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Environmental Security: A Geographic Information System Analysis Approach—The Case of Kenya

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ABSTRACT / Studies into the relationships between environmental factors and violence or conflicts constitute a very debated research field called environmental security. Several authors think that environmental scarcity, which is scarcity of renewable resources, can contribute to generate violence or social unrest, particularly within states scarcely endowed with technical know-how and social structures, such as developing countries. In this work, we referred to the theoretical model developed by the Environmental Change and Acute Conflict Project. Our goal was to use easily available spatial databases to map the various sources of environmental scarcity through geographic information systems, in order to locate the areas apparently most at risk of suffering negative social effects and their consequences in terms of internal security. The analysis was carried out at a subnational level and applied to the case of Kenya. A first phase of the work included a careful selection of databases relative to renewable resources. Spatial operations among these data allowed us to obtain new information on the availability of renewable resources (cropland, forests, water), on the present and foreseen demographic pressure, as well as on the social and technical ingenuity. The results made it possible to identify areas suffering from scarcity of one or more renewable resources, indicating different levels of gravity. Accounts from Kenya seem to confirm our results, reporting clashes between tribal groups over the access to scarce resources in areas that our work showed to be at high risk.

Since 1945, an increase in the number of domestic armed conflicts has been observed. Internal conflict has been the dominant form of conflict throughout most of the post-World War II period. Most of these conflicts took place in developing countries often affected by severe environmental degradation (Hauge and Ellingsen 1998). Gleditsch and others (2002), in their analysis of data relating to 220 violent conflicts that took place between 1946 and 2000, noted that 157 among them were intrastate conflicts and, in general, they observed a significant preponderance of conflicts classifiable as ''minor'' and ''intermediate'' compared with ''traditional'' wars. These ''new'' kinds of conflict present some peculiar characteristics: They are prevalently internal to states, present widespread and persistent violence, and have a high number of victims. In addition, these wars are fought by paramilitary and irregular groups and generally involve technologically low-level weapons.

Agriculture and natural resources availability seem to play an important role in many of these events of acute violence, which often occur in rural areas. Statistical data demonstrate that the more a state's economy depends on the agricultural sector, the more probable it is that these kinds of conflict occur (De Soysa and others 1999).

Studies into the relationships between environmental factors and violence constitute a research field called environmental security. The early beginnings of this research are rooted in the discussions of population and scarcity that began 200 years ago, when Thomas Malthus identified in the population growth the main cause of scarcity and famine (Malthus 1798). Malthus' essay gave rise to a long and still ongoing debate between the so-called ''Malthusians'' or ''Neo-Malthusians,'' such as Paul and Anne Ehlrich (Ehlrich 1968; Ehlrich and Ehlrich 1990), and the ''Optimists'' such as Julian Simon (Simon 1981). The former are concerned about the population growth and the scarcity that this will bring and appeal for a change in the mankind's patterns of behavior, whereas the latter argue that human life has the potential to adapt and always find new solutions to scarcities.

KEY WORDS: Environmental security; Violence and conflict; Developing countries; Renewable resources; Environmental scarcity; Geographic information systems; Kenya

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Records of this discussion can be found in Myers and Simon (1994).

The debate was boosted by the so-called Green Revolution, which from 1967 to 1978 allowed impressive increases in the agricultural yields worldwide and seemed, at least initially, to prove the optimistic current right. However, the environmental consequences of the new agricultural techniques turned out to be severe, with increased pest infestation and pollution due to overuse of fertilizers, mining of soil micronutrients, reductions in nutrient-carrying capacity of the soil caused by widespread erosion, buildup of soil toxicity, increased salinity, and water logging. All of this resulted in declining fertility in wide areas of the world.

In this context, the debate about population growth and scarcity was placed within a framework of environmental degradation and then explicitly linked to violent conflict, as a consequence of the general broadening of the concept of security. McNamara (1968) linked security to development, writing that ''without development, there can be no security'' and that ''our security is related directly to the security of developing world,'' whereas in 1987 the Brundtland Commission with its famous report (WCED 1987), which has a section on ''Peace, Security, Development and the Environment,'' marked the departure for environmental security by recognizing that ''the whole notion of security as traditionally understood—in terms of political and national threats to sovereignty—must be expanded to include the growing impacts of environmental stress—locally, nationally, regionally, and globally.''

The Debate on Environmental Security

The debate on environmental security began in the late 1980s and has always been quite intense, especially since 1994 (Kaplan 1994; Dabelko 2004), receiving an increasing political interest. The need for scientific assessments of the links between environment and conflict to promote conflict prevention, cooperation, and peace-building is, today, identified as a priority by many governments (Toepfer 2004).

Several research groups and individual researchers worked on these issues, and their findings constitute a source of still ongoing discussion. Among the others, we point out the Environmental Change and Acute Conflict Project (ECACP, known also as Toronto Group) led by Thomas F. Homer-Dixon (Trudeau Centre, formerly the Centre for Peace and Conflict Studies, University of Toronto), the Environment and Conflicts Project (ENCOP) of the Swiss Peace Federation led by Gunther Baechler and Kurt R. Spillmann, the Peace Research Institute of Oslo (PRIO), with Peter Gleditsch as a key figure, and the Environmental Change and Security Project (ECSP) of the Woodrow Wilson International Center for Scholars (Washington, DC) coordinated by Geoffrey Dabelko.

