Naivasha area, Kenya.

In the last decade dramatic changes have occurred in the Longonot-Kijabe Hill area, where land degradation, especially wind erosion has altered the landscape. Although several satellite images (Landsat) were taken of this area, the resolution of these images is too low to assess the current status of wind erosion in the study area. Aerial photographs are available, but 9 years old, just taken at the start of the wind erosion process.

Small Format Aerial Photography in combination with GPS is a low cost technology, with rapid results, an excellent tool to obtain actual photographs of the study area. With a hired Cessna 182 and a Minolta X300 camera (35mm) 130 photographs were made, covering the reconnaissance area with 5 flight lines. 28 photographs were selected which covered the study area. These photographs were rectified (projective transformation) with GPS observations made in the field.

During fieldwork a soil survey was carried out to obtain general soil information of the area and information about the Wind Erosion Features was annotated.

The conventional aerial photographs of 1991 were interpreted and resulted into three maps, geopedological map, land use map and status of land degradation 1991. Also the SFAP's were interpreted, giving the current status of land degradation and land use in the study area. With these maps of two different periods, trends and rate of land degradation for the period 1991-2000 was calculated.

A severity classification of the current land degradation situation in the study area was created, following the guidelines of the GLASOD methodology, adapted to the study area.

An analysis was made to the underlying factors of wind erosion in the area. The micro-relief and soil properties play an important role. One map unit in the Volcanic Plain consists of several low dunes, where a Bw-horizon with a low erodibility covers highly erodible dark grey sand layers. Destroying the Bw-horizon in this particular map unit will start the wind erosion process.

The agricultural function of the area has reduced significantly in these 9 years. Several complexes of deflation trenches are found on abandoned fields which were under agricultural practices

Ranatunga (2001)

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

Simfukwe (2001)

The knowledge of soil properties and their response to management practices is an essential requirement by any land user. Much of the Lake Naivasha area is under intensive horticultural and flower cultivation. Such land is susceptible to degradation when badly managed. Soil information is therefore on demand by a wide range of land users including farmers, planners, conservationists, developers, engineers, lenders and investors in the area. In other intensively used areas of the world, the soil series has proven to be an appropriate information carrier for particular management options. Soil series are relatively homogeneous units enabling specific management decisions, and typically occupy well-defined landscape positions and form compact spatial entities.

An unequal nested sampling design was adopted for soil characterisation and determination of the spatial variability of the soils in the area. Six centres with 600m spacing were established along a catena in the upper lacustrine and low-mid volcanic plains in the SULMAC farm. Closer sub-centres were established, with the geometric series with a basis of 600m, namely 190m, 60m, 19m, and 6m. This yielded 72 sampling points whose important soil properties were determined. The depth to the weathered zone, the thickness of the A-horizon, the depth of the B-horizon and the gravel percentage in the A and B-horizon were used to perform the multivariate analysis.

The data was analysed by descriptive statistics, one-way ANOVA, clustering of observations, and fully nested ANOVA. All observations were grouped into clusters in property space by similarity, using the minimum-distance-to-class centroid method. The result was a dendrogram of different clusters. The spatial distribution of these clusters was investigated by mapping and by comparaison with geopedological maps units. Spatial variability was investigated by the fully nested ANOVA.

Soil series were defined by two approaches: based on map units defined by geo-pedological mapping, and by multivariate cluster analysis. In the first approach, observations were grouped by map unit and their central concepts and range were established. This resulted in three proposed series. In the second approach to defining series, multivariate analysis defined clusters of individuals which are generally simi-lar to one another, and which form statistically different classes. The clusters are relatively homogeneous and can be used to define individual series with unique central concepts. However, these proposed series are not always mappable. In some cases, observations from different clusters were intimately mingled. Other clusters formed compact units, but these were smaller than the minimum legible delineation at de-tailed map scale (1:10 000).

The fully-nested ANOVA showed that the range of spatial dependence of soil properties varied from very short, i.e. <6m to 19m (thickness of the A horizon) through medium, i.e. 60m to 190m (weathering depth) to moderately long, i.e. 60m to 600m (gravel content). The longer-range properties should be more useful in defining mappable series.
All the series defined by both approaches fell within the boundaries of one class at the lowest levels of two hierarchical taxonomic systems. The soils classified as Ashy-pumiceous Mixed, Isothermic Vitriandic Haplustept, and Ashy, Glassy, Isothermic Aridic Ustpsamment (USDA family).

