A GIS Based Sustainable Developement Mapping in Quang Tri, Vietnam

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Abstract

A combination of a geographical information system with indicators to monitor sustainable development at provincial level. To establish sustainability maps as an effective tool for planners and decision makers. This study integrates and applies a three-step spatial analysis to monitor sustainable development. At first, spatial maps are produced using MapInfo as common geographical information system software. Second, based on expert's opinions, a set of sustainable development indicators is developed. In a third step, the IDRISI software is applied to map the indicators in a spatial way. Two sustainability maps of health and environment indicators are calculated. Finally, they are integrated in a sustainable development map of the year 2005. Sustainability and composite sustainable development maps can be established in an efficient way, using these methods. These maps are one of useful tools to support the decision-makers and planners.

1. Introduction

GIS (Geographical Information Systems) has been widely applied to detect, analyze, and develop sustainable development (SD) maps. The GIS technology provides a flexible environment to store, analyze, and display digital data on SD (Hai, 2005). Relations between society and nature in one place and between different places may range from mutualistic to competitive interactions. The mutualistic situations, together with cooperative and commensal relations, are preferred if SD is the target (Michael, 2002). Today, GIS is a common tool that provides support to planners and decision - makers. GIS contains four basic aspects: databases, software, equipments, and experts. Among these, the expert looks as the most important one. Moreover, GIS can be seen as geographic information tool. It emerged during the 1990s as a scientific approach of geographic informatics. To avoid confusion, geographic information science is often abbreviated as "GISci". The GISci studies GIS technology, with a focus on (remote) sensing, cartography, surveying, spatial statistics, computer science and related fields (Jupitermedia Corporation, 2008). To improve GIS for planning and designing, methods, techniques and models are needed (Arentze at el., 1996) using one of current power tools as the Analytic Hierarchy Process (AHP) developed in 1977 by Saaty. The AHP has the special advantage of using multi-indexes evaluation. That is one main reason why AHP is integrated in GIS. "The combination of AHP and GIS allows spatial analysis provides an effective means to describe the complexity of the human environment. A synthetic index system was set up including the natural environment, disasters, environmental pollution, and social economic factors" (Xuong et al., 2007). Additionally, to use GIS software to identify sustainability main area is its relatively low-cost. "Of the many GIS available, perhaps the most obvious low-cost choice for the study of the environmental factors associated with vector-borne disease transmission is the raster-based system developed…" (Connor et al., 1995). Recently, in Vietnam, GIS has increasingly been used to analyze the spatial and temporal aspects of SD, particularly in major cities such as Hanoi and Ho Chi Minh. Nevertheless, for Quang Tri, a poor and small province in the central part of the country, the combination between GIS and AHP are likely attractive as it is cheap and simple approach from a methodology point of view. Additionally, it has advantages of creating sustainability maps compared with other cases (Hai, 2005) more accurately and quickly. Nevertheless, it has not been applied yet to support authorities and decision-makers. This case study aims to establish sustainability maps using GIS through the IDRISI software. It was founded in 1987 as the IDRISI project by Geography Professor Ron Eastman. Up till now, it has become one the largest raster-based microcomputer GIS and image processing systems on the market (Eastman, 2003b). It contains the main interface program and a collection of nearly 200 other modules that provide facilities for the input, display and analysis of geographic data. The focus of this study is on the health and environmental aspects. Sixteen indicators for SD were selected. The outcome should support planners (e.g. Departments of Natural Rcsourccs and Environment, Agriculture, and Planning) and decision - makers at the levels of the district and province. This analysis focuses on the Trieu Phong district, Dong Ha town, and the Huong Hoa district. Data used in this paper reflects the situation in 2005, but the system easily allows introducing more recent data as soon as they are available.

