

GIS AND REMOTE-SENSING FOR HIGH-RESOLUTION MAPPING AND DIGITAL CARTOGRAPHIC DATABASE- BUILDING IN AFRICAN REMOTE AREAS

SANGA-NGOIE KAZADI

*Laboratory of Climate and Ecosystems Dynamics,
Faculty of Bioresources, Mie University*

ABSTRACT The possibility of using high resolution satellite data on a GIS platform for fast and low-cost map upgrading and digital cartographic database-building over remote areas in Africa is demonstrated. Using just one LANDSAT TM composite image, in combination with DEM (digital elevation model) and the author's GPS data, a series of base and derived maps (hydrography, territorial boundaries, villages location, road network, relief) was obtained in a digitized, highly accurate, updated and upgradeable GIS-friendly format for the remote Kayamba Chiefdom in Congo. From these digital layer maps, a set of quantitative cartographic metrics (coordinates, distance, length, area, slope, aspect, etc.) was reliably deduced. All these findings provide a solid base for further quantitative eco-climatic analysis or land/resources management and planning for the Chiefdom. Ground truth data are determinant in defining and/or identifying the surface features embedded in the satellite imagery. I recommend this analysis approach for those remote areas in developing countries where a full-scale ground survey is too costly or technologically too demanding.

Preliminary results highlight a strong village dynamics characterized by (i) relocations followed by sedentarization in the Northern and the Central parts, (ii) creation of new villages at important crossways, or (iii) village splitting followed by relocation and sedentarization along the main roads in the South. These changes more likely denote the adjustment that the local and traditional society is undergoing in order to adapt to the new economy-oriented way of life that is quickly spreading all over the Chiefdom.

Key Words: GIS, Digital cartography, Mapping, Remote-sensing, Africa, Congo.

INTRODUCTION

Unavailability of precise, concurrent, high-resolution maps is one of the most frustrating problems any researcher, environmental manager, development planner, journalist or even tourist, faces when dealing with Africa (Tayler, 2001). This makes it almost impossible to obtain reliable geographic metrics (coordinates, areas, distances, population density, available lands for development or conservation, administrative borders, etc.), hampering any quantitative evaluation or planning for sustainable development of African human or natural resources. This difficulty is presently made even stronger in the fast-changing world, where timely and easily upgradeable maps are needed for prompt decision-making not only on the local, but also on the national or continental levels.

The Kayamba Chiefdom is a remote administrative entity located along the northwestern border of the Katanga Province, Democratic Republic of Congo,

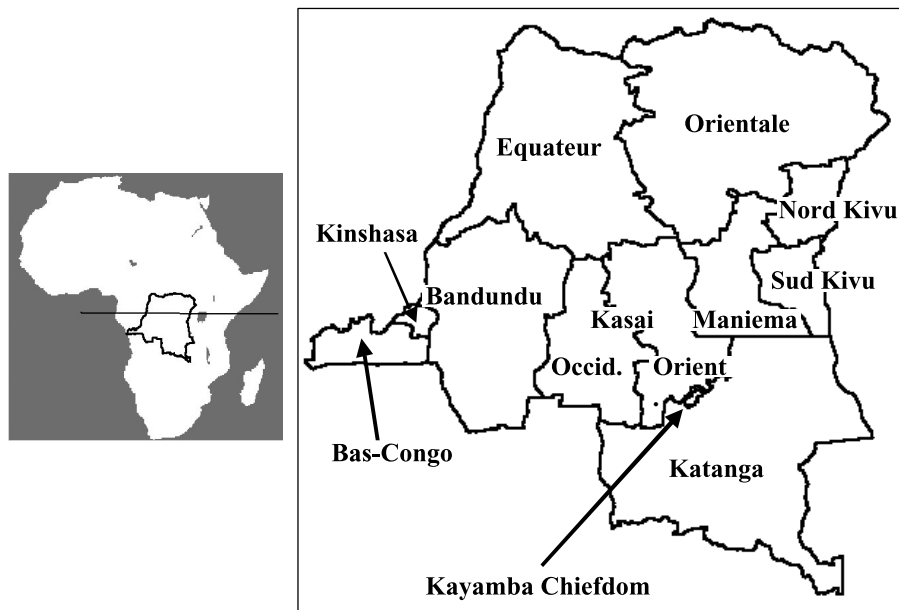


Fig. 1. The Kayamba Chiefdom and Its Location in the Katanga Province, Democratic Republic of Congo, Central Africa.

hereafter the Congo or the DRC (Fig. 1). I have conducted my field research there on eco-climatic change, and rural development projects (education, agriculture, environmental management, etc.) for the last decade. Suffice to stress here that the unavailability of accurate and detailed maps for this area had hampered any attempts for quantitative estimation of geographic metrics needed as an objective basis for further scientific research, environment or development planning and assessment.

The only base map available so far in the Congo is a 1:1,000,000 scale map dating back to 1961, produced by the *Institut Géographique du Congo, IGC* (Institut Géographique de Congo, 1961) after the sole and unique geographic national survey in this country (Fig. 2). A close analysis shows that, while some detailed surveys seem to have eventually been carried on over the southern half of the Chiefdom, the geographic and cartographic features over the northern part (with most of the population) are only approximate. In fact, all over the Chiefdom, village locations, river courses, water bodies and marshlands, roads and tracks, natural landmarks, as well as territorial boundaries, are either lacking or inaccurate. And now, more than 40 years after the country's independence, no attempt to update or upgrade this base map into its digital layers, has been planned, and nothing is foreseen in the near future, mostly due to economic reasons.

Traditionally, geographic surveys are carried out by national or commissioned institutions at regular intervals and using finer and finer spatial scales, with more and more sophisticated analytical tools as well as larger teams of special-

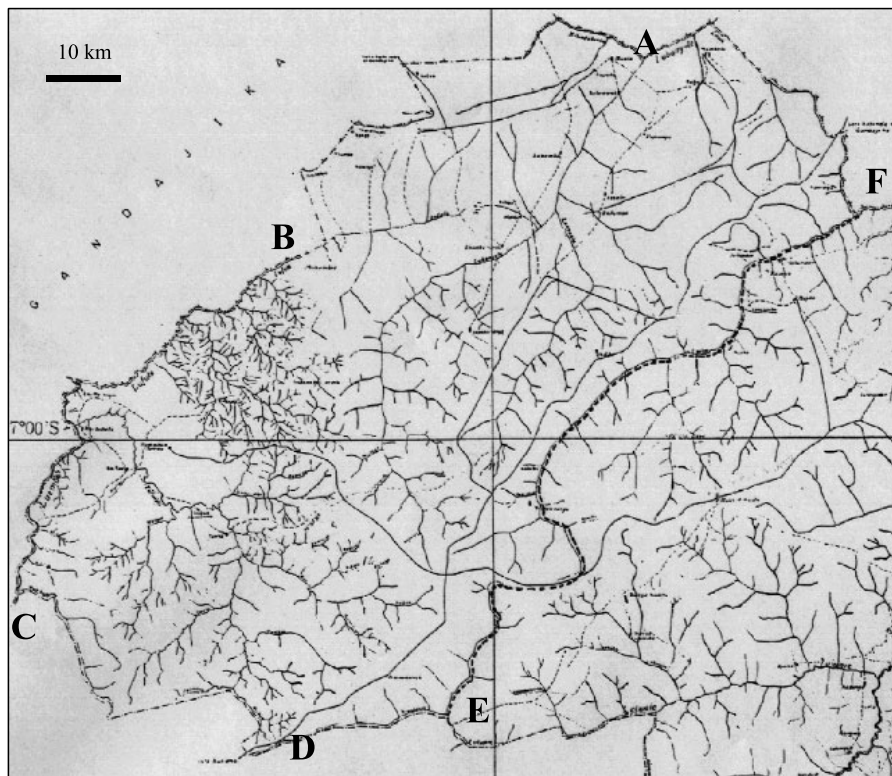


Fig. 2. The Kayamba Chiefdom as Scanned from the Official 1:1,000,000 Scale Hardcopy Map of the Kabongo Territory, Katanga Province, DRC Institut Géographique du Congo (IGC), 1961.

ized field researchers and analysts. As for budget-tight African countries, the huge costs hamper such time-consuming endeavors and these surveys have been held only sporadically, if not just once. Most of these countries therefore still rely on old, and surely outdated, hardcopy maps for their planning and assessment. The Kayamba Chiefdom, an administrative entity in the Congo, is no exception.

