Decision Support System (DSS) and GIS for Sustainable Watershed Management in Dong Nai Watershed

Nguyen Kim Loi
Nong Lam University(NLU), Ho Chi Minh City, Vietnam
Email: nguyenkimloi@yahoo.com

ABSTRACT

Decision makers today need to be able to rapidly find good solutions to increasingly complex problems. Optimization based on decision support system (DSS) can help decision makers to meet this challenge. Building such systems, however, is expensive and time consuming. The conflict between environmental protection and the economic development by different uses of land within a watershed is a problem that constantly confronts public officials in regional planning, as experienced in many developing countries. In this study, DSS was developed using linear programming (LP), goal programming (GP), and geographic information system (GIS) for sustainable watershed management in Dong Nai watershed, Vietnam. A case study approach is undertaken using 'what-if' planning scenarios. The multi-objective linear programming (MOLP) techniques and GIS have been applied to display the optimum land resource allocation in different scenario, in order to evaluate the sustainable strategy of land development in a watershed. The information incorporated into the optimization objectives include economic benefits characterized by net income, sediment yield, and water discharge. The constraint set thereby consists of the limitations of carrying capacity of various land-use programs and assimilative capacity corresponding to different impacts on water quantity, sediment yield. The type of spatial planning problems described in this paper allocates different land uses across a geographical region, subject to a variety of constraints and conflicting management objectives. This complex land use planning decisions were made not only on what to do (selection of activities) but also on where to do it (i.e., relocate a new set of suitable land use for different scenarios), adding a whole extra class of decision variables to the problem. The new location of suitable land use has been manipulated using the given criteria in term of slope, soil depth, and rainfall. The algorithm was developed in ArcView GIS software to relocate land use map in Dong Nai watershed. The developed DSS performed very well in Dong Nai watershed, and applicable to any watershed in Vietnam.
Keywords: *Decision support system (DSS), GIS, Sustainable watershed management; Dong Nai wateshed, Vietnam.*

1. INTRODUCTION

1.1 Justification

Degradation of watershed is a common phenomenon around the world. There are several reasons for such degradation, but most important is improper utilization of watershed resources, among which land use allocation is the most important. Land use allocation has affected watershed and land degradation. The most important consequence of land degradation in Vietnam is the loss of productivity, depletion of fauna and flora and reduction of agricultural land per capita. In terms of the estimated monetary loss on account of land degradation, water erosion and leaching accounted for more than half, salinisation, acidification, drought and water logging for about one third and decline in soil fertility for the rest. (Buckton. et. al. 1999). The consequences of flood inundation and water logging are very serious on humans and precious natural resources. For example, two floods in 1999 occurred in the southern central coast claimed 711 lives and caused economic loss estimated at more than US$ 235 million. Besides, millions of tons of soil from the hilly and mountainous regions was eroded and flowed into rivers, streams, plains and the sea.

In Dong Nai watershed, large forest area has been replaced by the expansion of agricultural area, for food subsistence and then, for cash crop production, especially since the beginning of the "open economy" in 1980s. Traditional management systems for forest, land and water have been replaced by subsidiary state-run enterprises and agencies, which were not well motivated to enforce formal regulations and to stop the trend of becoming an open-access situation.

Hence, this research attempts to solve the selected Dong Nai watershed in context of watershed management through the Linear Programming and GIS criteria-DSS (Decision Support Systems) approach.

1.2 Objectives

In order to formulate watershed management plan in Dong Nai watershed, the main aim in this investigation is how to apply LP and GIS criteria-DSS for optimizing land use allocation and relocating the solution in Dong Nai watershed. The specific objectives of this study are as follows:

1) to determine the decision variable coefficients for LP and GIS;
2) to apply LP technique for optimizing land use allocation in Dong Nai watershed under the criteria of multiple objectives, limited resources, and permissible impacts to the water yield;
3) to apply GIS and DSS techniques for relocating the optimal land use maps allocated by LP.

