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WATER USE IN THE RURAL ECONOMY OF A SEMI-ARID ENVIRONMENT: A NORTHERN NIGERIA CASE STUDY

By

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A Thesis
Submitted to the School of Graduate Studies
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WATER USE IN THE RURAL ECONOMY OF A SEMI-ARID ENVIRONMENT

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TITLE: **WATER USE IN THE RURAL ECONOMY OF A SEMI-ARID ENVIRONMENT: A NORTHERN NIGERIA CASE STUDY**

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ABSTRACT

Environmental (climatic) and economic (human) influences have contributed to the problem of water scarcity in arid and semi-arid areas of the world, particularly in the less developed countries. This has impeded economic development in these regions. Thus, the call for better methodological approaches for investigating the problem from an interdisciplinary perspective and at a local scale – the "bottom-up" approach. This study investigates the nature of water use in a selected drought-inflicted village and develops an analytical framework for assessing the water demands of alternative economic development scenarios in the village.

A review of hydro-climatological characteristics, land use practices, and technological development provides information on water resources availability and human activities in the region. Surveys of human activities and water use in the study village, Katarko indicate the following conditions: water scarcity, unsustainable agricultural development, and subsequent food and economic insecurity. Further investigations indicate that groundwater is the most dependable source of water. Its use is dominated by agricultural activities especially irrigation and animal rearing. These are also the most water intensive activities based on the ratio of water use to income generation. Results of the initial survey provide useful background information for the development of predictive models and water conservation strategies. A commodity-by-industry economic-ecological model (CIEEM) is developed for this purpose.

Estimates of direct and total requirements of both economic and ecological commodities showed sparse sectoral interdependence within the economic system but a heavy dependence of the economy on the environment. Such dependence is more on water, a scarce commodity in this semi-arid environment. The most intensive users of water based on the direct effects include animal husbandry, building and irrigated agriculture; based on total effects are catering, building and animal husbandry, in descending order.

A number of policy scenarios for local economic development and water conservation are formulated. They are derived based on our own observations in Katarko village and relevant literature for the semi-arid zone, and incorporate elements of indigenous knowledge systems and technologies (local initiatives) regarding water scarcity and drought mitigating strategies in terms of water procurement, delivery and processing, as well as national development strategies. These scenarios are simulated using the model to determine economic and environmental impacts in terms of changes in water use. An increase in production will require an increase in groundwater input while changes in the production process and water application efficiency will ensure a reduction in groundwater input and other environmental commodities. Results show that some of the production scenarios are more water intensive than others. The water conservation strategies discussed here will serve as policy options for sustainable development in this water-scarce village as well as other areas with similar economic and environmental conditions.

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I am particularly grateful for the financial support given by the Jos-McMaster drought and rural water use project (funded by the Canadian International Development Agency-CIDA). I appreciate the assistance offered by the staff of the Jos-McMaster Project, Jos, and the offices of McMaster International and the International Students Adviser, McMaster. I am also grateful to the University of Jos, Nigeria for granting me study leave and support during the field research and all the people of Katarko village, my field assistants, especially Ibrahim Wakil, for their cooperation during data collection. And McMaster University, Canada for creating an enabling environment for my studies and the contribution of its Staff, Faculty and student colleagues.

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Canada and elsewhere, too numerous to mention here. Worthy of mention however are Dr. Tarhule and family and Dr. Agyemang-Duah, for their encouragement, Bulus G. Shogos who has been a brother to me, all my colleagues in the struggle as well as members of Christ Apostolic Church, All Nations Full Gospel Church, ANNIC, WUREBS and their families. Thank you all for the support.

Most of all, I like to thank our Heavenly Father, Lord and Saviour, Jesus, for I have seen his goodness, mercy and compassion in my Life and with whom all things are possible now and in the future. Amen.

DEDICATION

This work is dedicated in evergreen memory of my late father, Da Rwang Pam Dabi, whose commitment to my success before his "departure" and silent prayers, ever since, have edified my effort, and to my mother, Ngo Kachollom Dabi and the rest of the family for their forbearance during this period. May the Almighty God Bless you All.

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PREFACE

This thesis is a collection of research papers that have either been accepted or submitted for publication. The introduction in Chapter 1 defines the study problem; aims and objectives; conceptual framework which discusses the nature of the problem, how it was approached, and the relationship among the different research papers that make up the subsequent chapters; and organization of the thesis. These research papers are contained in the chapters indicated below:

Chapter Two:	Dabi, D. D. and Anderson, W. P. (1998) Water scarcity and sustainable agricultural development in the drought-prone semi-arid zone of West Africa. Accepted for publication in the *Proceedings, International Conference on Tropical Climatology, Meteorology and Hydrology*. In Press.
Chapter Three:	Dabi, D. D. and Anderson, W. P. (1998) Water use for commodity production in Katarko Village, Northern Nigeria. Accepted for publication in *Applied Geography*.
Chapter Four:	Dabi, D. D. and Anderson, W. P. (1998) Application of a commodity-by-industry economic ecological model to water demand and use in a rural economy. Submitted to *Journal of Environment Management and Planning*.
Chapter Five:	Dabi, D. D. (1998) Indigenous knowledge systems, technology

transfer and rural water use in Northern Nigeria. Submitted to *Economic Development and Cultural Change*.

Chapter Six: Dabi, D. D. and Anderson, W. P. (1998) A simulation of economic and environmental impacts associated with changes in rural water use: toward policy formulation. Submitted to *Environmental & Resource Economics*.

These papers were written in different formats to satisfy the different journals but have been reformatted into chapters and to conform with the requirements for thesis presentation without changing the content. However, some amount of variation and repetitions are inherent. The major findings from these papers are summarized in Chapter 7.

Whereas most of the papers were co-authored with the research supervisor Dr. Anderson, who provided guidance on the research approach and direction, reviewed and edited the papers, the actual research including data gathering, compilation, processing and analysis, and writing was undertaken by the first author and candidate.

CHAPTER ONE

Introduction

1.1 Background to the study

This study investigates the nature of water use in the economy of a selected drought-inflicted village in semi-arid northern Nigeria. It aims at developing an analytical framework for assessing the water use of alternative economic development scenarios in the village. The research establishes the interrelationship between the village economy and environmental resources. It ascertains the total water requirement of the different production sectors of the economy and determines the associated impacts. Model parameters based on direct data collection and observation of indigenous knowledge systems are employed for this investigation.

Water is demanded for three major human functions: household (domestic), industrial, and agricultural uses. This water is accessed from three basic sources: rainfall, stream flow, and groundwater. However, it is not the amount of water available in the seas or ground storage that determine the availability of water resources for withdrawal but the amount in circulation; that is fresh water flow in rivers and streams, and groundwater flow. The gross amount of water available can be divided into two categories: exogenous supply in cross boundary aquifers and rivers from upstream countries or regions, and endogenous supply through precipitation over the territory in question (Falkenmark, 1989). For arid and semi-arid (ASA) environments groundwater is the most dependable source of water supply.

Of all the three uses of water, agriculture is the greatest consumer in the ASA areas including northern Nigeria. Prior to the oil boom period, agriculture was the most important sector of the Nigerian economy accounting for about 60 percent of GDP and more than 75 percent of export earnings (Oshikoya, 1990). Agriculture is still the major economic activity in the rural areas of Nigeria. It employs more than 75 percent of the ever increasing population and provides food for all including most of the urban dwellers. Therefore the importance of the agricultural sector cannot be overemphasised, even though the oil industry is now the major export earner for the country.

The relative decline in the agricultural sector may be partly attributed to the oil boom in the early 1970s but environmental conditions have also played important roles. Droughts, desertification and water deficits have occurred in the semi-arid zone of northern Nigeria due to climatic fluctuations (see for example Kowal and Knabbe, 1972; Adeniji and Gadzama, 1985; Ojo and Oyebande, 1987; Glantz, 1987; Woo and Tarhule, 1994; Hess, et al, 1995; Tarhule, 1997).

A combination of these conditions has impeded agricultural development in the region. However, it is necessary to encourage the development of other sectors of the economy, particularly agriculture, in order to reduce the tremendous dependence on oil and other non-renewable resources. Agriculture appears to be a viable option for the country's "sustainable development" at least within the limits of existing technologies for industrial and socioeconomic attainment. This will require the expansion of irrigated agriculture, "a strategically important sector of the economy" (Pradhan, 1993; Abubakar, et al, 1993) that presents a possible solution. Not only does it produce the food required for the ever increasing population but it also ensures food security and provides gainful employment to the large number of rural households during the traditionally idle period of the long dry season. With appropriate farming practices, such an effort will ensure sustainability by reducing the pressure on the precarious environmental resources.

Unfortunately, the large-scale irrigation projects and provision of support services embarked upon by the government to improve the agricultural sector and rural development in the drier northern part of the country have not been very successful (Oshikoya, 1990; Salau, 1990; Mitchell, 1994). The planning of these earlier water development projects did not take cognisance of the resultant social and environmental consequences. Most studies have focussed on the supply-side of the water problem and investigated issues of variability and decline (for example, Olaniran, 1991; Anyadike, 1993; Hess, et al, 1995; Tarhule, 1997). Those concerned with environmental predicaments of the region have been discipline specific and conducted at a regional rather than local scale (for example, Falkenmark, 1989; Falkenmark and Lindh, 1993).

Studies on water demand have focussed on residential water demand, analysing the quantity of pipe water used by households as a function of variables such as income and price using traditional water demand models (notably, those by Danielson, 1979; Agthe and Billings, 1980), or applied discrete choice models to analyse direct water use in terms of choice probabilities (Mu, et al, 1990; Madanat and Humplick, 1993). Although the second set of models are applicable to developing countries where alternative sources of water may exist, they only capture direct water use and therefore may not be comprehensive. This is because assessing water demand involves not only direct consumption but also use of water as an input for production. For this research, an input-output oriented model provides a more useful approach.

In order to understand the complexity of this man-environment relationship, Ruddle and Rondinelli (1983) observed that "a fundamental issue that now faces international development organizations and governments in most developing countries is how to generate the knowledge and methodologies needed to enable planners to design programs and projects for the sustained development of the impoverished rural areas in ways that will simultaneously provide solutions to urgent, short-term development problems at the local level and which in the long-term will conserve the biological and physical environment and the natural resource base that it presents." This has necessitated "studies aimed at investigating Africa's water scarcity problems more intensely using micro-scale approaches" (Falkenmark, et al, 1989) and locally generated ("bottom-up") initiatives at an interdisciplinary level (Koudstaal et al, 1992; Falkenmark and Lindh, 1993).

To gain a better understanding of the direct and indirect effects of the water problem and coping strategies in this vulnerable region, interdisciplinary studies conducted on a local scale are needed. An example of such interdisciplinary and locally focussed studies is the "Jos-McMaster Drought and Rural Water Use Research Project" being conducted in Katarko village, Nigeria. This village was selected for the study for three reasons: (i) similarity in physical (environmental) characteristics, sociocultural (generally homogeneous language and religion) groups, and economic (sedentary agriculturalists, pastoralists, craftsmen and traders) activities to the rest of the region; (ii) a typical rural area with limited urban interference and the lack of urban facilities such as pipe-borne water and electricity, as is the case with most rural areas in the region; and (iii) the existence of an enabling environment for data collection (a good rapport, familiarity, and the existence of on-going related research projects in the area). These gave high promise for primary data collection. Also, the use of a single village for this study facilitates an in-depth study of the problem. Moreover, data collection in developing countries, especially in rural areas, is rather expensive in terms of both money and time. However, the study is expected to be of wide applicability not only within the village but for most the semi-arid zone of northern Nigeria in particular and of West Africa in general.

Various components of the Jos-McMaster research project deal with different aspects of the water problem that relate to population, demography, and household water demand and use; crop farming, livestock husbandry, and water use; customs, culture, and perception; water supply, sanitation, hygiene, and health, among others. The research presented in this thesis is part of this interdisciplinary research project and incorporates both economic and ecological (environmental) factors in accounting for water use at the local level. It examines the problem from two perspectives: (i) the demand and use of water for economic activities and other aspects of rural development; and (ii) human behaviour and activities regarding water conservation (saving strategies) and drought mitigation efforts based on indigenous knowledge systems and technologies. It employs a bottom-up (micro-scale) approach that deals directly with the rural inhabitants at a local level. This approach encompasses the household; on-the-farm and activity level water demand and use; water, land (soil) and vegetation conservation measures; activity schedules (for example, animal watering); the use of local technologies in small-scale irrigation along small, local watercourses and seasonally flooded areas; and considers the involvement of the beneficiaries in the planning process towards sustainable agriculture and economic development. This is opposed to the earlier "top-down" approaches of addressing water problems in developing countries at an aggregate scale that resulted in the development of the large-scale water projects.

1.2 Aims and objectives

The main aim of this study is to develop an analytical framework for assessing the water demands of alternative economic development scenarios in a drought-afflicted village. This will be achieved through the following specific objectives:

1. To identify the various economic activities (industries) in the area and the nature of their water demands and use as well as the sources of water for these uses.
2. To define the direct input requirements for the production of goods and services (commodities) by a number of industries identified in (1). This is meant to determine the interrelationships existing among different activities in the local economy.
3. To ascertain the total water requirement (direct and indirect) of the different

industries in the economy (particularly in agriculture-related activities), their use of ecological commodities and their impact on the environment. In other words, how much does the level of each activity affect the available water supply and the environment.

4. To understand the indigenous knowledge systems regarding water scarcity and strategies aimed at mitigating the problem and to generate information required for developing scenarios of water use efficiency.
5. To develop policy measures aimed at managing the water resources of the area for sustainable agriculture and economic development. This will be based on information generated from (2&3) above to determine the impacts, on the economy and environment, associated with changes in production and water use.

These objectives are investigated and reported in a number of papers, some of which have been accepted or submitted for publication and compiled to form this thesis.

1.3 Conceptual framework

In order to achieve the objectives enumerated above, an interdisciplinary approach is needed. This interdisciplinary approach considers the interrelationships between the economy and the environment (as illustration in figure 1.1). It examines the nature of the problem from economic (human) and ecological (environmental) perspectives. Such an investigation requires a methodological framework that captures the two perspectives. The approach adopted for this research follows the framework of the input-output (I-O) model. The I-O

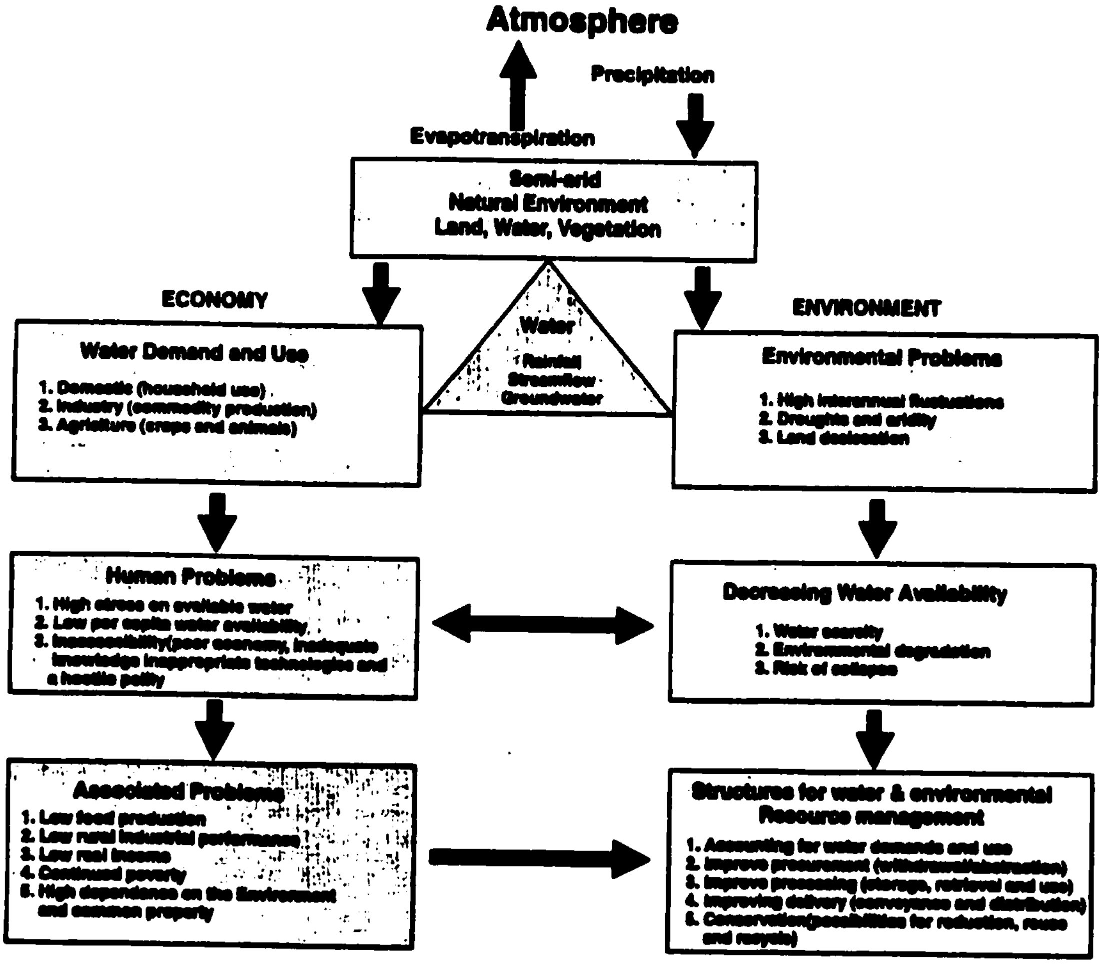

Figure 1.1 Economy-Environment interactions: toward environmental resource sustainability

model is a method of analysis that takes advantage of the relatively stable pattern of the flow of goods and services among the elements of an economy. It is an accounting framework that systematically quantifies the mutual interrelationships among the various sectors of an economic system (Leontief, 1986). It is a comprehensive way of defining the technical relationships between sectors or industries and its coefficients represent input-output relations.

The commodity-by-industry economic- ecological model (CIEEM) used for this study is an environmental extension of the I-O model. This approach considers the interactions within the economic system and between it and the ecological system with particular reference to water. This is because water, an environmental resource, serves as a major but crucial input in the economic activities of the study area (a semi-arid environment) particularly agriculture. The extended input-output framework facilitates the projection of water demand by estimating water requirements in the various use sectors. By incorporating the environmental (ecological) sector, the source of water and other environmental factors (ecological commodities), into the accounting system, it is possible to determine the direct and total (direct and indirect) water requirements of the region (Dabi, 1996). But if one is interested in improving water conservation, the technical coefficients of the model can be changed to investigate the impacts.

The use of a computer simulation model for this investigation facilitated the understanding of the complex functions of an integrated economic-ecological system. The model accounts for flows of ecological commodities withdrawn from the environment for use in the economy and of the waste products eliminated from the economy into the environment with a focus on water. However, the model restricts the ecological commodities to water, land and vegetation, the environmental resources upon which the rural inhabitants depend and which are also at risk of degradation. It does not attempt to simulate detailed interactions within the ecological subsystem. Therefore, the interrelationships between the economic and ecological commodities will be considered in terms of input/output flows of goods and services within the economic subsystem and between it and the ecological subsystem. Background information about this modelling framework and procedures is given in Appendix 1. Other descriptions are contained in the papers that make up this thesis.

Because the I-O model is not a behavioral model, the use of indigenous knowledge systems to investigate human responses to drought conditions is pertinent. It will help elucidate the nature of the problem and water scarcity coping strategies. Under drought conditions activities of the various industries will be constrained due to water scarcity. People may develop water conservation strategies or exploit all possible alternative sources of water including purchase or even adopt new technologies to facilitate their production process. For example, farmers may have to change farming methods, select suitable crops or adopt new irrigation techniques in order to reduce water use at the farm level. Households may also embark on rainwater harvesting and better water storage methods. Under such circumstances, the production process, and thus the technical parameters of the model, will be affected.

The connection between the extended input-output analysis and the indigenous knowledge systems is as follows: the indigenous knowledge systems will identify new water sources, methods of water use and water saving strategies that may be adopted under drought conditions or water scarcity. Consequently, some parameters of the model will have to be adjusted to accommodate the changes either actual or simulated. Results of the model can be used separately or in conjunction with indigenous knowledge systems to address various policy options for better water management strategies to enhance sustainable agriculture and economic development in the area.

1.4 Organization of thesis

The subsequent chapters in this thesis are made up of the different papers accepted or submitted for publication as indicated earlier. However, all the papers tie together into a comprehensive approach to water and economic analysis in Katarko village. Chapter two discusses the issues of economic development and sustainable agriculture in semi-arid region of West Africa in general. It sets the research work in context by introducing the problem at a local scale with Katarko village as the case study area. It concludes with an outline of possible solutions and stresses the need for further investigation toward developing more appropriate strategies for ameliorating the problem of water scarcity in the village in particular and the region at large.

Chapter three describes the first step in the water analysis as it gathered information on activities and how water is used for economic and domestic activities in Katarko. The paper identifies the various economic activities (industries) in Katarko village, the nature of their water demands and use, and sources of water for these uses. It relates groundwater use (the major source of water) to commodity output and income generation of the various industries. This chapter helped in achieving the first objective of the research.

Although Chapter three is a useful starting point in the water analysis, it only gives a partial picture of the impacts of water use because it does not show the indirect effects. In order to achieve that, Chapter four analyses the interrelationships between economic activities and their total input requirements (direct and indirect) for commodity production. It focuses on the use of water, an ecological commodity, as an input in the economy. The commodity-by-industry economic ecological model (CIEEM) forms the bases of the analysis. This chapter meets the second and third objectives. Because these total effects do not capture behavioral aspects of water use, it is necessary to include the human activities and water use to facilitate a meaningful analysis. Therefore, Chapter five examines the indigenous knowledge systems and technologies for water management. It considers strategies adopted by the villagers for coping with water scarcity during droughts or dry periods. Locally fabricated devices and introduced technologies for water procurement, delivery and processing are compared. The annual scheduling of activities *vis-a-vis* water availability is also considered. Alternative strategies ("appropriate technologies") are suggested. This chapter aims to generate information required to develop scenarios of water use efficiency analyzed in the next chapter and meets the fourth objective.

Chapter six uses data generated in Chapter three, the commodity-by-industry economic-ecological model (CIEEM) developed in Chapter four, information on human responses from Chapter five as well as literature on rural development policies in the area and others with similar environmental and human characteristics to develop scenarios for alternative economic development. These scenarios are useful policy approaches aimed at water and resource management and sustainable economic development in the village and the area in general. The policy approaches, therefore, are presented in two sets of scenarios (i) increase in production to meet new final demand for economic development and (ii) changes in water use to ensure conservation. These scenarios are simulated using the CIEEM in Chapter six to determine the impacts on the economy and the environment associated with the changes and meets the last objective. Chapter seven concludes the thesis with a summary of the major findings, contributions to the field of enquiry, and directions for future research.

The papers compiled to produce this thesis have already been accepted or submitted for publication but reformatted into chapters and to conform with the requirements for thesis presentation without changing the content. However, additional reference is made to Appendix 1 in Chapters four and six. This was necessary for purposes of clarity should a reader be interested in some of the detailed information which for lack of space were not included with the original papers. Because this thesis is a compendium of distinctive but mutually inclusive papers, some material is unavoidably duplicated.

My research supervisor, Dr. W. P. Anderson is a co-author of most of the said papers. He provided guidance on the research approach and direction, reviewed and edited the papers. By and large, data gathering during fieldwork, data compilation, processing and analysis, and writing were all done by the first author and candidate.

References

Abubakar, S., Arokoyo, T., Yiljep, Y., and Zaria, M. (1993) "Research and extension in irrigation technology development in Nigeria." In Nwa, E. and Pradhan, P. (eds) (1993) *Irrigation Research Priorities for Nigeria.* Proceedings of a National Seminar, University of Ilorin, Nigeria. IIMI, Kano. 58-61.

Adeniji, F.A. and Gadzama, N.M. (1985) "Recent developments in water resources management in the arid zone of Nigeria." *Ecological Disasters in Nigeria: Drought and Desertification.* Proceedings of the National Workshop on Ecological Disasters in Nigeria: Drought and Desertification, Kano, Nigeria. 362-373.

Agthe, D. and Billings, R. (1980) "Dynamic models of residential water demand." *Water Resources Research* **16(3)**, 476-480.

Anyadike, R.N. (1993) Seasonal and annual rainfall variations over Nigeria. International *Journal of Climatology*, **13**, 567-580.

Dabi, D.D. (1996) Water demand and use in the rural economy of a semi-arid environment: a northern Nigeria case study. - A Doctoral research proposal presented in the Dept. of Geography, McMaster Univ. (Hamilton, Canada, 22 September, 1996), 36 pp.

Danielson, L.(1978) "An analysis of residential demand for water using time-series data." *Water Resources Research* **15(4)**, 763-767.

Falkenmark, M. (1989) "The massive water scarcity now threatening Africa: Why is it not being addressed?" *Ambio* **18(2)**, 112-118.

Falkenmark, M., Lundqvist, J. and Widstrand, C. (1989) "Macro-scale water scarcity requires micro-scale approaches: aspects of vulnerability in semi-arid development." *Natural Resources Forum* **13**, 285-267.

Falkenmark, M. and Lindh, G. (1993) "Water and economic development." In Gleick, P.H. (ed.) *Water in Crisis: A Guide to World's Fresh Water Resources.* Oxford University Press, Oxford. 80-91.

Glantz, M.H. (1987) *Drought and Hunger in Africa: Denying Famine a Future.* Cambridge University Press.

Hess, T.M., Stephens, W., and Maryah, U.M. (1995) "Rainfall trends in the North Eastern Arid zone of Nigeria." *Agricultural and Forest Meteorology* **74** (1995), 87-97.

Koudstaal, R., Rijsberman, F.R. and Savenije, H. (1992) "Water and sustainable development." *Natural Resources Forum* **16**, 277-290.

Kowal, J. and Knabbe, D. (1972) *An Agroclimatological Atlas of the Northern States of Nigeria.* Ahamadu Bello University Press, Zaria.

Leontief W, 1986 *Input-Output Economics* 2nd ed. Chapters 1&2 (Oxford University Press, New York)

Madanat, S. and Humplick, F. (1993) "A model of household choice of water supply systems in developing countries." *Water Resources Research* **29(5)**, 1353-1358.

Mitchell, B. (1994) "Addressing the 'edge' problems in land and water management in the Sokoto-Rima river basin, Nigeria." *Geoforum* **25(2)**, 133-143.

Mu, X., Whittington, D. and Briscoe, J. (1990) "Modelling village water demand behaviour: A discrete choice approach." *Water Resources Research* **26(4)**, 521-529.

Olaniran, O.J. (1991) Evidence of climatic change in Nigeria based on annual series of rainfall of different daily amounts, 1919-1985. *Climatic Change* 19, pp 319-341.

Ojo, O. and Oyebande, L. (1987) "Trends in occurrences and severity of droughts in Nigeria." In Sagua, V.O., Enabor, E.E., Kio, P.R.O., Ojanuga, A.U., Mortimore, M., and Kalu, A.E. (1987) *Ecological Disasters in Nigeria: Drought and Desertification.* Federal Ministry of Science and Technology, Lagos. 11-53.

Oshikoya, T.W. (1990) *The Nigerian Economy: A macroeconomic and Input-Output Model.* Praeger Publications, New York.

Pradhan, P. (1993) "Research priority of irrigation in Nigeria." In Nwa, E. and Pradhan, P. (eds) (1993) *Irrigation Research Priorities for Nigeria.* Proceedings of a National Seminar, University of Ilorin, Nigeria. IIMI, Kano. 19-32.

Ruddle, K. and Rondinelli, D.A. (1983) "Resources, environment, and development policy: A resource system framework." *Resource Management and Optimization* **3(1)**, 1-22.

Salau, A.T. (1990) "Integrated Water Management: the Nigerian experience." In Mitchell, B. (ed.) (1990) *Integrated Water Management: International Experiences and Perspectives.* Belhaven Press, London. Chapter 8, 188-202.

Tarhule, A. (1997) "Droughts, rainfall and rural water supply in northern Nigerian." A PhD thesis, McMaster University, Hamilton, Canada, 163pp.

Woo, M-K. and Tarhule, A. (1994) "Streamflow droughts of northern Nigerian rivers." *Hydrological Sciences Journal* **39(1)**, 19-34.

CHAPTER TWO

Water scarcity and sustainable agricultural development in the drought-prone semi-arid zone of West Africa

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Abstract

This paper considers the potential water availability for sustainable agricultural development in drought-prone areas of West Africa. It provides overviews of hydro-climatological characteristics of the region, land use practices, and technological development. The first (rainfall, streamflow and groundwater) provides valuable information on water resources availability while the latter two provide the necessary information on human activity and its effect on the environment. Five different conditions responsible for the increasing severity of water scarcity are identified: aridity and intermittent droughts, attributed to climatic change and natural environmental conditions; land degradation; population growth; and weak economic, institutional and technological bases. These conditions are viewed to be mutually inclusive and operating in a form of vicious cycle. A survey of human activities from a selected rural area in semi-arid northern Nigeria support this assertion.

It is concluded that within the existing climatic, environmental, and human conditions, these areas will experience severe water scarcity, unsustainable agricultural development, and subsequent food and economic insecurity unless stringent water and environmental management strategies are developed. The paper suggests an integrated (multidisciplinary) approach to ensure sustainable agricultural development in the area.

Keywords: agriculture, drought-prone, economy, environment, resources, rural, scarcity, sustainable, water.

2.1. Introduction

Sub-tropical regions of the world have marked dry and wet climatic conditions and experience drought related problems, aridity and water scarcity. Falkenmark (1989) observed that most of the less developed countries (LDCs) are located in the water-scarce regions of the tropics and subtropics (arid and semi-arid regions, ASA). They have three basic characteristics: (i) located where water is scarce for most or part of the year; (ii) experience intermittent drought years; and (iii) experience a high evaporative demand, which prevents much rainfall from being used for human activities (Falkenmark and Lindh 1993; Clarke 1993). A larger part of the African continent, including the semi-arid (Sahelian) belt of West Africa, which depends on agriculture, lies in this zone where most of the year is arid with recurrent droughts which severely impede agriculture.

The impact of the intermittent droughts, particularly those of 1968-73 and 1984-85, coupled with rapid population growth in the arid and semi-arid (ASA) regions of Africa, have led to severe water shortages, environmental degradation and the consequent outcry for food security in the affected areas. However, food aid and other relief measures from various international donor agencies have not solved the problem. This has necessitated more internal investigations of Africa's water scarcity problems using micro-scale approaches (Ruddle & Rondinelli 1983; Falkenmark et al. 1989).

This paper reviews issues of water scarcity in the ASA zone of West Africa and points to new research directions. An ongoing study of Katarko village in northern Nigeria is used to illustrate the problem of water scarce regions and provide an example of a research agenda for addressing human-environment interactions using micro-scale and integrated approaches. (see figure 2.1).

(Figure 2.1 about here)

2.2. Water scarcity

Water scarcity is defined here as the difference between water availability and water demand. That is the shortfall in the amount of water available for human use. Significant water shortages (shortfalls) in most parts of Africa led the United Nations at the end of 1984 to declare most of sub-Saharan Africa as countries lying within the verge of aridity and to be suffering from 'abnormal food shortages'. However, as Clarke (1993) rightly argues, the real truth is that Africa was not so much short of food as of water. Although this water scarcity was related to droughts, controversial but exceptional meteorological events, water shortage in much of Africa and elsewhere is not exceptional but endemic, a part of everyday life (Falkenmark 1989).

2.2.1 Water availability

There are three basic sources of water for human use: rainfall, streamflow, and groundwater. These can be assessed through meteorological, hydrological and geologic surveys, and water balance studies (Mutiso & Thompson 1987). However, it is not the amount of water available in the seas or ground storage that determines the availability of water resources for withdrawal but the amount in circulation; that is fresh water flow in rivers and streams, and groundwater flow. The gross amount of water available can be divided into two categories: exogenous supply in cross boundary aquifers and rivers from upstream countries or regions, and endogenous supply through precipitation over the territory in question (Falkenmark 1989).

Falkenmark et al. (1989) and Clarke (1993) identified four causes of water scarcity: (i) aridity as a permanent shortage of water caused by a dry climate; (ii) droughts as an irregular phenomenon occurring in exceptionally dry areas; (iii) desiccation as a drying up of the landscape, particularly soil, resulting from activities such as deforestation and overgrazing; and (iv) water stress which is due to increased *per capita* demand over fixed levels of water supply. These can be regrouped in two categories: the first two are climatic and the latter are due to human activity.

West Africa's mean annual rainfall varies from more than 3500 mm in coastal (rainforest) areas of the south and south-west to less than 500 mm in desert fringe of the north. Although its semi-arid zone is endowed with many river systems and lakes, notably the rivers Niger, Senegal, the Gambia, and Volta, surface water (streamflow) is limited. This is because many of the rivers and tributaries traversing the region carry less water and easily dry up during the dry season due to high evaporative demand and siltation. The same problem in association with human activities is attributable to the shrinkage of Lake Chad in West Africa (Hutchinson et al. 1992). The region relies to a great extent on the groundwater found in fractures, joints and partially decomposed rocks (Agboola 1979).

Studies have indicated a progressive decline in the availability of water in the region.

For example, Glantz (1987) observed that desertification has occurred due to incidence of drought. Woo & Tarhule (1994) and Hess et al. (1995) have reported the seasonality, reduction in duration and amount of rainfall in northern Nigeria (see figure 2.2 & table 2.1). Similar conditions have been explained for Sierra Leone (Bah 1987).

(Figure 2.2 and Table 2.1 about here)

2.2.2 Water demand

Water is demanded for three major functions: household (domestic), industrial, and agricultural uses. Increasing water demand has been attributed to three major factors: rapid population growth; increased consumption due to improved standards of living; and expansion in water-related commodity production and service industries (United Nations 1976). Relating population growth and water scarcity, Falkenmark (1990) developed a hypothetical model on water availability and population size and constructed a global water scarcity index. By her projections, Nigeria among other West African countries, would be experiencing "absolute" water scarcity by the year 2025. Absolute water scarcity is a situation beyond the limits of water stress resulting from excess demand over water availability from the water cycle.

2.3. Human activities and the environment

Agriculture (animal and crop production) is the predominant human and economic activity in the semi-arid zone of West Africa. It provides the means of livelihood (food) and employment for the ever increasing population. The relative decline in *per capita* food production in this region (see figures 2.3 & 2.4) may be attributed in part to the recurrent droughts experienced in the zone and partly to other "man-induced" problems as discussed below.

(Figures 2.3 & 2.4 about here)

Sub-Saharan Africa suffers from endemic environmental problems which include deforestation, overgrazing, soil erosion, ecological degradation, and desertification. Although these are blamed on rapid population growth and poverty, there is no conclusive evidence to show that the people have been unconcerned with the quality of their environment. Rather, the problems are more insidious than meets the eye. Three factors: population pressure, heavy foreign debt burden, and political instability have impeded economic development in the region. It is confronted with consequences of inappropriate policies, poor economies and managerial incapabilities, as well as an increasingly hostile external economic milieu. Poverty has forced families to develop simple but problematic survival strategies, over-exploitation of natural resources: subsistence farming and grazing on marginal lands, overuse of surface water sources and wetlands, and fuel wood harvesting. Consequently, acute pressure is exerted on the environment leading to eventual degradation. (World Bank 1989; Mabogunje 1995).

Watts' (1987) review of the ecological context and conditions of operation, human knowledge and effort geared toward food production under environmental uncertainty, and the socio-political and economic changes in semi-arid West Africa, summarized as follows:

"peasant knowledge and practice is overridden by forces that compel peasants and pastoralists to destroy their own environment in attempts to delay their own destruction."

2.3.1 Sustainable agriculture

Declining water availability in semi-arid West African has serious repercussions on the agricultural development of the area. Rainfed farming is adversely affected, while irrigated agriculture and animal rearing are facilitated only at locations accessible to surface and groundwater sources. Otherwise, up to eight months of the year become an idle period for most of the rural population, except for those engaged in other non-farm economic activities (rural industry). Therefore, the demand for water for agriculture, rural industry, and domestic uses exerts tremendous pressure on the limited water resources and the environment.

Because water is a major input in the agricultural sector, which provides employment and food to the rural and urban populations, water must be exploited to facilitate agriculture. But in order to avoid the stated repercussions, there is need for better management of water resources to enhance sustainable agriculture and rural development in this semi-arid environment. The question may then arise "How sustainable can agriculture be in the ASA areas of LDCs?" The lack of a precise definition of the concept of "sustainable development" makes the question difficult to answer. However, a considerable consensus has evolved in support of the main idea that it is both morally and economically wrong to consider the world (natural resources) as a business liquidation (Daly 1991; Caldwell 1994), and this implies an increasing consensus on the need for sustainable development (Kumar et al. 1993).

A generally acceptable connotation of "agricultural sustainability" is feasible following Douglas' (1984) work. He identified three schools of thought regarding agricultural sustainability: (i) the economists' viewpoint which is concerned with greater production efficiency and views agriculture primarily as an instrument for food sufficiency; (ii) the ecological view point that sees agriculture as being unsustainable because it depletes, pollutes, or disrupts the ecological balance of natural systems, but subscribes to ecological stewardship; and (iii) the "alternative" agriculturalists whose ideas are similar to the second group but promote vital and coherent rural cultures for environmental preservation. Compromising these schools of thought, Douglas conceptualized that "agriculture will be found to be sustainable when ways are discovered to meet future demands for foodstuff without imposing on society real increases in social costs of production and without causing the distribution of opportunities or incomes to worsen." However, it is evident that current production structures are unsustainable.

van Kooten (1993) quoted Hileman's definition of sustainable agriculture as follows:

> "Sustainable agriculture is a system approach to farming that seeks to develop a multiyear practice that takes advantage of whatever is produced or can be produced on the farm, including naturally occurring beneficial biological interactions, to ensure soil fertility and keep losses from pest, weeds, animal diseases within acceptable levels. The aims are adequate productivity and profitability, conservation of resources, protection of the environment, and assured food safety." (Hileman 1990, p. 27).

This definition seems to embrace the three schools of thought noted by Douglas (increased productivity, stewardship, and preservation) and tends to relate sustainability with conservation. It is also in line with the doctrines of sustainable development (World

Commission on Environment and Development 1987). Therefore, it presents an acceptable definition of 'agricultural sustainability' for use in this study.

2.4. Towards a sustainable agricultural development

The growing concern over water scarcity and its effects on the world's population, particularly the developing countries, has called for better water management strategies. These have been viewed from different perspectives by various workers. For example Gustafsson (1980) suggested an ecological approach to water management which incorporates spatial variability in both water availability and population distribution on a regional rather than global scale. Mutiso & Thompson (1987) advocated an integrated rural-water resource development management strategy through the determination of water balance. It provides qualitative information on water resources potential, including spatial and temporal distribution of untapped water resources, possible resource exploitation, and optimal utilization. Falkenmark (1989) suggested an integrated soil-water-nutrient-vegetation conservation approach. And Mitchell (1990) has documented comprehensively the various approaches to integrated water management.

Since agriculture is still the predominant economic activity, the relationship between water and development is strong. Agriculture is the largest consumer of water and water is the most crucial input for agricultural production. Thus, water scarcity is a major impediment to agricultural development with a resultant food shortage and insecurity. In order to achieve sufficiency in food production the available water resources have to be augmented for both rainfed and irrigated agriculture. This must be carried out in a manner which ensures agricultural sustainability without jeopardizing future food production. Unlike water-rich developing countries, especially southeast Asia, where improved crop varieties have been the major technological breakthrough in agricultural advancement, existing water management practices in irrigated agriculture, the only option for water deficit areas, must be ameliorated.

Pradhan (1993) observed that irrigated agriculture is "a strategically important sector of the Nigeria economy" and needs to expand. Since this may lead to drastic increase in water demand within limited supply, it can only be sustained by good water management and conservation strategies. Most efforts at managing the water resources in the drier parts of developing countries have been through the construction of large-scale dams along major rivers for the provision of municipal water supply and irrigation development. Unfortunately, most of the river basin development projects, for example the Sokoto Rima river basin development (Bakolori dam) project in Nigeria have not performed to expectation due to managerial and institutional bottlenecks, and operational constraints among others(Mitchell 1994). Rather, they have contributed to more environmental problems, degrading wetland ecosystems and depriving water to users downstream (Adams 1986; Scudder 1989; Mabogunje 1995).

Although small-scale irrigation initiatives have been introduced, they have faced problems similar to the large-scale schemes, particularly, technological fixes (Kimmage 1991) and adverse effects on traditional activities (Kimmage & Adams 1992). However, many contributors have written in favour of small-scale irrigation projects and the need for farmer participation in decision making (Adams 1986; Gladden & Phillips-Howard 1992). Small-scale irrigation initiatives, if properly harnessed will provide the most viable and sustainable agricultural development in this semi-arid zone. Efforts at rainwater harvesting and rainwater farming in water-scarce North and East Africa have been reported by Asswad (1995) and Arntzen (1995) respectively.

2.5. Case study: Katarko village

Katarko is a village of about 3,000 people located in semi-arid north eastern Nigerian. Rainfall, streamflow, groundwater data for the village is not yet available. But it has similar environmental characteristics and human activities as the rest of northern Nigeria or the Sahel. Our literature suggests that most studies related to water resources in this region have been discipline specific and more generalized. An interdisciplinary perspective and on a micro-scale has therefore been taken to investigate the situation in this area. This will facilitate an understanding of the direct and indirect effects of this man-environment relationship and measures adopted by the people in coping with declining water availability, declining agricultural productivity, and degrading environment, towards sustainability.

The study investigates the nature of water demand in the entire economy with two main objectives: (i) establishing the relationship between the production of goods and services (commodities) and the use of ecological commodities (water, land, and vegetation) in the economy; and (ii) ascertaining the total water requirement (direct and indirect) of the different sectors of the economy (particularly in agricultural-related activities). In other words, determining the effect of each activity on water availability, their impact on the environment and interrelationships in the local economy. This will be investigated using the model parameters and indigenous knowledge systems.

This approach follows the framework of the input-output (commodity-by-industry economic- ecological) model. It considers the interactions within the economic system and between it and the ecological system with particular reference to water. This framework facilitates the projection of water demand by estimating water requirements in the various use sectors. By incorporating the environmental (ecological) sector, the source of water and other environmental factors (ecological commodities), into the accounting system, it is possible to determine the total water requirement of the region (community) by means of computer simulations. Indigenous knowledge systems will help elucidate the nature of the problem and coping strategies. Under drought conditions agricultural activities for example, will be constrained due to water scarcity. Farmers may develop water conservation strategies or adopt new technologies. Under such circumstances, the production process will be affected and thus the technical coefficients of the model (use and make matrices). Consequently, the coefficients of the model will be adjusted to fit such changes (Dabi, 1996).

Preliminary results from field data indicate that agriculture, compared to domestic and industrial uses, is the highest consumer of water in the village (see figure 2.5). Agricultural water is demanded mostly for irrigated farming and for watering animals. Existing technologies for water collection, storage, delivery and use are basically traditional. Few dry season farmers use machines to pump water from wash bore-holes to irrigate swamp rice and wheat for external markets. Generally, crops grown are traditional market garden vegetables consumed locally. Olsson (1993) and Hess et al. (1995) have indicated a close association between crop (grain) yield and the number of rainy days; therefore, rainfed farmers who grow staple crops may be forced to engage in some form of irrigation if the rate of rainfall decline in the region continues.

