JAPAN INTERNATIONAL COOPERATION AGENCY

REPUBLIC OF ZAMBIA
MINISTRY OF ENERGY AND WATER DEVELOPMENT

THE STUDY

ON

THE NATIONAL WATER RESOURCES MASTER PLAN

IN

THE REPUBLIC OF ZAMBIA

FINAL REPORT

SUPPORTING REPORT [D]

HYDROGEOLOGY

OCTOBER, 1995

YACHIYO ENGINEERING CO., LTD.
(YEC)

THE STUDY ON NATIONAL WATER RESOURCES MASTER PLAN
IN THE REPUBLIC OF ZAMBIA

SUPPORTING REPORT (D)
HYDROGEOLOGY

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CHAPTER 1 INTRODUCTION

1.1 Scope

This report summarizes all the results of the survey on hydrogeology. A new groundwater development plan is proposed based on these results. The contents of this report are as follows:

1) Physical environment of groundwater.
2) Hydrogeology
3) Organisation related to groundwater development
4) Groundwater development potential based on water balance analysis and numerical simulation
5) Current groundwater use
6) Future groundwater demand and groundwater development plan
7) Estimation of development cost
8) Recommendations for groundwater development

1.2 Content of Report

The contents of this report are as follows:
Chapter 1 introduces this report.
Chapter 2 describes the physical environment of groundwater.
Chapter 3 describes organizations related to groundwater development.
Chapter 4 describes distribution of aquifers and their hydrogeological characteristics.
Chapter 5 describes the current groundwater use
Chapter 6 describes groundwater development potential based on groundwater potential analysis and numerical simulation.
Chapter 7 describes available groundwater development potential, future groundwater demand and groundwater development plan.
Chapter 8 describes estimation of cost for groundwater development.
Chapter 9 describes recommendations for groundwater development.

CHAPTER 2 PHYSICAL ENVIRONMENT ON GROUNDWATER

2.1 Location

Republic of Zambia is located in the southern part of the African continent. It lies approximately between latitudes 8 and 18 degrees South; and longitudes 23 and 34 degrees East. It covers an area of 751,851 km^2 with a water surface of 8,657 km^2(1.2%). The Republic is an inland country and shares international boundaries with Mozambique and Malawi in the west, Tanzania in the northeast, Zaire in the north, Angola in the west, Namibia in the southwest, Botswana and Zimbabwe in the south.

2.2 Topographic Classification

The main topographic features of Zambia are represented by a series of gently undulating and flat plateau with isolated hills and low ridges, as shown in Figure 2-1. Broad shallow depressions can often be found in the plateau forming swamps and flats. The western part of the country is covered with loose sediment delivered by the Zambezi river which forms a wide flat plain. The plateau are abruptly broken by steep linear escarpments running in a NE-SW direction along the Luangwa and Zambezi rivers in the south western peripheral area of Zambia. The plateau have an average elevation of 1300m above sea level, varying from a maximum of 2164m in the east to a minimum of 325m at the Zambezi river. The majority of the country lies between 900m and 1500m and the main cities are mainly situated on the gentle undulating plateau. The topography of Zambia is classified in detail by satellite imagery interpretation as shown in Table 2-1 and 2-2, Figure 2-1 and 2-2.

Units of classification shown in Table 2-1 are based on "Preliminary Geomorphic Map (Ministry of Agriculture)".

Montane Zone

Montane Zone means mountain regions, and this unit consists of land at an elevation of more than 1,850m. This unit includes Montane Plateau (elevation of more than 2,000m) and Montane Escarpment. The distribution of the Montane Zone is narrow and limited to the Northern Province.

Central African Plateau

Most parts of Zambia are classified as Central African Plateau. The elevation of the plateau ranges from 1,850 to 600m. The highest parts of the plateau are located in the north and the north west of Zambia. The elevation gradually reduces toward the southwest/south to the Zambezi river. In general the plateau is gently undulating in all places. Central African Plateau is subdivided into two major sub units, that are Degraded Plateau and Aggraded Plateau. The surface of the Degraded Plateau shows the effects of erosion and is traversed by a network of rivers. The relief of the plateau is dominated by drainage density. Swamps, lakes, flood plains and isolated hills are included in degraded plateau. The surface of Aggraded Plateau is formed by sediments and characterized by very gently undulating plains with widely spaced rivers and by sand dunes and pans made by wind . The distribution of aggraded plateau is wide in Western Province and North Western Province.

Table 2-1 Classification of Topography of Zambia

First Order Unit	Second Order Unit	Third Order Unit	Area (%)
Montane Zone	Montane Zone	• Montane Plateau	
		• Montane Escarpment	
		<Total>	< 0.1
Central African Plateau	Degraded Plateau	• Level to Undulating Plateau	30.0
		• Dissected Plateau	2.4
		• Hills, Ridges, and Minor Escarpments	4.3
		• Swamps	2.0
		• Lakes	0.4
		• Flood plains	4.1
		• Terraces	0.02
		<Total>	51.4
	Aggraded Plateau	• Linear Dune Complex	6.1
		• Pan Complex	6.3
		• Dilungus	0.3
		• Slightly Dissected Plateau	13.7
		• Flood plains	2.1
		• Alluviated Valley	0.7
		< Total>	29.2
Escarpment Zone	Escarpment	• Escarpment	0.2
	Escarpment Complex	• Escarpment Complex	8.7
		<Total>	8.9
Rift Trough	Dissected Trough Floor	• Isolated Large Hills	0.5
		• Dissected Hilly Land	3.7
		<Total>	4.2
	Flat Trough Floor and Lakes	• Flood plains	0.4
		• Lakes	1.5
		• Gently Undulating Land	4.6
		• Swamps	0.2
		<Total>	6.3

Note: Unit of classification is based on "Preliminary Geomorphic Map (Ministry of Agriculture)".

Escarpment Zone

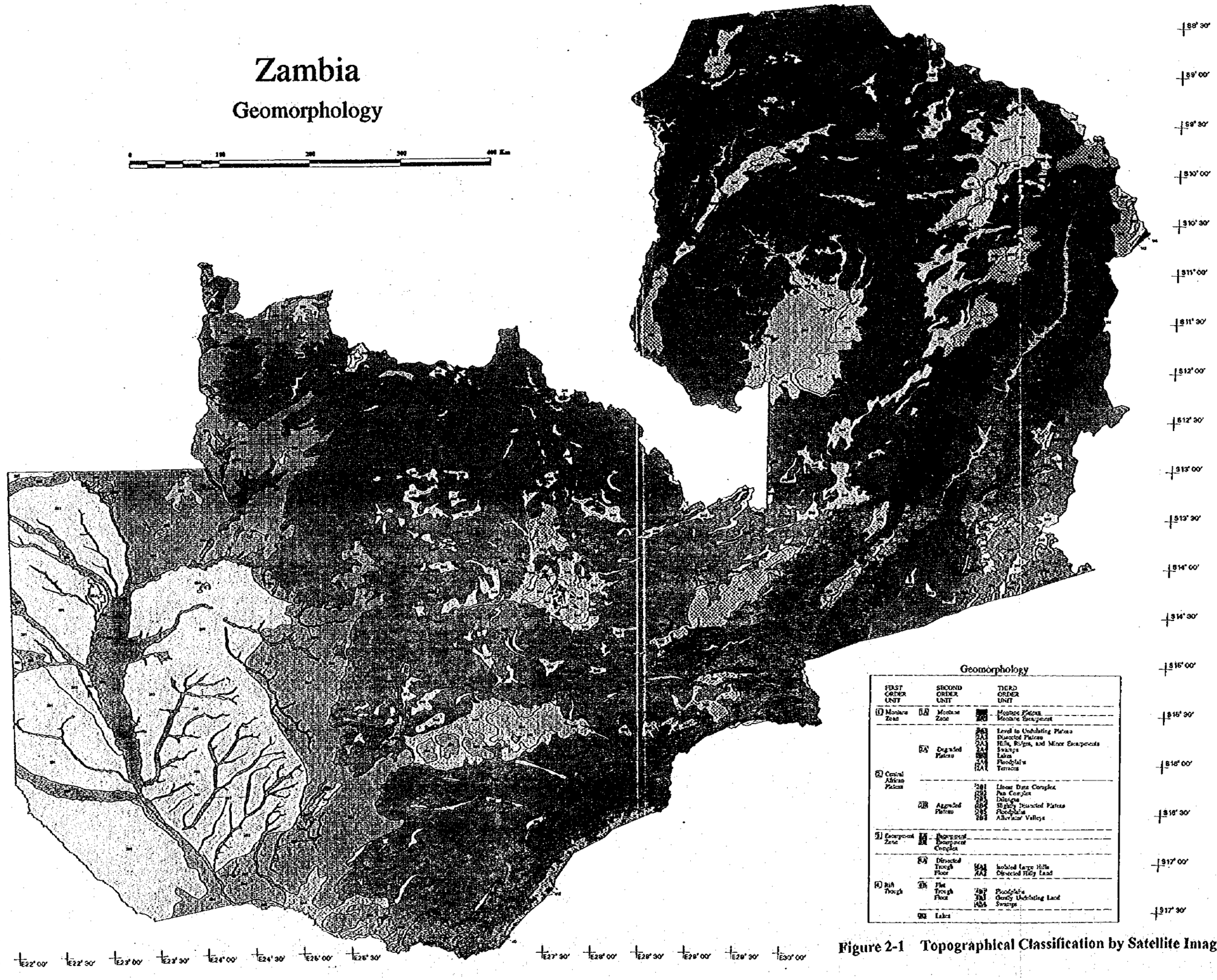
Escarpment Zone exists between the Central African Plateau and Rift Troughs, and is characterized by a steep escarpment. The Escarpment was made by major faulting and subsequent erosional processes and abruptly breaks the African Plateau. Escarpment zone is very clear along the Luangwa River.

Rift Troughs

Rift Troughs are located in the floors of large valleys which have been made by major faults. The main Rift Trough in Zambia exists along the Luangwa river and the elevation generally ranges from 325m up to 650m.

Zambia

Geomorphology



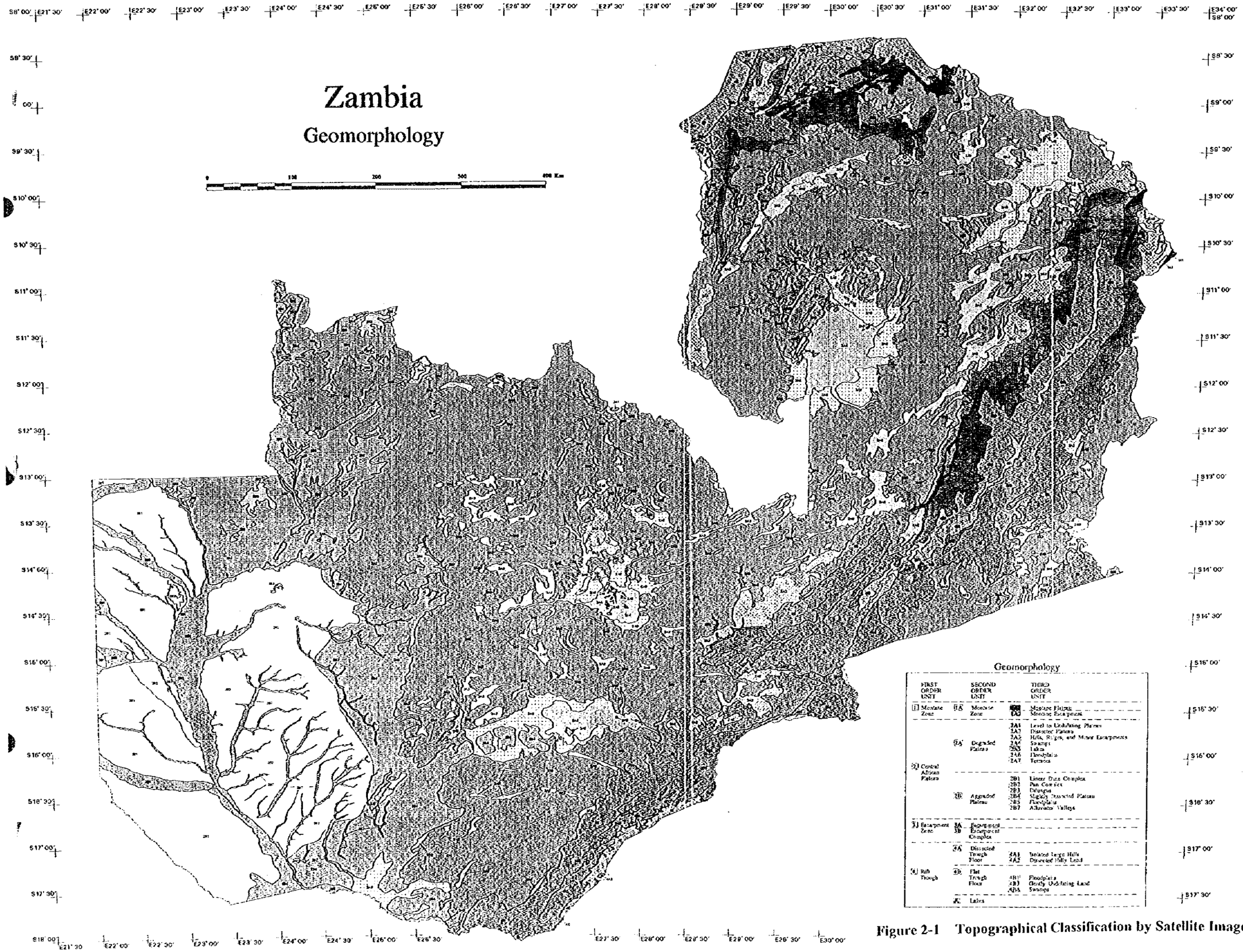
Geomorphology

FIRST ORDER UNIT		SECOND ORDER UNIT		THIRD ORDER UNIT
(1) Montane Zone	1A	Montane Zone	1AA	Montane Plateau
			1AB	Montane Escarpment
(2) Central African Plateau	2A	Degraded Plateau	2AA	Level to Undulating Plateau
			2AB	Dissected Plateau
			2AC	Hills, Ridges, and Minor Escarpments
			2AD	Swamps
			2AE	Lakes
			2AF	Floodplains
			2AG	Terraces
	2B	Aggraded Plateau	2BA	Linear Dune Complex
			2BB	Pan Complex
			2BC	Dunetops
			2BD	Slightly Dissected Plateau
			2BE	Floodplains
			2BF	Alluvium Valleys
(3) Escarpment Zone	3A	Dissected Escarpment Complex		
(4) Rift Trough	4A	Dissected Trough Floor	4AA	Isolated Large Hills
			4AB	Dissected Hilly Land
	4B	Flat Trough Floor	4BA	Floodplains
			4BB	Gently Undulating Land
			4BC	Swamps
	4C	Lakes		

