# DIGITAL MAPPING TO ASSIST RESIDENTIAL PLANNING USING LANDSAT DATA

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## 1. INTRODUCTION

In planning residential developments using meshed areas, data on the land are required to evaluate their suitabilities for residential sites. This paper describes a digital mapping system to evaluate the suitability of an area of 240m× 300m approx.(we will name it 250m² mesh-area) for residential purposes. The criterion of suitability is defined as : the increased amount of the residential area divided by the remaining undeveloped area within the mesh-area above. The digital maps are drawn using digital information from : transportation services, land-use, terrain, usage restriction and their degree of importance, estimated by "Hayashi's quantification theory".

## 2. DIGITIZING LAND-FORMATIONS

### 2.1 LAND-USE REPRESENTATION IN THE MESH-AREA USING LANDSAT MSS DATA

Landsat's informations on land-cover and land-use though not detailed in comparison with the existing ground surveys, they are advantageous geographically, economically and periodically regular.

We obtained the digital classifications of 10 land-cover categories in a study area (about 40km× 60km). Digital classifications of a part of the above study area (training area about 9.2km× 11.6km) are shown in Table 1. In this table, the manual photo-interpretation results were obtained by visually interpreting the cells of aerial color photographs. The table shows that the "Fields" and "Forests" have decreased in time while the urbanized areas increase.

In order to evaluate the suitability of 250m² mesh-area for residential purposes, it is necessary to represent the land-cover information derived from multi-spectral reflection into land-use information. For this purpose, the 10 land-cover categories were consolidated into 6 land-use classes, as shown in Table 2.

The mesh-areas were represented on the basis of the threshold values in covering percentages, using triangular coordinates as shown in Fig.1. However, the mesh-areas that were covered by 50% and over by "Water" were classified as 'Water'.

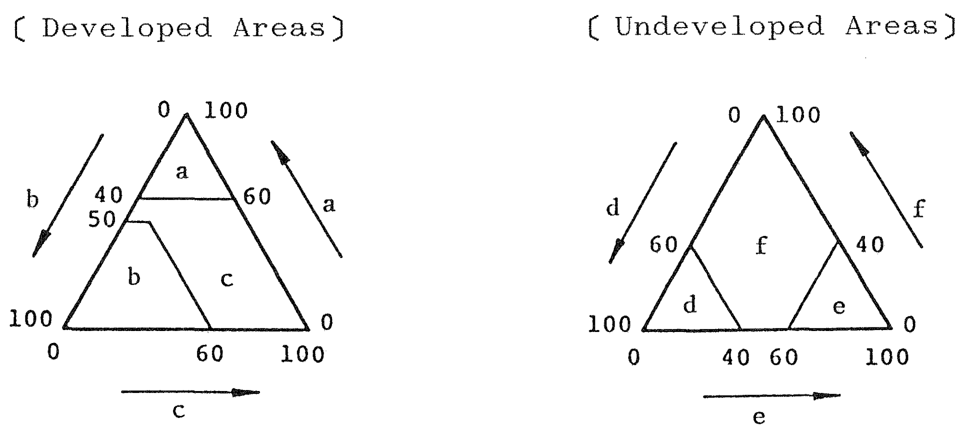
Table.1 Percentages(%) of Land-Covers in The Training Area (derived from reference 1)

| Land-Cover Categories | Photo 1981 Nov. | MSS Digital Classifications 1979 Sep. | 1980 Oct. | 1981 Nov. | 1984 Nov. |
|---|---|---|---|---|---|
| ① "Water 1" | 21.81 | 24.48 | 24.65 | 25.21 | 24.73 |
| ② "Water 2" | 3.35 | 3.50 | 3.11 | 3.03 | 3.37 |
| ③ "Fields" | 9.04 | 10.93 | 10.91 | 10.41 | 9.77 |
| ④ "Forests" | 8.71 | 10.07 | 9.45 | 9.30 | 8.87 |
| ⑤ "Open Land" | 4.59 | 5.78 | 7.55 | 7.64 | 8.34 |
| ⑥ "Waste Land" | 5.07 | 5.28 | 4.53 | 4.65 | 3.26 |
| ⑦ "Wild Field" | 6.64 | 7.00 | 6.31 | 6.54 | 5.21 |
| ⑧ "Industrial Areas" | 11.86 | 8.69 | 8.72 | 8.54 | 9.51 |
| ⑨ "Urban Areas" | 9.44 | 9.12 | 9.17 | 9.85 | 10.56 |
| ⑩ "Suburban Areas" | 14.50 | 15.13 | 15.60 | 14.83 | 16.40 |