(Figure 2.5 about here)

The model described above is being constructed by the authors to determine the transactions between the economy and the environment with particular reference to agriculture and water use. The research requires further field investigations. Thus, a second field season aimed at developing scenarios of water use efficiency has been scheduled for the next dry season.

2.6. Concluding remarks and suggestions

This paper identifies five interrelated conditions of water scarcity as follows: (i) aridity, a permanent shortage of water caused by a dry climate; (ii) droughts, irregular phenomena occurring in exceptionally dry areas; (iii) desiccation, drying up of the soil and landscape due to deforestation and overgrazing; (iv) water stress, due to increased *per capita* demand over fixed levels of water supply; and (v) inaccessibility, due to adverse economic, institutional (socio-political and educational), and technological bases to harness and manage the potential water available. These can be regrouped into two; the first two are climatic and the latter three man-made.

Further, the paper identify three problems of unsustainable agricultural development and environmental degradation emanating from this water scarcity: (i) a relative decline in *per capita* food production; (ii) continued poverty and food insecurity; and (iii) endemic environmental problems which include deforestation, overgrazing, soil erosion, ecological degradation, and desertification.

In order to achieve a sustainable agricultural development policy in the region, the following suggestions are advanced: (i) development of small-scale irrigation schemes and maintenance of a relatively high but sustainable levels of productivity; (ii) cultivation of drought resistant crop varieties with high utility value, adaptable to the natural and socio-economic setting; (iii) facilitate the use of local inputs, organic manures and other farm nutrients in order to optimize the rate of turn over and enhance the recycling of matter; (iv) use of appropriate technologies suitable to meet the needs of farmers and pastoralists; (v) development of rainwater harvesting and farming practices to maximize the use of water normally lost to evaporation; (vi) encourage better water management strategies during withdrawal, storage, delivery and use; (vii) establishment of an enabling political environment and willpower for and participation by the inhabitants; and (viii) conduct micro-scale multidisciplinary researches such as the one outlined for Katarko village to establish the possibility of attaining these suggestions. Authors of this paper are currently working along those lines. Their findings will be reported elsewhere.

Acknowledgement

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References

Adams, W.M. 1986. Traditional agriculture and water use in the Sokoto valley, Nigeria. - *The Geographical J.*, **152** (1): 30-43.

Agboola, S.A. 1979. An agroclimatological atlas fNigeria. Oxford University Press, Oxford.

Arntzen, J. 1995. Economic instruments for sustainable resources management: The case of Botswana's water resources. - *Ambio*, **24** (1); 7-15.

Asswad, R.M. 1995. Agricultural prospects and water resources in Libya. - *Ambio*, **24** (6): 324-327.

Bah, O. 1987. Rural water supply development in Sierra Leone. - *Singapore J. of Tropical Geography*, **8** (2): 84-96.

Caldwell, L. 1994. Sustainable development: viable concept and attainable goal? - *Environmental Conservation*, **21** (3): 193-195.

Clarke, R. 1993. Water: The international crisis. The MIT Press, Cambridge, Massachusetts.

Dabi, D.D. 1996. Water demand and use in the rural economy of a semi-arid environment: a northern Nigeria case study. - A Doctoral research proposal presented in the Dept. of Geography, McMaster Univ. (Hamilton, Canada, 22 September, 1996), 36 pp.

Daly, H.E. 1991. The steady-state economy. - *In*: Dobson, A. (ed.), The Green Reader. Andre Deutsch. 145-151.

Douglass, G.K. 1984. The meanings of agricultural sustainability. - *In*: Douglass, G.K. (ed), Agricultural Sustainability in a Changing World Order. Westview Press/ Boulder, Colorado.

Falkenmark, M. 1989. The massive water scarcity now threatening Africa: Why is it not being addressed? - *Ambio*, **18** (2): 112-118.

Falkenmark, M. 1990. Rapid population growth and water scarcity: The predicament of tomorrow's Africa. - *In*: Davis, K. & Bernstam M. (eds.), Resources, environment and population: Present knowledge and future options, pp. 81-94.

Falkenmark, M. & Lindh, G. 1993. Water and economic development. - *In* Gleick, P.H. (ed.), Water in crisis: A guide to world's fresh water resources. Oxford Univ. Press, Oxford, pp. 80-91.

Falkenmark, M., Lundqvist, J. & Widstrand, C. 1989. Macro-scale water scarcity requires micro-scale approaches: aspects of vulnerability in semi-arid development. - *Nat. Res. Forum*, **13**: 285-267.

Gladden, J.N. & Phillips-Howard, K. 1992. Policy approaches to agricultural development in Nigeria: Transfer of technology and farmer first. - Paper presented at the National Workshop on strategies for agricultural development (Univ. of Agric., Makurdi, April 8-10, 1992).

Glantz, M.H. 1987. Drought and hunger in Africa: Denying famine a future. Cambridge Univ. Press.

Gustafsson, Y. 1977. Variations in rainfall as a natural constraint on agriculture. - *Ambio*, **6** (1): 34-35.

Hess, T.M., Stephens, W., & Maryah, U.M. 1995. Rainfall trends in the North Eastern Arid zone of Nigeria. - *Agric. & Forest Met.*, **74**: 87-97.

Hileman, B. 1990. Alternative agriculture. *Chemical Engineering News*, **68** (March): 26-40.

Hutchinson, C.F., Warshall, P., Arnold, E.J., & Kindler, J. 1992. Development in arid lands: Lessons from Lake Chad. *Environment*, **34** (6): 16-20, 40-43.

Kimmage, K. 1991. Small-scale irrigation initiatives in Nigeria: the problems of equity and sustainability. *Appl. Geography*, **11**: 5-20.

Kimmage, K. & Adams, W. 1992. Wetland agricultural production and river basin development in the Hadejia-Jama'are valley, Nigeria. *The Geographical J.*, **158** (1): 1-12.

Kumar, R., Manning, E.W., & Murck, B. 1993. The challenge of sustainability. Don Mills, Ont.: Centre for a sustainable future, Foundation for training.

Mabogunje, A.L. 1995. The environmental challenges in sub-Saharan Africa. *Environment*, **37** (4): 4-9, 31-35.

Mitchell, B. 1990. Integrated water management: International experiences and perspectives. Belhaven Press, London.

Mitchell, B. 1994. Addressing the 'edge' problems in land and water management in the Sokoto-Rima river basin, Nigeria. *Geoforum*, **25** (2): 133-143.

Mutiso, S, K. & Thompson, R. D. 1987. Future water supply in the Machakos District of Kenya.- *Ambio*, **16** (6): 322-325.

Olsson, L. 1993. On the causes of famine - drought, desertification and market failure in the Sudan.- *Ambio*, **6**: 395-403.

Pradhan, P. 1993. Research priority of irrigation in Nigeria. - In: Nwa, E. & Pradhan, P.

(eds.), Proceedings of a National Seminar on irrigation research priorities for Nigeria (Univ. of Ilorin, Nigeria. IIMI, Kano) pp. 19-32.

Ruddle, K. & Rondinelli, D.A. 1983. Resources, environment, and development policy: A resource system framework. - *Resour. Management and Optimization*, **3** (1): 1-22.

Scudder, T. 1989. Conservation verses development: river basin projects in Africa. - *Environment*, **31** (2): March, 1989.

United Nations 1976. The demand for water: Procedures and methodologies for projecting water demands in the context of regional and national planning. Nat. Resour./Water Series 3, New York.

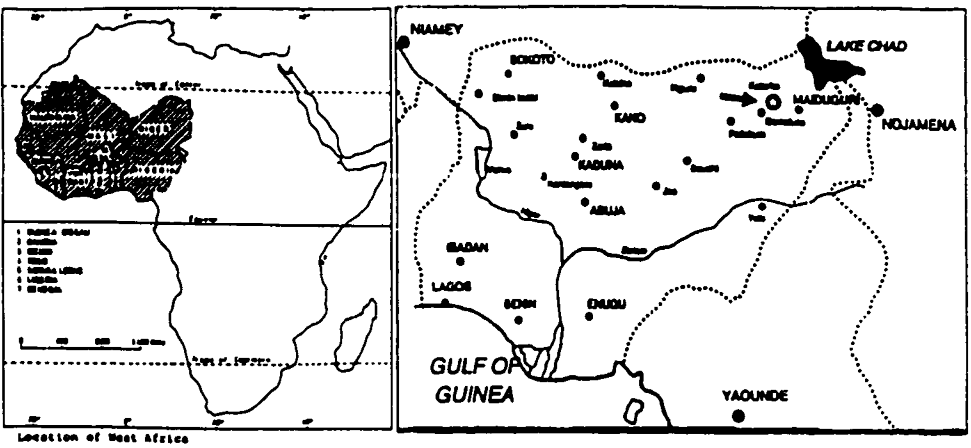
van Kooten, G.C. 1993. Conservation and sustainable development. - In: van Kooten, G.C. (ed.), Land resource economics and sustainable development: Economic policies and the common good. UBC Press, Vancouver, pp. 164-187.

Watts, M.J. 1987. Drought, environment and food security: some reflections on peasants, pastoralists and commoditization in dryland West Africa. - In Glantz, M.H. (ed), Drought and hunger in Africa: Denying famine a future. Cambridge University Press, Cambridge.

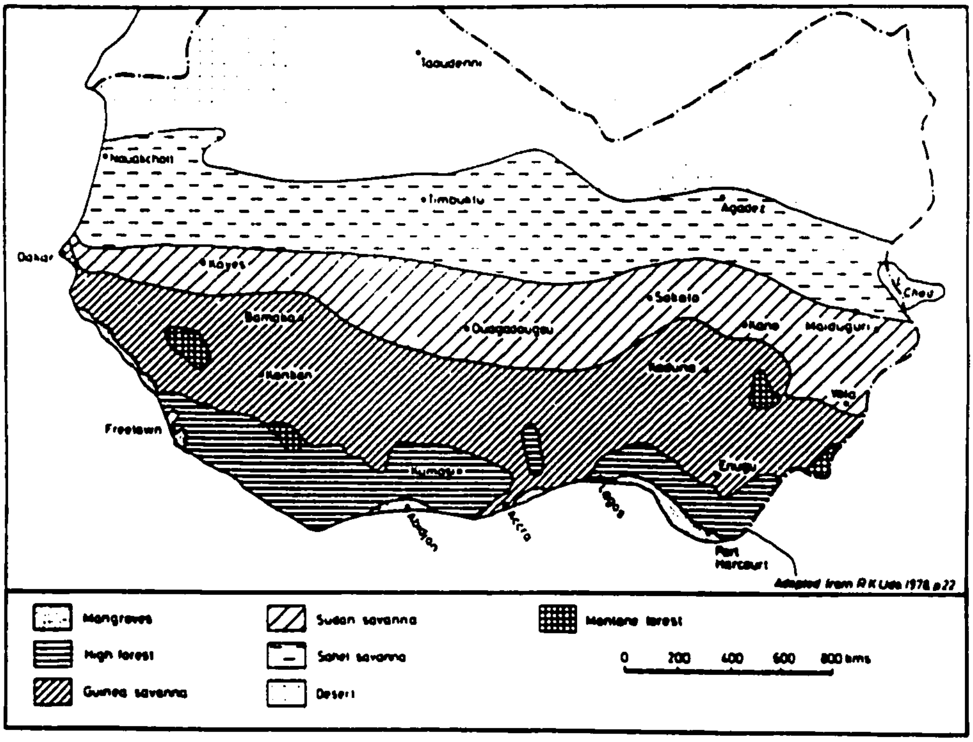
Woo, M-K. & Tarhule, A. 1994. Streamflow droughts of northern Nigerian rivers. - Hydrol. Sciences J., 39 (1): 19-34.

World Bank. 1989. Sub-Saharan Africa: from crisis to sustainable development: A long term perspective study. World Bank, Washington, D.C., 22 pp.

World Comm. on Env.& Devt. 1987. Our common future. Oxford Univ. Press, Oxford.



Location of West Africa



Adapted from R K Udo 1978 p22

The main vegetation belts of West Africa

Figure 2.1 General reference map showing location of West Africa and study area

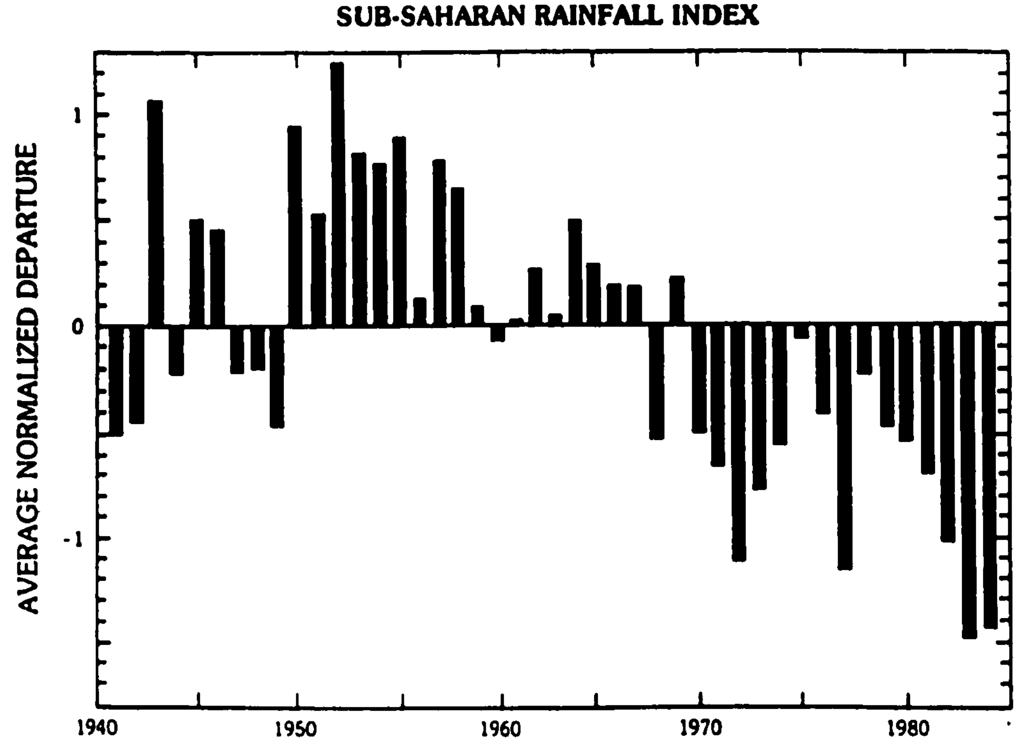


Figure 2.2 Rainfall index for 20 sub-Saharan stations in West Africa west of 10° E between 11° N and 19° N (developed by Lamb 1985); Source: Glantz (1987)

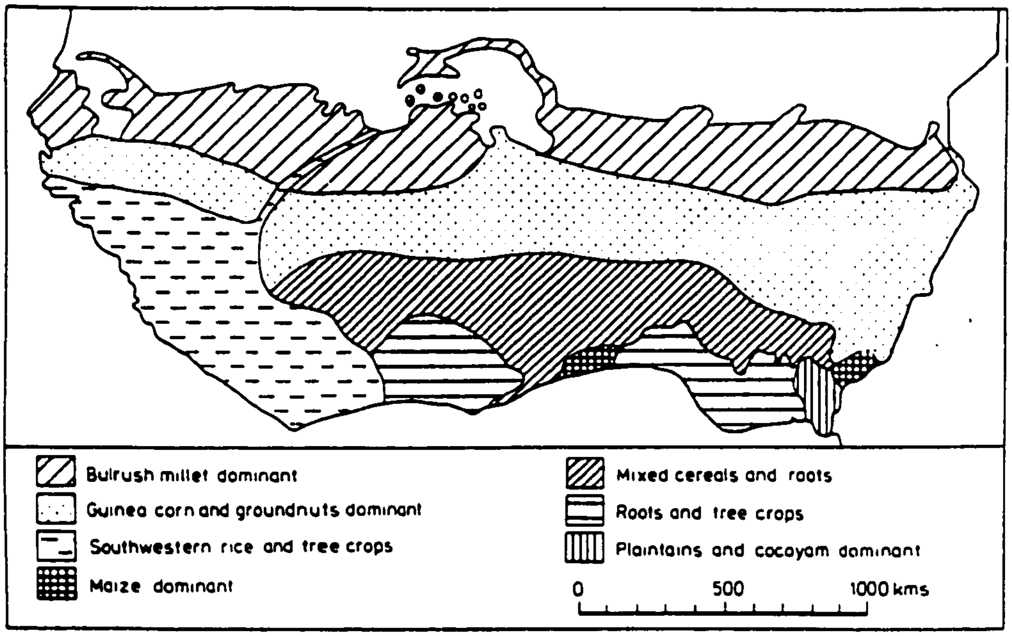


Figure 2.3 General pattern of crop production in West Africa

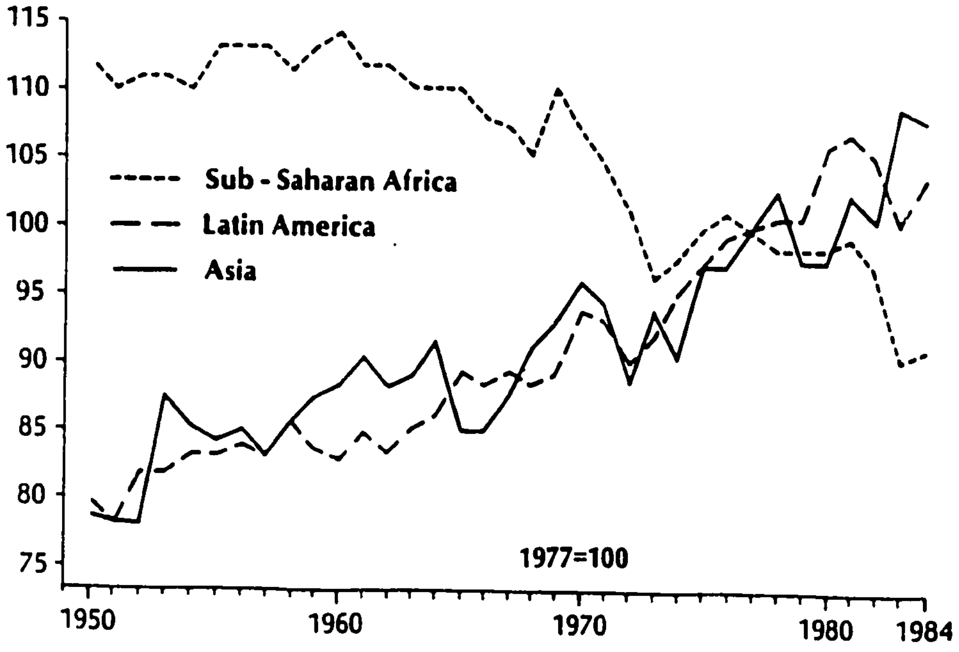


Figure 2.4 Regional trends in per capita food production. Source: Guthrie (1986)

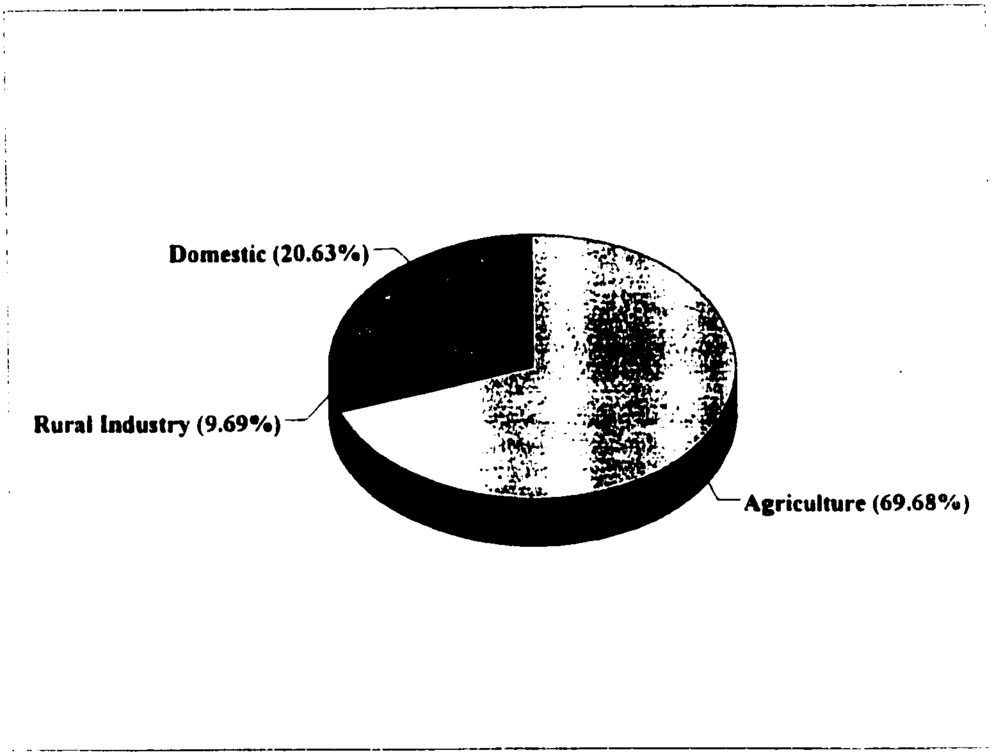


Figure 2.5 Pattern of water use in Katarko village, Nigeria.
Source: Field survey (1995)

Table 2.1: Number of rain-days per year and average rain per day for 1961-1970, 1971-1980 and 1981-19

Station	No rain-days			Mean rain per rain-day (m)		
	1961-1970	1971-1980	1981-1990	1961-1970	1971-1980	1981-1990
Potiskum	53.0	42.0	29.0	14.2	13.6	16.9
Maiduguri	47.0	35.0	30.0	12.0	14.1	12.5
Nguru	36.0	27.0	20.0	12.7	13.6	13.5
Maine Soroa	26.0	25.0	20.0	13.5	11.3	10.3

Source: Hess et. al., (1995)

CHAPTER THREE

Water use for commodity production in Katarko village, northern Nigeria

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Abstract

This paper investigates water use in a rural village in semi-arid Northern Nigeria. Water use is viewed from the perspective of four production sectors (agriculture, rural industry, trade and services) as well as domestic (drinking, cooking and sanitary) uses. Water for these uses may be from three sources: rain water, surface water, and groundwater. This study focusses on groundwater. Results of a detailed survey indicate that groundwater use is dominated by agricultural activities including irrigated vegetables and grains, tree crops, and animal rearing. A ratio of water use to income generated is used as a measure of water intensity that can be compared across activities and commodities. Agricultural commodities, especially irrigated vegetables, grains and trees, are shown to be the most water intensive. The results provide useful background information for the development of predictive models and water conservation strategies.

Key words: Water, Sahel, Village, Irrigation, Conservation.

3.1 Introduction

This paper presents an analysis of water use in a drought-inflicted village in northern Nigeria. It represents the preliminary findings of a research project whose objective is to assess the implications of alternative rural development scenarios for water use and water scarcity. As a first step toward such an assessment, detailed household surveys were conducted to determine the direct and indirect water requirements of all village activities. The goal is to help to identify scenarios for more efficient water use by determining those activities whose benefits to the local economy are greatest relative to their impacts on water resources.

At the heart of our analytical approach is the assignment of all village activities to categories for which input-output relations can be measured. The village economy is thus represented as a set of interrelated industries producing a larger set of commodities. *Industries* are groups of firms or households that produce goods or services for intermediate or final demand. *Commodities* are the individual products of the industries. Each industry produces one or more commodity, and in principle the same commodity can be produced by more than one industry. Goods such as water and fire wood which are extracted directly from the environment for use in the economy are referred to as *ecological commodities* (Miller and Blair, 1985; Dabi, 1996).

Data collected in the village chronicle the typical water use of a sample of households and firms engaged in various industries. Data on water use for domestic activities such as cooking and washing weer collected at the same time. On the basis of the sample, rates of domestic and industrial water use were inferred. Data on the sales and purchases of commodities within the village and trade of commodities outside the village were also recorded. These data on local economic relations serve two purposes: first, to produce measures of the economic benefits of various industries to be contrasted with their water requirements; and second, to provide a basis for calculating the direct water requirements implicit in the patterns of economic transactions. (Indirect water demand is beyond the scope of this paper. It will be discussed further in the conclusion section.)

The remainder of the paper is organised as follows. The next two sections provide background on the rural economy of Nigeria and on the village of Katarko, where our study was conducted. The next section describes our field survey methods. A "Results" section presents a variety of indicators summarizing water use and economic benefits at the industry level. Finally, a number of generalizations are drawn from the results and the next stage in our research is described.

3.2 Background

Agriculture is the major economic activity in the rural areas of Nigeria. It provides the means of livelihood (food) and employment for the ever-increasing population. Prior to the discovery of oil in commercial quantity, agriculture dominated the Nigerian economy, accounting for about 60 percent of GDP and more than 75 percent of export earnings (Oshikoya, 1990). The primacy of agriculture was diminished by the oil boom in the early 1970s. However, because of the fruitless efforts by the Nigerian government to industrialize the nation, and the dwindling nature of the oil industry, the agricultural sector, which still employs over 75 percent of the rural population, remains the mainstay of the Nigerian economy.

Conditions for agricultural production are in a state of decline. Desertification has been widespread in the semi-arid zone of northern Nigeria following the recurrent droughts between 1968 and 1987 (Glantz, 1987; Payne, et al, 1987; Sivakumar, 1991). Rainfall, the major source of water, is very seasonal lasting for a period of about four months in a year (June to September) and fluctuates considerably, with annual averages ranging between 500 and 1000 mm and the number of rain days between 40 and 100 per year (Woo and Tarhule, 1994). This means that the growing season is short and animal rearing adversely affected. Irrigated agriculture and animal rearing are viable only at locations where surface and groundwater sources are accessible. Without that, up to eight months of the year become an idle period for most of the rural population, although some people engage in other non farm economic activities such as rural industry, trade and services.

Various studies have indicated progressive decline in rainfall in the subregion (for example, Olaniran, 1991; Anyadike, 1993; Hess, et al, 1995). Thus, water demand for agriculture (crop production and animal husbandry), non farm activities (rural industry, trade and services), as well as domestic use is exerting tremendous pressure on the limited water resources (Kimmage, 1991). The allocation of water to these competing uses has been based entirely on traditional practise. Often, inefficient decisions are taken leading to severe shortages for some if not all the uses with inevitable adverse repercussions. There is the need for better management of water resources to enhance sustainable rural development in this semi-arid environment.

Large-scale dam projects aimed at improving agricultural production, promoting rural development and providing support services to urban centres have not performed up to expectations mostly due to institutional and managerial bottlenecks. This has shifted the research focus onto integrated water management (Salau, 1990; Mitchell, 1994) and the promotion of small-scale irrigation (Adams, 1986; Adams and Carter, 1987; Kimmage, 1990; Kimmage and Adams, 1992).

Most studies concerned with environmental predicaments of this region have been discipline specific and conducted at a regional scale (for example, Falkenmark, 1989; Falkenmark and Lindh, 1993). To gain a better understanding of the direct and indirect effects of this man-environment relationship and coping strategies in this vulnerable region, however, multi-disciplinary studies conducted on a local scale are also needed. The Jos-McMaster Drought and Rural Water Use Research Project is an example of such a multi-disciplinary and locally focussed study. It is a combined effort of Nigerians and Canadians working on such diverse topics as hydrology, regional economic analysis, demography, community development, health, and indigenous knowledge systems. All of this research is focussed on the village of Katarko (described below.) The work described in this paper is a component of the Jos-McMaster Project which examines the demand side of water use in the village economy.

3.3 Study area

Katarko village in Yobe State, Nigeria, is the area selected for the case study. Located within the semi-arid zone of northern Nigerian at 11°33'N and 11°55'E, it is about 20 km southeast of Damaturu, the State Headquarters (see figure 3.1). It has similar environmental characteristics and human activities to the rest of the Sahel region. It is prone to droughts, and experiences water scarcity, as described earlier. Agriculture and animal husbandry are the major economic activities. As in most rural areas in this region, the lack of most urban facilities such as piped water and electricity, and the limited nature of government assistance, leaves its people to the mercy of the environment.

(Figure 3.1 about here.)

The village came to being under the name Bijimiram by 1937. The early settlers were mostly the Kanuri who were subsequently joined by other tribal groups including the Hausa, Karekare, Shuwa Arab and Fulani. These tribal groups exhibit some spatial differentiation, with the Karekare, Shuwa Arab, and Hausa each concentrated into one or two village wards. The Fulani are mostly in the village outskirts, while the Kanuri, who are still the dominant group, are more widely spread. The settlement has been growing mostly due to immigration, particularly by the Hausa and Fulani groups and more recently due to natural increase. Our survey of May 1995 puts the population at about three thousand people.

The people of Katarko village depend on the limited rainfall, seasonal stream flow, and especially declining groundwater sources for their domestic and economic needs. This dwindling water availability is typical for its location in the Sahel savanna belt of the arid and semi-arid (ASA) zone of West Africa. The extensive sedimentary Chad Formation, which is recharged by seasonal surface flow, is the main source of its groundwater. Its undulating terrain is covered mostly by Sudan savanna-type vegetation, basically patchy grasses and scrub as well as scattered acacia and baobab tree species.

Human economic activities are typical of most rural areas in the ASA zone and tend to follow tribal affiliations: rainfed agriculture for the more settled Kanuri, Hausa, Kerekere and Shuarab groups; animal husbandry (herding or rearing) for the Fulani group; irrigated cultivation of vegetables and grains for the Kanuri group; some animal and vegetation gathering for food, fuel and construction for the Kerekere and Shuarab groups; and rural industrial production of goods and services, traded mostly within the local economy by the Hausa and Kanuri groups. Irrigated agriculture is limited to a short period and locations accessible to surface and groundwater sources along the seasonal Annuma river on fadama plots. (Turner (1985, p. 18) defined fadama as "land seasonally flooded or waterlogged.") Most of the fadama land is owned and cultivated by the Kanuri, and some by the Hausas who introduced the irrigation initiative.

The village economy is a combination of subsistence and market activities with limited external linkages. Each household produces agricultural commodities, some of which it consumes and some of which are traded in an active local market. Most households are involved in livestock (animal) husbandry, including poultry. Only the Fulani and a relatively small number among the other groups rear cattle. A limited amount of agricultural produce is traded to the nearby urban centre of Damaturu and other towns in the region including

Potiskum, Gujba, and Maiduguri. Many households engage in other economic activities including small scale manufacturing and handicrafts, construction-related activities, food preparation, and a variety of personal services.

3.4 Methods

The results presented in this paper are based on two surveys of households in Katarko Village. The first a survey of all households to obtain basic population and activity data and the second a sample survey to obtain more detailed economic and environmental (ecological) information. Prior to commencing survey activities, a number of key informants including the *Bulama* (village head), tribal group heads, major farmers, and school teachers, were consulted to solicit information on the socio-cultural setting of the village, economic activities, and the nature of water supply, demand and use. This information was useful for the design of the survey instruments. The data were collected with the aid of three field assistants (two males and one female who are residents of the village).

The population survey was conducted in May of 1995, as no population data were available from the National Population Commission of Nigerian. All households in the village were surveyed. Questions included the name of household head, number of wives, number of children, wards and other dependants; source of water for household use, quantity withdrawn, and purpose of use; and occupation(s) of household members and activities they are engaged in.

Figures from the population survey provide basic information and were also used for sampling purposes in the more detailed survey that followed. There were 424 households with a total population of 2,734 people. The economic activities of households were recorded and assigned to four sectors: agriculture, rural industry, trade, and services. Within each sector a number of industries were defined (27 in all.) Each industry produces one or more commodities, of which more than 100 were identified in the survey. Table 3.1 lists the industries and commodities, along with the number of households involved in the production of each commodity. All households were engaged in some form of rainfed agriculture. Somewhat less than half were engaged in various forms of animal husbandry and a rather small group of households were engaged in irrigated agriculture. Among non farm activities, large numbers of households were involved in weaving, trading, and vegetation gathering, while smaller but still significant numbers engaged in diverse industries and services.

(Table 3.1 about here)

In order to gain a better understanding of the "input-output" relationships in the village economy -- especially with respect to inputs of water -- a more detailed survey was conducted on a sample of village households and industries. A multistage (stratified) sampling procedure was used to draw the sample. Industries were stratified according to the number of households participating in each. A sample of at least 20 percent of the households engaged in each industry was taken. For those industries with fewer than ten households, a 50 percent sample was taken. A total enumeration (100%) was done for those industries with less than five households. In all more than 250 interviews were conducted (see Table 3.2). To ensure representativeness within the sampled industries, the enumeration included all possible commodities produced, by distributing the sample size for each stratum proportionately over the identified commodities. For example, the irrigated agriculture industry has nine (9) households producing five commodities by different numbers of households in the following order: combined vegetables (all 9 households); tomato (6 households); *gorongo*[1] (all 9 households); rice (5 households); and wheat (1 household). To ensure representativeness, one household producing each of the commodities was included in the sample of five, instead of taking more from those with all households and none from that with only one (1) household.

(Table 3.2 about here)

The respondents included men who were heads of households as well as men or women who were heads of the production units. They were asked to list quantities and, where applicable, market values of inputs used in the production of each commodity. Inputs included locally produced commodities, such as inputs of agricultural commodities to the milling industry or inputs of animals to butchery; inputs of ecological commodities including water, forest products, and land; and inputs of commodities imported from outside the village. The heads were also asked to divide their output of each commodity into amounts retained for their own consumption or use, sold or traded to other households and industries, and sold outside the village. (These data will eventually be used to develop an input-output modelling system for the village economy. In this paper, however, they are used primarily for descriptive

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[1] A local egg plant-like crop used as a stimulant and for coloring teeth by women.

purposes.)

Respondents did not generally keep records of their transactions, especially for quantities of items used in production processes and much of the information was based on imprecise memories because some of the activities took place at a season other than the one during which the data were collected. Efforts were therefore made to gather information and establish figures that are reasonable via cross checks and queries during data collection and use of standard measures from secondary sources. This gave rise to a lot of data that relate to the quantity of inputs (particularly water) used for the production of commodities and the quantity of output (sales) of these commodities to intermediate demand (other industries) and final demand (household consumption and export). The results were recorded using physical units (kilograms and litres) and monetary values (naira[2]) where applicable.

Quantities of water extracted and used for commodity production and household consumption were ascertained from the survey responses and measurements. The water basically comes from ground sources, deep wells within the village, shallow wells on the river bed, and wash boreholes around the river flood plains used specifically for irrigation. There are 33 village (deep) wells and several shallow wells. Twenty one of the deep wells are located within compounds and owned by individual households as private property. The remaining twelve are public, scattered around the village and accessible to all wards. The shallow wells are dug on the bed and flood plain of river Annuma which bypasses the village.

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[2] The Nigerian currency was pegged at twenty two naira to the US dollar in 1995.

Some of the shallow wells are owned by irrigation farmers and located within their farm plots. Most others on the river bed are common property and are within a walking distance (between 200m and 1 km) from all wards. Therefore, the problem of accessibility to water is not physical distance to the wells but reaching deep groundwater at the peak of the dry season.

Consequently, labour demand for obtaining water in the various industries is not necessarily different from most other unskilled tasks performed by the workers, except for the water vendors who are sole proprietors. Water extraction and hauling are not clearly defined along gender lines. Men, women and children (male and female) are all involved. However, adults perform more of the skilled labour while children assist with the menial jobs at home and at the production unit. In typical, fundamental Islamic households, particularly amongst the Hausa and Kanuri groups, only men and children and occasionally older women go out to fetch water. This is because the women are usually kept in seclusion under the Purdah system (a religious belief that restricts women from going out in public).

To a limited extent, surface water and rainwater are used in the rainy season. The shallow wells are ruined by the flowing river in this period, but the village wells are full and meet most of the demand. Surface water is only used for washing, bathing and recreation (when children go to swim) or for watering grazing animals. Rainwater is rarely harvested because of turbidity resulting from the thatched and mud roofs over most of the buildings.

For better measurements, field researchers (the first author and the three assistants) went to the deep and shallow wells to determine quantities extracted and conveyed to households and industries. Household water is meant for domestic use (drinking, cooking, and sanitary purposes) and industry for the production of commodities (goods and services) by various economic activities. The quantity of water was determined by measuring the volume of containers used for water extraction (withdrawal from wells) and those used for conveyance (delivery). For example, households were observed to withdraw between four (4) and 18 litres of water per day for domestic use, and up to 200 litres for other activities like construction or sale by vendors.

Water consumed by animals was measured by monitoring the number of times animals are watered and the quantity consumed in the process. The average size of containers (usually 4 litres) used for hauling water from the wells was determined. This was multiplied by the number of times the water is poured into the animal's drinking container (a half-sized barrel or an opened gourd), and the result then divided by the number of animals that drank from it. (The results were similar to estimates given by rearers.) The quantity of water extracted for irrigation was determined from the rate of pumping (the quantity of water released multiplied by the duration of irrigation) using 2-3 horse power engines (water pumps) or the number of calabashes (gourds) of water delivered to the cropped area using the Shadoof method, a traditional method of delivering water from the source through channels or gutters to the cropped area. These quantities were calculated for a week and multiplied by the number of weeks the crops were irrigated.

Data were collected on a daily basis (from morning to late evening) by monitoring the number of times individuals visit the wells. The monitoring was spread over the two seasons.

Water extraction data from deep and shallow wells was collected between May 16 to 19 and June 16 to 19 to cover every day of the week in the dry period. The same process was repeated for only deep wells between July 9 to 12 and August 9 and 12 for the rainy season. (This is because the shallow wells were inaccessible as indicated above.)

Some diurnal variations were observed. More water was extracted for use in the trade sector on Thursdays, the weekly market day in the village. For other activities, more water was extracted on the nonmarket days because people tend to concentrate on their routine activities. Water for domestic use was about evenly spread. Extraction was concentrated in the early mornings (6-8.00am) and late afternoons (4-5.00pm). Crops are usually irrigated after water has been drawn in the morning and evening, while animals are usually watered in the afternoon.

Seasonal variations were also observed. During the rainy period, water extraction for construction (brick making and building) and animal watering declined, and irrigation virtually ceased. Quantities extracted for the other industries and households did not show any significant change. Wells are usually recharged seasonally, during the rainy season. Groundwater draw down reaches its lowest level at the peak of the dry season (April/May to early June). This is when most of the village (deep) wells run dry. Henceforth, during the remainder of the dry or 'water scarce' period, the shallow wells are the most dependable source of water. At this period, we also noticed some daily fluctuations in water levels, reflecting diurnal variations in demand.

Quantities of vegetation (wet and dry leaves, branches, stems, and roots, of grasses, herbs, shrubs and trees as well as fruits) extracted for use in industries and households were also determined. Because this was wild vegetation extracted from the bush, which is very extensive and uncontrollable, it was difficult to determine the extent of degradation. However, these values present useful information for environmental resources accounting not covered in this paper.

The area of farmlands for all agricultural activities (rainfed, irrigated, annuals and tree crops) was measured as well as quantities of earth material extracted for use in the various industries. Quantities for building, brick making (moulding), and pottery were determined indirectly from the quantity of commodities produced. Another indirect method was to measure ditches left after these activities were carried out.

3.5 Results

Information from the sample survey was summarised to determine average household inputs, outputs, and earned income for each commodity on a daily or weekly basis. The average values were then multiplied by the number of households producing each commodity. The resultant values were then multiplied by the production period (duration over which commodities are produced). Whereas certain activities such as irrigated agriculture and rainfed crops are seasonal, others such as cassava growing, tree crops, and trade operate all year round. Services may be rendered seasonally or throughout the year. While certain goods from the rural industry may have even shorter durations, daily, weekly, or seasonal, depending on demand.

All the data were cautiously processed before the projections and aggregations were done. The projections were made from a sample of commodity producers to represent the population of all households involved. The aggregations involved regrouping of commodities to the production units (industries) and then into the four sectors: agriculture, rural industry (manufacturing), trade, and service. We expect some amount of error to have occured in the process, but it was necessary to allow a better description of the economy as a whole.

An income measure was calculated as an indicator of the volume of activity in each industry. The total income earned from the sale of each commodity to local or external markets was estimated based on the survey. This was crosschecked against prices observed in the market. This tells only half the story, however, since much of what is produced, especially in agriculture, is retained by the household for its own consumption or use. An *imputed* income is calculated by multiplying the amount retained of each commodity by an observed market price. (This represents the amount the household could have earned by selling the retained commodity – or, put differently, the amount it would have to pay to purchase that quantity.) The total income associated with each industry is taken as the sum of the earned and imputed incomes from all the commodities it produces. Table 3.3 shows the income estimates. Clearly agriculture dominates the local economy, accounting for 60% of total village income. Rainfed crops alone accounts for more than 40%. Irrigated agriculture, however, accounts for less than 1%. Of the non-agricultural activities, the largest is vegetation harvesting.

(Table 3.3 about here)

Another important indicator of activity levels in a rural economy is land under cultivation. Table 3.4 shows the distribution of cultivated land to the various rainfed, irrigated, annual, and tree crops. Clearly land use is dominated by a few rainfed crops: guinea corn, millet, maize, beans, and groundnuts. In fact, all crops requiring irrigation (including cassava, and tree crops) take up only .12% of land in cultivation. These crops are very important, however, from the perspective of water use.

(Table 3.4 about here.)

Figure 3.2 shows the breakdown of groundwater use into the four economic sectors and domestic uses. We focus in what follows on groundwater use despite the fact that smaller but still significant amounts of surface water are also used as discussed earlier. Surface water is available only during part of the year, drawn primarily from the seasonal river, and it is very difficult to measure the amount used (as, for example, when animals drink directly from the river.) More important, the amount of surface water used by the villagers does not impact significantly on its availability. Since groundwater availability is highly sensitive to the amount drawn out by villagers, it is the water source that most needs to be conserved, and therefore the focus of our analysis.

(Figure 3.2 about here)

Figure 3.2 indicates that despite the small amount of land devoted to non rainfed agriculture and the small number of households engaged, it accounts for the lion's share of groundwater use in the village. Even the domestic use of all 424 households is only one third as much as that used for irrigated crops, annuals, tree crops, and animals. Table 3.5 shows the breakdown of this to different types of activities. Combined plots, in which several vegetables are generally grown together, consume the most water, followed by the irrigated grain crops (wheat and rice.)

A couple of interesting things can be observed from Table 3.5. The first is that animals account for a surprisingly small share of groundwater use. This is because larger animals drink exclusively from surface water during the wet season and may be driven out of the village to areas where surface water is available during the rest of the year. Thus, groundwater is only a supplementary water source for most animals. The second observation is that water use is not directly proportional to land use. Cassava and tree crops use significantly less water than irrigated rice and wheat, despite the fact that the former two occupy much more land than the latter two.

The variation of water intensity across crops is borne out by Figure 3.3 which shows the use of water on a per-bag[3] of produce basis. Here rice and wheat are the most water intensive crops. Irrigation for combined vegetable plots involves a labour intensive method whereby water is directed to individual plants, and is therefore more water-efficient.