The research has been conducted mainly by international policy researchers and focused on the role of the scarcity of renewable resources such as cropland, forests, water, and fish stocks. Attention has been devoted to the theoretical analysis of the possible pathways, beginning with scarcity and leading to outbreaks of violence.

Two major academic projects have been completed in the 1990s. The ECACP gathered, from 1991 to 1998, a large number of researchers from different countries in the so-called Toronto Group, whereas the ENCOP was completed in 1995 and then was followed by the ECOMAN project on environmental management in the Horn of Africa. Both projects have conducted numerous case studies, mainly in developing countries.

The theoretical model of the Toronto Group focuses on the rather innovative concept of environmental scarcity, applicable to renewable resources, and the researchers concentrated on finding the links between this kind of scarcity and acute violence. Being the theoretical model we adopted as a framework for our analysis, it will be explained later more in detail.

The researchers of the ENCOP prepared a detailed and quite broad typology of what they define as seven types of environmentally induced conflict. These are not necessarily manifested as conflicts about depleted resources but develop along political fault lines like ethnicity or ideologies. Thus, they can be considered as traditional conflicts induced by environmental degradation in one or more of the following fields: overuse of renewable resources, pollution, or impoverishment in the space of living (Libiszewski 1992). Environmental degradation has various impacts on the behavior of the involved actors and might play a role as reason, trigger, target, channel, and catalyst of the conflict (Baechler 1998).

Although the ECACP and the ENCOP used different theoretical frameworks, their findings are quite similar and, in general, confirm each other's results (Baechler 1998). Environmental conflicts are more likely to occur in developing countries and tend to be intrastate rather than interstate. The only major exception is the case of interstate conflicts over shared river basins, although disputes over water tend to produce more cooperative efforts among states than violence (Giordano and Wolf 2003; Homer-Dixon 1999). Water scarcity, however, can lead to acute domestic violence (Elhance 2000). Although mainly internal to states, conflicts generated in part by environmental scarcity can have significant effects on international security (Homer-Dixon 1999). Developing countries and transitional societies, as well as the discriminated groups within them, are the most affected by the interactions with environmental degradation.

Using statistical quantitative methods, the researchers of the PRIO in Oslo tried to verify the connection between environmental scarcity and the actual presence of violence. The results show that environmental factors (and, in particular, soil degradation), even though with less power than economic and social factors, can play a role in creating favorable conditions for the development of conflicts and acute violence (Hauge and Ellingsen 1998). A distinction has been made on the consequences of abundance of resources, rather than scarcity, and on the role of nonrenewable resources. According to the statistical tests performed by former PRIO researcher Indra De Soysa (2000, 2002), it is the abundance of natural resources rather than the scarcity that is more strictly correlated to violence, according to the fact that ''armed conflict is often driven by greed-motivated factors rather than grievance.'' Abundance of natural assets, especially if nonrenewable (oil, minerals), seems to lead to political ''Dutch disease,'' with governance even worse than in conditions of scarcity and lower development performance. Collier and Hoeffler (2004) related the risk of conflict with the share of the exportation of lootable natural resources on low Gross Domestic Products (GDPs).

Since the beginning, the research of the ECACP and the ENCOP generated a lively debate, in particular about the work of the Toronto Group and Homer-Dixon's seminal articles (Homer-Dixon 1991, 1994, 1995). The ECACP's work is considered by several researchers as pioneering and foundational of environmental security studies (Ohlsson 1999; Matthew 1997; Griffiths 1997) and obtained much attention from NATO and North American political and military institutions (Clinton 1994; ECSP 1997). Several scholars have challenged the results of the two groups, with methodological and conceptual remarks. PRIO researcher Gleditsch (1998) identified a number of specific ''problems'' of conceptualization and methodology in the research on environmental security, sometimes singling out the work of the Toronto Group. Levy (1995), focusing on US interests, maintains that these groups have not brought a real contribution to security studies, by simply repeating ''conventional wisdom,'' and that the environment is not a major security issue. Peluso and Watts (2001) introduced a political ecology framework to criticize Homer-Dixon's stream of research and neo-Malthusian arguments in general. Homer-Dixon and his colleagues replied, defending their opinions and explaining and further defining their methodology and their concepts in a series of correspondences with their critics (Schwartz and others 2000; Homer-Dixon and Levy 1995; Homer-Dixon and others 2003). In some cases, the disagreement was probably more a matter of terminology than of real factual divergence (Gaulin 2000), and it is significant to notice that Homer-Dixon in his replies often defends not only his own group but also the ENCOP's work.

Some scholars criticized the environment–conflict link and claimed that the research adopted a simplistic explanatory approach, failing to address the complexity and multicausality of the problems (Levy 1995; Gleditsch 1997).

Considerable disagreement arose over the final outcomes of situations of environmental scarcity: According to Barnett (2000), Conca (1994), Levy (1995), and Gleditsch (1997), there is a lack of case studies about situations of environmental scarcity where cooperation and not conflict was the outcome of environmental change. A case study in this regard was carried out by Canter and Ndegwa (2002) in the Lake Victoria area in Africa and will be examined later.

Other scholars accuse the research of being motivated mainly by the need of Northern security institutions for new missions in the post-Cold War period (Waever, 1995), and Homer-Dixon himself agreed that his work was used by the US national security establishment for purposes other than he intended (Griffiths 1997).