2. Methods

The methods which allow and the establishment of standard factor images, weighting of fuzzy images, and sub-indexes and create sustainability maps, applied in this study follows the IDRISI Kilimajaro tutorial and manual (Eastman, 2003a, b). Multi-Criteria Evaluation (MCE), which is a common method, was used. In addition, a non-Boolean aggregation and weighted Linear Combination (WLC) methods was used to procedure and retain the variability from the continuous factors and also enable trade off of factors with each other (Eastman, 2003 b). The method builds mostly upon concepts discussed in the Decision Strategy Analysis chapter of the IDRISI Guide to GIS and Image Processing (Eastman, 2003a) as well as Exercise 2-8 of the Tutorial (Eastman, 2003b). Indicators applicd for this study are the ones generated from previous research in the study area. They were defined using the Delphi method (Hai et al., 2008). The main steps of the methods are illustrated in Figure 2.

2.1 Factor Images

In order to determine which a case study is more sustainable or verse, correlative indicators are based on available data, which are stored in the Excel environment (the real values dividing 8 and 8 of the aspects of health environment (Annex 1). Next, factor images were imported in the MapInfo environment from the correlative indicators (e.g. factor image 1 from the indicator of flood area per person) (step 1 in Figure 2). Finally, they were converted in the IDRISI environment at scale 1/50,000 to obtain images. All the correlative indicators are expressed as raster images.

Annex 1: Thematic (factor) images of health and environmental indicators of the Quang Tri province in 2005 from correlative indicators of SD

	Unit	Trieu Phong district	Dong Ha town	Huong Hoa district	Quang Tri province	Correlative indicator
Health aspect						
Factor image 1	ha/per	0.01	0.01	0	0	Flood area per person
Factor image 2	1,000 /year	35	8	76	21	Mortality rate under age five
Factor image 3	%	1.19	3.05	23.56	16	Nutritional status of infant
Factor image 4	%	48.15	80.4	25.67	41.54	Percentage of population with access safe water
Factor image 5	%	11.53	82.11	16.02	26.81	Number of household with adequate sewage disposal facilities
Factor image 6	%	99	98	98.23	98.61	Immunization against infectious childhood diseases
Factor image 7	%	46.21	46.14	29.41	35.52	Contraceptive prevalence rate
Factor image 8	%	95.87	99.7	90.14	94.87	Percentage of population with access to primary health care facilities
Environmental aspect						
Factor image 9	tons/ha /year	41.98	15.54	2,298.76	16.02	Soil erosion
Factor image 10	%	100	0	0	60.66	Percentage of population living in a coastal district
Factor image 11	ha/per	0.0701	0.0193	0.2029	0.11	Arable land per capita
Factor image 12	kg/ha	0.59	0.57	0.6	0.58	Use of agricultural pesticides
Factor image 13	ppm	0.06	0.33	0.052	0.08	Air pollutants
Factor image 14	MPN/ 100 ml	2,500	6,258	3690	2,900	Faecal coliforms in freshwater
Factor image 15	%	40.97	31.44	25.29	35.00	Percentage of forest area
Factor image 16	number	5	0	33	34	Abundance of selected key species

****** Note: All data were collected from the Institute of Geography, the Quang Tri Department of Health, the Centre of Rural Fresh Water and Sanitation, the General Statistical Office, and/or the Quang Tri Department of Natural Resources Environment in 2005.*

Annex 2: Steps of standardizing the factor image

Input factor image name	Specify factor image standardization with fuzzy		Membership function shape		Output fuzzy image name
	Min. data value	*Max. data value*	*Monotonically increasing*	*Monotonically decreasing*	
Health aspect					
Factor image 1	0	0.01		x	Fuzzy image 1
2	8	76		x	2
3	1.19	23.56		x	3
4	25.67	48.15	x		4
5	11.53	82.11	x		5
6	98	99	x		6
7	29.41	46.21	x		7
Factor image 8	90.14	99.70	x		Fuzzy image 8
Environmental aspect					
Factor image 9	15.54	2298.76		x	Fuzzy image 9
10	0	100		x	10
11	0.0193	0.2029	x		11
12	0.57	0.60		x	12
13	0.052	0.33		x	13
14	2500	6258		x	14
15	25.29	40.97	x		15
Factor image 16	0	34	x		Fuzzy image 16