These results create an impression that cultivation of irrigated rice and wheat is 'extravagant' in its use of groundwater resources. It is important to balance this view,

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[3] One bag equals roughly 50 kilograms, although this varies across crops. The bag is used as the basic output measure in the survey because it is a standard measure used in the village and therefore respondents could more easily estimate total bags than total kilograms.

however, by considering the benefits to the villagers of producing the various food commodities. To do this, we have estimated a measure of income associated with the production of each crop. (As before, both earned and imputed incomes were included.) We recognise that exchange values may be an imperfect measure of benefits, but they at least give us a "common denominator" on which to base comparisons of water intensity.

Figure 3.3 also shows the ratio of water to income (in litre per naira) of the same five irrigated crop types. Here combined plots and gorongo again appear to be more water efficient than tomatoes, owing to the low market value of tomatoes. The proportional difference between the water-income ratio of either rice or wheat and combined plots is smaller than the corresponding difference for the water-output ratio. This reflects the high market prices of rice and wheat which are sold to external markets. In light of this, the amounts of groundwater the villagers are willing to devote to irrigated grains is not as surprising.

A similar analysis was done for all four economic sectors. The water- income relationships for the aggregated sectors and their constituent industries are shown in Table 3.6. Agriculture is by far the most water intensive activity, although this conclusion may be exaggerated by the fact that only direct water use is measured here, and non-agricultural activities may have significant indirect water impacts. (See further discussion below.) Irrigated crops are the most water intensive followed by annuals (cassava) with animal husbandry as the least. (The value for trees is not shown because no income is yet being generated by the industry.)

The water-income relationship for individual industries in the rural industry sector are all low compared to the agricultural sector, but they show significant variation. In particular, the production of bricks and construction activities use far more water per naira of income than any of the other rural industries. Food preparation industries (butchering and catering) are more water intensive than other trade industries, but still very low even when compared with brick making and construction. All service industries have extremely low water intensities, with education being the highest because it includes the weather observatory which uses large quantities of water.

It is important to note that some of the results based on water-income ratios may be attributable to the fact that commodities sold locally generate less income than those (for example, rice, wheat, fish and firewood) sold in urban markets like Gujba, Damaturu, Potiskum or Maiduguri.

3.6 Discussion and conclusion

Groundwater is a critical resource for the rural villages in the semi-arid Sahel zone. Formulating conservation strategies and assessing the water impacts of alternative development scenarios requires baseline information on where available water is going and how it contributes to the local economy. The survey-based results reported here provide such information.

The most important result from the survey is that irrigated cultivation of vegetables and grains accounts for more than half of all groundwater consumed in the village. In spite of this, irrigated agriculture accounts for a very small proportion of the agricultural land, is practised by a relatively small proportion of households, and generates relatively little income in aggregate (although for those households engaged the income contribution is significant.) Animals also consume a significant amount of groundwater, but this amount is smaller than might have been expected given the large number of households that keep animals and the large amount of income they generate. However, animals often benefit from other sources of water from different locations especially while pasturing.

These results point to the need for a more comprehensive approach to water management that addresses the costs and benefits of alternative development scenarios -- especially in light of the emphasis placed on irrigation in rural Nigeria (Pradhan, 1993.) In particular, those responsible for water conservation should be aware that unchecked growth in irrigation, especially of grains, could lead to rapid depletion of already precarious groundwater stocks.

An important shortcoming of the analysis presented above is that it deals only with the *direct* water requirements of the various commodities produced in the village. This probably results in an underestimate of the total water impact of non-agricultural activities that have both direct and *indirect* requirements. For example, a butcher uses only limited direct water inputs for cleaning the carcass. The indirect water requirements for the meat he provides, however, includes the water provided to the animal during its lifetime, plus any water used to grow fodder fed to the animal. Thus the total (direct and indirect) water intensity of the commodity meat may be quite high. An approach to calculating the direct and indirect water requirements for all commodities will make it possible to estimate the impact of changes in the production of final goods for consumption in the village or for export on groundwater stocks. The authors are currently developing an input-output modelling framework based on the survey results that can produce such estimates.

Acknowledgement

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References

Adams, W.M. (1986) Traditional agriculture and water use in the Sokoto valley, Nigeria. - *The Geographical Journal*, 152 (1): 30-43.

Adams, W.M. and Carter, R.C. (1987) Small-scale irrigation in sub-Saharan Africa. *Progress in Physical Geography* 11, 1-27.

Anyadike, R.N. (1993) Seasonal and annual rainfall variations over Nigeria. International *Journal of Climatology*, **13**, 567-580.

Dabi, D.D. (1996) Water demand and use in the rural economy of a semi-arid environment: a northern Nigeria case study. - A Doctoral research proposal presented in the Dept. of Geography, McMaster Univ. (Hamilton, Canada, 22 September, 1996), 36 pp.

Falkenmark, M. (1989) The massive water scarcity now threatening Africa: Why is it not being addressed? - *Ambio*, 18 (2): 112-118.

Falkenmark, M. and Lindh, G. (1993) Water and economic development. - In Gleick, P.H. (ed.), *Water in crisis: A guide to World's Fresh Water Resources*. Oxford Univ. Press, Oxford, pp.80-91.

Glantz, M.H. (1987) *Drought and Hunger in Africa: Denying Famine a Future*. Cambridge Univ. Press.

Hess, T.M., Stephens, W., and Maryah, U.M. 1995. Rainfall trends in the North Eastern Arid zone of Nigeria. - *Agric. & Forest Met.*, 74: 87-97.

Kimmage, K. (1990) Nigeria's home-grown dust bowl. *New Scientist*, 7, July. pp 42-44.

Kimmage, K. (1991) Small-scale irrigation initiatives in Nigeria: the problems of equity and sustainability. *Applied Geography*, 11: 5-20.

Kimmage, K. and Adams, W. (1992) Wetland agricultural production and river basin development in the Hadejia-Jama'are valley, Nigeria. *The Geographical Journal*, 158 (1): 1-12.

Miller, R. E. and Blair, P. D. (1985) *Input-Output Analysis: Foundations and Extensions*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Mitchell, B. (1994). Addressing the 'edge' problems in land and water management in the Sokoto-Rima river basin, Nigeria. *Geoforum*, 25 (2): 133-143.

Olaniran, O.J. (1991) Evidence of climatic change in Nigeria based on annual series of rainfall of different daily amounts, 1919-1985. *Climatic Change* 19, pp 319-341.

Oshikoya, T.W. (1990) *The Nigerian Economy: A macroeconomic and Input-Output Model*. Praeger Publications, New York.

Payne, R., Rummel, L., and Glantz, M. (1987) Denying drought a future: Concluding remarks. In, M. Glantz (ed.) *Drought and Hunger in Africa*. Cambridge University Press, pp 435-443.

Pradhan, P. (1993) Research priority of irrigation in Nigeria. - In: Nwa, E. & Pradhan, P. (eds.), Proceedings of a National Seminar on irrigation research priorities for Nigeria (Univ. of Ilorin, Nigeria. IIMI, Kano) pp. 19-32.

Salau, A.T. (1990) Integrated Water Management: the Nigerian experience. In Mitchell, B. (ed.)(1990) *Integrated Water Management: International Experiences and Perspectives*. Belhaven Press, London. Chapter 8, 188-202.

Sivakumar, M.V.K. (1992) Empirical analysis of dry spells for agricultural applications in West Africa. *Journal of Climate*, 5, May. pp 532-539.

Turner, B. (1985) The classification and distribution of fadamas in central northern Nigeria. In Thomas, M.F. and Goudie, A.A. (eds) *Dambos: small channelless valleys in the tropics, formation and utilization*. Stuttgart: *Zeitschrift Fur Geomorphologie*, Supplementband 52, 222pp.

Woo, M-K. & Tarhule, A. (1994) Streamflow droughts of northern Nigerian rivers. *Hydrological Sciences Journal*, 39 (1): 19-34.

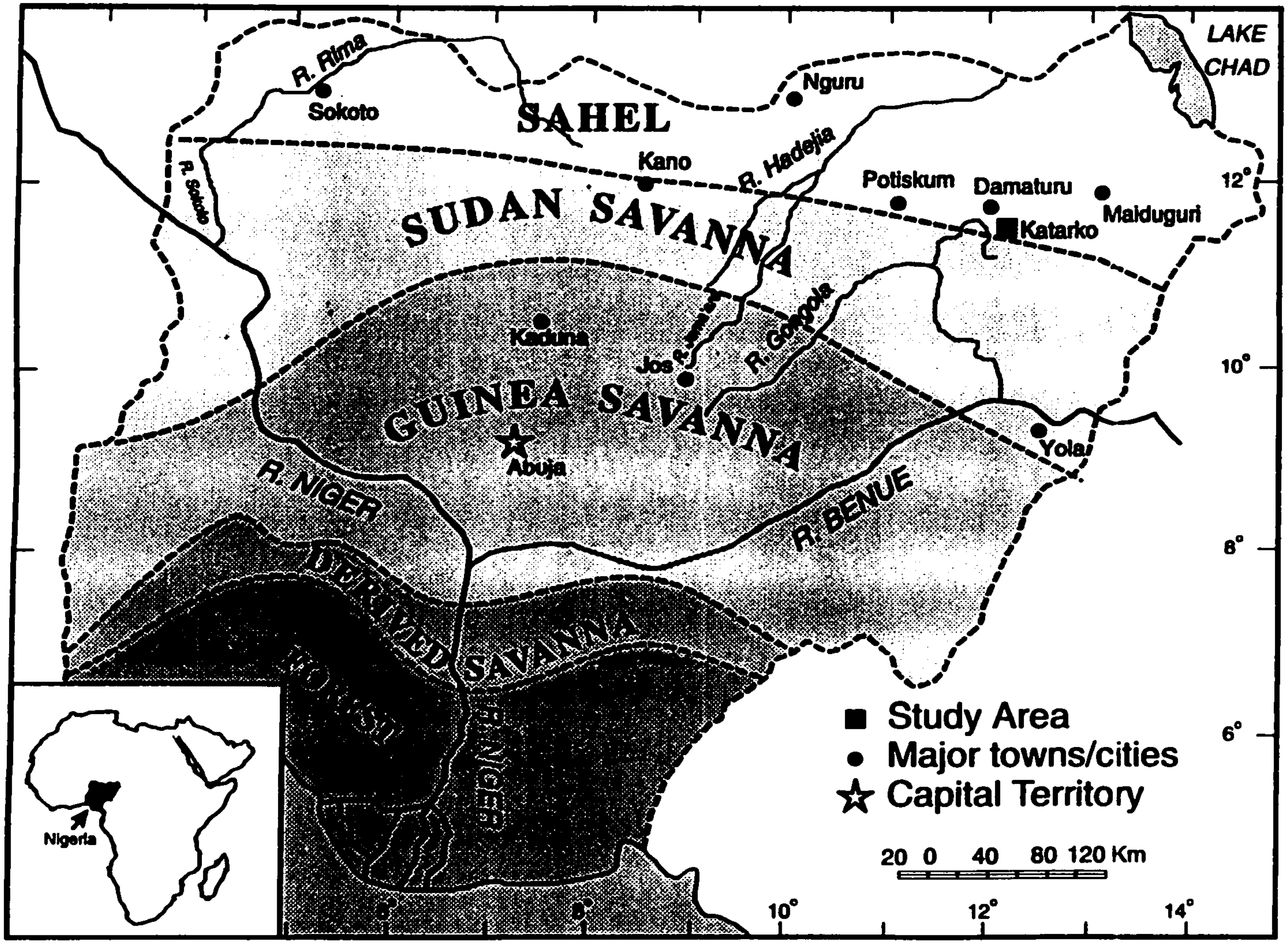

Figure 3.1 General reference maps

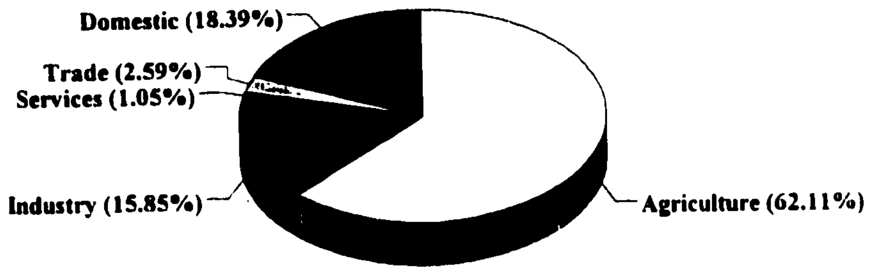

Figure 3.2 Distribution of groundwater consumption

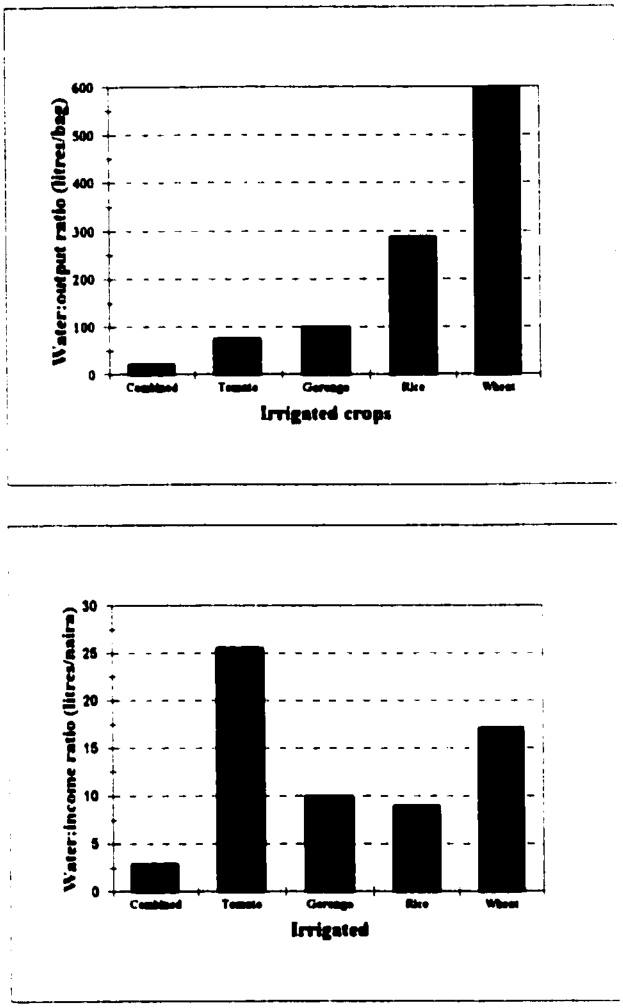

Figure 3.3 Ratio of water to output and income: irrigated crops

Table 3.1: Sectors, Industries, Commodities and Participants in Katarko

Agricultural Sector

Industry	Commodities	Number of Households *
1. Rainfed Agriculture	Guinea corn	424
	Millet	424
	Maize	424
	Ground (pea) nuts	254
	Beans (cow peas)	424
	Calabash	424
	Pumpkins	85
	Benniseed	85
	Okra	282
	Jute	40
	Vegetables	424
	Garden egg (local)	85
	Bambara nut	71
	Rice	22
	Cotton	3
2. Irrigated agriculture	Combined vegetables	9
	Tomato	6
	Egg plant (gorongo)	9
	Rice	5
	Wheat	1
3. Irrigated/rainfed (annuals)	Cassava	24
4 Tree crops (Orchards)	Cashew	1
	Mango	1
	Guava	2
	Orange	1
	Paw paw	1
5. Animal husbandry	Cattle	91
	Oxen	183
	Sheep	169
	Goats	169
	Poultry (birds)	175
	Donkeys	16
	Horses	2

Rural industry Sector

Industry	Commodities	Number of Households *
6. Brick making	Bricks	12
7. Building Constructors	Trad./Modern walls	
	Mud roofs and floors	5
8 Pottery	Pots	20
9 Blacksmithing	Farm tools	5
	Weapons	2
	Utencils	7
10. Wood carving	Handicrafts	25
11. Calabash carving	Calabashes & local spoons.	5
12. Weaving	Roof tops.	30
	Stalk fences (danga).	85
	Grass mats, palm mats.	71
	Ropes, brooms, thread.	5
	Mattresses	4
13. Milling	Grains threshing & milling.	5
	Ground nut oil extraction	35
	Ground nut cake	35

Trade Sector

Industry	Commodities	Number of Households *
14. Butchery	Meat processing	14
15. Catering/Trading	Yogurt & flour balls	125
	Cassava (boiled).	6
	Porridge	4
	Food (corn/rice&beans)	20
	Tea&bread	3
	Bean cake	20
	Local soft	6
16. Fishing	Fresh & roasted fish	16
17. Hunting	Bush animals	10
18. Water vendors	Water	7
19. Vegetation harvesting	Wood	20
	Leaves	20
	Fruits	15
	Grass/hay	125

Service Sector

Industry	Commodities	Number of Households *
20. Technical/Mechanical repairs	Radio, watches,	4
	Bicycles, tires	4
21. Carpentry	Roofs, windows & doors	4
	Kiosks, Furniture making	4
22. Transportation	Cattle track.	36
	Bicycles.	1
	Buses.	8
23. Tailoring & design	Clothe sewing & cap design.	5
24. Hairdressing/Barbing	Hair platting and barbing	8
25. Education	Teaching	6
26. Household labor.	Farm and off-farm labor	60
27. Other services	Health and farm extension services	5

* households with one or more member actively involved in production of the commodity

Table 3.2: Sample Sizes and Proportions

Industry	Active Households	Sample size	Sample Proportion
1. Rainfed Agriculture	424	85	20.0%
2. Irrigated agriculture	9	5	55.6%
3. Irrigated/rainfed (annuals)	24	5	20.8%
4. Tree crops (Orchards)	2	2	100.0%
5. Animal husbandry	175	35	20.0%
6. Brick making	12	3	25.0%
7. Building Constructors	5	3	60.0%
8. Pottery	20	4	20.0%
9. Blacksmithing	7	4	57.1%
10. Wood carving	25	5	20.0%
11. Calabash carving	5	3	60.0%
12. Weaving	85	17	20.0%
13. Milling	35	7	20.0%
14. Butchery	14	3	21.4%
15. Catering/Trading	125	25	20.0%
16. Fishing	16	4	25.0%
17. Hunting	10	5	50.0%
18. Water vendors	7	4	57.1%
19. Vegetation harvesting	125	25	20.0%
20. Technical/Mechanical repairs	4	4	100.0%
21. Carpentry	4	4	100.0%
22. Transportation	36	8	22.2%
23. Tailoring & design	5	3	60.0%
24. Hairdressing/Barbing	8	4	50.0%
25. Education	6	3	50.0%
26. Household labor.	60	12	20.0%
27. Other services	5	5	100.0%

Table 3.3: Household Income (by sector and industry).

Sector		Industry	Income ('000 Naira/yr)
Agriculture	1	Rainfed agriculture	25245
	2	Irrigated agriculture	652
	3	Cassava (annuals)	68
	4	Tree crops (Orchards)	0
	5	Animal husbandry	10373
		Total	**36337**
Rural industry	6	Brick making	734
	7	Building Constructors	619
	8	Pottery	323
	9	Blacksmithing	84
	10	Wood carving	534
	11	Calabash carving	28
	12	Weaving	1035
	13	Milling	742
		Total	**4099**
Trade	14	Butchery	1494
	15	Catering/Trading	312
	16	Fishing	632
	17	Hunting	147
	18	Water vendors	35
	19	Vegetation harvesting	12401
		Total	**15021**
Service	20	Technical & Mechanical repairs	132
	21	Carpentry	99
	22	Transportation	2049
	23	Tailoring & design	48
	24	Hairdressing/Barbing	17
	25	Education	144
	26	Household labor.	1785
	27	Other services	9
		Total	**4283**
		Grand Total	**59740**

Table 3.4: Cultivated Farmlands in Katarko

Commodity (crop)	Land Area (hectares)	Land ratio (percenatge)
1. Guinea corn (sorghum)	9280.2	29.846%
2. Millet	5192.5	16.700%
3. Maize (corn)	4650.3	14.956%
4. Beans (cow pea)	4254.3	13.682%
5. Calabash	146.8	0.472%
6. Vegetables	81.6	0.262%
7. Okra	93.5	0.301%
8. Ground (pea) nut	5767.8	18.550%
9. Pumpkin	5.8	0.019%
10. Beniseed	11.0	0.035%
11. Egg plant	6.8	0.022%
12. Bambara nut	443.2	1.425%
13. Jute	23.9	0.077%
14. Rice (upland)	950.4	3.057%
15. Cotton	138.8	0.446%
16. Combined vegs	8.3	0.027%
17. Tomato	1.4	0.005%
18. Gorongo	3.2	0.010%
19. Rice (wetland)	0.4	0.001%
20. Wheat	0.5	0.002%
21. Cassava (annuals)	20.2	0.065%
22. Tree crops	12.9	0.041%
Total	**31093.8**	**100.000%**

Table 3.5: Groundwater use for irrigation and animal husbandry

Commodity	Water (litres)	%
1. Combined vegetables	176000	25.4
2. Tomato	96000	13.8
3. Gorongo	60000	8.6
4. Rice (wetland)	144000	20.8
5. Wheat	120000	17.3
6. Cassava (annual)	7360	1.1
7. Trees	72000	10.4
8. Animals	18358	2.6
Total	**693718**	**100.0**

Table 3.6: Groundwater-output and groundwater-income relationships by sector

Sector		Industry	Groundwater:income (litres/naira)
Agriculture	1	Rainfed agriculture	N/A*
	2	Irrigated agriculture	6.455
	3	Cassava (annuals)	2.609
	4	Tree crops (orchards)	N/A*
	5	Animal husbandry	0.395
		Average	**3.153**
Rural industry	6	Brick making	1.412
	7	Building construction	1.210
	8	Pottery	0.046
	9	Blacksmithing	0.063
	10	Wood carving	0.022
	11	Calabash carving	0.015
	12	Weaving	0.018
	13	Milling	0.150
		Average	**0.367**
Trade	14	Butchery	0.066
	15	Catering/Trading	0.217
	16	Fishing	N/A*
	17	Hunting	0.006
	18	Water vendors	2.000
	19	Vegetation harvesting	0.010
		Average	**0.460**
Service	20	Technical & Mechanical re	0.022
	21	Carpentry	0.014
	22	Transportation	0.017
	23	Tailoring & design	0.055
	24	Hairdressing/Barbing	0.076
	25	Education	0.199
	26	Household labor.	0.010
	27	Other services	1.540
		Average	**0.241**

*** Not applicable**

CHAPTER FOUR

Application of a commodity-by-industry economic-ecological model to water demand in a rural economy

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Abstract

This paper examines the applicability of a commodity-by-industry economic-ecological model (CIEEM) in a water-scarce rural village economy in a less developed country (LDC). Our primary concern is model construction and determination of the direct and total requirements of both economic commodities (interindustry transactions) and ecological commodities (water, land and vegetation) used in the economy. Also considered is the discharge of ecological commodities (wastewater and solid wastes) back to the environment. Results show sparse sectoral interdependence within the economic system but a heavy dependence of the economy on the environment. The most intensive users of water based on the direct effects are animal husbandry, building and irrigated agriculture; based on total effects they are catering, building and animal husbandry, in descending order.[4]

Key words: commodity-by-industry, economic-ecological, economic commodity, ecological commodity, environment, water scarcity, rural economy, village, less developed country.

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4.1 Introduction

The main objective of this paper is to examine the applicability of a commodity-by-industry economic-ecological model (CIEEM) to the economy of a water-scarce rural village in a less developed country (LDC). The paper describes the model and presents the direct and total requirements of both economic commodities (interindustry transactions) and ecological commodities (water, land and vegetation) used in the economy. It also considers the discharge of ecological commodities (wastewater and solid wastes) back to the environment.

Studies on water demand in developing countries have focussed on residential water demand, analysing the quantity of pipe water used by households as a function of variables such as income and price using traditional water demand models (for example, Danielson, 1979; Agthe and Billings, 1980). (These studies, however, have been criticized as inappropriate for developing countries by Madanat and Humplick, 1993.) Extending the work of Mu, et al (1990), Madanat and Humplick (1993) applied discrete choice models where alternative sources of water are available, capturing direct water use in terms of choice probabilities. However, water demand involves not only direct consumption by people but also use of water as an input for production. Therefore, an input-output (I-O) type model that captures both direct and indirect requirements will provide a more comprehensive approach.

In developing economies, water is generally an unpriced input. Thus, a model that incorporates economy-environment interactions is needed for this application. The traditional I-O model has also been extended in several ways to accommodate environmental issues. These extensions are well documented in the literature (for example, Richardson, 1972; Miller and Blair, 1985; Lonergan and Cocklin, 1985; Huang, et al, 1994) and can be grouped into three categories: pollution-generation models, economic-ecological models and environmental commodity-by-industry models.

Although these extensions have had their criticisms (for example see Victor, 1972; Johnson and Bennett, 1981), they all present comprehensive frameworks on which modifications can be made. They have also contributed to the development of the emerging interdisciplinary field of ecological (environmental) economics (Costanza, et al., 1991; Lesser, et al., 1997) which differs from the conventional approaches in its accounting, modelling and analysis of human and environmental issues. Ecological economics addresses the relationships between ecosystems and economic systems and allows the quantification of environmental concerns in either monetary or physical units. Although the nature of these interrelationships is still being debated (Lesser, et al., 1997), the environmental extensions are credible for application in LDCs where heavy dependence on the environment and natural resources prevails and quantification is not always in monetary terms.

Most of the recent works on I-O models still adopt the traditional framework and have been rather theoretical and methodological, relating to issues like methods of compiling I-O tables (Viet, 1994), construction of coefficients (ten Raa, 1994), measurement and analysis of total factor productivity growth (Wolff, 1994), and the comparison of economic-base and I-O methodologies for economic impacts (Hughes, 1997). These studies involve applications to regions in developed countries whose economies are more stable and advanced than those in LDCs. Robison (1997) attempted to outline an I-O modelling approach suitable for rural areas by linking the economic base of an individual rural area in a developed economy with its I-O accounts. He went further to develop a social accounting matrix (SAM) for the region and model inter-community trade. Again, this study has relevance to rural areas but is not necessarily adequate for those in developing economies.

What is perhaps more relevant to developing economies, where there is heavy dependence on natural resources, is a modelling system that accounts for use of environmental (ecological) resources in the economy. Consequently, estimates of the contribution of natural resources at the lowest level possible should be accounted for, preferably using physical units. They can be aggregated and incorporated into the national accounts. Such a model can provide information necessary for a "bottom-up" interdisciplinary approach to sustainable community development.

This study employs such an approach by incorporating both economic and ecological factors in its accounting framework. It develops a valuable analytical tool for water resources management in a drought inflicted area. We have focussed on scarce environmental resources (water, land and vegetation) using a commodity-by-industry economic ecological accounting system. Results are expected to contribute to the understanding of the sustainability of a local economy dependent on the natural environment. The study will also provide some of the estimates required for a more accurate national accounting framework and determination of a feasible net domestic product.

4.1.1 Study area

For the purpose of this research a typical rural settlement, Katarko village, in the semi-arid environment of northern Nigeria was selected for a case study. By virtue of its location at 11°33'N and 11°55'E, it lies within the drought-prone Sahel of West Africa (see figure 4.1). Katarko village experiences similar environmental conditions as the rest of the region: recurrent droughts, water scarcity and ecological degradation. The limited groundwater, recharged annually by the declining rainfall and seasonal stream flow, is the major source of water for domestic and economic needs in the village. Groundwater is accessed by means of shallow and deep village wells from the extensive sedimentary Chad Formation. The undulating terrain is covered mostly by Sudan savanna-type vegetation, basically patchy grasses and scrub as well as scattered acacia and baobab tree species. These environmental conditions have social and economic implications on three thousand people of Katarko who depend heavily on the natural environment, and impose constraints on rural development.

(Figure 4.1 about here)

Human activities in most rural areas in this region are similar. Agriculture and animal husbandry are the major economic activities which tend to follow tribal affiliations. Rainfed agriculture is practised by the more settled sedentary farmers who grow similar crops mostly at subsistence level. Some of these farmers are also engaged in irrigated cultivation of vegetables and grains. Animal husbandry (livestock rearing) is predominated by the less settled nomadic groups who also engage in vegetation gathering for food, fuel and construction. These and other groups are engaged in rural industrial production (small scale manufacturing and handicrafts) of goods and services, traded mostly within the local economy.

Thus, the village economy is dependent on a combination of subsistence agriculture, the natural environment and market activities with limited external linkages. Agricultural commodities produced are either retained for household consumption or traded in an active local market. A limited quantity of agricultural produce and other commodities is traded in nearby urban centres: Damaturu (the state headquarters) as well as Gujba, Buniyadi, Potiskum, and Maiduguri (other major towns in the region). Therefore, the village can still be considered as an open economy. For a more detailed description of the village economy, see Dabi and Anderson (1998).

4.2 Background

4.2.1 Input-output analysis

I-O modelling is essentially a method of analysis that takes advantage of the relatively stable pattern of the flow of goods and services among the elements of an economy to bring a much more detailed quantitative picture of the system. I-O analysis therefore, is a method that "systematically quantifies the mutual interrelationships among the various sectors of a complex economic system" (Leontief, 1986).

In spite of their usefulness, I-O models have been criticized for their "homogeneity" assumption that an industry produces a single commodity. This led to the development of the commodity-by-industry I-O framework, an alternative approach that more accurately takes into account secondary production. An industry can produce more than one commodity and a commodity can be produced by more than one industry. Accounting for secondary production requires two sub-matrices, the make matrix (V) and the use matrix (U). Rows of the make matrix describe the commodities produced (outputs) by industries in an economy and columns describe the industry sources of commodity production. The use (absorption) matrix records commodity inputs to an industrial production process. Row totals of the make matrix plus row totals of final demand make up row totals of the use matrix. Subsequently, the environmental input-output models were introduced to link the environment and the economic sectors (Victor, 1972; Miller and Blair, 1985; Lonergan and Cocklin, 1985).

4.2.2 Environmental input-output analysis

Environmental extensions of the I-O model are meant to address environmental concerns and to facilitate quantification of ecological commodities in either monetary or physical units. The major problem has been the use of the appropriate unit of measurement (Miller and Blair, 1985). The traditional model uses monetary values, but not all ecological commodities have monetary values. In fact, in some rural areas in LDCs, not all economic goods and services have specified monetary values.

The three basic categories of environmental extensions of the I-O model include: (i) generalized input-output or pollution generation-elimination models, (ii) economic-ecological models, and (iii) environmental commodity-by-industry model (Victor, 1972; Miller and Blair, 1985; Lonergan and Cocklin, 1985; Huang et al., 1994).

4.2.2.1 Pollution generation-elimination models

The first attempt to incorporate environmental concerns into the traditional economic I-O model was by Cumberland (1966). He simply extended the rows and columns of the traditional I-O accounting framework, in the form of an interregional model (IRIO) first presented by Isard (1951), to encompass environmental costs and benefits of production sectors. Cumberland's model has been criticized (Richardson, 1972; Victor, 1972) for its ambitious attempt to place monetary values on environmental effects rather than measuring them in purely physical terms. Such extensions form the group of pollution generation-elimination models. Although interesting in their formulation they do not present a suitable framework for this study because our concern is more on water scarcity than pollution.

4.2.2.2 Economic-ecological models

Daly (1968) led the way with the economic-ecological extensions of the I-O model. The basis of these extensions is the incorporation of environmental activities into an I-O framework using flow matrices within and between economic activities and environmental processes. He employed a highly aggregated industry-by-industry characterization of the economic sub-matrix and a classification of ecosystem processes, including life processes such as plants, animals and bacteria, and non-life processes of the atmosphere, hydrosphere and lithosphere. The work is basically a theoretical attempt to link biology and economics. It also suggests a "general equilibrium system" not very differently from the material balance considerations of Ayres and Kneese (1969). This is the flow of material resources from the environment to the economy for the production of goods and a return flow from the economy of "externalities" back to the environment.

Isard (1968) had a similar approach, but instead of an industry-by-industry characterization, adopted the commodity-by-industry accounting scheme. Isard's model recognises secondary production and accounts for multiple commodities, economic and ecological, produced by a single industry. The model is "fully integrated" because it had an "ecosystem sub-matrix" that accounts for environmental (or ecosystem) flows linked to the "economic sub-matrix" of inter-industry economic flows. Although he attempted an empirical application of the model by estimating the technical coefficients directly from technical data, the model was not fully implemented because of the complexity of the ecosystem sub-matrix and data availability (Isard et al, 1971; Richardson, 1972; Victor, 1972; Miller and Blair, 1985; Lonergan and Cocklin, 1985; Huang et al., 1994).

Ecological commodities are nonmarketable quantities that are either inputs to an industry production process, for example water, or outputs generated (or discharged) by a production process, for example pollution. Ecological commodities can also be classified according to their sources of extraction and the sinks to which they are eventually discarded and may be restricted to nonmarket materials such as water, land, air, etc. (Johnson and Bennett, 1981; Miller and Blair, 1985).

4.2.2.3 Environmental commodity-by-industry models

Victor (1972), limited the scope of Isard's fully integrated economic-ecological model to account only for flows of ecological commodities from the environment into the economy and of ecological outputs (waste products) from the economy into the environment. Victor's "Limited commodity-by-industry economic-ecological model" is a conventional commodity-by-industry table augmented with additional rows of ecological inputs and columns of ecological outputs. It has two sub-matrices, the "Economic subsystem" and "Ecological subsystem." Compared with Isard's model, this model reduced the number of interactions considered, especially the interactions within the ecological subsystem. Because the data required are generally available, the model can be implemented with little difficulty (Miller and Blair, 1985). Applications of these extensions have mostly been related to energy use and pollution abatement for environmental and ecosystem management (Johnson and Bennett, 1981; Born, 1996). Huang et al (1994) applied an improved version of the commodity-by-industry input-output model for regional solid-waste management with promising results.

The emphases these studies gave to pollution abatement may be attributed to the fact that pollution in industrialized economies has reached intolerable limits, and is thus a problem of immense concern. However, in rural areas of LDCs where large-scale industries are nonexistent, the extent of environmental pollution is relatively small. What is of paramount importance, particularly in the arid and semi-arid (ASA) environments, is water required for domestic, rural small-scale industrial production and agricultural uses. Therefore, this study is more concerned with the use of ecological commodities, especially water, in the economy of rural communities in LDCs, and the impacts associated with such activities. Water use is modelled from two perspectives: (i) water traded in the economic sector by water vendors as an economic commodity, and (ii) water extracted directly by users from the environment (mostly, from shallow wells) as an ecological commodity for use in the economy. Both direct and total effects of commodity production will be evaluated.

4.3 Method

4.3.1 Data analysis

A commodity-by-industry economic-ecological model (CIEEM) provides the major analytical tool for this research. It is a conventional commodity-by-industry table augmented with additional rows of ecological inputs and columns of ecological outputs and made up of two sub-matrices: the "Economic subsystem" and "Ecological (environment) subsystem." The economic subsystem includes activities through which natural and human resources are used (consumed) to produce commodities for human need. The ecological subsystem on the other hand, includes all aspects of the natural environment that provide the support system for life. In order to avoid the limitations of the integrated economic ecological model, it takes advantages of Victor's "limited" commodity-by-industry economic-ecological model.

An *economic system* is an area, as large as a nation or even the entire world economy or as small as the economy of a metropolitan area, village or even a single enterprise for which an input-output model is constructed from observed data. The economic activities in the area are divided into a number of sectors made up of a group of industries producing a number of commodities. *Sectors* are groups of industries in an economic system (area). *Industries* are groups of firms (production units or activities) or households, which have similar inputs and outputs (the commodities), usually identified by their primary product or nature of activity, for example rainfed agriculture or a blacksmithing unit. *Commodities* are the individual products (goods and services) produced or delivered by different industries, for example *sorghum* (guinea corn) and farm tools. *Economic commodities* are traded in the local economy usually in monetary terms either for intermediate or final demand. In a commodity-by-industry model, each industry produces one or more commodities, and in principle the same commodity can be produced by more than one industry. *Ecological commodities* are nonmarketable quantities of goods such as water and vegetation (fire wood) extracted directly from the environment for use in the economy. They are either inputs to an industry production process, for example water or outputs generated by a production process and discharged back to the environment, for example wastewater or pollution (Miller and Blair, 1985; Dabi, 1996).

The village economy is thus represented as a set of interrelated industries producing a larger set of commodities. The interrelationships between these economic commodities and ecological commodities will be considered in terms of flows (input/output) of goods and services (commodities) between the economic activities (production sectors or industries) as intermediate demand, and flows of final demand of these commodities to households or for sale to external markets (export) as well as value added. A simple example of the model is illustrated in Figure 4.2. Details are contained in Dabi (1996).

(Figure 4.2 about here)

4.3.2 Model description

Most of the notations used here follow the work of Miller and Blair (1985). However, slight modifications may be observed. These were meant to portray our interests and conform with the problem we are considering.

4.3.2.1 The commodity-by-industry framework

The framework of the commodity-by-industry accounts is similar to the basic accounting identity from the general (traditional) I-O model which is a set of linear equations corresponding to the number of rows contained in the table whose matrix notation is represented as:

$$X = AX + Y \tag{4.1}$$

where X is the column vector (n x 1) of outputs; AX is the matrix (n x 1) of intermediate demand (industry-by-industry direct requirements multiplied by total industry output), with $[z_{ij}]$ as the flow of inputs from industry i to industry j and its input to output coefficients are given by the ratio $[a_{ij} = z_{ij} / X_j]$; Y represents the column vector (n x 1) of industry deliveries to final demand. The letter n refers to the number of industries.

The commodity-by-industry analogous form of equation (4.1) is as follows:

$$Q = BX + E \tag{4.2}$$

where Q is the column vector (m x 1) of total commodity output; B is the commodity-by-industry matrix (m x n); X is the column vector (n x 1) of total industry outputs; therefore, BX is the matrix (m x 1) of commodity intermediate demand; while E is a column vector (m x 1) of commodity deliveries to final demand. The letter m represents number of commodities.

For calculation purposes, equation (4.2) is used to determine the technical coefficients necessary for deriving the direct input requirements in the commodity-by-industry model which has the following matrix relationship:

$$B = U\,(\hat{\mathbf{X}})^{-1} \tag{4.3}$$

where B = [b_{ij}] is the matrix (m x n) of economic commodity-by-industry direct requirements, [b_{ij} is the amount of economic commodity i required to produce a unit output of industry j]; U=[u_{ij}] is the *use* matrix (m x n) which records the commodity inputs to an industrial production process, [u_{ij} represents the amount of commodity i used by industry j]; X is a vector (n x 1) of industry output, $\hat{X}$ is a diagonal matrix (n x n) with elements of X as diagonal, while $(\hat{X})^{-1}$ is the inverse of the diagonal matrix (n x n). For calculating the direct output requirements and coefficients, the following relationship is also important:

$$C = V'\,(\hat{\mathbf{X}})^{-1} \tag{4.4}$$

where $C = [c_{ij}]$ is the matrix (m x n) of industry direct output proportions [c_{ij} is the fraction of industry j's output that is distributed as commodity i]; $V = [v_{ij}]$ is the *make* matrix (n x m) that describes the industry sources of commodities in the economy, [v_{ij} represents the amount of commodity j produced by industry i], V' is the transpose of the make matrix; the elements X, $\hat{X}$ and $(\hat{X})^{-1}$ are as defined in equation (4.3).

In the commodity-by-industry model, several variations of total requirement matrices can be derived (Miller and Blair, 1985). For the data we have generated, it is only possible to use the industry-based technology assumption in order to meet the "conformability requirement" of our multiplications. Of course we have grouped our industries based on similarity of industry production requirements. To develop the commodity balance accounting identity, the commodity output proportion is required whose matrix form is given by:

$$D = V(\hat{Q})^{-1} \qquad (4.5)$$

where $D = [d_{ij}]$ is the matrix (n x m) of commodity output proportion [d_{ij} is the commodity output proportion with coefficients $d_{ij} = v_{ij} / Q_j$]; V is as defined in equation (4.4); Q is a vector (m x 1) of commodity output, $\hat{Q}$ is a diagonal matrix (m x m) with elements of Q as diagonal, and $(\hat{Q})^{-1}$ is the inverse of the diagonal matrix (m x m). The construction of D is referred to as the is an industry-based-technology assumption. Multiplying equation (4.5) through by $\hat{Q}$, becomes $V = D\hat{Q}$ and since total industry output is the sum of all commodities produced by each industry $X = V_i$, we can define the following relationship:

$$X = D\hat{Q}_i = DQ \tag{4.6}$$

Substituting this expression into equation (4.2), the commodity balance accounting identity, the following is obtained:

$$Q = BDQ + E \tag{4.7}$$

This equation can be converted to the following:

$$Q = (I - BD)^{-1} E \tag{4.8}$$

where Q is a column vector (m x 1) of commodity output (production); the matrix $(I - BD)^{-1}$ is the commodity-by-commodity total requirements matrix (m x m); I is the m x m identity matrix, $B=[b_{ij}]$ is the matrix (m x n) of economic commodity-by-industry direct requirements, [b_{ij} is the amount of economic commodity i required to produce a unit output of industry j]; $D=[d_{ij}]$ is commodity output proportions (n x m); and $E=[E_i]$ is a column vector (m x 1) of commodity deliveries to final demand. The accounting identity can also be expressed for industry output as:

$$X = [D(I - BD)^{-1}] E \tag{4.9}$$

where X is a column vector (n x 1) of industry output, the matrix $[D(I - BD)^{-1}]$ is the industry-by-commodity total requirements matrix (n x m); I, B, D, and E are as described in equation (4.8). Alternatively, the industry balance accounting identity can be represented as:

$$X = [(I - DB)^{-1}] Y \tag{4.10}$$

where X is column vector (n x 1) of industry output; the matrix $[(I - DB)^{-1}]$ is the industry-by-industry total requirements matrix (n x n); I, B, and D are defined in equation (4.8); and Y is column vector (n x 1) of industry final demand. Y is determined from the relationship Y = DE whose technical coefficients are $[Y_i = d_{ij}E_j]$.

4.3.2.2 The economic-ecological framework

The ecological commodity coefficients have been defined in the same manner as the technical coefficients of the commodity-by-industry framework (model) described above. We have based the use of water and other ecological commodities on industry output (X) instead of commodity output (Q). This is because it was not very practical to obtain data on quantities of the ecological commodities used for the production of individual economic commodities, especially when more than one commodity is produced. Thus, we the use of industry final demand (Y) instead of commodity final demand (E). However, this procedure will have little or no impact on accuracy. Therefore, when the accounting system is expanded to include ecological commodities, the technical coefficients are derived using the following relationships:

$$G = T(\hat{\mathbf{X}})^{-1} \tag{4.11}$$

where G = $[g_{kj}]$ is the matrix (e x n) of ecological commodity input coefficients, $[g_{kj}$ is the amount of ecological commodity k used per unit of output of industry j], the dimension e is the number of ecological commodities; T= $[t_{kj}]$ is the matrix (e x n) of ecological commodity-by-industry inputs $[t_{kj}$ is the amount of ecological commodity k used by industry j]; and $(\hat{\mathbf{X}})^{-1}$ is as earlier defined in equation (4.3). While the matrix of ecological commodity output coefficients will be as follows:

$$F = S'(\hat{\mathbf{X}})^{-1} \tag{4.12}$$

where F = $[f_{kj}]$ is the matrix (e x n) of ecological commodity output coefficients $[f_{kj}$ is the amount of ecological commodity k discharged per unit of output of industry j]; S' is the transpose of the industry by ecological commodity outputs matrix S = [s_{kj}, the amount of ecological commodity k discharged by industry j]; and $(\hat{X})^{-1}$ also as defined in equation (4.3).