Barnett (2000) questioned in depth the concept of security hitherto adopted, focused exclusively on the interests of the Northern world, and aimed at avoiding any kind of change, even in situations of pervasive injustice and discrimination. In so doing, environmental security is at risk of being a vehicle for the ''continued defense of injustice'' and a justification for continuing the inequitable power relationship between the North and South (Saad 1995).

The debate on these issues is still ongoing, but although there is no complete agreement on the way the environment can have a causal role, it is increasingly accepted that environmental threats are at least contributors to conflict and insecurity (Dabelko and others 2000). In recent years, environmental security issues received increasing worldwide interest by governments, scientific institutions, intergovernmental organizations, and nongovernmental groups, which called for a greater attention to the potential threats to security posed by environmental problems as root causes of armed conflicts (UNEP 2004; UN 2003; US Department of State 1997; Christopher 1997; ECSP 1997; Clinton 1998). The need for a closer cooperation between researchers and institutions aimed at making effective political responses has been often underscored (Dabelko 2004). Significantly, the Nobel Peace Prize 2004 was awarded to environmental activist Wangari Maathai of Kenya in recognition of her decades-long fight to protect Kenya's forests, driven by the belief that environmental protection is inextricably linked to improving human life conditions and, therefore, peace (Norwegian Nobel Committee 2004).

For a recent useful bibliography of the environmental security debate, we suggest Bruneau (2004). For sources of updates on the ongoing discussion, we recommend the ''Environment & Development Challenges'' newsletter and website maintained by Leif Ohlsson (www.edcnews.se) as well as the ECSP yearly reports (http://wwics.si.edu), probably the most useful source of commentaries, articles, publications, correspondences, and contributions from all the major scholars in this field.

It is not the goal of this article to take part in the theoretical debate on the links between environment and violence, or to support a current, as the authors belong to the field of environmental researchers and are not political scientists. Here, we want to propose tools and methodologies to analyze the state of environmental scarcity over a country. Owing to the nature of these problems, the necessity of a close collaboration among experts in a wide range of disciplines has already been underscored (Schwartz and others 2000). Quantitative and qualitative analyses are complementary in this field. The former reveal the extent and the location of environmental and social problems, whereas the latter permit us to analyze each specific case according to its political, social, and historical context.

The Contribution of Geographic Information Systems

The goal of this article is to explore the potential of the adoption of Geographic Information Systems (GIS) to approach environmental security studies, performing spatial analyses with easily available geo-referenced data in order to obtain an overview of the spatial placement of environmental scarcities within a country. Some scholars have recently highlighted the contribution that GIS can offer to environmental security studies and the fact that these technologies have not yet been fully utilized in this field (Matthew and others 2004). So far, the data used for quantitative analyses were from environmental statistical databases, generally on a national scale. Thus, they did not provide insight into the intrastate situation, whereas environmental scarcity contributes mainly to internal violence.

Geographic information systems are Information Technology (IT) tools that allow the collection, organization, spatial analysis, and linking of territorial data of different origins and nature in order to obtain new information that can be used to identify and visualize social and environmental patterns. GIS data are geo-referenced; therefore, they contain both the environmental information (e.g., average annual precipitations or vegetation indexes from remote sensing) and the positional information on the geographical location to which data refer (two- or three-dimensional spatial coordinates). These tools can be useful for assisting in research tasks, although no methodological innovation can replace robust theorizing about the links between the environment and conflict (Matthew and others 2004).

Quantitative environmental data are essential to analysis, but their poor quality and limited quantity are still serious constraints, as highlighted by virtually all of the researchers who engaged in quantitative analyses (Hauge and Ellingsen 1996; De Soysa 2000; Goldstone and others 2000; De Souza 2004). Moreover, the areas under examination are developing countries, hence often lacking in reliable structures in charge of data collection. Data on these countries are often gathered by Western intelligence and defense institutions using technologies such as Earth observation systems that can assist in environmental assessment and monitoring, but data are often classified. This issue has received considerable attention in the United States in the 1990s. Under the aegis of Vice President Gore, the Central Intelligence Agency permitted civilian scientists to examine archive material useful in assessing environmental degradation (Dabelko and others 2000; Jimerson 2000). Further collaborations are under discussion; however, the commercial use of remotely sensed data is carefully guarded (Gupta 1995; White House 2003). The lack of reliable environmental data requires researchers to compromise on what it is actually available. GIS might offer a useful contribution in dealing with these constraints, as they allow the integration of data from different databases, provided that problems of scale and standardization are carefully assessed. In this respect, initiatives have been taken lately in Western countries to improve the management and standardization of spatial data (Commission of the European Communities 2004; White House

1994). GIS offer also the opportunity to update data and results whenever new information is available.

The Theoretical Model of the Toronto Group

In this article, we chose to adopt as a framework the theoretical model proposed by the Toronto Group (Homer-Dixon, 1999). We believe that this model offers a very schematic and comprehensive frame of reference, permitting us to distinguish and separate quite easily the different interacting sources of environmental scarcity in order to map them separately with GIS. We share this opinion with many researchers who adopted the ECACP model as a framework for their works (e.g., Matthew 1997; Kahl 1998; Ohlsson 1999; Canter and Ndegwa 2002). Obviously, it is also a matter of personal preference, and this choice does not imply a negative opinion of other theories.