2.2 Standardizing the Factor Images

In order to compare values, standardization on a continuous scale is necessary to transform the disparate measurement units of the factor images (Eastman, 2003b). Each of the factor images is transferred to become a fuzzy image that an image is standardized to Boolean values by using the module FUZZY following the option of a 0-255 scale where 0 is not sustainable and 255 is perfectly sustainable. This step is illustrated in step 2 in Figure 2 and Annex 2. Start the standardizing by selecting it from the GIS Analysis → Decision Support → Fuzzy by the following 3 steps:

- ❖ Step 1: Specify the type of membership functions to apply: Sigmoidal, J-shaped, Linear or user-defined;
- ❖ Step 2: Enter the name of the input and output images;
- ❖ Step 3: Choose the output data format from the drop-down list: Byte (0-255 range).

For example, the fuzzy image of mortality rate under the age five was standardized: a 255 value is numbers lower than 8, a value which progressively decreases from 255 to 0 along a sigmoidal curve is from those between 8 and 76, and a value 0 is above 76.

2.3 Weighting the Fuzzy Images and the Sub-Indexes

Generally, weight is to estimate the importance of fuzzy images or sub-indexes (e.g. society, economy, and environment) by multi-experts in order to select reasonable ones and determine the relative weights. It identifies the priority of each indicator or sub-index. The individual importance of the indicators is difficult to determine with sufficient accuracy (Afgan and Carvalho, 2004). Weights of this nature can be derived by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparisons between the criteria (Eastman, 2003b). In order to weight the fuzzy images and the sub-index, we used AHP to implement pair-wise comparison in the Idrisi software and the Microsoft Excel environment.

2.3.1 Weighting the fuzzy images

In IDRISI, the module weight uses a pair-wise comparison technique to develop a set of factor weights that will sum to 1.0 (Eastman, 2003b) under the AHP method. The pair-wise comparisons are made for each pair of the fuzzy images in a (8 x 8) matrix A: where $a_{ik} = 1$: the diagonal and $a_{ki} = 1/a_{ik}$: reciprocal property, i, k = 1, …, 8 assuming: if indicator i is 'p-times' the importance of indicator k, then, necessarily, indicator k is '1/p-times' the importance of indicator i. A quick way to find the normalized weight of each indicator is normalizing each column in matrix A (dividing an indicator relative weight by the sum of relative weights in column), and then averaging the values across the rows; this average column is the normalized weight vector W containing the weights (W_{ji}) of selected sustainability indicators (Krajnc and Glavic, 2004). Ratings are provided on a 9-point continuous scale (Figure 1). A pair-wise comparison matrix is illustrated in step 3 in Figure 2, Annex 2, and Annex 4. An individual factor map compares every possible pairing. In addition, the last column shows factor weights that will sum to 1.0.

They are assigned to specify the relative importance of each factor in determining the aggregate output value.Start the standardizing by selecting it from the GIS Analysis → Decision Support → Weight by the following main steps:

- ❖ Step 1: Create new pair-wise comparison file;
- ❖ Step 2: Input factors for the new pair-wise comparison file;
- ❖ Step 3: Fill in the matrix cells (move from column to column from left to right);
- ❖ Step 4: Calculate weights. The Consistency Ration (C_R) of the matrix will be reported.

The weights for the each fuzzy image are evaluated in Annex 2, Annex 4, and step 3 in Figure 2:

- ❖ On the health aspect: The weights of the fuzzy images of sustainability in the SD are defined as fuzzy images 1 (weight = 0.1889), 2 (weight = 0.1723), and 3 (weight = 0.1488) strongest determinants vs. fuzzy images 4 (weight = 0.1084) and 7 (weight = 0.0700);
- ❖ On the environmental aspect: Fuzzy images 10 (weight = 0.1867) and fuzzy 9 (weight = 0.1753) are considered the most important ones vs. 13 (weight = 0.0745) and 12 (weight = 0.0814) are the lowest scores.