The ecological commodity input total requirements can also be derived using the inverse matrix (following the industry-by-industry total impacts) as follows:

$$G^* = [G(I-DB)^{-1}]\,Y \qquad (4.13)$$

where G* is the vector (e x 1) of total (direct and indirect) requirement matrix of economic commodity inputs for the production of economic output; G is the matrix (e x n) of ecological commodity input coefficients; $(I-DB)^{-1}$ is the industry-by-industry total requirements matrix, its elements are defined in equation (4.6); and Y is industry final demand. Similarly, the ecological commodity outputs as:

$$F^* = [F(I-DB)^{-1}]\,Y \qquad (4.14)$$

where F* is also a vector (e x 1) the of total (direct and indirect) requirement matrix of economic commodity outputs produced due to economic output; and F is the matrix (e x n) of ecological commodity output coefficients. The notations $(I-DB)^{-1}$, its elements, and Y are as defined above.

4.3.3 Data requirement and processing

Data required for this study are based on two field surveys (interviews, field measurements and observations) of economic activities in the study village, Katarko. First was a population survey of all households and their engagement in the various industries. The second was a sample survey to obtain more detailed information on economic activities (commodity production and sales) and use of environmental (ecological) commodities in the economic system. Key informants were consulted to solicit information on the socio-cultural setting of the village, economic activities, and the nature of water supply, demand and use. Information generated was used to design the survey instruments. The first author and three resident field assistants (two males and one female) participated in the data collection.

The population survey provides basic information used for sampling purposes in the more detailed survey that followed. There were 424 households with a total population of 2,734 people. The economic activities of households were aggregated into 26 industries and assigned to the four sectors. Each industry produces one or more commodities, of which more than 100 were identified in the survey. These were also aggregated into 81 commodities with a few being produced by more than one industry. This was particularly so between rainfed and irrigated agriculture which are defined here as different industries. (See Table 4.1 for lists of sectors, industries, and commodities.) All households were engaged in some form of rainfed agriculture. Somewhat less than half were engaged in various forms of animal husbandry and a rather small group of households were engaged in irrigated agriculture. Among non-farm activities, large numbers of households were involved in weaving, trading, and vegetation gathering, while smaller but still significant numbers engaged in diverse industries and services. The industries and commodities produced are listed and discussed in the subsequent section.

For the purpose of our model application, the detailed sample survey of households and industries gave the required data for establishing the input-output relationships in the village economy. A multistage (stratified) sampling procedure was used to draw the sample. Industries were stratified according to the number of households engaged in each and a sample of at least 20 percent taken. A 50 percent sample was taken from industries with fewer than ten households, while a total enumeration (100%) was conducted for those with fewer than five households. The enumeration included all possible commodities produced to ensure representativeness within the sampled industries. This was achieved by distributing the sample size for each stratum proportionately over the identified commodities. Field data was generated from the corresponding economic and ecological subsystems described earlier. Data generated were processed and then tabulated for analysis.

Generally, three kinds of tables are required for the I-O model: the transactions table that shows all transactions between the various industries in an economy for a given point in time as illustrated by the use matrix U or make matrix V in Figure 4.2; the direct requirements table that show how much of each input is required to produce a unit of output, established from analyses using equations (4.3) and (4.4) of the model; and the total (direct and indirect) requirements tables, from equations (4.6) to (4.11), used to determine the impact on the entire economy of a change in one sector or a combination of sectors.

Although the economies of rural areas in less developed countries (LDCs) are predominantly agricultural, they are sometimes diverse due to multi-crop production coexisting with the rural industry, trade and service sectors. All four sectors (agriculture, rural industry, trade, and service) are made up of an aggregate of 26 industries and 81 commodities in the economic subsystem (see Table 4.1). This gives an 81 x 26 matrix of commodities and industries in the use matrix (see Table 4.2) and same for the transpose of the make matrix (see Table 4.3). Three ecological commodity inputs (groundwater, land and vegetation) and two outputs (wastewater and solid wastes) are considered from the ecological subsystem (see Tables 4.4 and 4.5). The 3 x 26 and 2 x 26 sub-matrices of the ecological subsystem are appended as rows to the make and columns to the use matrices of the economic subsystem respectively. These produced our commodity-by-industry economic-ecological transactions table (illustrated on Figure 4.2). Solid quantities are measured in kilograms of mass and weight, liquid quantities in litres by volume, while monetary payments, sales and income are recorded in the local currency, naira (the Nigerian naira was pegged at twenty two naira to one US dollar in 1995). All other items and services are measured in absolute numbers. This was necessary because not all commodities have monetary values. However, these units are used consistently in our discussions. We have not attempted a valuation of the ecological commodities. Fortunately, the economic-ecological model was designed to handle transactions in physical and monetary terms (Richardson, 1972; Victor, 1972).

For the purpose of this paper, we have concentrated on model construction and the determination of both the direct and total (direct and indirect) requirements of each commodity for both the economic and ecological (environment) subsystems with a focus on water. The determination of impacts or effects associated with scenarios about demand and use of commodities, particularly water, on the economy and environment, will be subject of a later paper.

4.4 Empirical results and discussions

Table 4.1 presents a list of the economic sectors, industries and commodities produced in the village. Commodity outputs are given in physical units. The corresponding total income generated from the sale or consumption of these commodities are also provided. The total income associated with each industry is taken as the sum of the earned and imputed incomes from all the commodities it produces. An *imputed* income represents the amount the household could have earned by selling the retained commodity. In other words, the amount it would have to pay to purchase that quantity (Dabi and Anderson, 1998). Although our computations were based on the physical units, the monetary values of the total income are useful for purposes of comparison between commodities.

(Table 4.1 about here)

Transactions tables compiled for the use, make, ecological input, and ecological output matrices were used to calculate the direct and total and by implication indirect requirements using the CIEEM we have described. The transactions table show sparse interindustry transactions. The direct requirements (technical coefficients) also show that these linkages are not very significant (see Table 4.2). This is because most of the cells have zero coefficients. Such coefficients may be attributed to the low interdependence of industries within the economy. This is consistent with the general observation made by earlier workers on LDCs (for example, Bulmer-Thomas, 1982; 1986; Kol, 1991). Most commodities serve as inputs into their respective industries, particularly agriculture-related ones, and final demand (household consumption and export). The most significant interindustry transaction goes into the catering (trade or marketing) industry where most commodities serve as inputs. The other exception is perhaps labour which is employed by all but the labour industry; and farm tools from the blacksmiths' industry into as many as twelve industries, particularly in the agricultural sector and the rural industry.

(Table 4.2 about here)

Industries exhibiting high commodities direct input coefficients indicate their high dependence on economic commodities. The marketing industry is one such example. This can be attributed to the fact that commodities not consumed by households or exported (total final demand) are traded in the market, considered here independently as the marketing industry. Here, commodities are either sold as final goods or intermediate goods into other industries. However, most of the industries exhibit very small or no (zero) coefficients. Table 4.3 shows that the output coefficients from the make matrix are in fixed proportions and do not convey much information on interindustry transactions (interdependence) but the information has been used to calculate our commodity output proportion, commodity balance accounting identities and total requirements.

(Table 4.3 about here)

We went further to determine the total (direct and indirect) requirements of commodities for the economic sector (subsystem), using the industry-based-technology assumption which states that "all commodities produced by an industry are produced with the same input structure and thus commodities will have different input structures depending on the industry in which they are produced" (Armstrong, 1975). In some instances therefore, we have categorised similar commodities under different industries. For example, we have treated rainfed vegetables and rice as separate commodities from irrigated vegetables and rice. This is because they use different input structures. The irrigated ones use groundwater and different water application techniques not used in the former which rely on direct rainfall. The model commodity balance accounting identities reproduced the observed values indicating that the model is correctly specified.

On the other hand, the ecological commodity-by-industry direct inputs clearly show that the economic sector relies heavily on ecological commodities. Table 4.4 shows the direct and total inputs as well as the difference between the two (indirect), for all three ecological commodities being considered. Water is directly required in all industries but rainfed agriculture. Similarly, land (either in the form of farm land, space or material) in all but labour industry. Vegetation (either in the form of wood, leaves, roots or shrubs) is required into almost all the industries except technical, hair dressing, and education. The indirect water input is due to water required for the production of other commodities that serve as intermediate goods to the respective industries. For example, rainfed agriculture does not require groundwater directly, thus the zero entry, but requires it indirectly because draft animals are used for land ploughing and tilling or in producing bags and other farm inputs required in rainfed agriculture. These and other inputs require groundwater, therefore, an increase in rainfed production will demand an increase in these farm inputs and consequently groundwater.

(Table 4.4 about here)

The discharge of ecological commodity output was limited to wastewater and solid wastes (household refuse from animals and vegetative material). Wastewater is the quantity of water poured away after use or production. This is basically from all activities that do not experience "consumptive" water use (when water is used up during production). Most of the rural industry and services are in this category, unlike the agricultural sector as well as building, pottery, milling, water vending, transport, and labour which experience consumptive water use. Although large quantities of water are discharged from households after sanitary use (washing, bathing and ablution), this is not reflected on the requirements table because the household is considered exogenous for an open model such as this. Table 4.5 shows the ecological commodity direct, total and indirect outputs for wastewater and solid wastes.

(Table 4.5 about here)

Although comparisons cannot be easily made when commodities are measured in different physical units, it is very possible to deduce some variations from the ecological commodity-output and -income ratios calculated. For example, on Table 4.6, the highest direct groundwater input-output ratio in litres per unit of industry output are from animal husbandry (77.3), building (60.5) and irrigated crops (36.1). The lowest coefficients after rainfed agriculture (which is zero), is vegetation harvesting (0.003). All other industries lie between. Similar variations can be observed for the other ecological commodities. For example, most activities experience consumptive use of water and therefore do not have so much wastes produced per unit output.

(Table 4.6 about here)

The ecological commodity input/output to income ratios on Table 4.7 gave very interesting results that may be useful for economic development policies considering the use of ecological commodities and income generation. For example, irrigated agriculture had the highest ratio of about 4.8 litres of groundwater per naira. This followed by cassava (an annual crop that is partly irrigated), with about 2.6 litres per naira. The lowest ratio is of course rainfed agriculture because it requires only indirect groundwater. Most of the ecological commodity output-income ratios showed very low values because not much wastewater and solid wastes are produced by the various industries. The highest ratio of 2 litres per naira is from other services.

(Table 4.7 about here)

These tables indicate the heavy dependence of the economic sector on ecological commodities (groundwater, land and vegetation). All industries use various quantities of these ecological commodities in their production process. Water exhibits very large values per unit of output in the economy, an indication that water is indispensable in the area and its scarcity a constraint to sustainable development. For example, the catering (trade) industry exhibited the highest indirect input requirement. This may be attributed in part, to the fact that it is the only industry with a very significant interindustry transaction or interdependence within the economic sector and that such interdependence will generate further input requirements indirectly as more commodities come in from all the other industries. This shows that for the market economy of Katarko village to survive, large quantities (total requirements) of water and other ecological commodities (especially vegetation) have to be extracted to sustain the trade sector which is fundamental to cash income. Also more land may have to be put to use in the process. However, this may have deleterious effects on the environment where these ecological commodities are extracted. In a later paper we will consider the possible impacts on the economy and environment associated these effects and changes in water use.

4.5 Summary and conclusion

Our intention in this paper has been to construct a commodity-by-industry economic-ecological model (CIEEM), an input-output (I-O) type model for a rural village economy in a less developed country (LDC). We established the physical coefficients of the interindustry transactions as well as the extraction or use of ecological commodities (groundwater, land and vegetation) inputs from the environment into the economy and the discharge of ecological commodity output or externalities (wastewater and solid wastes or household refuse) from the economy back to the environment.

We discussed the direct, total and indirect effects of commodity production using the direct and total requirements (coefficients) based on a commodity-by-industry characterization for both the economic and ecological (environment) systems. Our major concern was the use of ecological commodities, particularly water, as inputs into the economic system. Also discussed are effects of commodities discharged from the economy back to the environment. Our results indicate that in considering ecological commodity inputs in an economy, it is very important to account for indirect effects which can be quite substantial.

Results indicate poor interindustry transactions (sparse sectoral interdependence) within the economy but a heavy dependence of the industries (economic subsystem) on ecological commodities from the environment (ecological subsystem). Such dependence is greatest on water which is a scarce commodity in this semi-arid environment. The major users of water (litres per unit output) based on the direct effects include animal husbandry, building and irrigated agriculture. The most intensive uses based on total effects are catering, building and animal husbandry, in descending order.

References

Agthe D, Billings R, 1980, "Dynamic models of residential water demand" *Water Resources Research* **16(3)** 476-480

Armstrong AG, 1975, "Technology assumptions in the construction of UK input-output tables" in *Estimating and Projecting Input-Output Coefficients* Eds. R I G Allen and W F Gossling (Input-Output Publishing Company, London) pp 68 - 93

Born P, 1996, "Input-out analysis: input of energy, CO_2, and work to produce goods" *Journal of Policy Modeling* **18(2)** 217 - 221

Bulmer-Thomas V, 1982 *Input-Output Analysis in Developing Countries: Sources, Methods and Applications* (John Wiley and Sons Ltd, Chichester)

Bulmer-Thomas V, 1986, "Application of input-output analysis for less developed countries (LDCs)" in *Readings in Input-Output Analysis: Theory and Applications* Ed. I Sohn (Oxford University Press, New York) pp 108 -129

Costanza R, Daly H, Bartholomew J, 1991, "Goals, agenda, and policy recommendations for ecological economics" in *Ecological Economics: The Science and Management of Sustainability* Ed. R Costanza (Columbia University Press, New York) pp 1 - 20

Cumberland J H, 1966, "A regional interindustry model for analysis of development objectives" *Papers of the Regional Science Association* 7 64 - 94

Dabi, D.D. (1996) Water demand and use in the rural economy of a semi-arid environment: a northern Nigeria case study. - A Doctoral research proposal presented in the Dept. of Geography, McMaster Univ. (Hamilton, Canada, 22 September, 1996), 36 pp.

Dabi D D, Anderson W P, 1998, "Water use and commodity production in Katarko village, northern Nigeria. *Applied Geography* (accepted)

Daly H E, 1968, "On economics of a life science" *Journal of Political Economy* **76** 392 - 406

Danielson L, 1978, "An analysis of residential demand for water using time-series data" *Water Resources Research* **15(4)** 763 - 767

Huang G H, Anderson W P, Baetz B W, 1994, "Environmental input-output analysis and its application to regional solid-waste management planning" *Journal of Environmental Management* **42** 63 - 79

Hughes W R, 1997, "A comparison of economic impacts with the use of economic base and input-output methodologies" *Environment and Planning A* **29(4)** 673 - 684

Isard W, 1951, "Interregional and regional input-output analysis: a model of space and economy" *Review of Economics and Statistics* **33(4)** 318 - 328

Isard W, 1968, "On the linkage of socio-economic and ecological systems" *Papers of the Regional Science Association* **21** 79 - 99

Isard W, Choguill C, Kissin J, 1971 *Ecologic and Economic Analysis for Regional Planning* (The Free Press, New York)

Johnson M, Bennett J, 1981, "Regional environmental and economic impact evaluation: an input-output approach" *Regional Science and Urban Economics* **11** 215 - 230

Kol J, 1991, "Key sectors, comparative advantage, and international shifts in employment: A case study for Indonesia, South Korea, Mexico and Pakistan and their trade with the European Community" in *Advances in Input-output Analysis: Technology,* *Planning and Development* Ed. W Peterson (Oxford University Press, New York) pp 199 - 210

Lesser J A, Dodds D E, Zerbe, Jr R O Eds., 1997 *Environmental Economics and Policy* chapter 19 (Addison Wesley Longman Inc., Reading)

Leontief W, 1986 *Input-Output Economics* 2nd ed. Chapters 1&2 (Oxford University Press, New York)

Lonergan S C, Cocklin C, 1985, "The use of input-output analysis in emvironmental planning" *Journal of Environmental Management* **20** 129 - 147

Madanat S, Humplick F, 1993, "A model of household choice of water supply systems in developing countries" *Water Resources Research* **29(5)** 1353 - 1358

Miller R, Blair P, 1985 *Input-output Analysis: Foundations and Extensions* chapters 5,6&7 (Prentice-Hall, Inc., Englewood Cliffs, New Jersey)

Mu X, Whittington D, Briscoe J, 1990, "Modelling village water demand behaviour: a discrete choice approach" *Water Resources Research* **26(4)** 521 - 529

Richardson H W, 1972 *Input-output and Regional Economics* (A Halsted Press Book John Wiley and Sons, New York)

Robison M H, 1997, "Community input-output models for rural area analysis with an example from central Idaho" *Annals of the Regional Science* **31(3)** 325 - 351

ten Raa T, 1994, "On the methodology of input-output analysis" *Regional Science and Urban Economics* **24(1)** 3 - 25

Viet V Q, 1994, "Practice in input-output table compilation" *Regional Science and Urban*

Economics **24(1)** 27 - 54

Victor P A, 1972 *Pollution: Economy and Environment* (Univ. of Toronto Press, Toronto)

Wolff E N, 1994, "Productivity measurement within an input-output framework" *Regional Science and Urban Economics* **24(1)** 75 - 92

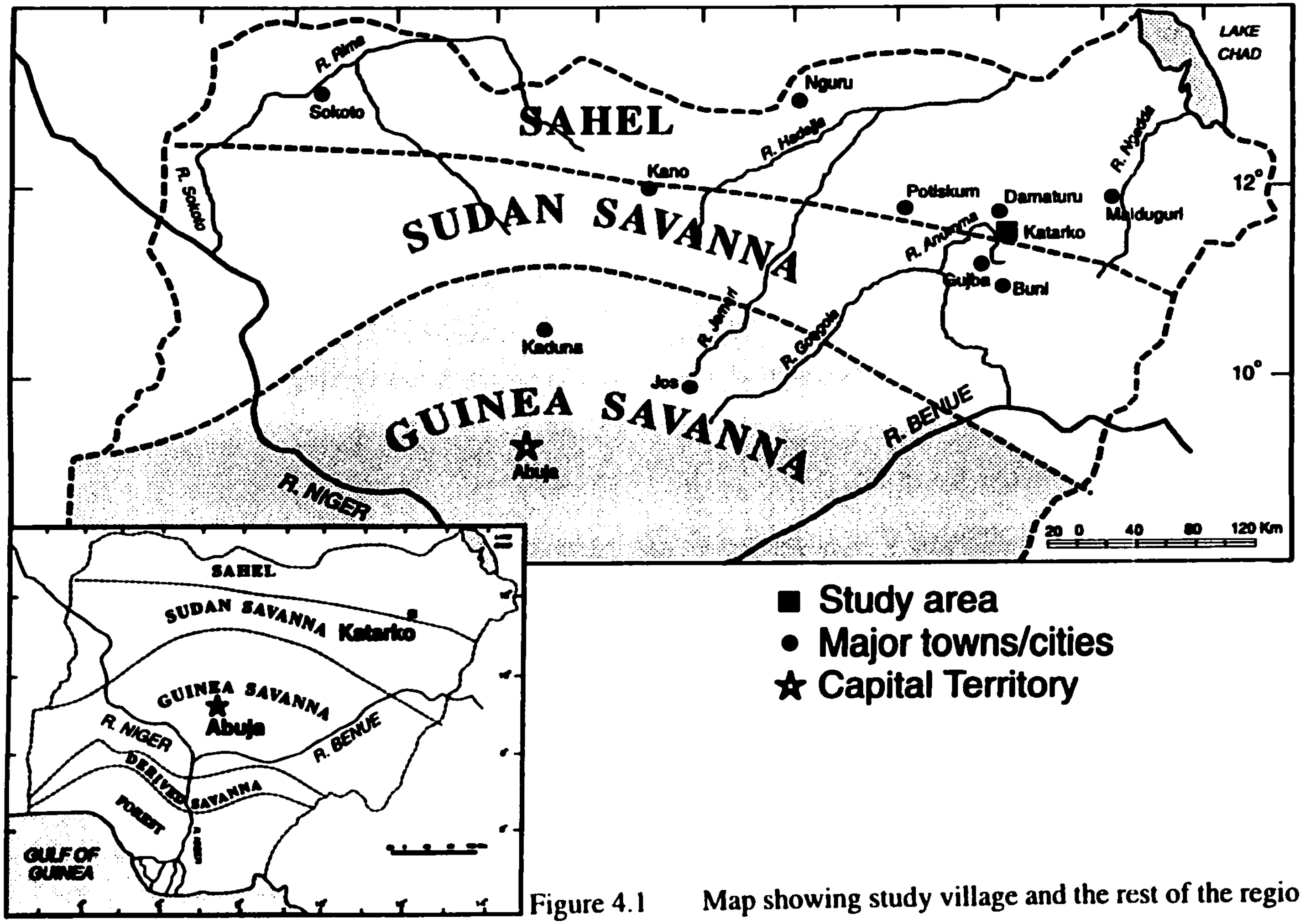
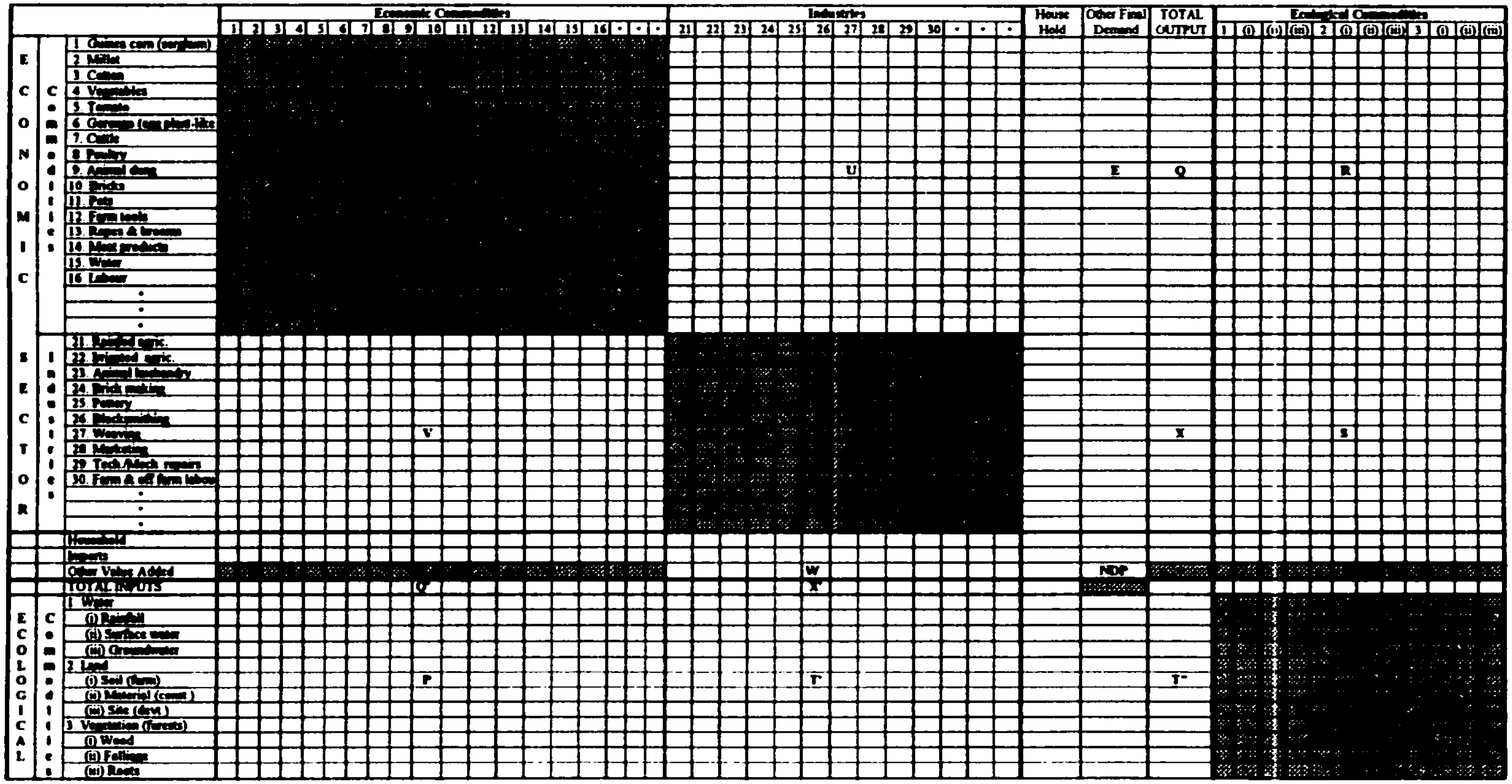


Figure 4.1 Map showing study village and the rest of the region



Notes: The Economic Subsystem:

$U = [u_{ij}]$ is the "use" matrix, u_{ij} represents the amount of economic commodity i used by industry j. For n industries and m commodities, U is $m \times n$

$V = [v_{ij}]$ is the "make" matrix, v_{ij} represents the amount of economic commodity i produced by industry j. V is $n \times m$.

$E = [E_i]$ is the vector of economic commodity final demands, E_i is final demand for commodity i, E is $m \times 1$

$Q = [Q_i]$ is the vector of economic commodity gross outputs; Q_i is the total production of commodity i, Q is $m \times 1$

$W = [W_j]$ is the vector of industry value-added inputs, W_j represents the total of value-added inputs to industry j. W is $1 \times n$

$X = [X_j]$ is the vector of industry total outputs, X_j represents the total output of industry j, X is $n \times 1$

The Ecologic Subsystem:

$R = [r_{ik}]$ is the matrix of economic commodity by ecologic commodity outputs, r_{ik} is the amount of ecologic commodity k discharged as a result o economic commodity i, for e ecologic commodities, R is $m \times e$

$S = [s_{jk}]$ is the matrix of industry by ecologic commodity outputs, s_{jk} is the amount of ecologic commodity k discharged by industry j, s is $n \times e$

$P = [p_{ki}]$ is the matrix of ecologic commodity by economic commodity inputs, p_{ki} is the amount of ecologic commodity k used in the production of economic commodity i, P is $e \times m$

$T = [t_{kj}]$ is the matrix of ecologic commodity by industry inputs, t_{kj} is the amount of ecologic commodity k used by industry j, T is $e \times n$

NDP = Net domestic product (when ecological commodities are discounted from the GDP)

Figure 4.2 An example of a structural matrix of the proposed commodity-by-industry economic-ecological model

Table 4.1: Economic commodity production (output) and income generation by industry and sector

Sector	Industry	Commodity	Total output *		Income ('000 Naira)§
Agriculture	Rainfed agriculture	Guinea corn (sorghum)	796590.0		8205
		Millet	393600.0		4333
		Maize (corn)	408100.0		3310
		Ground (pea) nuts	192616.7		4315
		Beans (cow peas)	190485.0		1786
		Calabash	61639.0		99
		Pumpkins	3612.5		35
		Beniseed	2762.5		16
		Okra	133950.0		1340
		Jute	9333.3		7
		Vegetables (rainfed)	276033.0		486
		Garden egg (local)	5100.0		41
		Bambara nut	32393.8		227
		Rice (upland)	30433.3		551
		Cotton	5400.0		86
	Irrigated agriculture	Tomato	7500.0		23
		Onions	18000.0		107
		Red peppers	18000.0		107
		Egg plant (garonga)	5400.0		54
		Vegetables (irrigated)	36000.0		332
		Rice (lowland)	1000.0		33
		Wheat	200.0		7
	Cassava (tubers)	Cassava	12400.0		68
	Animal husbandry	Cattle	228.0	[b]	4150
		Oxen	182.0	[b]	1836
		Sheep	608.0	[b]	839
		Goats	3143.0	[b]	3550
		Poultry (birds)	17296.0	[b]	783
		Donkeys	16.0	[b]	5
		Horses	2.0	[b]	0
		Animal dung	28370.1		0
Rural Industry	Brick making	Bricks	400000.0	[b]	734
	Building Constructions	Trad./Modern walls	9980.0	[b]	495
		Mud roofs and floors	2475.2	[b]	124
	Pottery	Pots	6400.0	[b]	323
	Blacksmithing	Farm tools	973.0	[b]	34
		Weapons	650.0	[b]	23
		Utensils	763.0	[b]	27
	Wood carving	Handicrafts	8160.0	[b]	134
	Calabash carving	Calabash carving	2760.0	[b]	28
	Weaving	Roof tops	1880.0	[b]	612
		Stalk fences (dunga)	3978.0	[b]	378
		Grass & palm mats	1278.0	[b]	88
		Ropes, baskets & brooms	180.0	[b]	5
		Mattresses	72.0	[b]	0
	Milling	Grains (flour)	643872.8		322
		Grain stalk	609372.5		899
		Grain chaff/hay	23104.6		18
		Grain husk	177274.1		89
		Ground nut oil	476100.0		674
		Ground nut cake	6120.0		67
Trade	Butchery	Meat (products)	149761.3		1494
	Catering/Trading	Yogurt & flour balls	28288.0	[b]	20
		Cassava (boiled)	33000.0		418
		Porridge	1508.0	[b]	9
		Food (canteen&home)	3244.0		32
		Toast bread	2000.0	[b]	25
		Bean cake	6370.0		86
		Local salt	1614.6	[b]	27
	Fishing	Fresh & roasted fish	1668.0		432
	Hunting	Bush animals	1872.0		147
	Water vendors	Water	69888.0	[c]	35
	Vegetation harvesting	Wood	3224000.0		709
		Leaves	104000.0		239
		Fruits	50700.0		203
		Grass	14270454.3		11416
Service	Technical & Mech. repairs	Radio & watches, repair	720.0		19
		Bicycles & tire mending	4264.0	[b]	113
	Carpentry	Roofs, windows & doors	858.0	[b]	49
		Kantu, Furniture making	858.0	[b]	49
	Transportation	Cattle truck	19094.4	[b]	1711
		Bicycles (transport)	200.0	[b]	24
		Buses (transport)	36400.0	[b]	802
	Tailoring & design	Clothe & cap design	280.0	[b]	48
	Hairdressing/Barbing	Hair dressing & barbing	5720.0	[b]	17
	Education	Teaching	783.0	[b]	144
	Other services	Medical dispensing	1148.0	[b]	1
		Traditional medicine	5548.1	[b]	6
		Farm extension	312.0	[b]	0
		Mass literacy	894.9	[b]	1
	Labour	Paid labour	89230.0	[d]	1783

Notes.

* All output is measured in kilograms (kg), otherwise as noted
[b] Items are counted in absolute numbers (#)
[c] Liquids are in litres (l)
[d] Human paid labour in man hours
§ In 1995 the naira was pegged at N22.00 to US$1.00

Table 4.2: Economic commodity-by-industry direct input requirements (technical coefficients), B = U[X]$^{-1}$ (naira)

Commodity	Industry Rainfed agric 82	Irrigated agric 83	Cassava 84	Animal hsbdry 85	Brick making 86	Building 87	Pottery 88	Blacksmith 89	Wood carv 90	Calabash 91	Weaving 92	Milling 93	Butchery 94	Marketing 95	Fishing 96	Hunting 97	Water vend 98	Vegetation 99	Tech/Mech 100	Carpentry 101	Transport 102	Tailoring 103	Hairdressing 104	Education 105	Other service 106	Labour (jobs) 107
1 Guinea corn (sorghum)	0.00403	0	0	1.99585	0	0	0	0	0	0	0	0	0	1.44089	0	0	0	0	0	0	0.11753	0	0	0	0	0
2 Millet	0.00401	0	0	0	0	0	0	0	0	0	0	0	0	2.09511	0	0	0	0	0	0	0	0	0	0	0	0
3 Maize (corn)	0.00565	0	0	0	0	0	0	0	0	0	0	0	0	1.38349	0	0	0	0	0	0	0	0	0	0	0	0
4 Ground (pea) nuts	0.00333	0	0	0	0	0	0	0	0	0	0	0.00003	0	0.71619	0	0	0	0	0	0	0	0	0	0	0	0
5 Beans (cow peas)	0.00149	0	0	0	0	0	0	0	0	0	0	0	0	1.00405	0	0	0	0	0	0	0	0	0	0	0	0
6 Calabash	0.00034	0	0	0	0	0	0	0	0	0	0	0	0	0.42211	0	0	0	0	0	0	0	0	0	0	0	0
7 Pumpkins	0.00003	0	0	0	0	0	0	0	0	0	0	0	0	0.82817	0	0	0	0	0	0	0	0	0	0	0	0
8 Beniseed	0.00001	0	0	0	0	0	0	0	0	0	0	0	0	0.00908	0	0	0	0	0	0	0	0	0	0	0	0
9 Okra	0.00009	0	0	0	0	0	0	0	0	0	0	0	0	0.01726	0	0	0	0	0	0	0	0	0	0	0	0
10 Jute	0.00066	0	0	0	0	0	0	0	0	0	0	0	0	0.09154	0	0	0	0	0	0	0	0	0	0	0	0
11 Vegetables (rainfed)	0.00009	0	0	0	0	0	0	0	0	0	0	0	0	1.00232	0	0	0	0	0	0	0	0	0	0	0	0
12 Garden egg (local)	0.00002	0	0	0	0	0	0	0	0	0	0	0	0	0.03423	0	0	0	0	0	0	0	0	0	0	0	0
13 Bambara nut	0.00003	0	0	0	0	0	0	0	0	0	0	0	0	0.00070	0	0	0	0	0	0	0	0	0	0	0	0
14 Rice (upland)	0.00033	0	0	0	0	0	0	0	0	0	0	0	0	0.11443	0	0	0	0	0	0	0	0	0	0	0	0
15 Cotton	0.00001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 Tomato	0	0.00066	0	0	0	0	0	0	0	0	0	0	0	0.00410	0	0	0	0	0	0	0	0	0	0	0	0
17 Onions	0	0.00003	0	0	0	0	0	0	0	0	0	0	0	0.09566	0	0	0	0	0	0	0	0	0	0	0	0
18 Red peppers	0	0.00002	0	0	0	0	0	0	0	0	0	0	0	0.09366	0	0	0	0	0	0	0	0	0	0	0	0
19 Egg plant ([illegible])	0	0.00001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 Vegetables (irrigated)	0	0.00001	0	0	0	0	0	0	0	0	0	0	0	0.19013	0	0	0	0	0	0	0	0	0	0	0	0
21 Rice (lowland)	0	0.00001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 Wheat	0	0.00002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 Cassava	0	0	0.10000	0	0	0	0	0	0	0	0	0	0	0.09380	0	0	0	0	0	0	0	0	0	0	0	0
24 Cattle	0	0	0	0.00220	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00041	0	0	0	0	0
25 Oxen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00126	0	0	0	0	0
26 Sheep	0	0	0	0.00073	0	0	0	0	0	0	0	0	0.00122	0	0	0	0	0	0	0	0	0	0	0	0	0
27 Goats	0	0	0	0.04796	0	0	0	0	0	0	0	0	0.60224	0	0	0	0	0	0	0	0	0	0	0	0	0
28 Poultry (birds)	0	0	0	0.19379	0	0	0	0	0	0	0	0	0.02407	0	0	0	0	0	0	0	0	0	0	0	0	0
29 Donkeys	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00029	0	0	0	0	0
30 Horses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0
31 Animal dung	0.00114	0.07410	0	0	0	0.97715	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 Bricks	0	0	0	0	0	17.30242	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 Trad (Adobe) walls	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14810	0	0	0	0	0	0	0	0	0	0	0	0
34 Mud roofs and floors	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02705	0	0	0	0	0	0	0	0	0	0	0	0
35 Pots	0	0	0	0.03071	0	0	0	0	0	0	0	0	0	0.04736	0	0	0	0.000001	0	0	0	0	0	0	0.00087	0
36 Farm tools	0.00030	0.00012	0.00034	0.00122	0.00001	0.00033	0	0.00125	0.00190	0	0	0	0	0.00001	0	0	0	0.000001	0	0	0	0	0.00217	0	0	0.00000
37 Weapons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20010	0	0	0	0	0	0	0	0	0	0
38 Utensils	0	0	0	0	0	0	0	0	0	0.00362	0	0.00022	0.00023	0.00273	0	0	0.00001	0	0	0	0	0	0	0	0.00071	0
39 Handicrafts	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07190	0	0	0.00001	0	0	0	0	0	0.00311	0.09482	0.00029	0
40 Calabash carving	0.00039	0.00049	0	0	0	0	0	0	0	0	0	0	0	0	0.01109	0	0.00010	0.00000	0	0	0	0	0.00171	0	0.00112	0
41 Roof tops	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01464	0	0	0	0	0	0	0	0	0	0	0	0
42 Bath fences (dungu)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02705	0	0	0	0	0	0	0	0	0	0	0	0
43 Grass & palm mats	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01420	0	0	0	0	0	0	0	0	0	0	0	0
44 Ropes, baskets & brooms	0.00063	0.00002	0	0	0	0	0	0	0	0	0.00901	0	0	0	0	0	0	0.000001	0	0	0	0	0	0	0	0
45 Mattresses	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00094	0	0	0	0	0	0	0	0	0	0	0	0
46 Grains (flour)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47 Grain malt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01510	0
48 Grain chaff/bran	0.00101	0	0	0.39112	0.00032	0.00295	0.01303	0	0	0	0	0	0	0.00623	0	0	0	0	0	0	0.00703	0	0	0	0.00177	0
49 Grain husk	0	0	0	1.49101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04363	0	0	0	0.01096	0
50 Ground nut oil	0	0	0	0	0	0	0	0	0	0	0	0.63194	0	3.00951	0	0	0	0	0	0	0	0	0	0	0	0
51 Ground nut cake	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00046	0	0	0	0	0	0	0	0	0	0	0	0
52 Milk (products)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.71372	0	0	0	0	0	0	0	0	0	0	0	0
53 Yogurt & flour balls	0	0	0	0	0	0	0	0	0	0	0	0	0	0.34362	0	0	0	0	0	0	0	0	0	0	0	0
54 Cassava (boiled)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.32450	0	0	0	0	0	0	0	0	0	0	0	0
55 Porridge	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01772	0	0	0	0	0	0	0	0	0	0	0	0
56 Food (cereals/cowbeans)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03705	0	0	0	0	0	0	0	0	0	0	0	0
57 Toothwood	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02460	0	0	0	0	0	0	0	0	0	0	0	0
58 Bean cake	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06742	0	0	0	0	0	0	0	0	0	0	0	0
59 Local salt	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01970	0	0	0	0	0	0	0	0	0	0	0	0
60 Fresh & roasted fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00407	0.19424	0	0	0	0	0	0	0	0	0	0	0
61 Bush animals	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01332	0	0	0	0	0	0	0	0	0	0	0	0
62 Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0.73401	0	0	0	0	0	0	0	0	0	0	0	0
63 Wood	0	0	0	0	0	0	0	0	0	0	0	0	0	24.34139	0	0	0	0	0	0	0	0	0	0	0	0
64 Leaves	0	0	0	0	0	0	0	0	0	0	0	0	0	0.45077	0	0	0	0	0	0	0	0	0	0	0	0
65 Fruits	0	0	0	0	0	0	0	0	0	0	0	0	0	0.27940	0	0	0	0	0	0	0	0	0	0	0	0
66 Grass	0	0	0	1.14416	0	0	0	0	0	0	1.13117	0	0	11.78249	0	0	0	0	0	0	0	0	0	0	0	0
67 Radio & watches repair	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00947	0	0	0	0	0	0	0	0	0	0	0	0
68 Bicycles & tire mending	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04040	0	0	0	0	0	0	0	0	0	0	0	0
69 Roofs, windows & doors	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00645	0	0	0	0	0	0	0	0	0	0	0	0
70 Kiosks, Furniture making	0	0	0	0	0.00063	0	0	0	0	0	0	0	0	0.30745	0	0	0	0	0.06200	0	0.00065	0.01190	0	0	0	0
71 Cattle truck	0	0	0	0	0	0	0	0	0	0	0	0	0	0.12070	0	0	0	0	0	0	0	0	0	0	0	0
72 Bicycles (transport)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00270	0	0	0	0	0	0	0	0	0	0	0	0
73 Buses (transport)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74 Clothe & cap design	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05214	0	0	0	0	0	0	0	0	0	0	0	0
75 Hair dressing & barbing	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04940	0	0	0	0	0	0	0	0	0	0	0	0
76 Teaching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77 Medical dispensing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78 Traditional medicine	0	0	0	0.00709	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79 Farm extension	0.00004	0.00081	0.00270	0.00170	0	0	0	0	0	0	0	0	0	0.00943	0	0	0	0	0	0	0	0	0	0	0	0
80 Mass literacy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81 Paid labour	0.00162	0.00121	0.00421	0.87194	0.00011	0.00047	0.00714	0.01102	0.17130	0.05018	0.24199	0.03887	0.09677	0.00242	0.24481	0.01232	0.00023	0.00921	0.00647	0.00672	0.00219	0.04118	0.00063	0.00443	0.00116	0

[X] implies diagonalization.