At the core of the Toronto Group's model lies the concept of environmental scarcity, defined as the decrease of the availability of renewable resources such as cropland, forestry, water resources, and fish stocks. Environmental scarcity does not correspond to an absolute physical limit. Rather, it is dynamically determined by the interaction of three sources of scarcity: the increase in the resources demand due to demographic growth (demand-induced scarcity), the qualitative or quantitative deterioration of the natural resources supply (supply-induced scarcity), and the limitations on the availability due to laws, rights of property, or situations of prevarication or discrimination (structural scarcity). These three sources can interact, generating ''resource capture'' or ''ecological marginalization.'' There is resource capture when powerful groups within a society recognize that a key resource is becoming scarcer (due to both supply and demand pressures) and use their power to shift in their favor the regime governing resource access. Ecological marginalization occurs when grave inequality in resource distribution joins with rapid population growth to drive resource-poor people into ecologically marginal areas. These negative interactions show the need to adopt a systems approach in environmental security, as different features are interdependent and a change in one part of a system can affect other parts (Dale and others 2004).

The contribution of environmental scarcity to the conflict is indirect, through various negative social effects, such as a decrease in the production in agriculture and other sectors, migration both within or out of states, social fragmentation, ethnic or religious divisions, and weakening of the state's institutions. The possible actual negative consequences of a situation of severe environmental scarcity in terms of violence and war depend mainly on contextual political, economic, and social factors, which have a crucial role (Homer-Dixon 1999; Kahl 1998). In fact, the negative social effects can be counteracted by the state's supply of social and technical ingenuity, which is the capacity of the society to face the condition of scarcity (Barbier and Homer-Dixon 1999). An ingenuity gap (a typical condition of developing countries) can create a vicious cycle with serious social effects, weakening of state power and different levels of intensity of violent episodes, ranging from rural brigandage of paramilitary groups to true civil war. On the other hand, in some cases, the state's institutions might have interest in capitalizing on the struggle generated by environmental scarcity by deliberately instigate intergroup violence in order to keep their group in power (Kahl 1998).

In some areas, so-called relative deprivation (Kahl 1998; Ohlsson 1999) can be observed. This kind of deprivation arises when there is a discrepancy between what people have and what they feel they are entitled to. When compared with bordering populations that are richer and have higher standards of living, the perception of poverty can give rise to grievances and frustrations. This particularly affects young men who feel obliged to accept a much lowlier situation in society than their prevalent culture has led them to believe they were entitled to in their position as men (Ohlsson 2000). In this situation, the poorer segment of the population can engage in violence or develop extreme survival strategies (De Soysa and others 1999; Baechler 1998) to improve its economic and social status. These strategies often include the exploitation of available natural resources in the area with poaching, trading in protected animal and vegetal species, and deforestation to cultivate cash crops, including drugs.

Homer-Dixon's focus on scarcity rather than degradation broadens the horizon of the analysis and puts the accent on the availability of each resource, which is what ultimately concerns the people living in a certain area. Thus, environmental degradation is only one of the possible sources of environmental scarcity, which can be caused also by demographic and socio-political factors. Figure 1 is the flowchart of the model proposed by the Toronto Group.

This study adopted the theoretical conceptualization of environmental scarcity to analyze a real case, namely Kenya, through GIS technology. We collected statistical and GIS datasets and created a system of thematic layers referring to the different sources of scarcity (e.g., soil degradation, deforestation, popula-

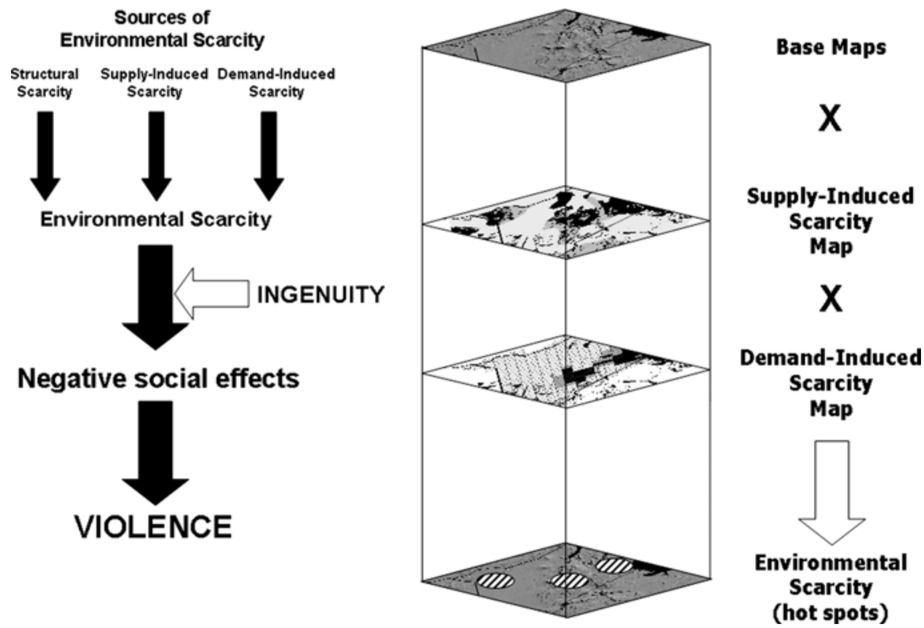

Figure 1. The theoretical model (modified from Homer-Dixon, 1999) and the plan of the GIS analysis.

tion) by means of spatial analyses and integration of different data. This allowed us to obtain a spatial representation of environmental scarcity of renewable resources over the entire state, according to the available data. Then, integrating the layers of each source, we located the areas that are suffering from different sources of scarcity at the same time. According to the theoretical model of the Toronto Group, these areas must be considered at a particularly high risk of experiencing the negative social effects produced by environmental scarcity.