Figure 2-1 Topographical Classification by Satellite Imagery Interpretation

Zambia

Geomorphology



Geomorphology

FIRST ORDER UNIT		SECOND ORDER UNIT		THIRD ORDER UNIT	
1 Montane Zone	1A	Montane Zone	1A1	Montane Plateau	
			1A2	Montane Escarpments	
2 Central African Plateau	2A	Degraded Plateau	2A1	Level to Undulating Plateau	
			2A2	Dissected Plateau	
			2A3	Hills, Ridges, and Minor Escarpments	
			2A4	Swamps	
			2A5	Lakes	
			2A6	Floodplains	
			2A7	Terraces	
	2B	Aggraded Plateau	2B1	Linear Dune Complex	
			2B2	Pan Complex	
			2B3	Dambos	
			2B4	Slightly Dissected Plateau	
			2B5	Floodplains	
			2B7	Alluvium Valleys	
3 Escarpment Zone	3A	Escarpment			
	3B	Escarpment Complex			
4 Rift Trough	4A	Dissected Trough Floor	4A1	Isolated Large Hills	
			4A2	Dissected Hilly Land	
	4B	Flat Trough Floor	4B1	Floodplains	
			4B3	Gently Undulating Land	
			4B4	Swamps	
	4C	Lakes			

Figure 2-1 Topographical Classification by Satellite Imagery Interpretation

Zambia

Geomorphology

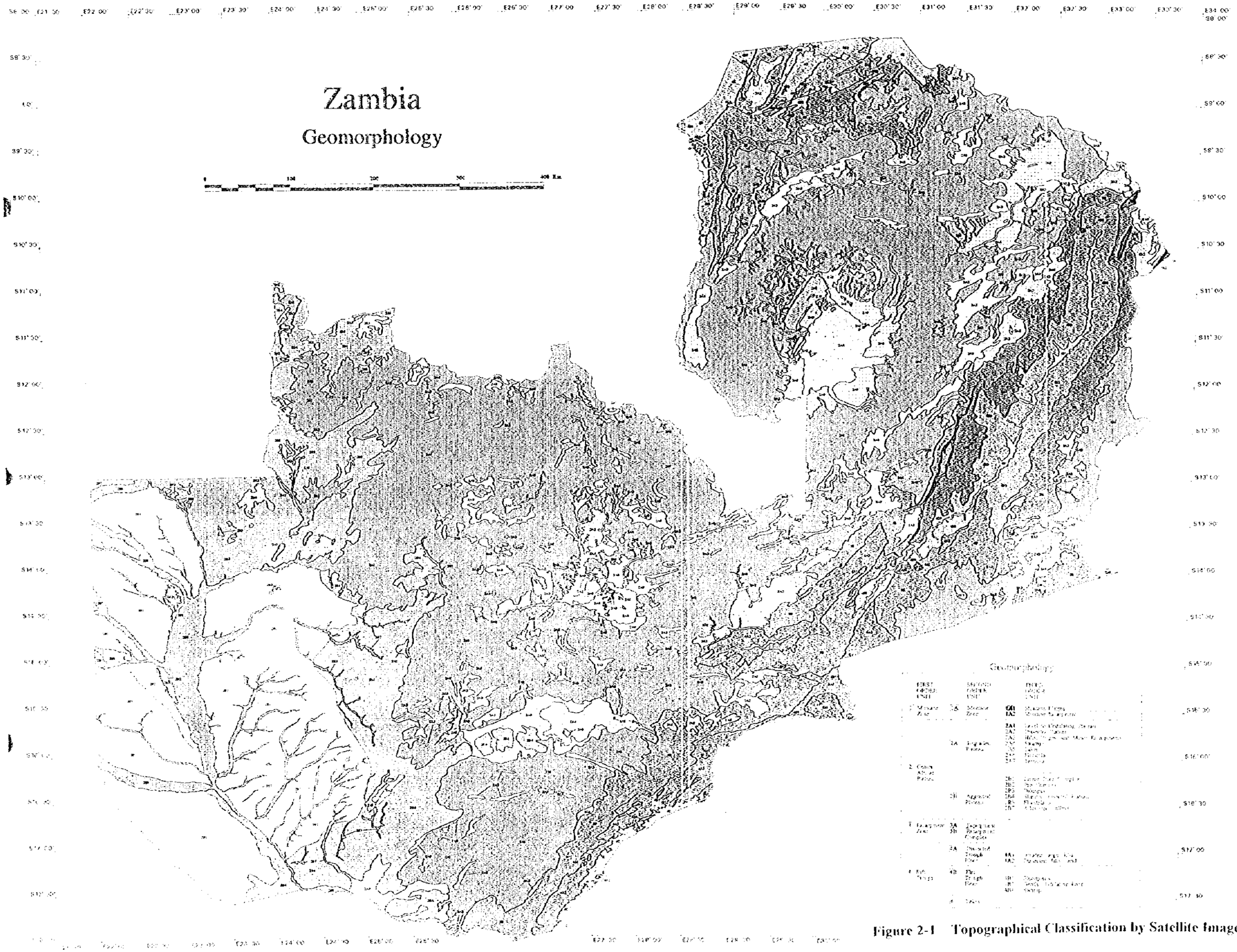


Figure 2-1 Topographical Classification by Satellite Imagery Interpretation

Table 2-2 Topographical Classification by Satellite Imagery Interpretation

(km2)

Province	District	Montane Zone		Central Africaan Plateau													Escarpment Zone		Rift Trough					Total
		Montane Zone		Degraded Plateau							Aggraded Plateau						Escarpment Zone		Dissected Trough Floor		Flat Trough Floor			Lakes
		Montane Plateau	Montane Escarp-ment	Level to Undulating Plateau	Dissected plateau	Hills, Ridges, and Minor Escarpment	Swamps	Lakes	Flood-plains	Terraces	Linear Dune Complex	Pan Complex	Dilungus	Slightly Dissected Plateau	Flood-plains	Alluviated Valleys	Escarp-ment	Escarpment Complex	Isolated Large Hills	Dissected Hilly Land	Floodplains	Gently Undulating Land	Swamps	Lakes	
Lusaka	Lusaka-Urban			423		12												6							441
	Lusaka-Rural			5,116	2,427	107	325	10	13									7,729		2,036	30				17,794
	Luangwa																	696	1,134	1,771	259				3,859
	Total			5,540	2,427	119	325	10	13									8,430	1,134	3,806	289				22,094
Copperbelt	Ndola-Urban			977		17																			993
	Ndola-Rural			19,106	990	1,272	213		1,843																23,423
	Chililabombwe			862		83		5	60																1,010
	Chingola			1,686				5	60																1,751
	Mufulira			1,272				8																	1,280
	Kalulushi			1,067		68																			1,135
	Kitwe			751																					751
	Luanshya			840		32																			873
	Total			26,561	990	1,473	213	18	1,963																31,217
Central	Kabwe-Urban			1,477		53																			1,530
	Kabwe-Rural			17,010	301	1,129	2,197	122	3,792	148							31	474		333					25,536
	Mumbwa			18,397		1,539	645	5	695					295											21,576
	Mkushi			10,887	3,859	1,775		75									149	2,757	7	2,832	128				22,470
	Serenje			11,815	713	3,252	288		726								332	3,353	198	2,335	174	388			23,572
	Total				4,873	7,747	3,129	201	5,213	148				295			512	6,584	205	5,500	303	388			94,684
Northwestern	Solwezi			27,090		652	698		416					1,266											30,122
	Mwinilunga			9,785		280	27						1,079	9,723											20,894
	Zambezi										8,731		409	7,327	2,279										18,746
	Kabompo			2,146		41	131					1	723	11,493											14,535
	Mfumbwe			13,216					28					5,677		157									19,078
	Kasempa			18,143		3,367			303							90									21,905
	Total			70,381		4,341	856		747		8,731	1	2,212	35,486	2,279	248									125,280
Western	Mongu											6,768			2,593	710									10,071
	Lukulu			343							4,114	7,774	59	224	3,125										15,639
	Kalabo										12,383	1,746			3,101										17,230
	Kaoma										16,472	9,819		448	3,994	1,124									31,857
	Senanga			188		1			593		4,011	12,028		10,247	475	1,979									29,522
	Sesheke			959								9,002		11,939	83	1,040									23,024
	Total			1,491		1			593		36,980	47,137	59	22,859	13,371	4,853									127,344
Southern	Livingstone					41			68					932											1,041
	Namwala			7,207		1,568	1,100	381	3,520					7,752											21,528
	Monze					269	270	45	180					3,305				832							4,901
	Choma					272								5,102				1,632		1					7,008
	Mazabuka					15	1,132		215					2,770		30		2,463							6,625
	Kalomo			128		1,174			1,862					24,746				3,442		72					31,425
	Siavonga																	520	302	1,706				80	2,609
	Gwembe													17				1,532	376	2,353				984	5,262
	Sinazongwe																	1,287	38	2,380				1,094	4,800
	Total			7,335		3,338	2,502	426	5,846					44,625		30		11,709	716	6,513				2,158	85,199
Luapula	Mansa			13,704	1,611	274	57	8	308									36							15,997
	Nchelenge				672													1,092				2,757	533	2,890	7,944
	Kawambwa			4,539		1,008	136	12	921									1,252				989	194	56	9,108
	Mwense			4,062	49	676	18	16	375									622				705	149		6,672
	Samfya			2,504			4,398	1,666	1,304																9,872
	Total			24,808	2,333	1,958	4,609	1,703	2,907									3,002				4,451	877	2,946	49,594
Northern	Kasama			15,102		1,689	182		3,484																20,457
	Kaputa			69	430				3									2,310		2,290		4,784	484	2,018	12,388
	Mbala			9,941	373	1,454		5	59								1,077	1,677		983		1,300	291	1,535	18,695
	Mporokoso			9,711	33	734			712									426				317			11,933
	Luwingu			7,639			335	6	1,051																8,831
	Chilubi			3,884			789	613	1,983																5,269
	Isoka	304	19	3,835	2,503	1,165	29		1,898									2,575	11		7	1,421			13,767
	Chinsali			7,882	1,320	3,927	209	6	1,622									480							15,445
	Mpika			15,654	1,169	2,351	2,226		2,954								278	3,763		5,401	878	5,832			40,505
	Total	304	19	71,716	5,828	11,320	3,570	630	13,766								1,355	11,231	11	8,674	885	13,654	775	3,552	147,292
Eastern	Chipata			3,747	559	891												4,578		8	50	2,358			12,189
	Chama	125	35	165	891	217												5,913	13	628	914	8,904			17,803
	Lundazi			6,448	430	315												3,999			77	2,419			13,687
	Chadiza			587		296												1,619							2,502
	Katete			2,215	14	607												1,005							3,842
	Petauke			5,129		351												6,969	999	2,996	382	2,296			19,123
Total		429	54	285,708	18,344	32,974	15,205	2,989	31,046	148	45,710	47,138	2,271	103,266	15,651	5,131	1,867	65,039	3,079	28,125	2,899	34,469	1,652	8,657	751,851

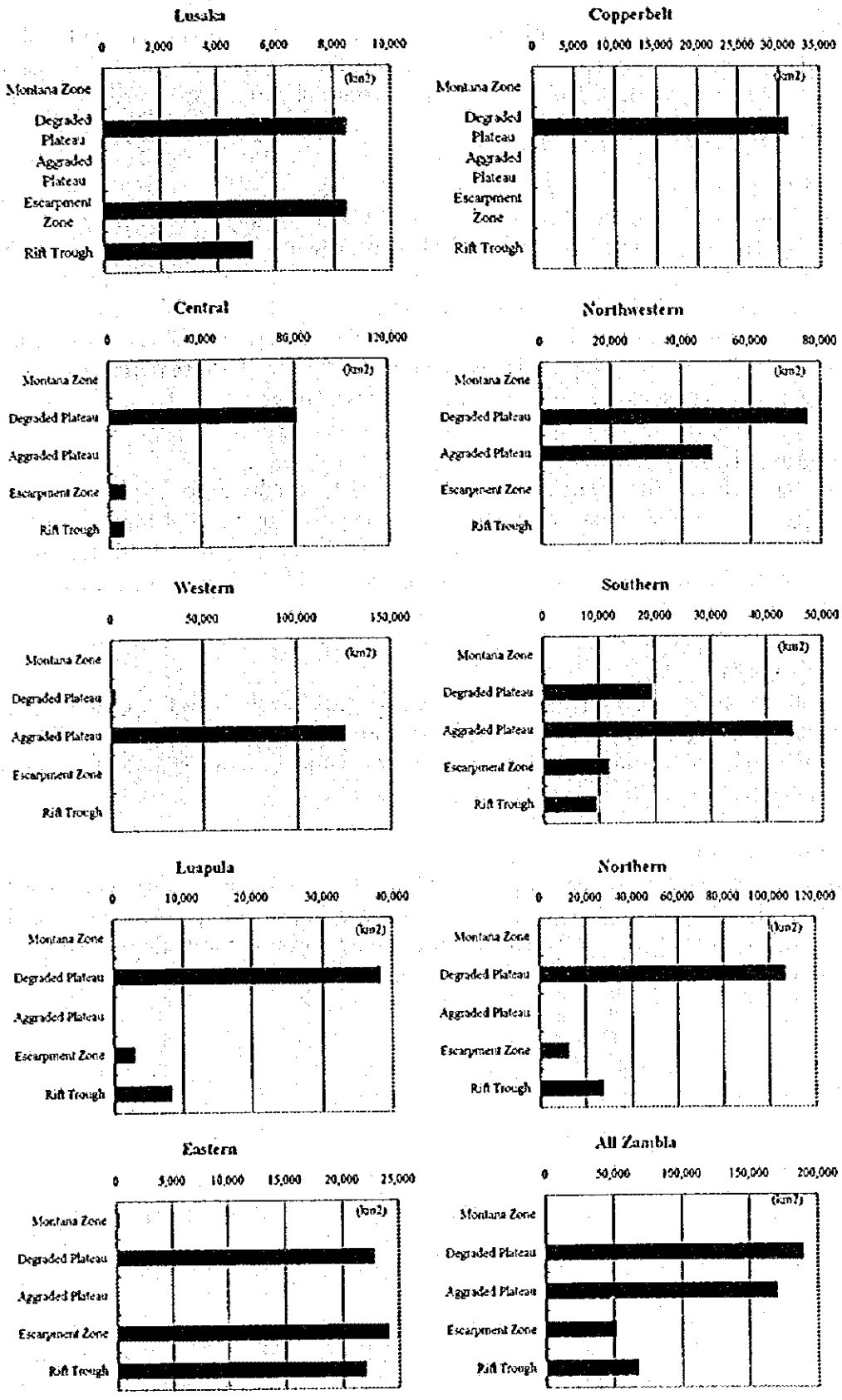


Figure 2-2 Topographical Classification by Province

2.3 Geology

The geology of Zambia comprises various rocks and layers dating from over 1,000 million years ago (Precambrian era) to more recent times. These rock formations consist of igneous, sedimentary and metamorphic rocks. The stratigraphy of Zambia is summarized in Table 2-3.