Some recent works report on the time and cost-efficient use of GIS (Geographic Information System) and the high-resolution (active or passive) remote-sensing data in order to build base maps and related thematic information databases (Cohen *et al.*, 1998). The same is also valid for surface features analysis and eventual land cover change detection for climate modeling (Bonan, 1995; Dobson *et al.*, 1995; Hill & Mehl, 1995). Kostak and Kramer (1995) suggest the use of this approach for remote areas in developing countries.

The main aims of this paper are:

(i) First, to show that high resolution map updating can be made at a low cost with GIS (Geographic Information System) and remote-sensing data (satellite and GPS (Global Positioning System)), especially over remote areas in Africa. The 1961 hardcopy map of the Kayamba Chiefdom (Fig. 2) is updated here by

correcting its inaccurate information and by including new inputs of the changes since 1961. The author's field data will be used as ground truth data.

(ii) Secondly, to upgrade the obtained map into a series of new digital base or derived layer maps (i.e., digital cartographic database-building), building thus a diversified digital cartographic database of the related thematic information, ready for further computer-based analysis in eco-climatic research (land cover and land use features and change, human ecological aspects and impacts, etc.), or in planning for the sustainable development and ecosystems management of the Chiefdom and its surrounding.

(iii) Finally, to attempt to make a detailed description and a preliminary analysis of the natural and geographic features (hydrography, territorial boundaries, landscape, infrastructure, village dynamics, etc.), in which sustainable development of the local people has to be understood, conceived and implemented. Kayamba is potentially a very promising region, notwithstanding its relative poverty nowadays. It boasts, among others, one of the highest literacy rates in the Congo, and was from the colonial times through the 1970s, the breadbasket for the surrounding big cities within a 150 km radius (Kabinda, Kabongo, Kamina).

THE GEO-POLITICAL CONTEXT

The poor quality of available maps in the Congo is notorious worldwide. Congo covers an area as wide as all of Western Europe, with large portions of its lands under hardly accessible areas. Congo land management as well as all its published maps (Charlier, 1998) are based on the map created in 1961 (Institut Géographique de Congo, 1961), date of probably the only one, nation-wide geographic survey. Notwithstanding its national character, this unique survey was not totally completed, because of the post-independence insecurity between 1960 and 1965. Geographic or cartographic features over large areas in the countryside are not only inaccurate or approximate, but a majority is simply unmarked.

The northwestern border of the Katanga Province shared with the Eastern Kasai Province, is one of these areas not completely surveyed (Fig. 2). Now, more than 40 years after independence, the boundaries of a number of counties and chiefdoms along this border are not well defined: many still do not know to which province they belong, ignoring where the official provincial/county boundary is located. This makes most of them behave as independent enclaves, with fiscal obligations to neither one of the two provinces. Unfortunately, they have also been out of anyone's development concern on both the national and the provincial levels.

DATA AND ANALYSIS METHOD

The analysis is based on the 9th June 1984 LANDSAT TM satellite image (175th path–65th row; 28.5 m×28.5 m pixel resolution) from which a mid-infrared composite image (BGR bands 3, 5, 7) was obtained, so as to emphasize the surface features for their easier identification, digitization and eventual classification. This analysis is centered on the 3,207×2,895 pixels region spanning from 24.53°E to 25.36°E, and from 6.57°S to 7.32°S, encompassing all the administrative territory of the Kayamba Chiefdom. The 1984 scene analyzed here is old enough to be considered as an initial state from which ulterior man-made or natural changes of surface features (using more recent satellite images) can be computed. Moreover, being the peak of the dry season here, June seems more appropriate for surface feature identification than the rainy season when all the surface (forests, grasslands and wetlands) is uniformly blanketed by the lush dark green vegetation carpet (Nonomura *et al.*, 2003).

The IDRISI32 (Release 2.2) software (Eastman, 2001) was used as the GIS analytical platform. Digital cartographic database building was performed either by on-screen digitizing from the scanned 1961 hardcopy map (1:1,000,000 scale) (Fig. 2) or from the mid-infrared composite image as backdrops, using IDRISI32 and CARTALINX, the database builder software. The overall analysis process was supported by a rich data bank of thematic information collected during regular field investigations conducted over the Kayamba Chiefdom during the past 10 years (Sanga-Ngoie, 1993, 1996).

First, two available versions of the IGC 1961 hardcopy map, the Katanga Province version (IGC61KAT), and the Kabongo Territory version (IGC61KAB), were scanned into digital data files, to be used later as backdrops for digitizing features. Then, georeferencing and geometrical corrections onto both these so-obtained scanned maps and the TM file, were made on the Latlon reference system, with control points chosen at significant crossways or at other geographic landmarks (rivers source or confluence, school or market, etc.) for which coordinates were eventually collected during field investigation using GPS. The Global 1-km resolution Digital Elevation Model (DEM) data (NIMA, 1997) were used to determine the overall and local topological features of every point of the Chiefdom.

Field investigation over the Chiefdom revealed that more than 95% of its territorial boundaries consisted of well-known permanent rivers. Considering that river course is only approximately represented in the 1961 map (Fig. 2), the 1961 geographic survey was probably not carried out throughout the Chiefdom, except perhaps for the Lwembe River area in the southwestern part. Making a precise tracking of these natural landmarks (rivers) was seen as a prerequisite to any map updating (territorial boundaries, village location, area calculation, roads networks) or their eventual upgrading into new digital (base and derived) map layers. The analysis strategy here was therefore to first obtain a precise river network map, and then to extract from it the territorial boundaries as well as many other cartographic metrics for both the Chiefdom and each one of its vil-

gages. These will be used as referential base maps for any further GIS analysis.

RESULTS

I. Hydrographic Settings

Using CARTALINX, the IGC 1961 data (IGC61KAT, IGC61KAB) and the mid-infrared LANDSAT TM composite image as backdrops, the main rivers and all their tributaries were digitized onto different vector layers shown in Figures 3a, 3b and 4, respectively. Comparison between Figure 4 from the TM data, and Figures 3a and 3b, from the IGC 1961 data, showed major discrepancies, which were henceforth updated:

First, a more comprehensive and precise hydrographic map, especially for river courses over the northern third of the Chieftdom, was obtained (Fig. 4). Second, the courses of most of the main rivers have been precisely identified. Also: (i) The Lweleji River, which is actually the main tributary into the Lungemia River (X mark in Fig. 3 & 4), flows directly into the Lungemia River and not into the Lubangule River as erroneously plotted on the 1961 maps. (ii) The precise course of the Kibindabinda River (along the northwestern

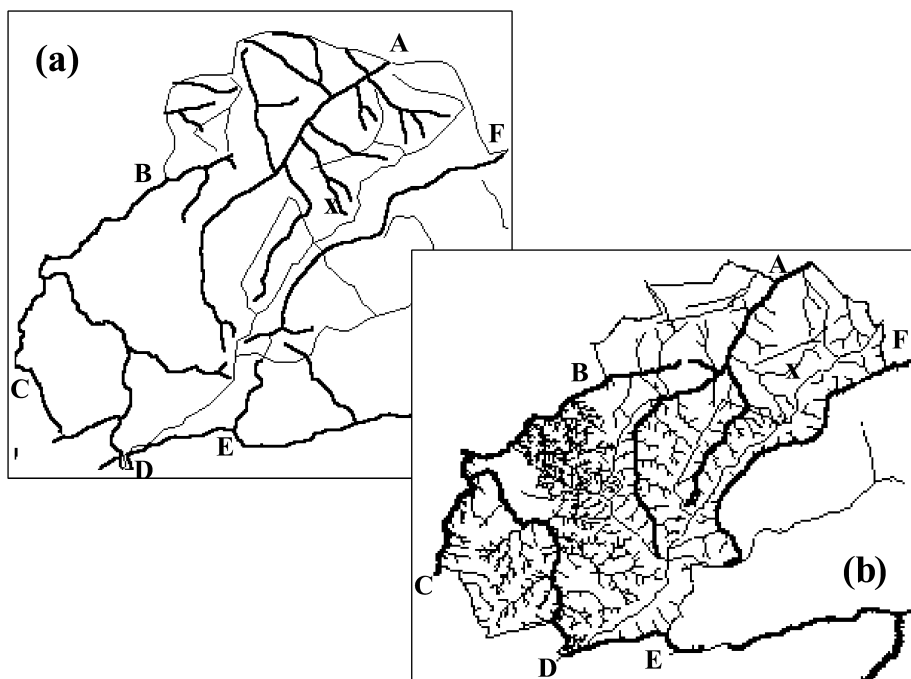


Fig. 3. Digitized Vector Layers Obtained from Georeferenced IGC 1961 Maps for (a) the Katanga Province and (b) the Kabongo Territory, Respectively. The capital letters (A, B, C, D, E F) delineate various border segments. (X marks indicate the Lweleji River, see Fig. 4)

