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West Africa Long Term Perspective Study (WALTPS): Database and User's Guide

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FURTHER INFORMATION

The principal WALTPS publications are given in the References. For further information about the WALTPS database, please contact:

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ACRONYMS

ADB	African Development Bank (Abidjan, Côte d'Ivoire)
CAR	Central African Republic
CNTIG	National Committee on Remote Sensing and Geographic Information (Abidjan, Côte d'Ivoire)
DCW	Digital Chart of the World (U.S. Defense Mapping Agency)
EDC	USGS/EROS Data Center (Sioux Falls, SD)
ESRI	Environmental Systems Research Institute, Inc. (Redlands, CA)
FAO	Food and Agricultural Organization of the United Nations (Rome)
FEWS	Famine Early Warning Systems (USAID/EDC)
GIS	Geographic Information System
NCGIA	National Center for Geographic Information and Analysis (Santa Barbara, CA)
OECD	Organization for Economic Cooperation and Development (Paris)
USAID	U.S. Agency for International Development
WALTPS	West Africa Long Term Perspective Study (OECD/Club du Sahel/ADB)
WRI	World Resources Institute (Washington, D.C.)

1. INTRODUCTION

The use of Geographic Information Systems (GIS) in development planning has grown rapidly over the last twenty years.

Advances in technology have contributed to a sharp increase in the supply of geographic information (satellite images, etc.) and have also led to an increase in the demand for geographic information as new hardware and software tools have made access to, and analysis of, this information possible at a low cost. It was previously necessary to manually create a new map for every new theme combination, caption edit, or format modification. These tasks can now be accomplished in a few seconds.

GIS software allows increasingly complex querying and analysis: what are the areas located within 10 km of a paved road or a community clinic? Which fraction of the population lives in these areas? What is the average rate of economic activity or disease prevalence within these populations compared to others?

However, the success of GIS does not depend upon geographic information or software alone. Data are not produced or analyzed without defined objectives. The success of GIS has more to do with the fact that geographic information is an important component of development planning for at least three reasons:

1. Regions are characterized by sharp differences in soils, climate, population pressure, agricultural systems, and physical infrastructure. The location and nature of development projects depend fundamentally on these characteristics. Differences in the physical and economic environments result in a geography of needs - and potential failures - that must be assessed.

2 Economic activity within developing countries is strongly influenced by transport costs to and from markets (both urban and international) of energy, agricultural products, agricultural inputs, and consumer goods. Transport costs are an important factor in determining which location is appropriate for which kind of activity (especially in the case of agricultural or road projects). These costs are in turn a function of two spatial parameters: distance and the nature of the transport networks (roads, rivers, etc.).

3. Development planning implies making choices about the distribution of national resources, public services, opportunities for economic development, even the distribution of the population. Should funds from developing countries and donors be evenly distributed throughout the country? Or on the basis of population? Or should investments be limited to areas where preconditions favor economic development? Or should funds be targeted at areas that could develop rapidly once certain facilities are in place? Should people remain in place at all costs to avoid the unrest associated with large scale migration? Or, on the contrary, should migration be encouraged to facilitate structural changes or a more equitable population distribution?

GIS will never provide the answer to these questions, if only because the choices are necessarily political in nature. Nevertheless, GIS has become one of the main tools available to decision makers as they formulate social and economic policy. A good understanding of the current and future socioeconomic geography is a prerequisite for any well informed planning activity or development intervention.

The use of GIS to help us better understand the behavior of the actors in economic development will grow. In many cases, the success of a particular project ultimately depends upon how its potential beneficiaries take advantage of the intervention. If financial and human resources are limited, it becomes necessary to assess the benefits expected from each project as accurately as possible and to identify those projects that offer the greatest potential benefits. We therefore need a tool to help us measure and map "average" human behavior to answer the question: will the intended beneficiaries actually benefit from the project and, if so, by how much? The standard economic approach looks at temporal changes in the physical and economic environments and then compares these changes with observed changes in human behavior. Unfortunately, the time series data required by such analyses are rare and/or the magnitude of the observed changes is smaller than the inherent variability in the observed data. GIS offers an alternative approach: spatial changes in the physical and economic environments within which a population is active are measured and compared with deviations from the average behavior observed for populations located elsewhere in the region of interest.

Experience has shown that human behavior and environmental conditions vary more over space than over time. Furthermore, these variations are typically much larger than the measurement error (which may be high for spatial data). This approach allows us to better assess the effects of development projects, especially in rural areas.

GIS is becoming increasingly easy to use and inexpensive to implement.

However, we first need the geographic information.

This is why the Club du Sahel of the Organization of Economic Cooperation and Development (OECD) and the World Resources Institute (WRI) decided to collaborate to develop and publish data collected by study of the long term ecomonic trends in nineteen West African countries: Benin, Burkina, Cameroon, Cape Verde, Central African Republic (CAR), Chad, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

2. WALTPS DATABASE

A. Goals of the WALTPS

In 1992-94, the Club du Sahel and the African Development Bank (ADB) conducted a long term assessment of the economic geography of West Africa. This study, the West Africa Long Term Perspectives Study (WALTPS), was funded by the European Union with support from the ADB, World Bank, and Belgium, Canada, United States, France and the Netherlands. The goal of the study was to project an image of West Africa to the year 2020, focusing on the long term effects of population growth and potential migration (especially rural-urban migration but also rural-rural migration both within and between countries). Appendix A of this document describes one of the many analyses carried out under the study.

One component of the study dealt with the economic geography of rural West Africa. One of its main goals was to try to answer the following questions:

* Where will the rural population be located in 2020?
* How will agricultural production vary geographically in 2020?
* How will the transport infrastructure in rural areas change between now and 2020?

Any predictive analysis requires an examination of past and present conditions. The WALTPS database was therefore built to help determine the key parameters that influence rural population density, agricultural production, and expansion of the road network across West Africa.

The WALTPS database is not the result of a database development project. It is rather a by-product of the study, developed to answer a few specific questions. It does not pretend to be exhaustive. Three constraints limited the quantity and quality of the data collected:

* The database had to be internationally-comparable with the same level of detail, same definitions, and same coverage for all nineteen countries.
* Any analysis requires a simplification of reality. In particular, it was necessary to limit the number of parameters to those that were considered a priori as most explanatory, and thus limit the number of parameters to be sampled.
* Due to time and resource limitations, it was not possible to develop a larger database: collecting the data presented here was already a large endeavor.

A database, however, is not static. It should be possible to extend and update the database with new information in

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response to future needs. The WALTPS database architecture is flexible and allows for developments in many directions.

B. Content of the WALTPS Database

The WALTPS database contains information on:

* *Demography:* estimates of rural, urban and total population for 2017 administrative units for 1960, 1970, 1980, and 1990.
* *Agriculture:* estimates of the area under cultivation and production of about 20 agricultural products for 428 agricultural census units for 1990.
* *Transportation infrastructures:* the primary, secondary, and main tertiary road networks for 1960, 1968, 1978, 1984, and 1989.
* *Towns:* actual or estimated location of the main town or towns within each administrative unit. This information is considered more accurate than the incomplete urban population information from censuses because it locates towns within their respective administrative units.
* *Market tension:* a theoretical indicator of the economic "pull" exerted by both urban and international markets over the rural hinterland. This indicator was designed to help us better analyze the effects of the economic and physical environments on rural population density, total agricultural production, and agricultural production per farmer for the years 1960 and 1990. This indicator gives a theoretical estimate at each location within an imaginary grid of the economic incentive for rural population to produce and market an agricultural surplus. The biophysical opportunities to produce a surplus ("soil fertility") can be combined with other variables to measure the incentive for farmers to produce more than subsistence demands.

The following chapters describe the methods used to develop each theme. Attribute definitions for each theme are given in Appendix B.

3. DEMOGRAPHIC DATA

A. Total Population per Administrative Unit

These data were primarily compiled from census and survey documents. These documents provided the total population for units at the third (or in some cases second) administrative level for each country. The national boundary is considered level zero. The main data sources are given in Appendix C.

Censuses and surveys were performed on different dates. Our estimates of total population per administrative unit are given for the reference years 1960, 1970, 1980, and 1990 (June 30) in thousands of inhabitants. Standardized estimates were derived by extrapolating or interpolating census data using the average inter-census growth rates for each unit.

When the administrative units used at the last census did not match those used at previous censuses, the smallest administrative units common to all censuses were identified. Population growth rates for these common units were used to derive inter-census rates for the other units.

Nigeria presents a special case. The 1952 census only recognized 320 administrative units, almost half the number of the 1991 census. Furthermore, some of these administrative boundaries had changed between the two dates. Only about 200 administrative units are common to both censuses. Other countries where this approach was applied are Burkina, Guinea Bissau, Liberia, and Mali.

Inter-census growth rates were applied to the rural population of each administrative unit, but not to the urban population which was estimated using additional data. Uncertainties in urban population growth remain the main cause of discrepancies in total population growth between neighboring administrative units. Calculation of the urban growth rates takes into account the fact that a fraction of the rural population may "disappear" between two censuses due to the development of new towns. Urban growth rate calculation required three steps:

1. Growth rate of the "corrected" rural population is calculated for the smallest units common to two censuses. The "corrected" rural population is the actual rural population for the older census. For the more recent census, it is the rural population plus the population that has become urbanized during the inter-census period.

2. This growth rate is applied to the rural population of each administrative unit to perform a backward extrapolation.

3. Once the rural population has been determined for the older census, populations that were not urban at that time and became urban during the inter-census period are added to it.

Some national census data have deliberately been eliminated. Again, Nigeria presents the extreme case where only the 1952 and 1991 censuses were used as all the others were considered highly misleading.