Basement Complex

The oldest system in Zambia is known as Basement Complex which is judged to be over 1,000 million years old (Lower Precambrian). The Basement Complex consists of highly deformed gneiss, schists, quartzites, conglomerates, crystalline limestone, migmatites and granites. The Basement Complex mainly outcrops in the east and south-eastern part of Zambia and its distribution areas mostly coincide with the "Bangweulu Block" as shown in Figure 2-3. The Basement Complex is overlain by undeformed Precambrian to Lower Paleozoic sediment known as the Plateau Series and Muva Group.

Katanga Super Group

The age of the Katanga Super Group ranges from late Precambrian to Cambrian (100 to 500 million years old). The Katanga Super Group comprises shale, sandstone, dolomites, quartzites, limestones and conglomerates. The Katanga Super Group is distributed in the northern and central parts of Zambia, and almost coincides with "Katanga System" shown in Figure 2-3.

Lower Paleozoic Super Group

The Kantanga Super Group is overlain by sedimentary rocks such as shales, quartzites and arkose sandstones. It is grouped as Lower Paleozoic Super Group and is extremely limited. Its existence is only evident in the western part of Zambia and the mid-Zambezi Valley by drilling investigations.

Karroo Super Group

The Karroo Super Group is composed of tillites (fluvo-glacial origin), coal seams, mudstones, marls, conglomerates and basalt. The Karroo Super Group corresponds to the Carboniferous to Jurassic Systems. The Karroo Super Group is distributed along the Luangwa river and western part of Zambia, as shown in Figure 2-3.

Table 2-3 Stratigraphy of Zambia

Geological Age		Super Groups	Groups or Formation	Rocks and Sediments
Cenozoic Era	Quaternary Tertiary	Cenozoic Super Group	Alluvium	Alluvium sands, Gravels with clay near lakes
			Kalahari Group	Fine sands, Sandstones with clay
Mesozoic Era	Cretaceous	Mesozoic Super Group	Lower Cretaceous Formation	Mudstones, Siltstones
	Jurassic Carboniferous	Karroo Super Group	Upper Karroo Group	Basalt, Interbedded sandstones, Sandstones, Mudstones, Siltstones
Palaeozoic Era			Lower Karroo Group	Mudstones with coal measure, Siltstones, Sandstones, Conglomerates
	Silurian Ordovician	Lower Palaeozoic Super Group		Quartzites, Shales, Sandstones
Precambrian Era	Early Palaeozoic Precambrian	Katanga Super Group	Kundelung Group	Carbonate rocks with shales, Shales, Siltstones, Sandstones
			Upper Roan Group	Dolomites, Argillites
			Lower Roan Group	Quartzites, Argillites, Dolomites, Conglomerate, Mine series shales
		Basement and Muva Super Group	Muva Group	Shales, Mudstones, Sandstones
			Basement Complex	Basement gneisses, Migmatites, Schists
Various age Precambrian	mainly older	Intrusive and Metamorphic Rocks		Basic-igneous rocks, Meta-igneous rocks, Amphibolites, Metasediments, Metavolcanics

Mesozoic Super Group

The basalt of the Karroo Super Group is overlain by mudstones along the Zambezi river and to the west of Zambia. These layers have been judged to be Cretaceous in age based on the discovery of certain fossils and are named the Mesozoic Super Group. The thickness of the Mesozoic Super Group has been estimated as up to 100m thick. The distribution area of the Mesozoic Super Group is shown in Figure 2-3 as "Cretaceous System".

Cenozoic Super Group

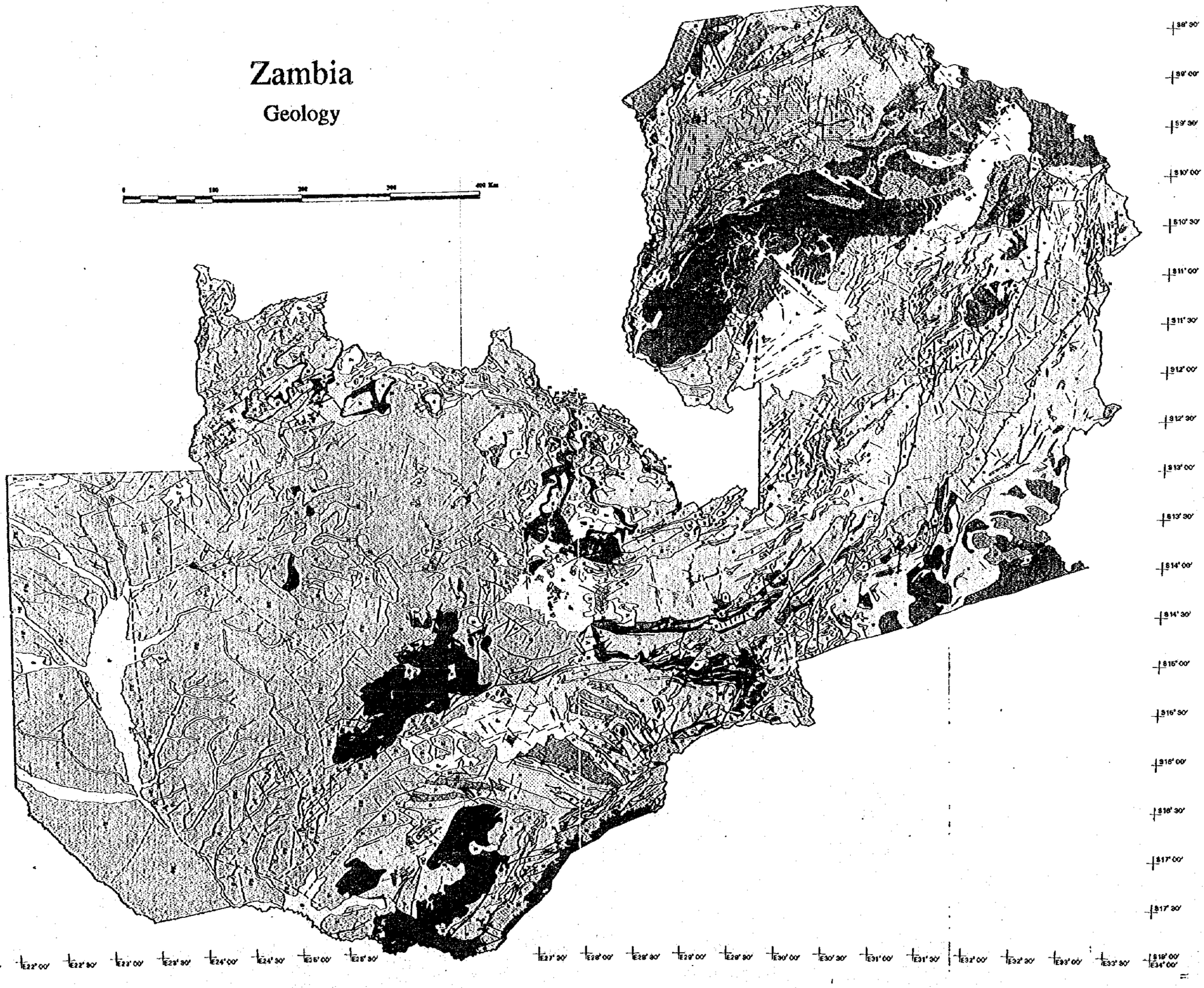
The Mesozoic Super Group is overlain in a large part of the extreme west of Zambia (Barotse Basin) by tertiary sandstone and quaternary consolidated sand layers (duricrusts) and clay layers. These layers have been named the Cenozoic Super Group and they are divided into two formations; namely the Zambezi Formation of the lower part and the Barotse Formation of upper part. The so-called "Kalahari Sandstone" is a member of the Zambezi Formation.

Intrusive Rocks

Intrusive rocks of varying age and type mainly intrude the Precambrian rocks. The majority consist of granite rocks and the remainder are gabbros, dolerites, syenites, etc.

Zambia

Geology



All symbols d

Lithe

- Alluvium, colluvium, later
- Kalahari Group with fossil
unconformity
- Basalts
- Upper Karroo (Zambezi Va
- Lower Karroo, undifferent
- Basal Formation and Coal
unconformity
- Upper Kundelungu Shales
- Kundelungu psammite and
(Includes Petit Conglomera
- Lower Kundelungu Shales
- Kundelungu carbonate rock
- Kundelungu undifferentiate
Predominantly shales, siltsto
- Mwashia - typically carbon
- Upper Roan - Typically dol
Lower Roan with basal con
Includes quartzites, conglon
- Mine 'Series'undifferentiate
province and at western en
Upper Roan around Luswis

unconfonnity

- Upper shales
- Upper quartzite
- Lower shales
- Lower quartzite
- Quartzite-pelite sequences
- Metamorphosed pelite, quart
associated meta-carbonate a
Mpanshya group, Sasare gro

unconfonnity

- Pre-Katanga schists, undiffe
(interlayered gneiss and sch
Provinces,
- Granulite facies rocks (excl
- Undifferentiated Basement C
some granite,
- Volcanics and meta-volcanic
- Meta-carbonate rocks of va
- Calc-silicate rocks undiffere
- Meta-quartzites of various a
- Quartz veins
- Mylonite and blastomylonite
- Granite
- Syenite, syenodiorite, diorit
- Basic Igneous and meta-ignee
- Carbonatite
- Kimberlite

Figure 2-3 Geolog

Zambia

Geology

All symbols d

Lith

- Alluvium, colluvium, late
- Kalahari Group with fossi
- unconformity
- Basalts
- Upper Karroo (Zambezi V
- Lower Karroo, undifferen
- Basal Formation and Coal
- unconformity
- Upper Kundelungu Shales
- Kundelungu psammite and
- (includes Petit Conglomer
- Lower Kundelungu Shales
- Kundelungu carbonate roc
- Kundelungu undifferentiate
- Predominantly shales, silts
- Mwashia - typically carbo
- Upper Roan - Typically do
- Lower Roan with basal co
- Includes quartzites, conglo
- Mine 'Series'undifferentiate
- province and at western e
- Upper Roan around Luswi
- unconformity
- Upper shales
- Upper quartzite
- Lower shales
- Lower quartzite
- Quartzite-pelite sequences
- Metamorphosed pelite, qua
- associated meta-carbonate
- Mpanshya group, Sasare gr
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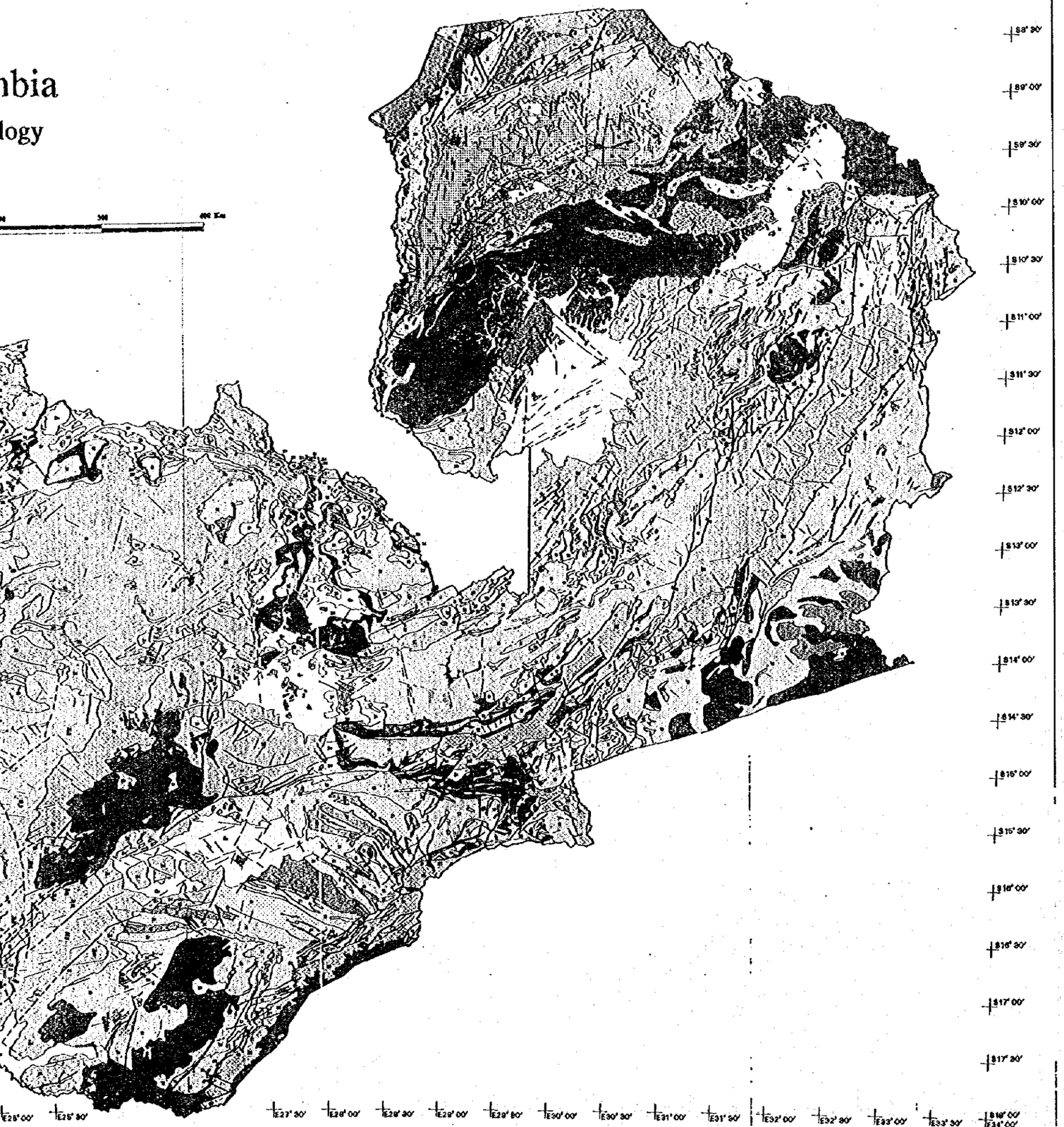
- Kimberlite