Synthesising the two approaches, three series were proposed, all in the same family: The Naivasha, the Sulmac, and the Longonot series. Thus soil series that are homogenous enough for intensive management can be defined in Lake Naivasha area.

Tilaye (2001)

This study was aimed at the design of a Soil Geographic Database (SGDB), as part of a Soil Information System (SIS), for the improved management of soil and land resource data relevant to an area around Lake Naivasha in Kenya. Emphasis is given both to the rescue of existing data, available in different formats from a variety of sources, and to the improvement of user access to adequate soil information for multiple purposes. The methods adopted for SGDB data modelling and for SIS development are the relational data model and the iterative structured information system development method, respectively. Two components of the SIS were designed: a relational database structure having twelve relations, and a prototype information system architecture consisting of four subsystems.

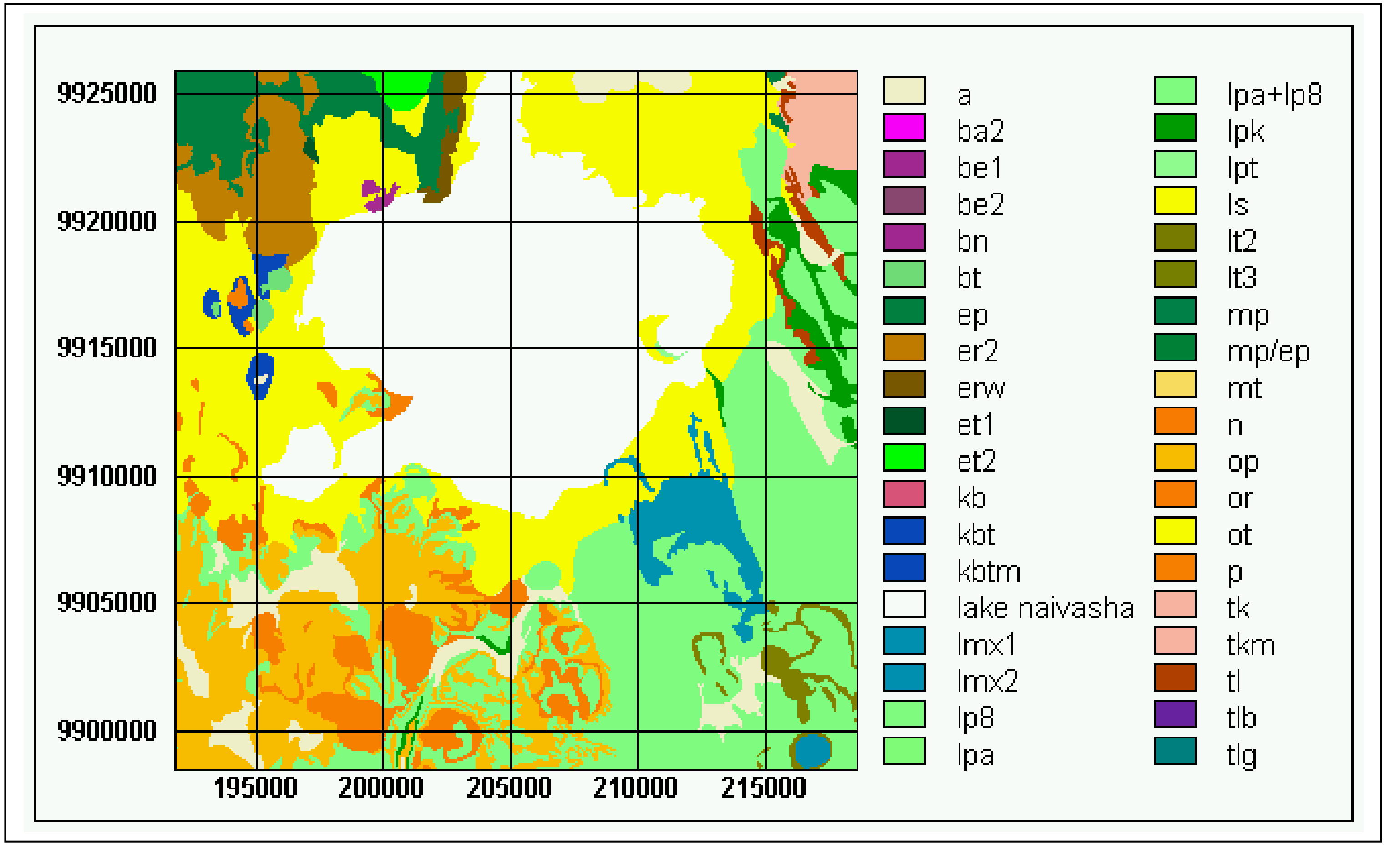
The analysis of users' information requirements provides the input to the actual SGDB design process. The user need assessment showed that 94% of the respondents have indicated a clear need for soil information for their current and future resource management activities. A large majority (73%) of the users obtain their soil information by sending soil samples abroad for further analysis. Users have a clear preference for digital rather than analogue data format primarily because of the ease of handling and further analysis.