For some countries, the extrapolated population estimates were checked with the counts from the last census to ensure consistency. The lastest census figures sometimes exceeded by several millions the extrapolated figures. There are only two possible explanations of this difference. Either earlier censuses underestimated the total population for several countries, or migrants were counted in both the source and destination countries (as was shown to be the case in Burkina, Mali, and Niger).

B. Urban and Rural Population Estimates

Towns can be defined in numerous ways. For the sake of convenience, and because it provides a homogenous criterion throughout the region, the WALTPS defines a town as any settlement larger than 5,000 inhabitants.

Town populations are usually given by censuses, or estimated by the national statistical services. The rural population of an administrative unit is thus equal to the difference between the total population and urban population. However, additional processing steps were also needed.

First, where town size is not taken directly from the census, rural population estimates equal to the difference between the total and urban populations are sometimes obviously incorrect (e.g., high population density where it is known to be low, low population density where it is known to be high). In these cases, it was necessary to calculate a more reliable estimate of the urban population. This was done by first estimating rural population density for the unit in question as the average rural population density within neighboring units with low levels of urbanization. The rural population is then obtained by multiplying the mean density by the total area of the administrative unit. "Adjusted" urban population is equal to the difference between total and rural populations.

Second, not all the countries within the study used the same definition of a town. As a result, there was sometimes a lack of information about the size of small towns (especially those with 5,000-10,000 inhabitants). In these cases it was necessary to plot "urban distribution tails" for each country to estimate the size of towns that were too small to appear in the national statistics. These estimates were helped by the existence of a relatively stable relationship, through time and space, between a town's rank and its size. This rank-size relationship was calculated for each country to estimate the number and size of towns that were too small to be recorded. The tails of the rank-size curves were extrapolated to estimate the number of towns larger than 5,000.

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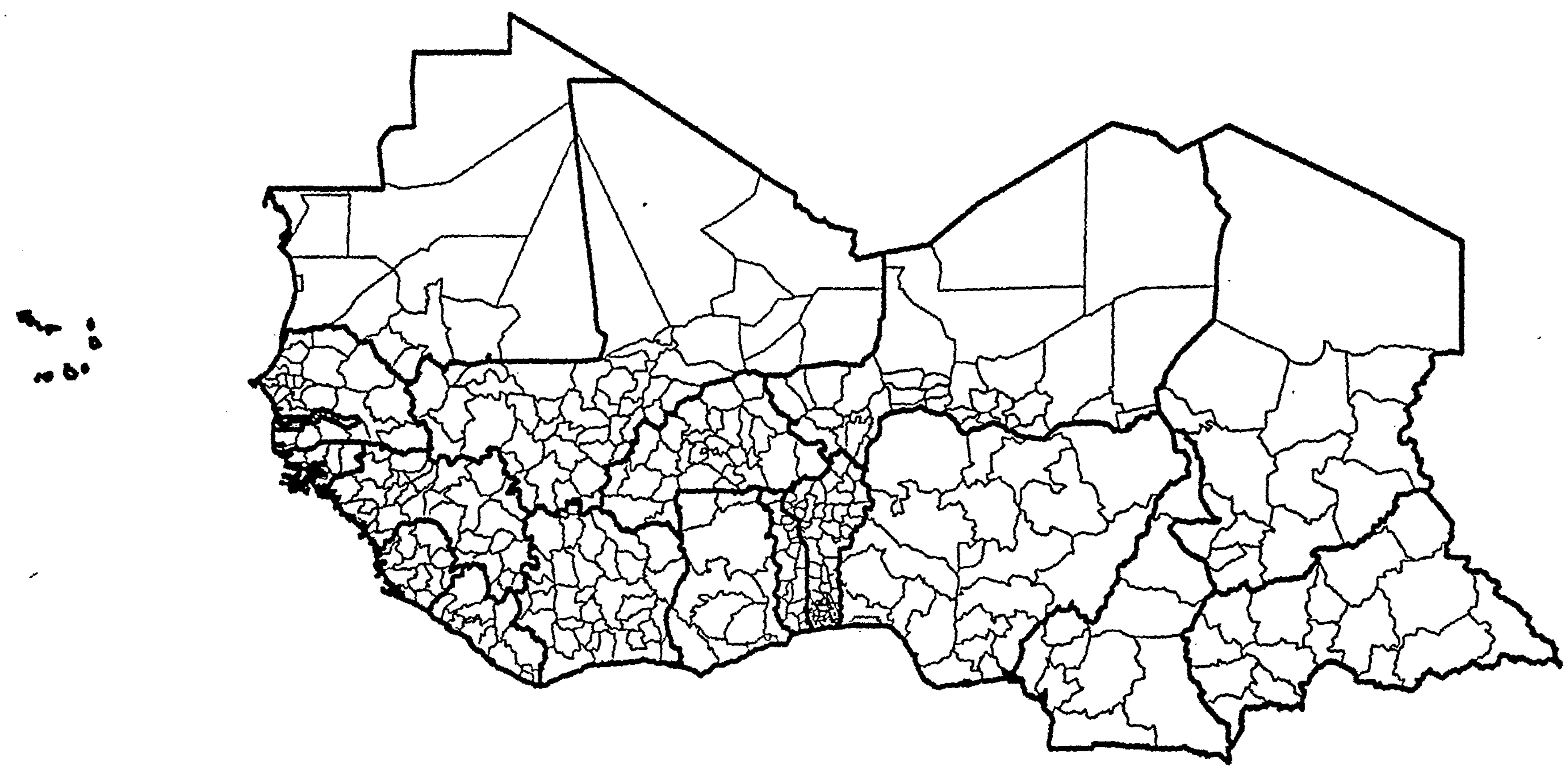
Country	A	B	C	D	E	F	G	H	I	J	K
Benin	5,409	112.6	70.2	38.2	6	77	76	'79,'92	'79(2)	'79(2)	
Burkina	10,319	274.1	34.3	30.2	30	301	30	'75,'85	'75,'85(1)	'75,'85(1)	
Cameroun	13,233	475.5	270.1	98.5	10	49	10	'76,'87	'87(2)	'87(2)	'87(2)
Cape Verde	392	4	43.6	21.2	9	0	0	'80,'90	'40-'90(1)	'80,'90(1)	
CAR	3,315	625	65	110.7	17	51	16	'75,'88	'75,'88(2)	'88(1)	'75'88(2)
Chad	6,361	1,284	454.4	302.8	14	14	14	'93			
Côte d'Ivoire	14,253	322.5	77	41.7	50	185	34	'75,'88	'88(2)	'88(2)	
Gambia	1,118	10.7	30.2	17	6	37	6	'83,'93	'83,'93(2)	'83,'93(2)	
Ghana	17,453	238.3	123.8	41.1	10	141	10	'84,'94	'70,'84(2)	'84(2)	
Guinea	6,700	245.9	203	86.3	7	33	33	'83,'94			
Guinea Bissau	1,073	36.1	29	31.2	9	37	8	'79,'91			
Liberia	3,039	99.1	56.3	42.8	14	54	13	'84,'94*	'74(2)	'74(2)	
Mali	10,795	1,240.1	39.7	67.5	46	272	46	'76,'87			
Mauritania	2,274	1,030.7	51.7	153.1	13	44	13	'77,'88			
Niger	9,151	1,186.4	261.5	184.1	7	35	35	'77,'88	'77,'88(2)	'77,'88(2)	
Nigeria	111,721	923.9	207.7	41.4	31	538	22	'91	'91(1)	'91(1)	
Senegal	8,312	196.7	89.4	46	30	93	28	'76,'88			
Sierra Leone	4,509	72.3	322.1	71.9	4	14	13	'85	'63,'74,'85(2)	'63,'74,'85(2)	
Togo	4,138	56.8	197	52	5	21	21	'81,'93*			
TOTAL	233,565	8,434.7	138.2	77.8	318	2,034	428				

Figure 1. Agricultural Census Units



Sources: Club du Sahel/WALTPS, NCGIA/FAO, USGS/EDC, CNTIG
Projection: Geographic

Small towns that probably exist but whose location was unknown were distributed among the various administrative units on the basis of geography, toponymy, infrastructure, and rural population density. An iterative procedure was used to ensure consistency.

This estimation procedure was only used for a very small proportion of the towns with the exception of Nigeria, where almost half the total urban population was estimated in this manner. From the 1991 census, information on town size was only available for cities larger than 50,000. The rank-size decision rule was supplemented by information on town size acquired for 1954 and 1963, and guided by the hypothesis that there is at least one town with 20,000 inhabitants in each administrative unit (unless this produced impossible results).

C. Additional Population Data

The WALTPS database includes population data that were processed to be consistent over time and space. However, the original census data could be useful for some applications. Variables such as the male/female ratio are also available for some countries. These additional data were converted to Lotus 1-2-3 format (.WK1) on a country by country basis and are included with the WALTPS database. These data can be linked to the WALTPS administrative units using a GIS software such as Arc/Info or MapInfo. Variable definitions and data sources are included in each .WK1 file. The following table summarizes what is available for each country:

Key

A: 1995 estimate of the total country population.
B: Total area of the country ('000 km^2).
C: Average population per administrative unit ('000).
D: Average administrative unit area (km^2).
E: Number of first level administrative units.
F: Number of second level administrative units.
G: Number of agricultural census units.
H: Dates of censuses carried out during the '70s, '80s, and '90s.
I: Additional data: total population for the given census and administrative level.
J: Additional data: male/female ratio for the given census and administrative level.
K: Additional data: urban/rural ratio for the given census and administrative level.
*: Census was planned but not carried out.

4. AGRICULTURAL DATA

The WALTPS team participated in an effort carried out by the Agroclimatology Service of the U.N. Food and Agricultural Organization (FAO) to collect and compile geographic data on agriculture. The main characteristics of these data are described in this chapter as well as the normalization and correction procedures adopted.