Figure 2-3 Geolog



Geologic Symbols

All symbols dashed where indefinite or concealed

- Thrust or Reverse fault. Triangles are on the upper plate.
- Fault. U/D on faults where sense of vertical movement is identified. Arrows show direction of strike-slip movement.
- Fault. Movement unspecified.
- Lineament. May indicate a fault or a fracture.
- Stratographic break.
- Foliation.
- Anticlinal axis.
- Synclinal axis.
- Dome

Lithologic Symbols

Alluvium, colluvium, laterite Kalahari Group with fossil seif dunes	Sub-crop of solid geology underlying these groups shown as follows: c-Cretaceous, Kb-Karroo Basalt, Kc-Karroo Clastics, BK-Basement, and Katanga System	TERTIARY TO RECENT
unconformity		
Basalts Upper Karroo (Zambezi Valley), Karroo undifferentiated (elsewhere). Lower Karroo, undifferentiated Basal Formation and Coal Measure		KARROO (Upper Carboniferous to Jurassic)
unconformity		
Upper Kundelungu Shales (Luapula Province) Kundelungu psammite and rudite formations (includes Petit Conglomerat in Luapula Province) Lower Kundelungu Shales (Luapula Province) Kundelungu carbonate rocks; may be Mwashia in part in some areas Kundelungu undifferentiated; may include some Mine 'Series' in the northwest Predominantly shales, siltstones, sandstones and mixtites. Mwashia - typically carbonaceous shale and argillite Upper Roan - Typically dolomite argillite Lower Roan with basal conglomerate; the main copper-bearing unit. Includes quartzites, conglomerates, argillites, arkoses, and some dolomite. Mine 'Series' undifferentiated. Upper Roan plus Mwashia in Northwestern province and at western end of Copperbelt; probably Lower and Upper Roan around Luswishi Dome. Status uncertain south of Copperbelt.		KATANGA (Late Precambrian and (?) Lower Paleozoic)
unconformity		
Upper shales Upper quartzite Lower shales Lower quartzite	Luapola and Northern Provinces	MUVA
Quartzite-pelite sequences		
Metamorphosed pelite, quartzite-pelite and psammite sequences, some with associated meta-carbonate and meta-volcanic rocks. Includes Chisamba Formation, Mpanshya group, Sasare group and Mwami group. Probably coeval in part.		PRECAMBRIAN ROCKS OF UNCERTAIN AGE: POSSIBLLY MUVA
unconformity		
Pre-Katanga schists, undifferentiated. Includes Lufubu Schists of Copperbelt (interlayered gneiss and schist) and various groups in Southern and Northwestern Provinces. Granulite facies rocks (excluding charnockites) Undifferentiated Basement Complex; mainly granitic gneisses and migmatites with some granite.		PROBABLY LARGELY OLDER PRECAMBRIAN
Volcanics and meta-volcanics Meta-carbonate rocks of various ages Calc-silicate rocks undifferentiated Meta-quartzites of various ages Quartz veins Mylonite and blastomylonite Granite Syenite, syenodiorite, diorite and metamorphic equivalents Basic igneous and meta-igneous rocks, amphibolites Carbonatite Kimberlite		LITHOLOGICAL UNITS OF VARIOUS AGES

Figure 2-3 Geological Classification by Satellaite Imagery Interpretation

2.4 Climate

For a land-locked tropical country, Zambia enjoys an enviably pleasant climate. Temperatures are remarkably moderate and this is mainly due to the altitude. The rainfall is not heavy and floods are rare. Winds are generally light and damage to life and property due to high winds is practically unknown.

In general, the year in Zambia can be divided into two distinct halves, a dry half from May to October and a wet half from November to April. However, from the synoptic point of view it is more convenient to divide the year into 4 unequal seasons as follows:

1) Winter season : June to August
2) Pre-rainy season: September to October
3) Rainy season: November to March
4) Post rainy seasons: April and May

Rainfall

In Zambia, more than 90% of the rainfall is concentrated in the rainy season from November to March. In particular, the months of December and January account for 40-50% of the annual rainfall. There is almost no rain from April to September.

Temperature

The distribution of temperature in Zambia depends on altitude rather than latitude. Regional variations of annual mean temperature in Zambia are 19.3-24.2℃. June and July are the coldest season, 3.6-12.0℃, and September and October are the hottest season, 27.7-36.5℃ . The hottest place in Zambia is Mfuwe and the maximum, mean and minimum temperature are 36.5℃, 24.2℃ and 10.3℃. One of the coldest places in Zambia is Kafironda and the maximum, mean and minimum temperature are 32.0℃, 19.8℃ and 3.6℃.

Evaporation

- Annual pan-evaporation is low, 1,700 - 2,000 mm in the north, very high in the east, 2,200-2,600 mm, and average in the centre, the west and the south.
- Annual pan-evaporation is the lowest in Copperbelt Province(1,865mm) and is the highest in Eastern Province (2,221mm).
- Monthly pan-evaporation is high from August to November at 200 - 300 mm per month, and is low from December to July at 100 - 200 mm per month.
- These figures indicate that evaporation is high in areas/months with little rainfall and is low in areas/months with higher rainfall.

Sunshine hours

- Annual sunshine hours are the lowest in Northwestern and Luapula province (about 2,670 hrs) and the highest in Southern and Western province (3,100hrs).
- Monthly sunshine hours are low from December to February, 150 - 200 hrs/month (5.0 - 6.7 hrs/day), and high from May to October, 250 - 300 hrs/month (8.3 - 10.0hrs/day), and high from May to October, 250 - 300 hrs/month (8.3 - 10.0 hrs/day).
- These figures indicate that sunshine hours are low in areas/months with higher rainfall and are high in areas/months of lower rainfall.

Relative Humidity

- Annual mean relative humidity is the lowest in Southern province (59.4%), while in Copperbelt, Northwestern, Luapula, Northern and Eastern provinces, relative humidity is high at more than 65%.
- Monthly relative humidity is high from December to March at about 80%, and is low from August to October at less than 50%.
- Obviously the rainy season is a period of high humidity and the dry season is a period of low humidity.

Wind Speed

- Annual mean wind speed ranges approximately from 1.4m/s to 2.0 m/s
- Monthly wind speed is weak in the rainy season at 1.0- 1.5 m/s and is strong in the dry season at 2.0- 2.5 m/s.

2.5 Land Cover

Land cover is divided into eight (8) categories, namely Forest, Savanna, Grassland, Barren, Agriculture, Wetlands, Urban and Water. Land use map made by Satellite Imagery Interpretation is shown in Figure 2-6 and summarized in Table 2-5. Land use of each province is shown in Figure 2-7. Outline of Land Use in Zambia is as follows:

Forest

Forest zones occupy 14.1% of Zambia. Distribution zone of forest is relatively high in Northern, Copperbelt and Lusaka Province where forests occupy 24% of each province. On the contrary, distribution zone is just 7% in Eastern Province. In general, zone of distribution is in proportion to annual rain fall. However, this trend does not always hold true in Zambia because of deforestation.

Savanna

Savanna zone is widely distributed throughout the country and covers 20.1% of the land. Distribution of savanna is greatest in Northern Province and covers 32% of the province. The smallest is 12 % in Southern Province. Savanna zones usually exist mixed with grasslands and forests and are sometimes difficult to distinguish from the latter 2 zones .

Grassland

Grassland zones covers 61.3% of the country and are the most common landscape. The percentage of grassland is more than 50% in all provinces. Especially, this percentage are high in Western province(75%), in Southern province(68%) and in Eastern province(70%). These 3 provinces have more grassland areas and less rain than other provinces. On the other hand, the percentage is the lowest in Luapula Province(51%). Grasslands are generally distributed over low elevation zones especially along the Luangwa and Zambezi Rivers. Grasslands include burned areas.

Wetlands

Wetlands cover 1.1% of Zambia. Larger areas of wetlands are limited to Kafue Flood Plain, southern part of Lake Bangweulu, Lukanga swamp and southern part of Lake Mweru. On the other hand, wetlands along many rivers are usually small and narrow. Wetland distribution is relatively large in Central Province (2%) , Lusaka (1%) and Northern (1%) .

Table 2-4 Annual Rainfall and Annual Rainy Days

Unit ; RF:mm, RD:days

Province	Station Name	Altitude (EL.m)	Average Annual Rainfall (RF) 10yrs.	20yrs.	30yrs.	Average Annual Rainy Days (RD) 10yrs.	20yrs.	30yrs.	Maximum Annual RF	RD	Minimum Annual RF	RD
Lusaka	Lusaka C.A.	1280	832	887	858	74	79	78	1366	112	483	49
	Lusaka I.A.	1154	810	894	865	72	76	77	1299	109	530	49
	Mt. Makulu	1213	883	899	848	77	77	77	1288	102	569	45
	Average	-	842	893	857	74	77	77	1318	108	527	48
Copperbelt	Kafironda	1242	1248	1282	1256	106	111	111	1748	139	895	89
	Ndola	1270	1183	1229	1205	109	111	111	1756	136	439	79
	Average	-	1216	1256	1231	108	111	111	1752	138	667	84
Central	Kabwe	1207	823	891	886	81	84	83	1451	111	619	59
	Kabwe Agro.	1165	833	902	897	72	75	74	1313	110	499	50
	Mumbwa	1218	873	931	900	80	85	84	1324	98	438	60
	Serenje	1384	1114	1100	1105	106	105	103	1585	151	708	66
	Average	-	911	956	947	85	87	86	1418	118	566	59
North-western	Kabompo	1026	1050	1028	1016	104	104	105	1338	125	593	74
	Kasempa	1235	1110	1151	1131	102	107	107	1559	136	654	76
	Mwinilunga	1362	1318	1375	1402	135	140	142	1761	167	1043	108
	Solwezi	1333	1263	1330	1300	124	127	125	1575	146	985	91
	Zambezi	1078	1026	1045	1017	110	112	111	1346	136	720	87
	Average	-	1153	1186	1173	115	118	118	1516	142	799	87
Western	Kalabo	1051	877 (last 7 yrs.)			95 (last 7 yrs.)			1084	104	617	77
	Kaoma	1152	843	913	882	95	99	97	1311	118	240	71
	Mongu	1053	851	914	903	86	92	94	1357	117	382	43
	Senanga	1027	745	800	791	77	82	84	987	97	463	64
	Sesheke	951	630	692	657	72	76	73	1546	112	379	48
	Average	-	767	830	808	83	87	87	1300	111	366	57
Southern	Choma	1267	744	800	779	82	86	83	1187	116	423	46
	Kafue Polder	978	694	753	744	63	66	68	1192	106	460	44
	Livingstone	987	617	688	679	67	75	76	1402	103	420	49
	Magoye	1018	694	753	744	62	65	67	935	76	461	49
	Average	-	687	749	737	69	73	74	1179	100	441	47
Luapula	Kawambwa	1324	1277	1349	1358	136	135	136	1758	154	865	114
	Mansa	1259	1125	1162	1159	107	109	110	1573	131	800	81
	Samfya(*1)	1172	1490	1445	-	109	108	-	2065	128	937	79
	Average	-	1201	1256	1259	122	122	123	1666	143	833	98
Northern	Isoka	1360	1062	1097	1094	109	109	112	1334	135	876	83
	Kasama	1384	1284	1337	1323	115	115	118	1888	146	801	92
	Mbala	1672	1190	1202	1219	105	109	114	1745	148	469	54
	Mfuwe	573	814	842	840	72	74	75	1062	89	495	42
	Misamfu	1536	1336	1345	1331	107	110	123	1751	127	1097	88
	Mpika	1402	1040	1054	1018	97	99	99	1498	127	644	71
	Average	-	1121	1146	1138	101	103	107	1546	129	730	72
Eastern	Chipata	1032	959	992	990	88	90	92	1471	115	656	70
	Lundazi	1143	983	906	878	96	92	93	1415	120	495	68
	Msekera	1025	992	1026	1024	90	92	94	1179	101	753	76
	Petauke	1036	965	981	951	86	91	91	1381	120	597	71
	Average	-	975	976	961	90	91	93	1362	114	625	71

Remarks :

(*1) : Data available untill 1984/7. Average was calculated excluding this station.

: Data estimated from the record of the nearest alternative station.

