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TOWARD A FRAMEWORK FOR MONITORING LAND DEGRADATION IN RWANDA

By

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ABSTRACT

TOWARD A FRAMEWORK FOR MONITORING LAND DEGRADATION IN RWANDA

By

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The use of indicators for monitoring land degradation has been proposed and justified over the last 30 years. Although a number of indicators and ways of monitoring them have been proposed individually, there has been no real suggestion of a systematic way of integrating these indicators. Often only the physical signs of land degradation are investigated. In this study both biophysical and societal indicators will be used for analysis. Regression, Principal Components Analysis, and a Matrix method are evaluated for efficiency and validity in monitoring land degradation in Rwanda based on the integrated use of indicators. Data from the Michigan State University Rwanda Society-Environment Project was used in this study as an example of available real world data. The results of the three methods was compared to those of the original project to assess the validity of this study's findings. The Matrix method was found to be the most useful method for monitoring land degradation.

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CHAPTER I

INTRODUCTION

Rwanda is one of the most densely populated countries in Africa. It is also a country whose people depend mainly on agriculture. This combination of dense population and dependence on land-based resources would to many be indicative of a country experiencing increasing land degradation. Experience has shown, though, that population density alone is not always a good indicator of degradation. Many researchers feel that increasing density can cause increased innovation and adaptation.

Much of the previous research on land degradation has focused only on the physical signs of degradation in choosing attributes for monitoring, such as soil crusts and deforestation, but the environment should not be taken separately from the actions of people who inhabit the land. Politics, economy, culture, and the environment are all part of a dynamic system. To only look at one part of that system is to miss important information, and possibly, early detection of land degradation.

This thesis will explore the utility and validity of using indicators of land degradation, both human and physical, to assess the level of land degradation present in Rwanda. Human and physical processes are inherently linked and cannot be monitored separately. Thus far, there has been no successful integration of these human and physical indicators. Indicators here will be defined as, "A phenomenon or statistic so strictly associated with a particular environmental condition that its presence can be taken as indicative of the existence of that condition" (Mabutt 1986). A more recent and refined definition by the UNDP/UNSO describes desertification indicators "as complex attributes that enable the grouping together of several underlying land characteristics or phenomena" (in Wangati 1996, p. 4). They also suggest that indicators should be "quantifiable, measurable and verifiable wherever possible" (in Wangati 1996, p. 4). Most authors also suggest that land degradation need not necessarily be limited to soil degradation, but rather to water, fauna and flora, as all of these contribute to the ecosystem under observation and its capacity to sustain communities that are dependent on the area (Wangati 1996, Berry 1996).

This thesis will examine ways of monitoring land degradation, using data on socio-economic and physical conditions in Rwanda. A framework based a systematic integration of socio-economic and physical indicators will be developed and compared to other statistical methods for assessing land degradation, specifically regression and principal components analysis. The framework will also be compared to findings from the original project from which the data was taken to assess validity.

The data to be used for analysis come from the Michigan State University Rwanda Society-Environment Project[1]. This was a large scale collection of data relating to both human and environmental characteristics of Rwanda. The data set from this project will be used: 1) because it is a large and fairly complete set of data for an African country, and 2) it includes both human (income, population, agriculture) and physical (soil capability, elevation, rainfall) information. The data set itself is indicative of what many researchers or government organizations would be monitoring for many other purposes besides land degradation. The lessons learned from this study may be indicative for many African countries.

Regional political ecology will be used as a framework for investigation in selecting indicators. The objective of this thesis is to test the utility of using a systematic approach based on indicators to monitor land degradation and also to evaluate the available information as to its feasibility with different methods. Recommendations will be made concerning suitability of data for the integrated analysis and suggestions for an optimal set of data will also be offered.

[1]The Rwanda Society-Environment Project began in 1989 in the MSU Center for Advanced Study of International Development (CASID). The project was a collaborative effort including the Center for Advanced Study of International Development, the MSU Department of Geography, the Government of Rwanda: Ministries of Environment and Tourism, Agriculture, and Department of Statistics, as well as, the National University of Rwanda Department of Geography and the United Nations Environment Programme (UNEP-GRID). Research in country continued until 1994.

Review of Literature

In this chapter a review of recent literature concerning topics relevant to monitoring of land degradation in tropical nations dependent on agriculture is presented. The first section introduces literature concerning interactions between humans and the environment. The review of human-environment interaction literature is broken down into 1) previous research in human geography and, 2) an examination of work concerning political economy and political ecology as a theoretical basis for research concerning land degradation. The third section is a review of research on population pressure and its effects on the environment. The fourth section focuses on the use of indicators for monitoring environmental degradation.

Human-Environment Interaction

The literature on human-environment interaction relevant to this study can be subdivided into two major areas of research. The first of these divisions is the area of research concerning human geography. The realm of human geography research initially evolved from the idea of environmental determinism. Environmental determinism purposes that human behavior is "determined" by nature and one's actions are thus decided not by individuals themselves, but by the environmental conditions of the area which they inhabit. This school of thought first appeared in the nineteenth century in geography in America and continued to be a recurring theme through the middle of the twentieth century (Palm 1990). The most important writers within this paradigm were Ellsworth Huntington with his work Climate and Civilization (1922) and Ellen Semple's American History and It's Geographic Conditions (1903). Huntington argued that civilizations first developed in moist and cool climates and had greater technology and innovation. Huntington based this in historical analysis, but this concept did not hold up when compared to the ancient civilizations such as Egypt and Mesopotamia. Semple's (1903) work included a proposal that living in or near mountain passes made people more apt to be robbers. This is now used as a good example of selective empirical analysis. Semple largely chose case studies that would further her argument, rather than investigating a general phenomenon. Within environmental determinism, though, there were actually degrees to which proponents ascribed nature's power in determining human behavior. Because of this dissension as to the degree of determination nature had in dictating the behavior of humans, determinism began to evolve into more plausible theories.

The next branch of ideas to evolve was called "possibilism." This way of thinking considered the environment as passive and humans as the active agents able to choose from a range of possibilities that nature offered (Palm 1990). Humans in this case were the decision-makers, but their options were constrained, as opposed to dictated by, nature. This branch of thought further evolved into "positivism." This theory "assumed general principles could account for the ways in which individuals decide among various environmental alternatives" (Palm 1990, p. 63). This concept basically ascribed human's motivation in decisions to maximization of economic benefits. In other words, a rational person would always choose the alternative that allowed him/her to make the most profit.

The influence of culture, space, and time were not considered in the model of decision-making as significant. Positivists do not necessarily propose that individual human behavior can be predicted, but some norm for a population could be suggested. This created a reactionary philosophy termed "humanism." In this branch of thought, the individual, not the generic group, was the focus of inquiry. The idea of economic maximization as humankind's only impetus in decision-making was rejected, and the focus changed to exploring the reasons for decision-making as opposed to relying on general principles.

The most recent philosophy is "structuralism." This branch of thought proposes that "political and economic structure determines or constrains individual adjustment to the environment" (Palm 1990, p. 69). In considering less developed regions, such as Rwanda, many proponents of structuralism argue that economic development and the accompanying political economic structure enhance the potential for natural hazards. Within this philosophy, structuralism can be divided into structural determinism and structural probabalism (Palm 1990). Structural determinism takes the power of free will out of the hands of the decision-maker, as the underlying political and economic structure determines the behavior of individuals. In structural probabalism, the behavior of decision-makers is not completely determined by, but is constrained by, political and economic structure. Inherent within structuralism, power in decision-making increasingly shifts from the individual to a hegemonic power structure.

Robert Kates distinguishes between the industrial and pre-industrial societies and their decision-making rationales. He argues that, "for preindustrial adjustments, criteria of environmental fit and social conformity seem most important, while those of technological feasibility and economic gainfulness appear more prominent in considering industrial adjustment" (Kates 1971, p. 441). Kates' work in natural hazards, while still encompassing the idea of a human decision-maker, is among the first to ascribe an active role for the environment. He argues that the "human use system" and the "natural events system" interact to create a hazard. This not only gives environment an active role, it also promotes the idea that human-land interaction is dynamic.

As well as ascribing a dynamic element to human-environment interaction, an element of complexity was added by Risa Palm in her work Natural Hazards (1990). In examination, she argues that potentially conflicting goals and objectives of different individuals, groups, and the political economic structure involved can create complexity in decision-making concerning natural hazards, including land degradation. In the most recent works in human geography the political economy, rather than merely structure has come to be used. One will not only find the term political economy in natural hazards research, but also in its own category as a philosophy outside on the hazards realm.

Political Economy and Political Ecology

Political economy at this point probably needs some clarification as a framework for investigation. The idea of political economy depends on historical development and its impacts on society. No society is without a past and investigation of events in a society's history is necessary to understanding current conditions. Political economy also includes the political and economic forces that act on all humans everyday. Power is also brought into the paradigm as it determines the use and distribution of available resources. Power according to Giddens is "the capacity or likelihood of actors to achieve desired or intended outcomes" (Giddens 1979, p.88). Structure is yet another element in this paradigm as was previously discussed. All of these together contribute to a methodology for looking at problems in a more holistic and realistic way. Much research involving political ecology looks at local level issues and then works "outward" toward influences coming from the larger scale, such as national and international policy.

The works of Kates were labeled under the banner of Human Ecology. This perspective placed societies in a position in which they developed both based on, and in reaction to, nature (Olson 1994). In response to this position the idea of political economy evolves. Many of the ideas of human and cultural ecology are included in political economy, such as that of political-economic structure. But political economy encompasses more than human ecology in creating a framework for investigation. Power and spatial scale begin to be included as factors in decision-making, and mono-causal factors are rejected in favor of chains of causation. This philosophy has many roots, the first of which is Marxism. In an explanation by Peet and Thrift in New Models in Geography, they explain "economy" as, "social economy, or way of life, founded in production. In turn, social production is viewed not as a neutral act by neutral agents but as a political act carried out by members of classes and other social groupings" (Peet and Thrift 1989, p. 3). The influence of Marx's writings in this element of political economy is clear, but political economy cannot be merely relegated to a neo-Marxist realm.

Other theories were also influential within political economy. Doreen Massey in her work Spatial Divisions of Labour (1984), introduces the idea of space. This, of course, should not be confused with the Ricardian value of space which has to do with the substance value of land (environment), as opposed to the locational (or non-primary producer) value of land. According to Massey, geographical space should not be thought of passive, but rather as an active force. She argues that, "Just as there are no purely spatial processes, neither are there any non-spatial processes" (Massey cited in Peet and Thrift 1989, p.14). The idea of space being an integrative part of political economy made it attractive to geographers.

Another influence in the development of political economy was once again the structure-agency debate, especially "structuration." The debate over structure (underlying political-economic structure) versus human agency (individual rationale) as the major influence in decision-making has been a long-standing problem for geographers. The structure-agency debate was a product of changing times, and with this, changing philosophies in all realms of social science. The debate began in the mid-1970's.

According to Peet and Thrift (1989), there were five catalysts for the ensuing debate over structure versus agency. These catalysts included changes in political views, a theoretical change toward realism and the limits of theory itself, space as a part the realm of society, changes in human geography, and changes in the nature of society itself (Peet and Thrift 1989). Combined, these catalysts produced a seemingly unsolvable problem for geographers.

The debate over structure versus agency focused on whether individuals make decisions of their own free will (human agency) or if the underlying political and economic structures of society created a defined pattern of behavior that dictated decision-making. Structuration, "emphasized the importance of hermeneutics at all scale levels" and made light of the importance of geography, thereby offering geographers an alternative to the structure-agency debate (Peet and Thrift 1989, p. 19). Agency needs to be situated as a "continuous flow of conduct" in time and space and should have a theory of an "acting subject" (Giddens 1979, p.2). Structuration according to Anthony Giddens began because of a lack of "theory of action in the social sciences" (Giddens 1979, p. 2). Giddens argues that without action there is no structure and without structure there is no action.

> "The same structural characteristics participate in the subject (the actor) as in the object (society). Structure forms 'personality' and 'society' simultaneously-but in neither case exhaustively: because of the significance of unintended consequences of action, and because of unacknowledged conditions of action" (Giddens 1979, p. 70).