FAO is planning to initiate a campaign to quality check these data. As it was not possible to wait for the results of this process within the time frame of the WALTPS, only a preliminary set of normalizations and corrections were performed. The data that appear in the WALTPS database are therefore not definitive. However, the FAO's corrected database should not differ greatly from the WALTPS database except in a few particular cases.

A. Main Features of the Database

* 428 agricultural census units for West Africa. The resolution in terms of number of units per country ranges from 77 units in Benin to 22 units in Nigeria (Figure 1).
* Area under cultivation in square kilometers and production in tonnes per agricultural census unit for about 20 products or groups of agricultural products.
* The major crops are: millet, sorghum, maize, rice, wheat, soybean, yam, manioc, plantain, banana, taro, coffee, cocoa, cotton, peanut, oil palm, hevea, legumes, and sweet potatoes.

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* For some countries, data are available for the following minor crops: fonio, berbere, tobacco, sugar cane, coconut, cocoyam, and tomatoes.
* On average, data were acquired for five years (only one year for Guinea), generally between 1985 and 1992 (except for Côte d'Ivoire where data were available from 1980 to 1986).
* Data originated mostly from national agricultural censuses, but also from the FAO's own estimates and those of other organizations (DIAPER/CILSS, FEWS, etc.).

B. Normalization

The data were converted into averages over the available time periods to minimize variations due to climate fluctuation and measurement error. When several different data sources were available for a particular country, we used the average of the annual averages calculated from each source and weighted by the number of years of observation for each source. Again, this procedure was used in an effort to reduce measurement inaccuracy.

Averages were then normalized to 1990 to make them compatible with the FAO/AGROSTAT estimates for 1990. There was one exception to this procedure: wheat production in Nigeria for which several other sources provided consistently higher values.

As a result of this processing, the WALTPS agricultural database is effectively a spatial version of the FAO's 1990 estimates by crop and by country.

C. Correction

It is clear that a database with more than 20 agricultural products, for 19 countries, collected over variable time periods could not be exhaustively checked within the time frame of the WALTPS. We therefore focused on correcting those data that appeared to be least reliable.

According to our assessments, the data are accurate to within 30%. However, this inaccuracy could be significantly higher, especially in less populated areas (small sampling size, sampling difficulties, etc.). It was necessary to correct aberrant yields in some cases. This was done by taking the mean production figure for neighboring agricultural census units located in the same climatic zone.

A second correction was to search by product and by agricultural census unit for annual figures that departed significantly from the long term average.

A third correction was to compare, whenever possible, data acquired from different sources to identify inconsistencies and possible errors.

We would like to emphasize that these corrections are provisional. FAO will perform a more complete quality check.

5. ROADS

This theme shows the development of the primary, secondary, and main tertiary road networks for 1960, 1968, 1978, 1984, and 1989.

The road networks were derived from the 1:3,000,000 ArcWorld database published by Environmental Systems Research Institute, Inc. (ESRI).

Road quality was derived from the Michelin road maps published for these five years. Use of the Michelin maps offers a temporally and spatially consistent classification scheme for the whole region. Road quality is defined by the following codes:

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0	N/A
1	Surfaced road with two or more lanes
2	Single lane surfaced road
3	Improved road
4	Partially improved road
5	Dirt road
6	Marked tracks

Codes 0-3 indicate all-weather roads (Figure 2). A few tertiary roads that appear on the Michelin maps but not on the ArcWorld database were digitized and added. Conversely, verification of the road network in Nigeria showed that a number of roads that appear in the Michelin maps were never built.

6. TOWNS

The location of towns within their administrative unit was not always accurately known, especially for small urban centers. This theme therefore only shows towns larger than 25,000 inhabitants. This information is complete and consistent for the whole region with the exception of Nigeria, where one town was assigned per Local Government Authority, even when there may be two.

Town size for the years 1960, 1990, and 2020 are defined as follows (Figure 3):

0	Less than 25,000 inhabitants
1	25,000 to 50,000
2	50,000 to 100,000
3	100,000 to 200,000
4	200,000 to 500,000
5	500,000 to 1,000,000
6	1,000,000 to 2,000,000
7	2,000,000 to 5,000,000
8	5,000,000 to 10,000,000
9	More than 10,000,000

7. MARKET TENSION

The database includes two maps in a raster format that show market tension across West Africa for 1960 and 1990 (Figure 4). A third map, for 2020, was generated, but has not been included in this version of the database.

Market tension is a purely theoretical representation of the economic "pull" exerted by the urban and international markets over the rural hinterland to satisfy their needs for agricultural products.

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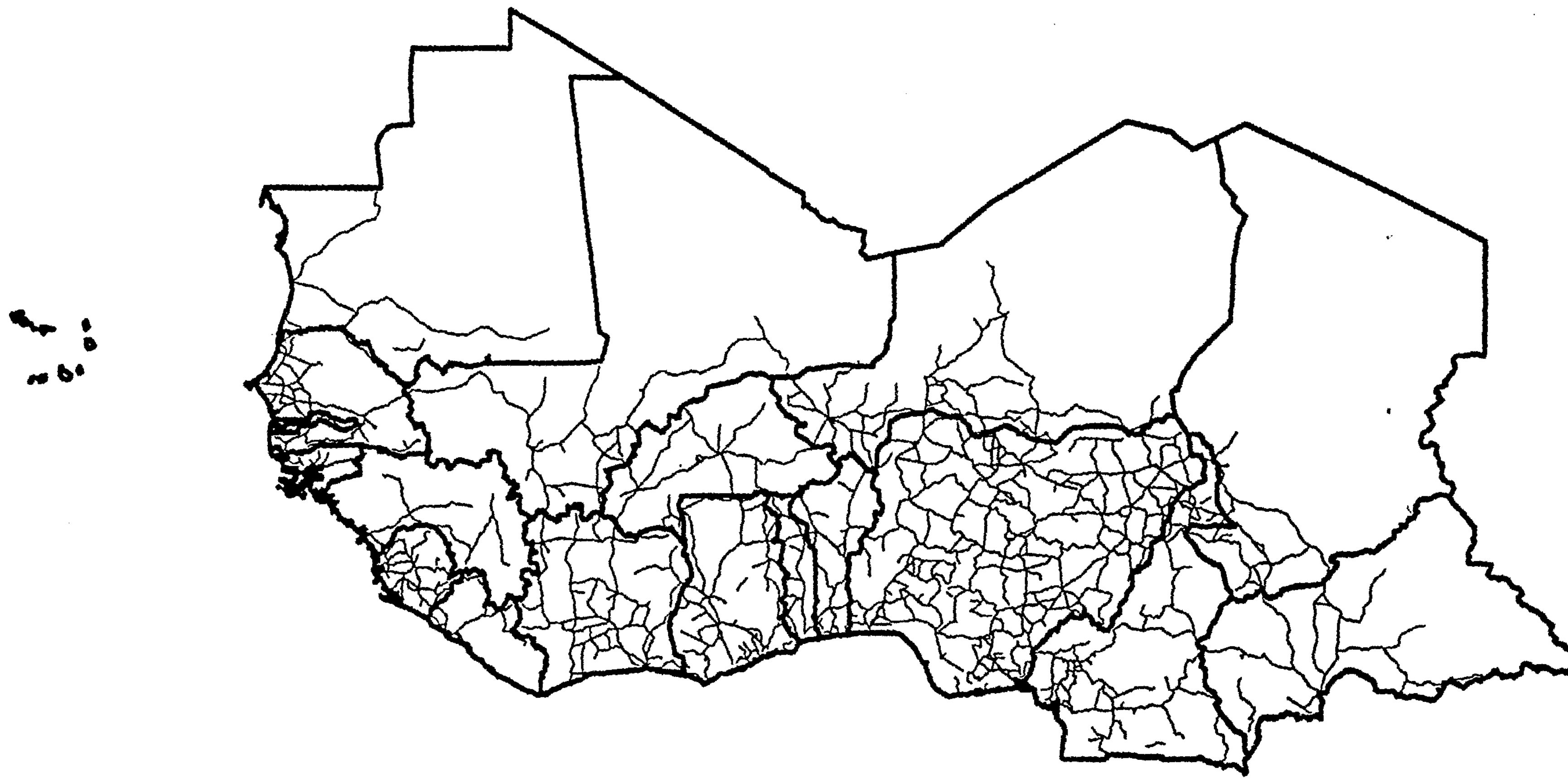
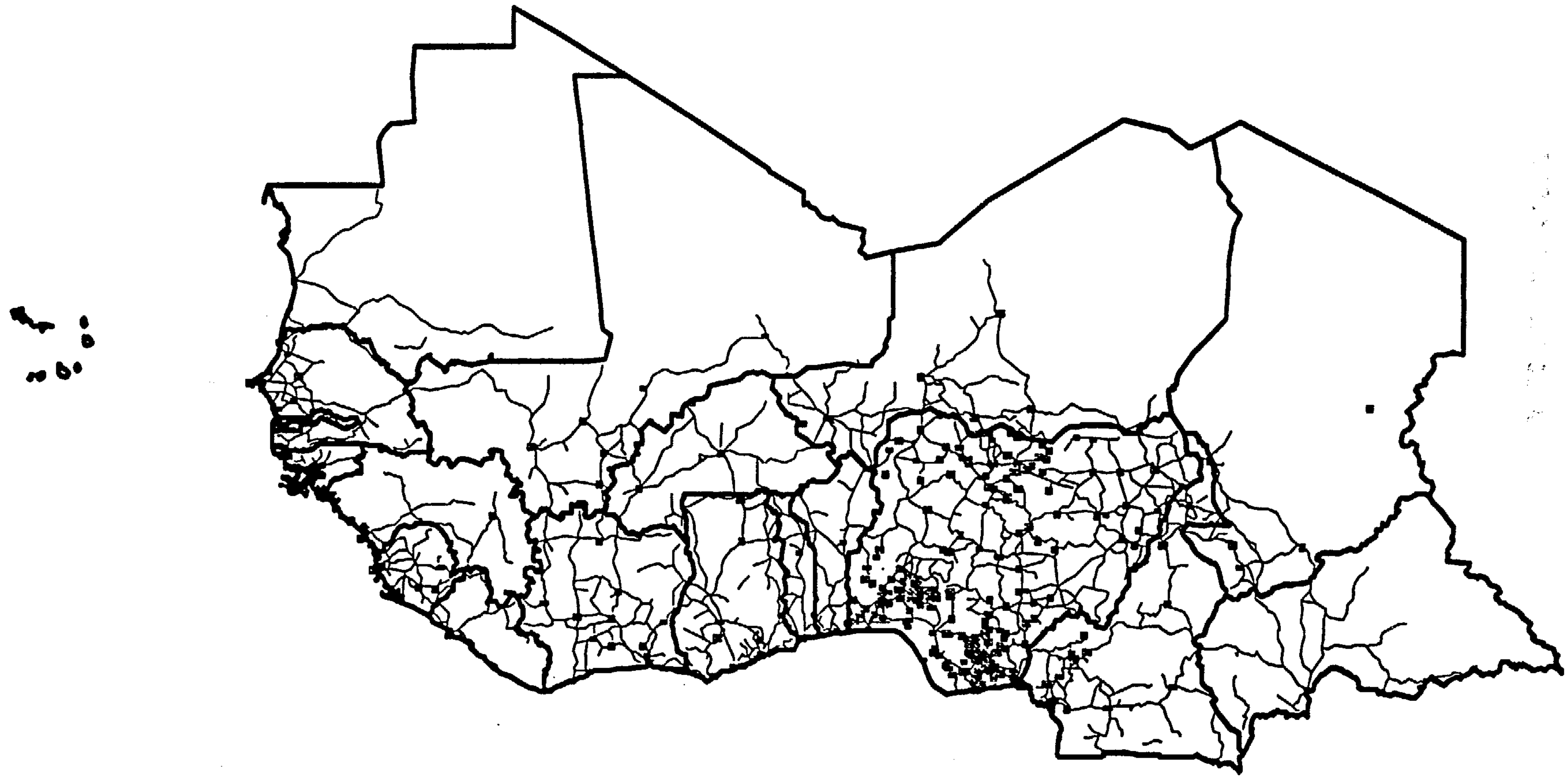
Figure 2. All-Weather Roads: 1989