Average period : 10yrs.(1983-92), 20yrs.(1973-92), 30yrs.(1963-92)

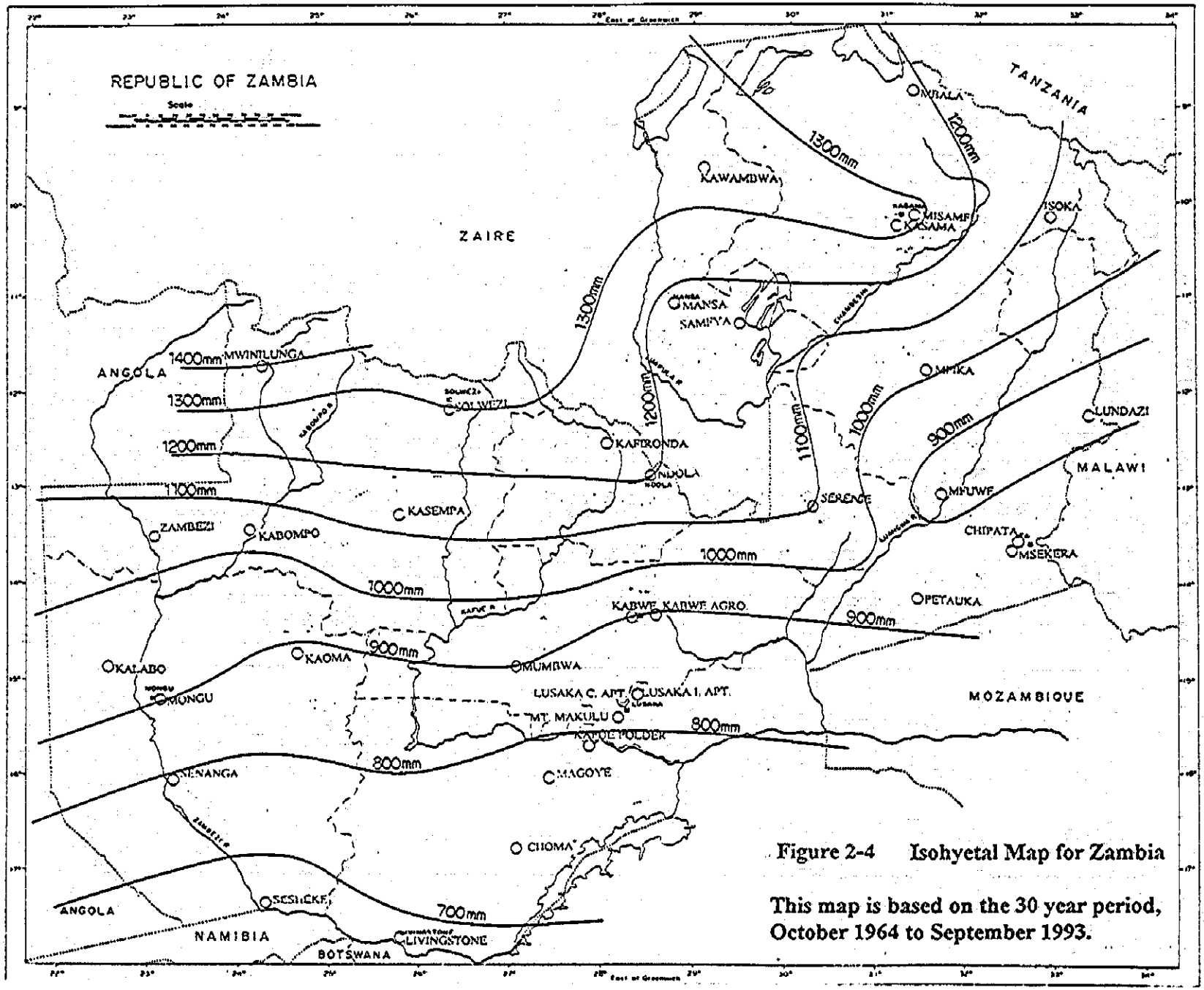


Figure 2-4 Isohyetal Map for Zambia

This map is based on the 30 year period, October 1964 to September 1993.

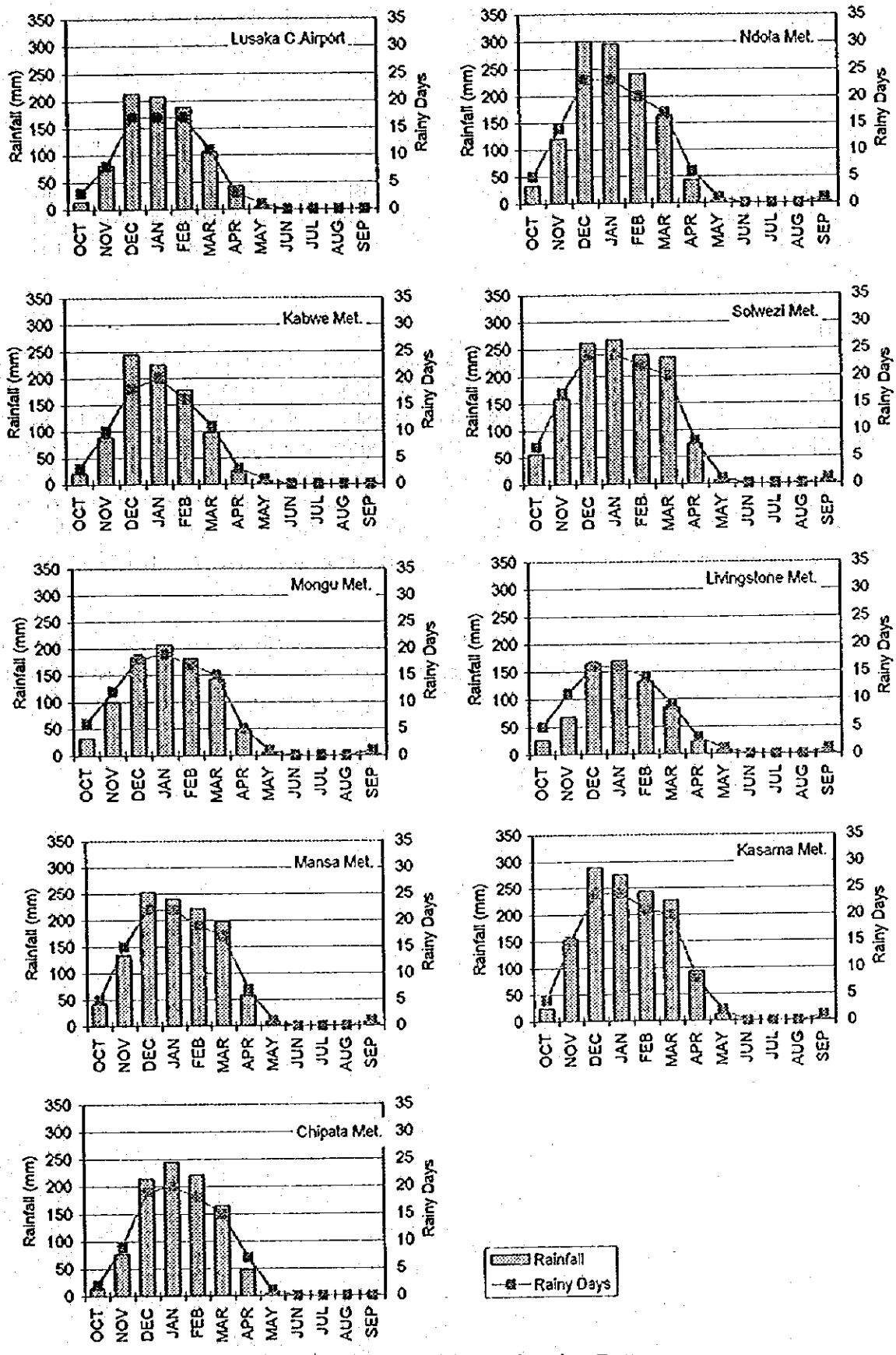


Figure 2-5 Monthly Rainfall and Rainy Days

Water

Water zones occupy 1.7% of Zambia. This category includes lakes like Lake Tanganyika, Lake Mweru, Lake Mweru Wantipa, Lake Bangweulu, Lake Kariba and Lake Itezhi-Tezhi. The distribution is the largest in Luapula province where water occupies 10% of the province.

Barren

Barren zones occupy only 0.1% of Zambia and distribution is very small and limited. A relatively large barren zone exists in the upper stream region of Luangwa River in Eastern province and many small barren zones are scattered on the right side of Zambezi River in Western province.

Agriculture

Agricultural zones occupy only 1.5% of Zambia. Most agricultural zones are small and scattered. In particular, agriculture is distributed along the main road and railway from Livingstone to Copperbelt. Therefore, the distribution of agricultural zones is high in Southern Province, Lusaka Province, Central Province and Copperbelt Province. Eastern Province also has a relatively high distribution. On the other hand, small scale agriculture zones are distributed along the road from Lusaka to Mongu, upper zone of Zambezi River and parts of Northern Province and Luapula Province. Small agricultural zones does not appear elsewhere on the satellite imagery interpretation map with scale of 1: 1,500,000.

Urban zone

Urban zones occupy 0.1% of Zambia. Most cities, municipalities and large townships are clearly shown on the satellite imagery interpretation map. However, small townships and villages are too small to appear on the satellite imagery interpretation map with scale of 1: 1,500,000.

Zambia

Land Cover

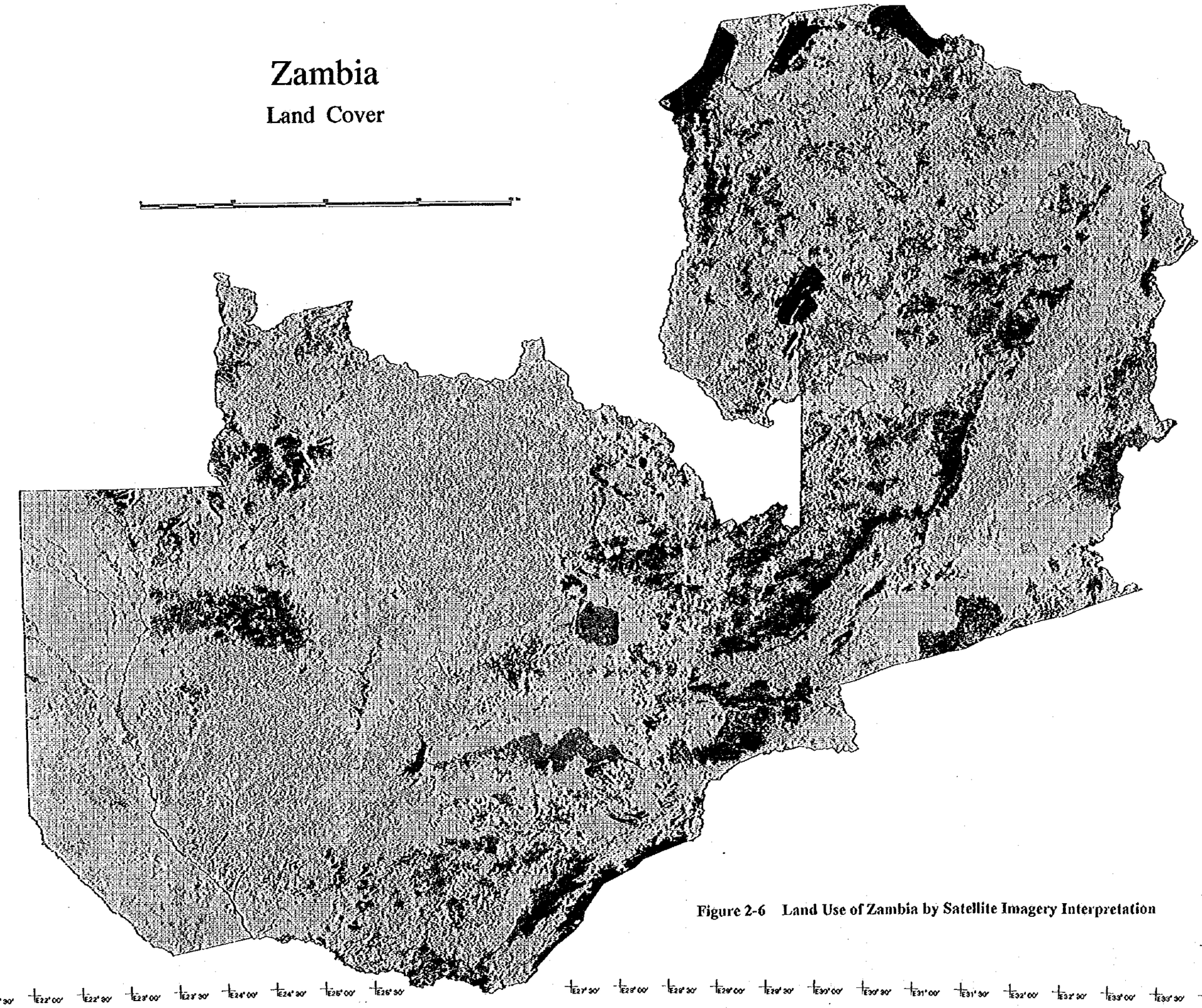


Figure 2-6 Land Use of Zambia by Satellite Imagery Interpretation

Table 2-5 Land Use of Zambia by Satellite Imagery Interpretation (km2)