In other words, neither structure nor agency works independently. Political and economic structures and human free will influence decision-making. So in examining human and environment interaction it is necessary to analyze hegemonic structures and human character traits that will influence how problems will be dealt with. Both the idea of structure versus agency and its critique, structuration, were major influences on what would become political ecology. These are just some of the many philosophies from which the paradigm of political economy, and later its prodecessor, political ecology, came.

Political ecology entails many of the same concepts as political economy, including power, structure, and political and economic forces. Political ecology, however, offers the researcher a more flexible framework. Political ecology argues that the relationship between humans and the environment is reflexive and dynamic (Blaikie and Brookfield 1987). According to Peet and Watts, political ecology was a response to "the theoretical need to integrate land-use practice with local-global political economy and as a reaction to the growing politization of the environment" (Peet and Watts 1993, p. 238). Moreover they argued that political ecology gained appeal as it attempted to synthesize production in a global economy with new environmental rules and management practices (Peet and Watts 1989). As Blaikie and Brookfield explain,

> "Three characteristics of the relationship between land degradation and society have been identified: the importance of interactive and feedback effects through time, the importance of scale considerations, and the contradictions between social and environmental changes through time. These have to be recognized as placing difficult demands upon the way in which land degradation and society is studied" (Blaikie and Brookfield 1987, p.15).

Although others argue for various scales, Blaikie and Brookfield further expanded on the paradigm of political ecology by arguing that problems should be studied at a regional scale. In this way "Regional Political Ecology" could take into account specific ecological, political, social, economic, and cultural context. Influences from both local, national, and global actors are examined, but the region itself is the area of focus. A region here could be defined as an area linked by either culture, environment, etc., that forms a functional space for research analysis. A watershed is an example of a region based on purely physical characteristics. The regional political ecological approach tries to integrate information concerning both humans and the environment to examine complex relationships without trying to over-simplify, and thereby, losing valuable insight and information. Regional political ecology has been criticized by some for being too complex (Peet and Watts 1993). Without looking into all facets of decision-making, though, the situation being examined becomes somewhat like that of a puzzle with a missing piece. Some other criticisms that have been directed at political ecology also include the lack of actual "politics" in the concept and that political ecology relies on outdated concepts of ecology, such as systems theory (Peet and Watts 1993).

In this thesis, political ecology will be used to examine the problem of land degradation in Rwanda. Political ecology recognizes that physical processes are also human processes. The two are linked and should be studied as such. The problem in studying land degradation to this point has been the narrow focus on only the physical processes and indicators. Political ecology has been chosen in this case as a framework to guide this research into ways of monitoring land degradation as a process involving the interaction of both biophysical and societal processes.

Population Pressure and Carrying Capacity

Rwanda has long had one of the densest and fastest growing populations in Africa. Many have argued that land degradation is a result of these demographic trends while others see this as a catalyst to agricultural innovation.

The earliest ideas of what a rapidly growing population would eventually face, were proposed by Thomas Malthus. Malthus argued that there was a critical threshold when population and its ability to feed itself were in equilibrium. If a population were to grow larger than its ability to feed itself, then war and/or famine would ensue. This philosophy assumes that the ability of a population to produce food is a constant. It also assumes that extensification of agriculture will occur, with good land being brought into production first and land of lesser quality being continuously brought into production as good land becomes scarce (Arizpe, et al., 1994). This also assumes that there is a finite amount of land available. The value of land seems, according to Malthus to be of constant value and that access to land is open. Malthusian outcomes in contemporary research have also been expanded to include land degradation, as well as war and famine. According to many, Malthus was wrong in his assumptions of catastrophic endings in all cases of rapid population growth (Boserup 1965; Arizpe, et al., 1994). In a study of

Rwanda, John May argues that, "demographic pressure induces utilization of marginal land, shortening of fallow periods, and conversion of pasture and (natural) forest lands into cropland" (May 1995, p.324). He goes on to explain that this will lead to soil degradation, which in turn reinforces the demographic pressure on the land. This will lead to a cycle of continuing environmental degradation, which neo-Malthusians would consider a Malthusian outcome.

The main disagreements most contemporary researchers on population have with Malthusian theory is that technological innovation and local action are ignored. According to many researchers studying the effects of population growth, such as Boserup (1965), Davis (1963), Bilsborrow and Okoth-Ogendo (1992), Malthusian outcomes can be averted, or mediated by, factors that make better and more efficient use of land as population grows. The first and most prominent advocate of sustainable population growth was Ester Boserup. In The Conditions of Agricultural Growth (1965), she argued that a growing population could sustain itself not through extensification, but rather intensification.

Boserup and others who disagree with Malthus, such as Mary Tiffen (Tiffen, et al., 1994), believe that population growth facilitates and encourages adoption of new technology. This is made possible by the addition of increased labor supply. Boserup saw changes in technology as coming from endogenous, rather than purely exogenous, causes. Some of the positive effects of population growth according to these authors include: increased labor supply, increased food needs, "increased interaction of ideas leading to new technologies, and economies of scale in the provision of social and physical infrastructure" (Tiffen, Mortimore, and Gichuki 1994, p.266). They believe, based on their research, that in the medium to long-term these positive effects could outweigh the negative effects of an increasing population.

The availability of additional labor gives farmers the opportunity to make improvements to farms or to grow crops that require more attention; in this way, addition of labor can be seen as an intensification strategy. Other systems of intensification often used are increased inputs, such as manure or fertilizer, and intercropping. Changes can be made in agricultural practices to increase output, but other changes may also occur. According to Kingsley-Davis (1992), there may be a "multi-phasic response." He hypothesized that several responses to population growth could occur at once. These responses included postponing marriage, out-migration, and reducing fertility. Only demographic changes were considered in this theory, whereas Boserup only considered non-demographic changes (Bilsborrow and Okoth Ogendo 1992). It is possible, however, that both demographic and non-demographic changes could be responses to increasing population. According to Bilsborrow and Okoth Ogendo, there are four phases of response that can occur as a result of increasing population: tenurial, extensification, technological, and demographic (Bilsborrow and Okoth Ogendo 1992). In this way they combine Malthusian ideas of extensification, intensification or technological change as argued by Boserup, the demographic changes as advocated by Kingsley-Davis, and the additional idea of changes in tenure created by increasing land scarcity. The extensification phase is when people in situations of increasing land pressure cultivate more area to make up for decreasing crop yields or additional food requirements brought on by a growing family. The tenurial phase is the adjustment in land tenure laws or customs to accommodate an increasing population, such as the process of fragmenting farms. The technological phase represents intensification, or using the same amount of land but with increased inputs to agriculture on that land. And finally, the demographic phase occurs when people facing increasing population pressure begin to change habits and customs concerning childbearing, such as limiting the number of children they have. The responses that occur are directly influenced by the "context" of the area. Quality of land, the country's history, structural factors, and attitudes of the population all help to determine which responses will be chosen from the available possibilities.

Thus far, a growing population has been considered as a rise in the number of people in a region. According to many researchers though, neither the actual number of people nor, the rate at which a population is increasing is as important as the density and distribution of that population. A theory that originated from biology is related to the idea of an upper limit above which degradation or destruction will occur. This is the concept of "carrying capacity." Fundamentally, carrying capacity refers to, "a given area can only support a given population of a particular species and at this upper limit-the carrying capacity-population will have reached its maximum sustainable level" (Pearce, Hamilton, and Atkinson, 1995). It is argued though, that when applying carrying capacity to human populations, one must also consider the amount and composition of economic pursuits (Pearce, Hamilton, and Atkinson, 1995). The idea of carrying capacity, though, is inflexible in that it does not allow for substitution of assets, creating the potential for a very pessimistic outcome in most cases. Carrying capacity is an intuitively attractive concept, but in the real world, there are too many variables to be specific in predicting the exact number of people that will put the population beyond that which the ecosystem can tolerate. As was mentioned earlier, many believe that a growing population will apply technology to increase the population's ability to inhabit an area. Density itself can be a catalyst for innovation through physical proximity. According to Mary Tiffen, et al. (1994), a higher population density makes communication of ideas easier and also creates new markets for products outside local areas. This exchange and application of ideas would not happen as quickly if people are separated by long distances and tend to produce food only for household or local use.

Contemporary research on population is beginning to adopt a political ecological stance, as well as, one that is purely demographic. According to Arizpe, et al. (1994), "the population problem does not just involve absolute numbers of people nor even just population densities or overall rates of increase, but also, in important ways, social, political, and institutional factors" (Arizpe, et al., 1994, p. 3). The authors call for additional comparative data at several scales, such as national, regional, and international. Research on population does seem to be coming to a consensus that numbers of people and rates of increase alone are not meaningful without a context in which to interpret them. Political ecology can help to interpret why the rates of increase are occurring by looking at causal factors, which most will agree is much more meaningful.

Indicators of Land Degradation

The use of indicators for looking at land degradation is a relatively recent occurrence. The first recognized work on using indicators was written by Berry and Ford in 1977. In this work, the authors suggest variables that could be used to suggest the presence of increasing degradation of arid and semi-arid environments. They offered suggestions as to what should be monitored and ways of measuring them. Both physical and socio-economic indicators were offered as possible ways of monitoring desertification. Although the work by Berry and Ford was called "a system for monitoring," it really did not suggest a way in which to integrate the collection and integration of data. Indicators and ways to monitor were offered, but each was considered separately.

A work by Patricia Reining the next year also offered suggestions for indicators that could be measured in the monitoring of desertification, as well as, ways of monitoring and justifications of why these indicators should be monitored (Reining 1978). This book came as a product of the United Nations Conference on Desertification, which was held in 1977. The Conference was among the first to recognize the severity of desertification (Krugmann in Hamby and Angura 1996). This in turn, brought on many studies suggesting indicators to monitor this problem. But again, monitoring of indicators of desertification were offered on a single indicator basis with conclusions stemming from a synthesis of summarized individual indicators. No way of monitoring multiple indicators as part of a system was offered, although both of these works broke ground in the field of monitoring based on use of indicators. Both works also attempted, quite efficiently, to justify why both physical and socio-economic indicators should be used, but a more systematic approach to monitoring using indicators is still missing. According to Bierly and Flagg, "examining individual indicators within the context of the behavior of related indicators is more informative than univariate analysis and reduces the possibility of decision error" (1995, p. 108).

International organizations also began to research the utility of indicator monitoring. In the late 1980's, the World Resources Institute began looking into the use of indicators for monitoring environmental health and development, and held a conference on the subject of environmental and development indicators in 1992 (Hammond, et al., 1995, p. 5). Also in 1992 the United Nations Conference on Environment and Development in Rio de Janeiro called for more research into the use of indicators in Agenda 21. More recently the United Nations has also recognized the utility and validity of using indicators to monitor desertification and land degradation. The Convention to Combat Desertification in 1994 set a mandate to address increasing concern over desertification by monitoring through the use of indicators. The recommendations from the conference were that programs should be initiated to, "support and further develop bilateral and multilateral programs and projects aimed at defining, conducting, assessing and financing the collection, analysis and exchange of data and information, including, inter alia, integrated sets of physical, biological, social and economic indicators" (cited in Berry 1996, p. 2).

Thus far, indicators have only been specifically recognized for monitoring of desertification. But in recent years the use of indicators for monitoring on non-dryland areas is also being put into use. The World Bank, FAO, UNDP, and UNEP have began supporting a joint project to use indicators in the measurement of land quality. Land Quality Indicators will be developed to monitor not only land degradation, but also soil and water conservation efforts and land use pressures (Berry 1996). The use of indicators in their capacity to monitor not only desertification, but other degradational processes is becoming more accepted, and in fact suggested.