border shared with the neighboring Eastern Kasai Province), from its head close to Kateo village all the way to its mouth into the Lubangule River North of Mwala village (point, A), is now apparent. This is in sharp contrast with the featureless straight lines plotted instead in Figure 2. (It has to be noted here that although the lower half of this river is locally called Lubo, the Kibindabinda name will be maintained hereafter to avoid confusion.) (iii) The precise flow of the Lubimbi River, the northbound as well as the southbound Lufute Rivers, and the complex array of their tributaries over the broad and harsh northwestern area of the Chieftdom has been obtained.

Having thus secured this high resolution and updated version of the hydrographical base map (Fig. 4), the territorial boundaries of the Chieftdom were defined and other features such as villages location and areas, roads network, landscape and relief, rivers drainage basins and catchments, could be identified.

II . Territorial Boundaries

The Kayamba Chieftdom (30,000 inhabitants) is located in the westernmost part of the historical *Baluba Shankadi Empire*. This historically known entity dominated all the central and northern part of the Katanga Province, DRC, from the 8th century to the early 1930s. At that time, it was finally and officially divided by Belgium, the then colonial power, into four main chiefdoms (ruled

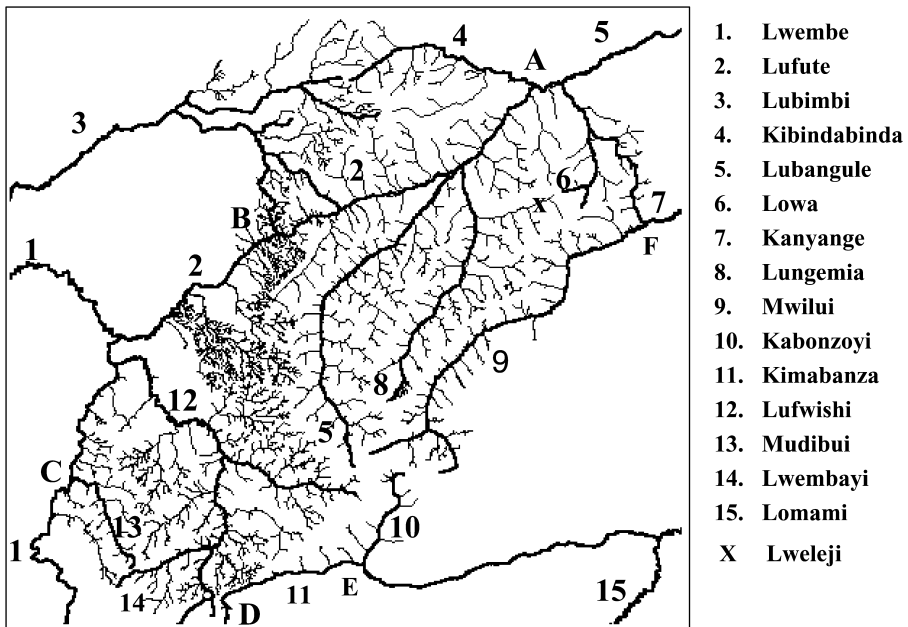


Fig. 4. The Main Rivers (Thick Lines) and All Their Tributaries (Thin Lines) within the Kayamba Chieftdom. (Capital letters are marked as in Figures 3a and 3b; the Lweleji River is indicated by an X mark.)

by their own kings of traditional lineage), which were the core of the lost *Baluba Shankadi Empire*, and a multitude of small sub-chiefdoms (with traditional hereditary landlords) or sectors (ruled by elected chiefs in 5-year terms). The Kabongo Territory is made of two chiefdoms (Kabongo and Kayamba) and one sector (North Baluba). The Katanga Province is made of about 20 territories and 3 cities of Lubumbashi, Likasi and Kolwezi.

Notwithstanding its modest size as compared to its huge neighboring chiefdoms (Kabongo on the east, Kasongo-Nyembo on the south and Mutombo-Mukulu on the southwest), Kayamba Chiefdom had known glorious days during the slave trade period, when its rulers strategically used all its natural geographic features to fight slave traders from Gandajika (Kasai people) or Kabinda (Basonge people) marketplaces, and to block their incursions further into the *Baluba Shankadi Empire*.

In its official form, the Kayamba Chiefdom is a southwest-northeast oriented parallelogram about 60 km-wide and 125 km-long, crossed by the 7°S parallel and the 25°E meridian. The northeastward flowing Lubangule River is its backbone, and Kamayi Village its capital.

For the Baluba (or *Luba people*), traditional wisdom has it that only non-equivocal, natural bounding landmarks, such as rivers or valleys, are accepted as boundaries between territorial entities, with the exception of the line joining the heads of two bounding rivers. The state of the Chiefdom territorial borders as obtained from Figures 3a and 3b is summarized in Table 1. It shows an acceptable matching of the official and the traditionally defined borders along the following segments: (i) the Lubangule, Lowa and Kanyange Rivers in the northeast, (ii) the Southbound Lufute and the Lwembe Rivers as southwestern borders; (iii) the Kimabanza, Lufwishi and Mudibui Rivers in the south and (iv) the Mwilui River and the Kabonzoyi, an affluent of the Kimabanza River, in the east.

However, the official boundary line (Figs. 3a & 3b) over the northwestern area, from the mouth of the Kibindabinda River (point A) to the Southbound Lufute River (point B) is still ill-defined and only approximately marked on maps. Huge marshlands on one side, and heavily eroded landscapes with tens of small meandering streams on the other side, more likely made the geographic survey of this area too challenging an endeavor for the colonial administration,

Table 1. State of Kayamba Chiefdom Territorial Borders.

Segments	Rivers	IGC61KT	IGC61KB
AB	Kibindabinda-Lubimbi	×	×
BC	Lufute(S)-Lwembe	○	○
CD	Mudibui-Lwembayi-Lufwishi	×	×
DE	Kimabanza	○	○
EF	Kabonzoyi-Mwilui	○	×
FA	Kanyange-Lowa(II)-Lubangule	×	×

(Refer to Figs. 3 & 4 for segments definition)

resulting in some featureless straight lines (Fig. 2) as territorial borders. Here, not only is this artificial border vague and set against the traditional wisdom of the local people, it is also located far away from the officially accepted territorial limits between the Kayamba Chiefdom and the neighboring Lubinda Sector in the Eastern Kasai Province. This is a cause of recurrent land frictions between the two entities, with Kayamba claiming its traditional rights, and Lubinda referring to the vague official limit to support its surplus of acquired lands. Another vaguely defined boundary is found between the heads of the Kimabanza and Mudibui Rivers, along the southwestern border shared with the Kasongo-Nyembo Chiefdom (segment CD, Figs. 3a & 3b).

Using the 1984 LANDSAT TM data, my own field investigation records on land ownership among people from both sides along the Chiefdom border, GPS measurements at some strategic locations, the GIS analysis (Fig. 4) produced a fine and complete drawing of the territorial boundaries around the Chiefdom, especially over the controversial northwestern (segment AB) and southwestern (segment CD) parts. This achievement provides the decision makers with a sound basis for an eventual solution to this controversial and long-pending problem of border definitions on the provincial and the local levels.