The Case of Kenya

Our case study was located in Kenya, a developing country in a strategic position in the Horn of Africa. Agriculture is the main economic sector and produces 30% of the country's GDP, whereas 70% of the population lives in rural areas. From a political point of view, Kenya is located in a very fragile area. Neighboring countries experienced long periods of war in recent years. Although the Kenyan situation has been relatively peaceful so far, the political stability of this country is considered very important for the whole Eastern African region.

The choice of a country not affected by the tremendous conflicts common in many parts of Africa is explicitly based on the suggestion made by some scholars to select case studies in areas that do not seem, at first, to present widespread violence, in order to avoid biased post hoc conclusions (Barnett 2000; Levy 1995). In our study, however, after performing the analysis, we obtained reports from the field confirming that episodes of violence over renewable resources have already occurred in some areas of the country.

Mapping Demand-Induced Scarcity

To map the demand-induced scarcity, data on population density provided by different databases were collected and organized in thematic layers. The World Gazetteer Database of the National Imagery and Mapping Agency (NIMA) provides the name and the geographical positions of thousands of cities and villages. A layer with human settlements classified according to their typology was provided by the Digital Chart of the World (ESRI) with data from the US Defense Mapping Agency Operational Navigation Chart (ONC).

Since 1965, the International Programs Center (IPC) of the US Census Bureau maintains its International Data Base (IDB), with data relative to all the regions of the world. The IDB combines data from country sources (in particular, censuses and surveys) with IPC's estimates and projections to provide information dating back as far as 1950 and as far ahead as 2050. Rural population is allocated to cells measuring 20' latitude by 30' longitude (in certain areas of the industrialized world, cells are smaller). Urban agglomerations of 25,000 people or more are covered by one or more circles including at least 95% of the population. These circles are known as P-95 circles and each contains at least 5000 people. Historical population data for each province are also collected from various sources by the Population Statistics website maintained by Jan Lahmeyer (http://www.library.uu.nl/wesp/populstat/populhome.html).

The Oak Ridge National Laboratory has developed an automated procedure to allocate rural and urban population distributions to 30'' by 30'' cells. Census counts at the subnational level were apportioned to each grid cell based on likelihood coefficients, which are based on proximity to roads, slope, land cover, nighttime lights from the National Oceanic and Atmospheric Administration (Sutton 1997), and other information. The resulting LandScan distribution integrates diurnal movements and collective travel habits into a single measure, aiming at representing the effective distribution of the population (''ambient population'') considering also where people travels and work (ORNL 2002; Dobson and others 2000). Estimates of the population in 2010 were calculated with a forecast model in the Global Database of Geospatial Indicators (Miller and others 2002), which uses as inputs, data from the United Nations Department of Economic and Social Affairs Population Division, national estimates from the US Census Bureau, and the ORNL LandScan Population Density product.

Mapping Supply-Induced Scarcity

Data on cropland, forestry, and water resources availability were considered in mapping supply-induced scarcity. The IIASA-FAO maps on the main natural constraints to agricultural practice were used to map the availability of land suitable for agriculture (Fischer and others 2002; FAO 1997). The considered constraints were slope, soil depth, natural fertility, drainage, soil texture and chemical content (e.g., salts), rated on a seven-level scale of limitations. The maps referring to the single constraints were combined in a unique layer representative of all of the constraints, offering a picture of the general natural availability of cropland. Then we assessed the human-induced reduction of this availability. Good, comparative, cross-national data on soil degradation are not available (Homer-Dixon 1999). For this work, we used data obtained from the sole study available on a global scale, namely the World Map on Status of Human-Induced Soil Degradation (GLASOD), produced by ISRIC and UNEP between 1988 and 1990 in collaboration with 300 experts from around the world (GLASOD 1991; Oldeman and others 1990). Using GLASOD was a debated choice, and it is an example of the necessity of reaching a compromise on the data actually available. The GLASOD map is still widely used and quoted in numerous scientific journals and policy documents of many international organizations, although its authors and critics alike recognize the need for a more detailed and more quantitative assessment (Gobin and others 2003). Based on the responses to a questionnaire sent to recognized experts in 21 designated regions, the GLASOD database presents a degree of subjectivity in the standards applied by different experts for different areas. This makes comparisons between different regions of the world often unreliable. GLASOD data are also highly aggregated and refer to a small scale. Nevertheless, it represents, at the time of this study, the only available document on global soil degradation (F. O. Nachtergaele, FAO, personal communication; UNEP 2002; Gobin and others 2003) and provides a useful overview of the extent and type of soil damage (Homer-Dixon 1999). The SOVEUR project for Eastern Europe and ASSOD for South Asia represent some more detailed recent update of GLASOD, but only for limited areas.