Indicators themselves are usually grouped into two categories, physical and socio-economic (human) indicators. Physical indicators, such as gullies and devegetation, are the most easily recognized and most easily justified group of indicators. Mabutt (1986) used the terms "direct" and "indirect" to denote physical and human indicators respectively, but this is not necessarily true. Human indicators can be directly caused by a degrading land quality. Human actions either in response to, or as causes of, land degradation can be acute predictors of a degrading situation. Changes in agricultural practices may come long before some physical signs of degradation appear on the landscape. According to Wangati,

> "It is widely recognized that the main causes of land degradation can be traced directly or indirectly to human activities. These in turn are influenced or driven by social and economic conditions to which the human population has to respond. Socio-economic pressures on the population, equitable access to available land resources, and the availability of alternative livelihood systems that reduce direct dependence on land for subsistence can therefore be good indicators of the probability (risk) that the available land resources will be

> exploited beyond their carrying capacity resulting in degradation. It is therefore accepted that poverty within a community can be an indicator of risk or existence of land degradation" (1996, p. 11).

Human indicators then can be considered as a valid and useful tool in examining land degradation. According to Bierly and Flagg, "A more accurate representation treats the human indicators as an integral part of the system, not merely as phenomena responding to feedback" (1995, p. 108).

In order to be useful, indicators need to have certain characteristics. According to Hammond, et al. (1995), these characteristics include being "user-driven, policy-relevant, and highly aggregated" (Hammond, et al., 1995, p. 2). Hartmut Krugmann suggests that indicators also need be hierarchical by scale, dynamic, contexturalized, quantitative or qualitative, and descriptive or performance-oriented (Krugmann in Hamby and Angura 1996). There have been two studies which attempted to use indicators for monitoring of land degradation very recently (Krugmann in Hamby and Angura 1996). One project was set in Kenya and focused on two field areas, the other project was undertaken in Western Mali and focused on two districts. Both of these projects attempted to use indicators to monitor land degradation, but again, the missing component seems to be a system whereby indicators are integrated. There were valuable lessons, however, to be learned from these projects. The first has to do with scale (spatial). Both projects concluded that monitoring needed to be done at a local or regional scale, as costs at a larger scale were prohibitive. Secondly, the researchers in the Kenyan case study also assumed that information would be available to them which they later found was unfortunately not available, because it was either not collected or too highly aggregated. These field studies offer valuable ways in which to modify monitoring systems and could offer new indicators for specific countries and regions.

The research on indicators has shown that they are of great value in monitoring land degradation. It is essential to remember, however, that indicators are based in the context of a society. According to Batie, "the expectation of a common set of indicators is naive" (Batie, ed., 1995, p. 1). Indicators used in Southern Africa will probably not be exactly like those used in Asia or South America. Many indicators are based on an assumed, and observed, pattern of behavior based on the cultural, political, economic, and societal context of a society. Before indicators are suggested for an area some knowledge of the land use system, customs, etc., must be examined. Indicators are geographically specific, and as such based on the behavior of individuals which is constrained by both societal and environmental context. Within this thesis, both human and physical indicators will be analyzed.

The literature to this point has shown that interactions between humans and the environment are complex and dynamic, with a reflexive relationship. The validity of indicators in addressing environmental problems has also been shown in past research. This paper attempts to contribute to the literature an assessment of methods for looking at the problem of land degradation. Guiding the analysis will be the framework of political ecology. This framework helps to contexturalize the data gathered, and will assist in the selection of indicators relevant to Rwanda, as well as, interpretation of results. The availability, utility, and validity of information concerning environmental and socio-economic information, as well as, necessity of future cooperative data collection will be discussed. Previous research has focused on identifying potential indicators of land degradation. This study seeks to assess the feasibility of a systematic approach to monitoring using these proposed indicators.

Data used in this study is an example of what could be available from some less developed countries. Rwanda is used as the case study for this thesis because of the availability of this data. If methods are not useful with the available data, then what information would be necessary to make the monitoring systems feasible? Other statistical methods are available, but how do the matrix results compare to these? This study will compare the results of a proposed matrix method, with the results of regression and principle components analysis, as well as, with the results from the original Rwanda Society-Environment Project. It is possible that the suggested monitoring scheme is more useful as a conceptual tool to show interaction of factors influencing land degradation as opposed to being a tool for monitoring.

CHAPTER II

REVIEW OF STUDY AREA

In this chapter physical, cultural, and historical characteristics of Rwanda will be examined. In using Regional Political Ecology as a framework for analysis of land degradation it is necessary to take into consideration the history and agricultural setting of Rwanda. No study of an area using a political ecology framework could be undertaken without first familiarizing oneself with important aspects of the area in question. History, politics, and economics contribute to contemporary situations and some knowledge of them is important. In this case, though, context will be used to identify indicators that will be most useful to assess land degradation.

Physical Characteristics

Rwanda is an area of the East African Plateau surrounded by Burundi to the South, Zaire to the West, Tanzania on the East, and Uganda to the North (Figure 1). The Congo-Nile Divide runs North to South through the country and separates Rwanda into two drainage basins. The average altitude in this divide is around 9,000 feet (Nyrop, et al., 1969). The Western side of the divide is mainly very steep slopes running into the Great Rift Valley. The Eastern side of the divide is characteristically rolling hills

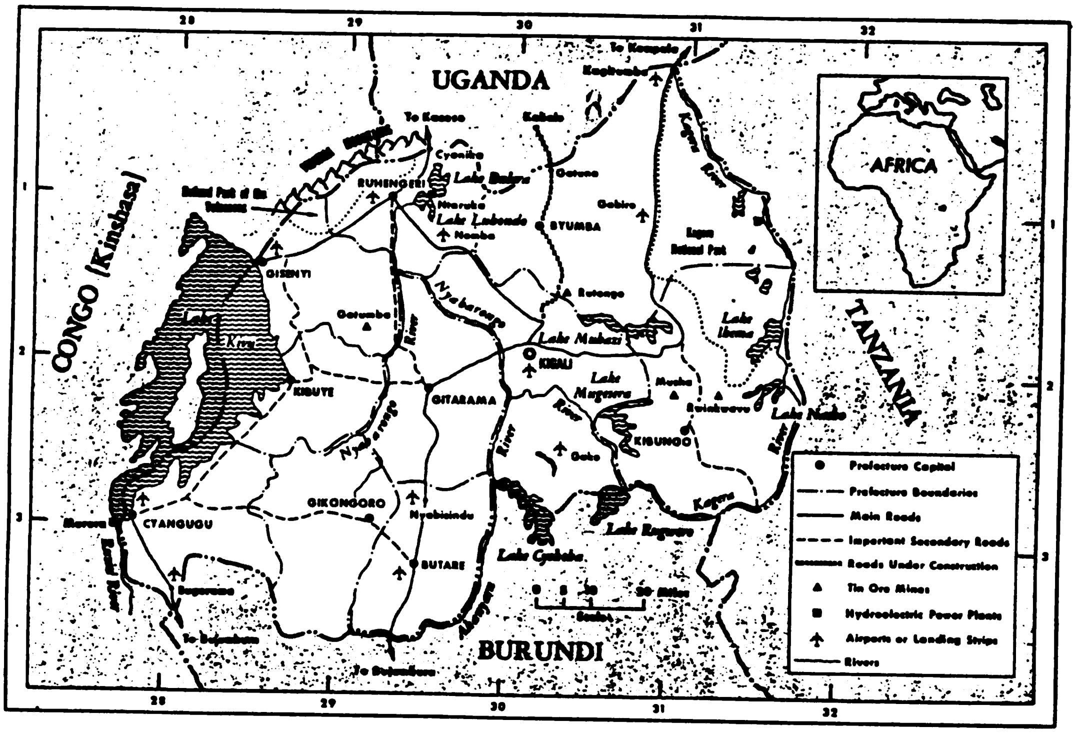

Figure 1: Map of Rwanda
(Source: Nyrop, et al., 1969)

descending into areas of savanna and swamp. Most of the population lives at elevations of around 5,000 - 7,500 feet, and the average elevation of the country itself is 5,200 feet (Nyrop, et al., 1969).

Most of the soils in Rwanda are granitic in origin, with the exception of the Northwest portion of the country where they are volcanic. Nyrop, et al. (1969), suggests that soils in Rwanda have many characteristics of laterite soils, but that they are more fertile and generally better for farming than true laterites (Nyrop, et al., 1996). It has also been suggested that erosion and leaching are major problems in Rwanda (Lewis, 1994, Nyrop, et al., 1969). The steep slopes of many areas, along with variable and often rapid rainfall account for much of the erosional problem (Lewis, 1994).

There are two wet and two dry seasons in Rwanda. The short wet season occurs from January to February and the long wet season from June through September. The longer dry season occurs from March through May with a shorter dry period from October through December. The average rainfall for the country is about 1200 millimeter annually, but is highly variable and dependent on elevation. Rainfall is generally greater in the high areas of the West, with decreasing precipitation in the lower altitudes of the Eastern Plains.

Temperatures in Rwanda also vary with elevation. The Central Plateau region has an average temperature of 65 degrees Fahrenheit daily, but the daily range may be as much as 25 degrees (Nyrop, et al., 1969). The lower savannas of the East can reach daily temperatures of 90 degrees. Some areas of the mountains in the West are too cold for even trees to grow, and temperature decrease quickly with increasing altitude in these steep Western mountains.

Historical Outline on Rwanda

Settlement in Rwanda first began about 1000 AD with the Hutu farmers in the Western Highlands of Rwanda. The Tutsi pastoralists arrived about four to five hundred years later from the north and settled in the eastern regions of the country. There was an ensuing patron/client relationship in which the Tutsi kingdom gradually expanded to include the Hutu regions. The period from 1744-1895 in which increasing area was incorporated has been called "Le Grande Expansion" (Olson 1990). The concept of ethnicity at this point was relatively open; it was more generally based on cattle ownership (Olson 1995). That was the type of relationship in place when the first Europeans entered Rwanda in 1880. The Western Highlands were still home to the farmers, with part of the Northwest controlled by the Tutsi king but governed by the Hutu elite that resided there.

In colonial times, Rwanda was first ruled indirectly by the Germans until 1915, and then by the Belgians. The Belgian government reinforced the system of rule already in place. Communal labor for erosion ditch building was enforced after this point. This would become an important point of contention between the indigenous people and the colonizers later. The population began to grow after the 1940's and, as a result intensification began. Farming was still limited to the highland areas, as the rest of the country was reserved for the pastoralists. It is suggested that because of the growth of population and the area reserved for farmers being limited politically, intensification began here earlier than in the rest of Africa (Olson 1995, Olson et al, 1996).

In 1959 a *Social Revolution* occurred in which the Tutsi monarchy was deposed and the Belgians switched their support to the new Hutu government (Olson 1995). The United Nations oversaw the first independent election in Rwanda in 1962, and the capital was moved to Kigali in the center of the country. In addition, there was also a wave of migration to the savanna of the east during the 1960's and 1970's in a government initiated resettlement scheme (*paysannat*)(Clay and Lewis 1990, Olson 1995). The east in turn became an area of large commercial farms considered rather wealthy in comparison to the rest of the country (Olson 1995, Olson 1990).

The year 1973 saw a new president installed though a coup d'etat, and Rwanda became an area of relative political and economic stability until the 1980's. During the 1980's the situation declined in most of the country, except the Northwest where government investment was channeled. The early 1990's were the origin period for formation of opposition parties to the ruling MRND and a breakdown in the stability of the country (Olson 1995). Eventually the political situation completely failed and resulted in the chaos that the region continues to confront.

Land Use in Rwanda

Rwanda is a small country of only 26,338 square kilometers with a population of 6.2 million people (Olson 1990). As a result, the country has the highest population density in Africa (238 people per square kilometer), and a rather high population growth rate at 3.2% (Olson 1990, Gourou in Olson 1990). Virtually all the arable land in Rwanda in now is cultivated, and 95% of the population is rural and involved in agriculture (Ford in Turner, et al 1993). The country can be divided into three broad ecological regions. The Western Highlands have the most abundant rainfall and most fertile soils of the three regions, and are historically the most densely populated. The center of the country is mostly foothills of the Highlands. This area receives less rainfall and has less fertile soils relative to the Highlands, and therefore, less agricultural potential. The savannas of the East have the least agricultural potential due to unreliable rainfall and poor soils. Rwanda in general has two rainy seasons: a short one from October to January, and a long one from March through May.