Photo = Visual-interpretation of arerial color photographs

Table.2 Classes for Representing 250m² Mesh-Areas' Land-Use

| Land-Use Classes | Consolidated Land-Cover Categories |
|---|---|
| 1 'Water' | ①"Water 1" ②"Water 2" |
| 2 'Fields' | ③"Fields" |
| 3 'Forests' | ④"Forests" |
| 4 'Waste Land' | ⑤"Open Land" ⑥"Waste Land" ⑦"Wild Field" |
| 5 'Urban Areas' | ⑧"Industrial Areas" ⑨"Urban Areas" |
| 6 'Suburban Areas' | ⑩"Suburban Areas" |




a : Undeveloped Areas(d+e+f)
b : 'Urban Areas'
c : 'Suburban Areas'

d : 'Fields'
e : 'Forests'
f : 'Waste Land'

Fig.1 Triangular Coordinates Used for Representation

Plate 1 shows 250m² mesh-areas' land-use using, Fukuoka city and its suburbs as, a part of the study area. It is seen that 'Fields(o)' and urbanized areas(@,#) are intricately mixed in the eastern region. In this region, there are difficulties in harmonizing the agricultural and urban usages for planners. 'Forests 1(+)' shown in Plate 1 are the mesh-areas that are not only represented by 'Forests', but also by less than ; the average altitude of 150m, and below the maximum gradient of 15° . 'Forests 2' are all other than 'Forests 1'.


Plate.1 Land-Use of 250m² Mesh-Areas

## 2.2 TRAFFIC ACCESSIBILITY

Traffic accessibility is an important factor that closely influences land-use. Using cars and trains as means for traffic accessibility within the mesh-areas, we are determining the shortest time-distance to center of the city, and define it as the traffic accessibility of the mesh-area. The road network was composed of 135 link-roads stemmed from 83 junctions. The time-distance was calculated by the following procedures:

1)Plotting the locations of the junctions into UTM coordinates by a personal computer and a digitizing unit,

2)The average speed of the link-roads used were derived from

an existing traffic census,
3)Calculating the distance between the junctions of link-road and putting it into time-distance. Then editing these data on to disk-files,
4)Calculating the shortest route from every junction to the center of the city,
5)Time-distance is the shortest time on the road calculated by : case 1, mesh-areas on a link-road with one junction : either the shortest distance in time between the junction to the next junction in one direction plus the distance from that junction to the center of the city or the distance from the junction within the mesh-area to the other junction in the opposite direction plus the distance from this junction to the center of the city; depending on the shortest of the above two.
Case 2 where there is no junction within the mesh-area, center point of the road is taken as starting point and calculated as in case 1,
6)Shortest time-distance for mesh-areas not located on a link-road is calculated by : access time from mesh-areas' center to the nearest link-roads in four opposite directions (using slowest speed taken from existing census ) then adding them to the above procedures of 4 and 5.

While for railway, time is derived from operational timetables. Therefore, time-distance for mesh-areas located on stations can be calculated by the same way as by road. We assumed access time to the station within 3 km radius to be 2 minutes per 250m² mesh-area. Therefore the time-distance by train is determined by adding : access time to the station, line's operation time and time from the egress station to the center of the city.

We have defined the shorter one of these time-distances in terms of minutes, as the traffic accessibility of the mesh-areas.