PROVINCE	DISTRICT	FOREST	GRASS-LAND	SAVAN-NA	BARREN	AGRI-CULTURE	WET-LANDS	URBAN	WATER	TOTALS
LUSAKA	LUSAKA-URBAN		290	1		25		125		441
	LUSAKA-RURAL	5,107	9,061	3,046		228	254	44	53	17,793
	LUANGWA	142	2,910	743	14	2	1	4	44	3,859
	Total	5,250	12,261	3,790	14	255	255	173	97	22,091
COPPERBELT	NDOLA-URBAN	25	691	38		160	1	72	2	993
	NDOLA-RURAL	6,800	12,595	3,322	1	224	64	10	8	23,423
	CHILILABOMBWE	173	671	124	1	13	3	20	5	1,010
	CHINGOLA	187	1,373	100	31	51		4	6	1,751
	MUFULIRA	124	914	148	5	28		52	9	1,280
	KALULUSHI	36	785	93	1	193		25	2	1,135
	KITWE	63	510	84	1	7		83	2	751
	LUANSHYA	53	699	42	5	23	1	46	3	873
	Total	7,462	18,641	3,951	44	700	69	312	37	31,217
CENTRAL	KABWE-URBAN	4	1,270	37		185		33		1,530
	KABWE-RURAL	3,043	18,086	2,017	2	986	1,232	22	147	25,536
	MUMBWA	1,981	17,083	1,980		121	331	17	64	21,576
	MKUSHI	7,567	9,275	4,408	55	1,072	1	15	76	22,470
	SERENJE	5,227	9,379	8,328	7	416	181	10	24	23,572
	Total	17,823	55,093	16,769	65	2,781	1,744	97	312	94,684
NORTHWEST	SOLWEZI	9,378	16,980	3,644		54	50	7	10	30,122
	MWINILUNGA	2,969	11,344	6,376	8	89	82	26	1	20,894
	ZAMBEZI	1,383	14,541	2,541	34	143	22	25	57	18,746
	KABOMPO	2,384	7,950	4,074		105		18	3	14,535
	MFUMBWE	1,328	12,358	5,332	7	30	8	2	14	19,078
	KASEMPA	4,396	12,629	4,834		13	14	6	13	21,905
	Total	21,838	75,802	26,801	49	435	175	83	97	125,280
WESTERN	MONGU	974	6,981	1,916	26	20	109	6	39	10,071
	LUKULU	3,410	11,200	905	10	47	3	4	62	15,639
	KALABO	99	15,079	1,641	229	26	135	4	17	17,230
	SENANGA	1,095	25,645	4,666	204	57	91		100	31,857
	SESHEKE	2,161	21,142	6,066	9	20	31	5	89	29,522
	KAOMA	5,606	13,643	3,636	8	110	3	6	12	23,024
	Total	13,345	93,689	18,830	486	279	372	25	318	127,344
SOUTHERN	LIVINGSTONE	330	427	209	1	21	2	46	6	1,041
	NAMWAIA	2,568	16,032	1,718		392	372	10	436	21,528
	MONZE	120	4,067	129		491	44	7	41	4,901
	CHOMA	1,501	4,814	388		286		18		7,008
	MAZABUKA	526	4,805	180		487	585	17	26	6,625
	KALOMO	4,595	18,915	7,164	1	661	60	11	18	31,425
	SIAVONGA	255	1,962	168	1	111	1		110	2,609
	GWEMBE	501	3,344	299		129	4		986	5,262
	SINAZONGWE	986	2,319	336	1	47	17	1	1,095	4,800
	Total	11,381	56,684	10,590	4	2,624	1,086	108	2,721	85,199
LUAPULA	MANSA	2,305	8,714	4,526	6	152	226	24	46	15,997
	NCHELENGE	432	3,085	761	7	207	515	14	2,923	7,944
	KAWAMBWA	1,620	4,275	2,836		24	264	21	69	9,108
	MWENSE	1,413	3,678	1,375		38	121	16	31	6,672
	SAMFYA	161	5,696	736	39	30	1,500	15	1,695	9,872
	Total	5,931	25,447	10,232	52	451	2,626	91	4,764	49,594
NORTHERN	KASAMA	2,209	12,512	5,550		53	70	44	19	20,457
	KAPUTA	357	8,053	1,377		169	390	7	2,035	12,388
	MBALA	2,045	9,388	5,431	6	74	189	20	1,542	18,695
	MPOROKOSO	949	4,646	6,108		88	121	14	7	11,933
	LUWINGU	1,179	5,000	2,496		35	90	4	27	8,831
	CHILUBI	288	3,799	101		6	451	2	622	5,269
	ISOKA	764	7,918	4,988	25	50	20	3		13,767
	CHINSALI	3,770	5,207	6,401	7	10	34	10	6	15,445
	MPIKA	6,083	18,353	15,095	228	35	675	28	6	40,505
	Total	17,644	74,878	47,547	266	520	2,040	133	4,264	147,292
EASTERN	CHIPATA	324	10,694	1,030	4	111		25	3	12,189
	CHAMA	1,710	10,702	5,349	4	29	6	1	2	17,803
	LUNDAZI	1,772	7,811	3,221	8	874		2		13,687
	CHADIZA	183	1,806	394		119				2,502
	KATETE	67	3,035	158		580		2		3,842
	PETAUKE	967	14,056	2,311	13	1,750	6	14	7	19,123
	Total	5,022	48,103	12,462	29	3,463	11	45	11	69,146
TOTALS		105,689	460,599	150,972	1,009	11,507	8,379	1,065	12,621	751,851

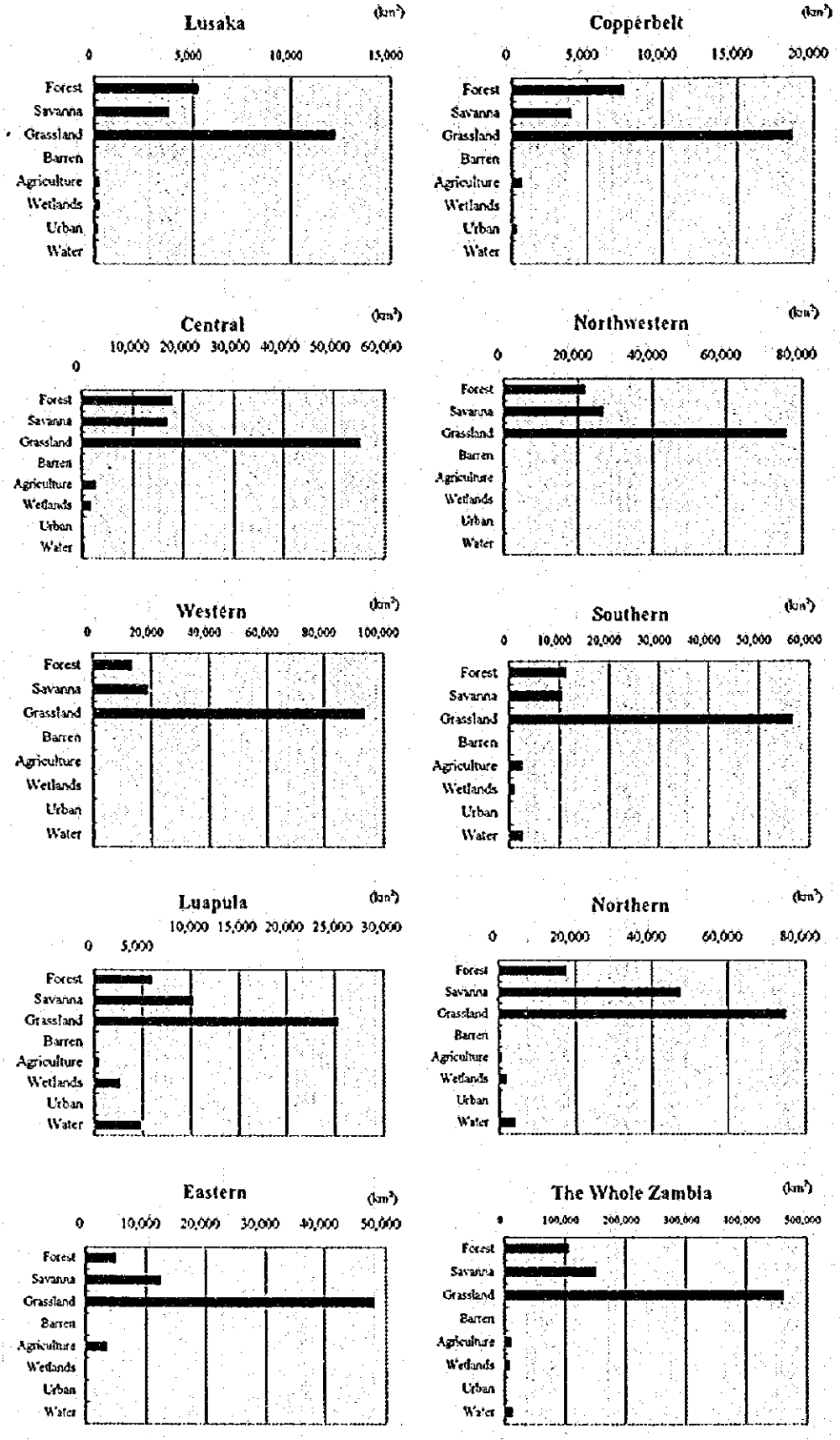


Figure 2-7 Land Use by Province

2.7 Soil

Soil in Zambia was classified by FAO. According to this classification, ferralsol and podzol are mainly distributed in northern part, and chestnut soil, brown soil and red-brown earth in other parts of Zambia. The soil distribution is related to topographical classification. Typical example of this is that fluvisol-vertisol are distributed only in the rift trough zone and arenosol is distributed in the aggraded plateau zone. Soil series reflect the condition of not only topography but also climate and geology. The soil distribution by province is summarized with relation to topographical classification as follows:

Lusaka Province
Main soil types are lithosol and cambisil. On the other hand, luvisol-phaeozem is distributed in Lusaka urban district.

Copperbelt Province
Main soil type is acrisol. On the other hand, ferralsol is distributed near the border with Northwestern province.

Central Province
Acrisol is distributed in degraded plateau zone. On the other hand, fluvisol-luvisol are distributed in escarpment and rift trough zone by the Luanguwa river. Other than these soils, gleysol is distributed in western part of Lukanga swamp.

Southern Province
Cambisol-luvisol and lithosol-cambisol are distributed in escarpment and rift trough zones along Zambezi river. On the other hand, in the degraded plateau zone, acrisol is distributed in the southern part and luvisol-phaeozem in the northern part. Other than these soils, vertisol is distributed in Kafue flood plain and in aggraded plateau zones near the border with Western province.

Western Province
Acrisol is distributed in pan complex zone which covers a large part of Western province. On the other hand, cleysol is distributed in flood plains along main course and tributaries of Zambezi river. Other than these soils, podzil is distributed in middle of Western province, namely eastern part of Mongu.

Northwestern Province
Ferralsol is distributed in level to undulating plateau zones which covers middle and eastern part of Northwestern province. On the other hand, arenosol is distributed in slightly dissected plateau zones which cover the western part of Northwestern province. Other than these soils, cleysol is distributed in the zone between Kasempa and main course of Kafue river.

Northern Province
Ferrasol is distributed in degraded plateau zone which covers middle part of Northern province. Lithosol-cambisol is distributed in escarpment and rift trough zone which covers northern part of the province. Lithosol-cambisol and fluvisol- vertisol are distributed in escarpment and rift trough zone along Luanguwa river. Other than these soils, acrisol is

distributed near boarder with Central province and gleysol is distributed in flood plains and around Lake Bangweulu.

Luapula Province

Ferralsol is distributed in level to undulating plateau zone. On the other hand, lithosol-cambisol are distributed in dissected plateau, escarpment and rift trough zone.

Eastern Province

Lithosol-cambisol are distributed in escarpment zones. On the other hand, fluvisol-vertisol are distributed in rift trough zones. Other than these soils, acrisol is distributed in level to undulating zones.

CHAPTER 3 ORGANIZATION RELATED TO GROUNDWATER DEVELOPMENT

3.1 Department of Water Affairs

3.1.1 Outline of DWA

Public groundwater development is executed by DWA. DWA plays a key role in administration and development of groundwater resources. The role of DWA is policy formulation, planning, setting technical and other standards and technical support to District Councils for overall management of groundwater. DWA is one of the largest departments in the Government with 249 administrative, professional or technical staff and a total of over 1,800 employees. The responsibilities assigned to the DWA are as follows:

1) Hydrological and Hydrogeological surveys(measurement and assessment)
2) Irrigation(design of large scale facilities)
3) Technical support to the Water Development Board.
4) River basin plans and catchment conservation.
5) Canals for inland navigation(design and dredging)
6) National water supplies

DWA has its headquarters in Lusaka, a provincial office in each province, and district office in each district. The present organization structure of the headquarters , provincial office and district office are illustrated in Figure 3-1, Figure 3-2 and Figure 3-3 respectively. Of the above six functions 1) to 5) are discharged by the Data and Planning Branch, while 6) is carried out by the Water Supply Branch.

3.1.2 Groundwater Development by DWA

Responsibilities of groundwater development by DWA are as follows:

1) Survey for groundwater resources and collection of hydrogeological data
2) Planning, design, construction, maintenance and management of water supply facilities.

Item 1) is carried out by DWA throughout Zambia. On the other hand, 2) is carried out by DWA in rural areas and 45 small urban areas. Of these small urban areas, 15 townships use groundwater resources for water supply. These townships are listed in Table 3-1.

