(4) APPLICATION OF FUZZY-GIS METHOD IN LOCATION ANALYSIS

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Topography is characterized by voluminous data coupled with imprecision and non-probabilistic uncertainty and has inhibited application of computers to solve complex spatial problems that are often faced in reality. Development of GIS technology, in recent years, has made it possible to create large spatial databases and analyze some of the problems. However the issues of imprecision and uncertainty still exists especially in expressing complex geographic features (geo-features). Among various combinations of methodologies in soft computing, the one that has highest visibility at this juncture is that of fuzzy logic. The salient feature of fuzzy being tractability and robustness was used to compliment GIS in representing complex geo-features for solving location analysis problem.

Fuzzy logic was applied in its wider sense, namely as a theory, which relates to classes of objects with unsharp boundaries, in which membership is a matter of degree. Topographic features including roads, rails, rivers, lakes, elevation, slope, aspect, houses, land use details, were digitized to create a spatial database, using a GIS software. Site selection problem was parallely developed as a fuzzy model. Fuzzy interpretation of complex geo-features was evaluated to create truth maps. Zadeh's compensatory function was used to screen sites. P-Median optimization model was used select the most suitable site for livestock evacuation center construction.

Key Words: Spatial Fuzzy Reasoning, GIS, P-Median

1. Introduction

Public sector civil engineering projects involving spatial problems had always been complicated because of many geographic features (henceforth called geo-features) that come into play. Urban facility location analysis including site selection for highway/rail construction, airport construction, township planning, facility planning, is a typical example of a spatial problem that uses many complex geo-features. Many other examples can be sited including those relating to decision making for planning and management of land use, natural resources, environment and transportation[1,2], where a method is required to handle complex geo-features effectively.

Many literatures can be sited discussing urban facility location analysis. Malczewski et.al[3] summarize the overall thought and state that the problem of location decision making has three phases- (a) *Intelligence phase*, where the problem and the environment/scope of problem are identified. (b) *Modeling phase*, where model is constructed and solved to obtain a feasible set of solutions and (c) *Choice* of the best location.

Modeling phase involves development of evaluation criteria, constraints, solution techniques, generating alternative solutions and graphic presentation of the alternatives. Until recently, in-spite of immense research in location decision-making, most of the real life location decisions was solved through qualitative inference because of the complexity and imprecision involved in modeling. Lately, expert systems approach and multi-criteria linear programming approaches have been used to solve location decision. However, empirical evidence often shows that too much of the human imprecision and spatial systems complexities are being sacrificed when attempting to model complex models[4,5]. From an engineering consultant's perspective alternative procedures need to be identified that can provide a practically acceptable solution.

2. Geographic Information Systems (GIS)

Digital maps have become popular with the advent of geographic Information Systems (GIS). GIS is defined as an information system that is used to input, store, retrieve, manipulate, analyze and output geographically referenced data otherwise called geospatial data[6]. A computer system for GIS consists of hardware, software and procedures designed to support the data capture (including digital cartographic maps, information from aerial photographs, satellite images), processing, analysis, modeling and display.

Geo-features of similar type are grouped together as one layer (All roads as one layer, all rivers and lakes as one layer, etc.,). Layers can be overlaid over one another to perform useful spatial analysis.

3. Two-stage Fuzzy-GIS framework

GIS stores information using three basic elements, namely, points, lines and polygons. Geo-features including houses, facilities, roads, rails, rivers, administrative boundaries, contours, lakes, parks have a crisp boundaries. Such features can be easily represented as GIS objects using these basic elements.

However objects such as congestion, pollution, accessibility, visibility, homogeneity, and heterogeneity, are complex geographic features. They don't have any clearly defined boundaries and are difficult to represent even in conventional methods of cartography. Complex objects are often coerced into shapes with boundaries. However using such objects in GIS environment often produce unreliable output. Further, spatially distributed informations are difficult to collect and maintain. There is a lag between data collection and map creation. Imprecision and inherent ambiguity are often associated with spatial data and considering them as certain leads to erroneous results. Further, people often use the names of geographic objects to specify locations or express analysis. Object reference works well enough to constrain the focus of attention in human discourse, particularly when meanings can be disambiguated iteratively. Thus, current computer technologies are only useful if positions in space are known crisply.