While the Western Highlands and foothills of the central areas were originally forested, they had been degraded to grass covered hills by the time of European contact (Olson et al, 1996). A traditional pattern of agricultural has emerged from the original settlement in the Highland areas, though not found often today in its original pure form (Clay and Lewis 1990). In this traditional pattern farmers located their settlements near the tops of hillsides (Figure 2). Within this settlement, near the center, was a home *(urugo)*. Banana trees usually surrounded the *urugo*, this area being called the *urutoke*.

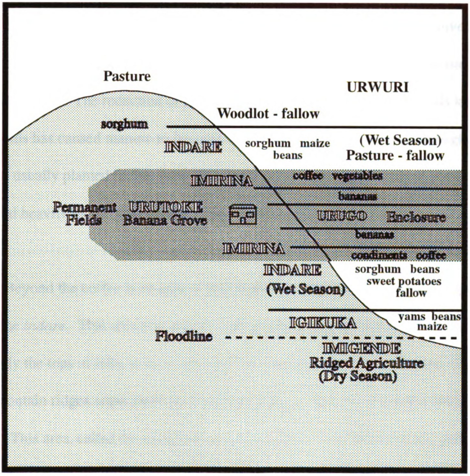

Figure 2: Typical Farm
(From: Ford 1993)

Bananas are an important crop both economically and socially in Rwanda as it is used to make traditional banana beer. According to Clay and Lewis 40% of Rwandans obtain income from the production and sale of banana beer (Clay and Lewis 1990).

The most important crops for the household are planted near the bananas, such as coffee, condiments, and vegetables. This area is called the *imirima*, and receives most of the fertilizer available. Traditionally, manure from animals and household waste has been used as fertilizer. The reduction of pasture and decreasing amount of animals kept by households has caused manure to become scarce in more recent periods, though. Coffee, which is usually planted farther from the *urugo*, is the main export crop of Rwanda and promoted heavily by the government (Clay and Lewis 1990).

Beyond the coffee is an area of less important crops such as sorghum, maize, and beans, the *indare*. This area may also be used for fallow in the wet season in some areas. Typically the tops of hills, *urwuri*, are used for woodlots, fallow, or pasture. The base of slopes contain ridges areas, built up to ensure drainage, that are cultivated during the dry season. This area, called the *imigende*, contains crops such as beans, yams, and maize. Increasing population in the face of a finite amount of land has caused many changes in this system (Clay and Lewis 1990). The main effects have been that plots of land are smaller and more fragmented, plots are often discontiguous, and often less fertile areas such as hilltops are cultivated. The system of tenure rights has also contributed to this more recent system of fragmented farm. In this tenure system sons inherit land from their fathers, but an increasing scarcity of land has reduced both the availability of land to give and a reduction in size of plots given.

Although brief, this overview of Rwandan agriculture and history has been presented to provide context for analysis of land degradation in the country. A Regional Political Ecological approach to looking at the problem of land degradation requires that one look not for a single cause, but rather a for a process catalyzed possibly by many factors. Regional Political Ecology is a holistic way of assessing dynamic and complicated processes. Historical, economic, and social context needs to be taken into consideration. Rwanda is a poor country, with a large subsistence-farming based population. The land use patterns evolved from former dominant pasture and regional hillside farming to cultivation of virtually all areas, including very marginal land. Political and demographic pressures have shaped the landscape so that today it is characterized by small, fragmented farms often on marginal land. Most farms lack manure to fertilize crops as the amount of pasture and fodder for animals has become increasingly scarce. Much of the loss of soil fertility has been attributed by farmers to this lack of manure (May 1995, Olson 1995). This having been said Rwanda did once enjoy a period where intensification kept pace with rising population densities. This thesis will attempt in the following section to assess the level of land degradation at the time of data collection.

Previous Studies on Rwanda

This study uses information obtained from the Rwanda Society-Environment Project undertaken by the Department of Geography and the Center for Advanced Study of International Development at Michigan State University. This project was a collaborative effort by the university departments, United Nations Environment Programme (UNEP-GRID), various government agencies in Rwanda, and the Department of Geography at the National University of Rwanda. The objectives of the project were to "assess data needs for environmental management in developing countries in Africa and to determine how to effectively use physical and socio-economic data sets interactively to address Natural Resource Management (NRM) policy" (Campbell 1994b). A series of working papers each related to specific issues addressed in the project was produced. Within these only those most relevant to this study undertaken in this thesis will be reviewed.

The data used in the Rwanda Society-Environment Project was a compilation of both physical and socio-economic data, and the analysis was done in the context of regional political ecology (RPE). Suggestions included in the conclusions of the papers included requirements for minimum and optimal data sets. The minimum data set was more specific in offering basic data that most African countries could and should be collecting for monitoring of natural resources issues, while the optimal included broad principles. Included in this data set as minimums were a topographical map of the country, a decennial population census, and basic human and environmental data to compliment them. Suggestions for scales, both temporal and spatial, are also offered in association with suggested information assessment.

Some of the most important findings to come out of these works included analysis on population and land degradation. David Campbell argues, "that there is no direct relationship between the distribution of population and that of environmental stress" (Campbell 1994a). This argument is based on analysis of stress variables and population density as they are correlated across the country. The author concedes, though, that the environmental stress variables used in this analysis were indirect. An interesting premise is put forward later in that areas of low environmental stress also had high population growth rates. If this process of growth in these areas continues there could be resultant degradation unless other alternatives to the current patterns of land use are made. The findings from this study then should be examined for not only the state of degradation at the time of the study, but also keeping in mind the implications of future changes based on the project data.

One of the main problems found in assessing data available to the study was that information came from many different sources, but also at many different scales spatially. As a consequence, results could only be relied on to show broad regional patterns, as that was the lowest level of aggregation for some of the data. The differences in scale and source of data collection also brought about some questions as to the ability and validity of analyzing data from different data sets. These same problems will hold true in my analysis as regards data, although in this study utility of the methods for assessing land degradation is the central question, rather than the validity of the data.

Results in this study will be compared to results in the Rwanda Society-Environment Project. Some of the broad conclusions of the project were: the need for cooperation in collection of data, illustration of broad patterns representing the state of environmental stress in Rwanda, as well as, future implications of this state, and recommendations for future data collection within Rwanda and other non-national areas. The conclusions also stated that land degradation, "is a multi-dimensional process and encouraged further analysis that integrated societal and environmental processes" (Campbell 1994a, p.23). The project itself was both an exercise in data collection and exploration, as well as, an exercise in approaching land degradation analysis from a regional political-ecology perspective by examining both human and environmental factors within the context of a specific country.

According to two other sources dealing specifically with Rwanda, the agricultural situation has been on a continuous decline in recent years (Clay and Lewis 1990, May 1995). Rushahigi attributed the decline in the situation to rising density with much adoption of technology (in Arizpe, et al., 1994). According to Rushahigi, poor countries like Rwanda have little access to advanced technology because of their limited economic capacity (in Arizpe, et al., 1994). Clay and Lewis on the other hand suggest that, "the traditional settlement pattern and the organization of farming, coupled with more recent demographic pressure, have impeded the development of a cropping system that effectively contributes to the conservation of precious land resources" (1990, p. 149). Clay and Lewis go on to present the typical farming patterns traditionally found in Rwanda and empirical evidence to suggest a declining agricultural situation. The authors found that most farmers say they attributed declines in production to over-cultivation and soil erosion (Clay and Lewis 1990).

Both the study by Clay and Lewis and the comments by Rushahigi are limited by their focus on a single or limited cause for the complex problem of land degradation. Rushahigi leaves out societal and environmental characteristics present in Rwanda that could also be factors in the role land degradation. And Clay and Lewis (1990) leave out important political and economic forces that play a large part in decision-making in Rwandan agriculture. Both studies seem to lack an integrative framework for analysis that takes into account economics, politics, societal and cultural, and environmental characteristics that make the study area unique and contribute to the processes they are describing.

The World Wildlife Fund and USAID conducted a study of the area adjacent to the Nyungwe Forest Reserve had more positive results, although with some exceptions. This project was interested in land use changes at the edge of the aforementioned forest preserve. The study area in question was and still is a high population density area. The researchers in this case found that a combination of intensification processes and migration has been relatively successful in areas that have better soils and resources. The counterside is that poorer households that have less suitable ecological bases are not faring as well and are, in fact, experiencing land degradation. The overall findings suggested, though, that in some areas productivity had improved through "local strategies to mitigate land shortage" (Olson, et al, 1996, p. 7). The specific study findings concluded that, "total forested area and biodiversity of forest-agriculture landscape have increased" (Olson, et al, 1996, p. 57). The root cause of the degradation occurring was proposed to be caused not by population density and rapid growth, but rather poverty.

One of the most interesting issues to be addressed in the World Wildlife Fund paper is deforestation. It had been widely believed that deforestation was a fairly recent occurrence, but through use of historical photographs the study determined that Rwanda is actually less deforested now than before 1960. The authors suggest that pastoralists cut down trees for over 1500 years in order to clear grazing land for their herds (Olson, et al, 1996). Relatively recent changes in land use from pastoralism to cultivation of crops has helped to convert a previously severely degraded landscape to one of increased production (Schyns, cited in Olson, et al, 1996).

The most positive outlook on the situation in Rwanda comes from Robert Ford. Ford's case study of the Ruhengeri prefecture of Northwest Rwanda (1993). This area, as in the previously mentioned case study, is also a densely populated area. Ford suggests in his work that, "all indications show that total production has improved over the last few years" (Ford 1993, p. 175). Although this is proposed, he also notes that 82 percent of farmers in the prefecture think that the productivity of the land has declined. Ford argues, though, that through a government strategy of keeping food production just above population growth the population will be able to feed itself until its growth stabilizes in 20-30 years. He does admit that if stabilization does not occur then land degradation and economic hardship will ensue. His conclusions were that "the rate of intensification and political maturation is sufficient for the near future to maintain current living standards and even improve them slightly without degrading the resource base" (Ford 1993, p. 180). This is a positive outlook, but there are still other factors to be considered in looking at environmental health.

There has been widespread disagreement in previous case studies, such as Ford (1993), May (1995), and Olson (1994) concerning Rwanda as to the amount, rates, and causes of land degradation. In all of the studies the rapid growth of population is mentioned, but the importance given to population growth varies considerably. Many of the studies cited here were also regional studies and as such did not draw conclusions for the entire country, such as Olson (1994) using a prefecture as a study area, rather than the country. The previous studies provide valuable insight into the assessment of land degradation to this point in Rwanda. The present study examines a number of methods for monitoring land degradation at both regional and national levels, using a combination of indicator variables of both physical and societal processes.

CHAPTER III

METHODS

Need For Research

Research into the use of indicators has shown that they are a valid way of monitoring land degradation. The use of indicators has been justified in previous research and suggestions for monitoring specific indicators have been proposed. The problem lies in the integration of indicators, both physical and human, in a systematic and efficient way. Indicators are much more effective when analyzed together, thereby eliminating merely monitoring a trend in a specific indicator. A monitoring scheme, composed of many indicators, should give a better picture of the broader situation, as opposed to looking at single indicators. By using a multiple indicator scheme there is less chance of missing information that could lead to early detection, and hopefully, alleviation of degrading situations.

There are agencies at the local, national, and international levels, all of which collect data on environmental problems. But what data are being collected and how are data being aggregated? The collection of information is important not only for monitoring the environment, but also the economy and demographics. To expect one agency to collect all relevant information for all of these is impossible. Data should be shared by those for whom it is useful and should be accessible. Accessibility is not the case in most nations. Information is often difficult to come by, if it is available at all. Nations need to organize what information is most necessary to be collected and work to delegate these information needs to appropriate organizations and departments.

Statement of Problem

Political Ecology identifies land degradation as arising from complex interactions between biophysical and societal processes (Blaikie and Brookfield 1987). This suggests a need for monitoring systems to incorporate indicators that reflect these interactions. Previous studies have shown that indicators are a valid way of monitoring land degradation, but they have been dominated by biophysical indicators and have not integrated the societal ones. In the real world the processes illustrated by the indicators do not work independently, and as such should be monitored together.