The new "official" Kayamba Chiefdom polygon (Fig. 5) is a complete and precisely georeferenced digital image of the Chiefdom, as compared to its approximate 1961 hardcopy version (Fig. 2). For the first time ever, the exact location of every single point of the Chiefdom, together with many other

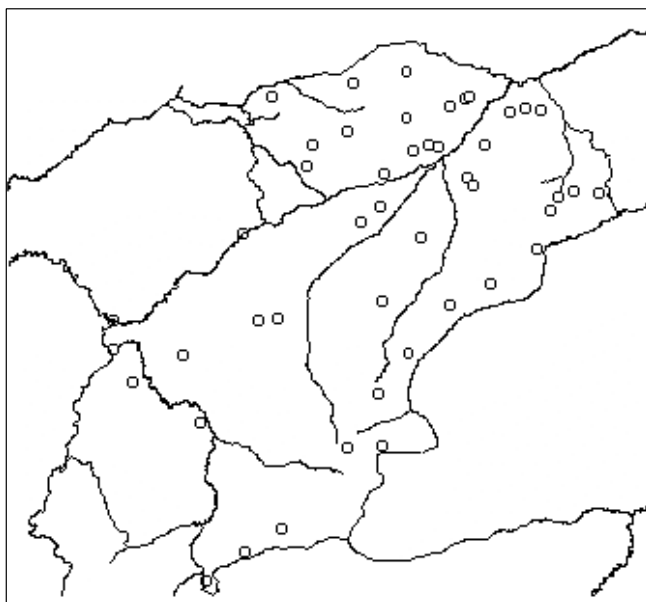


Fig. 5. Precise Official Territorial Boundaries of the Kayamba Chiefdom, as Defined by the Bounding Rivers and the 7 Non-River Segments. Open circles mark the position of each village, as obtained by visual identification from the LANDSAT/TM composite image or from our GPS measurements.

Table 2. The Non-River Segments of the Territorial Border of the Kayamba Chiefdom.

NRS#	LOCATION	LENGTH (km)
NRS1	Lubimbi-Kibindabinda Rivers (near Kateo)	1.0
NRS2	Lowa (II)-Kanyange Rivers (near Beshinka)	0.5
NRS3	Kamitondo-Kabonzoyi Rivers (near Kamitondo)	3.0
NRS4	Kimabanza-Lufwishi Rivers (near Kya-Numbi)	1.5
NRS5	Lwembayi-Mudibui Rivers (Yamba)	0.3
NRS6	Yumba (?) -Katongo Rivers (near Yumba)	0.3
NRS7	Katongo-Lubimbi Rivers (artificial) (near Tanka)	3.0
TOTAL		9.6

important geographical metrics, such as the Chiefdom's total area (3,127.30 km²), its total perimeter (409 km), its population density (9.6 inh/km²), etc., were quantitatively obtained.

It is interesting to note here that no more than 10 km of its borders (< 3%) from the total perimeter consists of non-river segments (NRS1-7 in Table 2). The short and straight demarcation lines joining boundary rivers heads at 6 of the 7 locations are traditional borders, while the 3 km line along the divide between the Lubimbi River and its main left bank tributary in the northwest corner of the Chiefdom, is an artificial boundary set by the colonial rule.

III. Village Dynamics

Traditionally, the Kayamba Chiefdom consisted of 33 main villages. However, due to the population increase, transmigrations, the splitting of former villages, as well as the creation of new communities, the total number of villages has recently grown up to 45, with a total population of about 30,000 inhabitants. These include Kibwe, the invading village whose entire population comes from the neighboring Lubinda Sector, across the northwestern border. Recent population census data for each village is not yet available. I found that village populations ranged from about 200 to 3,500 inhabitants. Kamayi, the head village at the heart of the Chiefdom territory, has about 3,500 inhabitants.

Most of the villages consist of one or several clans (more than four in average), each one a group of direct descendents from a common ancestor along paternal lines. Each clan possesses its own traditional lands (*clanic lands*), 'spiritually managed' (and not owned!) by the clan patriarch (the oldest male member). Each village territory encompasses the total lands owned by every one of its clans, as well as the broad *common lands* under the direct authority of the village chief, elected for a 6-year term by the village people (Sanga-Ngoie, 1993, 1996). However, many villages in the sparsely populated southern part of the Chiefdom are mono-clanic. They are the present-day final products of multiple and successive splittings of initially multi-clanic villages over time. Their populations seldom exceed 200 persons.

Although most of the initial 33 villages are shown on the 1961 map (Fig. 2), their geographical locations are, at most, only approximate, especially over the

Table 3. Villages Location, Area and Altitude in the Kayamba Chiefdom.

No	Village Name	Longitude (°)	Latitude (°)	Altitude (m)	Area (km ²)
1	Kateo	24.97	-6.66	923	91.96
2	Kibwe	25.04	-6.65	840	24.73
3	Mwala	25.12	-6.68	765	
4	Nselemamba	25.12	-6.68	760	57.08
5	Kahako	25.10	-6.69	781	31.26
6	Kabamba	25.07	-6.74	791	—
	Kabamba Centre	25.08	-6.74	784	73.82
	Kyanzayi	25.05	-6.74	801	—
	Kilumbu	25.04	-6.70	822	—
7	Kitoha	25.01	-6.77	825	47.02
8	Kisaho	24.97	-6.72	914	80.51
9	Katongo	24.92	-6.74	918	16.19
10	Yumba	24.91	-6.76	924	110.14
11	Tanka	24.87	-6.68	822	38.02
12	Nkoba	25.18	-6.69	759	27.96
13	Mombela	25.19	-6.61	752	—
14	Lowa	25.22	-6.69	749	108.14
15	Kidyanga	25.14	-6.74	776	26.24
16	Kisulo	25.12	-6.78	794	26.65
17	Kalamba	25.13	-6.79	796	86.95
18	Kilamboyi	25.21	-6.87	785	74.01
19	Nsulo-a-Lowa	25.24	-6.81	772	16.63
20	Mwenyi	25.23	-6.82	775	34.24
21	Beshinka	25.26	-6.80	764	14.23
22–23	Kanyange/Katondo	25.29	-6.80	751	31.90
24	Kamayi	25.06	-6.86	833	157.03
25	Ntanda	25.01	-6.82	825	32.60
26	Lwamba-Sakadi	24.98	-6.84	830	143.61
27	Lwamba-Songe	25.01	-6.94	878	142.84
28	Kebale	25.15	-6.92	824	48.98
29	Kafuku	25.10	-6.95	849	67.71
30	Mukaya I	25.04	-7.01	897	50.80
31	Mukaya II	25.00	-7.06	915	112.94
32	Kamitondo	25.01	-7.13	914	41.85
33	Kibila	24.97	-7.13	913	130.12
34	Kabonzoyi	24.88	-7.23	932	77.90
35	Kimabanza	24.83	-7.26	918	35.35
36	Kya-Numbi	24.79	-7.30	920	28.15
37	Mukumbye	24.83	-6.85	806	41.09
38	Mudindwa-Bashiya	24.85	-6.96	842	96.07
39	Kondo	24.88	-6.96	858	30.27
40	Mudindwa-Sampu	24.75	-7.01	867	243.05
41	Kayi-Masango	24.67	-6.97	728	16.87
42	Kayi-Nzaji	24.69	-7.04	769	121.97
43	Kayi-Kahele	24.67	-7.00	731	—
44–45	Yamba/Kabwe-ka-Ntanda	24.78	-7.10	834	490.48

densely populated northern part of the Chiefdom. Moreover, all other cartographic features (village borders, roads, rivers, landmarks) are only poorly provided. From field investigations over this region (Sanga-Ngoie, 1993, 1996), I have shown that local people tend to move their villages to some new sites every 20 to 50 years, where they rebuild them anew in the open savannas, at a walking distance from natural forests. The villages of Mwala and Nselememba, which are located in deep forests, are a unique exception. After some decades of existence, these villages take the shape of an open street-like strip (20-80 m wide) bordered on each side by a narrow band (20-50 m wide) of newly-born forests, in the middle of the vast grasslands. Larger villages can boast up to 5 adjacent strips or more. Using both GPS records and the mid-infra red LANDSAT TM composite image as backdrop, I identified each one of the Chiefdom's 45 villages and digitized their actual positions as points into a new vector layer (Fig. 5, Table 3).

Moreover, in a recent questionnaire using the hardcopy print of the composition map obtained from the river network (Fig. 4) and the village points layers (Fig. 5), I asked local people to delineate on the map their own village territory according to the traditionally accepted borders. This was then digitized into *village polygons* (Fig. 6), from which precise village areas as well as other geographic features were deduced (Table 3).