One possible solution to this problem is the application of fuzzy-set theory and express complex geo-features as a combination of a fuzzy interpretation and a geographic object context. Wang et.al[7] have summarized the advantages of using this approach to represent complex objects. Many researchers have explored this idea by applying mainly to soil related problems[8,9,10].

A two-stage approach was developed, based on the ideas put forth by Wang et.al, to solve location problems at a practically acceptable level consisting of:

Stage-1: Preliminary site screening using the fuzzy-GIS set theoretic approach.

Stage-2: Selection of best sites from screened sites by means of enumerative modeling techniques.

4. Case Study

Kami-furano town of Hokkaido, located on the base of Mt. Tokachi volcano, experienced a mudflow disaster in 1926 resulting in loss of 144 lives. Another mudflow disaster is expected in the imminent future. Mitigation measures to contain the damage are currently under progress. The town office has demarcated hazardous area and has assigned 31 locations as evacuation centers, where plans have been made to

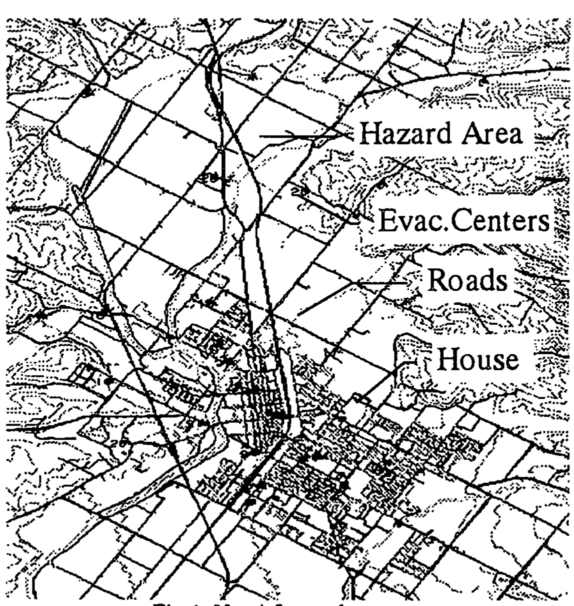

Fig-1: Kami-furano base map

evacuate residents in case of emergency.

Statistics collected during previous mudflow disasters indicate that many residents hesitated to evacuate because of their livestock (and pets)[11]. Also, Kami-furano is an agricultural town and livestock forms an important form of residents' livelihood. It is felt that livestock evacuation centers will be necessary so that resident can evacuate their livestock population in case of emergency. Selecting suitable sites for livestock evacuation center construction was targeted in our research, as a part of the overall study on evaluation of Kami-furano's evacuation system.

Kami-furano's elevation, road/rail network, land use information, residence's location and important public facilities were digitized into a computer to make a GIS spatial database at a resolution of 1:2500~1:5000. Gradient map was calculated from elevation map by differentiating the elevation map. Further, using the digital elevation map as input topography, the mud-flow simulation was undertaken separately to calculate the maximum flood height at each location and the hazard zone. Base map of kami-furano with the hazard zone is as shown in fig-1.

Lands that were basically accessible, cheap, watery, plain and safe was screened and possible site for livestock evacuation center construction.