The objective of this thesis is to examine approaches for monitoring land degradation by comparing regression analysis, principal components analysis, and a matrix framework based on indicators. Data on societal and biophysical characteristics available collected by the Rwanda Society-Environment Project will be used to determine which method is most effective in assessing the extent of land degradation in a simple and clear manner using data that might be available in many developing nations.

The study will attempt to answer three main questions. 1) Based on the assumption that the data set acquired for use in this study is among the better available on any African country, which methods are feasible with the available information? 2) If monitoring is not feasible with the data currently available, what would the optimal set of data include? 3) The final research question is concerned with how the results of each method compare to those of the Rwanda Society-Environment Project. The results of the Michigan State University Rwanda Society-Environment Project will be used as ground-truthing for this remote analysis.

Data Set

The choice of variables from within the available set of data is based on suitability as an indicator of land degradation in Rwanda. A range of relevant indicators is found in the works of Berry and Ford (1977), Reining (1978), Mabutt (1986), and others. Justification of the use of specific indicators is grounded in previous literature and reflects an approach based on Political Ecology in which the historical, socio-economic, and environmental conditions were taken into account in choosing indicators that best fit the conditions in Rwanda.

Analytical Methods

Three approaches to the evaluation of indicator sets are considered. Two, principal components analyses and regression analysis, examine a set of discreet variables while a third, a matrix framework developed by Bierly and Flagg (1995), attempts to provide an approach in which the co-impact of different indicators is explicit. The matrix approach is compared with PCA and Regression to assess its validity.

The proposed scheme for monitoring land degradation is based on the use of paired human-physical indicators (Figure 3). The matrix itself is presented in three dimensional space: physical indicators comprise the x-axis, human indicators comprise the y-axis, and the z-axis represents time.

Indicators are arranged on the x- and y-axes in sequence according to relative severity, with indicators near the origin being the least severe and severity of contribution to land degradation increasing away from the origin of the axes. Less severe are considered as those whose occurrence might be temporary, easily reversed, or does not necessarily mean degradation is ensuing. An example would be decreased precipitation, which is often an anomaly and does not necessarily signal intense degradation without other signs being apparent. On the other hand, severe indicators are often considered chronic symptoms (i.e., persistent deforestation or devegetation) usually thought to more strictly

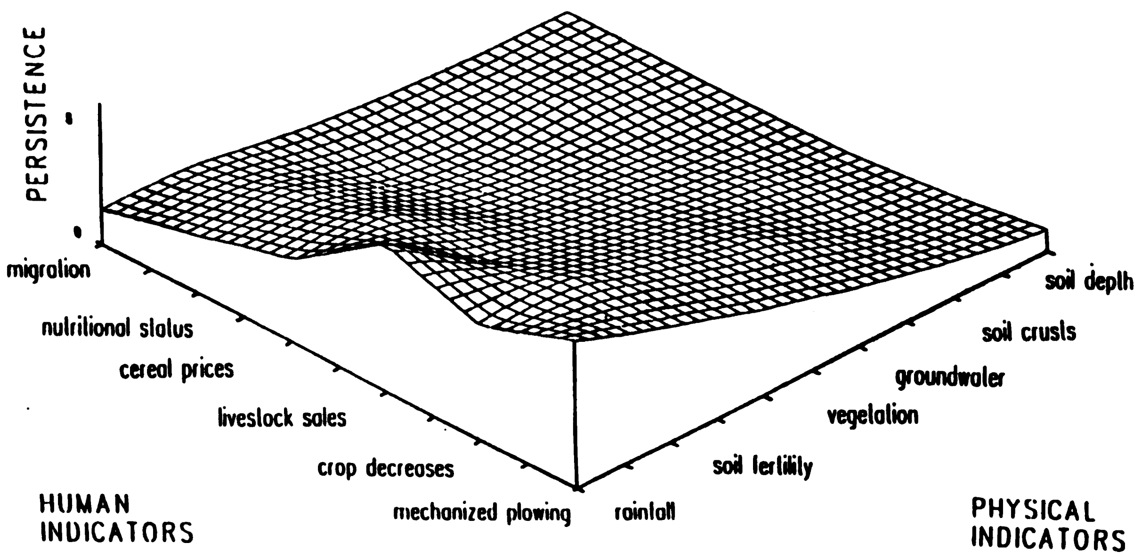

Figure 3: Hypothetical Matrix and Indicators
(Source: Bierly and Flagg, 1995)

accompany degradation. The relative severity of the variables is assessed by reference to the literature on land degradation discussed previously.

Sampling sites (commune, region, etc.) within the study area are checked for the occurrence of variables chosen as most suitable indicators. A Pearson r-value is calculated for each of the human/physical variable pairs. The correlation value is based on tallies indicating occurrence or lack of occurrence on a binary scale (1= occurrence, 0= no occurrence). The Pearson r-values are used to weight the pairs multiplicatively. These weights for each pair should be indicative of association and degree of coincidence. Assessment of correlation values of each pair recognizes that the symptomatic and causal nature of degradation is not governed by human or physical systems independently of one another (Bierly and Flagg 1995). Additional multiplicative weights may also be applied to indicate severity of each variable through analysis of the observed normal statistical distribution of each indicator. Percentile rankings within the distribution are used to calculate these weights.

Each pair of human/physical indicators is also given an actual value which is the mathematical product of the ordinal rank of both variables. Indicators at the origin of both axes, the "weakest," are given a score of 1. The scores increase by one with each discrete indicator as variables move away from the axis. "Multiplication is appropriate because variables are expected to be proportional (after empirical weighting) to desertification levels" (Bierly and Flagg 1995, p. 109).[2] The sum of the products of all human/physical indicator pairs after the aforementioned weights are applied are equal to a Composite Land Degradation Index (CLDI) value.[3]

A temporal dimension is added through the inclusion of a z-axis. Earliest periods of monitoring occur near the axis with chronological movement away from the axis. The most recent monitoring period is furthest from the origin of the z-axis. All z-values for the entire matrix describe a surface indicating the relationship and severity of "each physical and human indicator occurring in tandem and the contribution" to the degradation scenario (Bierly and Flagg 1995, p. 110). The shape of the surface indicates both the level of degradation occurring and also important areas of interaction of indicators that may need more intense assessment or remediation. Logically, an intense scenario of land degradation that has been monitored from an early stage of progression should show strong correlation of highly ranked indicators.

A single value indicative of a level of degradation in a region is achieved through the sum of the weighted components of the matrix. The sum is compared to "a scale of critical levels based upon geography and distribution of population" (Bierly and Flagg

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[2]It should be noted here that this matrix was originally intended for assessing the level and progression of desertification in dryland areas. Desertification is, in essence, degradation limited to dryland areas, and therefore, the principles behind the matrix are still applicable. The difference lies in that land degradation may occur anywhere while desertification in limited in its spatial extent by climate and landscape.

[3]In the original publication of the matrix concept the sum of the weighted products was called the Composite Desertification Index or CDI. From this point on the sum of the weighted products in this study will be referred to as the Composite Land Degradation Index or CDLI for clarity.

1995, p. 111). The CLDI table (Table 1) presented, "is based upon severity and r-values incremented by 15 percent during each phase, beginning with the weakest indicators and adding one human and one physical variable with each iteration" (Bierly and Flagg 1995, p. 111).

Table 1: Critical Values of CDLI INDEX

Observed CDLI	Description of Conditions
1 - 9	Slight Development/Degradation
10 - 51	Minor Development/Degradation
52 - 175	Intermediate Degradation
176 - 478	Advanced Degradation
479 - 1073	Critical Degradation
1074 or >	Extreme Degradation

The matrix, in summary, seeks to use indicators of land degradation specific to the region of study to assess the presence and status of land degradation. This is accomplished statistically through the computation of a composite score from the matrix, which is then compared to critical scores of the Composite Land Degradation Index (CLDI). The breakpoints in the table shown are based on 15 percent increases in r-values and also by addition of one human and physical variable pair as an occurrence for each class. A graphical illustration of the matrix itself can also be accomplished by plotting the scores of the communes on a national degradation surface. This will then show areas in the country where the most critical interaction of indicators is occurring. It also shows regional patterns well and anomalous areas. The findings within this study will compare only the composite scores with the results of principal components and multiple regression, as well as, the results of the Rwanda Society-Environment Project analysis.

Principal components analysis will be used to look for surrogate indicators that could be used in monitoring land degradation. Two principal components analyses were performed; one regarding the larger pool of possible, suitable indicators from within the data set, and the other only on the indicators chosen for the matrix. The regression analysis was used to determine if there is a relationship between the scores and the indicators chosen for use within the matrix. A regression was also performed using the compound stress scores determined in the original Rwanda Society-Environment Project as the dependent variable. These regressions will be compared to determine if either of the two equations has a better fit with the project data. The process of data analysis and findings will be discussed in the following chapter.

CHAPTER IV

DATA ANALYSIS AND FINDINGS

Selection of Indicators

The first step in the analysis of the available data was selection of indicators. As previously mentioned, the pool of all possible indicators was taken from the previous literature concerning the use of indicators in monitoring degradation. Indicators were also selected on the basis of suitability to the specific conditions and socio-political context of Rwanda. All analysis was done on the spatial scale of the commune. A commune is a lower political unit in Rwanda, of which there are one hundred forty-three. The commune is analogous to a county in the United States.

For this study four physical and four human variables were selected to illustrate the approaches to monitoring land degradation. The physical variables chosen include mean annual rainfall, propensity to erode, soil capability, and intensity of cultivation. Mean annual rainfall in millimeters was available in raw data form[4]. The data is the average for the years 1929-1988. Rainfall was chosen as an indicator because although Rwanda is not a dryland area, rainfall is still a limiting factor in areas. Rwanda depends almost totally on agriculture, and the effect of rainfall on agricultural options is important. Climate must be included in some form in any attempt to monitor human-environment interaction, and in this case, rainfall was chosen as a surrogate for climate.

The "propensity to erode" variable is the weighted sum of two variables taken from GIS data[5]. This indicator was not available as an average per commune within the data set itself, but rather, was calculated from available data. Rainfall and slope variables were summed and multiplied by the area in each polygon in the GIS data. These sums were then added together for the entire commune and divided by the total area of the commune. Both variables were divided into six sub-classes for each variable before the data was summed. As a result, the highest possible score in the propensity to erode is twelve (Table 2).

This indicator was chosen because Rwanda is a country with high relief in which steep slopes are often farmed. Cultivation in these conditions is limited by erosion. According to Clay and Lewis (1990), the most serious declines in productivity in Rwanda are on the slopes of 15 degrees or more. Most soil loss equations are derived in the temperate latitudes and reflect farming practices analogous to the United States. There is no intensive soil loss equation for the tropics and all soil loss equations, even the United States models, are generally useful only where exact conditions to those used in test plots

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[4]This variable was calculated by the Michigan State University Rwanda Society-Environment Project from statistics in MINITRAP, 1992.

[5]In this case some of the data was in digital form and had to be interpolated from the polygons in ARCINFO.

Table 2: Slope and Rain Classes

Slope Classes

1) 0 - 2 %
2) 2 - 6 %
3) 6 - 13 %
4) 13 - 25 %
5) 25 - 55 %
6) > 55%)

Rain Classes (mm per commune average)

1) 745 - 1041
2) 1042 - 1150
3) 1151 - 1250
4) 1251 - 1298
5) 1299 - 1354
6) 1355 - 1545

are replicated. The propensity to erode is also a somewhat crude variable, but areas recognized by high scores are more susceptible to erosion if proper care is not taken. Conservation measures such as choice of crops with low C- values[6] or erosion ditches and terracing can help to prevent erosion. These measures can be labor and/or capital intensive, though, and are not assumed for all areas. This variable then, simply targets areas with highest potential for degradation due to soil erosion and its associated effects.