Table 3-1 Groundwater Supply in Small Township by DWA

Province	Project	Province	Project
Copperbelt	Kasumbalesa Mokambo Sakania Tshisenda	Western	Namushakende Lukulu Kaoma
		Luapula	Kawambwa
Central	Chisamba Mumbwa	Northern	Isoka
Northwestern	Mufumbwe	Eastern	Chama Katete Petauke

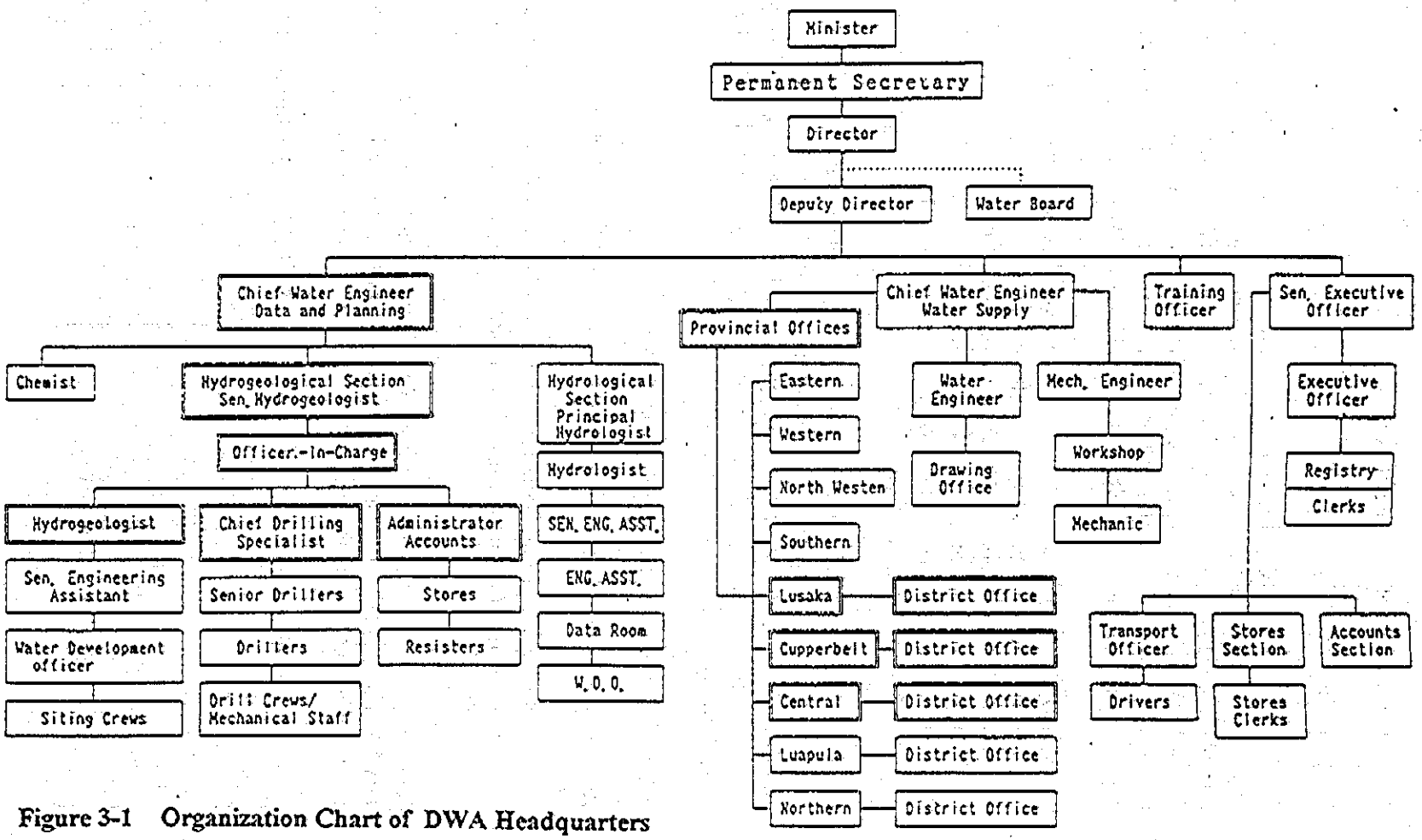


Figure 3-1 Organization Chart of DWA Headquarters

DWA has two branches, the Data and Planning Branch and the Water Supply Branch. Under these branches, there are several sections and local offices relating to groundwater development. Their roles are as follows:

Hydrogeological Section

Hydrogeological section has equipment for geological surveys and carries out siting of boreholes and assessment of water resources. There are five hydrogeologists in this section. One of them is in charge of drilling section and two are engaged in JICA and NORD projects respectively.

Senior Hydrogeologist	1
Hydrogeologist of NORAD Project	1
Hydrogeologist of Headquarters	1
Hydrogeologist of Drilling Section	1
Hydrogeologist of JICA Project	1
Total	5

Drilling Section

The drilling section is in charge of drilling boreholes. There are four drilling workshops in DWA, located in Lusaka(Lusaka Province), in Kabwe(Central Province), in Monze(Southern Province) and in Mongu (Western Province). The drilling workshops are y equipped with drilling rigs. There are eight (8) rigs in DWA, and these rigs are down the hole hammer type from JICA. The number of drilling rigs in each workshop is, three rigs in Lusaka, two rigs in Kabwe and three rigs in Monze. In these workshops, there are groups for drilling and siting. Drilling section undertakes drilling boreholes for both public and private water supply. However, drilling section gives priority to public water supply such as rural water supply projects and drought relief projects. The numbers of staff are as follows:

Hydrogeologist	1
Chief Drilling Supervisor	1
Senior Driller	1
Driller	5
Learner Driller	5
Total	13

Other than the above listed, there are about 30 experienced technicians and about 60 inexperienced technicians for drilling.

Provincial Water Engineers Office and District Office

Provincial Water Engineers Office and District Office are in charge of rural and small urban water supply. For rural water supply, they carry out digging of shallow wells, construction, maintenance and repair of small water supply facilities including repair of hand pumps. For small urban water supply, they carry out construction, maintenance and repair of piped water supply system.

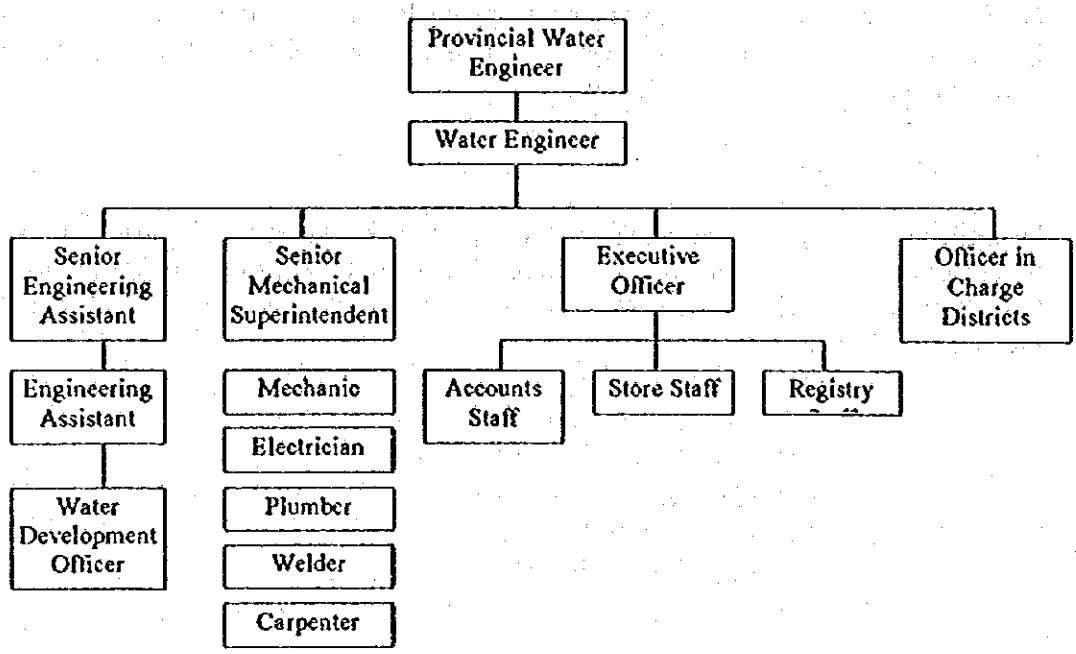


Figure 3-2 Provincial Engineering Office of DWA

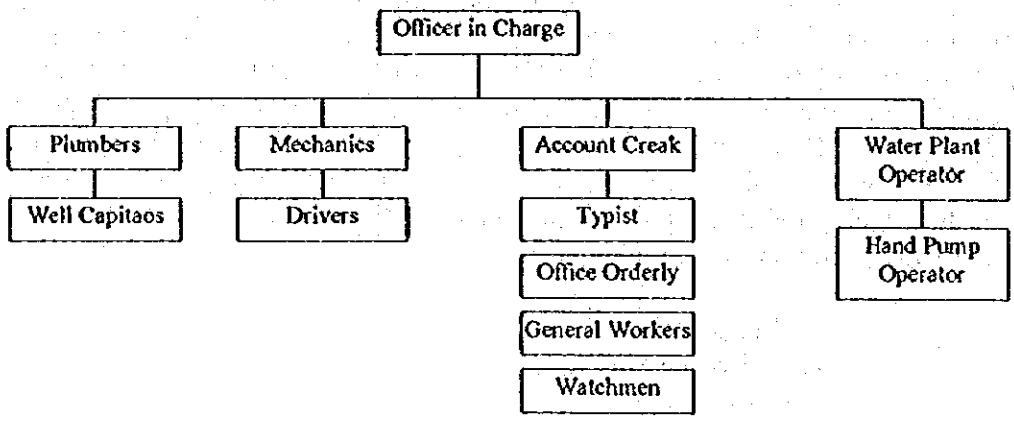


Figure 3-3 District Office of DWA

3.1.3 System of Completion of Water Well

Groundwater development is carried out by drilling boreholes and digging shallow wells. Boreholes and shallow wells are completed by the procedure shown in Figure 3-4.

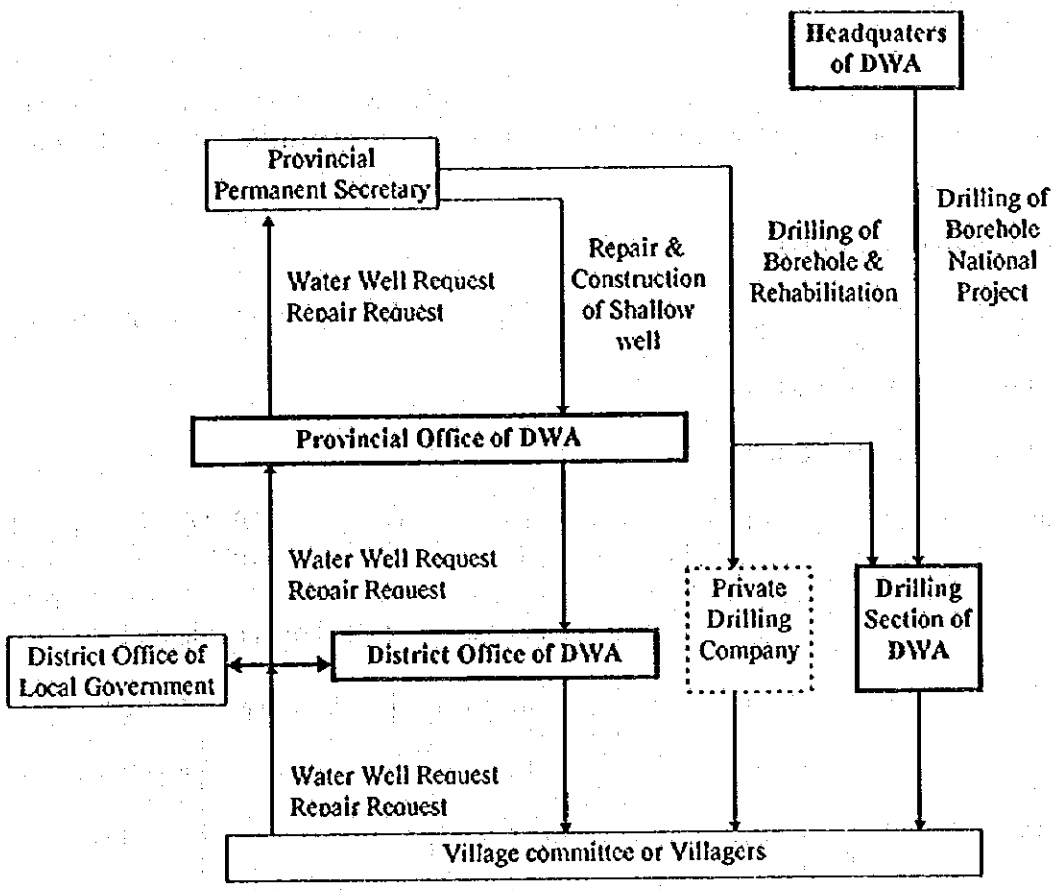


Figure 3-4 Procedure of completion of Borehole and Shallow Well

3.2 Other Executing Organizations

Groundwater development is carried out by other government organizations and private companies as well as DWA. These organization are as follows:

3.2.1 Ministry of Local Government and Housing

Under Ministry of Local Government and Housing, city councils, municipal councils and district councils carry out groundwater development. Lusaka Water and Sewerage company provides groundwater to Lusaka city and also in Chipata Water and Sewerage company provides groundwater to the Chipata.

3.2.2 Ministry of Health

Ministry of health is in charge of groundwater supply for hospitals and clinics in the whole country especially in rural areas.

3.2.3 Ministry of Education

Ministry of Education is in charge of groundwater supply for schools in the whole country, especially in rural areas

3.2.4 ZCCM

ZCCM provides groundwater to the mining claims in Kabwe district and urban districts of Copperbelt Province. Furthermore, ZCCM is studying the pattern of groundwater flow in the Copperbelt area.

3.2.5 Zambian Railways

Zambian Railways provides groundwater to residences of its employees along the railway.

3.3 Foreign Donor Agencies

(1) Foreign Donor Agencies

Foreign donor agencies related to groundwater development are, NORAD, KFW & GTZ, JICA, SNV, Irish Government, World Bank, EEC, UNDP and UNICEEF. Groundwater development projects supported by these donors are shown in Table 3-2. These projects include on-going projects. The area of each donors activities is shown in Figure 3-5.