Table 4.3: Economic commodity by industry direct output requirements (technical coefficients), $C = V'([X])^{-1}$

Commodity / Industry	Rainfed agric 82	Irrigated agric 83	Cassava 84	Animal hbdry 85	Brick makin 86	Building 87	Pottery 88	Blacksmith 89	Wood carv 90	Calabash 91	Weaving 92	Milling 93	Butchery 94	Marketing 95	Fishing 96	Hunting 97	Water vend 98	Vegetation 99	Tech/Mech 100	Carpentry 101	Transport 102	Tailoring 103	Hairdr·ing 104	Education 105	Other service 106	Labour (jobs) 107
1 Guinea corn (sorghum)	0.20830	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 Millet	0.21432	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 Maize (corn)	0.14872	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 Ground (pea) nuts	0.07810	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 Beans (cow peas)	0.07233	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 Calabash	0.02346	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Pumpkins	0.00132	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 Beniseed	0.00301	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9 Okra	0.04001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 Jute	0.00340	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 Vegetables (rainfed)	0.00841	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 Garden egg (local)	0.00180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 Bambara nut	0.01181	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 Rice (upland)	0.01180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 Cotton	0.00197	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 Tomato	0	0.08711	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 Onions	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 Red peppers	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 Egg plant (garden egg)	0	0.06372	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 Vegetables (irrigated)	0	0.41012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 Rice (lowland)	0	0.01141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 Wheat	0	0.00232	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 Cassava	0	0	1.00000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24 Cattle	0	0	0	0.00436	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25 Oxen	0	0	0	0.00364	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 Sheep	0	0	0	0.01215	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27 Goats	0	0	0	0.06200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28 Poultry (birds)	0	0	0	0.34361	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 Donkeys	0	0	0	0.00012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 Horses	0	0	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 Animal dung	0	0	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 Bricks	0	0	0	0	1.00000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 Total thatched walls	0	0	0	0	0	0.80000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 Mud roofs and floors	0	0	0	0	0	0.20000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 Pots	0	0	0	0	0	0	1.00000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 Farm tools	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 Weapons	0	0	0	0	0	0	0	0.27485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 Utensils	0	0	0	0	0	0	0	0.31071	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39 Handicrafts	0	0	0	0	0	0	0	0	1.00000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40 Calabash carving	0	0	0	0	0	0	0	0	0	1.00000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 Roof tops	0	0	0	0	0	0	0	0	0	0	0.14631	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42 Bath fences (danga)	0	0	0	0	0	0	0	0	0	0	0.34433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 Grass & palm mats	0	0	0	0	0	0	0	0	0	0	0.17488	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44 Ropes, baskets & brooms	0	0	0	0	0	0	0	0	0	0	0.02443	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 Mattresses	0	0	0	0	0	0	0	0	0	0	0.00005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46 Grains (flour)	0	0	0	0	0	0	0	0	0	0	0	0.34224	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47 Grain stalk	0	0	0	0	0	0	0	0	0	0	0	0.33321	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48 Grain chaff/hay	0	0	0	0	0	0	0	0	0	0	0	0.01301	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49 Grain husk	0	0	0	0	0	0	0	0	0	0	0	0.00096	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50 Ground nut oil	0	0	0	0	0	0	0	0	0	0	0	0.30019	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51 Ground nut cake	0	0	0	0	0	0	0	0	0	0	0	0.00341	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52 Meat (products)	0	0	0	0	0	0	0	0	0	0	0	0	1.00000	0	0	0	0	0	0	0	0	0	0	0	0	0
53 Yogurt & flour balls	0	0	0	0	0	0	0	0	0	0	0	0	0	0.34703	0	0	0	0	0	0	0	0	0	0	0	0
54 Cassava (boiled)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.43930	0	0	0	0	0	0	0	0	0	0	0	0
55 Porridge	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01961	0	0	0	0	0	0	0	0	0	0	0	0
56 Food (corn/rice/beans)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04219	0	0	0	0	0	0	0	0	0	0	0	0
57 Traditional	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02701	0	0	0	0	0	0	0	0	0	0	0	0
58 Bean cake	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00283	0	0	0	0	0	0	0	0	0	0	0	0
59 Local salt	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03069	0	0	0	0	0	0	0	0	0	0	0	0
60 Fresh & roasted fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00000	0	0	0	0	0	0	0	0	0	0	0
61 Bush animals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00000	0	0	0	0	0	0	0	0	0	0
62 Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00000	0	0	0	0	0	0	0	0	0
63 Wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.10367	0	0	0	0	0	0	0	0
64 Leaves	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00300	0	0	0	0	0	0	0	0
65 Fruits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00287	0	0	0	0	0	0	0	0
66 Grass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00034	0	0	0	0	0	0	0	0
67 Radio & watches, repair	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14583	0	0	0	0	0	0	0
68 Bicycles & tire mending	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.85417	0	0	0	0	0	0	0
69 Roofs, windows & doors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.50000	0	0	0	0	0	0
70 Kiosks, Furniture making	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.50000	0	0	0	0	0	0
71 Cattle truck	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.34347	0	0	0	0	0
72 Bicycles (transport)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00444	0	0	0	0	0
73 Buses (transport)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.61306	0	0	0	0	0
74 Clothes & cap design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00000	0	0	0	0
75 Hair dressing & barbing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00000	0	0	0
76 Teaching	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00000	0	0
77 Medical dispensing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13394	0
78 Traditional medicine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.69336	0
79 Farm extension	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03000	0
80 Mass literacy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11182	0
81 Paid labour	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00000

[X] implies diagonalization, V' transposition

Table 4.4: Ecological commodity-by-industry direct, total and indirect input requirements

Industry	Groundwater input (litres)			Land input (sq. metres)			Vegetation input (kg)		
	Direct	Total	Indirect	Direct	Total	Indirect	Direct	Total	Indirect
	$G=[T\|X\|^{-1}]Y$	$G^{*}=[G(I-DB)^{-1}]$	$G^{*}-G$	$G=[T\|X\|^{-1}]Y$	$G^{*}=[G(I-DB)^{-1}]$	$G^{*}-G$	$G=[T\|X\|^{-1}]Y$	$G^{*}=[G(I-DB)^{-1}]$	$G^{*}-G$
1. Rainfed agriculture	0.0	580492.8	580492.8	19470980.2	20600674.1	1129693.9	10155.0	66545.9	56390.9
2. Irrigated agriculture	2031715.1	2486119.3	454404.1	9048.5	547422.5	538374.0	769.1	43910.0	43140.9
3. Cassava (annuals)	57747.7	64206.7	6459.0	6606.9	7341.5	734.6	185.9	217.6	31.7
4. Animal husbandry	809175.0	1092675.9	283500.9	719063.1	1299861.2	580798.1	70045.1	103986.8	33941.7
5. Brick making	576000.0	576023.6	23.6	5315.4	5325.2	9.8	52.9	56.2	3.4
6. Building Constructors	119556.3	312151.7	192595.4	113.9	142377.7	142263.8	2.6	11336.4	11333.9
7. Pottery	1942.1	1943.6	1.5	519.7	521.0	1.3	201.3	201.4	0.1
8. Blacksmithing	630.5	632.0	1.4	5.2	5.2	0.0	119.6	119.7	0.2
9. Wood carving	3183.1	3201.8	18.7	40.5	40.6	0.1	19980.0	19981.9	1.9
10. Calabash carving	237.4	251.1	13.7	19.8	19.9	0.1	1560.0	1562.4	2.4
11. Weaving	7690.2	7884.3	194.1	195.9	197.9	2.0	11177.4	11901.4	724.0
12. Milling	16937.8	31854.3	14916.5	618.9	139742.9	139124.0	4751.6	5515.1	763.5
13. Butchery	60482.5	341763.8	281281.2	57.0	334598.7	334541.7	293.6	27065.9	26772.3
14. Catering/Trading	22283.5	3792750.7	3770467.2	41.3	11368751.5	11368710.2	11501.0	1736017.1	1724516.1
15. Fishing	558.0	709.0	150.9	50.8	63.2	12.4	148.8	199.2	50.4
16. Hunting	392.9	887.9	495.0	8.8	12.9	4.1	374.2	467.6	93.4
17. Water vendors	13377.0	13379.6	2.6	2.7	2.7	0.0	0.7	8.2	7.5
18. Vegetation harvesting	27052.4	27178.8	126.4	245.0	253.8	8.8	1861525.2	1861584.5	59.3
19. Technical & Mech. repairs	308.8	310.5	1.8	1.5	1.5	0.0	0.0	0.2	0.2
20. Carpentry	327.8	328.3	0.5	2.4	2.4	0.0	63.0	63.0	0.0
21. Transportation	52652.9	73693.3	21040.4	86.4	87539.4	87453.0	3111.8	5154.6	2042.8
22. Tailoring & design	928.6	930.3	1.7	3.5	3.6	0.0	13.7	13.9	0.2
23. Hairdressing/Barbing	449.1	460.9	11.8	6.4	6.6	0.2	0.0	59.6	59.6
24. Education	14320.0	14439.4	119.4	20080.0	20081.4	1.4	0.0	684.1	684.1
25. Other services	18239.2	18280.1	40.8	223.2	249.6	26.4	5752.4	5784.4	32.0
26. Labour	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$|X|$ implies diagonalization

$[(I - DB)^{-1}]$ is the industry-by-industry total requirements matrix

Table 4.5: Ecological commodity-by-industry direct, total and indirect output requirements

Industry	Wastewater output (litres)			Solid wastes output (kg)		
	Direct $G=[T'|X|^{-1}]Y$	Total $G^*=[G(I-DB)^{-1}]$	Indirect $G^* - G$	Direct $G=[T'|X|^{-1}]Y$	Total $G^*=[G(I-DB)^{-1}]$	Indirect $G^* - G$
1. Rainfed agriculture	0.0	1618.9	1618.9	28194.8	34328.5	6133.6
2. Irrigated agriculture	0.0	269.3	269.3	0.0	4265.5	4265.5
3. Cassava (annuals)	0.0	28.7	28.7	408.0	453.3	45.3
4. Animal husbandry	0.0	396.9	396.9	5977.2	10298.8	4321.7
5. Brick making	0.0	12.3	12.3	0.0	2.6	2.6
6. Building Constructors	0.0	46.1	46.1	0.0	1122.3	1122.3
7. Pottery	0.0	0.0	0.0	0.0	0.3	0.3
8. Blacksmithing	567.5	568.2	0.7	0.0	0.0	0.0
9. Wood carving	2864.8	2873.4	8.7	1998.0	1998.0	0.0
10. Calabash carving	178.0	189.3	11.2	0.0	0.0	0.0
11. Weaving	6921.2	6994.6	73.4	0.0	11.8	11.8
12. Milling	0.0	595.3	595.3	35983.6	37402.6	1419.0
13. Butchery	45361.9	45509.0	147.1	0.0	2650.6	2650.6
14. Catering/Trading	11141.8	108811.9	97670.2	0.0	68583.6	68583.6
15. Fishing	279.0	348.0	69.0	0.0	0.0	0.0
16. Hunting	196.4	639.7	443.3	0.0	0.0	0.0
17. Water vendors	0.0	1.8	1.8	0.0	0.6	0.6
18. Vegetation harvesting	13526.2	13563.6	37.4	36003.3	36003.4	0.0
19. Technical & Mech. repairs	277.9	278.7	0.9	0.0	0.0	0.0
20. Carpentry	245.8	245.8	0.0	0.0	0.0	0.0
21. Transportation	0.0	30.6	30.6	0.0	356.8	356.8
22. Tailoring & design	696.4	697.1	0.7	0.0	0.0	0.0
23. Hairdressing/Barbing	404.2	413.3	9.2	0.0	5.6	5.6
24. Education	7160.0	7258.4	98.4	0.0	68.4	68.4
25. Other services	13679.4	13694.1	14.7	0.0	7.9	7.9
26. Labour	0.0	0.0	0.0	0.0	0.0	0.0

$|X|$ implies diagonalization; S', transposition

$[(I - DB)^{-1}]$ is the industry-by-industry total requirements matrix

Table 4.6: Ecological commodity input and output to economic commodity output ratios

Industry	Ecological commodity input			Ecological commodity output	
	Gwater:output (Liters/unit output)	Land:output (m^2/unit output	Vegtn:output (kg/unit output)	Wwater:output (Liters/unit output	Swaste:output (kg/unit output)
1. Rainfed agriculture	0	11.31425	0.00590	0	0.01638
2. Irrigated agriculture	36.09756	0.16076	0.01366	0	0
3. Cassava (annuals)	14.15385	1.61935	0.04556	0	0.10000
4. Animal husbandry	77.28556	68.67883	6.69011	0	0.57089
5. Brick making	2.11765	0.01954	0.00019	0	0
6. Building Constructors	60.50420	0.05763	0.00129	0	0
7. Pottery	2.28483	0.61141	0.23684	0	0
8. Blacksmithing	2.20468	0.01827	0.41813	1.98421	0
9. Wood carving	1.43382	0.01824	9.00000	1.29044	0.90000
10. Calabash carving	0.15217	0.01268	1.00000	0.11413	0
11. Weaving	2.80460	0.07144	4.07635	2.52414	0
12. Milling	0.01328	0.00049	0.00373	0	0.02822
13. Butchery	0.66288	0.00062	0.00322	0.49716	0
14. Catering/Trading	1.10105	0.00204	0.56827	0.55053	0
15. Fishing	0.57554	0.05236	0.15348	0.28777	0
16. Hunting	0.47222	0.01060	0.44979	0.23611	0
17. Water vendors	1.00000	0.00020	0.00005	0	0
18. Vegetation harvesting	0.00278	0.00003	0.19144	0.00139	0.00370
19. Technical & Mech. repairs	0.59375	0.00280	0	0.53438	0
20. Carpentry	0.78788	0.00578	0.15152	0.59091	0
21. Transportation	1.14933	0.00189	0.06793	0	0
22. Tailoring & design	9.28571	0.03545	0.13690	6.96429	0
23. Hairdressing/Barbing	0.22727	0.00326	0	0.20455	0
24. Education	18.24204	25.57962	0	9.12102	0
25. Other services	2.50156	0.03061	0.78895	1.87617	0
26. Labour	0.19227	0	0.00067	0	0

Table 4.7: Ecological commodity input and output to income ratios

Industry	Ecological commodity input			Ecological commodity output	
	Gwater:income (Liters / Naira)	Land:income (m^2 / Naira)	Vegtn:incom (kg / Naira)	Wwater:income (Liters / Naira)	Swaste:income (kg / Naira)
1. Rainfed agriculture	0.00000	1.24009	0.00065	0.00000	0.00180
2. Irrigated agriculture	4.76920	0.02124	0.00181	0.00000	0.00000
3. Cassava (annuals)	2.60937	0.29854	0.00840	0.00000	0.01844
4. Animal husbandry	0.37265	0.33115	0.03226	0.00000	0.00275
5. Brick making	1.41176	0.01303	0.00013	0.00000	0.00000
6. Building Constructors	1.21008	0.00115	0.00003	0.00000	0.00000
7. Pottery	0.04570	0.01223	0.00474	0.00000	0.00000
8. Blacksmithing	0.06299	0.00052	0.01195	0.05669	0.00000
9. Wood carving	0.02189	0.00028	0.13740	0.01970	0.01374
10. Calabash carving	0.01522	0.00127	0.10000	0.01141	0.00000
11. Weaving	0.01981	0.00050	0.02879	0.01783	0.00000
12. Milling	0.01823	0.00067	0.00511	0.00000	0.03873
13. Butchery	0.06629	0.00006	0.00032	0.04972	0.00000
14. Catering/Trading	0.27140	0.00050	0.14008	0.13570	0.00000
15. Fishing	0.00152	0.00014	0.00040	0.00076	0.00000
16. Hunting	0.00602	0.00014	0.00573	0.00301	0.00000
17. Water vendors	2.00000	0.00040	0.00010	0.00000	0.00000
18. Vegetation harvesting	0.00396	0.00004	0.27245	0.00198	0.00527
19. Technical & Mech. repairs	0.02241	0.00011	0.00000	0.02017	0.00000
20. Carpentry	0.01368	0.00010	0.00263	0.01026	0.00000
21. Transportation	0.03128	0.00005	0.00185	0.00000	0.00000
22. Tailoring & design	0.05462	0.00021	0.00081	0.04097	0.00000
23. Hairdressing/Barbing	0.07576	0.00109	0.00000	0.06818	0.00000
24. Education	0.09944	0.13944	0.00000	0.04972	0.00000
25. Other services	2.15600	0.02638	0.67997	1.61700	0.00000
26. Labour	0.00961	0.00000	0.00003	0.00000	0.00000

CHAPTER FIVE

Indigenous knowledge systems, technology transfer and rural water use in northern Nigeria

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Abstract

This paper investigates water use and conservation measures in Katarko village in northern Nigeria. It looks at indigenous knowledge systems (local initiatives) regarding water scarcity and strategies aimed at mitigating the problem in terms of water procurement, delivery and processing. It also considers some of the introduced technologies used for solving water problems with the aim of developing scenarios of water use efficiency at the household, industry and particularly, irrigation farms. The survey indicates that the people possess unsophisticated techniques and indigenous knowledge systems for water use and conservation (management), and depend on some unsustainable forms of introduced technologies, although they indicate their willingness to accept new innovations. They also lack specialized but sustainable skills for making the best use of the 'excess' water supply during the rainy season. Additionally, the annual scheduling of activities does not take proper cognisance of the timing of water availability. A number of strategies ('appropriate technologies') for the enhancement of water management in the area are suggested, the ultimate being public enlightenment (education), empowerment and encouragement. This will enable the people to exploit further their own technologies and knowledge systems and to participate in the planning and implementation of any strategies or projects to ensure their acceptability and sustainability.[5]

Key words: Water use, Conservation, Scarcity, Drought, Village, Less developed country, Arid and semi-arid environment, the Sahel, Water procurement, delivery and processing, Indigenous knowledge systems, Technologies (introduced, transferred, appropriate).

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5.1 Introduction

The sharp increase in water demand in recent times has been due to rapid population growth, an increased consumption per capita associated with improved standards of living, and expansion in water-related commodity production, agriculture and service industries (United Nations, 1976). In addition to this human problem of water stress which is attributable to increased per capita demand over fixed levels of water supply and its concomitant land desiccation resulting from activities such as deforestation and overgrazing, there has been continued water scarcity in arid and semi-arid areas (ASA) due to precursory climatic conditions of aridity and droughts. Together these have led to acute water scarcity and consequently, a shortfall in the amount of water available for human use (Falkenmark et al., 1989; Clarke, 1993).

There is growing evidence of a decline in water availability in northern Nigeria due to rainfall seasonality and variability (see among others, Woo and Tarhule, 1994; Hess, et al, 1995). At the same time, the competition for water by human activities is exerting tremendous pressure on the limited water resources and the environment (Kimmage, 1991; Dabi and Anderson, 1998a). The allocation of the water to these competing uses has been based entirely on traditional practice following indigenous knowledge systems. When inefficient decisions are taken, severe shortages may occur for some if not all the uses with inevitable adverse repercussions. This, in combination with the quest to increase food production, has contributed to the recent drive for western technology in the form of water pumps, tube wells, boreholes and dams to augment water supply particularly for irrigated agriculture (Kimmage, 1991). However, these innovations have been met with further complications and concomitant problems.

Over the past five decades, technology and growth have increased the total water use in the world up to four times. This has been achieved through the construction of dams, reservoirs and conveyance structures that made up to 44 percent of the world's reliable runoff water resources accessible to man. Also, through various means of water harvesting, an increased utilization of rainwater has been made possible. However, of all the water available, the challenge is to allocate it to the best possible use in order to maximize the benefits, particularly for people living in areas prone to droughts (Clarke, 1993).

Essentially, the challenge is to promote a strategy which aims at proper management of the demand for water and not a continued supply-oriented management (Falkenmark, et al, 1989). Notwithstanding, the combined effects of complex environmental (climatic) conditions and human activities now threatening arid regions have necessitated the development of methods for investigating the problem from a multi-disciplinary perspective and on a micro-scale. This will facilitate better management of water resources and enhance sustainability in the development process. This "bottom-up" approach will ensure a better understanding of the problem as experienced by the affected people rather than assumed from a larger perspective.

This paper is part of a study that seeks to account for the total water used in the economy of Katarko village in northern Nigeria. The paper aims at understanding the indigenous knowledge systems regarding water scarcity and strategies aimed at mitigating the problem to ensure continued production from one season to another. It adopts a "bottom-up" approach and examines four issues: (i) strategies adapted for water procurement (sourcing and withdrawal) vis-a-vis seasonal fluctuations, to ensure long term availability and use; (ii) strategies at the household, activity and farm levels for ensuring safe delivery (conveyance and distribution) of water to final demand, through the production system and minimising losses; (iii) technologies available for water processing (storage, retrieval, use, conservation), considering the high production requirement and excessive evaporative demand by the economy and environment respectively; and (iv) strategies employed during use (production) in order to maximize the utility of water in terms of reuse, recycling or reduction in quantity used. The use of introduced technologies for the same purposes will also be considered and compared with indigenous ones. The paper reports findings of field observations and measurements made in this regard. Information generated from this study will be used in conjunction with results of an extended input-output model to address various policy options or water management strategies in a later paper.

5.2 Conceptual considerations and perspectives

Indigenous knowledge systems are defined in the context of innovation, technical knowledge, associated social organization and decision-making processes (Brokensha et al., 1980; Kidd and Phillips-Howard, 1992). These four basic components of knowledge systems are based on 'factual knowledge' that relate to concepts, prepositions, symbols or memory derived through human perception, and 'procedural knowledge' that follow the rules of logic and empiricism. Here, technical knowledge is considered as factual; innovation as procedural; social organization as both factual and procedural; and decision-making as procedural. Together, these components enable the utilization of the knowledge systems that affect decision-making and cause a certain pattern of behaviour. The pattern of behaviour in turn determines the use of resources. Thus, "the incorporation of indigenous knowledge systems in rural studies is a means toward the practical realization of a viable development policy" (Kidd and Phillips-Howard, 1992).

Technology is defined as "the skills, knowledge, and procedures used in the provision of goods and services for any given society" (Hope Sr., 1996). It is seen as a mode of production that carries within it economic, social, cultural and cognitive structural codes that differ from one society to another (Galtung, 1978; Vanderburg, 1986). Technology transfer involves the two-way relationship of sending and receiving technology primarily between and among firms, industries, and governments (Hope Sr., 1996). The "transfer of technology (TOT) paradigm is a mutually supported set of concepts, analyses, methods, and behaviour in which western-trained scientists generate technologies on research stations and in laboratories, to be transferred through extension services to farmers" (Chambers, et al., 1989; Gladden and Phillips-Howard, 1992). Therefore the transfer of Western technology to the less developed countries (LDCs) is seen as a structural invasion, fragmented and perceived poorly because of the difference in structures (Galtung, 1978; Vanderburg, 1986).

Appropriate technology is a term used to describe both a method and a movement. As a method it is considered to be the appropriate application of scientific knowledge to development, while the movement is believed to have started in the 1960s and is now active globally (Kerr, 1989). Appropriate technology is based on interactive innovation where an interactive process occurs, and its techniques or tools are transformed by incorporation into the recipient culture (Pacey, 1983). Idealistically, "appropriate technology uses production methods that are less damaging to the environment of communities than previously used methods, consume less energy and fewer resources, and recycles wastes or handles them more acceptably" (Hope Sr., 1996).

The notion of 'appropriate technology' or 'intermediate technology' has been met with criticisms based on a neo-colonial connotation of "superior goods for the developed nations and inferior ones for the third world" or LDCs (Schumacher, 1991). But the fact is that LDCs need access to technologies which are appropriate to their stage of development, rather than 'state-of-the-art' technologies imported from the developed world. Needed are technologies that build on the structures of existing traditional (indigenous) technologies and take advantage of those from developed countries. Such 'intermediate' technologies would be immensely more practical and productive than the indigenous ones but more affordable and accessible than the sophisticated, highly capital-intensive technologies of the West (Schumacher, 1991).

Less developed countries in ASA need technologies that are sustainable, those that are acceptable, affordable, usable, and manageable by the users. Such technologies also consider the precariousness of environmental and economic conditions they face. Thus, the idea of appropriate technology must be looked at in terms of demand with basic needs as goals and supply using the desired production process (Hope Sr., 1996). This is only achievable if the needs and aspirations of the people, their capabilities, and deficiencies are known. An understanding of indigenous (technical) knowledge systems is therefore paramount.

In Africa, as elsewhere, there is an increasing interest in traditional systems of agriculture and indigenous technical knowledge (ITK) (Chambers, 1983; Richards, 1985; Adams, 1985; Gladden and Phillips-Howard, 1992). Most this interest emanated from the fact that the large-scale dam projects meant to replace the agelong small-scale initiatives and to boost agricultural production and water supply in different parts of Africa, especially Nigeria, have not performed to expectation (Moris, 1987; 1989; Mitchell, 1990; 1994; Salau 1990). Such introduced 'solutions' only outperform the indigenous initiatives in certain favoured situations. Moreover, the formal irrigation schemes were very expensive in terms of construction costs, external management, and infrastructure (Moris, 1987; 1989). Other problems have been noted. Priorities were distorted as emphasis was placed on commercial crops to the detriment of food crops. And the large dams cut off the downstream seasonal flood affecting traditional practices (Scudder, 1980) or fadama cultivation in parts of Nigeria (Turner, 1985; 1986; Adams, 1986; Adams and Carter, 1987; Moris, 1989; Kimmage, 1991; Kimmage and Adams, 1990; 1992). In addition, there are the environmental and human problems associated with the water development projects (Biswas, 1978; Scudder, 1989; Mitchell, 1990; 1994; Salau, 1990).

The World Bank-sponsored work undertaken by Briscoe and deFerranti (1988) is one major example of the use and performances of introduced technologies for water supply in rural community of developing countries. They observed that many water improvement projects have proved to be neither sustainable nor replicable. The gains of the new water supply systems were eroded because of the widespread failure attributed to inadequate maintenance. Such failure was more because of the top-down approaches in the design of systems and maintenance of facilities such as hand-pumps and boreholes or pipe connections, with central governments and external (donor) agencies taking dominant roles, rather than the complexity of the technology. Furthermore, the improved systems often did not meet local expectations; local institutional realities were not taken into account, while government support was very erratic. Moreover, the nonchalant attitude of the people toward water supply schemes, regarding such projects as governmental provisions and for which they need take no responsibility is pernicious.

Interestingly, Briscoe and deFerranti (1988) advocated for a community-based (bottom-up) approach to water development, in which communities develop primarily through self-help activities. Such an approach allows users to decide on the type of improvement to be made, pay for most of the costs (usually by providing the required labour), and take responsibility for maintaining the facilities they have chosen and implemented. While government and external donors create the enabling environment, supplemented with technical and training support, and provide materials.

Gladden and Phillips-Howard (1992) acknowledged that resource-poor farmers in LDCs posses active and useful indigenous knowledge systems -- including experimentation, technical knowledge, social organization and decision-making systems as noted by Warren et al. (1989). However, they suggested a combination of transfer of technology and farmer first paradigms. These permit mutual learning and effective 'co-research' and lead toward well-facilitated, participatory action programmes. Again, in our opinion, this is parallel to the idea of appropriate technology which Smith et al (1994) argued for in that it contributed to the intensification of agriculture more significantly than population and market driven forces.

5.3 The case study village and information gathering

The case study village for this study is Katarko in semi-arid zone of northern Nigeria located at the 11°33'N and 11°55'E coordinates, some 20 km from the Yobe state capital, Damaturu. In 1937, the Kanuri ethnic group settled in the village. Later the Hausa, Kerekere, Shuarab and Fulani groups joined. Ever since, population growth has been largely due to immigration, particularly by the Hausa and Fulani groups and more recently due to natural increases. The current population is about 3000. Islam is the sole religion with Arabic (Koranic teaching) as the basic form of education. Decision-making is mostly based on a hierarchy of community leadership and religious beliefs.

It is a typical village with similar environmental characteristics and human activities to the rest of the region. As indicated in the introduction, drought conditions and water scarcity are prevalent; rainfall is limited to four months of the year; stream flow is seasonal; and groundwater which serves as the major source of water is declining. The extensive sedimentary Chad Formation, recharged by seasonal surface flow, is the main source of the groundwater. The undulating terrain is covered mostly by Sudan savanna-type vegetation, basically patchy grasses and scrub as well as scattered acacia and baobab tree species. These provide wild animals and fruits for their consumption and sale, leafs and pasture for their domestic animals; and wood for fuel and construction. Wood extracted from the bushes is also sold as "export commodities" at neighbouring markets.

The major economic activity in the village is rainfed agriculture by sedentary farmers who grow staple crops mostly at subsistence level. All households are involved in rainfed agriculture but the activity is predominated by the more settled Kanuri, Hausa, Kerekere and Shuarab groups. Animal husbandry of cattle, sheep, goats and poultry is perhaps the next most widespread activity the households participate in, particularly among the Fulani group. Irrigated cultivation of vegetables and grains is also practised, mostly by the Kanuri who own the land and some of the Hausas who introduced it. Irrigation is limited to a short period of the year and few locations accessible to surface and groundwater sources called fadamas[6] along the seasonal Anumma river that bypasses the village. The Kerekere and Shuarab groups are also involved in animal and vegetation gathering for food, fuel and construction. Other economic activities include rural industrial production (small-scale manufacturing) of goods (processed food and handicrafts) and services traded mostly within the local market by the Hausa and Kanuri groups.

The village lacks most urban facilities such as piped water and electricity. Government

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[6] Turner (1985:18) defined fadama as "land seasonally flooded or waterlogged". In other words, low lying land seasonally inundated due to water intrusion.

assistance is limited 'forcing' the people to depend on their traditional heritage and environmental resources. Therefore, water procurement, delivery and processing for the activities enumerated above rely on traditional initiatives with few modern methods. This has made water use and conservation a problem in the area (see figure 5.1).

(Figure 5.1 about here.)

In a previous work (Dabi and Anderson, 1998b), we reported the use of water for commodity production in this village. The agricultural sector consumes more than 60% of the groundwater, basically for irrigation and animal watering. And later (Dabi and Anderson, 1998c) we developed and applied a commodity-by-industry economic-ecological model (CIEEM) which accounts for the direct and indirect use of groundwater in the village. This provides the major analytical tool for the research. This analytical procedure is ideal for depicting water use under normal circumstances. It incorporates input-output relations defined under normal rainfall conditions. However, it is expected that during drought periods (dry spells) there will be severe water shortage and people are bound to develop alternative measures for coping with the situation. They may develop new water sources and storage systems, new methods of water use, and new water saving strategies. Such strategies are revealed through field monitoring of indigenous knowledge systems and technologies reported in this paper. Cases of introduced (transferred) technologies and strategies for future development ("appropriate technologies") are also considered.

Data required for this research were collected during two field seasons (wet and dry) in the study village. Most of the data required for this paper were gathered during the dry season (January to April, 1997). The field exercises targeted activities undertaken during this dry period. Resultant changes in water use and their effects on the economy and environment were noted. Key informants, including the *Bulama* (village head), *mai 'ungwa* (ward or tribal group heads), *manomi* (major farmers), and *malamai* (religious and school teachers), were consulted to ascertain changes in activities and possibly water use. Field assistants were then selected and trained before actual data collection. Data gathering was based on 10% sample survey of households engaged in industries that exhibited the highest demand for water in an initial study. Therefore, emphasis was placed on the agricultural sector particularly, irrigated agriculture and animal watering.[7]

Field observations and measurements were made regarding indigenous knowledge systems and technologies for water demand, use and management, and water shortage coping strategies including (i) changes in water sources, (ii) water use behaviour and decision-making process, (iii) methods of water procurement (withdrawal or abstraction), (iv) methods of water processing (storage, retrieval, use and reuse or conservation), (v) methods (techniques) of water delivery (conveyance and distribution), and (vi) economic and social costs involved.

The first author and the three assistants (one female and two male residents) visited the only sources of water at this time of the year, the deep village wells and shallow wells on fadamas. Facilities for water withdrawal and conveyance were noted. And quantities of water

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[7] Dabi and Anderson (1998b) have indicated a total population of 2,734 people with 424 households engaged in 27 industries and producing more than 100 commodities in Katarko village. The agricultural sector (especially irrigated agriculture and animal husbandry) being the highest consumer of groundwater.

extracted and conveyed to households and industries determined. Quantities were determined by measuring the volume of containers used for water extraction (withdrawal from wells) and those used for conveyance (delivery). For example, households were observed to withdraw between four (4) and 18 litres of water per day for domestic use, and up to 200 litres for other activities like construction or sale by vendors.

Quantities of water used by animals was measured by monitoring the number of times animals are watered and the quantity consumed in the process. The average size of containers (usually 4 litres) used for hauling water from the wells was determined. This was multiplied by the number of times the water was poured into the animal's drinking container (a half-sized barrel or an opened gourd). The result was then divided by the number of animals that drank from it. Results from these measurements were similar to estimates given by rearers. The quantity of water extracted for irrigation was determined from two perspectives. First, the traditional methods of delivering water from the source to the crops whereby the number of calabashes (gourds) of water delivered to the cropped area are counted. Second, the introduced form of technology in which the rate of pumping and quantity of water released is multiplied by the duration of irrigation, using 2-3 horse power engines (water pumps). These quantities were calculated for a week and multiplied by the number of weeks the crops were irrigated. Irrigation and animal watering were done *in situ*, that is at location of the shallow wells.

Data were collected on a daily basis (from morning to late evening) by monitoring the number of times individuals visited the wells. The monitoring was spread over the sampled industries and households during the period of the survey. Detailed results of these observations are reported below.

5.4 Indigenous (traditional) initiatives for water management in Katarko Village

The various indigenous equipment or facilities used for water procurement, delivery, and processing are shown on Tables 5.1, 5.2, and 5.3 below. Techniques for water procurement (sourcing and withdrawal) and those for delivery (conveyance and distribution) are labour intensive, time consuming and perhaps inconvenient. Men are responsible for sourcing (digging) wells. This requires a lot of energy and expertise.Water withdrawal (fetching or extraction) does not follow gender lines and is performed by men, women and children (male and female). The same goes for water delivery, but adults convey larger quantities of water and perform more of the skilled labour. Children carry smaller containers and assist with the menial jobs at home and at the production unit. However, in typical fundamental Islamic households, particularly amongst the Hausa and Kanuri groups who keep their women under Purdah[8], only men and children and occasionally older women go out to fetch and convey water.

The nature, size and capacity of facilities (tools) for water processing (storage, retrieval and use/reuse) in households and most other industries are rather small. Quantity of water stored in these containers is equally small (less than 100 litres). Thus, the need for more

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[8] The Purdah system is a religious belief that keeps women in seclusion and restricts them from going out in public or meeting visitors, especially male ones.

effort and time investment for water procurement. The construction or building industry uses larger containers (up to 200 litres) for water storage, although most of it or even more can be used in a day. Only irrigation and animal watering use water at location of shallow wells, as indicated earlier. Water contained or stored in these wells depend on recharge and withdrawal rates. At the peak of the dry season, the recharge rate is minimal but withdrawal rates very high. All these indicate that water management and conservation are in jeopardy.

(Tables 5.1, 5.2, and 5.3 about here)

These observations show that local techniques for water extraction, storage, retrieval and delivery in the village are very simple (capital extensive) but manually operated (labour intensive) and perhaps sustainable because they are based on local materials and initiatives thereby reducing purchase and maintenance costs. But there are no specialized skills for rainwater harvesting and farming to take advantage of the 'excess' rainfall and runoff water stored in ponds and stream at the end of the rainy season. This may be attributed to their lack of interest in developing these measures as confirmed by the comments, made by some of the key informants. For example, "water from the mud-constructed roofs gets contaminated with sand, thatched roofs do not yield sufficient water for us to bother with and water in ponds does not look good for use." However, these sources of water could be developed as discussed later. The water can be stored and retrieved for use during periods of scarcity.

The annual scheduling (timing) of activities tends to depend on water and labour availability. Generally, activities start at the end of the dry season in agricultural societies such as this. Just before the rains in June, land is prepared (clearance and tillage), to await the new planting season for rainfed crops. All other activities (including animal husbandry, the rural industry, trade, and services) except for irrigated agriculture also take place during the rainy season. Activities undertaken at this period, rely on direct rainfall, stream flow and 'abundant' water in the village wells and ponds. During the dry season, irrigated agriculture thrives along the Anumma river. Other activities with the exception of rainfed farming are intensified at this period. Unfortunately, the only dependable source of water is the shallow wells. Deep groundwater may not be accessible because most of the village (deep) wells are dry and Tube-wells / water pumps broken down (see figure 5.2). The diagram illustrates the scheduling of activities during the year. These have been spread around in form of a clock. Starting with January at one o'clock and going clockwise with December at twelve, the activities and water availability are located appropriately.

(Figure 5.2 about here)

The main activities requiring so much groundwater during the dry season are irrigated agriculture, animal rearing and building construction (Dabi and Anderson, 1998b). It is very disheartening to note that all these high water demand activities are concentrated at about the same time of the year during which groundwater from shallow wells is the main source of water. At this period, deep groundwater becomes inaccessible as most of the deep village wells dry up. This arrangement seems to create undue pressure on the limited water sources and increase the potential for conflict among users.

However, the daily timing of water extraction during the water scarce dry seasons is based on a well defined social and cultural organisation which allows for the use of shallow wells at different times of the day by the different users. For example, water for domestic and other activities requiring less water, is extracted early in the morning (from about 6.00am) while animal watering is done in the afternoon (starting from 2.00pm), while other high water demand activities like irrigation and construction extract theirs afterwards (from 4.00pm). Some of the irrigated farms have private shallow wells for use at other times of the day, especially in the morning and late afternoon. In between these schedules, the wells are given 'sufficient' time to recharge. This process has tended to minimize or eliminate any possible conflict between the different users.

There are other indigenous knowledge systems used for water conservation by the villagers. For example, at the farm level, farmers do a lot of mulching to reduce the rate of evaporation and to maintain soil moisture. Irrigation activities are usually de-intensified when water becomes inaccessible. Farmers resort to delivering water at a per plant basis rather than pouring water into the whole plot through a channel. From field data, some of which is discussed Dabi and Anderson (1998b), this practice can save at least 15% of irrigation water or up to 2.12% of total groundwater used in the village. Animal rearers embark on transhumance[9] activities to take advantage of distant watering points and to reduce pressure on existing sources of water around the village. And at the household and industry levels, some form of water reuse is practised. Normally, people do not pour away water they may have used for washing or cleaning but it is stored to be used again for some other purpose,

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[9] The seasonal transfer of livestock to areas of greener pasture practiced by pastoral nomads in arid and semi-arid areas.

say, wetting fibre or grass for weaving and sand for mending cracked or fallen walls. Such water could even be poured under a plant to add soil moisture for its growth. If all the wastewater generated from household and industry is reused, another 10.02% of groundwater would be saved, although this may be too ambitious for Katarko village because of technological constraints.

5.5 The role of introduced (transferred) technology

Table 5.4 describes the nature and type of introduced technology available in the community. Most, if not all, are for water sourcing and storage for agricultural purposes. A wash borehole is used for extracting deep groundwater with the aid of water pumping machines or hand pumps. There are two types of facilities for water storage in the village: two commercial (manufactured) water tanks and one ground cistern. The tanks were used to store water extracted from the wash borehole and the ground cistern was meant for a fish pond. None of these contains water now all but seem to have been abandoned. This attests to the argument that local people are nonchalant about facilities provided by government or other external organisations as discussed earlier. This is often the case, when they do not initiate or participate in planning for such facilities. At the household or place of production, facilities like connection pipes and standing pipes/taps are not available for water delivery. Neither are facilities for water storage, except for containers like empty oil barrels and jerry cans that are converted into storage tanks.

(Table 5.4 about here)

The most sophisticated introduced technology in this village, as is the case in most parts of northern Nigeria, is the water pumping machine. The pumping machine is a very efficient facility for water extraction, either from a shallow well or tube-well. It has enabled farmers to increase production and thereby increase their income. This has led to the overwhelming acceptance of the innovation here in Katarko and elsewhere. Table 5.5 gives a detailed differentiation between traditional initiatives (indigenous technology) and the use of water pumps (transferred technology) for irrigation in the village. Almost 80% of the irrigation farmers use water pumps on their farms. Although only four of the farmers own the machines, the others lend them to use on their farms. The rest (a little more than 20%) use the traditional method to irrigate their crops. However, those who rely entirely on the water pumps have had tremendous disappointments at times due to the sudden breakdown of engines. Farmers have had to abandone parts or even a whole farm prepared for irrigation farming during the dry period.

For example, the *Bulama* had to delay his irrigation activity for the 1996/97 season because his machine broke down. He had to purchase the part required to fix it from Jos more than 400 km away because we could not even find it in Maiduguri, the biggest city in that region, about 120 km from the village. Even then, he would not do it immediately. Asked why he made such a decision, he said "if I fix it now, other farmers would want to lend it from me and soon there will be a breakdown again and I may not cultivate any crops this year." Eventually, he had it fixed at Damaturu but had to reduce his plot size because it was already too late to manage a large farm. Water in the shallow well was fast declining and reducing the amount available for irrigation. Soon the rains would come and it would be time to prepare other lands for rainfed crops, thus diverting labour.

Another problem associated with water pumps is the loss of water during delivery to the crops. During irrigation, water delivery is usually through small channels (furrows) into a larger farm plot. This process allows excess water loss by infiltration, seepage and evaporation, without reaching the targeted crops. Therefore, more water has to be extracted and delivered before the plants get sufficient moisture for their growth and development (again, see Table 5.5).

(Table 5.5 about here)

The point to note here is that, although the water pumping machine is very useful in accessing groundwater and making the irrigation process more efficient and rewarding, there are problems associated with it as enumerated above. These problems tend to make the whole irrigation operation using water pumps counterproductive and unsustainable. This is because the cost of engines is prohibitive, they require expensive maintenance (sometimes total breakdowns), and contribute to excessive water demand. This is always met with technological dilemmas, whether to go traditional or rely on introduced technology (machines). Farmers who own water pumps keep complaining about the problems involved with using and maintaining the engines. Many who do not have water pumps keep yearning for theirs, while 'skeptics' stick to the traditional methods.

5.6 Strategies for the future (appropriate technology)

Numerous strategies for water procurement, delivery and processing exist especially in and around the ASA, all of which can be enhanced or introduced in this village. Such technologies have been tried and proven useful in areas with similar physical and human characteristics but will be deemed appropriate only when tried and accepted in the village. These include simple (sometimes, complex) technologies such as rainwater harvesting and farming (eg in India and Botswana); earth dams, and windpumps (in the Turkana desert); solar pumps (in Somalia); Ferro-cement tanks (Papua New Guinea) and so forth (see Pacey and Cullis, 1986; Kerr, 1989, Lee and Visscher, 1992). Notwithstanding, the appropriate technologies are those that will ensure adequate supply (procurement), moderate water use (processing) and at the same time convenience in terms of maintenance and functionality (delivery) and thus, be sustainable (Moris, 1989).

Let us consider rainwater harvesting and farming as an example. Changes may be required in the roofing style of buildings. Thatched roofs may have to be replaced with corrugated iron sheets (zinc) as seen over a few buildings including the primary school, dispensary and staff quarters. Alternatively, mud roof surfaces may have to be paved with cement or other similar impermeable material. Rainwater incident on these 'new' surfaces (roofs) can then be channelled down into ground tanks or cisterns through gutters. The cistern can be made from local material like earthen pots or other larger containers, jerry cans and fabricated metal tanks and the gutters made from local carved wood, bamboo or fabricated metal sheets. Blacksmiths in the village indicated that they can construct some of these materials.

The three large ponds around the village can be converted into water storage tanks or cisterns during the rainy season for use in the dry period. The sides and floor of the ponds can be straightened and built with brick and cement with some reinforcement, and then plastered into a kind of Ferro-cemented ground cistern similar to the one meant for the fish pond. Some material, such as a plastic sheet or a thin oil layer, can be used to prevent or reduce the excessive evaporation. With this arrangement, water can be secured for use in activities as brick making and building construction which do not require higher quality water. For all of these, local materials can be used except for the cement, plastic and oil and constructed using direct labour by the villagers. These innovations are possible as they have been done in water scarce areas of Zimbabwe, Kenya, Indonesia and Thailand (see Pacey and Cullis, 1986).

Recently, the Yobe state government has proposed building a dam across the Annuma river (Yobe State of Nigeria, 1997). Dam construction is another form of introduced technology for large-scale water supply and irrigation development projects in parts of northern Nigeria. The problems associated with these have been discussed earlier but are perhaps unfamiliar to the people. Thus, the people of Katarko, Damaturu, and the neighbouring settlements received the news with great enthusiasm. However, this may not necessarily be a good idea for the village and other users downstream. (This is due to the problems associated with large-scale dam projects discussed earlier.) Rather, simpler strategies for water storage and conservation such as groundwater dams including sub-surface dams and sand-storage dams, may be worth considering (for more information, see Nilsson, 1988).

Other conservation methods may include the "3R" water saving strategies of reduction (using less water per activity or modifying the irrigation practice/crops to reduce water use), reuse (using already used 'gray' water again for activities requiring low quality), and recycle (a long term attempt to improve the quality of larger volumes of waste water for subsequent use especially for activities requiring water of medium quality). This idea is consistent with the "3R" policy approach to waste management (waste recycling, reuse and reduction) described by Baetz et al. (1991) and Huang et al. (1994). Moreover, the reuse of waste water for irrigation is very important as it can supply almost all of the nitrogen, most of the phosphorus and potassium, as well as the important micronutrients required by many crops (Bartone, 1991).