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	strongly	Moderately	Equally	Moderately	strongly	Very strongly	Extremely
Less important					More important			

Figure 1: The continuous rating scale (Eastman, 2003b)

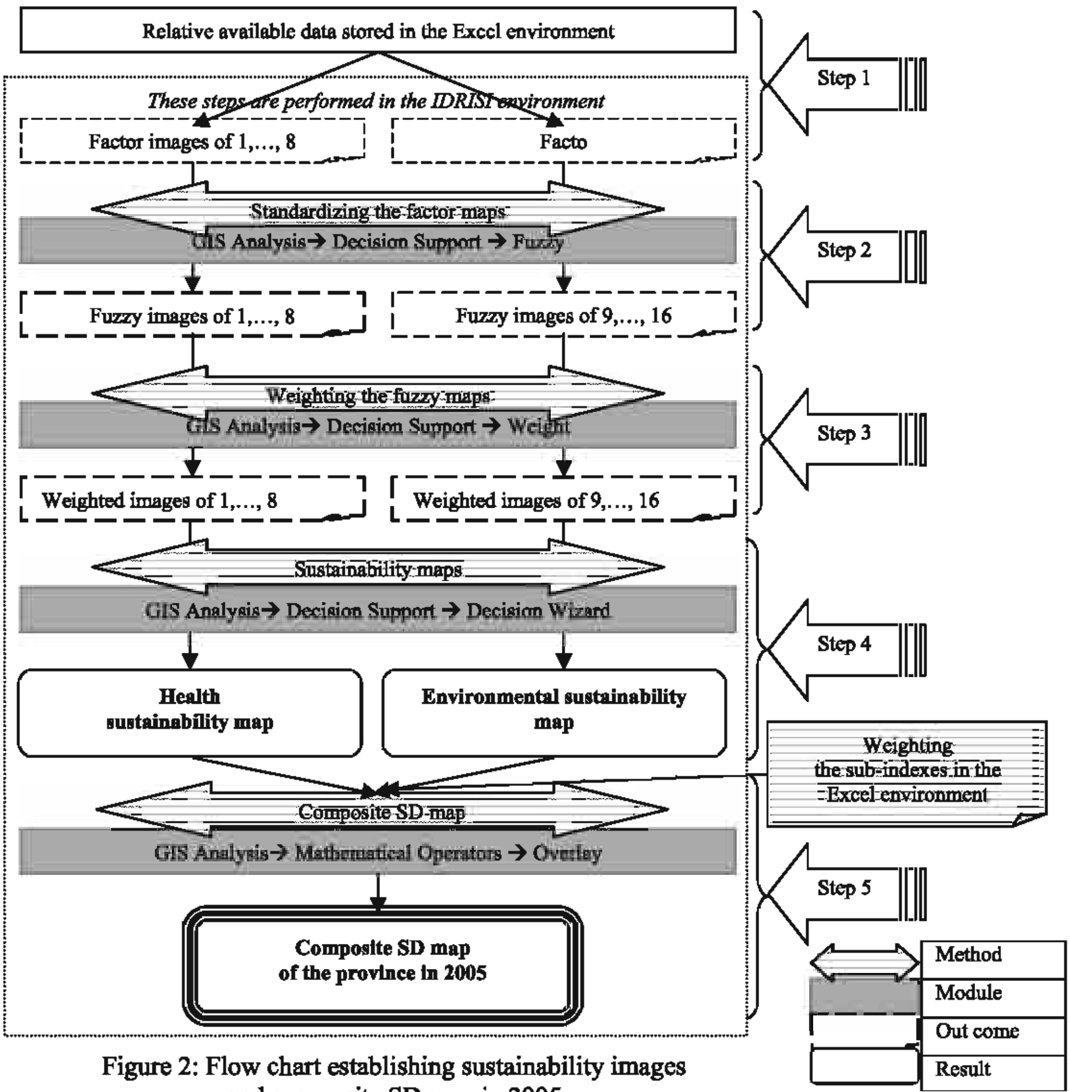


Figure 2: Flow chart establishing sustainability images and composite SD map in 2005

2.3.2 Weighting the sub-indexes
These pair-wise comparisons result in a (3 x 3) matrix A (Annex 5):

- ❖ From 1/2 to 1: one sub-index is times more important of the one to which it is to be compared;
- ❖ The value of 1: sub-indexes are equality between both sub-indexes;
- ❖ From 1 to 2: one sub-index is times less importance of the one to which it is be compared.