In general, village number and population density are higher, and their area

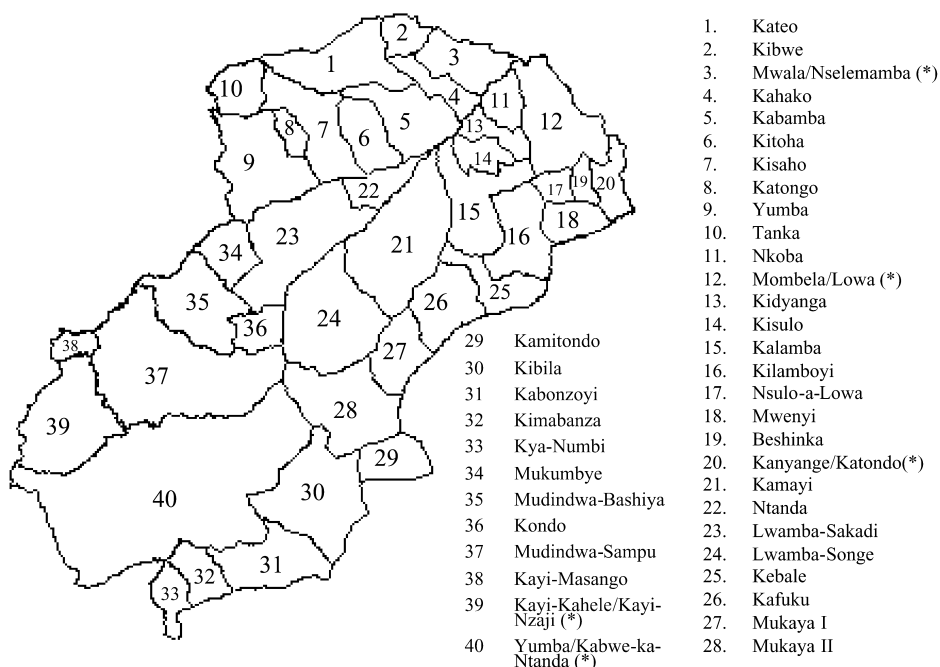


Fig. 6. Kayamba Villages and Their Territorial Borders (Polygons).

Asterisk marks denote those couples of villages sharing the same traditionally defined living space.

smaller, over the northern region than in the south, where huge but sparsely populated entities, such as Yamba village (490 km²), are found. The following dynamics has been detected, as related to the change in the number, the size and the location of villages in the Chiefdom.

1. *Newly created villages (Kibila, Kondo, Nsulo-a-Lowa)*

Kibila and Nsulo-a-Lowa (meaning "*Sources of Lowa*") started almost spontaneously in the 1980s at two strategic crossroads, with population from every part of the Chiefdom. Kondo (30.27 km²) was created as a settlement for road workers along the then newly built road across the empty space between Lwamba-Sakadi and Kibila. None of these three new villages were based on the clanic structure. Nor did they possess any land of their own at the spontaneous creation of the village. They had thus been allocated new lands from the *common lands* of neighboring traditional villages, mostly in a *de facto* manner. Now, Kibila (130.12 km²) and Nsulo-a-Lowa (16.63 km²) have each a permanent market and a school, and their respective populations are increasing rapidly.

2. *Split villages (Kayi-Masango, Kamitondo, Kabonzoyi, Kimabanza, Kya Numbi)*

These are also newly created villages. They consist mostly of some clanic members who split from their original villages to settle into an autonomous new village with clear-cut natural borders, somewhere on their own clanic lands. Kayi-Masango Village, the oldest of the group, is made of clanic folks from Kayi-Nzaji village who settled over the rich agricultural lands of theirs at the confluence (*masango*) of the Lwembe and Lufute Rivers. The same is true for Kamitondo Village (members from the then isolated Mukaya-Lenge Village) and other villagers in Kabonzoyi, Kimabanza and Kya-Numbi, who had left their remote Yamba Village to position themselves along the main artery of the Chiefdom. Considering their strategical positions, I foresee these villages to eventually evolve into some new larger entities, if they could integrate new non-clanic settlers.

3. *Splitting villages*

This group includes those villages that had effectively split into autonomous villages as in the previous case, but for which the territorial boundaries of the new villages are no longer the traditionally accepted rivers or streams, but the dividing lines among the *clanic lands* for people initially belonging to the same village, now living in separated entities, but still within the former territory. These borders cannot, in general, be easily identified on the map or the TM image. Falling into this category are the following village pairs: Kanyange/Katondo (31.90 km²), Kayi-Kahele/Kayi-Nzaji (121.97 km²), Mombela/Lowa (108.14 km²) and Yamba/Kabwekantanda (490.48 km²). Here the first name indicates the original village, and the second name, that of the split one. Yumba (110.14 km²) in the northwestern corner of the Chiefdom seems to be in this splitting process.

Most of the new villages of these pairs are multi-clanic, and village forma-

tion occurred during the colonial time. It is worth noting that, in general, their new locations do not seem to be economically more strategic than earlier ones, but rather following traditional patterns. Extensive field investigation is needed to delineate the new villages territories along the *clanic lands* borders using GPS, and to shed some more light on the reasons behind the split.

4. *Absorption (Mwala-Nselemamba)*

Mwala and Nselemamba are two traditionally autonomous neighboring villages that uniquely share the same location (57.08 km²), with no particular natural boundary between them. After consecutive village relocations over generations, these two neighbors find themselves now so close to each other that any differentiation is hard. An eventual absorption of the small Nselemamba village by the more powerful (with a school and a health center) and highly populated Mwala is foreseen in the near future.

5. *Decentralization (Kabamba)*

Kabamba Village (73.82 km²) consists of 4 mid-size multi-clanic entities (Kabamba, Centre, Kyanzayi and Kilumbu) under the rule of the same village chief and the same village council of elders. Kabamba and Centre are located 1 km apart in the broad *common lands* of the village, with Centre close to the Lubangule River. Kyanzayi is built across the Tungulwe River, 3 km west of Kabamba, on the clanic land of the main clan of this entity. Kilumbu is a new entity created in the 1980s over the village's common lands 8 km north from Kabamba, in order to accommodate a high school with students from all over the Chiefdom.

6. *Relocations*

In general, all the villages in the Chiefdom and the surrounding area undergo periodic relocations to new sites within their own territory every twenty to fifty years. This normally happens as the village becomes old, and near-by resources become scarce due to decreasing land fertility or when the newly-born forest surrounding the village grows so dense as to hamper social life such as gathering, dance and ceremonies within the village (Sanga-Ngoie, 1996).

However, early in the 1960s, most of the larger villages in the northern part of the Chiefdom relocated themselves to new sites, from which they had not moved since. Following this trend late in the 1970s, most of the mid-scale villages in the central part of the Chiefdom underwent significant relocations along the closest main road, sometimes many kilometers away from their initial location. This is the case for the villages of Ntanda and Lwamba-Sakadi (along the Kondo-Kisaho Road), for Lwamba-Songe (along the Kamayi Road), and for Kebale and Mukaya II (relocated to the northern and southern crossings between the Main Road and the Kamayi Road, respectively). Economical imperatives, such as accessibility to main roads, but not the traditional ones, seem to be the main forces behind these deep changes. This trend eventually reached the southern area in the 1980s, and resulted in the splitting of old villages, where

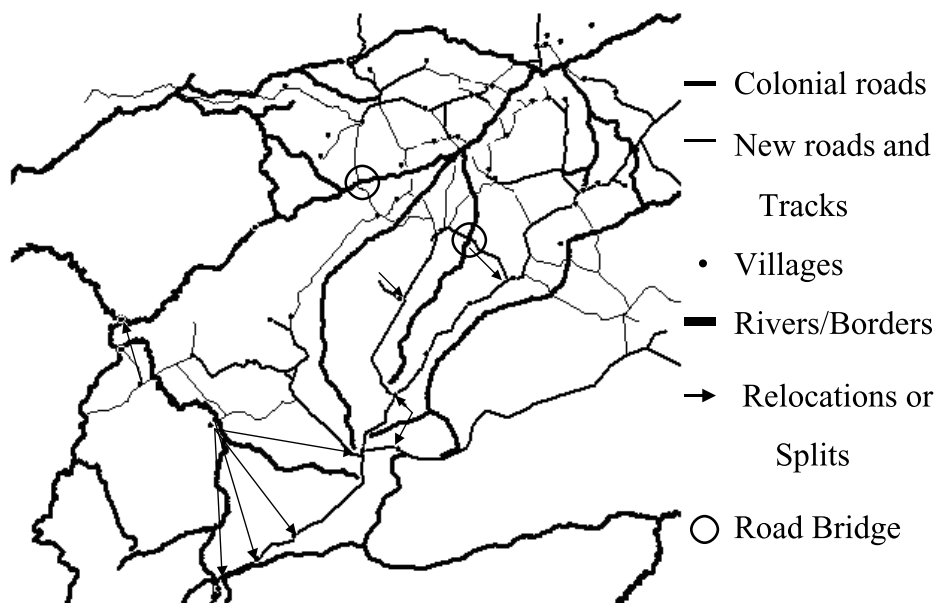


Fig. 7. Map of Roads and Tracks.