"Accessible" in the context of livestock evacuation center can be thought basically as any land within a range of 250m~1km. In other words regions within 250m can be considered easily accessible and were assigned a value of 1. Regions beyond 1km were considered far and were assigned a value of 0. A simple linear function was constructed and a value between 1 and 0 were assigned depending on the distance between 250m~1km to create a fuzzy variable, "accessible". Using this fuzzy interpretation and the road network of Kami-furano, the accessibility geo-feature was calculated (Fig-2(a))

Land prices were difficult to obtain. To calculate "cheap" the following method was used (fig-2(b)):

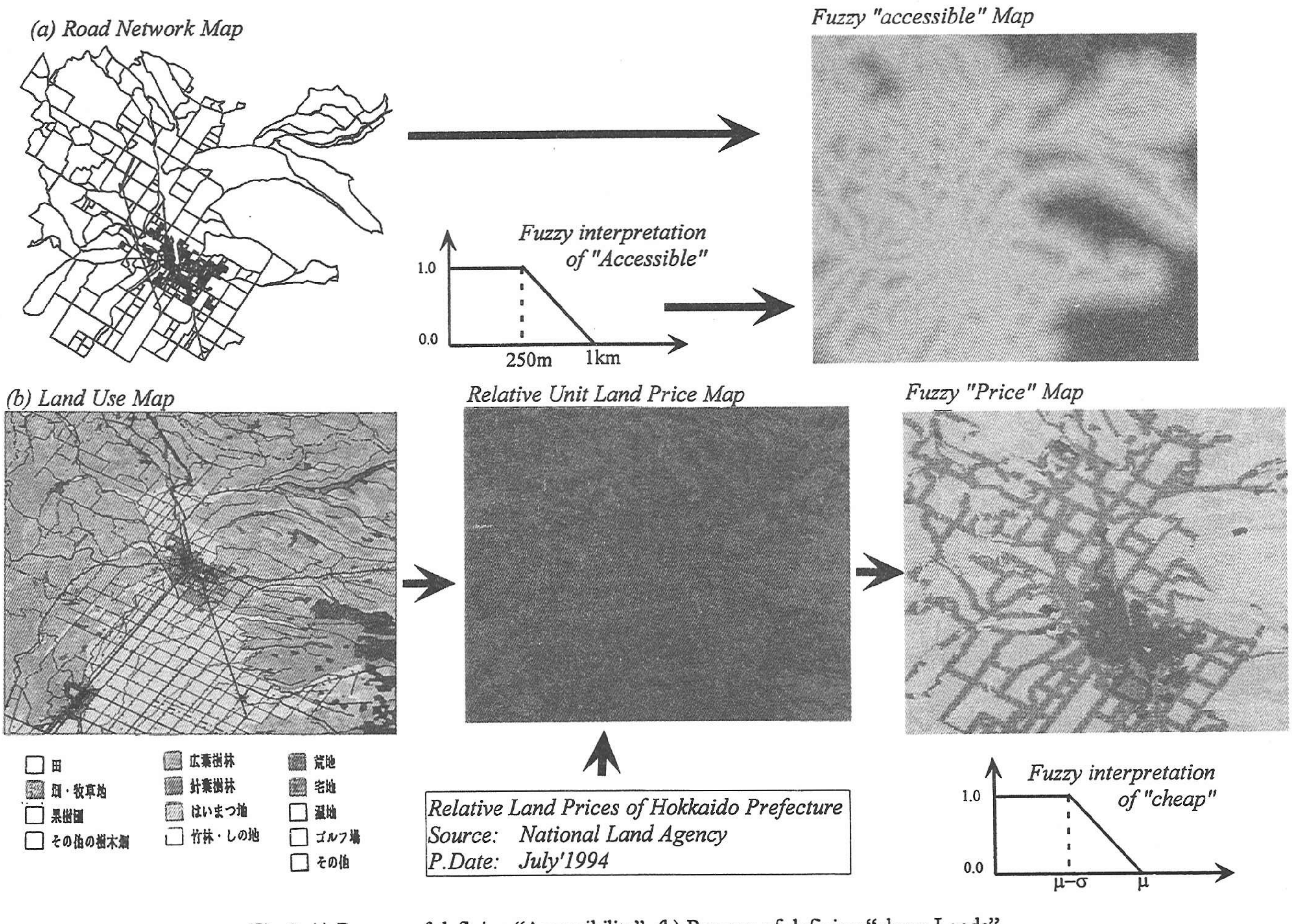

Fig-2: (a) Process of defining "Accessibility". (b) Process of defining "cheap Lands"