Both the fuzzy images and sub-indexes are weighted by multidisciplinary experts in 2007 at the Institute of Geography. To check the consensus among the judgments for both weighting indicators and sub-indexes is measured using this definition. It relates the Consistency Index (C_I) and the Random Consistency Index (R_I) using the formula: (Krajnc and Glavic, 2004).

$$C_R = C_I / R_I$$

Equation 1

C_R must be smaller than 0.1, otherwise it is be necessary to re-evaluate until it is finally less than the value. For instant, the economic sub-index (weight = 0.460) is the most important of sustainability aspect in the case studies and followed by the environmental (weight = 0.293) and social (weight = 0.247) sub-indexes (Annex 5). According to the rules of AHP, all consistency ratios are 0.1 and therefore are acceptable.

2.4 Sustainability Maps
In fact, this step integrates the steps of 2.1, 2.2, and 2.3.1 into one module. It is options to derive the weights and to compute a sustainability map, e.g. the sustainability maps of health and environment (step 4 in Figure 2). It integrates factor images in the form of a weighted linear combination (WLC). "The procedure is optimized for speed and has the effect of multiplying each factor by its weight, adding the results. Since the weights sum to 1.0, the resulting suitability maps have a range from 0-255."(Eastman, 2003a). Start the standardizing by selecting it from the GIS Analysis → Decision Support → Decision Wizard by the following steps (Annex 2):

- ❖ Step 1: Specify the number of factor images to be used for the study's objectives; enter the input and output factor image filenames;
- ❖ Step 2: Include four sub-contents of Specify factor standardization, Membership function shape, Membership function type, and Control points.

2.5 Composite SD Map
This step is the final stage to produce a composite SD map through overlay the two sustainability maps (health and environment) (step 5 in Figure 2). For this map, the following formula was used:

$$SD = \sum w_i m_i$$

Equation 2

where SD = Sustainable development map, w_i =weight of sub-index i (given from Figure 4), m_i = sustainability map i. An evaluation system using (in 2.2, 2.5, and 2.6) in the IDRISI software ranks images/indicators or sustainability maps from zero to 255 scale. The raking system means the more closes to 255, the more sustainability is and verse. Start the standardization by selecting it from the GIS Analysis → Mathematical Operators → Overlay.