Table 3-2 Groundwater Development Project by Foreign Donor

Donor	Project	The number of water wells completed	Area	Population supplied
NORAD	-Water Supply Programme	1,062	Western Province	139,000
GTZ, KFW	-Rural water supply	560	Central Province	65,000
JICA	-Rural groundwater Development. -Water supply for Lusaka satellite	342	Southern, Central, Lusaka, Copperbelt Province	194,000
SNV	-Rural water for health project	232	North-western Province	32,000
Irish Government	-Rural water supply programme	326	Northern Province	27,000
World Bank	-Rural water Northern sector	649	Copperbelt, Luapula, Northern Province	97,000
UNICEF	-Drought relief programme	75	Southern, Eastern Province	19,000

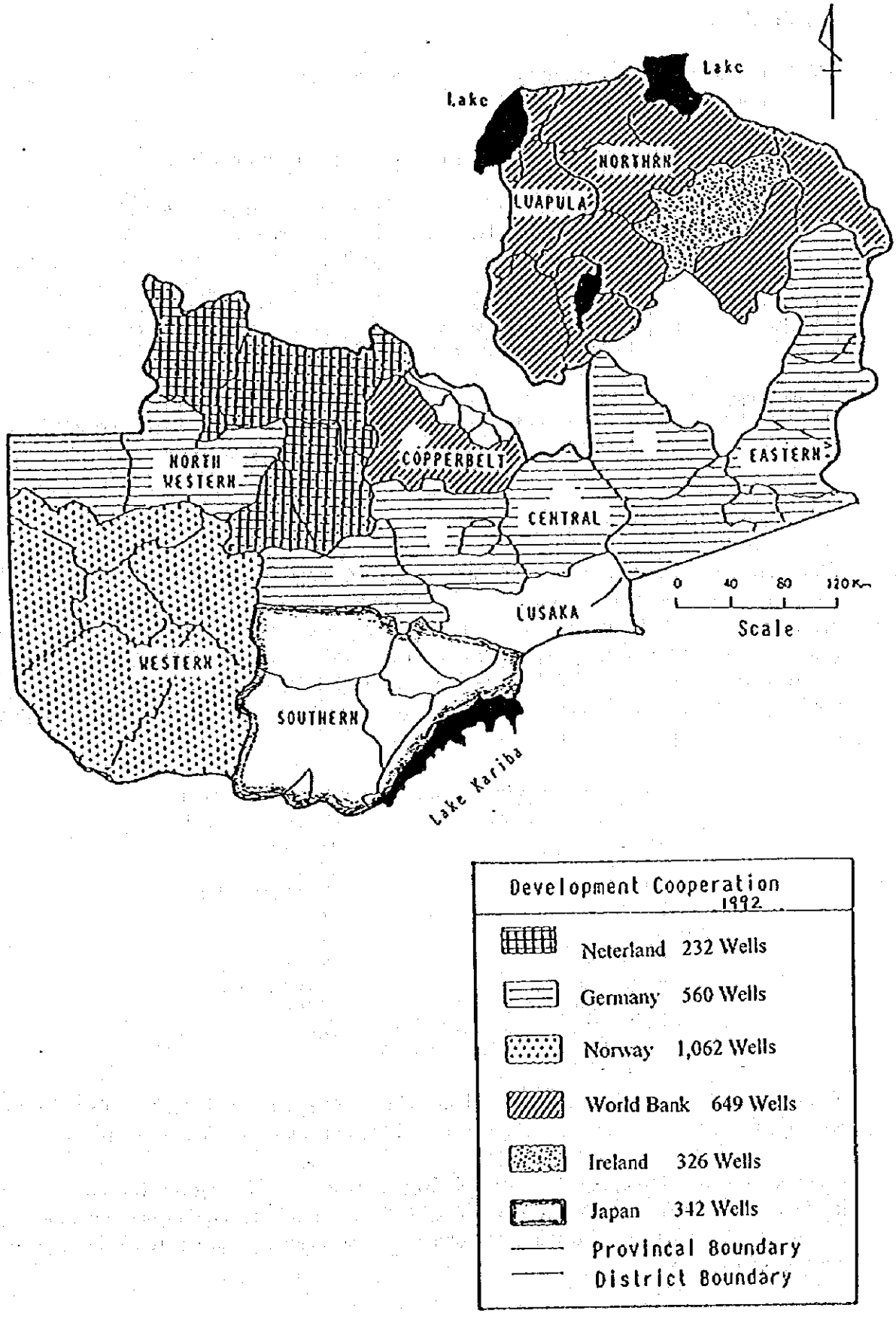


Figure 3-5 Area of Foreign Donors' Activity

(2) JICA Grant Aid

JICA started support for groundwater development since 1981 in Zambia. The outline of the support is summarized as follows:

Table 3-3 Outline of Groundwater Development by JICA

Project	Period	Area	Outline of project
Groundwater Development Phase I , II	1985 - 1989	Southern Province	- Completion of 150 boreholes. - Rehabilitation of 140 boreholes. - Supply of drilling tools, materials, casing, hand pumps, vehicles.
Groundwater Development in Rural Areas	1991 - 1995	- Lusaka Province - Central Province - Copperbelt Provinces	- Completion of 220 boreholes. - Rehabilitation of 160 boreholes. - Supply of drilling tools, materials, casing, hand pumps, vehicles.
Water Supply Project in Lusaka Satellite	1994 - 1997	- Lusaka City	- Completion of 8 boreholes. - Construction of water supply system for 130 thousands people.

3.4 Private Drilling Company

There are about 18 private drilling companies in Zambia. Most of these private drilling companies have their basic activity in Lusaka and undertake drilling boreholes for the central government, local government, private companies and individuals. However, their groundwater development projects are for other than national projects, because such projects are carried out by DWA. Generally speaking, drilling costs of private companies are higher than those of DWA. However, they can mobilize more quickly than the DWA. Main drilling companies are shown in Table 3-4.

Table 3-4 Main Drilling Companies in Zambia

Private Drilling Company	Type of Drilling Rig
Foradex	DTH x 3
Water Wells	PC x 22
Besto Bell	PC x 1 , DTH x 1
Get Well	DTH x 2
Pegasas	PC x 2
Boart Zambia	PC x 3
Mpelembe Drilling	DTH x 2
Cyclone Drilling Company	DTH x 2

(Note): DTH = Drilling Rig of Down the Hole Hammer Type
PC = Drilling Rig of Cable Percussion Type

The drilling companies other than those listed above are small. Total number of staff of the 8 companies listed in Table 3-4 is about 380, and the total number of engineers is about 80.

It takes 1 - 4 weeks to complete a borehole by percussion type drilling rig. On the contrary, it takes only 2-3 days to complete a borehole by down the hole hammer type drilling rig. Therefore, the capacity of drilling companies whose main rigs are percussion type are considered to be low.

CHAPTER 4 HYDROGEOLOGY

4.1 Occurrence of groundwater

Groundwater occurs in secondary developed features such as weathered zones, joints, fractures, faults or solution features within consolidated hard rocks. The weathered zones usually form shallow aquifers which are shallower than 20m in depth. Fracture zones have been developed under weathered zones and usually extend to around 30m-40m in depth and often to more than 90m. The thickness and permeability of aquifers are closely related to the original rock type. The aquifers in Zambia are classified into three types (Chenov, 1976) as follows:

Aquifers where intergranular groundwater flow is dominant

The alluvial formations, Kalahari Group and Karroo Group are included in this category. This type of aquifers are distributed mainly in the western half of Zambia, in Western Province and parts of North-Western Province and Southern Province as shown in Figure 2.2-4. However, in the eastern half of Zambia, these aquifers are also distributed around Chambeshi river and lake Bangweulu in Luapula and Northern Province and along Luangwa river in Eastern and Northern Province.

Aquifers where groundwater flow is mainly in fissures, channels or discontinuities

The type of aquifer is subdivided into two types.

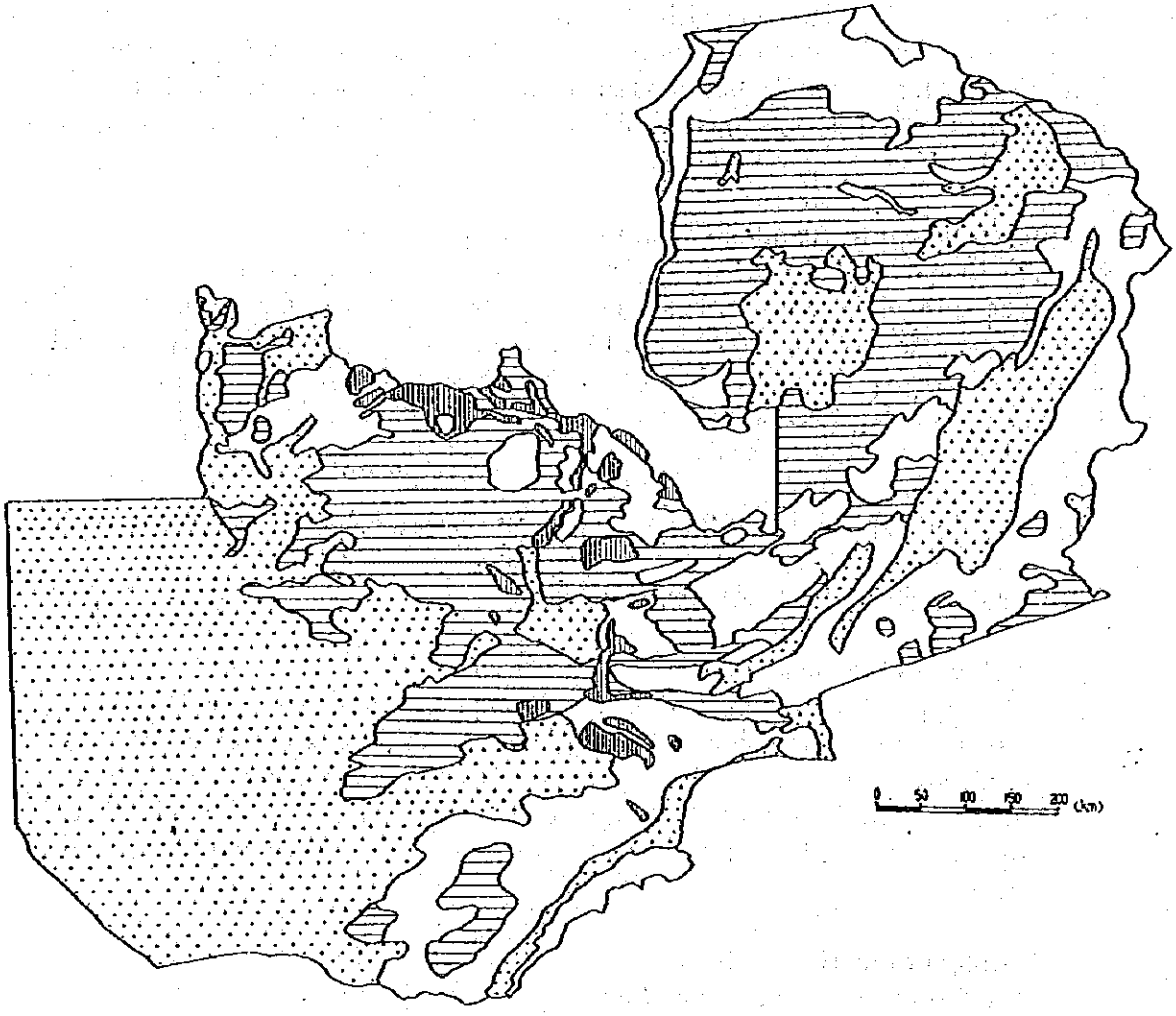
- **Highly productive aquifers**
  The Upper Roan dolomite and Kundelungu limestone are included in this category. Limestone, dolomites and dolomitic limestones are often the most productive aquifers in Zambia. This type of aquifer is distributed in Copperbelt, Lusaka, North-Western and Central Province. The area of distribution is limited and very narrow, but some large cities are located in the vicinity of this type of aquifer.

- **Locally productive aquifers**
  The Lower Roan quartzite, Muva sediments, granites and undifferentiated Kundelungu formations are included in this category. These aquifers are distributed largely in Northern, Luapula, Central, North-Western, and Copperbelt Province.

Low yielding aquifers with limited potential

This category includes the major part of argillaceous formations, Karroo basalts and the older Basement Complex. This type of aquifers are distributed in almost half of Eastern, Southern and Lusaka Province, and parts of Northern, Luapula, Central, Copperbelt and North-Western Province.

Distribution of three aquifer types mentioned above is shown in Figure 4-1.
On the other hand, based on a borehole data-base developed by Study Team, the number of existing boreholes and representative yield of the boreholes by aquifer type are shown in Table 4-1.



Legend

Aquifers where intergranular groundwater flow is dominant

Aquifers where groundwater flow is mainly in fissures, channels or discontinuities

Highly productive aquifers

Locally productive aquifers

Low yielding aquifers with limited potential

Figure 4-1 Types of aquifer

Table 4-1 Type of Materials Forming Borehole Aquifer

Type	Number and %	Yield (l/s)	Type	Number and %	Yield(l/s)
Fractured rock	2,491 (59%)	2.2	Cavernous rock	54 (1%)	4.2
Weathered rock	1,034 (24%)	2.0	Fresh rock	56 (1%)	3.3
Coarse grained	361 (9%)	1.5	Others	4 (<1%)	1.33
Fine grained	190 (5%)	1.48			

4.2 Aquifer Characteristics and Distribution

4.2.1 Classification of Aquifers Lithology

(1) Aquifer Classification

From a hydrogeological view-point, the classification of geology of Zambia is simplified into the following groups and component rocks, as shown in Table 4-2. Based on the classification indicated in Table 4-2, the distribution of aquifers by district has been clarified. The results are shown in Table 6-4. As shown in Table 4-1, firstly fractured rocks form aquifers, secondly weathered rocks form aquifers. These 2 types form more than 80% of aquifers tapped by boreholes. On the other hand, unconsolidated aquifers such as sand & gravel layer are only 14%. However, many boreholes were drilled in Western Province where unconsolidated Kalahari formation are widely distributed. The borehole data-base has relatively little data on Western Province, so actual ratio of unconsolidated aquifers may be higher than shown in Table 4-1.

Table 4-2 Classification of Aquifers

Litho Stratigraphic Unit		Main Aquifer Lithology	Productivity of Groundwater	Area Ratio (%)
Cenozoic Super Group	Alluvium	Sand, Gravel	Medium-High	11.9
	Kalahari	Sand	Medium-High	23.8
Karroo Super Group	Upper Karroo	Basalt	Low	0.5
		Sandstone	Medium-High	4.5
	Lower Karroo	Mudstone	Low	0.7
Katanga Super Group	Kundelungu	Carbonate Rock	High	2.0
	Undifferential Kundelungu	Shale	Low	12.9
	Upper Roan	Dolomite	High	0.4
	Lower Roan	Quartzite, Dolomite	Medium-High	0.8
	Mine Series	Quartzite, Shale	Low-Medium	3.7
Muva Super Group		Shale	Low	9.4
Basement Complex		Gneiss, Migmatites, Schist	Low-Medium	14.2
Granite		Granite	Low-Medium	15.2
Other Igneous Rocks		Basic igneous Meta igneous	Low	
Metamorphic Rocks		Meta sediment, Meta volcanics	Low	

[Source]: Hydrogeological Map of Zambia (scale 1:1,500,000)
Groundwater Resources Inventory of Zambia (Chenov, 1978).