- Average land price of residential area in Hokkaido, based on 1994 survey, was 33,200 yen/m^2 [12]. 20m mesh land use digital map was prepared from 1:50,000 topographic map of Kami-furano.
- For each land use type, by considering the ownership, land restriction and its commercial value, a grade between 0 and 3 was attributed to show the possible price variation, specific to Kami-furano. These grades were used to modify the average land price appropriately to obtain relative unit land price. If it seemed difficult to buy the land, it was marked as non-purchasable land.
- Relative unit land price and land use data were used to obtain the land price map.
- The average (μ) and standard deviation (σ) values of this map were calculated. Any land below μ-σ was considered very cheap and attributed a value of 1. Any land with price above μ was considered expensive and attributed a value of 0. The remaining areas were fuzzified using a linear relationship.

In a similar fashion other geo-features were also calculated. Descriptions of the fuzzy variables are summarized in table-1 (d_1 is the radial distance from roads/rails and d_2 is the radial distance from residence, river and lakes).

"Suitable livestock land is those lands that are Safe AND Cheap AND Watery land that are Plain and Accessible". This can be expressed as $\mu_{cheap}(x,y) \otimes \mu_{watery}(x,y) \otimes \mu_{plain}(x,y) \otimes \mu_{safe}(x,y) \otimes \mu_{accessible}(x,y)$ where $\otimes$ is the intersection operator. Zadeh

Table-1: Fuzzy interpretation of complex geographic features:

Fuzzy Variable	*Fuzzy Value*	
$\mu_{plain}(x,y)$	= 1 = 1–(slope-20)/10 = 0	if slope < 20 Deg. if 20 < slope < 30 Deg. if 30 < slope
$\mu_{cheap}(x,y)$	= 1 = 1–(cost - μ)/(μ - σ) = 0	if cost < μ - σ if μ - σ < cost < μ if μ < cost
$\mu_{safe}(x,y)$	= 1 = 1–(fld hght-0.5)/0.5 = 0	if fld hght < 0.5m if 0.5m < fld hght < 1.0m if 1.0 < fld hght
$\mu_{access}(x,y)$	= 1 = 1–(d1-250)/750 = 0	if d_1 < 250m if 250m < d_1 < 1km if 1km < d_1
$\mu_{watery}(x,y)$	= 1 – d2/1000 = 0	if d_2 < 1km if 1km < d_2

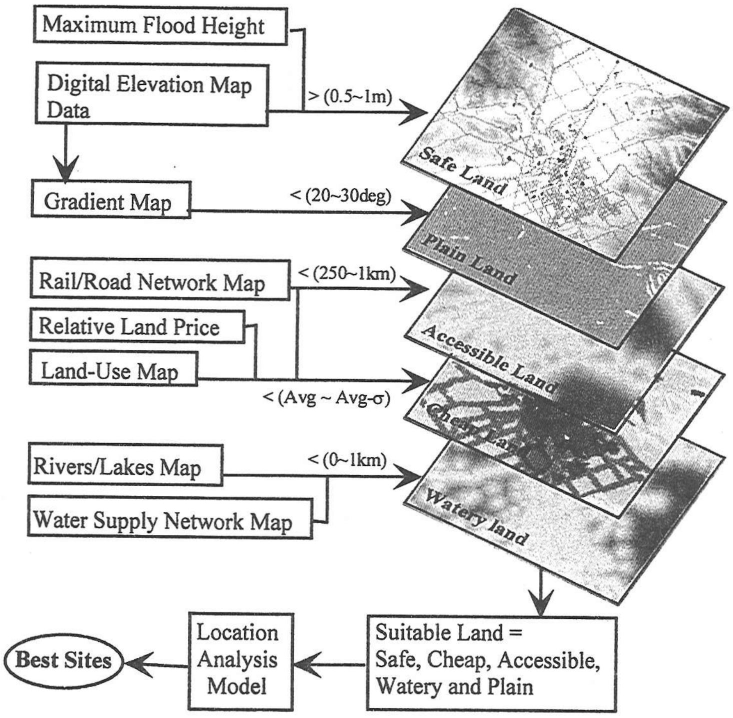

Fig-3: Overall process of location decision making

style compensatory function was used to evaluate this expression and obtain the suitable locations for constructing the livestock evacuation center. Fig-3 summarizes the overall process of livestock evacuation center selection.