Nonetheless, a better conservation measure may rest on the rescheduling of activities during the year to correspond with the timing of water availability. Figure 5.3 illustrates some of the suggested strategies for the annual rescheduling of activities in the area. By and large, the diagram is similar to figure 5.2. But rather than congesting the higher water demanding activities when the 'only' source of water is the shallow wells, some of the activities are spread to take advantage of the 'surplus' rain and surface water during the rainy season. For example, construction activities are rescheduled to commence soon after the rains and before irrigation activities. Although the villagers understand the need to schedule activities more appropriately when water is available, they enumerated a number of problems associated with such an arrangement. For example, one farmer said that "if we leave our crops in the farms for too long, animals will intrude and consume everything. But we also have to mend our houses and fences too. So we have to harvest the crops and bring them home first before building. And if we build in the rainy season, the rains will destroy the walls."

These constraints are understandable, but labour availability is apparently the main impediment to any kind of adjustment that can be made. Evidently, the rescheduling of activities is achievable if communal effort (participation) is employed in carrying out tasks rather than individualistic production. Groups of four to five people were seen constructing roofs for friends or colleagues who indicated that such effort was meant to save money, time and energy. In the same disposition, larger groups can come together and be involved in different aspects of farm work and construction. Such an arrangement will make more labour available, thereby saving even more effort and time to warrant the rescheduling of activities. Fadama farmers on the Jos Plateau mine lands in Nigeria have demonstrated the value of such communal effort and the possibility of shifting activities to take advantage of the dry season farming period which would otherwise be almost impossible once the rains come (Dabi, 1992).

(Figure 5.3 about here)

As indicated earlier, decision-making is mostly based on a hierarchy of community leadership and religious beliefs. The *Bulama* (village head) is at the top of the hierarchy (answerable to the local and state governments). His subordinates are the *mai 'ungwa* (ward head), *maigida* (family head), and the *uwargida* (a senior wife), in descending order. These people are vested with other responsibilities including decision making from domestic and household, through the ward back to the community levels in a reverse order. The *imam* (religious leader) and *malamai* (religious teachers) also partake in decision-making on religious matters and when prayers are required to invoke rain and making water available. Other bodies also play significant roles. For example, Fadama Farmers Association, Katarko Youths Organization, and Katarko Women Association. These bodies have a great deal of knowledge to handle most of their immediate problems. However, they look forward to external assistance when it comes to major ones such as intermittent droughts and water perennial scarcity as well as the need to increase water supply.

Ultimately, the people have to be educated and empowered to be able to achieve most, if not all, the suggested strategies. Most importantly they must be involved right from the planning and implementation stages for the projects to be fully participatory and acceptable. The dissemination of information is also through the same channel as decision-making, community and religious leaders. One major example of innovation diffusion and acceptance is the use of water pumps for irrigation. The people also need encouragement in order for them to exploit further their own technologies and knowledge systems. This is exemplified by the recent collaboration between Jos (researchers) and the Katarko people to improve on earthen pots for water storage. Besides, there is general consensus and evidence supporting conventional knowledge, that education has a positive effect on the performance and efficiency of rural people in LDCs (Lockhead, et al., 1980; Phillips, 1994).

5.7 Summary and conclusion

Increase in the demand for water during the dry season is attributable to two major factors: inherent scarcity at this period of the year; and an escalation of activities requiring larger quantities of water. Irrigation farming, animal watering, brick making and housing construction are intensified just when water is most scarce in the area. This paper has revealed that little or no sophisticated technologies exist in the village for water procurement (sourcing and withdrawal), water delivery (conveyance and distribution) and processing (storage, retrieval and use). The villagers tend to depend on a number of introduced technologies for water procurement (the tube well and water pumping machines) and for water storage tanks. These technologies have proved to be unsustainable due to high purchase and maintenance cost, and contribute to excess water loss by infiltration, seepage and evaporation. Additionally, the annual scheduling of activities does not take proper cognisance of the timing of water availability. The villagers also lack specialized skills for rainwater harvesting and farming, and making the best use of excess water stored in ponds and stream at the end of the rainy season.

However, a number of indigenous technologies are available for these processes. Such technologies are locally fabricated tools and facilities manually operated by the villagers. Although these are labour intensive, they are capital extensive, have the advantage of water conservation, and are perhaps sustainable. There is also evidence of wastewater reuse and the villager's willingness to accept new innovation and/or technologies. All these efforts are geared toward reducing the impact of water scarcity and therefore sign of the drought mitigation process. But the perpetuation of the problem and the people's yearning for assistance also indicate the need for alternative approaches to water conservation in the area.

Therefore, a number of appropriate strategies based on a combination of indigenous knowledge systems and the transfer of technology to enhance water use and conservation in the area are suggested. These among others include: rainwater harvesting and farming, utilization of water ponds, construction of groundwater dams, rescheduling of activities and communal participation. However, the ultimate strategies are education, empowerment and encouragement. These will enable the people exploit further their own technologies and knowledge systems and to participate in the planning and implementation of any strategies or projects for them to be fully acceptable and sustainable. Some of these ideas are being simulated as policy scenarios for water use efficiency using a commodity-by-industry economic-ecological model (CIEEM). Results of these simulations will serve as policy options for economic development and technology use but are subject for discussion elsewhere.

References

Adams, W.M. (1985) River basin planning in Nigeria. Applied Geography 5, 297-308.

Adams, W.M. (1986) Traditional agriculture and water use in the Sokoto valley, Nigeria. *The Geographical Journal*, 152 (1): 30-43.

Adams, W.M. and Carter, R.C. (1987) Small-scale irrigation in sub-Saharan Africa. *Progress in Physical Geography* 11, 1-27.

Baetz, B.W., Pas, E.I., and Vesilind, P.A. (1991) Waste reduction primer for managers. ASCE Journal of Management in Engineering, 7, 33-42.

Bartone, C.R. (1991) International perspectives on water resources management and wastewater reuse-Appropriate technologies. Water Science and Technology, 23, 2039-2047.

Biswas, A.K. (1978) "Environmental implications of water development for developing countries."In Widstrand, C. (ed.) (1978) *The Social and Ecological Effects of Water Development in Developing Countries.* Water Development, Supply and Management, 7. Pergamon Press. 283-297.

Briscoe, J., de Castro, P.F., Griffin, C., North, J., and Oslen, O. (1990) "Toward equitable and sustainable rural water supplies: a contingent valuation study in Brazil." *The World Bank Economic Review* 4(2), 115-134.

Brokensha, D., Warren, D.M., and Werner, O. (eds.) (1980) *Indigenous Knowledge Systems and Development*. Lanham: University Press of America.

Chambers, R. (1983) *Rural Development: Putting the Last First*. Longman, Harlow.

Chambers, R., Pacey, A., and Thrupp, L. (1989) *Farmer First: Farmer Innovation and Agricultural Research*. Intermediate Technology Publications, London.

Clarke, R. (1993) *Water: The International Crisis.* The MIT Press, Cambridge, Massachusetts.

Dabi, D.D. (1992) An Evaluation of Farming Activities on the Jos Plateau Mineland. Paper presented at the International Seminar of the Jos Plateau Environmental Resources Development Programme (JPERDP), held at the University of Jos, Nigeria, December. *Jos Plateau Environmental Resources Development Programme*. Final Report (In press).

Dabi, D.D. and Anderson, W.P. (1998a) Water scarcity and sustainable agricultural development in the drought-prone semi-arid zone of West Africa. International Conference on Tropical Climatology, Meteorology and Hydrology, Brussels, May 22-24, 1996. In press.

Dabi, D.D. and Anderson, W.P. (1998b) Water use in Katarko village, northern Nigeria. Accepted, Applied Geography.

Dabi, D.D. and Anderson, W.P. (1998c) Application of a commodity-by-industry economic-ecological model to water demand and use in a rural economy. Submitted to the *Journal of Environmental Management and Planning*.

Falkenmark, M., Lundqvist, J. and Widstrand, C. (1989) "Macro-scale water scarcity requires micro-scale approaches: aspects of vulnerability in semi-arid development." *Natural Resources Forum* 13, 285-267.

Galtung, J. (1978) Toward a new international technology order. *Alternatives IV(1978-79)*, 277-300.

Gladden, J.N. and Phillips-Howard, K.D. (1992) "Policy approaches to agricultural development in Nigeria: Transfer of technology and farmer first." *Paper presented at the National Workshop on Strategies for Agricultural Development.* University of Agriculture, Makurdi, Nigeria, April 8-10, 1992.

Hess, T.M., Stephens, W., & Maryah, U.M. 1995. Rainfall trends in the North Eastern Arid zone of Nigeria. - *Agric. & Forest Met.*, 74, 87-97.

Hope Sr, K.R. (1996) Promoting sustainable community development in developing countries: the role of technology transfer. *Community Development Journal* 31(3), 193-200.

Huang, G. H., Anderson, W.P. and Baetz, B.W. (1994) "Environmental Input-Output Analysis and its Application to Regional Solid-Waste Management Planning." *Journal of Environmental Management* 42, 63 -79.

Kerr, C. (ed). (1989) *Community Water development.* Intermediate Technology Publications Ltd, London. Chapter 4, 72-93.

Kidd, A.. and Phillips-Howard, K.. (1992) Indigenous knowledge systems and viable rural development policy. *Jos Plateau Environmental Resources Development Programme*. Interim Report 26, 22pp.

Kimmage, K. (1991) Small-scale irrigation initiatives in Nigeria: the problems of equity and sustainability. *Applied Geography*, 11, 5-20.

Kimmage, K. and Adams, W.M. (1990) Small-scale farmer managed irrigation in northern Nigeria. *Geoforum* 21(4).

Kimmage, K. and Adams, W.M. (1992) Wetland agricultural production and river basin development in the Hadejia-Jama'are valley, Nigeria. *The Geographical Journal*, 158(1), 1-12.

Lee, M.D. and Visscher, J.T. (1992) *Water Harvesting: A Guide for Planners and Project Managers.* Intermediate Technology Publications Ltd, London. Technical Paper Series 30.

Lockhead, M.E., Jamison, D.T., and Lau, L.J. (1980) Farmer education and farm efficiency: a survey. *Economic Development and Cultural Change*, 29(1), 37-76.

Mitchell, B (ed) (1990) *Integrated Water Management: International Experiences and Perspectives.* Belhaven Press, London.

Mitchell, B. (1994) "Addressing the 'edge' problems in land and water management in the Sokoto-Rima River Basin, Nigeria." *Geoforum* 25(2), 133-143.

Moris, J. (1987) "Irrigation as a privileged solution in African development." *Development Policy Review* 5(2), 99-123.

Moris, J. (1989) Indigenous verses introduced solutions to food stress in African. In Sahn, (ed.), 209-234.

Nilsson, A. (1988) Groundwater Dams for Small-scale Water Supply. Intermediate Technology Publication Ltd, London. 69pp.

Pacey, A. (1983) *The Culture of Technology.* The MIT Press, Cambridge. Chapters 1-4 &

8.

Pacey, A. and Cullis, A. (1986) *Rainwater Harvesting: The collection of rainwater and runoff in rural areas.* London, Intermediate Technology Publications.

Phillips, J.M. (1994) Farmer education and farm efficiency: a meta-analysis. *Economic Development and Cultural Change*, 43(1), 149-165.

Richards, P. (1985) *Indigenous Agricultural Revolution: Ecology and Food Production in West Africa.* Hutchinson, London.

Salau, A.T. (1990) "Integrated Water Management: the Nigerian experience." In Mitchell, B. (ed.). (1990) *Integrated Water Management: International Experiences and Perspectives.* Belhaven Press, London. Chapter 8, 188-202.

Schumacher, E.F. (1991) "Intermediate technology." In Dobson, A. (1991) *The Green Reader.* Andre Deutsch. 128-132.

Scudder, T. (1980) River basin development and local initiatives in African savanna environments. In Harris, D.R. (ed.) *Human Ecology in Savanna Environments.* Academic Press, London.

Scudder, T. (1989) Conservation verses development: river basin projects in Africa. *Environment* 31(2), March 1989.

Smith, J., Barau, A.D., Goldman, A., and Mareck, J.H. (1994) The role of technology in agricultural intensification: the evolution of maize production in northern Guinea savanna of Nigeria. *Economic Development and Cultural Change*, 42(3), 537-554.

Tarhule, A.A. and Woo, M-K. (1997) Characteristics and use of shallow wells in a stream fadama: a case study in Northern Nigeria. *Applied Geography* 17(1), 29-42

Turner, B. (1985) The classification and distribution of fadamas in central northern Nigeria. In Thomas, M.F. and Goudie, A.A. (eds) *Dambos: small channelless valleys in the tropics, formation and utilization.* Stuttgart: *Zeitschrift Fur Geomorphologie*, Supplement band 52, 222pp.

Turner, B. (1986) The importance of dambos in African agriculture. *Land Use Policy* 3(4), 343-347.

Vanderburg, W.H. (1986) "Society as the socio-cultural milieu of traditional technologies." *Man-Environment Systems* 16(2&3), 76-82.

Warren, D.M., Slikkerveer, L.J., and Titilola, S.O. (eds.), (1989) Indigenous knowledge systems: Implications for Agriculture and international development. Studies in Technology and Social Change, 11. Iowa State University, Ames, Iowa.

Woo, M-K. and Tarhule, A. (1994) Stream flow droughts of northern Nigerian rivers. *Hydrological Sciences Journal*, 39 (1), 19-34.

Yobe State of Nigeria (1997) Estimates of the Government of Yobe State of Nigeria. 265pp.

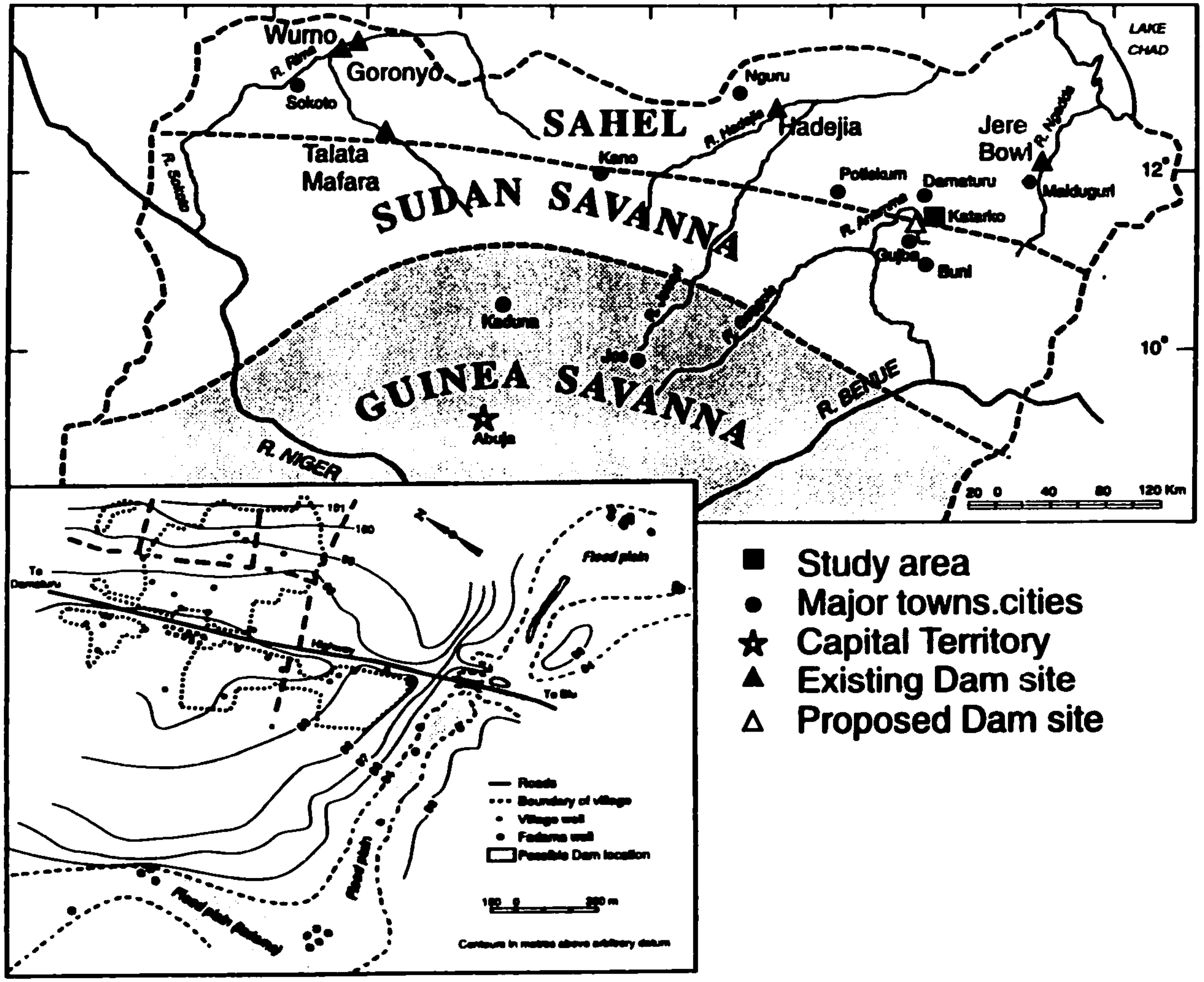

Figure 5.1 Study village in relation to adjoining towns, dam sites, and village setting showing location of wells and fadama.

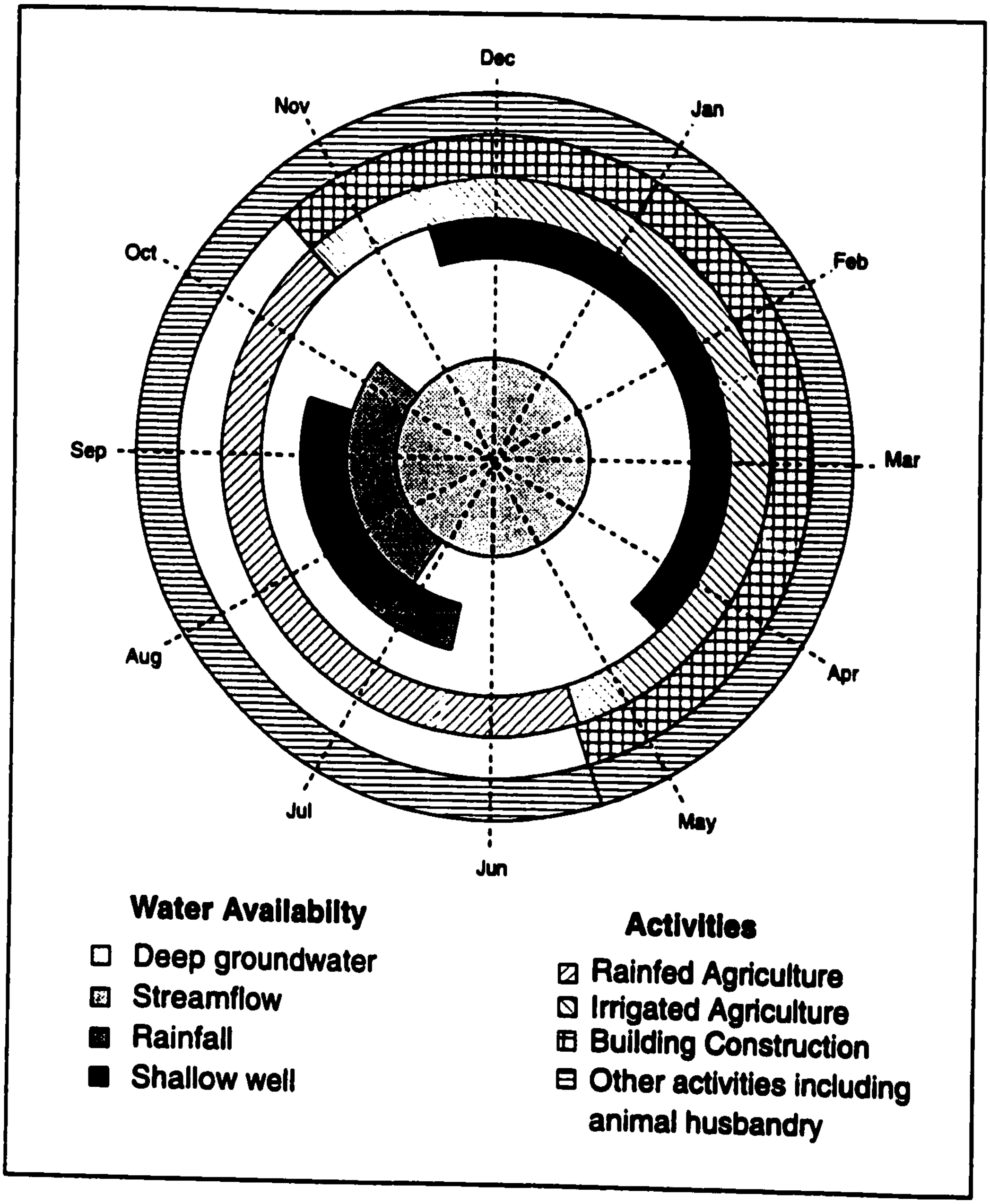

Figure 5.2 Approximate timing of water availability and activity schedule (modified from Tarhule and Woo, 1997)

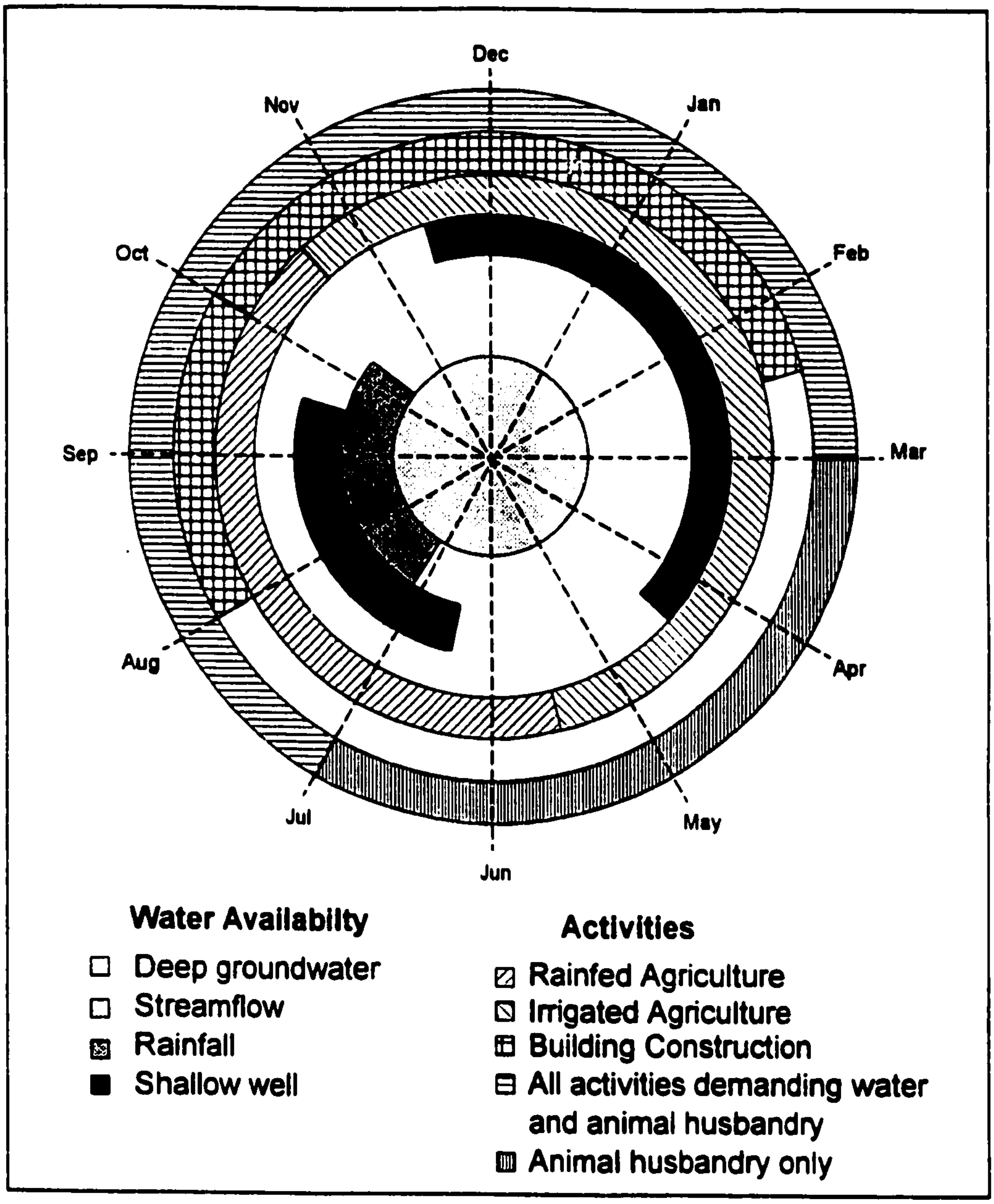

Figure 5.3 Rescheduling of activities to take advantage of water availability

Table 5.1: Indigenous technical knowledge for water procurement

Activity	Item	Description and use	Capacity/size
Digging (sourcing)	Digger *(matoni)*	Metallic tool of two sharp ends with a wooden handle used for digging wells.	0.5m long
	Shovel *(chebur)*	A flat metallic blade fitted into a wooden handle used for removing dug soil (overburden).	0.15 - 0.6m
	Iron bar *(kwalaha)*	A heavy spear-like metallic bar with one sharp end used for digging harder overburden (eg duricrust).	0.35m
	Bucket *(bokati)*	Usually, a metallic container tied to a long rope used for drawing dug material from a deep well.	18 litres
Fetching (withdrawal)	Calabash *(gora)*	Half cut calabash tied to a rope used for withdrawing water from a well.	4 - 5 litres
	Rubber bag or plastic *(roba)*	A small rubber- or plastic-fabricated container tied to a rope used for drawing water from a deep or shallow well.	3 - 4 litres
	Metal pale *(guga)*	A smaller metallic container also used for drawing water from a deep or shallow well.	4 litres
	Rope *(igiya)*	Usually, a long woven or synthesized material used for tying water drawing containers.	10 - 50m long

***** Words in italics are local names given to the different items***

Table 5.2: Indigenous technical knowledge for water delivery

Activity	Item	Description and use	Capacity/size
Conveyance	Small pot *(tukunya)*	A smaller sized earthen pot, container used for carrying water by human portage from source to point of use.	16 - 20 litres
	Gourd *(gora)*	A smaller calabash-like container also used for carrying water by human portage from source to point of use.	10 - 20 litres
	Metallic cart &containers *(cuscus)*	A metal-sided vehicle mounted on two motorcycle wheels and carrying 10, 25 litre jerry cans or 12, 18 litre tins for transporting water (usually by water vendors) from source to point of sale or use.	Usually up to 216 - 250 litres
	Cattle track/ drag animal *(amalanke)*	A wooden-sided vehicle mounted on two-car wheels which can carry ½, 1 or 2 drums (barrels) containing water from source to the location it is to be used, usually building	Ranging from 100 - 400 litres
Distribution	Metal tin *(garwa)*	A metallic container used to water crops from one plant stand to another, 3 - 4 plants at a time.	18 litres
	Calabash *(kwarya)*	Medium size calabashes cut into half used for scooping water from a shallow well or stream onto a cropped (planted) area during irrigation.	10 - 15 litres
	Shadoof *(jego)*	A local device consisting of medium size calabash tied with rope to a wooden pole pivoted at the middle and a balancing weight (load) at the other end used to raise water from a shallow well or stream and poured into narrow channels (furrows) then directed to the cropped area during irrigation.	Usually 10 - 15 litres irrigation continues until soil is wet
	Water basin *(kwano)*	A metallic bowl used to water animals, usually at well sites, occasionally at household. Water is withdrawn from the well using 'fetching or withdrawal' facilities.	10 - 15 litres
	½ drum or barrel *(rabin gangga)*	A metallic barrel cut into half used to water animals as described above.	Up to 100 litres
	On site use *(fadama)*	Crops may be planted at inundated locations to utilize flood water at the end of the rainy season. Animals are always driven to drink from standing pools of water and ponds. The brick making industry also takes advantage of these water sources before percolation or evaporation	Quantity varies but depends on water availability and need (supply and demand)

* ***Words in italics are local names given to the different items***

Table 5.3: Indigenous technical knowledge for water processing

Activity	Item	Description and use	Capacity/size
Storage	Large sized pots *(tukunya)*	Spherical earthen container (pot) used for storing water in households and industry locations	60 - 100 litres
	Medium sized pots *(tulu)*	Similar to the description above but mostly used at household level	40 - 80 litres
	Calabash *(kwarya)*	Bigger calabashes (gourds) with small openings used for storing water usually in households	60 - 80 litres
	Water basin *(kwano)*	A metallic bowl for storing water meant for immediate use at household and activity level	10 - 15 litres
	Bucket *(bokati)*	A cylindrical metallic or plastic container (pale) used for storing water in households	18 litres
	Jerry can *(babban roba)*	A rectangular plastic (usually gasoline & oil) containers used for storing water for most activities	25, 30, 40 & 50 litres
	Drum or barrel *(gangga)*	A rectangular metallic (empty oil) containers used for storing water for activities requiring larger quantities of water (eg building)	Usually 200 litres & 100 lt (for half barrel)
	Shallow well *(rijiya)*	Wells, usually not deeper than 5 m, dug in the river bed during the dry season and depending on groundwater recharge, used mainly for irrigation and animal watering.	Depends on recharge and withdrawal rate
Retrieval	Cups, cans & calabashes *(madiba)*	Small containers used for fetching water from storage, usually for drinking or ablution	0.5 - 1 litre
	Water basin *(yarkwano)*	A smaller bowl used to fetch water from the storage facility into a conveying one before use	1 - 4 litres
	Calabash *(yarkwarya)*	A smaller calabash or gourd cut into half (½) used for fetching water as described above	2 - 5 litres

* ***Words in italics are local names given to the different items***

Table 5.4: Introduced technologies available in Katarko village

Activity	Item	Description and use	Capacity/size
Sourcing	Tube well & wash borehole	A narrow well (hole) normally constructed by drilling from the surface without construction workers entering into the ground and water extracted by means of a engine-driven pump.	Water yield depends on groundwater recharge and pumping rates
Extraction (withdrawal)	Water pumping machines	Petrol-driven 3-4 Hp-engines used for lifting (pumping) water from either ponds, stream, shallow wells, tube well or wash borehole.	180-1000 litres per hour.
	Hand pump	A simple hand-operated (manual) device for raising (lifting) water from a tube well or borehole into a container.	Quantity extracted depends on effort used
Storage	Water tank	Manufactured cubelike metallic and spherical plastic containers used for storing water	2000 & 1000 litres respectively
	Ground cistern	A brick and cement ground (surface to subsurface) tank used for storing water extracted from a tube well or borehole	Can contain up to 5000 litres of water

Table 5.5: Difference in irrigation activity

Facility used	No. of farmers (households)	%	Farm size (hactares)	%	Groundwater (litres)	%	Output (kilograms)	%
Indigenous initiative	2	22.2	3.2	23.2	540000	17.4	5400	6.3
Introduced (water pumps)	7	77.8	10.6	76.8	2568000	82.6	80700	93.7
Total	**9**	**100.0**	**13.8**	**100.0**	**3108000**	**100.0**	**86100**	**100.0**

CHAPTER SIX

A simulation of economic and environmental impacts associated with changes in rural water use: toward policy formulation

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Abstract

This paper uses a commodity-by-industry economic-ecological model (CIEEM) to simulate the economic and environmental impacts associated with water use in the economic development of a drought-prone village in Nigeria. Two policy scenarios, increasing production of a number of commodities to improve economic development and water application efficiency to conserve groundwater, were developed and simulated to investigate these impacts. Results show that an increase in production will be met by an increase in groundwater input while changes in the production process and water application efficiency will ensure a reduction in inputs of groundwater as well as other environmental commodities. The water conservation strategies discussed in the paper will serve as policy options for sustainable development in this water-scarce rural village and other areas with similar economic and environmental conditions.[10]

Key words: commodity-by-industry economic-ecological model (CIEEM), economic and environmental impacts, policy scenarios, economic development, water application efficiency, water conservation, rural economy, village, less developed country (LDC).

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[10] This work is supported by the Jos-McMaster drought and rural water use project (funded by the Canadian International Development Agency-CIDA). The contributions of the University of Jos, Nigeria and McMaster University, Canada as well as the cooperation of the people of Katarko village in Nigeria are also acknowledged.

6.1 Introduction

This paper develops hypothetical policy scenarios which are simulated using a commodity-by-industry economic-ecological model to investigate their impacts on water and other ecological commodities. Results are expected to contribute to the establishment of alternative policy options for water resources management and sustainable economic development in the area.

The impact of economic development on the environment is now a global issue and cannot be ignored. However, the extent of these impacts at local and regional levels in less developed countries (LDCs) is not fully understood. Unlike the rich industrialized countries where development is large-scale and the impacts associated with immense consumption of fossil fuels are basically in the form of environmental pollution, development in the LDCs is rather at a small-scale and the nature of impacts is often in the form of severe resource depletion (World Bank, 1992; Lesser, et al., 1997). Therefore, the challenge of sustainable development[11] in these poor countries is an urgent matter of concern (WRI, 1992). This concern can be investigated from two perspectives, economic development and environmental degradation.

Unfortunately, the advancement of environmental economics and its associated discourse on sustainable development have not resolved the links between long-term

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[11] Sustainable development is considered here to encompass economic, human, environmental, and technological dimensions as defined in WRI (1992) including the agricultural connotation contained in Dabi and Anderson (1998a).

economic growth and environmental quality. The two schools of thought, that environmental degradation is a necessary outcome of economic growth and that economic growth and environmental quality go together, are still being debated (Antle and Heidebrink, 1995). Thus, "one of the strident areas of environmental policy debate continues to be the relationship between economic growth and environmental quality" (Lesser, et al., 1997, p587).

According to Ruddle and Rondinelli (1983, p2), "a more accurate and increasing conclusion about economic development in relation to conservation of the natural environment is that some development policies are indeed detrimental to environmental quality and natural resources, but others have created opportunities for large numbers of people to improve their levels of living in ways that are compatible with, comparable to, or capable of enhancing the natural resource base. The form development takes, and the way policies are designed and carried out (implemented), determine the effects on a country's natural resource system." Regrettably, many development policies have neither benefited the rural peasants nor ameliorated the menace of environmental degradation. There is therefore the need to advance better economic development policies that will not only improve the lots of the rural poor but also reduce environmental degradation and ensure sustainability.

Most economic development policies in the rural areas of LDCs have centred on agriculture. The agricultural sector is fundamental to rural economic development in these countries because it still employs more than 75% of the population (for example, see Dabi and Anderson, 1998a; 1998b). Consequently, countries like Nigeria have emphasized the agricultural sector as a stimulant to rural economic growth over the past four decades. Most of the strategies adopted however, were not very successful. Therefore, present day policy makers are trying to take advantage of the lessons learned from the failures of the past (see for example, Eicher and Staatz, 1990; FMI, Nigeria, 1991).

This paper describes an analysis of several hypothetical policy approaches toward local economic development and sustainable water and resource management in drought prone areas with particular reference to agriculture. A case study village in northern Nigeria (described below) was selected for this study. These policy approaches represent development scenarios drawn from the literature for the area and others with similar environmental and human characteristics as well as empirical results from previous work. Each hypothetical approach is formulated as a scenario and simulated using a commodity-by-industry economic-ecological model to see the impact associated with such changes. Proposed changes in the structure of production will be represented as exogenous final demand, and proposed changes in technology and water conservation will be represented as changes in technical coefficients. The results provide a more comprehensive measure of policy impacts than would be possible without the model. The paper takes into consideration water use changes and the associated impacts on the economy and the environment.

6.1.1 Case study area

Our case studies have been centred on a selected drought-inflicted village, Katarko in Yobe State, Nigeria. This village is located within the semi-arid zone of northern Nigeria, at 11°33'N and 11°55'E. It experiences similar environmental conditions as the rest of the

Sahel region of sub-Sahara Africa. Droughts, water scarcity, and the threats of desertification are inherent. Rainfall is limited to four months of the year with annual amounts ranging between 500 and 1000 mm. Stream flow and other surface water sources fed by the rainfall are seasonal, suffering from the menace of excessive evaporative demand and siltation. And groundwater accessed by wells (deep and shallow) from the extensive sedimentary Chad Formation which is recharged by the seasonal surface flow and is rather declining. Notwithstanding, groundwater serves as the major source of water in the region. Its undulating terrain is covered mostly by Sudan savanna-type vegetation, basically patchy grasses and scrub as well as scattered acacia and baobab tree species upon which the inhabitants derive food, fuel and construction material (see figure 6.1).

The major economic activities in the village as the rest of the region, include agriculture (rainfed, small-scale irrigation, animal husbandry), rural industrial production (small-scale manufacturing of goods, food processing, and handicrafts) as well as trade and services transacted mostly within the local economy. The village economy is a combination of subsistence and market activities with limited external linkages. Each household produces agricultural commodities for both intermediate and final demand.

The village, as in most rural areas in this region, lacks urban infrastructures and facilities such as piped water and electricity with government policies and assistance rather unfavourable. Therefore, there is heavy dependence on traditional heritage, nature and environmental resources. Water procurement, delivery and processing for economic and domestic activities also depend on traditional initiatives and to a smaller extent, introduced technologies. These often have adverse repercussions on water use and conservation in particular, and the environment at large. (For detailed descriptions see Dabi, 1998; Dabi and Anderson, 1998b.)

(Figure 6.1 about here)

6.2 Background

The main objective of this paper is to assess how alternative development scenarios affect the use of ecological commodities, especially water, in the local economy of Katarko village. In other words, to determine the impacts, on the economy and environment, in terms of production and water use and to develop policy measures aimed at managing the water resources of the area for sustainable agriculture and economic development. This requires a model that can express these scenarios in terms of exogenous changes in final demand – principally representing production of commodities for sale in markets outside the village.

Basically, there are three approaches to economic impact analysis for any given region, viz.: the economic base (EB) methodology, input-output (I-O) methodology, and Keynesian income expenditure theory (Mulligan, 1994; Hughes, 1997). Both EB and I-O methodologies consider the region as consisting of different disaggregate sectors. Interactions between these sectors are analysed in order to measure the total impact of activity in one or more of these sectors on the region. For the purpose of this study, we have employed the I-O methodology because it has sectoral detail and has the ability to show different multipliers for the different industries, through dissaggregation (Treyz, 1993). This allows us to define accurate coefficients for the use of ecological commodities on a sector-by-sector or industry-by-industry bases.

I-O models are used at the national, regional or local level to identify the effects of changes in deliveries to final demand on aggregate gross output, incomes, and employment. They provide an integrated framework for assessing the impacts of increased final demand from one economic sector (or industry) on all other sectors (or industries). Changes in final demand are treated as exogenous, and their total impacts (direct and indirect) are endogenous (Miller and Blair, 1985; Hastings and Brucker, 1993; Sadoulet and de Janvry, 1995).

6.2.1 Application of I-O models for environmental impact assessment: an overview

A more exhaustive model for regional impact evaluation requires the inclusion of the environmental sector which takes into account flows of nonmarketable materials into and out of the economic sector. Such flows, expressed in units of weight, may be treated in much the same manner as economic inputs and outputs in the standard I-O model (Johnson and Bennett, 1981). The traditional I-O model developed by Leontief (1970) has been extended to accommodate these environmental concerns, linking the environment and the economy.

There are three categories of environmental extensions of the I-O model. The first, the pollution generation-elimination model was developed by Cumberland (1966). The model was an extension of the rows and columns of the traditional I-O accounting framework to include environmental concerns, in the form of an interregional model (IRIO). Daly (1968) led the way with the second category, economic-ecological models, employing a highly aggregated industry-by-industry characterization of the economic sub-matrix and a classification of ecosystem processes. Isard (1968) also contributed to this category using a commodity-by-industry accounting scheme in his model which recognises secondary production and accounts for multiple economic and ecological commodities. The last category, the environmental commodity-by-industry model, was first developed by Victor (1972), who limited the scope of Isard's model to account only for flows of ecological commodities from the environment into the economy and of the waste products from the economy into the environment in two sub-matrices, the "Economic subsystem" and "Ecological subsystem." These sets of extensions have had their successes and failures and in various applications; most of which have been to analyse the impacts of policy scenarios with particular reference to air and water pollution (Huang et al, 1994).

Huang et al (1994), developed a commodity-by-industry input-output model for regional solid-waste management. The model improved on the commodity-by-industry work of Victor (1972) by introducing an environmental policy initiative composing of waste recycling, reuse and reduction activities (3R), reflecting economic and environmental effects. It also improved on the work of Johnson and Bennett (1981) by introducing a regional solid-waste management area to analyse (using hypothetical data) the relationships between economic development and regional solid-waste management alternatives. Such a model is useful for identifying waste sources, their generation rates, as well as their environmental impacts corresponding to the different industries, environmental policies and regional economic development alternatives. For more review on the earlier extensions of the I-O model, see Johnson and Bennett (1981); Miller and Blair (1985); Lonergan and Cocklin (1985); Huang et al (1994); Dabi and Anderson (1998c).

Most applications of these extensions are basically suitable for developed economies characterized with highly integrated industrial complexes accompanied by immense environmental and air pollution, but they are less appropriate for rural areas of less developed countries (LDCs), where production is done in small-scale local industries with relatively little environmental pollution discharge. The more pressing problem in these rural areas is scarcity of environmental resources and associated environmental degradation, rather than environmental pollution. Therefore, a more desirable model will be one that captures the use of scarce environmental resources in the economy, properly accounts for the depletion of these resources by the economy or the interdependence between the economy and the environment (resources), and ascertains impacts associated with such interactions.

In this paper, we simulate the impacts of development scenarios and water use on the economy and environment using estimates from a commodity-by-industry economic-ecological model (CIEEM) applied to the study village (Dabi and Anderson, 1998c). This approach is consistent with Giarratani and Garhart's (1991) observation that computer simulated models can be an appropriate and effective means of evaluating particular aspects of regional I-O analysis. This can be done in either of two ways (i) changes to an existing I-O model (either deterministically, by substitution or changing certain parameters arbitrarily) or (ii) computer generated I-O model components (either by actual observation or otherwise). We are using the first approach by making hypothetical changes to the final demand category and changes in the water input (an ecological commodity) component of the model as described in the development and water use scenarios below. This will reveal some of the critical commodities that may impact on the village economy and its environment. We are more interested in the applicability and potential insights of the model than its predictive power.

6.3 Methods

The categorisation of all village activities as a set of interrelated industries producing a larger set of commodities for which input-output relations can be measured allows us to adopt the commodity-by-industry economic-ecological model (CIEEM). *Industries* are groups of firms or households, for example, rainfed agriculture and labour, that produce goods or services for intermediate or final demand. *Commodities* are the individual products of the industries, for example sorghum (guinea corn) and paid farm labour. Each industry produces one or more commodities, and in principle the same commodity can be produced by more than one industry, for example rice can be produced by both rainfed and irrigated agriculture (see Table 6.1). *Economic commodities*, described above, are traded in the local economy usually in monetary terms. *Ecological commodities* are nonmarketable quantities of goods extracted directly from the environment as inputs to an industry production process, for example, water, land and vegetation or as outputs generated by a production process, for example wastewater and solid wastes discharged back to the environment (Miller and Blair, 1985; Dabi and Anderson, 1998b; 1998c).