The third physical variable is soil capability, which was derived from digital data and associated polygons[7]. Soil capability is also a variable weighted by area. Potential soil capability was divided by actual soil capability and this number was then multiplied by the area of the polygon. The sum of the weighted products was then computed and divided by the total unweighted area. This variable is essentially the ratio of the actual capability has to the potential the soil has in an area. Because the classes decreased in potential as value of the capability rose in each variable the reciprocal ratio of the intended ratio was used. Thus, the soils with the highest potential and actual capabilities had the lowest class numbers (Table 3). The given formula provided a measure of the degree to which the soil was being used compared to its potential capability. For example an area that had an actual capability of 4 and a potential of 2 was considered as only being maintained at 50 percent of its potential capability. Although averaging this data which is computed from smaller spatial units (soil unit level) is crude, it is offset by the use of the weighting by

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[6] A c-value is the ratio of soil loss from an area with a specified cover (vegetation\ crop mix) to the soil loss from that same area if it were in continuous fallow (Clay and Lewis, 1990).
[7] These values are derived from Carte Pedologique du Rwanda (1992).

Table 3: Soil Capability Classes

--Actual and potential soil capability classes bound by most limiting soil variable.
--Potential is determined by the class the soil would be if all possible soil improvements were to be made.

1--Very suitable for most crops but unsuitable for tea. Unsuitable in current conditions for rice, but with improvements could be suitable for irrigated rice.

2--Very suitable for most crops, but marginally suitable for tea. Unsuitable in current condition for rice, but with improvements could be suitable for irrigated rice.

3--Medium suitable for most crops, but marginally suitable for tea. Unsuitable in current conditions for rice, but with improvements could be suitable for irrigated rice.

4--Marginally suitable. Unsuitable for demanding crops, but marginally suitable for less demanding crops. The deeper soils are very suitable for tea.

5--Suitable for pasture, and for appropriate valley crops during the dry season. Also suitable for irrigated rice and tea.

6--Suitable for pasture. Unsuitable as arable land in current conditions, but suitable for less demanding to demanding crops with major improvements.

7--Suitable for forest. Unsuitable as arable land in current conditions, but suitable for less demanding to demanding crops with major improvements.

8--Very intense limitations. This class evaluated according to soil depth (shallow, medium, deep).

(From: Carte Pedologique du Rwanda (1992) as reported in Rwanda Society-Environment Project, 1994.)

area. This variable was chosen to target areas where the soils were not as productive as they could potentially be. This indicator is basically a surrogate for soil health. The larger the difference between what could be grown given the full potential of the soil and what the soil can sustain in reality the lower the resulting percentage.

The last physical variable is intensity, which was computed from two raw data variables, total available area in a commune and the area being cultivated. The cultivated area was divided by the total available area to provide a measure of how much land was still available for farming. Rwanda is a country in which sons inherit land from their fathers. When the population begins to become too large, the first response is for people to move to unoccupied, uncultivated areas. When all available land is taken the practice of inheritance continues farm size begins to shrink and farms become fragmented. This indicator then is a measure of the pressure on the available land in a commune. It measures the ability of the commune to absorb a growing population as well as to accommodate agriculture.

The four socio-economic variables chosen include population density, agricultural yield, amount of tubers grown, and migration. The first of these variables, population density, was taken from raw data for the year 1991 and is the number of persons per square kilometer. In any situation where subsistence farming is the major activity of the population, density and distribution of the population can have strong influences on opportunities and options for farmers. Density can reduce available land for fallow, growing of fodder, and wood fuel, as well as, for gifts to sons (May 1995). Population density is not directly attributable to environmental stress. Intensification of agriculture can alleviate problems and according to Boserup (1965) may even be a catalyst for technological innovation. Often, though, intensification and innovation are limited by capital, both human and financial. In this case, however, the assumption is that density may have some effect on alternatives available to farmers. It limits the use of extensification as a mitigating strategy and, if the rate of technology adaptation is less than the rate at which density is rising, then intensification may not be enough to prevent degradation. In conclusion, density is included because of its potential to impact agricultural societies more heavily than those that are more diversified.

Yield is an indicator taken directly from raw data (MINAGRI 1989)[8]. This variable is the total agricultural production per commune in kilocalories. The data in this case was already adjusted in the previous study for size of commune. So in this case yield is defined as output per hectare for the commune. Yield was chosen as an indicator, once again, because Rwanda is an agriculturally based society. Higher yields per unit theoretically indicate that soils are more fertile or that more efficient agricultural techniques are being practiced (i.e. higher yielding varieties being used, intercropping, etc.). Yield should give a measure of the overall agricultural health of a commune.

The next indicator chosen was a surrogate for tuber production. This variable is the sum of manioc (cassava) and sweet potatoes grown in a commune divided by the total

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[8] Data are for the year 1987.

cultivated area (MINAGRI 1989). According to Clay and Lewis (1990), tubers are planted when soil productivity declines and/or land holdings become insufficient for other more land extensive crops. Tubers have a higher caloric value and grow in even highly degraded soils. Olson (1994) has suggested from research in Rwanda that manioc is the choice of farmers when few other cropping options exist. Manioc, as well as, sweet potatoes are often grown in Rwanda because of their hardiness and ability to feed larger quantities of individuals. This indicator is also related to the propensity to erode. Tubers have a relatively low C-value, reflecting a minimal amount of protection by the plants to soil from erosion. According to Lewis (1988), the presence of manioc in certain areas, especially those of moderate to steep slopes, generally is indicative of soil loss and degradation. Only manioc and sweet potatoes as undesirable because in reasons for increasing/decreasing areas under certain crops, white potatoes were mentioned as having monetary value (Olson 1994). In these same interviews, the main reason for increasing area under sweet potatoes and cassava were because of their value as an inexpensive food source adapted to poor soils (Olson 1994). Land under these two crops significantly increased in areas where the perception was that productivity of the land was declining (Olson 1994). This indicator points to a change in people's behavior as a response to degrading conditions when measured along with other accepted indicators of land degradation. Interviews have shown that the tubers used in this variable are not planted as a source of monetary income. The taste is not preferred compared to other foods and that the main reason for growing is to compensate for lower soil productivity (Olson 1994). These reasons combined suggest that the use of tubers as an indicator of degradation is a rational decision and reflect the context of Rwandan agriculture.

The migration variable was computed from the rates of population growth from 1978-1991. This was the best amount of time for which census information was available, because it is closest to the time period being monitored for the rest of the indicators. Data for 1987 was included in the available set, but the 1987 data were estimated. In this study, the use of actual data as opposed to derived was preferred, because of the loss of accuracy already incurred in scoring for the matrix. The data for population growth was divided by considering observations less that one-half standard deviation from the mean as out-migration and those above one-half standard deviation as in-migration. In this indicator out-migration is considered a sign of, or reaction to, environmental or social stress. Olson (1990) argued that migration patterns may reflect degrees of environmental stress. Areas of perceived low stress attract people from areas of high density or environmental stress because of the availability of land in the low stress or density areas. Olson (1990) also suggests that in-migration may have future effects upon the area depending upon the choice of livelihood and degree of technology available. The out-migration portion of the data, then, was considered the most indicative of degradation. The communes with a rate suggesting in-migration were considered to be potentially degraded in the future. And finally, areas where the rate of growth near the average were considered to be most stable and perceived as the best case scenario.

Adjustments in Matrix

Some adjustment was necessary to the matrix because of the characteristics of the available data. The first of these changes was in the occurrence/ lack of occurrence tally system. Without baseline values (i.e., what is the normal level) for each variable there was no starting point with which to compare observations. It was observed within this analysis that without some sort of knowledge concerning the maximum level a variable may reach before it is considered a problem, there was no way to define occurrence and lack of occurrence. The problem was exacerbated by the lack of time series data. Observations could not be compared over time to look for continuous increases in severity of a variable which could have been interpreted as occurrence. To compensate for this problem the data was divided into three classes. The classes were derived by separating data into thirds by using one-half standard deviation from the mean as the break between classes. In each indicator, the observations were given ranks from one to three suggesting severity relative to the rest of the communes. The rank of one suggested the least problematic observations and three indicates a problem area. The assumption here is that the relative values at one time period will target areas of most degradation concerning that indicator. This adds a degree of robustness to the matrix by giving weights not only to the specific indicators, but also to observations within those indicators.

This made changing critical CDLI values necessary. The new critical values reflect both the relative scores from the communes in the final analysis using the matrix and the total of hypothetical scores possible (Table 4). The lowest possible score for any commune is 100 reflecting a commune that was in the "best" categories for every indicator. The highest/ worst possible score theoretically is 900 reflecting assignment to the three category in every indicator instance. Critical evaluation of scores will be more useful using the observed values computed for each commune, as it will show the relative level of degradation compared to the rest of the country. Classes were divided into groups based on one-half standard deviation increments. Each successive class is an increase in the critical score of one-half standard deviation.

Table 4: Adjusted Critical Values for CDLI

Scores	Relative Situation
100 - 200	Least Degradation
251 - 350	Slight Degradation
351 - 450	Minor Degradation
451 - 550	Intermediate Degradation
551 - 650	Significant Degradation
651 - 800	Severe Degradation
801 - 900	Most Degraded

**Classification of scores is relative to scores within Rwanda.

Only one period of analysis is possible due to availability of data. This made the use of the Pearson's r-value unnecessary. The Pearson's r is only of value when data can be compared over a long monitoring period where observed values can be analyzed over time. The addition of the weighting within indicators compensates for the removal of the Pearson's r-value as well.

Data Analysis

The first step in the analysis of the data was to score each observation within each indicator for relative severity. As previously mentioned, this was accomplished by dividing the data into thirds based on breaks one-half standard deviation from the mean. One was the score given to those observations falling into the "best" category and three was the score of areas with the relatively "worst" situation.

The next step was the summation of the matrix for each commune. An equation was derived where the scores of each observation would be weighted, multiplied by its human or physical match, and summed for the entire matrix. This equation is as follows:

$$(h1w1)(p1w1) + (h2w2)(p1w1) + (h3w3)(p1w1) + (h4w4)(p1w1) +$$
$$(h1w1)(p2w2) + (h2w2)(p2w2) + (h3w3)(p2w2) + (h4w4)(p2w2) +$$
$$(h1w1)(p3w3) + (h2w2)(p3w3) + (h3w3)(p3w3) + (h4w4)(p3w3) +$$
$$(h1w1)(p4w4) + (h2w2)(p4w4) + (h3w3)(p4w4) + (h4w4)(p4w4) = \text{score}$$

where: h1 = observation for intensity
h2 = observation for yield
h3 = observation for tubers
h4 = observation for migration
p1 = observation for rainfall
p2 = observation for propensity to erode
p3 = observation for capability
p4 = observation for intensity
w1 = weight of 1
w2 = weight of 2
w3 = weight of 3
w4 = weight of 4

The resultant scores computed for the matrices of the 143 communes in Rwanda ranged from a minimum of 120 to a maximum of 784. The mean was 395 with a standard deviation of 141. The scores were mapped (Figure 4) and regional patterns were able to be identified. The highest scores relative to the rest of the country were in the Northwest and the Southwest. The lowest scores, or best situations for the time period monitored, were in the Eastern part of the country. The Central part of the country had mixed values, as did the far Southwest near Lake Kivu. The categories for the map were once again aggregated as to compare relative scores. Each increase in class is a one-half standard deviation increase in the scores.

Comparisons

The first comparison that should be made is to that of the findings of the Rwanda Society-Environment Project. Campbell (1994a) used three indicators to calculate a summary environmental stress score. These indicators were calorie production in 1987 as a percent of need within the commune, potential additional calorie production, and uncropped arable land. These three indicators were standardized and the z-scores were summed to find an environmental stress score for each commune. The comparison of these scores with the scores from the matrix became the most important element in the data analysis, because of the element of "ground truth" it added to the matrix scores. The stress scores for each commune were verified to be true both regionally and on the commune level by colleagues of the project authors living in Rwanda (Campbell 1994a).