Two GLASOD maps were summarized: The first one referred to the rate of degrading processes and the second one referred to the degree of soil degradation at the time of the survey. To partially compensate for the lack of recent updates, a double weight was assigned to the map of the rate. The resulting map was then integrated with the map resulting from the sum of the six IIASA-FAO maps of agricultural constraints. The derived map represents the general availability of suitable cropland for Kenya. It identifies areas with scarcity due to natural constraints and human-induced soil degradation.

The forests and vegetation assessment used multitemporal satellite imagery and two desertification layers from the Global Database for Geospatial Indicators (Miller and others 2002). These two raster maps of 1 km × 1 km cells refer to the 1996 situation and to forecasts of the 2010 situation. Three vegetated areas of the Kenya territory were identified under particularly high rates of deforestation.

The *FAO Atlas for Water Resources and Irrigation in Africa* (FAO 2001) was used for studying water resources availability. A water balance was prepared using the methodology described in the atlas. Annual Average Precipitation layers were based on an IIASA dataset prepared by FAO in 1991, with data averaged over the period from 1961 to 1990 on a raster map with cells of about 60 km × 60 km. Reference evapotranspiration data calculated with the Penman–Monteith methodology were also provided by IIASA for FAO (FAO 2000) with the same resolution of the precipitation dataset. Soil data related to the maximum soil moisture storage

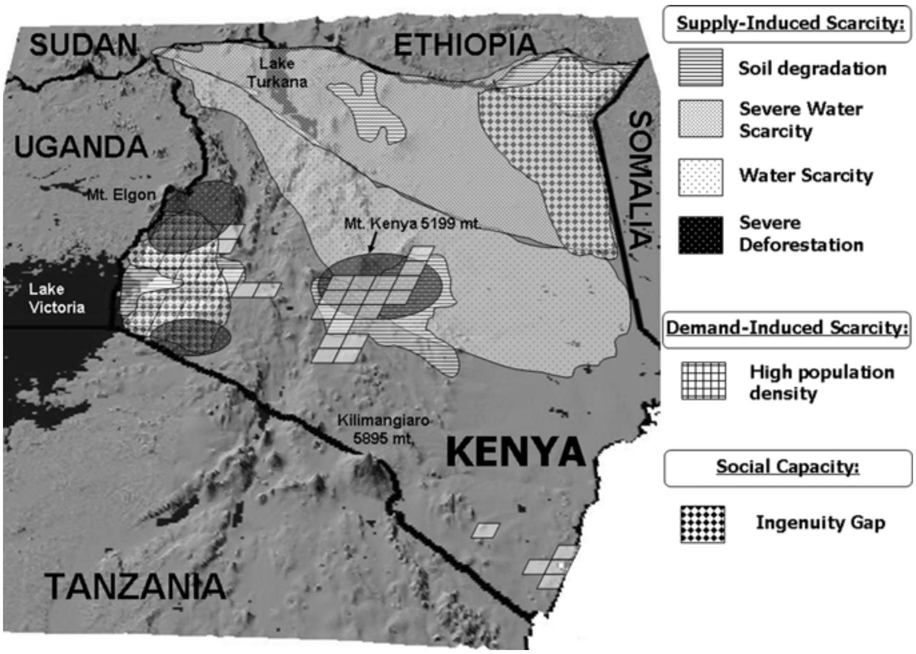

Figure 2. The results of the Kenyan case study.

capacity and to the easily available soil moisture were derived from the *FAO Digital Soil Map of the World* (FAO 1998) and used to assess the actual evapotranspiration, which is a function of the available soil moisture (FAO 2001).

A raster layer giving a picture of the dryness of the different areas in Kenya was obtained by calculating the difference between the potential and the actual evapotranspiration in each cell (Marchetti 1993; FAO 2001). The total renewable water supply (RWS) was calculated by adding runoff to the groundwater minus evapotranspiration. The map of the RWS was obtained by combining the precipitation and evapotranspiration layers with layers related to the average annual total runoff and the groundwater discharge coefficient surface, provided by the ESRI ArcAtlas. On the map of Kenya, we obtained a picture that identifies the country's richest areas with reference to water resources, which turned out to coincide with the so-called Kenya Water Towers. Other information was obtained by considering the latest data about precipitation and glaciers.

Mapping the Supply of Ingenuity

To map the capital of ingenuity throughout the country, we considered a model based on the Human Development Index (HDI) and on the GDP developed by the United Nations Development Programme (UNDP 2003) to classify states. A country with a higher rank in the HDI classification than in the GDP classification has been capable of converting wealth into human welfare (and vice versa where the opposite occurs). Therefore, the ingenuity in the different areas of a country can be evaluated by comparing the indicators about population, human development, and wealth in the different regions. Where the HDI rank is higher than the GDP rank, people living in the administrative unit show better living conditions than expected and, therefore, have been able to develop a good capital of social and technical ingenuity to improve their situation. When this does not occur, the individuals and the society are not able to improve their condition, and they most likely will not be able to independently face a worsening of the environmental scarcity without suffering negative social effects. In this study, we used GDP data, aggregated at the province level (UNDP Kenya 2001) as well as disaggregated over the entire country, HDI data (UNDP Kenya 2001), and data on the percentage of population living under the threshold of income required to satisfy basic needs, both nutritional (to reach the minimum threshold of 2250 kcal per capita per day) and nonnutritional (access to health services and structures, suitable clothes, and education). This threshold was indicated in 1239 Kenyan shillings (ksh) per month per capita for rural areas and 2648 ksh for urban areas (Republic of Kenya 2002). The disaggregated wealth surface, representing the total GDP in 1998 purchasing power parity dollars per square kilometer, was produced by means of a model by Earth Satellite Corporation and ISciences. The model allocates World Bank World Development Indicators (WDI) national GDP estimates in 1998, dividing them among industrial, agricultural, and service sectors. Economic sectors were mapped, assessing the suitability of the landscape for sector economic wealth using IGBP land cover, NOAA nighttime lights, and ORNL 1998 LandScan population. The agricultural sector wealth suitability is based on a model to assess agricultural primeness (Miller and others 2002).

Results

Figure 2 shows the results obtained with reference to the demand-induced scarcity, the supply-induced scarcity, and the supply of ingenuity. The map also considers the ingenuity gap and gives a representation of the impact of the population on the territory. This reaches the maximum where a high population density is associated with conditions of ingenuity gap and relative deprivation. In such a situation, according to the theoretical model, the population might not be able to adequately face the increase in demand for goods and services due to the corresponding population growth.

The northeastern areas of the country suffer severe, almost permanent water shortage and severe soil degradation, especially in the area between Ethiopia and Somalia. The Mount Kenya region suffers seasonal water shortages also, due to the decrease of the storage capacity of the snowpack and the glaciers. In fact, the 12 most important glaciers of the Mount Kenya lost up to the 92% of their volume during the last century and are shrinking at a rate of 1 m/year (Hastenrath 1995; Hastenrath and Kruss 1992; Young and Hastenrath 1991). This affects the water basins depending on the Mount Kenya storage capacity. Tana and Ewaso Ngiro rivers, the most important in the country, have their sources in the Mount Kenya massif, and most of the population lives in their basins. This means that about 7 million people are affected by water shortage in this region. At the same time, data show that precipitations are decreasing all over the country, also because of massive deforestation, which alters hydrological cycles and patterns, changing the thermal relations between the ground and the atmosphere. Therefore, water scarcity is becoming a problem for all of Kenya and the areas at the highest risk are the northeast and the basins directly dependent on Mount Kenya, as confirmed by several documents (IRIN 2002a; Pkalya and others 2003).

The results of the deforestation assessment in the Mount Kenya area were similar with those obtained by the Kenya Wildlife Service in an aerial survey carried

Table 1. The areas that result affected by environmental scarcity

Area	Demand-induced scarcity	Supply-induced scarcity			
		Soil	Water resources	Forests	Ingenuity
Mount Kenya	High population density and high population growth	Fast soil degradation (overgrazing and agricultural practices)	Reduction in the volumes of the perennial glaciers and in the snowfalls.	Massive deforestation (cultivations, overgrazing, and expansion of the urban areas)	Areas of relative deprivation
Mount Elgon – Lake Victoria	High population density and high population growth	Fast soil degradation (overgrazing and agricultural practices)	Good availability in quantity	Massive deforestation (cultivations, overgrazing, and expansion of the urban areas)	Ingenuity gap
Mombasa	High population density in the urban area	Low degradation	Scarcity	—	Areas of relative deprivation
East of Lake Turkana	Low population density	Degradation (overgrazing)	High scarcity	—	Widespread poverty
Somalia–Ethiopia border	Low population density	Degradation (overgrazing)	High scarcity	—	Ingenuity gap

out from February to June 1999, which focused on the destruction of the Imenti and Nagare Ndare forest reserves (Kenya Wildlife Service 1999). Deforestation does not allow the ground to retain the water and facilitates erosion processes, very common in the Mount Kenya area. Also, in the Lake Victoria area, degradation and deforestation processes can be observed. According to GLASOD maps, overgrazing is the main cause of soil degradation across the country. The integration of the thematic layers of the supply-induced scarcity, the demand-induced scarcity, and the ingenuity provides a general description of the environmental scarcity over the Kenyan territory. Table 1 describes the situation in the most affected areas.

The Mount Kenya area presents widespread soil degradation, deforestation, and seasonal water shortages. Lake Victoria and Elgon Mountain areas present soil degradation and deforestation with also a situation of probable ingenuity gap and reportedly heavy pollution of water resources (Canter and Ndegwa 2002). Being the most populated areas of the country, these three areas should be considered as having a high risk of suffering the consequences of environmental scarcity according to the Toronto Group's model. Compared to them, the northeast areas of the country are more scarcely populated but very arid and massively grazed, causing soil degradation. Also, these areas should be considered at high risk because water is recognized by several researchers as the most conflict-prone renewable resource (Canter and Ndegwa 2002; Elhance 2000).

The Importance of Surveys and Reports from the Field

Geographic information system analyses can be a useful tool to support and orientate the analysis, but they cannot be considered as a sort of ''crystal ball'' able to predict exactly what will happen in a certain area. As Dabelko and others (2000) emphasized, computer-based systems can serve as useful supplements—but not substitutes—to information from the field. Direct field surveys are expensive and, in general, it is often impossible to visit thoroughly all of the areas within a country. The examination of reports, newspapers, news, and web resources about the area is fundamental to checking the results and to formulating hypotheses about the consequences of environmental scarcity in that context.

In our case, because of budget constraints, we have not been able to perform a real survey over the entire Kenyan territory and we could only visit the Mount Kenya southern area during December 2003. The trip was useful for observing what seemed to be a typical process of ecological marginalization. The shamba system, an integrated system of agro-sylviculture adopted by the government after independence, provides that farmers have temporary concessions to deforest in order to cultivate crops, on the condition that they plant new young trees. According to this system, after 3 years the trees have grown, and farmers should move and deforest another area. Since 1980, the system has been subjected to abuses and bad management: Trees are not planted, and after cultivation, deforested area are either grazed or illegally rented out to other farmers. This does not allow for recovery of the soil-carrying capacity and leads to permanent soil loss. We also observed a widespread cultivation of drugs like *Cannabis sativa*. Despite the efforts of the Kenya Wildlife Service rangers we met, the situation is out of control and seems to confirm what had been well expressed by the Kenyan newspaper *Daily Nation* on August 29, 2002:

In recent years a variety of problems affected natural resources, including excessive water withdrawals from rivers, destruction of forests, cultivation of marijuana, illegal grazing and the reduction of Mount Kenya's twelve glaciers. Rising environmental problems are driving to the conflict between little and large landowners, farmers, shepherds and anyone else and the environment.

Reports and newspaper articles show that clashes over natural resources already occurred in Kenya in the recent past, mainly in the areas that we discovered to be at risk. In the Tana River basin, depending on Mount Kenya, violent clashes have occurred since December 2000 between Pokomo and Orma tribal communities. The two groups, the first composed of farmers and the second composed of shepherds, accuse each other of not allowing the other to use the river's water and of occupying the other's land. More than 130 people were killed and 3400 refugees had to leave the area (IRIN 2002b). In 1991–1993, acute scarcity of cropland due to demographic pressure, soil degradation, and uneven distribution of the land was at the root of widespread ethnic violence in Rift Valley, Nyanza and Western Province, the regions between Mount Kenya and Lake Victoria. In most parts of this area, our analysis highlighted increasing soil degradation. President Moi's regime exploited existing intergroup grievances to its political and economic advantage, inciting pastoral communities to violence in order to discredit the process of democratization and punish the opposition (Kahl 1998).

Widespread and increasingly severe conflicts occurred, especially in the northern regions. Even though this is a region of scattered population, environmental scarcity has already caused clashes between different tribal groups in their attempts to access water and pastures (i.e., Wajir North conflict), causing loss of human life and property, displacements of large segments of the communities, disruption of socioeconomic activities and livelihoods, increased hatred between communities, and further environmental degradation (Pkalya and others 2003). Lack of these resources has also pushed foreign tribes to cross the borders in both directions, causing clashes between Kenyan tribes and groups from abroad (e.g., Magadi Soda conflict and Isiolo conflict). Representatives in the parliament of Kenyan tribes living in the area asked the army's intervention to chase away the Somali tribes. In these regions, baboons have been reported to have killed cattle and attacked villages, looking for water and food. The very severe soil degradation due to overgrazing is confirmed by the Livestock Early Warning System reports (http://cnrit.tamu.edu/lews).

There are also reports about situations of environmental scarcity that boosted cooperation rather than violence, even though mainly at a government level. Canter and Ndegwa (2002) found that on the Lake Victoria cross-border shores, environmental scarcity due to water pollution, weed infestation, and declining of fish stocks indeed generated widespread latent conflict, and vigilante groups were paid by villagers to patrol ''their'' waters and control fishing. Nevertheless, only few incidents of violence were reported, and local authorities and especially the national governments of Kenya, Tanzania, and Uganda, which share the lake's shores, have reacted to the emerging scarcity with an increase in cooperation. Among the results, there were efforts to harmonize permits and licenses on fishing, the simultaneous approval by each country of a National Environmental Action Plan (NEAP) in 1994, and a collaboration in the efforts to eradicate the invasive water hyacinth weed. The cooperation that Canter and Ndegwa pointed out was mainly at a government level and was explained with strategic and contextual reasons. For example, the authors argue that in Kenya, the lakeside ethnic groups are politically and economically marginalized and that in none of the three countries is the lake the core economic asset. Carter and Ndegwa's fieldwork on the Lake Victoria shores confirms our results about the ingenuity gap and population growth in that area.

Conclusions

Geographic information system analyses allow the integration of data from different sources and can be an inexpensive, useful tool for obtaining a general yet quite reliable overview of the situation of environmental scarcities within a country. The examination of reports from the field and, when possible, field surveys are necessary to examine the context and allow a check and, in case, the correction of the results. The main difficulties we had to face in this study were related to the scarcity of available data and to their heterogeneity in scale and reliability. This required compromises about the choice of the data, carefully weighing the arguments for and against, in order to make choices that are inevitably partially subjective. The decision to use the GLASOD database to integrate the FAO-IIASA data is an example, because of the scarcity of reliable data often highlighted by many researchers. Nevertheless, using the data available and making spatial analyses with them, we obtained quite reliable results.

This approach can be useful to students of environmental security interested in obtaining an overview of the situations of environmental scarcity of a country, so as to orientate their analyses. Further research and the improvement of the available databases will allow more reliable results in order to determine priorities in interventions, land management, and planning. This can constitute a useful contribution to prevent possible negative consequences for the populations and the stability of many areas of the world.

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