When using the commodity-by-industry characterization[12] for impact analysis or forecasting the following relationships are used:

$$Q = (I - BD)^{-1} E \tag{6.1}$$

where Q is a column vector (m x 1) of commodity output (production); I is the m x m identity matrix, $B=[b_{ij}]$ is the matrix (m x n) of economic commodity-by-industry direct requirements, [b_{ij} is the amount of economic commodity i required to produce a unit output of industry j]; $D=[d_{ij}]$ is commodity output proportions (n x m). Therefore, $(I - BD)^{-1}$ is the commodity-by-commodity total requirements matrix (m x m), analogous to the Leontief inverse $(I - A)^{-1}$. Its entries are called the interdependency coefficients that represent the direct and indirect requirements. $E = [E_i]$ is a column vector (m x 1) of commodity deliveries to final demand. In a similar fashion, output can be defined at the industry level as:

$$X = [(I - DB)^{-1}] Y \tag{6.2}$$

where X is a vector (n x 1) of industry total outputs, $[(I - DB)^{-1}]$ is the industry-by-industry

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[12] A commodity-by-industry characterization differs from the traditional industry-by-industry (square matrix) model because the former, takes into account secondary production. In other words, it considers the production of commodities irrespective of the industries from which they are produced. However, the industries are divided based on the similarity of production inputs (see Dabi and Anderson, 1998c).

total requirements matrix (n x n); the component D and B are as defined in equation (6.1); and Y is a vector (n x 1) of industry deliveries to final demand, Y = DE (industry final demand is a product of commodity output proportions (D) and commodity final demand (E). We have adopted this relationship for our study by aggregating the changes in commodity production into their respective industries.

Because we were unable to obtain data on quantities of the ecological commodities used for the production of individual economic commodities, especially when more than one commodity is produced, we have based the use of water and other ecological commodities on industry output (Y) instead of commodity output (E). However, we expect that this procedure will have little or no impact on the accuracy of our calculations. Thus, the ecological commodity input total requirements are as follows:

$$G^* = [G(I-DB)^{-1}]\, Y \qquad (6.3)$$

where G* is a vector (e x 1) of total (direct and indirect) ecological commodity inputs required for the production of economic outputs, G is the matrix (e x n) of ecological commodity input coefficients, e is the number of ecological commodity inputs. The elements of $(I\text{-}DB)^{-1}$ and Y are as defined in equation (6.2). The ecological commodity output total requirements are given by:

$$F^* = [F(I-DB)^{-1}]\, Y \qquad (6.4)$$

where F^* is also a vector (e x 1) the of total (direct and indirect) requirements matrix of ecological commodity outputs produced due to economic commodity production, and F is the matrix (e x n) of ecological commodity direct output coefficients, e also represents the number of ecological commodity outputs. The notations $(I\text{-}DB)^{-1}$ and Y are as defined in (6.2) above.

To facilitate our simulations, changes were made to either the final demand category of the model equations or the water input requirement components. For changes in the final demand category, the following sets of relationships are used:

$$\Delta X = [(I - DB)^{-1}]\,\Delta Y \qquad (6.5)$$

where ΔX is a vector of new industry output following the change in the final demand category ΔY used for the simulation. $[(I - DB)^{-1}]$ is as defined above;

$$\Delta G^* = [G(I\text{-}DB)^{-1}]\,\Delta Y \qquad (6.6)$$

where ΔG^* is a vector of new ecological commodity total (direct and indirect) inputs required to meet the change in final demand ΔY used for the simulation. G is as defined in equation (6.3) and $[(I - DB)^{-1}]$ as defined earlier in equation (6.2) above. Then

$$\Delta F^* = [F(I\text{-}DB)^{-1}]\,\Delta Y \qquad (6.7)$$

where ΔF^* is a vector of new ecological commodity total (direct and indirect) outputs produced following a change in the final demand ΔY. F is as defined in equation (6.4), and $(I-DB)^{-1}$ also as defined in equation (6.2) above. Whereas for the change in the water input requirement, we have the following relationship:

$$\Delta G^* = [\Delta G(I-DB)^{-1}]\, Y \qquad (6.8)$$

where ΔG^* is a vector of new ecological commodity total (direct and indirect) inputs required following the change in water input requirement ΔG; G and $[(I-DB)^{-1}]$ are as defined earlier. The final demand category Y is unchanged, that is, the industry final demand described in equation (6.2).

6.3.1 Data and simulation procedure

Data used in this paper are based on two field surveys conducted in Katarko Village. The first a survey of all households to obtain basic population and activity data and the second a sample survey to obtain more detailed economic and environmental (ecological) information. A complete description of data collection is found in Dabi and Anderson (1998b). Data generated have been used in our earlier paper (Dabi and Anderson, 1998c) which developed and applied a commodity-by-industry economic-ecological model (CIEEM) that accounts for the direct and indirect use of water in the village. Data for the simulation is based on the results of that paper (Dabi and Anderson, 1998c), with information on local initiatives (indigenous knowledge systems and technologies) for water use and conservation in the village (Dabi, 1998), and secondary information on development policy issues in the region, from relevant literature (for example, Eicher and Staatz, 1990; FMI, Nigeria, 1991).

The first set of scenarios is based on changes in the structure of production represented by adjusting the exogenous final demand. The hypothesis here is that an increase in output of certain export commodities will lead to a corresponding increase in the quantity reserved for sale to external (exogenous) markets. It is expected that income generated from such an activity will improve the economic base of the village and consequently, the welfare of its people as they invest further. However, the model will enable us to determine the impact on other sectors of the economy and environment (particularly, water) associated with such changes. A 10 percent increase in final demand for the corresponding commodities is used to establish three sub-scenarios to investigate the resultant changes. The commodities used for these simulations have been reflected as increases in their respective industries to establish the changes in industry output.

Scenario (1a) uses information given by households to increase the final demand of *selected commodities*. These are combinations of traditional and introduced agricultural commodities (crops) and handicrafts of which most households indicated willingness to increase their production. Households were asked to list, in order of preference, commodities they are willing to produce more of. The following were identified: groundnuts (pea nuts), cotton, rice, wheat, sheep, goats, calabashes and a variety of handicrafts.

Scenario (1b) uses information generated from the agriculture and rural development policies in Nigeria to increase the final demand on *national cash crops (commodities)*. The national cash crops considered here are those contained in the Nigerian agricultural development plans since independence. The production of these crops was promoted by government institutions and agricultural research and extension workers (see Eicher and Staatz, 1990; FMI, Nigeria, 1991). In our study village these crops include groundnuts (pea nuts), cotton, rice, wheat and cattle.

Scenario (1c) uses information from our earlier work that established the income generation from commodity production in Katarko village (Dabi and Anderson, 1998b), to increase the final demand of '*strategic cash commodities*,' crops that generate more income per head to the farmers engaged in their production. These commodities include groundnuts (pea nuts), beans (cow peas), gorongo (a local egg plant-like crop), vegetables (irrigated), sheep and goats.

The differences between these sub-scenarios are that scenario (1a) includes sheep, goats, calabashes and handicrafts in addition to major cash crops, groundnuts, cotton, rice and wheat. Scenario (1b) is similar to (1a) except that it added only cattle, which is absent in (1a), to the major cash crops. Scenario (1c) is also similar to (1a) but the difference between them is that, scenario (1c) excludes all the major cash crops but groundnuts, excludes calabashes and handicrafts, and instead, added three other crops: beans, gorongo and irrigated vegetables.

Based on the above scenarios, changes in total output to meet these new final demands were established by multiplying the change in the final demand category with the industry-by-industry inverse matrix (technical coefficients) already calculated. The differences between these 'new' total outputs and the initial (observed) total output were also determined. The corresponding income generated was calculated by multiplying the new total output with the unit price for each commodity and aggregated for each industry. For the ecological input and output categories, the same method was adopted but the changes were established by subtracting the initial total input or output, as the case may be, from the corresponding new total input or output respectively. A simulation of all three scenarios combined (a maximum of 10% increase in any commodity changed in the three scenarios to form a new final demand category) was also done to determine total groundwater use should all the changes be implemented, and the percentage increase from the initial total groundwater withdrawal determined. Finally, ecological commodity inputs and outputs to income ratios were calculated to observe the intensity of ecological commodity use and production.[13] These intensity values are useful for purposes of comparison among the three sub-scenarios.

The second set of policy scenarios relates to water use efficiency based on technology and water conservation strategies drawn from an earlier paper (Dabi, 1998) and other relevant literature (Eicher and Staatz, 1990; FMI, Nigeria, 1991), as indicated above. These scenarios are represented as changes in technical coefficients (water requirements for commodity production) as well as in the final demand of the model. Traditionally the model uses coefficients as 'constants' but it is possible to change the ecological commodity coefficients

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[13] Income is used here as a measure of 'development' and to serve as a common denominator rather than output which was measured in different physical units.

in this model. We have therefore changed the water input coefficients to enable us to observe the possible effects on production and water demand. A simulation of these changes will also reveal the possible impacts on the economy and environment. For Katarko village and the rest of the region, water conservation is perhaps feasible through either or a combination of three approaches which have been developed into three other sub-scenarios as follows:

Scenario (2a) is based on water application efficiency by adopting new farming strategies (technologies) that will reduce the quantity of water used for irrigation.[14] Although some of 'most efficient' (introduced) irrigation water application techniques used have proved to be "inappropriate" due to their sophistication as well as the high purchase and maintenance cost, the indigenous (traditional) plant-to-plant method is perhaps a better option for this village and others in the region (Dabi, 1998). The use of this traditional technique will reduce the quantity of irrigation water by at least 10% even though it cannot achieve the 30% efficiency claimed for the introduced types. However, labour requirements will be affected, but income generation may remain the same since the same quantities of commodities are produced. Therefore, a 10% reduction in the groundwater requirement per kg in the irrigated is made, but there is no change in the final demand and all other input requirements are expected to remain the same. The total groundwater saved will be determined by the model.

Scenario (2b) represents elimination or transfer of hydrophytic (water-loving) crops,

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[14] Earlier studies have indicated that water application efficiencies, using especially subsurface irrigation methods, can reduce the quantity of water used by between 30-90% with an average of less than 50%. Water application efficiency refers to the quantity of water required to grow a plant to maturity (Criddle and Haise, 1957; Bertrand, 1965).

that use more groundwater per unit of output, from the irrigation industry. For example, rice and wheat consume about 13% of the irrigation water in the village (Dabi and Anderson, 1998b). Irrigated rice can be conveniently cultivated as a rainfed crop. Such an adjustment will take advantage of the rainfall but will require additional labour during the rainy season which can be met through communal effort. However, it will reduce the demand for groundwater and labour by the irrigated agriculture during the dry season. Therefore, the final demand category of rice and wheat are eliminated from irrigated agriculture industry and cultivation of rainfed rice increased to meet the same final demand. It is expected that some percentage of groundwater use for irrigation will be conserved in the process and all other inputs will be affected (changed) as will be revealed by the model.

Scenario (2c) represents shifting or rescheduling of rural industry activities (especially, building, brick making and pottery) to depend on rainwater harvested from rooftops and mini-catchment areas or surface water and stream flow collection into surface or groundwater dams (see Pacey and Cullis, 1986). With this adjustment, water and other input requirements as well as income will remain basically the same. However, labour input requirements will increase during the rainy season but groundwater will be conserved and the labour problem can be solved through communal effort (Dabi, 1998). Therefore, there will be an elimination of groundwater requirement in the rural industry, there will be no change in the final demand, all other input requirements will remain the same, the total quantity of groundwater conserved in the process will be determined by the model. (This will be represented by a change in groundwater input requirement in the respective industries to zero.)

The analysis of these new scenarios is based on changes in the values of the groundwater input requirements for commodity production for scenarios (2a) and (2c). For scenario (2b), there was a change in final demand in addition to the change in groundwater input. The new values are multiplied by the corresponding commodity or industry output to determine the new direct and total groundwater requirements and the new industry output for scenario (2b). A simulation of all three scenarios combined (a summation of all three changes, since there are no repetitions in the different scenarios) was also done to determine the total groundwater used should all the changes be implemented, and the percentage decrease from the initial total groundwater withdrawal determined. Finally, ecological commodity use and production intensities were also calculated to facilitate the comparison among the three sub-scenarios.

Both sets of policy scenarios are based on possible options available for the sustainable development of this rural village as well as others in the region. Results will enhance our understanding of these economy-environment relationships.

6.4 Results and discussions

The model we have used here allows calculations in physical units making it suitable for application in this village where some of the commodities, especially ecological commodities, do not have monetary values. However, this leaves us with the problem of interpreting the results, especially making comparisons between the different scenarios. It is even worse or probably impossible to compare items measured in different physical units. It is also very unclear how to compare scenarios of different magnitudes developed for this economy. The ecological commodity use and production intensity measures (ratios) described earlier, however, prove useful for making direct comparisons between scenarios.

Simulation results from the two sets of scenarios gave 'new' commodity and industry outputs which were subtracted from the corresponding initial (observed) values to establish the implied changes (differences). These changes and the intensity values have been tabulated for easier assessment. Table 6.1 shows the changes in industry production and income generation for first set of scenarios. Comparing among the sub-scenarios for rainfed agriculture, as an example, scenario (1c) has the highest increase in industry output to meet the new final demand. This is followed by scenario (1a) then (1b). Correspondingly, scenario (1c) indicated the highest increase in income generated, again followed by scenario (1a) and scenario (1b) as the lowest. Similar trends are observed for irrigated agriculture and animal husbandry. The labour requirements for the three sub-scenarios tend to follow the same pattern. However, looking at calabash carving, for instance, the trend is fairly different. Scenario (1a) leads the way with the highest increase in industry output followed by scenarios (1c) then (1b). The same order is reflected in the increase in income generation.

(Table 6.1 about here)

Table 6.2 show similar trends for the respective industries in their requirements for ecological commodity inputs. The total values also exhibit the same trend, for example, scenario (1c) requires, significantly, the highest quantity of groundwater, land and vegetation, followed by (1a) then (1b). Table 6.3 which shows ecological commodity (production) outputs exhibits some variation. Scenario (1a) leads with wastewater production followed by (1c) and lastly (1b). However, for solid wastes production, the former trend is repeated, with scenario (1c) as the highest producer, the next being (1a), and then (1b).

(Tables 6.2 & 6.3 about here)

These trends may be attributed to the variation in changes made to generate the hypothetical data. However, taking these figures at face value can obscure some valid information which makes comparisons difficult. Therefore, we have established percentages of the increase in groundwater use required to meet the new final demand and ecological commodity use and production intensities to facilitate our comparisons as suggested earlier. Table 6.4 gives a summary of percentage increases in groundwater use as well as ecological commodity use and production intensities for each scenario. The following percentage increases are observed: scenario (1a), 0.13%; (1b) 0.09%; and (1c) 1.11%. From these, it is evident that scenario (1b), increasing the production of national cash crops (commodities), will require less groundwater input to meet the new final demand. This will be more appropriate toward meeting our objective, water conservation. But a simulation of all three scenarios combined, will lead to a 1.17% increase in groundwater requirements. That is, an increase of nearly one hundred and forty thousand liters of groundwater.

(Table 6.4 about here)

The ecological commodity use and production intensities which show the quantities of commodities used or produced for every naira generated, present a better base for comparison and perhaps the determining factor for selection of scenarios. Naira is the

Nigerian currency, pegged at N22.00 to US$1.00 in 1995 when most of the data were collected. Interestingly, only the intensity values for groundwater follow the trends demonstrated by the analytical (simulation) figures in which scenario (1c) dominated in its use and production of ecological commodities followed by (1a) and (1b). For land use intensity, the trend is reversed with scenario (1b) as the highest followed by (1a) and then (1c) as the lowest. But for vegetation input, wastewater and solid wastes intensities, an entirely different trend is observed where scenario (1a) leads, followed by (1c) and then (1b).

The initial trends observed for groundwater intensity may be attributed, for example, to the fact that the strategic cash commodities reflected in scenario (1c) only generate more income per head but excluded the major cash crops which generate more total income. Therefore, scenario (1c) generates less total income than scenarios (1a and b) and is bound to be more water intensive, even though irrigated crops like gorongo and vegetables are included in scenario (1c), the more water demanding crops like irrigated rice and wheat are excluded.. Scenario (1a) that follows with the water intensity, generates less total income than scenario (1b) because it had only sheep and goats instead of cattle (a bigger income earner than sheep and goats) reflected in (1b), consequently, the differences in the respective intensities.

In the second trend in which (1b) leads followed by (1a) and then (1c) as exhibited by land intensity may be attributed, in part, to the transfer of irrigated rice to rainfed agriculture which requires more farmland (usually, rainfed agriculture is more land intensive than irrigated agriculture, see Dabi and Anderson, 1998b) and to the fact that the other scenarios do not involve any change in production *per se*. The third trend exhibited by vegetation, wastewater and solid wastes where the order is scenario (1a), (1c) and (1b) as the lowest may be attributed, in part, to the quantity of vegetation required for wood carving and the corresponding wastes generated and the combination of commodities suggested for scenario (1a).

Most probably, the trends described above are a reflection of the total quantities of the different commodities as the income values per commodity are the same in each case. By and large, it is clear that scenario (1c) will be the least preferable because it requires the most groundwater and vegetation per naira. It also generates the most waste water and solid waste per naira. Ideally, scenario (1b) will be the most preferable but requires the most land per naira. Scenario (1a) which shows, generally, the lowest intensities across all other ecological commodities and conform with the villagers' willingness to increase the production of a number of commodities, would have been the most preferred, but requires more groundwater per naira than (1b).

Results of the second set of our policy scenarios (water use efficiency) on Table 6.5, indicate that production in scenarios (2a) and (2c) remained the same but scenario (2b) showed some changes (increase or decrease). This is attributable to the fact that no change in the final demand category of the former two scenarios was made for the simulation. Literally, scenario (2b) shows a decline in total production in the irrigated industry as well as animal husbandry, milling and vegetation. Other changes were rather insignificant. Surprisingly, there was also a decline in paid labour, perhaps because irrigated agriculture requires more paid labour than rainfed. Rainfed agriculture into which rice cultivation is transferred, relies more on unpaid household labour. Correspondingly, there was a decrease in income accruing to the industries indicated above. The most significant decrease was in the animal husbandry industry followed by the irrigation industry. But as expected, there was an increase in income in the rainfed industry, because of the transfer of irrigated rice to the industry.

(Table 6.5 about here)

Table 6.6 show the analytical results for changes in ecological commodity inputs. All industries but rainfed agriculture that had some amount of change showed a decrease in groundwater use. The increase in groundwater use for rainfed agriculture in scenario (2b) is because of the shift of irrigated rice to that industry. The same trend is observed for land and vegetation inputs owing to the same reason as in groundwater use. But in general, all scenarios (2a, b, and c) recorded a decrease in groundwater input. Scenario (2c) recorded a decrease of more than nine hundred thousand liters of water, scenario (2a) about two hundred and fifty thousand liters, and scenario (2b) a little more than fifty thousand liters. For other ecological commodity inputs, land and vegetation, only scenario (2b) was affected. This was between the irrigated and rainfed industries where the transfer of rice was made. There was a general increase in land input due to the significant increase for rainfed agriculture. Rainfed agriculture uses more land, in total, than irrigated. The decrease in irrigated agriculture was low. Similarly, for vegetation input, there was a small increase into rainfed agriculture but a decrease into irrigated.

(Table 6.6 about here)

However, for ecological commodity outputs, waste water and solid wastes, on Table 6.7, only scenario (2b) show some rather insignificant changes. Rainfed agriculture shows an increase in both cases while irrigated, a decrease. The total figures show a general decrease even though rainfed showed some increase. In general, these analytical values for ecological commodity inputs and outputs are a reflection of the changes made to establish the hypothetical data.

(Table 6.7 about here)

To understand the extent of water conservation, the three sub-scenarios were compared with the initial groundwater input to establish the percentage decrease in water use. Ecological commodity use and production intensities were also established. Table 6.8 gives a summary of these values according to the three sub-scenarios. The following percentage changes are observed: scenario (2a), 2.12%; (2b) 0.4%; and (2c) 7.95%. This suggests that scenario (2c), rescheduling of rural industry activities to take advantage of water harvesting will conserve more groundwater. A simulation of all three scenarios combined yielded up to 10.47% savings of groundwater. That is, a conservation of more than one million liters of groundwater.

(Table 6.8 about here)

Ecological commodity use and production intensities could be calculated only for scenario (2b). Scenarios (2a) and (2c) did not show any changes because their final demand categories were not altered in the simulation as indicated earlier. Hence, changes observed in scenario (2b) cannot be compared with the others. However, some deductions can be made with regards to conservation. Mathematically, the positive (+) values in this case indicate a decrease and the negative (-) ones, an increase. This is because income generation generally declined, showing negative values. When used to divide corresponding negative values reflecting decreases in ecological commodity use or production will yield positive (+) results and *vice versa*. Therefore, only land input appreciated, that is, for every naira generated, more land will be required. But for the groundwater intensity, there is a higher amount of conservation. For example, for every naira generated there will be a reduction or conservation of about two liters of groundwater. Vegetation input, and waste water and solid waste outputs are also low, but a decrease per naira.

6.5 Summary and conclusion

This paper uses a commodity-by-industry economic-ecological model (CIEEM) to simulate the economic and environmental impacts associated with a number of development scenarios. In the process, we did a simulation of changes in production and groundwater use to investigate their impacts on the economy and environment. Our simulations are based on two sets of policy scenarios: increase in production of goods aimed at improving the economy of Katarko village and water use efficiency to conserve groundwater and maintain the environment. Our results show that while an increase in production will be met by an increase in groundwater input, changes in the production process and water application efficiency will ensure a reduction in groundwater input as well as other environmental commodities.

The model employed for this analysis has been useful in illuminating economy-environment relationships that would not have been evident without it. We have been able to demonstrate from our first set of policy scenarios that, increasing the production of a number strategic cash commodities, those that earn farmers more income per output (scenario 1c) will generate more income per head but require more groundwater. The production of national cash crops, scenario (1b), is perhaps a better option because it requires less water in the process, although less income is generated. However, the ecological commodity use and production intensities further clarified the nature of the relationship. For example, the groundwater intensity shows that scenario (1c) requires more water per naira and is therefore the least preferable option.

We also elucidate from the second set of our policy scenarios that it is possible to conserve large quantities of groundwater through realistic improvements in water application methods and better choice of irrigated crops or transfer of say irrigated rice to rainfed agriculture. Even more groundwater will be conserved if activities are rescheduled to take advantage of rainwater harvesting. Better still is a combination of all strategies whereby huge sums of groundwater can be conserved. These strategies can serve as policy options for sustainable development in this water-scarce village. They can also be applied to other areas with similar economic and environmental conditions.

However, achieving this dual advantage, increasing production and at the same time reducing the use of or impacts on environmental commodities (especially water), may only be feasible with some tradeoffs. These tradeoffs are not the subject of discussion in this paper.

Such an investigation will require the use of other tools like social cost-benefit analysis. This is because other sociocultural and political factors not considered in the model may be important. It would also be interesting to introduce time-series data to investigate the possible impacts over time using a dynamic approach. This will allow us to observe rather than just simulate changes in water use associated with changes in agricultural practice. Another useful extension would be to investigate the problem from a regional setting to observe possible linkages with and feed back effects from the rest of the region, using interregional input-output (IRIO) or multiregional input-output (MRIO) approaches.

References

Antle, J.M. and Heidebrink, G. (1995) Environment and development: theory and international evidence. *Economic Development and Cultural Change* 43(3): 603-625.

Bertrand, A.R. (1965) "Water conservation through improved practices." In Pierre, W.H., Kirkham, D., Pesek, J., and Shaw, R. (eds.) *Plant Environment and Efficient Water Use*. American Society of Agronomy and Soil Science Society of America. 207-235.

Criddle, W.D. and Haise, H.R. (1957) *Irrigation in arid regions*. US Dept. Agr. Yearbook. p. 359-368.

Cumberland, J.H. (1966) "A regional interindustry model for analysis of development objectives" *Papers of the Regional Science Association* 7 64 - 94

Dabi D.D. (1998) Indigenous knowledge systems, technology transfer and rural water use in northern Nigeria. Submitted to *Economic Development and Cultural Change*.

Dabi D.D. and Anderson, W.P. (1998a) Water scarcity and sustainable agricultural development in the drought-prone semi-arid zone of West Africa. Proceedings. International Conference on Tropical Climatology, Meteorology and Hydrology. Brussels, May 22-24, 1996. In press.

Dabi D.D. and Anderson, W.P. (1998b) Water use for commodity production in Katarko village, northern Nigeria. Accepted for publication in *Applied Geography*.

Dabi D.D. and Anderson, W.P. (1998c) Application of a commodity-by-industry economic-ecological model to water demand and use in a rural economy. Submitted to the *Journal of Environmental Management and Planning*.

Daly, H.E. (1968) "On economics of a life science" *Journal of Political Economy* **76** 392 406

Eicher, C.K. and Staatz, J.M. (1990) Introduction. In Eicher, C.K. and Staatz, J.M. (eds.) *Agricultural Development in the Third World*. John Hopkins University Press. 550pp.

Federal Ministry of Information, Nigeria. (1991) *Towards Self-Sufficiency in Food*. Know Nigeria Series No.1. 32pp.

Giarratani, F. and Garhart, R.E. (1991) Simulation techniques in the evaluation of regional input-output analysis: a survey. In Dewhurst, J.H., Hewings, G.J.D. and Jensen, R.C. (eds) *Regional Input-Output Modelling: New Developments and Interpretations*. Avebury Academic Publishing Company, Aldershot, England: 14-50

Hastings, S.E. and Brucker, S.M. (1993) An introduction to regional input-output analysis. In Otto, D.M. and Johnson, T.G. (eds) *Microcomputer-based Input-output Modeling: Applications to Economic Development*. Westview Press, Boulder: 1-27

Huang, G.H., Anderson, W.P. and Baetz, B.W. (1994) Environmental input-output analysis and its application to regional solid-waste management planning. *Journal of Environmental Management* 42:63-79

Hughes, W.R. (1997) A comparison of economic impacts with the use of economic base and input-output methodologies. *Environment and Planning A* 29(4):673-684

Isard, W. (1968) "On the linkage of socio-economic and ecological systems" *Papers of the Regional Science Association* **21** 79 - 99

Johnson, M. and Bennett, J. (1981) Regional environmental and economic impact evaluation: an input-output approach. *Regional Science and Urban Economics* 11:215-230

Leontief, W. (1970) Environmental repercussions and the economic structure: an input-output approach. *Review for Economics and Statistics* 52:262-271

Lesser, J.A., Dodds, D.E., and Zerbe, Jr., R.O. (1997) Economic growth, the environment, and sustainable development. In *Environmental Economics and Policy.* Addison Wesley Longman, Inc., Reading. 585-620.

Lonergan, S.C. and Cocklin, C. (1985) The use of input-output analysis in environmental planning. *Journal of Environmental Management* 20: 129-147

Miller, R.E. and Blair, P.D. (1985) *Input-output Analysis: Foundations and Extensions.* Prentice-Hall, Inc., Englewood Cliffs, New Jersey

Mulligan, G.F. (1994) Multiplier effects and structural change: applying economic base analysis to small economies. *Review of Urban and Reg Development Studies* 6:3-21

Pacey, A. and Cullis, A. (1986) *Rainwater Harvesting: The collection of rainwater and runoff in rural areas.* London, Intermediate Technology Publications. Chapter 1, 1-21.

Ruddle, K. and Rondinelli, D.A. (1983) Resources, environment, and development policy: A resource system framework. *Resource Management and Optimization* 3(1), 1-22.

Sadoulet, E. and de Janvry, A. (1995) Input-output tables, social accounting matrices, and multipliers. In *Quantitative Development Policy Analysis.* John Hopkins Univ. Press, Baltimore. 273-301

Treyz, G.I. (1993) Policy simulation modeling. In Otto, D.M. and Johnson, T.G. (eds.) *Microcomputer-Based I-O Modeling: Applications to Economic Development.*

Westview Press, Boulder.

Victor, P.A. (1972) *Pollution: Economy and Environment*. Univ. of Toronto Press, Toronto.

World Bank. (1992) *World Development Report 1992: Development and the Environment*. Oxford University Press, New York.

World Resources Institute. (1992) *World Resources 1992-93.* A report by World Resources Institute in collaboration with The United Nations Environment Programme and The United Nations Development Programme. Oxford University Press, New York. 1-12.

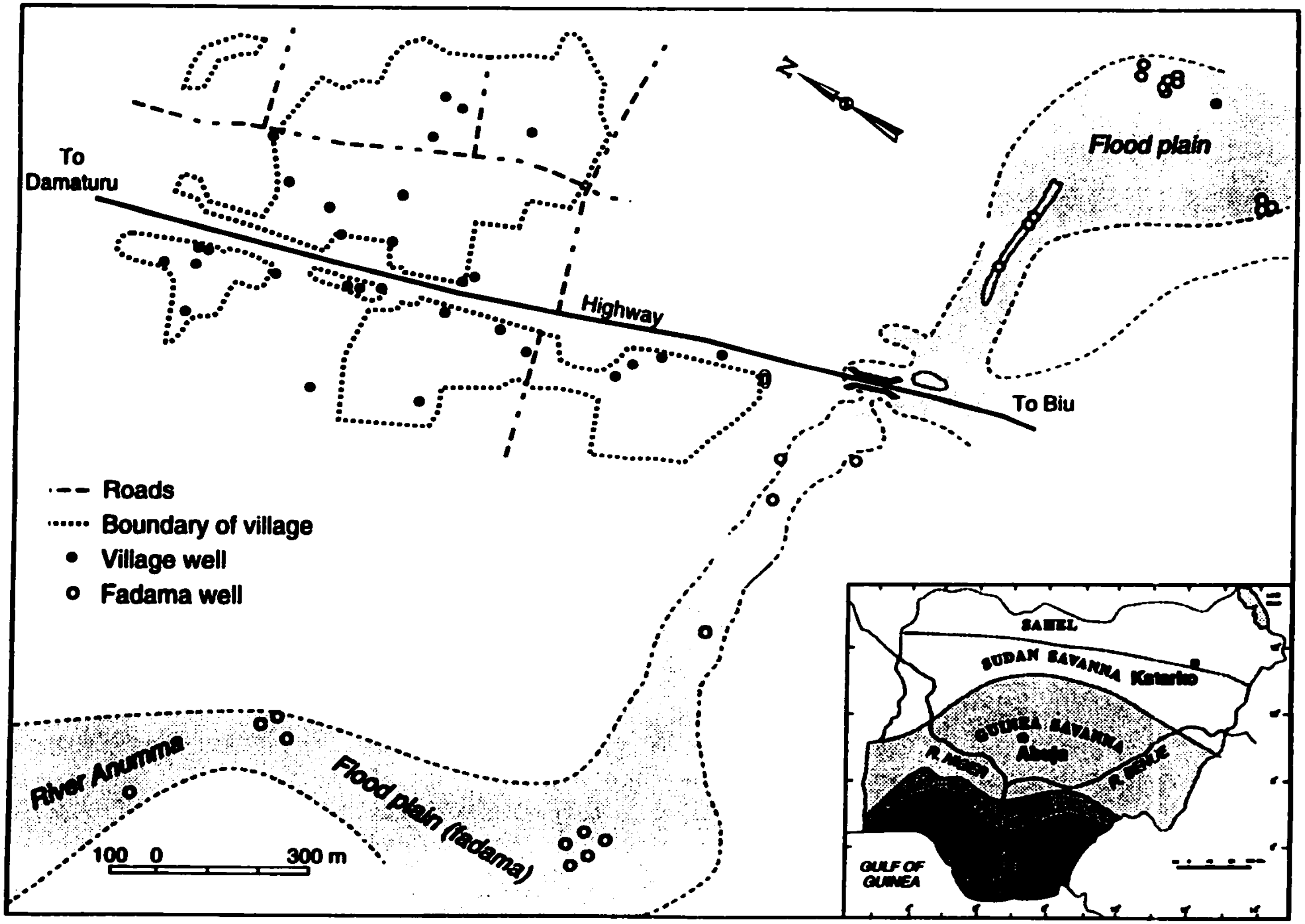

Figure 6.1 Boundary of study village and its regional setting

Table 6.1: Increase in industry production ($<X - X$) to meet new final demand and income generated in each scenario

(Using Industry total requirements, $<X = [(I - DB)^{-1}] <Y$)

Industry	Increase in industry production			Increase in income (Naira)‡		
	1a	1b	1c	1a	1b	1c
1. Rainfed agriculture •	12280.93746	12167.37486	23746.36234	112047.82	111011.70	216655.12
2. Irrigated agriculture •	119.80018	119.80018	2679.29052	906.75	906.75	20279.27
3. Cassava (annuals) •	0.00000	0.00000	0.00000	0.00	0.00	0.00
4. Animal husbandry [1]	130.14191	75.47788	441.19081	26963.35	15626.21	91473.86
5. Brick making [1]	0.00000	0.00000	0.00000	-0.00	-0.00	-0.00
6. Building Construction [1]	0.00000	0.00000	0.00000	0.00	0.00	0.00
7. Pottery [1]	5.03972	2.92307	17.08605	251.99	146.16	854.31
8. Black smithing [1]	5.00301	3.84993	8.43093	175.11	134.75	295.09
9. Wood carving [1]	222.00052	0.00037	0.00210	14541.04	0.03	0.14
10. Calabash carving [1]	160.88140	4.83588	10.63809	1608.82	48.36	106.38
11. Weaving [1]	0.41900	0.41501	0.86811	59.32	58.75	122.90
12. Milling •	534.98232	315.55314	1794.96065	389.78	229.91	1307.78
13. Butchery •	0.00000	0.00000	0.00000	0.00	0.00	0.00
14. Catering/Trading • [1]	0.00000	0.00000	0.00000	0.00	0.00	0.00
15. Fishing •	0.00000	0.00000	0.00000	-0.00	-0.00	-0.00
16. Hunting •	0.00000	0.00000	0.00000	0.00	0.00	0.00
17. Water vending [2]	0.00000	0.00000	0.00000	0.00	0.00	0.00
18. Vegetation harvesting •	435.69743	252.88839	1476.40883	306.14	177.69	1037.39
19. Technical & Mech. repairs [1]	0.00000	0.00000	0.00000	0.00	0.00	0.00
20. Carpentry [1]	0.00000	0.00000	0.00000	0.00	0.00	0.00
21. Transportation [1]	0.00000	0.00000	0.00000	0.00	0.00	0.00
22. Tailoring & design [1]	0.00000	0.00000	0.00000	0.00	0.00	0.00
23. Hairdressing/Barbing [1]	0.00000	0.00000	0.00000	0.00	0.00	0.00
24. Education [1]	0.00000	0.00000	0.00000	0.00	0.00	0.00
25. Other services [1]	1.78243	1.26547	7.19507	2.23	1.63	8.51
26. Labor [3]	97.39079	79.01234	224.02461	1947.83	1580.26	4480.51
Total	N/A	N/A	N/A	**159200.18**	**129922.21**	**336621.26**

Note:

• Output measured in kilograms (kg)

[1] Items are counted in absolute numbers (#)

[2] Liquids are in litres (lt)

[3] Human paid labour in man hours

Scenario 1a (selected commodities)

Scenario 1b (national cash commodities)

Scenario 1c (strategic cash commodities)

‡ In 1995 the naira was pegged at N22.00 to US$1.00

Table 6.2: Increase in ecological commodity input ($<G^{*} - G^{*}$) to meet new final demand in each scenario

(Using total input requirements, $<G^{*} = [G\,(I-DB)^{-1}]<1$)

Industry	Increase in groundwater input (liters)			Increase in land input (m^2)			Increase in vegetation input (kg)		
	1a	1b	1c	1a	1b	1c	1a	1b	1c
1. Rainfed agriculture	3961.19286	3961.19286	7529.47092	140575.81294	140575.81294	267207.76615	454.09902	454.09902	863.15549
2. Irrigated agriculture	5287.26593	5287.26593	118247.91364	1164.21141	1164.21141	26037.19437	93.38400	93.38400	2088.50157
3. Cassava (annuals)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4. Animal husbandry	5186.84943	949.70483	5186.84943	6170.34228	1129.78098	6170.34228	493.61747	90.38066	493.61747
5. Brick making	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6. Building Constructors	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
7. Pottery	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8. Black smithing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9. Wood carving	320.17627	0.00000	0.00000	4.05825	0.00000	0.00000	1998.18556	0.00000	0.00000
10. Calabash carving	25.11353	0.00000	0.00000	1.58860	0.00000	0.00000	156.23709	0.00000	0.00000
11. Weaving	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12. Milling	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
13. Butchery	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
14. Catering/Trading	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
15. Fishing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
16. Hunting	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
17. Water vendors	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
18. Vegetation harvesting	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19. Technical & Mech. repairs	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
20. Carpentry	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
21. Transportation	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
22. Tailoring & design	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23. Hairdressing/Barbing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24. Education	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
25. Other services	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
26. Labor	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Total	**14780.59802**	**10198.16362**	**130964.23399**	**147916.41348**	**142869.80533**	**299415.30280**	**3195.52314**	**637.86368**	**3445.27452**

Note:
Scenario 1a (selected commodities)
Scenario 1b (national cash commodities)
Scenario 1c (strategic cash commodities)

Table 6.3: Increase in ecological commodity output ($<F^* - F^*$) to meet new final demand in each scenario

(Using total output requirements, $<F^* = [F (I-DB)-1]<Y$)

Industry	Increase in waste water production (liters)			Increase in solid waste production (kg)		
	1a	1b	1c	1a	1b	1c
1. Rainfed agriculture	11.04743	11.04743	20.99906	234.25216	234.25216	445.26861
2. Irrigated agriculture	0.57263	0.57263	12.80663	9.07156	9.07156	202.88236
3. Cassava (annuals)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4. Animal husbandry	1.88401	0.34496	1.88401	48.88776	8.95128	48.88776
5. Brick making	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6. Building Construction	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
7. Pottery	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8. Black smithing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9. Wood carving	287.34347	0.00000	0.00000	199.80000	0.00000	0.00000
10. Calabash carving	18.92737	0.00000	0.00000	0.00000	0.00000	0.00000
11. Weaving	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12. Milling	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
13. Butchery	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
14. Catering/Trading	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
15. Fishing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
16. Hunting	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
17. Water vending	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
18. Vegetation harvesting	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19. Technical & Mech. repairs	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
20. Carpentry	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
21. Transportation	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
22. Tailoring & design	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23. Hairdressing/Barbing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24. Education	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
25. Other services	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
26. Labor	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Total	**319.77492**	**11.96502**	**35.68970**	**492.01148**	**252.27500**	**697.03873**

Note:

Scenario 1a (selected commodities)
Scenario 1b (national cash commodities)
Scenario 1c (strategic cash commodities)

Table 6.4: Summary of increase in groundwater use with ecological commodity use and production intensities

Scenario	Total increase in Gwater input (Liters)	Total Gwater (% increase)	Gwater intensit (Liters / Naira)	Land intensity (m^2 / Naira)	Vegtn intensity (kg / Naira)	water intensit (Liters / Naira)	Swaste intensity (kg / Naira)
Ia	14780.6	0.13	0.09284	0.92912	0.02007	0.00201	0.00309
Ib	10198.2	0.09	0.07849	1.09966	0.00491	0.00009	0.00194
Ic	130964.2	1.11	0.38906	0.88947	0.01023	0.00011	0.00207
Combined	137723.6	1.17	0.18680	0.97275	0.01174	0.00074	0.00237

Note: Scenario Ia (selected commodities)
Scenario Ib (national cash commodities)
Scenario Ic (strategic cash commodities)
Combined (a combination of all three scenarios)
In 1995 N22.00 = US$1.00

Table 6.5: Change in industry production ($<X$ - X) to meet new water conservation measure and income generated in each scenario
(Using industry total requirements, $<X = [(I - DB)^{-1}] <Y$)

Industry	Change in industry production			Change in income (Naira)‡		
	2a	2b	2c	2a	2b	2c
1. Rainfed agriculture *	0.00000	977.0447	0.00000	0.00	8914.28	0.00
2. Irrigated agriculture *	0.00000	-1198.0018	0.00000	0.00	-9067.55	0.00
3. Cassava (annuals) *	0.00000	0.0000	0.00000	0.00	0.00	0.00
4. Animal husbandry [1]	0.00000	-118.9886	0.00000	0.00	-24705.50	0.00
5. Brick making [1]	0.00000	0.0000	0.00000	0.00	-0.00	0.00
6. Building Construction [1]	0.00000	0.0000	0.00000	0.00	-0.00	0.00
7. Pottery [1]	0.00000	-4.6082	0.00000	0.00	-230.40	0.00
8. Black smithing [1]	0.00000	-0.1010	0.00000	0.00	-3.53	0.00
9. Wood carving [1]	0.00000	-0.0006	0.00000	0.00	-0.04	0.00
10. Calabash carving [1]	0.00000	-0.2040	0.00000	0.00	-2.04	0.00
11. Weaving [1]	0.00000	0.0047	0.00000	0.00	0.66	0.00
12. Milling *	0.00000	-476.3837	0.00000	0.00	-347.08	0.00
13. Butchery *	0.00000	0.0000	0.00000	0.00	0.00	0.00
14. Catering/Trading * [1]	0.00000	0.0000	0.00000	0.00	0.00	0.00
15. Fishing *	0.00000	0.0000	0.00000	0.00	-0.00	0.00
16. Hunting *	0.00000	0.0000	0.00000	0.00	0.00	0.00
17. Water vending [2]	0.00000	0.0000	0.00000	0.00	0.00	0.00
18. Vegetation harvesting *	0.00000	-397.9098	0.00000	0.00	-279.59	0.00
19. Technical & Mech. repairs [1]	0.00000	0.0000	0.00000	0.00	0.00	0.00
20. Carpentry [1]	0.00000	0.0000	0.00000	0.00	0.00	0.00
21. Transportation [1]	0.00000	0.0000	0.00000	0.00	0.00	0.00
22. Tailoring & design [1]	0.00000	0.0000	0.00000	0.00	0.00	0.00
23. Hairdressing/Barbing [1]	0.00000	0.0000	0.00000	0.00	0.00	0.00
24. Education [1]	0.00000	0.0000	0.00000	0.00	0.00	0.00
25. Other services [1]	0.00000	-2.0435	0.00000	0.00	-2.21	0.00
26. Labor [3]	0.00000	-23.5677	0.00000	0.00	-471.34	0.00
Total	**N/A**	**N/A**	**N/A**	**0.00**	**-26194.34**	**0.00**

Notes:

* Output measured in kilograms (kg)
[1] Items are counted in absolute numbers (#)
[2] Liquids are in litres (lt)
[3] Human paid labour in man hours
‡ In 1995 the naira was pegged at N22.00 to US$1.0

Scenario 2a (water application efficiency)
Scenario 2b (transfer of irrigated rice & wheat to rainfed)
Scenario 2c (shifting/rescheduling of rural industry activities)
Positive (+) values indicate increase
Negative (-) values indicate decrease

Table 6.6: Change in ecological commodity input (<G* - G*) to meet new final demand in each scenario
(Using total input requirements, $<G^* = [G\,(I-DB)^{-1}]<Y$*)*

Industry	Change in groundwater input (liters)			Change in land input (m²)			Change in vegetation input (kg)		
	2a	2b	2c	2a	2b	2c	2a	2b	2c
1. Rainfed agriculture	0.00000	403.76507	0.00000	0.00000	14328.91695	0.00000	0.00000	46.28639	0.00000
2. Irrigated agriculture	-248611.92623	-52872.65932	0.00000	0.00000	-11642.11414	0.00000	0.00000	-933.84000	0.00000
3. Cassava (annuals)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4. Animal husbandry	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5. Brick making	0.00000	0.00000	-576023.55755	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6. Building Constructors	0.00000	0.00000	-312151.68019	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
7. Pottery	0.00000	0.00000	-1943.56725	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8. Black smithing	0.00000	0.00000	-631.97946	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9. Wood carving	0.00000	0.00000	-3201.76269	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
10. Calabash carving	0.00000	0.00000	-251.13526	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
11. Weaving	0.00000	0.00000	-7884.30988	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12. Milling	0.00000	0.00000	-31854.31112	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
13. Butchery	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
14. Catering/Trading	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
15. Fishing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
16. Hunting	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
17. Water vendors	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
18. Vegetation harvesting	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19. Technical & Mech. repairs	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
20. Carpentry	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
21. Transportation	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
22. Tailoring & design	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23. Hairdressing/Barbing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24. Education	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
25. Other services	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
26. Labor	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Total	**-248611.92623**	**-52468.89424**	**-933942.30340**	**0.00000**	**2686.80281**	**0.00000**	**0.00000**	**-887.55361**	**0.00000**

Note:

Scenario 2a (water application efficiency)
Scenario 2b (transfer of irrigated rice & wheat to rainfed)
Scenario 2c (shifting/rescheduling of rural industry activities)

Positive (+) values indicate increase
Negative (-) values indicate decrease

Table 6.7: Change in ecological commodity output ($<F^{*} - F^{*}$) to meet new final demand in each scenario
(Using total output requirements, $<F^{*} = [F\,(I-DB)-1]<Y$)

Industry	Change in waste water production (liters)			Change in solid waste production (kg)		
	2a	2b	2c	2a	2b	2c
1. Rainfed agriculture	0.00000	1.12607	0.00000	0.00000	23.87736	0.00000
2. Irrigated agriculture	0.00000	-5.72628	0.00000	0.00000	-90.71560	0.00000
3. Cassava (annuals)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4. Animal husbandry	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5. Brick making	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6. Building Constructors	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
7. Pottery	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8. Black smithing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9. Wood carving	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
10. Calabash carving	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
11. Weaving	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12. Milling	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
13. Butchery	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
14. Catering/Trading	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
15. Fishing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
16. Hunting	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
17. Water vendors	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
18. Vegetation harvesting	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
19. Technical & Mech. repairs	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
20. Carpentry	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
21. Transportation	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
22. Tailoring & design	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
23. Hairdressing/Barbing	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24. Education	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
25. Other services	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
26. Labor	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Total	**0.00000**	**-4.60021**	**0.00000**	**0.00000**	**-66.83823**	**0.00000**

Note:		
	Scenario 2a (water application efficiency)	Positive (+) values indicate increase
	Scenario 2b (transfer of irrigated rice & wheat to rainfed)	Negative (-) values indicate decrease
	Scenario 2c (shifting rescheduling of rural industry activities)	

Table 6.8: Summary of groundwater conservation with ecological commodity use and production intensities

Scenario	Total decrease in Gwater input (Liters)	Total Gwater (% saving)	Gwater intensity (Liters / Naira)	Land intensity (m^2 / Naira)	Vegtn intensity (kg / Naira)	Wwater intensity (Liters / Naira)	Swaste intensity (kg / Naira)
2a	248611.9	2.12	0.00000	0.00000	0.00000	0.00000	0.00000
2b	52468.9	0.45	2.00306	-0.10257	0.03388	0.00018	0.00255
2c	933942.3	7.95	0.00000	0.00000	0.00000	0.00000	0.00000
Combined	1229735.9	10.47	0.66769	-0.03419	0.01129	0.00006	0.00085

Note: Scenario 2a (water application efficiency)
Scenario 2b (transfer of irrigated rice & wheat to rainfed)
Scenario 2c (shifting/rescheduling of rural industry activities)
Combined (a combination of all three scenarios)
In 1995 N22.00 = US$1.00

CHAPTER SEVEN

Summary and Conclusion

7.1 Introduction

The purpose of this study was to investigate the nature of water use in Katarko, a drought-inflicted village in the semi-arid zone of northern Nigeria. Economic development in this area is constrained due to the occurrence of intermittent droughts, desertification and water scarcity. The aim of this research therefore, was to develop an analytical framework for assessing alternative economic development scenarios in the village and to advance policy measures for a sustainable economy without endangering the environment. Chapter 1 of this thesis is an introduction which identified the problem of study, outlined the aims and objectives, and discussed the conceptual framework. Chapter 2 set the problem in context of sustainable agriculture and economic development, identified broad strategies toward solving it, and indicated the need for an analytical approach.