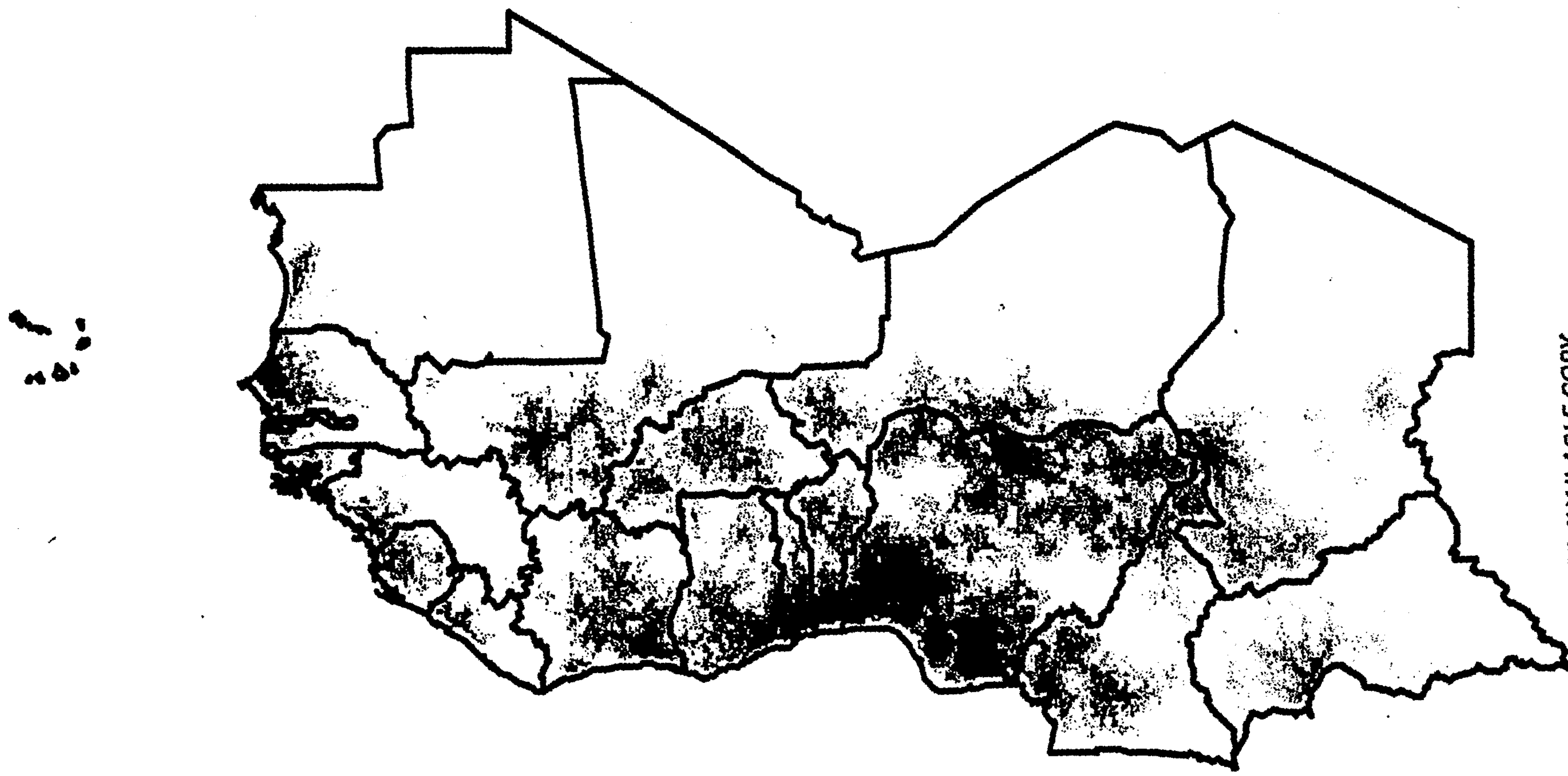
Sources: Club du Sahel/WALTPS, NCGIA/FAO, USGS/EDC, CNTIG
Projection: Geographic

Figure 3. Towns Larger Than 100,000: 1990



Sources: Club du Sahel/WALTPS, NCGIA/FAO, USGS/EDC, CNTIG
Projection: Geographic

Figure 4. Market Tension Estimated for 1990



Sources: Club du Sahel/WALTPS, NCGIA/FAO, USGS/EDC, CNTIG
Projection: Geographic

Before describing the main components of market tension, we need to emphasize that these data are fundamentally different from the other themes: they are based on a theoretical concept, not on a priori observed data. Only because analyses performed by the WALTPS have shown that this information was a posteriori relevant, at a given level of simplification and within the framework of a regional study, have we considered it useful to include these files in the database. Appendix A gives the main findings from a comparison between the observed data (population, agriculture, roads, soils, climate, towns) and market tension.

Economy x Fertility: this is the basis of the equation that was used to measure the attraction of the various rural areas and thus their potential population levels. The most important factors determining rural quality were considered to be the biophysical endowment (soils and climate), and opportunities to sell agricultural surpluses. Thus, a very fertile area may have little appeal if there is no possibility of selling agricultural surpluses (if the market is either too distant or too small). Conversely, a rural area close to a large and open market may not be very attractive if local biophysical conditions are poor (i.e., economic potential x zero = zero; zero x fertility = zero).

The opportunities to market agricultural surpluses were modeled using a spatial supply and demand model derived from a synthesis of earlier theoretical models (mainly Von Thunen and Samuelson). The details of the model are not described here. However, the model was developed according to the following principles:

1. The "pull" of a market on the surrounding area increases with the size of the market (market size is defined here by the demand for food of this market population minus this population's food imports, plus potential food exports from this location; it is not defined simply by the volume of agricultural products traded). A large market has a larger supply area than a smaller one, which in turn affects the average cost of food transportation.

2. Market tension around a small town can, however, be high if the city is located within the supply area of a larger one.

3. Market tension exerted by a compact group of small towns is similar to that exerted by a single town with a population equal to the sum of their populations, all else being equal.

4. Market tension also increases if unfavorable conditions for agricultural production (soils, climate) prevail (i.e., the supply area for a town with 100,000 inhabitants will be larger in a low fertility area than in a high fertility area).

5. Market tension decreases with distance from the market and decreases faster off-road than on-road, and faster along dirt road than along paved road. The distance to market that interests us is the economic distance, defined in terms of transport costs, rather than straight line distance.

The market tension maps for 1960 and 1990 were calculated based on the prevailing market demand and road network. The growth of areas of high agricultural commercialization opportunity is a function of increased market demand and expansion of the transport network.

The market tension maps may be interpreted as an estimate of the economic component of the "pull" exerted by a market, the other important component being soil fertility. WALTPS showed that multiplying market tension by fertility gave an acceptable estimate of rural population and agricultural production for the region compared to the statistical data (1990 for agriculture, 1960 and 1990 for population).

That such a relationship was detected suggests that market tension plays an important role in spatial economic analysis. However, one must bear in mind the fact that market tension only "explains" agricultural production and population distribution at the regional scale. At smaller units of observation (e.g., at the national or subnational levels), local factors may exert the primary control. The market tension maps are therefore only qualitative models, useful at the regional scale, to answer questions such as: "If this area was typical of the region as a whole, we would expect to see..."