2. METHODOLOGY

The Decision Support System (DSS) techniques namely Mathematical programming, Linear Programming (LP), Goal Programming (GP), MINMAX formulations, Geographic information system (GIS), and multi-criteria decision analysis were employed to ranking the desirable priorities, their potential outcomes, and quantifying their achievement level respectively. Mathematical programming makes it possible to obtain the optimal solution of the problem in order to make the objective function maximum or minimum while fulfilling all other requirements at the same time. Mathematical programming is able to give a synthetic approach to complex situations. The results and problem structure are discussed in the next section, before that an out look of the necessity for integrating the GIS along with analytical model has been elaborated in the following section. The methodology employed herein can be described as follows:

2.1. Study Area Description

Dong Nai watershed locates in the Southern of Vietnam which is one of three province at East – Southern, Vietnam. It is situated between $10^{0}31^{'}$ - $11^{0}35^{'}$ latitude and $106^{0}42^{'}$ – $107^{0}35^{'}$ longitude. The region occupies an area of approximately 586,427 ha.

2.2. The Scenario planning methodology

The principal planning task is to bring about the efficient planning of future in Dong Nai watershed. The objectives from each of these plans assist in deciding upon the socio-economic, physical and environmental data required to formulate the different planning scenarios. The objectives are also used later in the methodology to evaluate the efficiency of each proposed planning scenario.

The next step of the planning methodology is to formulate possible land-use scenarios. Three land-use planning scenarios are formulated for Dong Nai watershed. Scenario A -'future trends' is based on existing socioeconomic trends. Scenario B – 'Land allocation for maximizing economic' will be derived using optimization modelling of land valuation data. Scenario C – 'Land allocation for environment' will be derived using a number of environmental layers and assigning weightings of importance to each layer using a multiple criteria analysis (MCA) approach.

2.3. Relocating Land use allocation mapping

Based on results from linear programming, and goal programming of three scenarios (Scenario A "Future Trends" scenario, scenario B "Land Allocation for Maximizing Economic"scenario, scenario C "Land allocation for environment" scenario), the final step of this research is to mapping the location of land uses allocated by different scenarios using GIS techniques with the given criteria.

RESULTS AND DISSCUSION

1. The Derived Variable Coefficients for Linear Programming, Goal Programming Model

Since a few of decision variable coefficients related to income, water discharge, sediment yield, according to the land use complex on the Dong Nai watershed, had been made available. The derived input data applied as decision variable coefficients in this study were thus based on the previous research finding, theoretical background, and surveying study particularly income.

The decision variable coefficients derived for applying in LP model, and GP in this study are presented for the watershed scale. These quantitative coefficients and their application in solving the land use allocation for sustainability is shown in Table 1.

2. Solution of Quantitative Planning Management Scenarios of Dong Nai Watershed, Vietnam

2.1. MINMAX formulation

- **The Present Watershed Scenario (Scenario A)**

Based on existing socio-economic trend in Dong Nai watershed, and relationship between gross income, water discharge, sediment yield, and land use change in Dong Nai watershed, the multiple objectives achievement levels of present watershed management scenario on watershed net income, water discharge, and sediment yield were approximately 10,093,650,805 thousands VND/yr, 509 m^3/s, 1,291,011 m^3 with the proportion of land allocation are Natural Forest (X_1 = 22.216 % or 131,089 ha), Forest Plantation (X_2 = 8.325% or 49,120), Industrial Crops (X_3 = 28.520% or 168,284 ha), Paddy Field (X_4 = 22.805% or 134,561 ha), Residential / Urban (X_5 = 1.822% or 10,751 ha), Open land (X_6 = 4.787% or 28,245 ha), and Special land (X_7 = 11.546 % or 68,013 ha).

- **The Land Allocation for Maximizing Economic Scenario (Scenario B)**

The maximizing economic scenario that means the economic objective (net income) is the first priority to optimize decision variables as shown in the first row in Table 2.