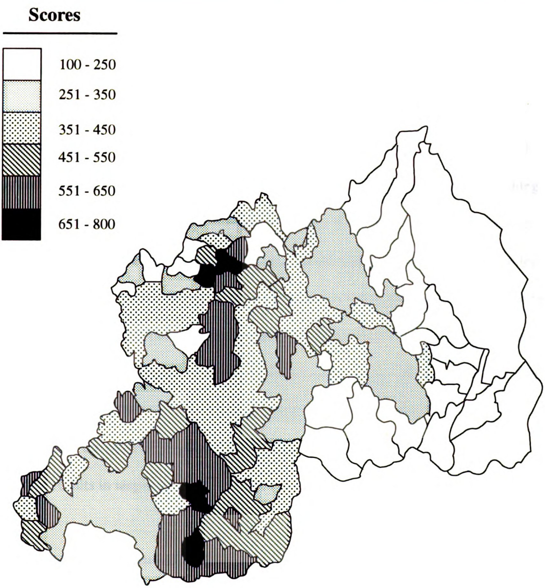

Figure 4: Map of Matrix Scores

The matrix scores, when compared to relative regional patterns of the original environmental stress scores (Figure 5, Campbell, 1994a), are similar over most of the country. Both measures have low scores in the east and high scores in the southwest. The only area of the country that differs is the northwest. The region as a whole is not significantly different, but some communes do differ from those of the environmental stress summary scores. The Rwandan colleagues of the original project authors had cautioned that the maps they were shown were univariate and suggested a more integrated process of analysis be considered (Campbell 1994a). Comments by those knowledgeable about the situation in Rwanda reflect concern that the summary scores were not integrated enough. These comments encouraged my continued belief in the validity of the matrix scores. The differences between the summary stress scores of the original project and the matrix scores are only slight. I believe the matrix scores to be reliable because of their regional patterns reflecting the acknowledged areas of high stress by the Rwandan colleagues of the original project authors. In general the matrix seemed to produce effective results in targeting areas of stress present during the period being monitored.

Correlations were run on the variables that were chosen for use in the matrix. The results seem to suggest that the hypotheses concerning relationships were correct. The first of these correlations was the negative relationship between out-migration and tuber production. The original hypotheses for using these variables was that degrading areas will have higher tuber production and low population growth rate interpreted as out-migration. The negative correlation in this case results from the use of the real data as

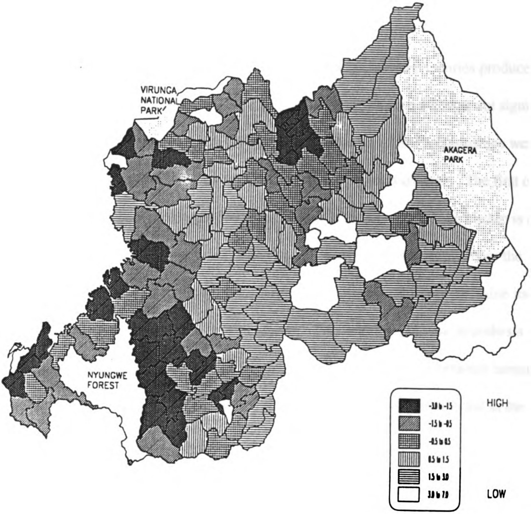

Figure 5: Map of Summary Environmental Stress Scores
(Source: Campbell 1994a)

opposed to the scores. High values on population growth (in-migration) correlated with low values in tuber production. The opposite relationship can also be considered true, that is, high tuber production is correlated with out-migration. This was found to be an important point in justifying the use of these two indicators within the matrix.

The next correlations found positive relationships between calories produced in the commune and level of intensity. This relationship seems intuitive and was not significant in the justification for use of the variable within the matrix. Three relationships were found to be statistically significant though regarding physical variables. The first of these is the relationship between propensity to erode and capability. This relationship is a negative one, because large erosion values are correlated with the areas where the disparity between actual and potential erosion is the greatest, or rather the value itself is small because it is a percentage of its potential. This also supports the hypothesis in the original selection of the indicators that areas without significant conservation measures would have a better chance of being degraded. This degradation is reflected in the small value for the capability.

Rainfall and propensity to erode are also significantly positively correlated, but this relationship is also an intuitive one. Both of the indicators here are based on rainfall, at least in part, and should be correlated. Soil capability and rainfall were also found to be significantly negatively correlated. The hypothesis here is that areas of less degradation will receive relatively high amounts of rainfall. This hypothesis is confirmed in that high capability values (actual and potential capability equal) were correlated with areas that actually received lower rainfall totals. Although this is counter to the hypothesis, I still feel rainfall is important. The low rainfall areas here are those of less population and intensity so the difference between the condition the soil could be in and the condition the soil is actually in is a relatively small one. So although the correlation did not confirm my hypothesis, it does help to confirm matrix findings. It should be kept in mind also that rainfall was given the lowest weight, or least importance, in the weighting system because of this lack of significance to the causation of degradation. All of these correlations usually confirming hypotheses about individual indicators, have furthered the explanation and validity of matrix scores as shown in spatial patterns on the Rwandan landscape.

Regressions

Two regressions were performed on the indicators used within the matrix. In one the matrix scores were used as the dependent variable and in the second the environmental summary stress score from the original project was the dependent. In the regression performed on the stress scores by Campbell, the equation itself was found to be significant (F-ratio), but problems were encountered concerning the independence of variables and the heteroscedasticity of residuals. The tolerance values in all except for tuber production were too low to consider the indicators as independent. This was especially pronounced, as it should be, with the related variables of rainfall and erosion. The adjusted r-squared of .657 was high, but not enough to be considered statistically significant. The overall regression using these variables was strong, but some problems such as tolerance make the findings suspect.

The regression performed using the scores from the matrix had a higher adjusted r-squared at .794. The overall equation (F-ratio) was still significantly high, but tolerance problems were the main concern. The tolerance values in this case were higher, but only two were found to be significantly independent (tubers, population density). The residuals in this case all fit the necessary criteria (homoscedastic, normal, and probability plot in a diagonal line). The independent variables here, with the exclusion of rain and erosion, were all statistically significant to the 95 percent confidence level. Overall the linear regression in the second case, that of the matrix scores, fit the model better than that of the summary scores (Table 5).

Principal Components Analysis

Two principal components analyses were performed; one was exploratory and the other specifically examines the indicators used within the matrix. The exploratory PCA[9] analysis was done to look for surrogate indicators. The variables used in this analysis were greater in number than those used in the matrix. The pool of the variables best suited to indicator use were selected and put through a principle components analysis.

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[9] PCA denotes Principal Components Analysis.

Table 5: Regression Results

Dependent Variable: Matrix Scores

Independent Variables:

	Tolerance	T-Value	Prob Value
Constant	0.000	7.780	0.000
Rain	0.096	-1.475	0.143
Erosion	0.080	2.097	0.038
Capability	0.438	-5.086	0.000
Migration	0.508	-4.693	0.000
Pop. Density	0.828	2.011	0.046
Intensity	0.456	7.295	0.000
Total Kcal	0.482	-3.840	0.000
Tubers	0.713	7.816	0.000

Adjusted r2 = .794   F-Ratio = 69.472   Probability F = 0.000

Dependent Variable: Summary Stress Scores

Independent Variables:

	Tolerance	T-Value	Prob Value
Constant	0.000	-5.815	0.000
Rain	0.093	-0.279	0.780
Erosion	0.080	-1.386	0.168
Capability	0.437	2.439	0.016
Migration	0.552	4.867	0.000
Pop. Density	0.390	-7.125	0.000
Intensity	0.306	5.714	0.000
Total Kcal	0.479	1.579	0.117
Tubers	0.723	5.825	0.000

Adjusted r2 = .657   F-Ratio = 33.774   Probability F = 0.000

The loadings were saved and analyzed for the most significant in each dimension (Table 6). The high loadings in the first dimension represented the same as those of the principal components using only the indicators included in the matrix analysis. These high loadings in the first dimension represented physical variables including rainfall, erosion, and capability. In the PCA on all possible variables, income and percent of calories needed produced in the commune also had significantly high loadings. This appearance of the first dimension to be related to physical characteristics of a commune furthers the justification for using physical indicators in monitoring for land degradation.

The second dimension loaded highly in the PCA of all possible variables on variables involving tuber production. Manioc, tubers, and sweet potatoes all had positive loadings, while white potatoes showed a negative loading. This reinforces my conclusion that white potatoes are a tuber unlike sweet potatoes and manioc. I had earlier based my hypothesis concerning tubers and the differences in use on previous work by Olson (1994) and this dimension of the PCA seems to confirm the hypothesis that white potatoes are not highly related to tuber production. The second dimension in the PCA, on only the matrix variables, was mainly one of agricultural production. Tubers, intensity, and total production in kilocalories were the three highest loading variables.

The third dimension in the overall PCA was concerned with stress in land use. The high loading variables here were intensity, population density, total production in kilocalories, and land remaining uncropped. The third dimension in the PCA concerning

Table 6: Principal Components Loadings

Only Matrix Indicators

Dimension	1	2	3
Indicator			
Rain	0.856	0.339	-0.194
Migration	-0.570	0.042	-0.680
Pop. Density	-0.099	0.293	-0.543
Total Kcal	-0.491	0.702	0.198
Erosion	0.885	0.254	-0.256
Capability	-0.804	-0.107	0.168
Intensity	0.030	0.768	0.513
Tubers	0.441	-0.515	0.380
Percent of Variance Explained	36.695	20.322	16.696

All Possible Indicators

Dimension	1	2	3
Indicator			
Elevation	0.855	-0.278	-0.027
Rain	0.907	0.100	0.043
Migration	-0.376	-0.642	-0.083
Pop. Density	0.460	0.073	0.622
Income	-0.694	-0.322	0.228
Total Kcal	-0.303	-0.272	0.710
Kcal Needed	-0.682	0.417	0.399
Cattle Number	-0.401	0.143	-0.569
Sweet Potatoes (pc)	0.132	0.820	0.014
Irish Potatoes (pc)	0.427	-0.559	0.129
Manioc (pc)	-0.507	0.586	-0.109
Land Remaining	0.001	-0.388	-0.688
Erosion	0.902	0.094	-0.044
Capability	-0.688	-0.293	0.072
Intensity	0.082	0.286	0.888
Tubers	0.032	0.834	-0.361
Percent of Variance Explained	30.357	20.179	17.890

only the matrix variables was similar in that population density and intensity both loaded highly, but population growth was also high here.

My conclusions from running both the exploratory and analytical PCA were that the indicators selected for the matrix were roughly equivalent to the best of the available pool. In both analyses, physical characteristics included in the matrix, variables related to agricultural production, and variables related to population density were found to be significant components. The indicators chosen for the matrix seem to reflect the surrogate dimensions discovered through the principal components analysis as these three dimensions were accounted for in the matrix.

CHAPTER V

SUMMARY AND CONCLUSIONS

This thesis has attempted to assess the efficiency of various methods of monitoring land degradation. This was accomplished through comparison of results from three different methods (PCA, regression, and matrix) with results from the Rwanda Society-Environment Project through which the original data was compiled. The use of indicators has been suggested and justified in previous research. The use of regional political ecology as a framework for investigation of suitable indicators for monitoring has proven to be useful. Historical, political, environmental and socio-economic contexts were taken into consideration when selecting indicators relevant to the specific Rwandan situation at the time of data collection.

Variables chosen as indicators were ranked according to severity. In the final matrix analysis, the resulting scores were also ranked relative to the rest of the country. The matrix also has a weighting system to rank indicators according to severity along both the x and y-axes. By ranking observations within the indicators chosen, identification of areas of greatest potential degradation can be achieved. A constraint in using this adjusted matrix system is that the matrix scores can only be compared with those in the rest of the country. Because all elements of the adjusted matrix are relative to the observations and indicators used, comparisons cannot be made across areas not included in the specific matrix. For example, matrix scores from Rwanda cannot be compared with those of Sudan because of differences in climate, agricultural practices, etc. (Batie, ed., 1995). Not only would scores be different, but so would the indicators chosen for analysis.

The matrix analysis included in this thesis also included scores for only one time period due to data availability. This analysis did show the utility of using the matrix to target areas, but whether this process can be continually integrated to continue monitoring over time has yet to be proven. The results of the Rwanda Society-Environment Project were used as "ground-truth" information in comparing the matrix scores to the probable real-world situation in Rwanda at the time of data collection. The scores computed within the matrix analysis were similar to the patterns found in the original project and as such should be considered to resemble the situation in Rwanda.