8. ADMINISTRATIVE BOUNDARIES

Population and agricultural census data were compiled for a hierarchy of administrative units. Except for Chad and Cape Verde, population data were collected at the second administrative level which corresponds to arrondissements or districts in anglophone countries (Figures 5 and 6). There is no international consistency regarding administrative divisions. Consequently, the average surface area of a particular division varies by country. Furthermore, in some countries, certain divisions have no administrative function. For example, Côte d'Ivoire is divided into 10 regions, 50 prefectures and 185 sous-prefectures, but the regions have no administrative function. In this case, the second administrative level (prefectures) was taken as the first level and the third level (sous-prefectures) as the second level.

This level of detail is termed "medium resolution" because it fills the gap between generalized databases usually available at the national level and detailed databases developed for limited areas by particular projects. The resolution for each country can be measured in terms of the average number of inhabitants per administrative unit or the average size of each unit in square kilometers.

For the WALTPS study, the administrative boundaries for each of the 19 countries were digitized and processed using Idrisi (Clark University, Worcester, MA). Administrative boundaries for most countries were replaced by more accurate boundaries derived from more up-to-date sources than those used by the WALTPS. All the coordinates were converted to latitude and longitude in units of decimal degrees.

A. Database Structure

The WALTPS database was developed using Arc/Info. Arc/Info is a vector-based GIS program that uses a relational database system. The administrative units were compiled as an Arc/Info theme that contains information about the coordinates of each polygon as well as their attributes. Each polygon includes a unique 7-digit identification number (ADMINID) that is made up of numeric identifiers for the country, and the first and second level administrative units. The attributes include the name of the country, and the first and second administrative units that belong to each polygon (COUNTRY, NAME1, NAME2).

The variables DEMOFLAG, AGFLAG, SQKM, ADMSQKM, AGSQKM, and FEATURE require a more detailed explanation. A particular problem when dealing with georeferenced census data is the fact that one administrative unit could be made up of several polygons. For example, a unit could include a continental polygon and several islands. We have adopted the conventional approach which is to repeat the attributes for every polygon making up the unit. However, this approach would lead to double counting in cases where a particular variable within the database is summed for each polygon. For that reason, a flag item (DEMOFLAG) is included. DEMOFLAG = 1 for the largest polygon belonging to the same unit, and DEMOFLAG = 0 for the others. In other words, for each administrative unit, there is only one polygon with DEMOFLAG = 1. The same approach has been adopted for the agricultural census units. In most countries, agricultural data are only available at the first administrative level. In Nigeria, for example, each agricultural census unit consists of up to 40 second level administrative units. A second flag item (AGFLAG) is therefore included to indicate a unique polygon for each agricultural census unit.

Several variables in the database contain areal information. The first of these (SQKM) contains the area in square kilometers of each polygon. Because of the problem of administrative units that consist of several polygons, a second variable (ADMSQKM) contains the total area in square kilometers of the administrative unit (i.e., the sum of the SQKM values for all the polygons belonging to the same unit). Similarly, AGSQKM contains the total area of each agricultural census unit. To account for major inland water bodies (lakes or lagoons), IWSQKM contains the area of the administrative unit that is covered by water (the water bodies contained in the ArcWorld database were used for that purpose). This item can be used to derive more accurate estimates of density figures. For example, to calculate population density in terms of the number of inhabitants per square kilometer, the following expression can be used (Figure 7):

$$D90 = (P90 \times 1000) / (ADMSQKM - IWSQKM)$$

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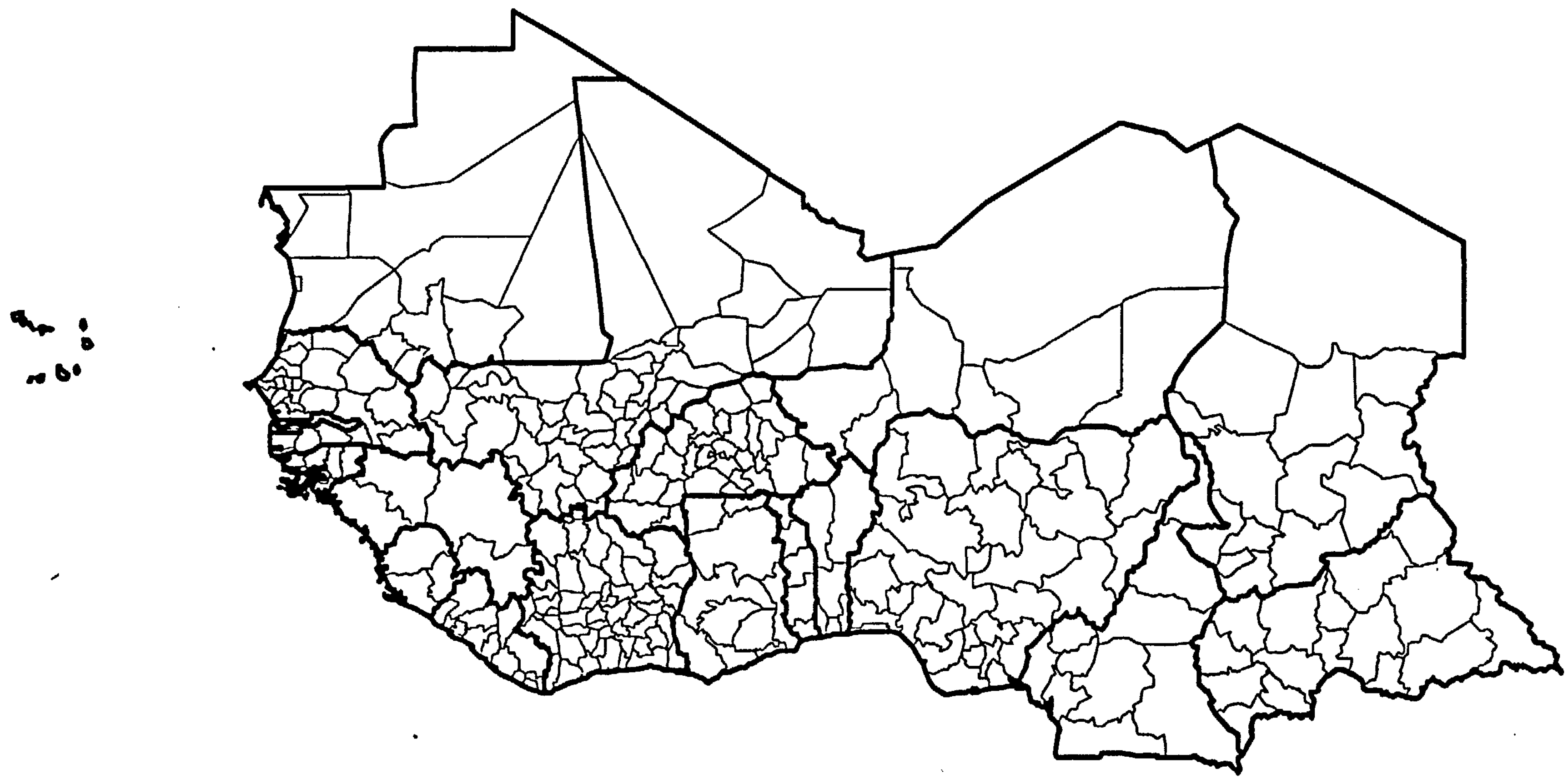
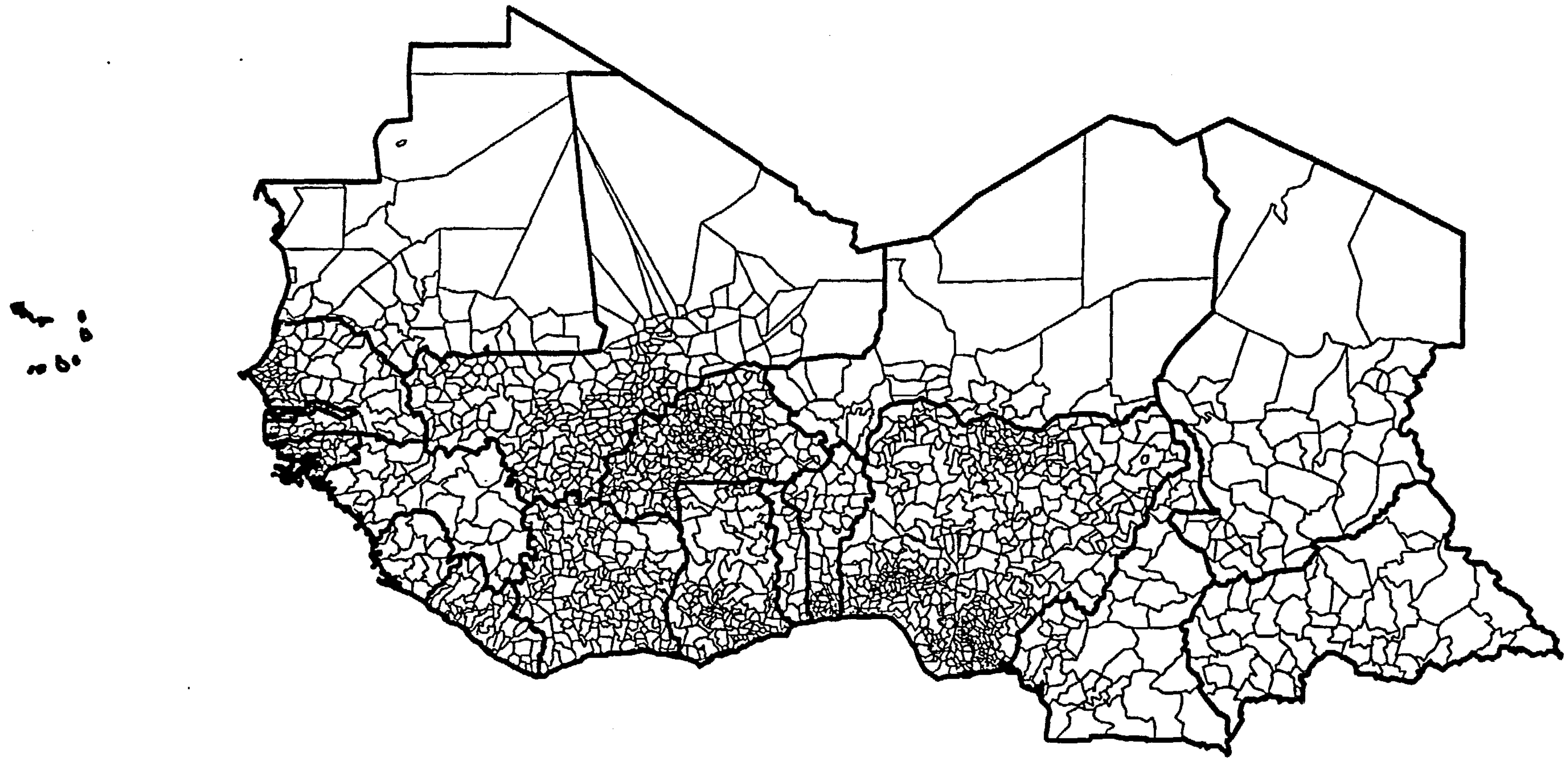
Figure 5. First Level Administrative Units