Note the lack of bridge between the eastern and the western parts of the Chieftom. The round marks denote the Lungemia River Bridge (sole bridge built during the colonial time) and the Northbound Lufute Bridge (built by the Center for African Resource Development in 1993). Arrows show the direction of new sites for relocations or split villages.

some villagers remained in their isolated location, while other moved to new sites along the main roads (Fig. 7).

IV. Roads and Tracks

Kayamba road network is poor and mostly in a state of total abandon. Notwithstanding, roads are the attraction poles for all the village dynamics (relocations, splittings, new villages) discussed in the previous sub-section. An investigation about their condition all over the Chieftom could help shed some new light concerning strategic old roads to repair, potential sites for new roads or bridge building or eventual village relocation for an integrated development of this area.

Using CARTALINX and the mid-infrared composite of LANDSAT image as backdrop, a precise drawing of the Chieftom road network was digitized into new vector layers (Fig. 7). These include (a) the colonial era roads, (b) the main tracks spanning densely between villages in the north, or those from Mudindwa-Sampu to Yamba/Kabwekantanda and to the 3 Kayi (Kahele, Masango and Nzaji); and (c) the recently created new roads, such as the one from Kondo to Kisaho, through Lwamba-Sakadi; it has a branch to near-by Ntanda and a new bridge built over the South-bound Lufute River.

The colonial roads and main tracks (Figs. 2 & 7) were built before 1960 for

transporting local agricultural products to the consumption centers or processing factories. As a general rule, colonial roads were constructed along catchments or watersheds divides, in order to avoid river crossing and minimize construction and maintenance costs in this area known for its dense river network and its wide marshlands. This often resulted in long roundabout ways, or total absence of roads between neighboring villages when separated by a river or marshlands. The only bridge (and a wooden one) in the Chiefdom was built on the Lungemia River, on the Kamayi-Kebale segment. The only gates into or out of the Chiefdom are through 4 of the 7 non-river segments of its borders (NRS1-4 in Table 2). No part of this road system was paved.

The main road of the Chiefdom (Fig. 7) runs all along the eastern border from the head of Kimabanza River (NRS4) in the southeast to the northern border into Eastern Kasai Province (through NRS2): it is the backbone of the communication network. The east-west main road goes from Mudindwa-Sampu along the Lufwishi/Lufute divide, passes south of the heads of the 3 main rivers (Lubangule, Lungemia, Mwilui) near Kibila, heading to Kabongo far in the east (through NRS3). The Kamayi Road, along the Lungemia/Lubangule divide from the new location of Mukaya II to Kamayi, is another important branch in the Chiefdom. After crossing the Lungemia River over the sole bridge of the Chiefdom built during colonial times, it joins again into the main road at the new location of the Kebale village. The 1961 hardcopy maps (Figs. 2, 3a & 3b) show various trackings of this segment: this road seems to cross 4 different streams on the Kamayi-Kebale section, which is far from its real position as confirmed by the satellite data (Fig. 7). The Kalamba Road runs along the Lweleji River from Nsulo-a-Lowa to Kalamba, with an important branch leading to Mombela and Lowa.

The western side of the Lubangule River, as well as the southern third of the Chiefdom, are underdeveloped, notwithstanding their respective importance in terms of population density and agricultural potentials. Only a short road network, less than 30 km long, from Mwala to Kateo, with branches to Kabamba and Kisaho, links this formerly cotton-rich region (through NRS1) to the processing factories in Kabinda far to the north-west, or to Kalemie, on the shores of Tanganyika Lake. The tracking of this road on the 1961 hardcopy map (Fig. 2), as well as that of some important tracks over this area, is only approximate.

All these roads are unpaved: they provide a good communication network only during the dry season (May-September), turning muddy and unpractical during the rainy season (October-April). Upgrading both their condition and their poor distribution over the Chiefdom is the most important of the major challenges for a sustainable overall development of this area. With no roads in their respective territories, Kitoha (famous for the immense swamps surrounding it), Nkoba and Kidyanga (on Lubangule's right bank), as well as many other villages in the southwest (Yamba/Kabwe-ka-Ntanda, the 3 Kayi), remain non-accessible by car so far.

V. Relief and Landscape

The Global 1-km resolution DEM data (NIMA, 1997) shows that the Kayamba Chiefdom is located at the northernmost tip of one of the protrusions of the southern plateau into the Congo Depression. This dominates all the southern part of the Chiefdom, with its highest points at the source of Lwembayi (1026 m above sea level (ASL)), a tributary of the Lufwishi, and northeast of Kabonzoyi village (990 m ASL). Most of the main rivers of the Chiefdom start from these southern highlands. In general, the landscape is characterized by a smooth slope from the high plateau toward the northeast along the Lubangule/Mwilui Rivers catchments, and an abrupt descent to the west toward the Lwembe River valley, down at 724 m ASL near Kayi-Masango (Fig. 8).

Another small-scale high plateau (> 920 m ASL) dominates the northwestern corner of the Chiefdom between Kateo and Yumba, where the sources of Kibindabinda, Lubimbi and that of its main tributaries, are located. The slope here is the steepest toward the Southbound Lufute Valley that separates this northern high plateau from the main one in the south.

The lowest altitudes of the Chiefdom are observed at the Lubangule-Lowa confluence in the northeast (732 m ASL), and the Lwembe-Lufwishi confluence (724 m ASL) in the southwest, both located in the last reaches of the Congo River's depression. At 932 m of altitude, Kabonzoyi, in the south, is the high-

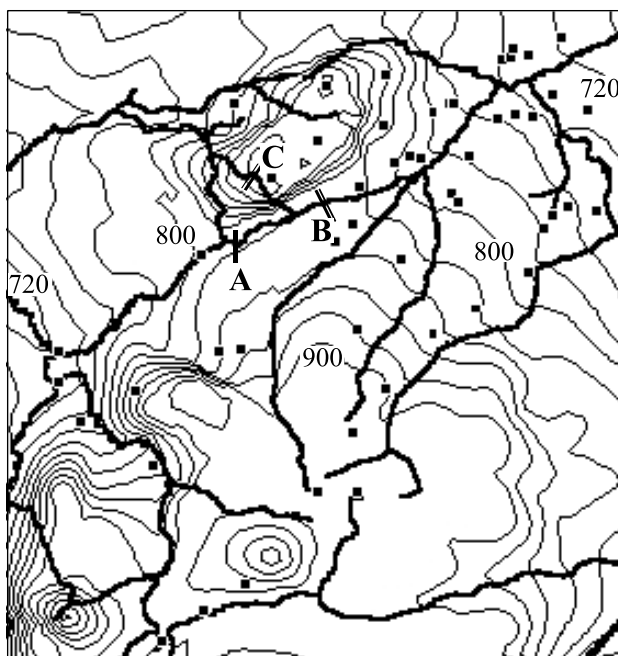


Fig. 8. Contour Lines (20 m) of the Chiefdom's Relief Map Based on the DEM Data. Letters A, B and C refer to points discussed in Fig. 9.

est village of the Chiefdom, and Lowa (749 m ASL) and Kayi-Masango (728 m ASL) the two lowest ones. Tanka (822 m ASL) is the lowest point in the north-west region. A total of 10 villages are located at more than 900 m of altitude: 4 over the northwest plateau (Kateo, Kisaho, Katongo, Yumba) and 6 others (Mukaya II, Kibila, Kamitondo, Kabonzoyi, Kimabanza and Kya-Numbi) in the south along the main road. Most of the remaining villages are located over the flat and lower lands over the northeastern quarter between 750 and 900 m above sea level (Table 3).