❖ The Land Allocation for Environment scenario (Scenario C)

The types of environmental impacts in this research for control as part of land use planning have to reflect directly the needs in the current watershed, which consist of sediment yield from soil erosion, and water discharge. The scenario is thus set the sustainable development the environmental impact as the first priority. The environmental objectives function are then included sediment yield and water discharge. Firstly, sediment yield will be put as the first priority to optimize decision variables as shown in the third column in Table 2, then water discharge will be put as the first priority to optimize decision variables as also shown in the second column in Table 2.

2.2Solution based on Goal Programming

The problems associated with managing land water and other resources have never been simple. The concept of watershed management which tries to compromise water yield, socio – economic, and other impacts utilization in the system seems impossible to determine for the best management practice. Because of the desirable conflicts for the maximum or minimum value of each individual objective to achieve its own benefit, the objective in this model is thus manipulated separately corresponding to the same constraint set. However, the solution sets suggest that only two broad-based planning objectives-economic development (net income) and environmental quality (water discharge, and sediment yield) need to be considered independently. The LP technique could not combine among objectives while the GP model can plays around with multi-objectives.

The previous objectives and their potential target values or aspiration were formulated in term of multiple objectives management functions. The achievement level of those objectives and land uses allocation were evaluated using GP model. The model solutions of Dong Nai watershed can be described as follows:

The optimum land use derived from GP model consists of 29.09 % for natural forest (X_1) or 171,357 ha; 8.4% for plantation forest (X_2) or 4,482 ha; 25.53% for industrial crops (X_3) or 150,385 ha; 21.79% for paddy field (X_4) or 128,418 ha; 2.07 % for urban/residential (X_5) or 12,193 ha; 2.829% for open land (X_6) or 16,666 ha; and 10.260% for special land or 60.450 ha. The output from GP model indicated that the multi-objectives (net income, water discharge, sediment yield) contributes net income at about 10,810 million thousand VND comparison about 10,899 million thousand VND potential objective obtained from Scenario B. That is the achievement level of net income was 99.18% of potential target value or under the target by 0.082%. The achievement level of water discharge in GP model was at about 461 m^3/s, which is about 12 times smaller than potential target water discharge (6,174 m^3/s). The under achievement of positive impact (water discharge) is unsatisfied but, in practice it is still normal range of 410 – 540 m^3/s which have been recorded. Thus, this achievement of water discharge could be in the acceptable level. The soil erosion in GP model estimated about 1,247,046 m^3 comparison about 1,222,000 m^3 potential objective. The achievement level of negative impacts (sediment yield) was 102.05 % of potential target value which is 2.05% over the achievement level and still below the given standard.

Table 1. Determination of decision variable coefficients in individual objective

	Constant/ Intercept	Forest land		Agricultural land		Residential (X_5)	Open land (X_6)	Special land (X_7)
		Natural Forest (X_1)	Plantation forest (X_2)	Industrial crops (X_3)	Paddy flied (X_4)			
Z_1	-	2094724	212422.7	65638608	34447878	389441580 0	0	25300836
Z_2	5,322,520	-42902.8	-44648.2	-43294.8	-43286.8	-326300	-52347.7	-80560.8
Z_3	484,190,000	-4,105,530	-4326230	-4074280	-4052680	-22992500	-4792260	-7121250

Where the three objectives considered in this analysis:

Z_1 = the objective function of income (thousand VND)
Z_2 = the objective function of water discharge (m^3/s)
Z_3 = the objective function of sediment yield (m^3)

and the seven decision variables are defined as:
X_1 (%) = the optimal percent prepared for natural forest conservation;
X_2 (%) = the optimal percent allowed for plantation forest;
X_3 (%) = the optimal percent for industrial crops;
X_4 (%) = the optimal percent for paddy flied;
X_5 (%) = the optimal percent for residential/ urban;
X_6 (%) = the optimal percent for open land/ bare land;
X_7 (%) = the optimal percent for special land.