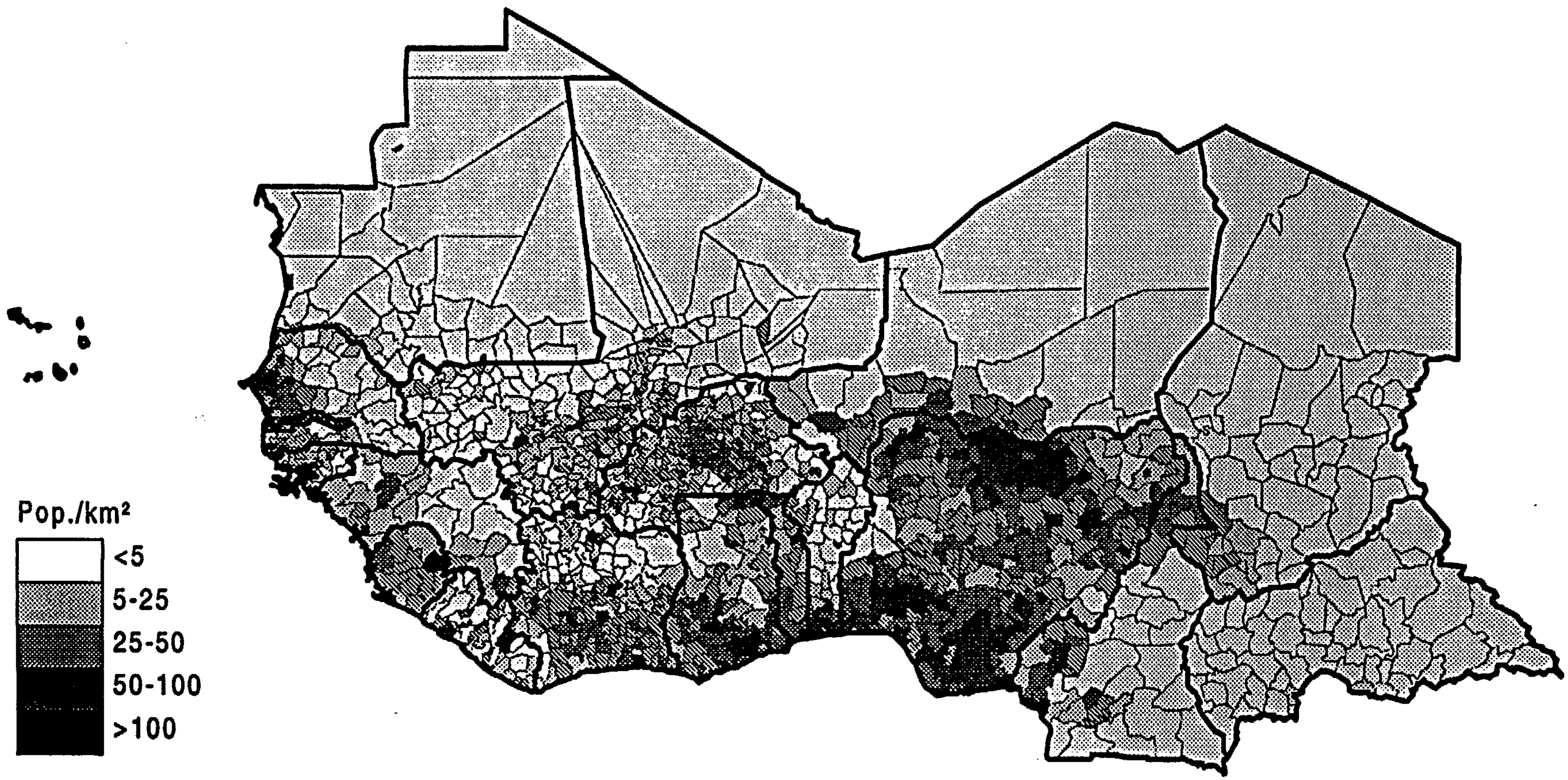
Sources: Club du Sahel/WALTPS, NCGIA/FAO, USGS/EDC, CNTIG
Projection: Geographic

Figure 6. Second Level Administrative Units



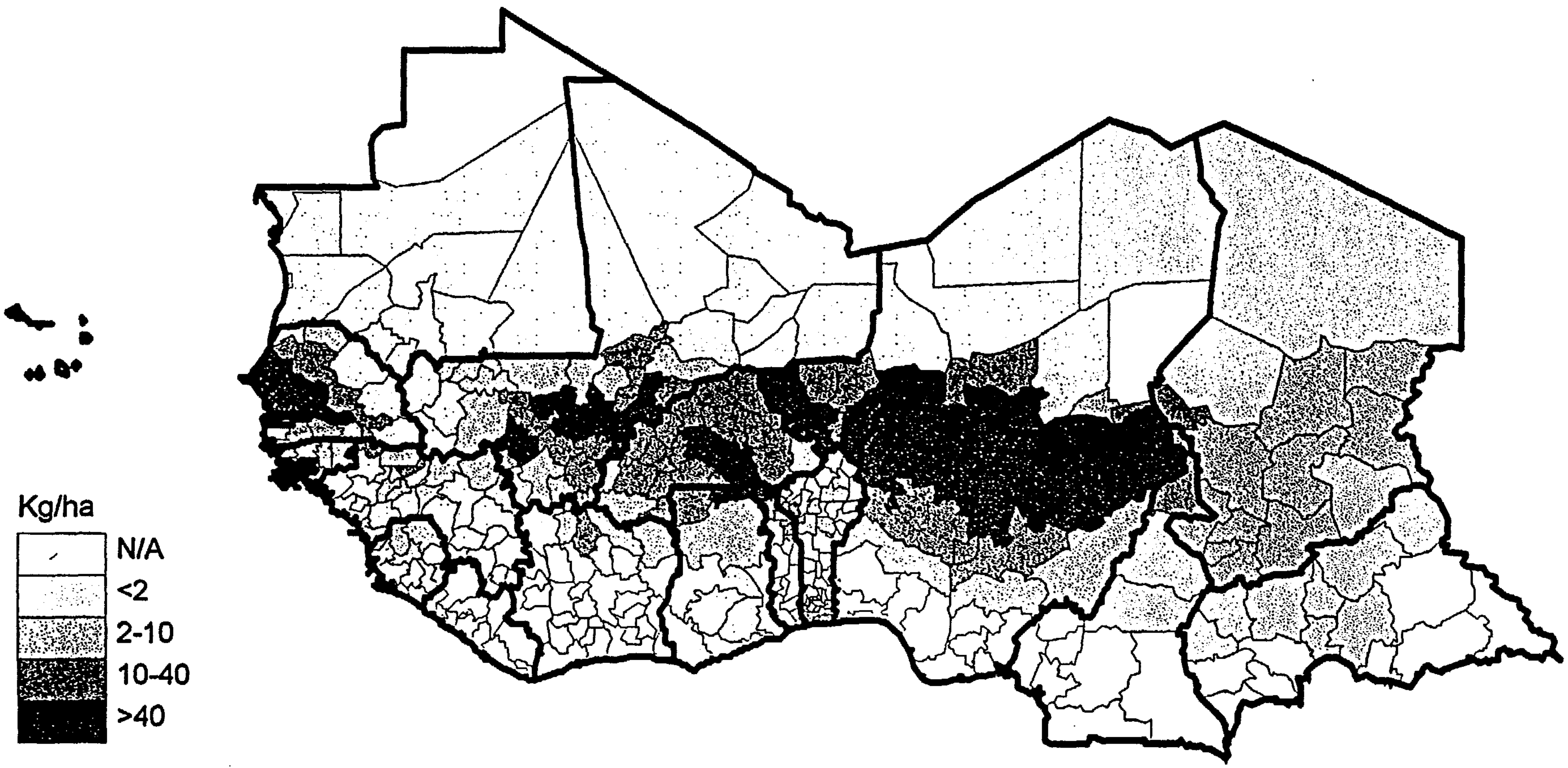
Sources: Club du Sahel/WALTPS, NCGIA/FAO, USGS/EDC, CNTIG
Projection: Geographic

Figure 7. Population Density Estimated for 1990



Sources: Club du Sahel/WALTPS, NCGIA/FAO, USGS/EDC, CNTIG
Projection: Geographic

Figure 8. Millet Production Estimated for 1990



Sources: Club du Sahel/WALTPS, NCGIA/FAO, USGS/EDC, CNTIG
Projection: Geographic

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Similarly, millet production in kilograms per hectare can be calculated by the following expression (Figure 8):

$$DMIL = (TMIL \times 1000) / (100 \times (AGSQKM - IWSQKM))$$

The boundaries (or "arcs") have been labeled according to their position in the administrative hierarchy. FEATURE denotes this position. International boundaries are assigned FEATURE = 0, boundaries between first level units FEATURE = 1, and boundaries between second level units FEATURE = 2. The coastline and "outside boundary" are assigned FEATURE = 9. In addition, boundaries that divide two agricultural census units are assigned AGBOUND = 1, and all the others AGBOUND = 0. FEATURE and AGBOUND allow for the selective drawing of boundaries or for the use of different symbols (e.g., color, line thickness) for different boundaries.