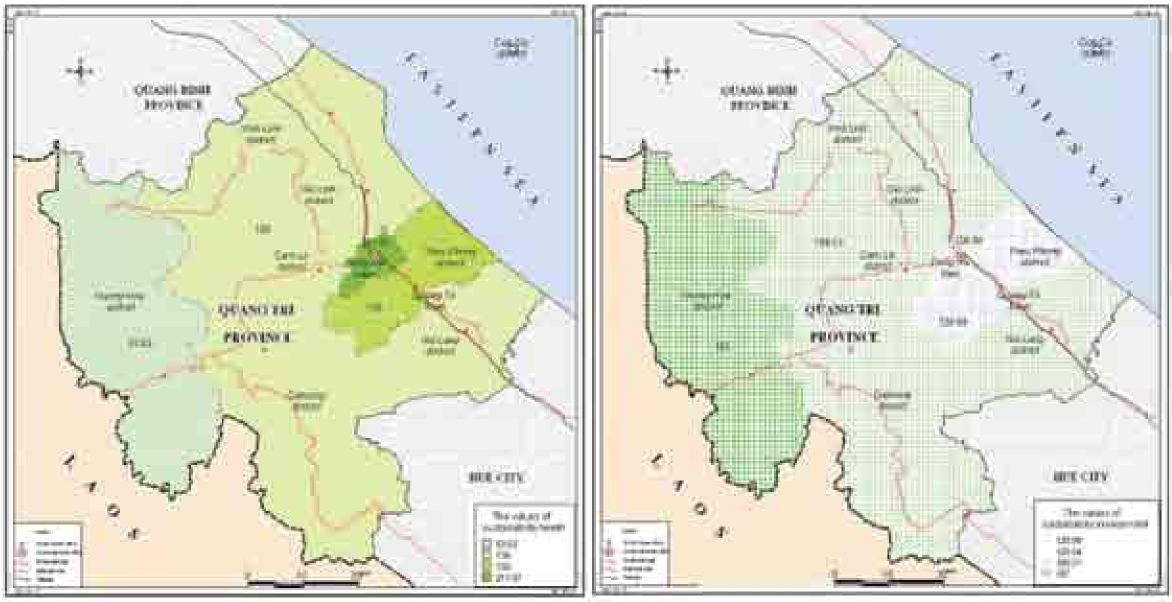
3. Results and Discussion
3.1 Sustainability Maps
The ranking the values (the higher score the more sustainability) of the case studies in the province is shown in Table 1. For example:

- ❖ On health: Dong Ha town ranks first (211.01) and is followed by the Trieu Phong district (133.00), the Quang Tri province as a whole (130.00), and to Huong Hoa district (52.63). This means that Dong Ha responded best on development programmes on health care, safe drinking water, and sanitation;

- ❖ On the environment: The environmental scores are the highest in the Huong Hoa district (157), followed by the Quang Tri province (156.01), Dong Ha town (128.84) and the Trieu Phong district (120.99). Huong Hoa is a mountainous and remote district. The high environmental value shows that the district is less polluted than the other areas in this study.

In addition, these values were presented on sustainability maps (Figure 3).

3.2 Composite SD Map
A SD map integrates the health and environmental sustainability maps using an overlay approach. Each of the constituting maps is weighted (e.g. the health weighting factor is: 0.247 while the environmental one is 0.293). The overlay of the two weighted maps constitutes a SD map. It shows the spatial distribution of the SD criteria in the study areas.



a) b)

Figure 3: Sustainability maps of the health (a) and environment (b) aspects in 2005

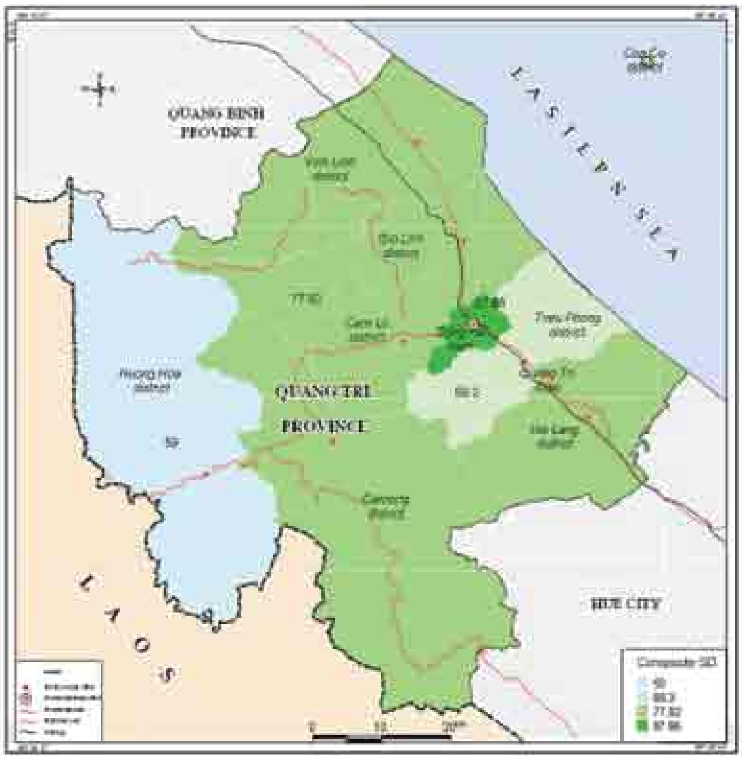


Figure 4: Composite SD map of the province in 2005

Table 1: The estimated values for sustainability maps on health and environment aspects of the case studies in Quang Tri province in 2005