VI. Hydrographic Features

It has been shown in subsection I that Kayamba Chiefdom is very well drained by a dense river network (Fig. 4), that can be divided into two main drainage basins, each one having a typical relief signature. The 25°00'E meridian is roughly the east-west divide.

On the eastern part of the Chiefdom, the eastbound Kimabanza River, the northeast-bound Mwilui and Lubangule Rivers as well as their tributaries, are parts of the north-flowing Lomami River basin. All together, these rivers lazily flow across the broad plateau 750-920 m high, featuring broad valleys (most of them marshlands) and long tributaries pouring into the main streams at almost right angles and regular distances (Fig. 4).

The western portion of the Chiefdom is part of the Lwembe River basin. It is drained by a multitude of meandering streams and rivulets flowing from the western limits of the high plateau to discharge into the Lwembe River in the southwest. Here, the landscape consists of steep and strongly eroded slopes, with fast-flowing and tortuous streams running within narrow and deep valleys. Headwaters from the main rivers such as Lubimbi and Lufwishi are broad fans tens of kilometers-wide (Fig. 8). Natural hazards such as flash floods, erosion and landslides, almost unknown in the eastern part, are frequent.

Of significant geographical and hydrographical interest is the *capture* phenomenon. This landscape phenomenon happens when gully erosion over the head region of a stream pushes the stream source point back uphill to the point that it catches and deflects into its own course the headwaters of another stream initially flowing on the opposite side of the divide line. Captures are frequently present between high plateau rivers and stream headwaters over the eroded slopes, making drainage basin demarcation rather complex. The case of the Lufute River is worth noting. From the vast marshlands located west of Ntanda and Lwamba-Sakadi villages at 826 m of altitude, flow two rivers in opposite directions, each called *Lufute River*: one flows towards the Lubangule River in the northeast, which I call here the *Northbound Lufute River*, and the other one to the Lwembe River in the southwest, the *Southbound Lufute River* (Fig. 9).

Capture occurred across the western escarpment between the plateau and the western lowlands, deflecting into the Lwembe River the original Lufute River (or one of its minor tributaries), which initially flowed northeastward to the Lubangule River. Although it can be supposed that this phenomenon initially

happened at point A, the current water flow in this complex river network (see flow directions as indicated by arrows in the figure) indicates the intra-valley divide at location B (Fig. 9), owing more likely to northeastward advancing erosion in geological times. The same phenomenon is also detected for a number of small tributaries over the complex landscape drained by the Southbound

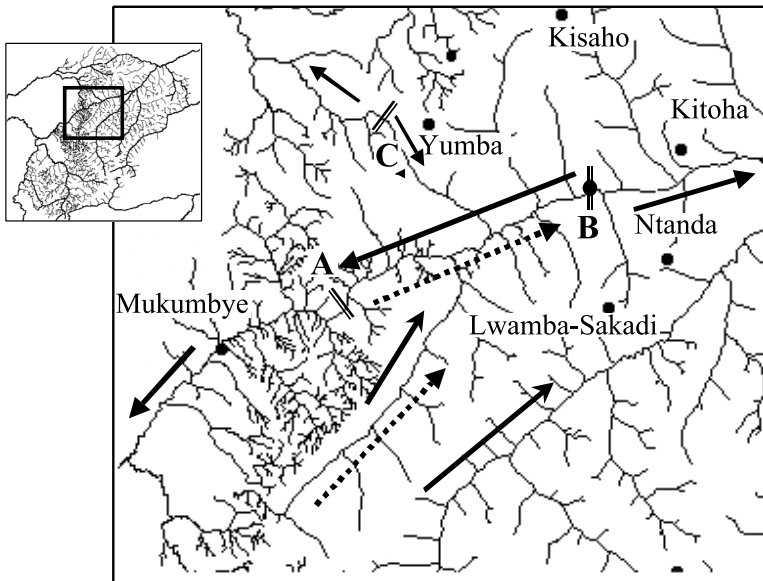


Fig. 9. Capture Phenomenon in the Lufute River Valley. Location A is the place where the capture eventually took place, deflecting Lubangule River Basin water into the Lwembe River Basin. Then, with advancing erosion, this intra-valley divide point was progressively pushed to its actual position in point B. Dotted arrows indicate the pre-capture flow between points A and B, while solid arrows show the actual river course over this complex area.

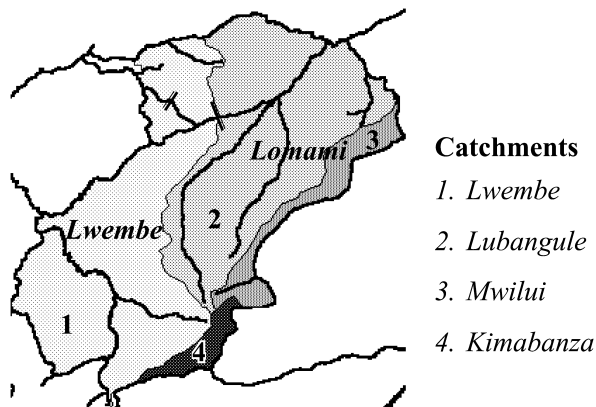


Fig. 10. Kayamba Chiefdom's Two Main Drainage Basins (Lomami and Lwembe) Subdivided into Four Main Catchments (Lwembe, Lubangule, Mwilui and Kimabanza).

Table 4. Hydrographic Metrics of the Main Drainage Basins in the Kayamba Chiefdom.

Drainage Basins (km ²)		Catchments (km ²)		Main Rivers
1. Lwembe	(1,455.12)	1. Lwembe	(1,455.12)	Lwembe, Southbound-Lufute, Lufwishi, Lubimbi, Mudibui, Lwembayi
2. Lomami	(1,672.18)	2. Lubangule	(1,324.88)	Lubangule, Lungemia, Kibindabinda, Lowa, Northbound-Lufute
		3. Mwilui	(243.79)	Mwilui
		4. Kimabanza	(103.50)	Kimabanza

Lufute and Lubimbi Rivers over the northwestern area (e.g., in location C, Fig. 9).

Having thus set the demarcation point between the two drainage basins (Fig. 10), their respective areal cover were calculated, giving 1,455.12 km² for the Lwembe basin and 1,672.18 km² for the Lomami basin. Furthermore, these basins can be divided into four main catchments, along the following main rivers (Fig. 10; Table 4):

(i) *The Lwembe River catchment* (1,455.12 km²) covering most of the southern plateau, together with all the western slopes and lowlands. Its main tributaries, all on the right bank, are the Mudibui (18.40 km), the Lwembayi (15.88 km long; source at 1,026 m) and the Lufwishi (68.88 km) Rivers in the south, the Southbound Lufute (59.94 km) in the center, and the Lubimbi (source at 909 m) over the northwest.

(ii) *The Lubangule River catchment* (1,324.88 km²), draining the largest portion over the central and the northern parts of the Chiefdom, from the Lubangule River (104.82 km long, of which 78.69 km in Kayamba) source near Kibila (913 m) to its confluence with Lowa River at altitude 732 m. Its main tributaries within Kayamba are the Lungemia (39.42 km long; source at 916 m) and the Lowa (19.58 km) on the right bank, and the Northbound Lufute (10.12 km) and the Kibindabinda (31.82 km long; source at 922 m) on the left bank.

(iii) *The Mwilui River catchment* (243.79 km²) along the eastern border. The Mwilui River (88.23 km long, of which 62.10 km in Kayamba; source at 914 m) has no major tributary on its left bank (Kayamba side).

(iv) *The Kimabanza River catchment* (103.51 km²) in the southeastern strip. It consists of the Kimabanza River (70.76 km long, of which 21.98 km in Kayamba) and the Kabonzoyi River (16.01 km), its main tributary on the left bank.