This study took up this task using the case study village of Katarko. Base data on water use and commodity production were generated in Chapter 3. An analytical model, a commodity-by-industry economic-ecological model (CIEEM) was developed in Chapter 4. It is an environmental extension of the input-output (I-O) model and useful for determining direct and total (direct and indirect) input requirements. Because it does not include human responses, an indigenous knowledge systems and technology (local initiatives) investigation was done in Chapter 5. To facilitate a comprehensive assessment of alternative economic development policies in the village, data generated in Chapter 3, the model developed in Chapter 4, and information deduced from Chapter 5 and other relevant literature were used to develop two sets of policy scenarios. The established scenarios were simulated using the model to determine the impacts associated with each development approach. The findings are expected to be applicable not only to the village but to the rest of the region. The major findings of the study are summarized in the next section.

7.2 Major Findings

The major concern in this study was that of water scarcity. Aridity, droughts, land desiccation, water stress, and inaccessibility to water are the environmental (climatic) and economic (human) but interrelated conditions responsible for water scarcity in the region. These have contributed to unsustainable agricultural development and environmental degradation in the area. Therefore, there is relative decline in per capita food production, continued poverty and food insecurity within the economy. There are also endemic environmental problems such as deforestation, overgrazing, soil erosion, ecological degradation, and threats of desertification. The study identified steps toward ameliorating the problem one of which was conducting micro-scale interdisciplinary researches such as the one undertaken and reported here.

Results from the field research reported in Chapter 3 indicate that groundwater is a critical resource for the rural villages in the semi-arid zone of northern Nigeria, as in the rest of the region. Irrigated cultivation of vegetables and grains on a small proportion of the agricultural land accounted for more than half of all groundwater consumed in Katarko Village. It is practised by a relatively small proportion of households and generates relatively little income in aggregate, although a significant contribution to the income of the households involved. Animals also consume a significant amount of groundwater, but often benefit from other sources of water while pasturing at locations outside the village area. These results deal only with the *direct* water requirements of the various commodities produced in the village. To facilitate the estimation of the total (direct and *indirect)* water requirements or impacts associated with a change in production in any one activity, a better estimation procedure was needed. Hence an input-output modeling framework was developed in Chapter 4.

A commodity-by-industry economic-ecological model (CIEEM) was used to establish the technical coefficients of the interindustry transactions of economic and ecological commodity inputs and outputs. Direct, total and indirect effects of commodity production were discussed. The village economy exhibited sparse sectoral interdependence within the economy but a heavy dependence on ecological commodities, particularly water, a scarce ecological commodity in this semi-arid environment. The major users of water (liters per unit output) based on the direct effects include animal husbandry, building and irrigated agriculture; and based on total effects are catering, building and animal husbandry, in descending order. The ability to estimate impacts associated with these effects and changes in water use will contribute to the development of better water management strategies for the area. However, a more sustainable strategy will require an understanding of local initiatives for mitigating the problem of water scarcity.

Consequently, some technologies for water management used by the villagers were investigated and reported in Chapter 5. Observations show that activities requiring larger quantities of water are concentrated during the dry season, even though local technologies for water procurement, delivery and processing are unsophisticated. The villagers tend to depend on introduced forms of technology such as water pumping machines and storage tanks. Although these are useful in facilitating water supply, they have proved unsustainable due to purchase and maintenance costs, and do not necessarily conserve water. Other issues are the inadequacy in annual scheduling of activities in relation to timing of water availability and absence of specialized skills for rainwater harvesting and farming to take advantage of "excess" water during the rainy season.

However, there are locally fabricated tools and facilities, based on indigenous initiatives, used for water procurement, delivery and processing. Although these facilities (tools) are manually operated and labour intensive, they require less capital investment, conserve water, and perhaps sustainable. The villagers' willingness to accept new innovation and/or technologies and their effort in wastewater reuse are indications of indigenous knowledge systems geared toward reducing the impact of water scarcity. Despite these efforts, the water scarcity problems have been persistent. Concerted calls for assistance by the people also indicate the need for alternative approaches to water conservation in the area. Hence, the strategy of adopting "appropriate technologies" for water use is suggested.

Prominent among these are rainwater harvesting and farming, utilization of water ponds, construction of groundwater dams, rescheduling of activities to take advantage of water availability, and communal participation in terms of work, planning and implementation of projects. These will require education, empowerment and encouragement of the people to enable them exploit further their own technologies and knowledge systems. Ideas generated from this study were also used to develop policy scenarios for water use efficiency. The established scenarios were simulated using the commodity-by-industry economic-ecological model (CIEEM) in Chapter 6.

The two sets of policy scenarios used in the simulation model were: (i) increase in production of goods aimed at improving the economy of Katarko Village and (ii) water use efficiency to conserve groundwater and the environment. Results from our first set of policy scenarios show that increasing the production of a number strategic cash commodities, those that earn farmers more income (scenario 1c) will be worthwhile because they actually generate more income per head but require more groundwater. But the production of national cash crops (scenario 1b) is perhaps a better option because it requires less water in the process, although less income is generated. However, the ecological commodity-income ratios further clarified the controversy in which the groundwater-income ratio shows that scenario (1c) requires more water per naira and therefore, the least preferable option. The second set of our policy scenarios indicate the possibility of conserving large quantities of groundwater through better water application methods and better choice of irrigated crops as well as transfer of irrigated rice and wheat to rainfed agriculture. More groundwater will be conserved if activities are rescheduled to take advantage of rainwater harvesting. A combination of all strategies will conserve even larger quantities of groundwater.

Achieving this dual advantage, increasing production and at the same time reducing the use of or impacts on environmental commodities (especially water), involves some tradeoffs. Either irrigation farmers, who are usually the land owners, sacrifice the cash flow and conserve the water for the benefit of the rest of the community or insist on making money to the detriment of the rest of the community and the environment. Conflicts may also emanate from the strategies suggested in this study, but with education and a better approach that involves the participation of the people, some amount of success can be achieved. These issues are only identified and outlined here, determining the credibility of these tradeoffs is however, not within the scope of this research.

7.3 Directions for future research

The results of this study summarized in the preceding section contribute a great deal of knowledge on the nature of the problem, actual and potential, of water scarcity and water use in this drought-prone village. The associated impact on the economy and environment as well as strategies geared toward a sustainable economy and environmental rehabilitation were identified and discussed. The model employed in this study produced results and a more comprehensive measure of economic and environmental policy impacts than would be possible otherwise.

Having estimated the possible economic and environmental effects in this village, it will be interesting to introduce time-series data to investigate the possible impacts over time using a dynamic approach. A dynamic input-output (DIO) model facilitates the description of the relationships and impacts over time (say from now to the year 2000 and beyond). This association can also be investigated over space using either an interregional input-output (IRIO) model (for example between Katarko and the rest of the region) or a multiregional input-output (MRIO) model (say among the different districts or village areas within the region including Katarko). The problem with these approaches will be data requirements. For information on the structure of these possibilities, see for example, Isard (1951); Leontief et al (1953); Richardson (1972); Polenske (1980); Hewings (1985); Miller and Blair (1985); Johnson (1986).

It will perhaps be more interesting and rewarding to investigate further the tradeoffs inherent in the implementation of policy options identified in this study. Even though the input-output-type model employed here is useful for describing the type of relationship and the impacts of proposed development policies, economic and environmental, it does not incorporate criteria for decision making such as project selection or rejection (Lonergan and Cocklin, 1985). Such an investigation will require the use of other tools, for example (social) cost-benefit analysis ([S]CBA), the formal procedure for comparing the costs and benefits or assessing the consequences of alternative public policies (Peskin and Seskin, 1975; Haveman and Weisbrod, 1975; van Kooten, 1993; Munashinge, 1993; Lutz and Munashinge, 1994; Schulze, 1994). The social accounting matrix (SAM) in which socio-cultural and political factors (for example, van Kooten, 1993) not considered in this study are included can also be used. However, the use of these analytical techniques at this stage of the study will obscure the inherent environmental implications illuminated by the CIEEM used.

Other areas worthy of further study include labour availability and annual rescheduling of activities. The study suggested rescheduling of activities to take advantage of the "abundant water" during and immediately after the short rainy season. However, more labour input will be required to make the changes. Although communal effort based on field observations and interviews discussed in Dabi (1998) have been suggested, it will be interesting to investigate further how such an arrangement can be made and how much success will be achieved.

References

Dabi D.D. (1998) Indigenous knowledge systems, technology transfer and rural water use in northern Nigeria. Submitted to *Economic Development and Cultural Change*.

Haveman and Weisbrod, (1975) The concept of benefits in cost-benefit analysis: with emphasis on water pollution control activities. In Peskin, H. M. and Seskin, E.P. (Eds.) *Cost-benefit Analysis and Water Pollution Policy*. The Urban Institute, Washington, D.C. 37-66.

Hewings, G.J.D. (1985) *Regional Input-output Analysis*. SAGE Publications, Beverly Hills. 96pp.

Isard, W. 1951. Interregional and Regional Input - Output Analysis: A Model of a Space Economy. *Review of Economics and Statistics* 33

Johnson, T.G. (1986) A dynamic input-output model for small regions. *Review of Regional Studies* 16(1): 14-23

van Kooten, G.C. (1993) "Input-output models for regional and community development." In van Kooten, G.C. (1993) *Land Resource Economics and Sustainable Development: Economic Policies and the Common Good.* UBC Press, Vancouver. Chapter 8, 164-187.

Leontief W., Chenery, H.B., Clark, P.G., Duesenberry, J.S., Ferguson, A.R., Groose, A.P., Groose, R.N., Holzman, M., Isard, W., and Kistin, H. (1953) *Studies in the Structure of the American Economy: Theoretical and Empirical Explorations in Input-Output Analysis*. Oxford University Press, New York.

Lonergan SC, Cocklin C (1985) The use of input-output analysis in environmental planning. *Journal of Environmental Management* 20: 129-147

Lutz, E. and Munasinghe, M. (1994) "Integrating environmental concerns into economic analysis of projects and policies in an operational context." *Ecological Economics* **10**, 37-46. The World Bank, Washington, D.C.

Miller R E, Blair PD (1985) *Input-output Analysis: Foundations and Extensions.* Prentice-Hall, Inc., Englewood Cliffs, New Jersey

Munasinghe, M. (1993) "Environmental Economics and sustainable development." *World Bank Environment Paper* **3**, 1-20.

Peskin and Seskin (1975) Introduction and overview. In Peskin, H. M. and Seskin, E.P (Eds.) *Cost-benefit Analysis and Water Pollution Policy.* The Urban Institute, Washington, D.C. 1-33.

Polenske, K. 1980. *The U.S. Multiregional Input-Output Accounts and Model*, Lexington, Mass.: Lexington Books.

Richardson, H. W. (1972) *Input-Output and Regional Economics.* A Halsted Press Book. John Wiley and Sons, New York.

Schulze, P.C. (1994) "Cost-benefit analyses and environmental policy." *Ecological Economics* **9**, 197-199.

Appendix 1A:

Background information on the Input-Output modelling framework

1A.1 Input-output analysis

Input-Output Analysis (also referred to as Interindustry analysis) is essentially a method of analysis that takes advantage of the relatively stable pattern of the flow of goods and services among the elements of our economy to bring a much more detailed statistical picture of the system. It defines the model of the economic system by classifying and aggregating the facts concerned with real situations. Input-Output analysis therefore, is a method of systematically quantifying the mutual interrelationships among the various sectors of a complex economic system (Leontief, 1986).

In other words, the Input-output analysis, is an accounting system that considers the interactions between the different sectors (groups of firms or industries producing similar goods or output) of the economy of a given region at a particular time. The flow of goods and services within and between those sectors is used to model their interdependence. The goods and/or services produced (output) from one sector are either used within that sector, transferred to other sectors as inputs for their own production or sold to final consumers. Similarly, other sectors may use some of their products (goods and/or services) as input for further production and transfer (sell) some as output to the other sectors as inputs for production (Technical details are provided in Appendix 1B).

1A.2 Definition of terms

1A.2.1 Economic area

An economic area is that for which an Input-Output model is constructed from observed data in a nation, region, state, etc. It is also considered to be an economic system and may be as large as a nation or even the entire world economy, or as small as the economy of a metropolitan area or even a single enterprise .The economic activity in the area must be divided into a number of sectors (Miller and Blair, 1985; Leontief, 1986).

1A.2.2 Sectors and commodities

Sectors are groups of firms or industries that produce goods and/ or services in an economic system (area). These are usually primary products of the said industries, either for the production of other goods or for final consumption. Sectors are classified according to primary (characteristic) products. The necessary data are the flow of products from each of the sectors (as a producer) to each of the sectors (as a purchaser). Commodities are the individual items produced either as primary or secondary goods or services for consumption (final demand) or to be used for the production of other goods or services (intermediate demand).

Commodities are the individual items produced (as primary or secondary goods or services) by a sector. Examples of commodities are, from the economic sectors: grains, vegetables, meat, calabashes, hoes, fried potatoes, barbing/hair plating, class or home lessons, health care services, etc.; and from the ecological subsystem include certain quantities of water, pieces of land, soil nutrients, vegetative cover, firewood, etc.

1A.3 Assumptions

(i) The fundamental assumption of the input-output analysis is that the intersectoral flows from sector i to sector j over a given period of time, depend entirely and exclusively on the total output from sector j for that same period. In other words, there is a fundamental relationship between the volume of the output of a sector (industry) and the size of inputs going into it. That is the flow of products from each of the sectors (as a producer) to each of the sectors (as a purchaser) for their own production. This implies constant returns to scale (Miller and Blair, 1985).

(ii) The input-output sector consists of plants producing a single homogeneous product with similar techniques. This means that there is no substitution in the production system. This involves lumping together many separate activities into one sector. The prevalence of multi-product plants makes it impossible to group together only those plants with similar output and input structures. However, the practical solution is to group processes and products which differ in some respects but which behave sufficiently uniformly to be used as a basis for aggregation (Richardson, 1972).

(iii) Input-output analysis requires that a sector use inputs in fixed proportions. This specification of a fixed (linear) production function also means constant returns to scale.

Thus, any proportional growth in all inputs will produce an equally proportional increase in output. Similarly, any proportional decrease in production input will result in an equally proportional decrease in production output. However, the addition of only one input is useless from the point of view increasing the output. Only when all inputs are increased proportionately can the output increase (Miller and Blair, 1985).

(iv) The model also assumes that the amount of each product which each sector consumes depends only on the output of the consuming sector. And that an equilibrium in the economy is attained when output of each sector equals total purchases from that sector, these purchases being determined by the outputs of all other sectors. Everything is governed by the dictates of productive necessity where each output requires only its inputs (Richardson, 1972)

(v) There are no constraints on resource availability. It is assumed that supply is infinite and perfectly elastic. Also, local resources are believed to be efficiently employed and no underemployment of resources (Hastings and Brucker, 1993).

Input-output models have been criticized more on their assumptions of homogenous industries producing a single commodity using only one scarce primary factor. This led to the development of the Commodity-by-Industry Input-Output accounts which recognises that each industry may produce more than one commodity and that a commodity can be produced by more than one industry. Later, the Environmental input-output models were introduced to link the environment and the economic sectors. These are of relevance to this research and are discussed in the subsequent sections.

1A.4 Commodity-by-industry input-output accounts

According to Miller and Blair (1985), the Commodity-By-Industry Input-Output Accounts is an alternative approach to the Input-output accounts which more accurately takes into account secondary production. Data is collected according to two distinctive classification schemes, namely: industry accounts of primary production, and commodity accounts of either primary or secondary goods or services. Accounting for secondary production is the only difference between industry and commodity accounts (that is, if no secondary production exists, the industry and commodity accounts will be identical). The commodity-by-industry input-output account is made up of two sub-matrices, the make matrix and the use matrix.

Make Matrix: This is a flow matrix, the rows of which describe the commodities produced (outputs) by industries in an economy and the columns describe the industry sources of commodity production. However, this matrix does not provide the complete picture of the interindustry activity, because value added, destination of commodity deliveries from an industry, and final demand are not recorded (see Table 1A.1).

Use Matrix: This is also called the absorption matrix and records the commodity inputs to an industrial production process in order to complete the picture presented by the make matrix. It therefore, presents the destinations of commodities delivered into industries and final demand (see Table 1A.1).

(Table 1A.1 about here)

1A.5 Environmental input-output analysis

The input-output model has been extended (or modified) to facilitate the measurement of environmental (or ecological) quantities, either in monetary or physical units. However, the major problem of this extension has been the appropriate unit of measurement (Miller and Blair, 1985).

There are three basic categories of environmental extensions of the input-output model as follows: (i) Generalized Input-Output or pollution generation-elimination models, (ii) Economic-Ecological models, and (iii) Environmental Commodity-by-industry model.

1A.5.1 Pollution generation-elimination models

The traditional input-output model was first extended by Cumberland (1966) for the analysis of environmental problems. The interindustry model simply extended the rows and columns of the traditional input-output accounting framework to encompass environmental costs and benefits effects of production sectors. This model has been criticized for its ambitious attempt to place monetary values on environmental effects rather than measuring them in purely physical terms. Such extensions form the group of pollution generation-elimination models. Although interesting in their formulation they do not present a suitable framework for this study.

1A.5.2 Economic-ecological models

Daly (1968), incorporated environmental activities into an input-output framework using flow matrices within and between economic (human) activities and environmental (non-human) processes. He employed a highly aggregated industry-by-industry characterization of the economic submatrix and a classification of ecosystem processes, including life processes such as plants, animals and bacteria, and non-life processes of the atmosphere, hydrosphere and the lithosphere. The work is basically theoretical, an attempt to link biology and economics and suggested a "general equilibrium" model which considered the human economy from an ecological perspective.

Isard et al. (1968) had a similar approach to the work of Daly, but instead of an industry-by-industry characterization, adopted the commodity-by-industry accounting scheme which allows accounting for multiple commodities, economic and ecological, produced by a single industry (that is recognising secondary production). Although they attempted an empirical application of the model by estimating the technical coefficients directly from technical data, the model was not fully implemented, most likely, due to complexity of the ecosystem submatrix and data availability (Isard et al, 1971; Richardson, 1972; Victor, 1972; Miller and Blair, 1985; Huang et al., 1994).

Ecological Commodities: Ecological commodities are distinguished into two categories namely: (i) inputs to an industry production process, for example water; and (ii) outputs generated by a production process, for example pollution. These may be viewed as flows out of and into the ecosystem in which the interindustry economic system exists, that is the ecological input and output commodities. Ecological commodities can also be classified according to their sources of extraction and the sinks to which they are eventually discarded and may be restricted to nonmarket materials such as water, land, air, etc. (Johnson and Bennett, 1981; Miller and Blair, 1985).

Ecological commodities are nonmarketable quantities that are either inputs used or outputs discharged from a production process. The notion of commodity-by-industry accounts can be extended to accommodate environmental activities in terms of these ecological commodities. This can be achieved in two ways, (i) by appending the environmental intensity rows to the technical coefficients; and (ii) by creating an "ecosystem submatrix" that is linked to interindustry economic flows that account for environmental (or ecosystem) flows. Such a model is often called a "fully integrated model." (see Table 1A.2).

1A.5.3 Environmental commodity-by-industry models

Victor (1972), limited the scope of Isard's fully integrated economic-ecological model to account only for flows of ecological commodities from the environment into the economy and of the waste products from the economy into the environment. The model is referred to as the "Limited Commodity-By-Industry Economic-Ecological Model." It limited the scope of analysis by reducing the number of variables considered, the data required are generally available, and therefore, the model can be implemented with little difficulty. The model is a conventional commodity-by-industry table augmented with additional rows of ecological inputs and columns of ecological outputs. The model has two submatrices, the "Economic subsystem" and "Ecological subsystem." (see Table 1A.3).

Table 1A.1 Summary of commodity and industry accounts

	Commodities		Industries		Final Demand	Total Output
	A	B	A	B		
Commodities A B			U		E	Q
Industries A B	V					X
Value Added			W		GNP	
Total Output	Q'		X'			

Source: Miller and Blair (1985), p161

Table 1A.2 Basic structure of the economic-ecologic Model

	Industries	Ecologic Process
Industries	Flows between Economic sectors	Flows from Industry to the Ecosystem
Ecologic Process	Flows from the Ecosystem to Industry	Flows within the Ecosystem

Source: Miller and Blair (1985), p252.

Table 1A.3 The limited commodity-by-industry economic-ecological model

	Economic Subsystem				Ecosystem
	Commodities	Industries	Final Demand	Total Output	Ecologic Commodities
Commodities		U	E	Q	R
Industries	V			X	S
Value Added		W	GNP		
Total Output	Q'	X'			
Ecologic Commodities	P	T			

Source: Miller and Blair (1985), p253

Table Notations

The Economic subsystem:

U = $[u_{ij}]$ is the "use" matrix; u_{ij} represents the amount of economic commodity i used by industry j. For n industries and m commodities, U is m x n.

V = $[v_{ij}]$ is the "make" matrix; v_{ij} represents the amount of economic commodity i produced by industry j. V is n x m.

E = $[E_i]$ is the vector of economic commodity final demands; E_i is final demand for commodity i; E is m x 1.

Q = $[Q_i]$ is the vector of economic commodity gross outputs; Q_i is the total production of commodity i; Q is m x 1.

W = $[W_j]$ is the vector of industry value-added inputs; w_j represents the total of value-added inputs to industry j; W is 1 x n.

X = $[X_j]$ is the vector of industry total outputs; X_j represents the total output of industry j; X is n x 1.

The Ecological subsystem:

R = $[r_{ik}]$ is the matrix of economic commodity by ecological commodity outputs; r_{ik} is the amount of ecological commodity k discharged as a result of economic commodity i; for l ecological commodities; R is m x e.

S = $[s_{jk}]$ is the matrix of industry by ecological commodity outputs; s_{jk} is the amount of ecological commodity k discharged by industry j; s is n x e.

P = $[p_{ki}]$ is the matrix of ecological commodity by economic commodity inputs; p_{ki} is the amount of ecological commodity k used in the production of economic commodity i; P is e x m.

T = $[t_{kj}]$ is the matrix of ecological commodity by industry inputs; t_{kj} is the amount of ecological commodity k used by industry j; T is e x n.

Appendix 1B:

Model Description And Mathematical Notations

1B.1 The Input-output equations

The Input-output transactions can be represented by the following equation:

$$X_i = \sum_{j}^{n} z_{ij} + (C_i + I_i + G_i + E_i) \qquad (1B.1)$$

where X_i is the total output from sector i, z_{ij} is intermediate demand from sector i to sector j, C is household consumption, I is investments, and G is government purchases, as domestic final demand; and E is exports, as foreign final demand. Again, there may be additional rows at the bottom of the table to show the primary inputs (labour, capital, etc.) which are termed value added (to include wages, profit, rent, interest, and taxes) and imports. This may be represented as:

$$X_j = \sum_{i}^{n} z_{ij} + (L_j + V_j + M_j) \qquad (1B.2)$$

where X_j is total outlays, z_{ij} is intermediate demand from sector i to j, L is labour consumed in household, V_j is value added, and M_j is imports. If the total gross output is derived by summing across (row totals) or down (column totals) represented by a single vector, Y, then the equations can be summarized as follow:

$$X_i = \sum_{i=1}^{n} z_{ij} + Y_i \qquad \textit{for } i, j = 1,2,\ldots n \qquad (1B.3)$$

Where X_i is the total output, z_{ij} is the Intermediate demand (sales) from sector i to j, and Y_i is the Final demand. This interdependence among the sectors of the given economy is described by a set of linear equations expressing the balances between the total input and the aggregate output from each good and service produced and used within a specified period of time. The technical structure of the entire system is represented by a matrix of technical input-output coefficients of all the sectors.

1B.1.1 Technical coefficients

The technical coefficient which is also referred to as the input coefficient is the ratio of the flow of input from sector i to sector j, and the total (gross) output of sector j. That is the output of sector i absorbed by sector j per unit of its total output. This is represented by the equation:

$$a_{ij} = z_{ij} / X_j \qquad (1B.4)$$

Where a_{ij} is the technical coefficient, z_{ij} is the flow of input from i to j, and X_j is the total (gross) output of j. It follows from normal algebra that equation (1B.4) is the same as:

$$z_{ij} = a_{ij} X_j \qquad (1B.5)$$

1B.1.2 Structural matrix

Structural matrix is the complete set of technical coefficients of all sectors of a given economy arranged in the form of a square table (matrix) corresponding to the flow of goods and services for the same economy. It is normally computed from the input-output table described in value terms.

1B.2 The simple input-output model

If the assumptions of the input-output are taken into consideration and the interdependence between sectors as represented in equation (1B.3) and the technical coefficients as in equation (1B.5) are substituted into it, the input-output account can be transformed into an analytical model by considering all rows simultaneously. This gives a set of linear equations corresponding to the number of rows contained in the table. For example, the first row will look like this:

$$X_i = a_{i1} X_1 + a_{i2} X_2 + \ldots + a_{in} X_n + Y_i \qquad (1B.6)$$

Also using the algebraic notation, equation (1B.6) can be represented in the form:

$$X = AX + Y \qquad (1B.7)$$

Where X is an n x 1 vector of outputs X_i, AX is the intermediate demand, A is an n x n matrix of direct input coefficients, a_{ij}., and Y is column vector (n x 1) of the final demand. For calculation purposes, the matrix notation takes a "hat" to produce a diagonal matrix from a vector in the form:

$$\hat{\mathbf{X}} = \begin{matrix} X_1 & 0 & 0 \ldots \\ 0 & X_2 & 0 \ldots \\ 0 & 0 & X_3 \ldots \end{matrix}$$

then the equation can be represented as follows:

$$A = Z\,(\hat{\mathbf{X}})^{-1} \qquad (1B.8)$$

Where A is the n x n matrix , Z is the an n x n matrix of inputs, and $(\hat{\mathbf{X}})^{-1}$ is the inverse of the diagonal matrix.

However, if we wish to determine the final demand from that sector of the economy, it means finding the value of Y by simply bringing all X terms to the right as follows:

$$X - AX = Y \qquad (1B.9)$$

This equation can be rewritten in the form :

$$(I - A)X = Y \tag{1B.10}$$

This is similar to the form AX = B denoted to a set of linear equations. In Input-Output analysis, the notation (I-A) is used and it is termed the matrix of coefficients and I is the identity matrix.

1B.2.1 Leontief inverse

However, if we wish to determine the total output of the economy, X has to be made the subject of the equation which can be expressed thus:

$$X = (I - A)^{-1} Y \tag{1B.11}$$

Where $(I - A)^{-1}$ is the Leontief inverse and it similar to the inverse of a number. X is a function of Y, where Y is exogenous. If the elements of $(I-A)^{-1}$ are denoted by α_{ij}, then the equation (1B.11) will become a set of equations in the form, using the first row as example:

$$X_1 = \alpha_{11}Y_1 + \alpha_{12}Y_2 + \ldots + \alpha_{1n}Y_n \tag{1B.12}$$

Where X_1 is the output, α_{ij} are the entries of the inverse matrix (i = 1 and j = 1 to n) called interdependency coefficients and represent the direct and indirect requirements of sector i per unit of final demand for sector j, and Y_j are the units of final demand.

1B.3 The commodity-by-industry framework

The framework of the commodity-by-industry is similar to the basic accounting identity from the general input-output model, equation (1B.6). The industry output identity is:

$$X_i = v_{i1} + v_{i2} + \ldots + v_{im} \qquad (1B.13)$$

where X_i is the total output of industry i, v_{ij} is the values of commodities (j= 1,2,...,m) produced by that industry. While the commodity output identity is:

$$Q_i = u_{i1} + u_{i2} + \ldots + u_{in} + E_i \qquad (1B.14)$$

where Q_i is the vector (m x 1) of commodity gross output, u_{ij} the amount of commodity i consumed by industry j, and E_i is the vector (m x 1) of commodity deliveries to final demand. Similarly, (as in the input-output model), the sum of all commodity inputs to a production process, plus any value-added inputs, is equal to the value of the total output of that industry as:

$$X_j = u_{1j} + u_{2j} + \ldots + u_{mj} + W_j \qquad (1B.15)$$

where X_j is the vector (n x 1) of industry total output, u_{ij} is the commodity inputs, and W_j is value-added inputs.

1B.3.1 Technical coefficient

This is similar to that of the general input-output model equation (1B.4). In commodity-by-industry, the relationship is:

$$b_{ij} = u_{ij} / X_j \qquad (1B.16)$$

where b_{ij} is amount of commodity i required to produce a proportional output of industry j, u_{ij} and X_j as defined in equation (1B.15).

In matrix terms, this can be rewritten as in equation (1B.8), as follows:

$$B = U\,(\hat{X})^{-1} \qquad (1B.17)$$

Where B = $[b_{ij}]$ is the matrix (m x n) of economic commodity-by-industry direct requirements, [b_{ij} is the amount of economic commodity i required to produce a unit output of industry j]; U=$[u_{ij}]$ is the use matrix with the dimension m x n, [u_{ij} represents the amount of commodity i used by industry j]; X is a vector (n x 1) of industry output, $\hat{X}$ is a diagonal matrix (n x n) with elements of X as diagonal, and $(\hat{X})^{-1}$ is the inverse of the diagonal matrix (n x n).

1B.3.2 Total requirement matrix

The total requirement matrix which is the same as the Leontief Inverse, equation (1B.11), and the element of the matrix α_{ij}, equation (1B.12), define the output of industry i required both directly and indirectly to deliver a proportional amount of industry j's output to final demand. In commodity-by-industry model, several variations of total requirement matrices can be derived. But if one is interested in total commodity production of a region (regardless of the industry that produced the commodities), then a commodity-by commodity or a commodity-by-industry total requirements matrix will be desired. To determine this, we begin with a commodity balance equation, as in equation (1B.14). In matrix terms it can be rewritten as:

$$Q = Ui + E \tag{1B.18}$$

where Q is column vector (n x 1), U is the use matrix (m x n), i is commodity inputs and E is a vector (m x 1) of commodity deliveries to final demand. If equation (1B.17) is postmultiplied by $\hat{X}$, it becomes:

$$U = B\hat{X} \tag{1B.19}$$

substituting this expression into equation (1B.18), gives:

$$Q = B\hat{\mathbf{X}}_i + E \qquad (1B.20)$$

and since $\hat{\mathbf{X}}_i$ is equal to X

$$Q = BX + E \qquad (1B.21)$$

That is, total commodity output is equal to intermediate commodity production (commodity-by-industry direct requirements multiplied by total industry output) plus commodity deliveries to final demand. This equation is analogous to the basic identity in the traditional Leontief (input-output) model, equation (1B.7):

$$X = AX + Y$$

But if one is interested in total output of industries, regardless of what combination of commodities by those industries, the we need to define the make matrix as:

$$X_i = v_{i1} + v_{i2} + \ldots + v_{im} \qquad (1B.22)$$

where X_i is total industry output, v_{ij} are the elements (commodity entries) of the make matrix (n x m). The technical coefficients are derived by dividing the elements of the make matrix, v_{ij} by the total output of industry i as follows:

$$c_{ij} = v_{ij} / X_i \tag{1B.23}$$

where c_{ij} is the industry output proportion. The matrix formation is given by:

$$C = V' (\hat{X})^{-1} \tag{1B.24}$$

where C = $[c_{ij}]$ is the matrix (m x n) of industry direct output proportions [c_{ij} is the fraction of industry j's output that is distributed as commodity i]; V' is the transpose of industry by economic commodity outputs, V = $[v_{ij}]$ is the make matrix (n x m), v_{ij} represents the amount of commodity j produced by industry i; X, $\hat{X}$ and $(\hat{X})^{-1}$ are as defined in equation (1B.17).

Therefore the total production of commodities, regardless of the from which they are produced is derived as:

$$Q_j = v_{1j} + v_{2j} + \ldots + v_{nj} \tag{1B.25}$$

where Q_j is total production of commodities, v_{ij} are the elements (industry products) of the make matrix (m x n). The technical coefficients are derived by dividing the elements of the make matrix, v_{ij} by the total production of commodity j as follows:

$$d_{ij} = v_{ij} / Q_j \tag{1B.26}$$

where d_{ij} is the commodity output proportion whose matrix formation is given by:

$$D = V (\hat{Q})^{-1} \tag{1B.27}$$

where $D = [d_{ij}]$ is the matrix (n x m) of commodity output proportion; V is as defined in equation (1B.24); Q is a vector (m x 1) of commodity output, $\hat{Q}$ is a diagonal matrix (m x m) with elements of Q as diagonal, and $(\hat{Q})^{-1}$ is the inverse of the diagonal matrix (m x m). D is referred to as the is an industry-based-technology assumption which states that "the total output of a commodity is provided by industries in fixed proportions" (Miller and Blair, 1985, p165). Multiplying equation (1B.27) through by $\hat{Q}$, becomes

$$V = D \hat{Q} \tag{1B.28}$$

Since total industry output is the sum of all commodities produced by each industry $X = V_i$, substituting equation (1B.28) into (1B.27), the new form is:

$$X = D\,\hat{Q}_i = DQ \tag{1B.29}$$

Substituting the expression for this into equation (1B.21), the commodity balance accounting identity, the following is obtained:

$$Q = BDQ + E \tag{1B.30}$$

which by matrix algebra, is the same as:

$$Q = (I - BD)^{-1} E \tag{1B.31}$$

where Q is a column vector (n x 1) of commodity output (production); the matrix $(I - BD)^{-1}$ is the commodity-by-commodity total requirements matrix (m x m); I is the m x m identity matrix, $B=[b_{ij}]$ is the matrix (m x n) of economic commodity-by-industry direct requirements, [b_{ij} is the amount of economic commodity i required to produce a unit output of industry j]; $D=[d_{ij}]$ is commodity output proportions (n x m); and $E=[E_i]$ is a column vector (m x 1) of commodity deliveries to final demand. Combining equations (1B.26) and (1B.31) we can establish the industry balance accounting identity as:

$$X = [D(I - BD)^{-1}]\,E \tag{1B.32}$$

where X is a column vector (n x 1) of industry output, the matrix $[D(I - BD)^{-1}]$ is the industry-by-commodity total requirements matrix (n x m); I, B, D, and E are as described in equation (1B.31).

Alternatively, we can redefine the final demand of commodities, E, to that of industries irrespective of the commodities from the commodity output proportions matrix, D, to derive the following technical coefficient:

$$Y_i = d_{ij} E_j \qquad (1B.33)$$

which has its matrix formation as:

$$Y = DE \qquad (1B.34)$$

where the element $D=[d_{ij}]$ is the proportion of total production of commodity j produced by industry i; other elements are as defined earlier. Therefore, we can derive the industry balance accounting identity by solving equation (1B.32) and substituting the commodity final demands with the industry final demands, equation (1B.34) as follows:

$$X = D(I - DB)^{-1} E$$

$$X = (I - DB)^{-1} DE$$

$$X = [(I - DB)^{-1}] Y \qquad (1B.35)$$

where X is column vector (n x 1) of industry output; the matrix $[(I - DB)^{-1}]$ is the industry-by-industry total requirements matrix (n x n); I, B, and D are defined in equation (1B.31); Y is column vector (n x 1) of industry final demand.

1B.4 The ecological commodity input-output coefficients

The ecological commodity input-output coefficients can be defined in the same way the technical coefficients in the Leontief model, equation (1B.8) and the commodity-by-industry form equation (1B.17) as:

$$R = M\,(\hat{X})^{-1} \qquad (1B.36)$$

where $R = [r_{kj}]$ specify the amount of commodity k required for a proportional output of industry j. And the ecological commodity output coefficients as:

$$Q = N'(\hat{X})^{-1} \qquad (1B.37)$$

where $Q = [q_{kj}]$ specifies the amount of commodity k generated proportional to the output of industry j, and N' is the transpose of the matrix of ecological commodity output flows.

1B.4.1 Technical Coefficient

Following the same considerations as in the general input-output model equation (1B.4), and the commodity-by-industry model, equation (1B.16); when the accounting system is expanded to include the ecological commodities, the technical coefficient relationship is:

$$f_{kj} = s_{kj} / X_j \qquad (1B.38)$$

where f_{kj} is the amount of ecological commodity k discharged proportional to the output of industry j, s_{kj} is the amount of ecological commodity k discharged by industry j, and X_j is output of industry j. Thus, the matrix of ecological commodity output coefficients will be as follows:

$$F = S' (\hat{\mathbf{X}})^{-1} \qquad (1B.39)$$

where $F = [f_{kj}]$ is the matrix of ecological commodity output coefficients, S' is the transpose of S which is the matrix of industry by ecological commodity outputs, and $(\hat{\mathbf{X}})^{-1}$ as earlier defined in equation (1B.17) is the inverse of the diagonal matrix. F is e x n. The letter e represent the number of ecological commodities.

Similarly, the technical coefficient relationship for inputs is:

$$g_{kj} = t_{kj} / X_j \qquad (1B.40)$$

where t_{kj} is the amount of ecological commodity k used in the production of a proportional output of industry j, t_{kj} is the amount of ecological commodity k used by industry j, and X_j is output of industry j. And the matrix of ecological commodity input coefficients will be as follows:

$$G = T(\hat{X})^{-1} \qquad (1B.41)$$

where $G = [g_{kj}]$ is the matrix of ecological commodity input coefficients, T is the matrix of ecological commodity by industry inputs, and $(X)^{-1}$ is the inverse of the diagonal matrix. G is $e \times n$.

The ecological commodity input total requirements can also be derived using the inverse matrix (following the industry-by-industry total impacts) as follows:

$$G^* = [G(I-DB)^{-1}]\,Y \qquad (1B.42)$$

where G^* is the vector (e x 1) of total (direct and indirect) requirement matrix of economic commodity inputs for the production of economic output; G is the matrix (e x n) of ecological commodity input coefficients; $(I-DB)^{-1}$ is the industry-by-industry total requirements matrix, its elements are defined in equation (1B.31); and Y is industry final demand. Similarly, the ecological commodity outputs as:

$$F^* = [F(I-DB)^{-1}]\ Y \qquad (1B.43)$$

where F* is also a vector (e x 1) the of total (direct and indirect) requirement matrix of economic commodity outputs produced due to economic output; and F is the matrix (e x n) of ecological commodity output coefficients. The notations $(I-DB)^{-1}$, its elements, and Y are as defined above.

Most of the notations used in this appendix follow the descriptions provided by Miller and Blair (1985). However, variations that may be observed are intensional to conform with model formation and conditions for its application.