	Trieu Phong district	*Dong Ha town*	*Huong Hoa district*	*Quang Tri province*
Health sustainability	133.00	211.01	52.63	130.00
Environmental sustainability	120.99	128.84	157.00	156.01

Table 2: Sustainability indexes for health, environment and the composite SD index for Quang Tri in 2005

	Weights	Trieu Phong district	Dong Ha town	Huong Hoa district	Quang Tri province
Health sub-index	*0.247*	32.85	52.12	13.00	32.11
Environmental sub-index	*0.293*	35.45	37.75	46.00	45.71
Composite SD		**68.30**	**87.86**	**59.00**	**77.82**

Annex 3: Pair-wise comparison matrix for evaluation of estimated weights of indicators of the health aspect

	Fuzzy image 1	**Fuzzy image 2**	**Fuzzy image 3**	**Fuzzy image 4**	**Fuzzy image 5**	**Fuzzy image 6**	**Fuzzy image 7**	**Fuzzy image 8**	***Weights***
Fuzzy image 1	1								*0.1889*
Fuzzy image 2	1/2	1							*0.1723*
Fuzzy image 3	1	1/2	1						*0.1488*
Fuzzy image 4	1/3	1/2	1/2	1					*0.1084*
Fuzzy image 5	1/2	1/2	1/2	1	1				*0.1234*
Fuzzy image 6	1	1/2	1/2	1/2	1	1			*0.0778*
Fuzzy image 7	1/2	1/2	1	1/2	1/3	1	1		*0.0700*
Fuzzy image 8	1/2	1/2	1/2	1/2	1/3	5	2	1	*0.1104*
								Total	**1.0**

Annex 4: Pair-wise comparison matrix for evaluation of estimated weights of indicators of the environmental aspect

	Fuzzy image 9	**Fuzzy image 10**	**Fuzzy image 11**	**Fuzzy image 12**	**Fuzzy image 13**	**Fuzzy image 14**	**Fuzzy image 15**	**Fuzzy image 16**	***Weights***
Fuzzy image 9	1								*0.1753*
Fuzzy image 10	1	1							*0.1867*
Fuzzy image 11	1/2	1/3	1						*0.1656*
Fuzzy image 12	1	1/3	1/3	1					*0.0814*
Fuzzy image 13	1/2	1/2	1	1/2	1				*0.0745*
Fuzzy image 14	1/2	1	1	1	1	1			*0.0953*
Fuzzy image 15	1	1/2	1/5	2	2	1	1		*0.1038*
Fuzzy image 16	1/3	1	1/2	3	2	2	1	1	*0.1174*
								Total	**1.0**

Annex 5: Pair-wise comparison matrix for evaluation of estimated weights of sub-indexes

Sub-index	**I_{ECO}**	**I_{ENV}**	**I_{SOC}**	
Economic sub-index (I_{ECO})	**1**	2	3/2	
Environmental sub-index (I_{ENV})	1/2	**1**	3/2	
Social sub-index (I_{SOC})	2/3	2/3	**1**	
$\sum$	**2.17**	**3.67**	**4**	**Weights**
Economic sub-index (I_{ECO})	0.461	0.545	0.375	*0.460*
Environmental sub-index (I_{ENV})	0.230	0.272	0.375	*0.293*
Social sub-index (I_{SOC})	0.309	0.183	0.250	*0.247*

The main elements of variation are:

- ❖ Trieu Phong is a coastal district. The values of the health and environmental indexes range between 32.8 and 35.5. The district implemented well and improved on both health and environmental programmes, e.g. the health care, safe drinking water, and sanitation programmes resulted in changeable improvements. The composite SD value points to (68.30) this situation;
- ❖ Dong Ha is the capital town of the Quang Tri province. Here, the composite SD index is the highest (87.86). This means that the town shows the highest SD value as compared to the other towns and districts in the province. Furthermore, the health sub-index is also the highest (52.12) in Dong Ha. The environmental sub-index ranks in between those of the Trieu Phong and Huong Hoa districts. This affects a policy that putted more emphasis on health improvement and less on environmental quality. Currently, the town is more polluted than the other areas e.g. by air pollution and faecal coliforms in the drinking water;
- ❖ Huong Hoa is a mountainous and, remote district. It is onc of thc poorest districts in the province. Here the hcalth sub-index scores low (13.00). Although thc environmental aspcct is acceptable, the composite SD value is the lowest in the province (59.00). This reflects a lack of investment, insufficient policy, and limited financial resources. Characteristic for this situation are the limited number of the people have access to safe drinking water and sanitation and a high percentage of the mortality rate under the age of five. Soil erosion and use of pesticides are common;
- ❖ Quang Tri is one of the poorest provinces in Vietnam. Although the environment has improved during recent years, the health care programmes face problems. Consequently, the provincial authorities have to address socio-economic (c.g. poverty, fast population growth, ect) and institutional (c.g. insufficient instruments, weak capacity, and limited financial resources, ete) issucs.

3.3 GIS, AHP, and Decision Making

IDRISI is a useful software package to establish a sustainability map. Actually, the same issues can be addressed using other software packages like ARCGIS or ARCVIEW integrated with the AHP formulations. However, these approaches will take more time than the IDRISI option. Although the AHP method is widely accepted to solve multi-criteria problems, the accuracy of the results depends on the available sources of spatial data (Rajesh and Yuji, 2007). For Small Island Developing States it has been shown that "Regardless of how SD is approached in SIDS, the availability of current, accurate, and comprehensive geographic data is essential" (Read and Wei - Ning, 2006). Furthermore, SDI's data should be understandable and reflecting the local concern. For decision making, SD maps have to be calculated for different scenarios, which are based on different scores of factor images, different weight on evidences of sustainable factor images (Hai, 2005). The SD maps have to support planners and decision-makers, and should classify the consequences of the policy options. In fact, to construct and find sustainability areas is widely applied for sensitive objectives and fields, for example, combining AHP with GIS in synthetic evaluation of eco-environmental quality-a case study of Hunan province, China (Xiong et al., 2007) or land evaluation for pre-urban agriculture using AHP and GIS techniques: a case study of Hanoi, Vietnam (Rajesh and Yuji, 2007), etc. However, it is the first time that this study was performed for the Quang Tri province as a case study, particularly in apply GIS. Beside the advanced AHP tool to calculate indicators, GIS necd to integrate other tools (e.g. computing the sub-indexes of society, economy, and environment or selecting indicators).

4. Conclusions

GIS integrated with AHP allows to map sustainability. In practice, this can be done using the IDRISI software. This means that GIS and AHP are packaged in one by integrating a three step spatial analysis (MapInfo environment, Expert's option and IDRISI application) to create sustainability maps. This paper shows how this approach can be used for the Quang Tri province. As such, the paper shows that it is possible to construct SD maps through a 5-basic step for a province. IDRISI is casy to use and a low-cost compare to other GIS software. Thc SD maps may help the policy makers and planners to assess the SD status, which are the results of a calculation of original values of indicators. This study focuses on hcalth and environmental issucs in 2005. As the main results, three main sustainability maps are produced. As such, the results show that the SD situation in Dong Ha is better than the others and followed by Trieu Phong and Huong Hoa. They are most pronounced in Huong Hoa district. Decision-makers, planners and the public should not only be concerned about economic and institutional aspects but also about the environmental and health care programmes in general.

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