In comparing both the results and the functions of the different methods of analysis, the matrix was found to be the most useful for both data analysis and visualizing results. Maps of the matrix scores for the country are efficient in showing areas of least and most degradation. The mathematical concepts behind the matrix are also easier to conceptualize than those of regression and PCA. The computations could possibly be done with only a simple calculator, while the other methods (PCA and regression) require computers and a statistical background to perform analysis and interpret results. Regression was found to be the least useful in analyzing indicator interaction. Principal components was found to have value as an exploratory tool for finding indicators or surrogate, composite indicators from available data. Within this analysis, agriculture, population density, and physical characteristics of the country were found to be the dimensions explaining the greater part of the variance of the data set. Within these three dimension, indicators picked for use in the matrix had high loading suggesting that they were appropriately picked.

Principal components could be used in available data sets to help to validate indicators chosen for use within the analysis. Caution should be exercised though, in that PCA alone can suggest indicators, but suitability for use must also be considered. Previous literature and theory should guide the initial selection of indicators in order to incorporate suitability of indicator to the study area.

Data Gaps

The most important problem encountered in this analysis was the use of data from different spatial scales. Two of the indicators chosen were taken from soils data. This then had to be weighted and averaged to coincide with the other data. By aggregating to larger spatial units much of the detail and data validity was lost. Political boundaries are the most often used level of analysis because of ease of collection for different agencies, as these units are the most commonly recognized. The problems that can be encountered by using political units, though, is that they may overlap more than one environmental category. Depending on the level of political unit, there maybe steep hills, forests, and grass lands all included within one region. This makes analysis of physical variables difficult to analyze. This problem is also encountered with socio-economic interaction when groups of people with different sociological characteristics are both included in a single political region for analysis. These different traits could include farming practices, land tenure systems, etc.

Another problem encountered in analyzing data is that much of the data is collected by different agencies. As a result, duplication of collection may be encountered, different levels of sampling may be practiced, and different levels of access to the public for integrative analysis may occur. There seems to be no integrative, focused system of monitoring human-environmental problems. Often socio-economic data is collected, but is only used for analysis concerning socio-economic phenomena rather than as part of a larger system. A system, or ministry, needs to be established to organize data collection and sharing. Targets for monitoring need to be set as well. A larger matrix system might provide some conceptual insight into data needs for monitoring land degradation, while at the same time collecting information for other purposes (economic reports, natural resource reports, etc.).

Within the available data set, the indicator found to be missing that could have added the most to the analysis generally concerned vegetation. It is possible to measure vegetation as biomass, or with a leaf area index, through the use of remote sensing. Other physical variables such as soil moisture and albedo also could be measured through use of remote sensing platforms. The costs of monitoring are the most prohibitive factor here, as this type of data would be costly for countries that are already economically stressed. If an optimal data set were to be established, though, a more complete overall vegetative indicator, either biomass or health, would have to be included.

Conclusions and Work Still to be Done

The matrix framework for monitoring land degradation has been found within this case study to be a useful statistical and conceptual tool for targeting areas of land degradation within a country. The mathematical computations and graphic visualizations of the matrix make it a useful instrument for those that lack a statistical background. The results are also easy to interpret, as they are not as abstract as those of regression or PCA. The results can be easily mapped to show areas of high and low stress, and these results can be communicated to an informed audience. The simplicity of the matrix is its strongest point.

There are weaknesses in this method. The reliance on relative measures means that the results can not be compared to other regions. This, along with the subjectivity of indicator rankings along the axes based on perceived severity, make the matrix method one that could give misleading results if caution is not exercised. The matrix still needs to be tested on other areas and with other available data sets to identify key groups of indicators that might be collected. The temporal element of the matrix also needs to be tested in the future to evaluate the monitoring potential of the matrix in the long term. These could not be accomplished with this thesis alone.

It is important in using this method to remember that the context, sociological, economic, environmental, and political is key to selecting indicators. That is why the use of regional political ecology for exploring the problem at hand is necessary before indicators can be selected, as well as, for interpretation of results. Indicators were selected based on characteristics specific to Rwanda. As such, the results can be interpreted to represent the relative power of these forces in action within each commune. The national degradation surface represents the relative magnitude of these indicators and their collective power in interaction. Political ecology helps both to construct the matrix, as well as, to deconstruct results in order for their component parts to be interpreted.

In conclusion, the matrix seems to have value and utility as a conceptual and analytical tool for a broad group of users as compared to regression and principal components analysis. The results of the matrix are easily communicated and mathematical concepts kept simplified. The matrix framework, in conjunction with regional political ecology, could be an effective method for targeting areas of highest land degradation within a country relative to other areas. This may facilitate early remediation of high stress situation areas. Work is still necessary to find the full capabilities of the matrix framework, but to this point it seems a valuable tool for general targeting of potential areas of land degradation.

LIST OF REFERENCES

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Arizpe, Lourdes, M. Priscilla Stone, and David C. Major, eds. 1994. Population and Environment: Rethinking the Debate. Boulder, CO: Westview Press.

Batie, Sandra S. ed. 1995. Developing Indicators for Environmental Sustainability: The Nuts and Bolts. Washington, D.C.: The Resource Policy Consortium.

Berry, Leonard. 1996. "Dryland Assessment and Monitoring for Sustainable Development." Draft of Proposal to UNSO/UNEP.

Berry, Leonard, and R.B. Ford. 1977. Recommendations for a System to Monitor Critical Indicators in Areas Prone to Desertification. Program for International Development and Change, Worcheter, Massachusetts: Clark University.

Bierly, Gregory, and Julia Flagg. 1995. Development of a Composite Index for Desertification. In Papers and Proceedings of Applied Geography Conferences, ed. F. Andrew Schoolmaster. v. 18.

Bilsborrow, Richard E., and H.W.O. Okoth Ogendo. 1992. Population-driven Changes in Land Use in Developing Countries. Ambio v. 21, n. 1, pp. 37- 45.

Blaikie, Piers, and Harold Brookfield. 1987. Land Degradation and Society. London: Methuen.

Boserup, Ester. 1965. The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure. London: Earthscan Publications, Ltd.

Campbell, David J. 1994a. "Environmental Stress in Rwanda No. 1: Preliminary Analysis." Rwanda Society-Environment Project, Working Paper 4.

-------------. 1994b. "Conceptualizing Global Change as Society-Environment Interaction: From the Local to the Global in Rwanda." Rwanda Society-Environment Project, Working Paper 6.

Campbell, David J., Len Berry, and Noberto Fernandez. 1994. "Institutional Structures to Facilitate Data Collection, Management and Analysis for NRM in Sub-Saharan Africa." Rwanda Society-Environment Project, Working Paper 9.

Clay, Daniel C. and Laurence A. Lewis 1990. Land Use, Soil Loss, and Sustainable Agriculture in Rwanda. Human Ecology v. 18, n. 2, pp. 147-161.

Davis, Kingsley. 1963. The Theory of Change and Response in Modern Demographic History. Population Index v. 29, pp. 345-366.

Ervin, David E., Sandra S. Batie, and Marie Livingston. 1995. In Developing Indicators For Environmental Sustainability: The Nuts and Bolts. ed. Sandra S. Batie. Washington, D.C.: Resource Policy Consortium.

Ford, Robert E. 1993. "Marginal Coping in Extreme Land Pressures: Ruhengeri, Rwanda" Chapter 5 in Population Growth and Agricultural Change in Africa. B.L. Turner II, Goran Hyden, and Robert W. Kates, eds. Gainesville: University of Florida Press.

Giddens, Anthony. 1979. Central Problems in Social Theory: Action, Structure and Contradiction in Social Analysis. Berkeley: University of California Press.

Hammond, Allen, Albert Adriaanse, Eric Rodenburg, Dirk Bryant, and Richard Woodward. 1995. Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development. Washington, D.C.: World Resources Institute.

Huntington, Ellsworth. 1922. Climate and Civilization. New Haven: Yale University Press.

Kates, Robert W. 1971. Natural Hazard in Human Ecological Perspective: Hypotheses and Models. Economic Geography v. 47, pp. 438-451.

Krugmann, Hartmut. 1996. In Grassroots Indicators for Desertification: Experience and Perspectives from Eastern and Southern Africa. eds. Helen Hambly and Tobias Onweng Angura. Ottawa: International Development Research Center.

Lewis, Laurence A. 1988. Measurement and Assessment of Soil Loss in Rwanda." Catena Supplement 12, 151-165.

Lewis, Laurence. 1994. "Environmental Data Needs for Assessing Agricultural Land Degradation in the Rwandan Context" Rwanda Society-Environment Project, Working Paper 10.

Mabutt, J.A. 1986. Desertification Indicators. Climatic Change v. 9, pp. 113-122.

Massey, Doreen B. 1984. Spatial Division of Labour: Social Structures and the Geography of Production London: Macmillan.

May, John F. 1995. Policies on Population, Land Use, and Environment in Rwanda. Population and Environment: A Journal of Interdisciplinary Studies v. 16, n. 4, pp. 321-324.

Min. de l'Agriculture (MINIGRI). 1989. Production agricole en 1987: Bilan d'autosufficance alimentaire par commune et par habitant. Kigali, Rwanda: Ministere de l'Agriculture, de l'Elevage et des Forets.

Min. du Plan (MINIPLAN). 1992. Recensement general de la population de l'habitat au 15 aout 1991: Analyse des princepaux resultats (echantillon au 10eme). Kigali, Rwanda: Minstere du Plan, Service National de Recensement.

Nyrop, Richard F., Lyle E. Brenneman, Roy V. Hibbs, Charlene A. James, Susan MacKnight, Gordon C. McDonald. 1969. Area Handbook for Rwanda. Washington, D.C.: The American University.

Olson, Jennifer Maria. 1990. The Impacts of Changing Socio-Economic Factors on Migration Patterns in Rwanda. M.A. Thesis, Michigan State University, East Lansing, MI.

-----------. 1994. Farmer Responses to Land Degradation in Gikonoro, Rwanda. Ph.D. Dissertation, Michigan State University, East Lansing, MI.

------------ 1995. Behind the Recent Tragedy in Rwanda. GeoJournal v. 35, n. 2, pp. 217-222.

Olson, Jennifer M., Gichana Manyara, David J. Campbell, and David P. Lusch with Daniel G. Brown, and Jue Hu. 1996. Exploring Methods for Integrating Data on Socio-Economic and Environmental Processes that Influence Land Use Change: A Pilot Project. Report to the Biodiversity Support Program, World Wildlife Fund.

Palm, Risa. 1990. Natural Hazards: An Integrative Framework for Research and Planning. Baltimore, MD: The Johns Hopkins University Press.

Pearce, David, Kirk Hamilton, and Giles Atkinson. 1995. Indicators for Sustainable Development: Economic Principles as Informed by Ecology. In Developing Indicators For Environmental Sustainability: The Nuts and Bolts. Sandra S. Batie, ed. Washington, D.C.: The Resource Policy Consortium.

Peet, Richard and Nigel Thrift, eds. 1989. New Models in Geography: The Political-Economy Perspective. Vol. I &II. London: Unwin Hyman.

Peet, Richard, and Michael Watts. 1993. Development Theory and Environment in an Age of Market triumphalism. Economic Geography 69 (3): pp. 227-253.

Reining, Patricia. 1978. Handbook on Desertification Indicators. Washington, D.C.: American Association for the Advancement of Science.

Semple, Ellen. 1903. American History and It's Geographic Conditions. Boston: Houghton Mifflin.

Tiffen, Mary, Michael Mortimore, and Francis Gichuki. 1994. More People, Less Erosion: Environmental Recovery in Kenya. New York, NY: John Wiley & Sons Ltd..

Wangati, Frederick J. 1996. Approaches and Methodology for Land Degradation Assessment and Mapping at National Level: The Kenyan Case Study. Nairobi: UNEP/DEDC-PAC.