B. Data Sources

For each country, we have used the best available boundary data set that we could find. The principal sources are as follows:

FAO

Countries: Benin, Cameroon, CAR, Guinea, Guinea Bissau, Liberia, Niger, Sierra Leone, Togo.

Some of these data were derived from the ArcWorld database. In addition, several of the coverages were modified by the NCGIA to include the second level boundaries and to take into account recent boundary changes.

USAID

Countries: Burkina, Chad, Gambia, Mali, Mauritania, Senegal.

Administrative boundaries were digitized by EDC on behalf of the FEWS Project from the following base maps:

* IGN-Paris (1960-85): le Burkina Faso: 1:200,000, 33 sheets.
* IGN-Brazzaville (1974): République du Tchad, Carte Routière: 1:1,500,000.
* Gambia: SAID/ORS Project No. 635-0203-01, Office of Remote Sensing, South Dakota State University: 1:125,000.
* IGN-Paris (1971): République du Mali: 1:2,500,000, Comité Militaire de Libération Nationale, Bamako (1978), Administrative Divisions Map of Mali.
* Government of Mauritania, Central Bureau for the Census of Population and Habitat (1986-87), Administrative Maps of Mauritania, Departments: 1:1,000,000.
* Carte Administrative du Sénégal, U.N. Development Programme, Direction de l'Aménagement du Territoire (1984), "Schéma National d'Aménagement du Territoire: Version Préliminaire", Dakar, Senegal: 1:1,000,000.

WALTPS

Countries: Ghana, Nigeria.

For these two countries, the original WALTPS boundaries were converted from Idrisi to Arc/Info format and converted to geographic coordinates. Although the accuracy of the boundaries is judged to be lower than that of the other sources, these were the most up-to-date and detailed boundaries available for these countries.

CNTIG

Countries: Côte d'Ivoire.

This data set was produced by the CNTIG from 1:200,000 base maps and converted from Universal Transverse

Mercator (UTM) meters to geographic coordinates.

Digital Chart of the World (DCW)

Countries: All.

Because of the heterogeneity of data sources, international boundaries typically did not match up perfectly. To ensure international consistency, we replaced all international boundaries with those from the DCW. The DCW was digitized from the 1:1,000,000 Operational Navigation Charts (ONC) published by the U.S. Defense Mapping Agency (DMA). The DCW is the most complete and consistent global digital base map available. It has therefore become a de facto standard for regional and continental scale studies. Many other GIS databases for Africa have been georeferenced to the DCW (e.g., a 1 km resolution Digital Elevation Model developed jointly by UNEP/GRID-Sioux Falls and EDC, the Africa Data Sampler maps developed for every country in Africa by WRI, a vegetation map developed by the University of Maryland from vegetation index data).

Countries: Cape Verde.

The first level administrative units for Cape Verde correspond to the major islands of the country. We therefore used the DCW as the basis for the demographic data. There are no second level boundaries or agricultural data for Cape Verde.

C. Data Quality

Because of the lack of information about data sources, scales, and lineage, it is very difficult to attach an accuracy measure to the boundaries. Subnational boundaries are often absent on properly referenced maps. This may be due to the fact that, unlike physical features, political boundaries cannot be directly observed or measured. Furthermore, boundaries below the first subnational level are often poorly defined. Digitizing and coordinate conversion can also introduce errors.

A word of caution is therefore necessary. A GIS stores data with very high precision regardless of the accuracy. Furthermore, the replacement of international boundaries by the DCW masks some of the distortion and registration error that was apparent in the original database when adjacent countries were compared. Finally, due to the heterogeneity of the data sources, there is no consistent scale or level of line generalization.

Consequently, the accuracy of the data is likely to be lower than it may appear at first glance. The purpose of the WALTPS was to investigate large scale economic processes in West Africa. For regional studies, investigations that rely on visualization and modeling at small cartographic scales, the accuracy of the database is certainly sufficient. However, the database is not appropriate for analyses at much more detailed levels (e.g., investigating processes within a subnational unit). The WALTPS database is therefore not a replacement for carefully compiled digital maps or GIS databases generated from large scale topographic maps.

9. INSTALLATION

The WALTPS database includes three 3½-inch 1.44 MB diskettes numbered #1/3 through #3/3 and a User's Guide (this document). The themes are stored in PC Arc/Info version 3.4.2 format and organized as sub-directories that contain both the geographic coordinates and attributes. The coordinates are stored in the proprietary Arc/Info format and the attributes as dBase files (.DBF). The attributes can therefore be edited by any program that can read and write .DBF files (e.g., dBase, Access, Excel, Quattro Pro for Windows). The themes can be viewed and manipulated using Arc/Info or ArcView. Several views are also provided as .AV files (ArcView 1). These views can also be read by ArcView 2. The additional demographic data are provided as spreadsheet files (.WK1). Users will need Arc/Info to connect these data to the administrative units in the WALTPS database.

To install the WALTPS database, carry out the following steps:

* Type **CD ** *<Enter>* to move to the root directory of the hard drive.
* Insert diskette #1/3 in a 3½-inch 1.44 MB capacity diskette drive.
* Type **A:\PKUNZIP -D A:\WALTPS.ZIP***<Enter>* to decompress and transfer the files to the hard drive.
* If the diskette drive is B:, replace all references to A: with B:.
* Insert diskettes #2/3 and #3/3 as prompted.

The following sub-directories under \WALTPS will be created:

Sub-directory	*Themes/Files*
UNITES	Administrative units, demographic and agricultural data in Arc/Info format.
ROUTES	Road network in Arc/Info format.
VILLES	Towns in Arc/Info format.
MARCHE	Market tension images in .TIF format.
WK1	Additional demographic data in .WK1 format.
VIEWS	ArcView 1 views in .AV format.

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Eléments de Vision Economique Prospective. l'Afrique de l'Ouest à l'Horizon Décennal. Document de travail n. 3. SAH/D(93)411. J.D. Naudet. November 1993. English version available.

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Naudet. January 1993.

A Medium Resolution Population Database for Africa. Uwe Deichmann. National Center for Geographic Information and Analysis, University of California, Santa Barbara. World Resources Institute. Febuary 1994.

APPENDIX A

Principal Findings from the Rural Economic Geography Component of the WALTPS

Market tension, an indicator of the economic impact of urban and international markets on rural areas, was developed using a spatial supply and demand model.

Market tension measures the "pull" that markets must exert on rural areas to satisfy their needs for export, food, and industrial agricultural products. Simplistically, market tension increases with:

* Proximity to a market.
* Size of the demand from a market.
* Good quality transport links.
* Unfavorable physical conditions for agricultural production.

Market tension was then compared with:

* Rural population.
* Agricultural production.
* Quantity and quality of the transport network.
* Agricultural potential as inferred from soils, water, and climate.

The main results of these analyses are:

1. There is a strong correlation between rural population density and market tension. To a first approximation, rural population density varies exponentially as a function of market tension.

2. When this correlation is examined within different soil fertility zones, it is consistent within each zone for 1960 and 1990 despite important changes in the rural population distribution between these dates.

3. This relationship exists not only at the regional scale but at more detailed units of observation:

* There is a consistent decrease in rural population density with distance from the main urban centers across West Africa for both time periods. On average, rural population density falls by three-quarters 100 km away from the town.
* Detailed analyses within 14 climatic zones and three soil quality classes show a strong relationship between market tension and rural population density for all soil-climate combinations, except for arid areas or areas with very poor soils where the population density may have reached saturation (i.e., the human carrying capacity threshold may have been reached).

4. Where population densities are low (less than 20 inhabitants per square kilometer) and in non-arid climates, we observed little variation in population density as a function of soils or climate.

5. Variations in rural population density as a function of soils and climate increase with greater population density. Soils and climate are thus likely to become increasingly important as populations grow. However, with the exception of arid areas and areas with very poor soils, market tension provides a reliable first order explanation of population distribution within the region. This effect accounts for variations in population density that range by a factor of 50, whereas soils and climate only account for variations in population density that range by a factor of 3.

6. Differences between the actual rural population in 1960 and the WALTPS estimates are mostly the result of historic factors (old population centers, etc.). These differences tend to diminish over time, as the smaller differences for 1990 suggest.

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7. Rural population and market tension grew in tandem between 1960 and 1990: rural areas with the largest population growth showed the highest relative increase in market tension.

8. Indicators of agricultural activity, such as the percentage of agricultural land or the ratio of agricultural production (calorie-equivalent) to agricultural area, are also highly correlated with market tension.

9. The previous statement is not surprising considering the relationships that exist between rural population density and the level of agricultural activity. More interestingly, this study establishes a strong correlation between agricultural production per farmer and market tension: despite strong population pressure on agricultural lands, farmers produce more in areas near large markets than in more distant locations, even those with a richer biophysical endowment.

10. One remarkable observation is the apparently similar behavior exhibited by farmers in both savanna and more humid zones. Although physical constraints differ, especially in terms of the calorific yield of the crops, agricultural production per farmer was very similar in both ecological zones for a given level of market tension.

11. However, savanna areas near large markets are relatively disadvantaged in terms of agricultural growth because most of the potential agricultural land is already cultivated.