There were 30 sites that were suitable and provided enough space for construction of a livestock evacuation center by the screening process. Fig-4 summarizes the identified sites.

For the evaluation of the screened sites, "convenience" was considered as the key criteria and was defined as "being near potential users and being close to main roads" All residents

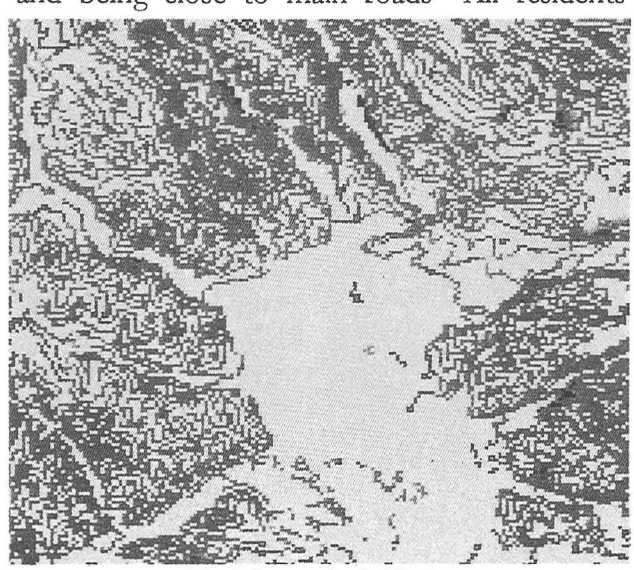
Fig-4: Screened suitable sites

outside of city center were assumed to hold livestock and were considered potential users. Only the main roads were considered and slow vehicular transportation was assumed to calculate the travel times and create an OD matrix form between residents and screened sites.

Indices

Let potential user be 'I';

I = 1,2,...n; n = Total no. of houses in outskirts

Let screened site be 'j';

j = 1,2,...m; m = 30

Available Data

Livestock at 'I' = w_I

I = 1,2,3,...n

O-D Matrix T = [n x m]

Each cell represents travel time tij obtained by shortest path method

Decision Variable

X_{ij} = 1 if 'I' assigned to 'j'

= 0 if Otherwise

y_j = 1 if site is selected

= 0 if Otherwise

Objective Function

$$\text{Minimize } Z = \sum_{I\in n}\sum_{j\in m} w_I X_{ij} t_{ij}$$

Constraints

$$\sum_{\forall j} X_{ij} = 1 \quad I = 1,2,3,\ldots n$$

$$\sum_{\forall j} y_j = p \quad (p = \text{no. of sites to select})$$

A simple P-median location-allocation model as shown above was considered to evaluate the screened sites for their vicinity to the potential users. The most convenient sites were selected as suitable sites for construction of livestock evacuation center.

5. Concluding Remarks

We presented a way to incorporate complex geo-featuresin a facility location analysis problem. Some of the important benefits of using this method are

(a) Spatial analysis using conventional method often produce null sets during the screening process. Using a fuzzy approach provides a robust solution procedure.

(b) Fuzzy representation offers a tractable way to handle imprecision and uncertainty in data using computers.

Real life urban facility location problems have complexity and imprecision that one cannot avoid from modeling. Fuzziness should be regarded as the basic characteristics pertinent to the construction of spatial models that mimic human perception, thought and behavior and efforts must be made to incorporate them in modeling. We can also adopt the same method for complex cases.

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