Table 2. The optimal solution in the case of the inclusion of each individual objective independently

	Objective function		Forest land		Agricultural land		Residential	Open land (X_6)	Special land (X_7)
		value Z_k	Natural Forest (X_1)	Plantation forest (X_2)	Industrial crops (X_3)	Paddy flied (X_4)	(X_5)		
Scenario A	Z_1	10,093,650,805	22.216% (131089)	8.324% (49120)	28.519% (168284)	22.805 (134561)	1.822% (10751)	4.786% (28245)	11.524 (68013)
	Z_2	509							
	Z_3	1,291,011							
Scenario B	Z_1	10,899,260,000	26.600% (156,694)	8.400% (49,482)	26.600% (156,694)	23.250% (136,960)	2.063% (12,152)	2.830% (16,665)	10.260% (60,439)
	Z_2	398.5							
	Z_3	1,987,056							
Scenario C	Z_1	10,590,623,950	27.550% (162291)	11.880% (69982)	23.630% (139199)	21.790% (128419)	2.049% (12070)	2.829% (16665)	10.260% (60439)
	Z_2	184.8							
	Z_3	1,222,000							
	Z_1	10,562,626,711	31.032% (182803)	8.400% (49483)	23.299% (137255)	22.130% (130357)	2.049% (12070)	2.829% (16671)	10.260% (60439)
	Z_2	6,174							
	Z_3	2,200,960							

Note: Z_1 = Net Income (thousands VND); Z_2 = Water discharge (m^3/s); Z_3 = Sediment yield (m^3)

2.3Mapping the Goal Programming Results

The final step of DSS involves with the geographical distribution of the land allocation of different proportion land use from GP solution. For instance, the new forest land can be located by using the given criteria, such as slope, rainfall, soil depth. For goal programming, a figure of 14,809 grid cells of non-forest land (or 370,228ha consisting of industrial crops, paddy field, bare land/open land, and special land) about 1,625 grid cells (or 40,630 ha) would be selectively transformed to forest land by the setting criteria. The sustainability map for each land use, and the sustainability land use allocation map is presented in Figure 3.

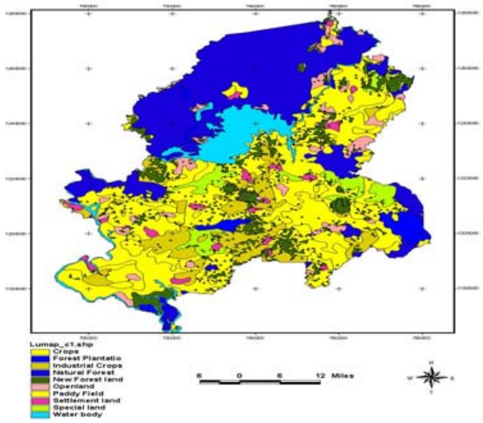

Figure 3 Land use map in Dong Nai watershed based on goal programming solution (after relocated)

CONCLUSION

The decision support system (DSS) herein is a typical SDSS (Spatial Decision Support System) developed for formulating the plans for sustainable watershed management in Dong Nai watershed, Vietnam. It is a mathematical combination approach consisting of linear programming (LP), goal programming (GP), and geographic information system (GIS). The tools employed for deriving the sustainable watershed management plans in this study were Statgraphics Plus 5.0, LINDO software, and GIS system of Arc View program. Three management scenarios i.e., Scenario A “Based on Existing Socio-Economic Trend”; Scenario B “Land Allocation for Maximizing Income”; and Scenario C “Land allocation for environment” have been applied to find alternative land – use planning for Dong Nai watershed. The last two scenarios (S_B + S_C) were then combined by GP model to obtain the most favorable land –use proportion in order to optimize their target levels.

REFERENCE

Nguyen Kim Loi (2004). *Decision support system for sustainable watershed management in Dong Nai watershed – Vietnam: Conceptual framework a proposed research techniques*. Paper presented in **Forest and Water in Warm Humid Asia, IUFRO Workshop**, July 10-12, 2004 **Kota Kinabalu, Malaysia.**

Nguyen Kim Loi (2004). *Applying Linear Programming and Goal programming Techniques for Land Allocation in Dong Nai Watershed-Vietnam.*. Paper presented in **International Environmental Modelling and Software Society iEMSs 2004 International Conference .** Complexity and Integrated Resources Management Session. 14-17 June 2004 **University of Osnabrück, Germany**