DISCUSSION AND COMCLUDING REMARKS

In this paper, the potential of using high-resolution satellite data on a GIS platform for low-cost mapping and digital cartographic database building over remote areas in Africa has been shown. A concurrent digital map of the Kayamba Chiefdom, on which a set of base and derived digital features layers can be freely overlaid as shown in Figure 11, shows quite an improvement as compared to the vector layers (Figs. 3a & 3b) digitized from scanned and

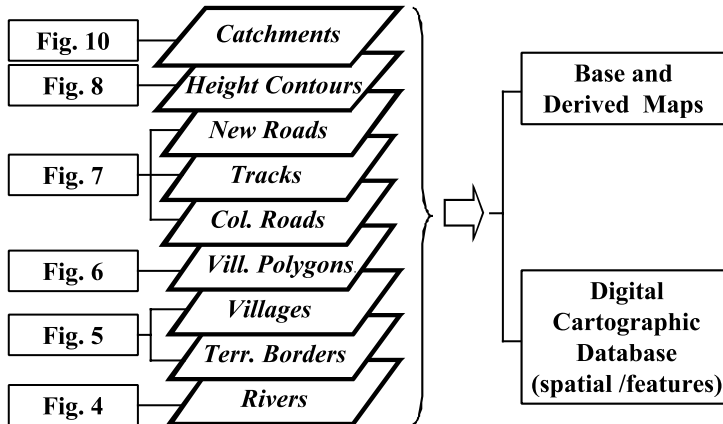


Fig. 11. A Summary of the Analysis and Its Main Results: A Set of Digital Layer Maps and a Digital Cartographic Database for the Kayamba Chiefdom.

georeferenced hardcopy maps on the provincial and the territory levels, respectively (Institut Géographique de Congo, 1961).

Further field investigation using GPS is still needed, however, to define more precisely the detailed territorial boundaries between the pairs of villages located within the same traditionally defined village space (Katongo/Kanyange, Kayi-Kahele/Kayi-Nzaji, Mwala/Nselemamba, Mombela/Lowa, Yamba/ Kabweka-Ntanda). The same investigation is also needed to impartially set the borders over those places where questionnaire respondents showed some discrepancy in boundary location, especially over some remote and hard-to-reach areas between Yumba and Tanka, and between Kondo and Mudindwa-Bashiya).

Some important village dynamics became apparent, providing thus useful elements for integrated rural development planning and environmental management with the participation of local population over the Chiefdom. First of all, periodical relocations of villages tend to occur every 20 to 50 years within their own traditional territories upon general agreement. Among other reasons, this likely occurs in response to the gradual depletion of available resources within walking distances from the village, or the aging of the newly-born forest within and around the village.

In this perspective, recent relocations after a village split can be seen as a reactionary process of village members to move to an economically more viable place (new road, crossroad, river proximity) notwithstanding the traditional inertial attitude of the majority who do not feel the need for moving. This is mostly observed in the southern part of the Chiefdom, where former villages were traditionally located close to big rivers, and far away from the main road network.

The recent moves occur for non-traditional causes: they are deeply rooted in an indigenous trend of modernization initiated in the 1960s, and which really needs encouragement and support from both the government and the international community. In fact, since the late 1960s, many villages, especially the

larger ones in the north (Kamayi, Mwala, Kahako, Kabamba, Mombela, Lowa, Kalamba), relocated to strategic locations and had remained there since. Schools, shops, health centers or other public facilities are built in these new locations, strengthening the stability of these villages. For these villages, the importance of roads as attraction poles for relocation has to be highlighted, and the need for an economically viable road network for a sound and integrated development of the Chiefdom has to be stressed.

Many mid-scale villages in the central part of the Chiefdom (Lwamba-Songe, Lwamba-Sakadi, Mukaya II, Ntanda, Kebale, etc.) embodied this trend, relocating near the main arteries (old or newly built) since the late 1970s. This village dynamics eventually reached the remote southern highlands late in the 1980s when some villages were newly founded (Kibila, Kondo) as well as old villages split into new settlements along, or near, the outlets of the main north-south (Kabonzoyi, Kimabanza, Kya-Numbi from Yamba) or east-west (Kamitondo from Mukaya-II) roads. In general, the traditional custom of periodical village relocation is being abandoned all over the Chiefdom, as more villagers opt for permanent location at economically strategic new sites.

Further eco-climatic and ethno-ecological analysis on land use and land cover, as well as an exploration of future sustainable development perspectives in terms of land management, infrastructure and communication network building, zoning for conservation of the nature, etc., will be reported in a separate paper (Sanga-Ngoie, in preparation). Any endogenous and integrated development for this area has to incorporate the complex dynamics for the best use of the local resources (human and natural), taking in consideration the local features (soil, water, relief, land use, land cover, infrastructure, etc.) in reference to the diversified digital cartographic database (base and derived maps or their future updates) presented in this paper.

ACKNOWLEDGEMENTS This work has been financed by the Grant-in-Aid (No. 11480132), Ministry of Education, Science and Technology, Government of Japan. Heartfelt gratitude to Prof. K. Fukuyama and to the members of the GIS and Ecoclimate Seminar for fruitful comments. Thanks to Ms. Y. Yomogita for digitizing from the IGC 1961 maps. Field investigations have been supported by the CARD (Center for African Resources Development) as part of its rural development program in Africa, the SAVE AFRIKA PROJECT.

REFERENCES

- Bonan, G.B. 1995. Land-atmosphere interactions for climate system models: Coupling biophysical, biogeochemical, and ecosystem dynamical processes. *Remote Sensing of Environment*, 51: 57-73.
- Charlier, J. 1998. *Atlas du Congo*, Africa Editions, Kinshasa, D. R. of Congo.
- Cohen, W.B., M. Florella, J. Gray, E. Helmer & K. Anderson 1998. An efficient and accurate method for mapping forest clear cuts in the Pacific Northwest using Landsat imagery. *Photogrammetric Engineering & Remote Sensing*, 64(4): 293-300.

- Dobson, M.C., F.T. Ulaby & L.E. Pierce 1995. Land-cover classification and estimation of terrain attributes using Synthetic Aperture Radar. *Remote Sensing of Environment*, 51: 199-214.
- Eastman, J.R. 2001. *IDRISI32 Release 2: Guide to GIS and Image Processing, Volume 1*. Idrisi Production, Worcester.
- Hill, J. & W. Mehl 1995. Improved forest mapping by combining corrections of atmospheric and topographic effects in Landsat TM imagery. In (J. Askne, ed.) *Sensors and Environmental Applications of Remote Sensing*, pp. 143-151. Balkema, Rotterdam, The Netherlands.
- Institut Géographique du Congo 1961. *Carte géographique du Congo*, IGC, Léopoldville, D. R. of Congo.
- Kostak, R. & W. Kramer 1995. Maps and remote sensing in mountainous areas of Third World countries: Example of the upper Mustang district in Nepal. In (J. Askne, ed.) *Sensors and Environmental Applications of Remote Sensing*, pp. 155-162. Balkema, Rotterdam, The Netherlands.
- NIMA 1997. *Global Land One-km Base Elevation (GLOBE) Ver 0.5, Vol. 3*. National Geophysical Data Center, Boulder. CDROM.
- Nonomura, A., Sanga-Ngoie K. & K. Fukuyama 2003. Devising a new digital vegetation model for eco-climatic analysis in Africa using GIS and NOAA/AVHRR data. *International Journal of Remote Sensing*, in press.
- Sanga-Ngoie K. 1993. A new approach to the coexistence of man and the nature: Learning from the traditional life expertise of the rural African (in Japanese, with English Abstract). *Journal of Arid Land Studies*, 3: 35-49.
- 1996. *Our Planet and Sustainable Human Development: Learning from our Mismanagement of the Tropical Rainforests?* Lecture notes, UNU (United Nation University) Global Seminar, Kobe Session, October, 1996. Kobe, Japan.
- Taylor, L.J. 2001. *Facing the Congo*. Little, Brown and Company, London, U.K.

——— Accepted May 1, 2003

Author's Name and Address: SANGA-NGOIE KAZADI, *Laboratory of Climate and Ecosystems Dynamics, Faculty of Bioresources, Mie University, TSU 514-8507, JAPAN.*
E-mail: sanga@bio.mie-u.ac.jp