12. Some areas, such as the cotton, coffee, and cocoa producing areas in Côte d'Ivoire, deviate from the general pattern. Surplus production per farmer is higher in these areas than elsewhere for a given level of market tension. This can be explained by specific crop production characteristics (in the case of cotton), the cultivation of agricultural lands by emigrant plantation workers, or lower rural population density. All three factors would allow rural inhabitants to exploit more intensively their natural resources.

13. Cultivated area per farmer does not vary significantly as a function of market tension. Production gains per farmer, as we approach important markets, result mainly from increased productivity. This suggests that there is very little mechanized farming. Most improvements result from the use of more fertilizers.

14. The stability in the cultivated area per farmer within each climatic zone is assumed to result from a limit that has been reached in the area that one individual can cultivate using traditional methods. This limit strongly depends upon the crop type: high for coffee and cocoa, cotton, and "extensive" millet-sorghum (especially in Niger), medium for cereals, and low for roots and tubers which require more labor. Cotton production is on average an intermediary product because it makes extensive use of animal traction.

15. The spatial structuring effect of markets on agricultural activity shown here is not specific to West Africa. An earlier study in Ecuador using the same analytical tools gave similar results.

16. Agricultural surpluses from an area are calculated by multiplying the rural population density by agricultural production. Both variables are correlated with market tension. The need to market these surpluses largely determines the transport needs for the region. It is therefore not surprising that road density and quality increase around markets, especially around important markets. More interestingly, our analysis shows that this relationship has not changed across West Africa since 1960.

These remarks support our initial assumption that markets strongly influence the rural economic landscape, favoring some locations rather than others in terms of their integration into a market economy based on a sectoral and geographic division of labor. Markets act as strong incentives for farmers to produce more. Assuming that the land can be cultivated, it is near the larger markets that the incentives to produce surpluses are greatest. This explains the concentration of the rural population in these areas. It is interesting to note that high population density in these areas does not limit agricultural production: there are almost no areas where population density exceeds 50 inhabitants per square kilometer and farmers do not produce large agricultural surpluses.

There are only two examples to the contrary, the Fouta Jallon in Guinea and the area around Ouagadougou in Burkina.

Both areas have higher than expected population densities given their biophysical endowment. In the case of Ouagadougou, the trend may be reversing: the area may, despite severe soil degradation, evolve into a pattern of land use and agricultural production similar to that around Kano in northern Nigeria where agriculture has greatly intensified. Both enjoy similar soils and climate. Kano thus offers a vision of how Ouagadougou may evolve.

These results have for the most part already been observed or anticipated (by Ricardo and Von Thunen 150 years ago, by Richard Cantillon three centuries ago). But these lessons are sometimes forgotten. The effects of distance and town size on local production are rightly of less and less concern to most economists working in developed countries. However, they remain important issues in developing countries, especially for economists studying the rural economy for whom agricultural revenues, transport costs, and the level of demand are essential data. They are also of concern to transport economists studying the balance between the supply and demand for goods.

Our contribution does not reside in the statements themselves, but in their implications. Thanks to advances in computer technology, it is now possible to quantify phenomena, including the effects of distance on human behavior, and use this information as inputs to numeric models.

The WALTPS model was used to better understand some of the major trends in the long term behavior of the rural population across West Africa. However, our results have a significance that goes beyond the narrow focus of the study:

1. First, they demonstrate the need for all agencies designing or implementing development projects in West Africa to establish an "intervention geography" and recognize the fact that the region is characterized by a high degree of heterogeneity.

2. Second, they suggest the need for different econometric tools from those traditionally used by development projects that have a potential impact on the economic geography, especially large scale agricultural and transport projects. The need for new tools is even more important if success depends on how the rural population responds to, and benefits from, an intervention. This response was shown by our analysis to depend largely on the size and proximity of the market. The study also shows that spatial analysis can provide quantitative answers to these questions, or at least reasonable estimates. Quantitative answers are needed because costs and benefits must be compared both within and between projects.

3. Finally, the study suggests a new departure for GIS analyses. Frequently, physical data (soils, climate, slopes, etc.), human data (population, agriculture, etc.), or the results of these interactions (soil degradation, etc.) are compared in isolation of the larger scale economic forces. However, if the effects of market size and proximity are ignored, the results may be greatly biased. For example:

* Area under production is not necessarily greatest under the best soil and climate conditions.
* Agricultural production is not necessarily greatest under the best soils and climate conditions.
* Soil degradation is not necessarily worse where agricultural activity is highest. This may depend critically upon the incentive for the rural producer to preserve soil fertility (which is directly related to the opportunity to market agricultural surpluses which are the principal source of rural income).
* Market tension helps to explain the distribution of apparently "over-populated" or "under-populated" areas. An understanding of this pattern is a prerequisite for the formulation of effective development policies.

We also need to bear in mind the fact that despite its apparent complexity, the WALTPS model remains a simplification of reality. Many other parameters need to be included to better understand the economic geography of West Africa.

Nor is the model intended for detailed local level analysis. When working at larger scales, the model may provide a reference against which to compare reality. However, additional site-specific information is always needed to fully understand the environmental and economic forces at work.

Finally, the analysis described here represents only a single use of GIS. There are many other potential applications. First, the questions raised by the WALTPS about the rural economic geography are only some of many questions that can be asked. Second, other users may want to make different working hypotheses to answer the same questions. Finally, and most importantly, the use of GIS is not limited to the analysis of demographic and agricultural conditions in rural areas. The distribution of service facilities and access to these facilities are essential parameters within both the health and education sectors.

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APPENDIX B

Attribute Definitions

All the themes contain standard attributes that are generated automatically by Arc/Info (e.g., AREA, PERIMETER, FNODE_, TNODE_). Each theme also contains added attributes that describe the points, arcs, or polygons that make up the theme.

UNITES

UNITES is composed of arcs (lines) as well as polygons. The arcs have the following attributes:

Field	Type	Description
FEATURE	Numeric	Type of arc: 0 - national boundary 1 - first level administrative boundary 2 - second level administrative boundary 3 - third level administrative boundary 7 - islands within inland water bodies 8 - inland water bodies 9 - coastline and off-shore islands

The polygons have the following attributes:

Field	Type	Description
SQKM	Numeric	Area of the polygon in km^2
ADMSQKM	Numeric	Area of all the polygons making up the administrative unit in km^2
AGSQKM	Numeric	Area of all the polygons making up the agricultural census unit in km^2
IWSQKM	Numeric	Arc of all the inland water bodies within the polygon in km^2
CODE	Numeric	Type of polygon: IW - inland water IS - island L - land
ADMINID	Numeric	Identification number for the polygon
COUNTRY	Alpha	Short version of the country name
NAME1	Alpha	Name of the first level administrative unit
NAME2	Alpha	Name of the second level administrative unit
DEMOFLAG	Numeric	Type of polygon: 0 - others 1 - largest polygon making up the administrative unit
AGNAME	Alpha	Name of the agricultural census unit

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AGFLAG	Numeric	Type of polygon: 0 - others 1 - largest polygon making up the agricultural census unit
P60	Numeric	Total population (1960)
U60	Numeric	Urban population (1960)
R60	Numeric	Rural population (1960)
D60	Numeric	Population density (1960)
etc.		
AMIL	Numeric	Cultivated area under millet in km^2
ASORGHO	Numeric	Cultivated area under sorghum in km^2
AMAIS	Numeric	Cultivated area under corn in km^2
etc.		
TMIL	Numeric	Millet production in tonnes (1.000 kg)
TSORGHO	Numeric	Sorgum production in tonnes (1.000 kg)
TMAIS	Numeric	Corn production in tonnes (1.000 kg)
etc.		

ROUTES

ROUTES is made up of arcs with following attributes:

Champs	Genre	Description
STAT89	Numeric	Type of arc: 0 - N/A 1 - Paved road with two or more lanes 2 - Single lane paved road 3 - Improved road 4 - Partially improved road 5 - Dirt track 6 - Marked out dirt track
STAT84	Numeric	etc.

VILLES

VILLES is made up of points with the following attributes:

Champs	Genre	Description
CLASS20	Numeric	Type of point: 0 - Town with less than 25,000 inhabitants (2020) 1 - 25,000-50,000 2 - 50,000-100,000 3 - 100,000-200,000 4 - 200,000-500,000 5 - 500,000-1.000,000 6 - 1,000,000-2.000,000 7 - 2,000,000-5.000,000 8 - 5,000,000-10.000,000 9 - More than 10,000,000
CLASS90	Numeric	etc.

MARCHE

MARCHE is a raster image without attributes.

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APPENDIX C

Population Data Sources by Country

Benin

1. ILTA (Etude d'une Image à Long Terme de l'Afrique).
2. Recensement général de la population et de l'Habitat. Tableaux statistiques, 1986.
3. INSEE-Service Coopération: République du Dahomey, Enquête démographique 1961. Résultats définitifs, Paris 1964.
4. Venard J.L: Urbanisation au Bénin. Area International, Paris, Septembre-Octobre 1990.
5. Lopez-Escartin N.: Données de base sur la population, Bénin: CEPED, No. 6, Paris, Août 1991.

Burkina

1. ILTA.
2. INSEE-Service Coopération: Enquête démographique par sondage en République de Haute Volta 1960-61, Paris 1970.
3. INSD: Recensement général de la population du Burkina, 1985:
   a: Résultats provisoires.
   b: Analyse des résultats définitifs.
   c: Structures par âge et sexe des villages du Burkina.
   d: Principales données définitives.
4. Courel M.F., A. Courel, R. Lardinois: Population de la Haute Volta au recensement de Décembre 1975.

Cameroon

1. ILTA.
2. Dackam Ngantchou R., B. Hovy, E. Ngwe: Introduction à l'analyse démographique des villes moyennes du Cameroun, Vol. I: IFORD, Juillet 1989.
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