This study proposes a working approach for multi-source data integration and standardisation in a common database structure. Correlation tables have been developed to handle the multi-category issues when dealing with different soil survey approaches and/or soil classification systems. A nested database design approach is applied to integrate data resulting from surveys at different levels of detail and map scale.

The conversion of existing soil data from analogue to digital format involved a geometric correction process supported by additional ground control. For spatial data capture in the field two approaches have been followed. In those cases where not enough identifiable ground control points (GCP) could be selected on a geometrically-accurate base map, a directional compass traversing method was applied with distance measurement using a measuring tape and GPS readings. Whenever enough GCP could be identified, only GPS readings have been used. In both cases the spatial data have been successfully converted from analogue to digital format, using the same geometric definition. However, when the locational accuracy of the geometrically corrected soil maps is compared, the compass traversing approach provides better quality.

Both metadata documentation and user interface design has been applied to improve user access to the organised soil data. The Content Standard for Digital Geospatial Metadata (CSDGM) as developed by the Federal Geographic Data Committee (FGDC) of the USA has been applied. The user interface design has been done using Ms Access navigation screens.

Appendix B Geological map of the area (Clarke etal., 1990)



NB: The legend is described next page

The Geological map legend

a : Alluvial deposits
kbt: Surtseyan tuff cones
ls : Lacustrine Sediments
n : Ndabibi comendite lava flows, domes and pyroclastic
lpa: Akira pumice
op : Olkaria comendite, pyroclastics
p : Pantellerite lava flows
or : Olkaria comendite, lava flows and domes
lpk: Kedong Valley tuff, Trachytic ignimbrites and associated fall deposits
lp8: Longonot ash
lpa+lp8: Akira pumice, Longonot Ash
lmx1/lmx2: upper (lmx2) and Lower (lmx1) longonot mixed basalt/trachyte lava flows, and pyroclastic cones
lt2/lt3 : Upper (lt3) and lower (lt2) Longonot trachyte, lava flows and pyroclastic cones
lpt : tuff cones
Ba^{2} Akira basalt; basalt and hawalite lava flows and pyroclastic cones
Be1/Bn Older Elmentia (Be1) and Ndabibi (Bn) basalt and hawaiite lava flows and pyroclastic cones
Bt/Kbt/kbtm: Surtseyan tuff cones (KBt) with laterally equivalent fall tuffs (kBtm), and transitional surtseyan/Strombolian ash cones (Bt)
Er2: Eastern Eburu pantellerite; lava flows and pyroclastic cones
Et1/Et2; Older (Et1) and Younger (Et2) Eburu trachyte; lava flows and pyroclastic cones
Kb: Kijabe Hill basalt
Tlg: Gilgil trachyte
Mp: Maiella pumice, trachyte and ? pantellerite pumice and ash fall deposits
Ot: Olkaria trachyte; lava flows
Tk/Tkm: Kinangop tuff (Tk) eastern rift margin. Mau tuff (TKm) Western rift margin
TI Limuru trachyte
Tlb Karati and Ol Mogogo basalts
Tlg Gilgil trachyte
Lake naivasha: