LAND USE CONFLICTS RESOLUTION IN A FRAGILE ECOSYSTEM USING MULTI-CRITERIA EVALUATION (MCE) AND A GIS-BASED DECISION SUPPORT SYSTEM (DSS)

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Key words: land use, decision-making, conflict resolution, participatory approach.

ABSTRACT

Population pressures and increasing affluence levels within the arid and semi-arid areas have necessitated a shift from pastoralism to sedentarization. This shift is causing some environmental and socio-economic land use conflicts. A land use conflict resolution process that uses a geographic information system-based decision support system for optimising land use allocation in a semi-arid area within Baringo district in Kenya is presented. The system considers multiple land use objectives, determines the amount of land required by each together with their ecological requirements. An appropriate digital database is then created from which the twin processes of multi-criteria evaluation and multi-objective decision-making are applied so as to allocate the available land such that all the objectives are satisfied with minimal environmental and socio-economic conflicts. The decision-making tools incorporated within the decision support system (DSS) module of the IDRISI for Windows are used. The participatory decision making approach, where stakeholders strive to reach a consensus on land use prioritisation, is adopted.

1. INTRODUCTION

Land use changes and the consequent changes in land cover characteristics are readily observable in the Baringo landscape. Widespread transformation of vegetated areas to almost bare surfaces consisting of farms, grazing lands, human settlements and degraded patches are readily visible. Rapid sedentarization of this area, which has been predominantly occupied by pastoralists, is causing two types of land use conflicts. First, environmental conflicts arise from putting land into uses that are not compatible with the its characteristics. Cultivation of areas with little and unreliable rainfall resulting into frequent crop failures leaves most of the cultivated land bare for long periods. Similarly, intensified tree harvesting to satisfy growing demands for charcoal in rapidly growing sub-urban centres and distant cities such as Nakuru and Nairobi, also leaves large areas of land bare due to slow vegetation regeneration. Increased bare surfaces, accompanied by cultivation on steep slopes, inevitably accelerates the process of soil erosion as evidenced by the muddy water of L. Baringo.

The second conflict arises from competition for land by different land uses, i.e. pastoralism, sedentary agriculture, tree harvesting and conservation. For many years the communities that inhabit semi-arid areas have depended on pastoralism as the main socio-economic activity.

However, population pressures and increasing affluence levels have necessitated a shift in production systems. Demand for more food and money for purchasing non-food commodities such as education and health has forced these communities to increase their stocks, practice crop production and over harvest trees to produce charcoal for sell. At the same time, the glaring evidence of increasing degradation has not gone unnoticed. Several projects, e.g. the Baringo fuel and fodder project (BFFP), and reforestation programmes by FAO and other agencies, have been carried out to restore and conserve degraded lands. All these activities compete for the same land.

These conflicts can be avoided through planning and control of the changing production system by making the choice and allocation of land use activities consistent with the principles of sustainable development. It is argued that the growing demand for food, fuel and fodder can be met without causing excessive degradation if proper decisions on land use allocation and utilisation are made. This argument is based on three premises. First, most land degradation can be minimised or eliminated if land was put to the most compatible uses from the ecological point of view. Second, meaningful conservation efforts will only take place after the needs of the land users are satisfied. For example, the destruction of vegetation to meet local energy demands and income generation through charcoal selling cannot be stopped before alternative energy resources and income generating options are provided. There is need to develop a land use planning and management system that takes into account the needs of all actual and potential land users. Finally, efforts to protect and/or rehabilitate degradation lands in most cases are hampered by lack consensus on the need and ways to manage the common resources at the community level. While individuals may recognise the need to protect common resources, mechanisms to co-ordinate there decisions and efforts may not be available.

This paper presents a land use conflict resolution process that uses a geographic information system (GIS) based decision support system to optimise land use allocation in a semi-arid area within the Baringo district in Kenya. The decision-making tools incorporated within the decision support system (DSS) module of IDRISI GIS are used. The proposed system uses the participatory decision making approach where multiple land users strive to reach a consensus on land use objectives and their prioritisation.

2. THE STUDY AREA

The study area is located in the Rift Valley Province of Kenya. It is bounded by latitudes 0° and 0° 45' N and longitudes 35°45' and 36° 15' E, covering an area of approximately 4,500 km^2 (Figures 1 and 2). It is situated in a semi-arid climate zone with very low annual rainfall averaging 600 mm and fairly high average temperatures (25-30 °C). The uplands are covered by old volcanic soils, mostly shallow, with deeper red clays in the cooler and more humid parts. The hills are dominated by soils formed on old (Pliocene) volcanic rocks. These soils are quite shallow and stony due to the prevailing steep and long slopes. The foothills are covered by badly eroded soils, developed on largely unconsolidated materials. The gently undulating hills within the plateau are covered by shallow and stony clay loam soils of the steep-faulted basalt plateau. The soils within the plains are mostly well-drained, deep, friable silty loams or heavy cracking clays, with a promising potential for irrigation (Herlocker, *et al*., 1994). Several rivers and streams, most of them seasonal, drain the area.

The natural vegetation is also highly heterogeneous in response to topographic, climatic and edaphic variations. There is high species diversity and significant intra-species variations in physiognomic characteristics along the elevation gradient. The lowlands are dominated by several acacia species with no or little undergrowth vegetation. At higher elevations, a wider variety of woody plant species combine with acacias to form the main vegetation layer with an under-storey vegetation of moderate to dense perennial forbs and grasses. Vegetation densities also vary widely reflecting differences in edaphic conditions and anthropogenic disturbances. Patches of remnant natural forests are found within the hills and along perennial water bodies.

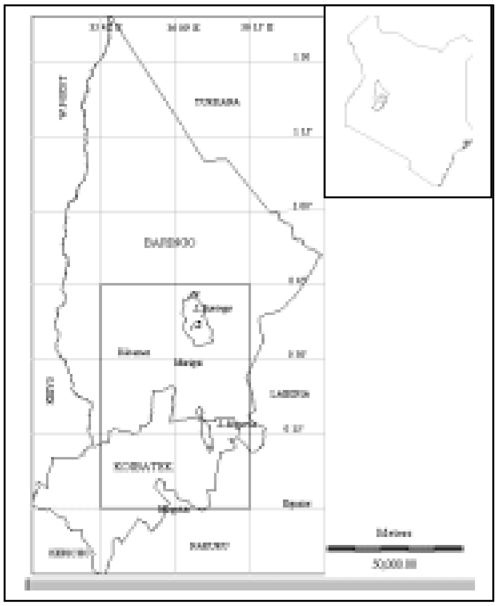

Figure.1 Location of Study Area

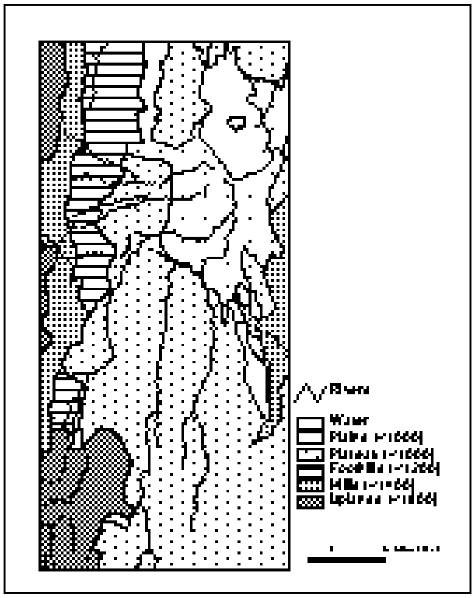

Figure 2 Physical Characteristics

The main land use activity in the northern half of the study is livestock rearing. Apart from the irrigation schemes around Marigat, most land in this part communally owned. Bee keeping and charcoal burning are also significant socio-economic activities. Subsistence farming, i.e. cultivation of maize, beans, millet and groundnuts, predominate the southern half. Here most of the land is privately owned. Sisal plantations are found in the southeastern portion of the study area. Several sub-urban centres have developed, mainly along the permanent roads. These centres, consisting of 5 to 20 buildings, provide commercial and administrative services at different levels. Educational and health facilities have been developed in the area.

3. LAND USE DECISION MAKING

In Kenya more than 75 per cent of the land is categorised as low potential. This percentage is even higher in the arid and semi-arid areas (ASALS) due to steep slopes, shallow soils and low and unreliable rainfall. Competition for the available good land by different development activities is thus very high. Agriculture, human settlement, recreation, communication networks and even conservation prefer flat to gently sloping land with medium textured well-drained soils. As human society develops both in size and complexity, so does the demand for land. Being a finite resource, programmes designed to increase the area allocated to one use automatically results in a decrease in land available for other uses, resulting in serious land use conflicts. This problem becomes more severe when the available land can hardly be used sustainably for anything. This not withstanding, the land in question is expected to meet food and energy demands, support income-generating activities and perform ecological functions. Land users and policy makers have to make choices between usually conflicting/competing land uses, which in most cases are of more or less equal priority.

The goal of sustainable land use is to meet the needs of all prospective land users while at the same time ensuring the natural resource base is protected (WCED, 1987). To achieve this goal four issues need be considered when making decisions on land use allocation. First, all land use objectives need to be identified and where possible quantified in terms of how much land each of these objectives require. Second the ecological requirements for all these land uses need to be defined. Third, there should be a mechanism for ecologically matching these objectives with the available land i.e. the ability to identify optimal lands for different objectives. Finally there has to be a mechanism for making decisions on the most optimal allocation, i.e. the allocation which maximises the attainment of all objectives while minimising conflicts with other land uses and land characteristics. This requires comprehensive data on land and land use demands.

The need for comprehensive land use data has been recognised for a long time and has provided an incentive for the development of land inventory and classification systems (CLI, 1965; USDA, 1969 and FAO, 1976). These systems have been implemented using both manual and digital systems. With manual systems, analog data sources i.e. maps; aerial photographs and statistical data are systematically analysed using techniques such as overlay (McHarg, 1969) to produce land capability/suitability maps on the basis of which decisions on land allocation are made. While such processes produce objective decisions, manual analysis methods have several limitations including, inflexibility, cumbersome to use and difficulty to up-date. Most of these deficiencies can be overcome by computerising data sources and analysis using geographic information systems. Besides enhancing data analysis, computerised data systems provide a medium for data integration, where spatial and non-spatial data from disparate sources are captured and stored together in a digital database. If properly organised, such databases allow easy data access for both utilisation and update. Finally, the flexibility with which output can be displayed ensures that information gets to the various users in formats and details most suitable to them.

Although the use of standard geographical information systems alone can greatly assist in selecting sites that simultaneously satisfy some pre-determined criteria, they do not assist the user in deciding on which among the sites offers the most benefit. Most GIS do not provide the user with specific tools for evaluation and decision making for problems involving multiple criteria and conflicting objectives (Carver, 1991). The limitations of GIS in decision-making have been summarised by Janssen and Rietveld (1990). Additional procedures based on multi-criteria evaluation (MCE) techniques are therefore required to evaluate the suitability of sites falling within the feasible areas identified using the standard GIS analytical procedures (Carver, 1991).

Besides technical problems, decision making on land use/land allocation in the rural areas also suffers from some logistical problems. First, since master plans for rural development do not exist, decisions on land use are made at the individual household level. Such decisions can easily be competitive and/or conflicting. Rural land use development is regulated by some restrictive legislative mechanisms meant to protect and conserve land for ecological functions. However, legislative approaches to environmental management have been found to be ineffective in many parts of the world (Horen, 2001). Most of the legal rules are often ignored or simply so out of touch with the actual development taking place such that their implementation is impossible. Second, while the communities may be aware of the consequences of irrational land use practices, they lack a framework within which they can by consensus identify and resolve land use conflict. A participatory decision making process using a GIS based decision support system can help in solving both these technical and logistical problems.

Land use allocation involves making decisions on how to use available land to satisfy land users' needs. These decisions are based on evaluations of several ecological criteria and user preferences, which are often conflicting (Voogd, 1983; Malczewski, 1996). In making these decisions, the impacts of satisfying each objective on all other objectives and on the environment are considered. The role of a decision support system is to assist the decision maker in selecting the 'best' alternative from among the number of feasible alternatives (Jankowski, 1995). Due to the lack of appropriate decision making tools, GIS as they exist today perform very poorly in terms of providing support to the decision making process (Carver, 1991). Two approaches have been used to improve the decision-making capabilities of GIS. In the first approach relevant decision making tools are developed within the GIS (Eastman *et al.*, 1995). In the alternative approach, GIS are coupled with other general software packages (statistical) or with specialised analytical models such as environmental or socio-economic models (Jankowski, 1995). Whichever approach is used, the DSS should assist in the evaluation of both the land use criteria and the land users' objectives and in the making the of the final land allocation decision. The former approach was used in this study.

4. MATERIAL AND METHODS

The proposed land use conflict resolution system using the IDRISI decision support module is implemented using the steps summarised in the flow chart shown in Figure 3 below. The system considers both complementary and conflicting land use objectives. Complementary objectives need to be satisfied simultaneously, i.e. areas that suit two or more land use objectives simultaneously are required. Conflicting objectives compete for the same land but only one objective can be allocated at any one time. Some form of objective prioritisation or means of conflict resolution is thus necessary.

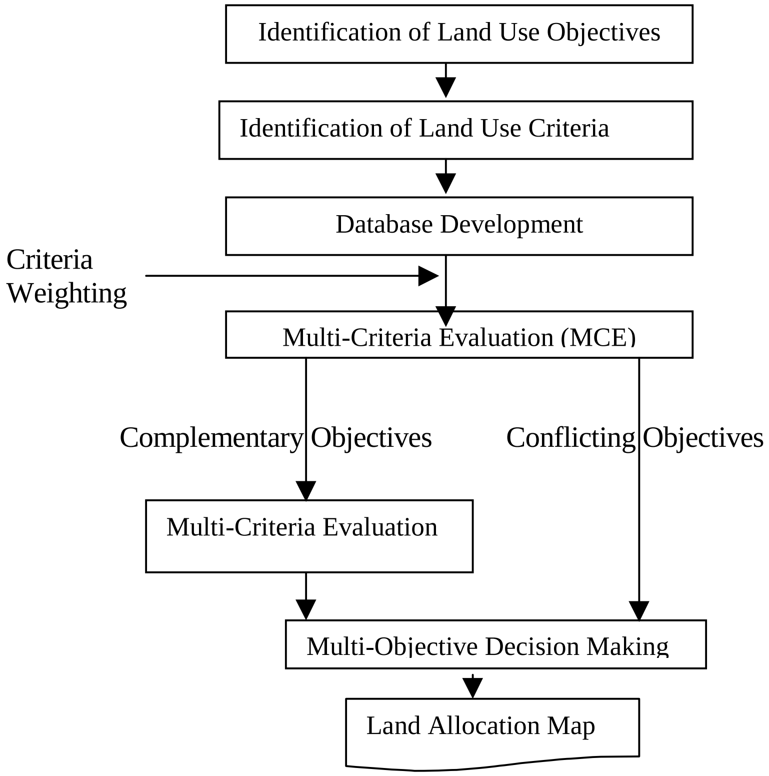

Figure 3. Flow Chart for the MCDM Process

4.1 Setting the Land Use Objectives

The setting of the land use objectives is a group activity where all possible stakeholders state what they require from the land under consideration. The total acreage required by each objective should also be determined at this stage. From background knowledge, field campaign and published materials six broad land use objectives namely; rain-fed agriculture, irrigation, livestock rearing, suburban developments, commercial fuelwood extraction and soil erosion control were identified for this area. However, commercial fuelwood extraction is a destructive activity that should be stopped. It was therefore not included in the analysis. The remaining broad land use objectives were refined into eight specific land use types as shown in Table 1 below.

Table 1. Land Use Objectives

Land Use	Area Ha	Land Use	Area Ha	Land Use	Area (Ha)	Land Use	Area (Ha)
1. Maize	20,000	3.Groundnuts	10,000	5.Irrigation	1,000	7. S/Urban	2,000
2. Sorghum	40,000	4. Sisal	15,000	6. Grazing	70,000	8. Erosion	125,000

4.2 Identification of Criteria

Criteria are measurable basis on which decisions about land quality and its suitability for a specified use can be made. Two types of criteria i.e. factors and constraints can be distinguished (Eastman *et al.*, 1995). A factor is a continuous geographic attribute that enhances or diminishes the suitability of an area towards meeting a specific objective, e.g. available rainfall, soil depth, slope or temperature. A constraint limits the available alternatives by imposing restrictions e.g. the exclusion from development of all areas designated wildlife reserve or areas with slopes exceeding 100%. Besides the surface to near surface land qualities, criteria may also arise from situational conditions i.e. the relationships between a site and surrounding areas. Such conditions include proximity to communication infrastructure, service/facility centres or power sources (Eastman *et al.*, 1995). All criteria are presented as maps.

Identification of criteria is a technical activity, which is based on theory, empirical research or common sense. Criteria identification can be done using the participatory approach by a group of experts from various disciplines. In this study criteria identification was done by the author with assistance of a group of professionals, who included an agronomist, a sociologist, an economist, a demographer and a wildlife scientist. Eleven factors i.e. population density, land capability, slope, rainfall, distance from perennial rivers, degree of surface rockiness, extent of area affected by erosion, cation exchange capacity (cec), distance from an existing powerline, distance to a road and costed distance to an existing sub-urban centre were identified. Land capability maps for different crops were derived from estimated yields for different agro-ecological zones according to Jaetzold and Schmidt (1983). Two constraints, i.e. water bodies and the Lake Bogoria National Park were identified.

4.3 Database Development

Maps for most of the identified criteria were available in analog forms. These were digitised using ARC/INFO GIS. The digital maps were exported to IDRISI for use in the decision making process. Factors were presented as continuous value maps while constraints were presented as Boolean maps with excluded areas coded zero (0) and areas open for consideration coded one (1). Eleven factor maps and two constraint maps were created. Since factor maps for different criteria consist of values measured in different units it was necessary to standardise them for comparative evaluation. Several standardisation techniques are available (Voogd, 1983). Standardisation of factor maps was done using the IDRISI Stretch command. Where higher values represent lower suitability, the stretched images were inverted.

4.4 Criteria Weighting

Different criteria usually have different levels of importance, for example the criterion "available rain" is much more important for rain fed agriculture than "closeness to a market". It is therefore necessary to incorporate of some form of criteria weighting to take care of their relative importance. Criteria weighting was done by the author using the analytical hierarchy process (AHP) developed by Saaty (1980), which translates pairwise comparison matrices for different land uses into vectors of relative weights.

4.5 Multi-Criteria Evaluation

Next the criteria for all land use objectives are evaluated to identify the spatial locations where the criteria for each objective is best satisfied. The MCE command of the IDRISI Decision Support System module with the Weighted Linear Combination Option was used to produce land suitability maps for each objective. Suitability maps for complementary objectives are combined through a hierarchical application of the multi-criteria evaluation using standardized weighted suitability maps as the new factors to produce hybrid suitability maps.

4.6 Multi-Objective Decision Making

Most objectives will tend to pick the same land units. At this stage decisions on the best way to allocate the available land such that all the objectives are satisfied simultaneously needs to be made. Where a clear-cut prioritisation of land use objectives is possible, a sequential process of ranking, allocation and elimination can be done until all land use objectives are allocated. In most cases clear-cut prioritisation is not feasible. Some form of conflict resolution mechanism is thus required. The IDRISI multiple-objective land allocation (MOLA) command provides such a mechanism.

The suitability maps need to be standardised before the multi-objective land allocation is carried out. Standardisation was done using the RANK command which ranks the suitability maps according to their closeness to the ideal point (Eastman *et al.*, 1995). The ranked images were then prioritised using the analytical hierarchy process before they were submitted to the multi-objective land allocation (MOLA). Prioritisation was done on the basis of the weights shown below.

Table 2 Objective Weights

Sisal	Urbanization	Groundnuts	Maize	Grazing	Millet	Irrigation	Conservation
0.0256	0.0331	0.0575	0.1079	0.1226	0.1317	0.2031	0.3184

5. RESULTS AND DISCUSSIONS

Figure 7 below shows the optimised land use allocation obtained from MOLA (a) and present land use patterns obtained from classified 1995 Landsat-TM image (b).

Optimal lands for rainfed agriculture (maize, millet and groundnuts cultivation) seem to agree with present land use patterns. Land currently occupied by sisal plantations has been allocated to millet and grazing. This is because sisal and millet compete for the same lands and millet and grazing were given higher priorities relative to sisal in order to enhance food security. The Loboi plains, which are currently occupied by irrigation schemes, were allocated to conservation. This was caused by their high ratings in rockiness and erosion extent. The sites identified as ideal for urban development were strongly influenced by population density than by any other factor. Although vegetation characteristics was not a criteria, there seems to be a general trend towards protecting sparsely vegetated areas.

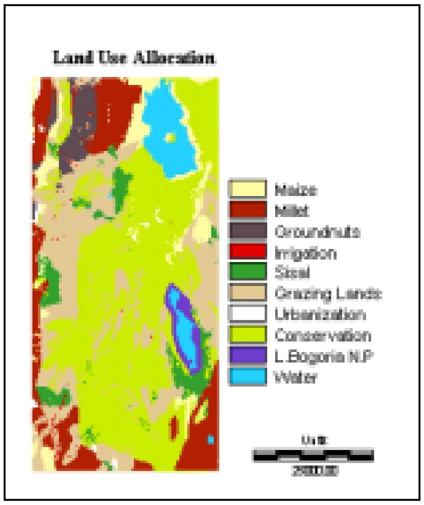

Figure 7a Land Allocation

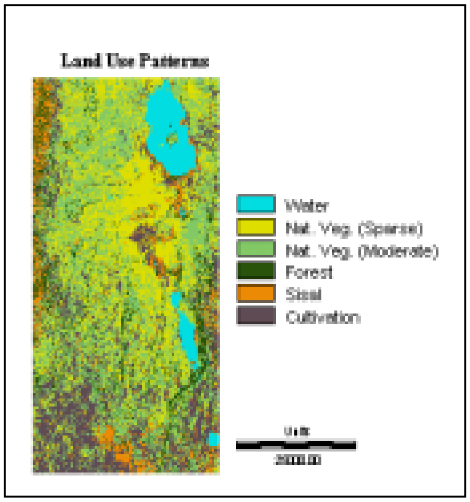

Figure 7b Present Land Use Patterns

6. CONCLUSIONS

The decision support system presented can be used to formalise the decision making process for rural land use planning. The complex problem of allocating limited land to satisfy unlimited needs can be solved by such a system, which allows the incorporation of several criteria and offers a means for combining them into decision alternatives. The system provides a framework for participation of all stakeholders – farmers, technical personnel, environmentalists and policy makers, hence an ideal entry point for the introduction of scientific findings into rural land use planning while making use of the available indigenous knowledge.

The results indicate that although the factors and their weights strongly influence the land allocation, objective prioritisation seems to have the most significant impact. A higher priority objective will be allocated land before a lower one even if the land is more suited to the latter objective. For good results it is therefore necessary to carefully identify land use criteria, produce accurate criteria maps and use a flexible but objective criteria weighting and objective prioritisation systems.

Finally, better results will be achieved if the process is carried out iteratively, giving the participants a chance to view the preliminary allocations before a final land allocation map is made. To improve on criteria accuracy, smaller units with more detailed data may considerably improve the results.

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BIOGRAPHICAL NOTES

Ben Mwasi holds a B.Sc degree in Surveying and Photogrammetry from the University of Nairobi and an M.A in Geography from Carleton University, Ottawa. He has worked as a land surveyor with the Ministry of Lands and Settlements (1985-1991) and as a lecturer in Geography at Egerton University, Kenya (1991-1995). Currently he is a research fellow at the School of Environmental Studies, Moi University, Kenya and a Ph.D student at the Department of Physical Geography, University of Amsterdam. His main career interests fall within the broad area of applications of GIS and digital image processing to both natural and socio-economic resource mapping and management. His present research involves analysing the dynamics of landscape changes in the semi-arid areas within the Lake Baringo area of Kenya.

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