## 2.3 TERRAIN

In Japan, altitude data of 250m² mesh-areas' intersecting grid points are derived from "National Digital Information on Land". Therefore, we calculated the average altitudes of the mesh-areas using it's four corners from the data obtained above. While, the six gradients of each mesh-area were calculated by dividing the difference of two corners' altitude with the distance between them. And we named the greatest one of the six gradients as the maximum gradient.

## 2.4 LAND-USE RESTRICTION

Usually, data on the coverages of land-use restriction have been supplied by conventional maps. The map has an advantage of representing a lot of information. However, in order to utilize its information for regional analysis, it is necessary to put it into digital form. Here we present a practical way of digitizing, by using a personal computer and a digitizing unit. The digitized land-use restrictions are shown in Table 3.

As boundary lines of land-use restrictions are usually complicated, it is necessary to represent approximately the restricted areas into polygons. We gave every corner of the polygon an address on the grid shown in Fig.2. Fig. 2 shows an example of a row (we named $L_c$) crossing two sides of the polygon. One of these sides, between corners $P_i(L_i, C_i)$ and $P_{i+1}(L_{i+1}, C_{i+1})$; its intersecting column $C_c$ can be calculated by the following formula:

$$C_c = C_i + \frac{(L_c - L_i)}{(L_{i+1} - L_i)}(C_{i+1} - C_i) \quad (1)$$

Where, $L_i \geqq L_c > L_{i+1}$ or $L_i < L_c \leqq L_{i+1}$

When we sort these column-addresses, we find all the rows they intersect, crosses even number of sides and the restricted areas lie within the polygon's sides. Hence we can identify the overall restricted areas by summing them up in order of row-numbers. We selected an area of 60m× 60m as our unit area for digitizing. We represent the land-use restriction of 250㎡ mesh-areas by the largest restricted part within each one of them.

Table.3 Digitized Restrictions of Land-Use

| Land-use Restrictions | Description of Restriction |
|---|---|
| Areas Promoted for Urbanization | exclusively for urban usage |
| Areas Restricted from Urbanization | for urban usage with restrictions |
| Areas Planned for Urbanization | have potential for urban usage |
| Areas Promoted for Agricultural use | for agricultural usage only |
| Unrestricted Agricultural Areas | Designated as agricultural areas, but allowed to develop for urban usage |
| Forest Areas | exclusively for forestry |

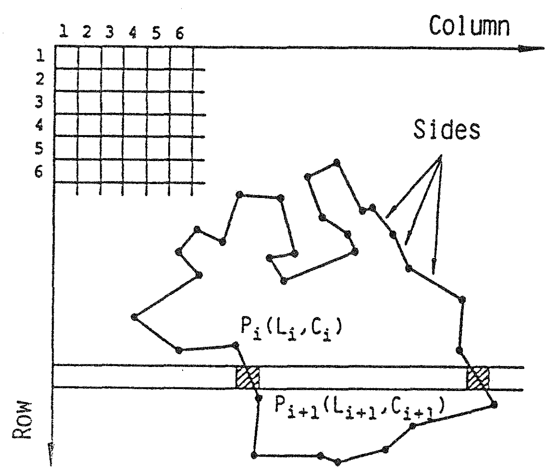



Fig. 2 Addresses Used for Representing Land-Use Restrictions

## 3. DIGITAL MAPPING AND ITS USES

### 3.1 EVALUATION OF SUITABILITY FOR RESIDENTIAL AREAS

Usually, suitability has been evaluated by totalizing predictive factors' points given by planning experts. However, planners still face the difficulty in evaluating the importance of predictor factors and score points.

We are here proposing a method to evaluate the importance of factors technically, based on ; Hayashi's quantification theory I . In applying this evaluation theory for suitability, the suitability must be numerically designated as the criterion variable. We designated it as per formula below and named it "Suitability Index($SI$)". And we used the digital data obtained in section 2 above as the predictor factors.

$$SI = \frac{\text{surface areas of new housing sites}}{\text{surface areas of undeveloped grounds}} \times 100 \qquad (2)$$

Whereby, the surface areas of new housing sites were obtained from existing 1979 and 1980 surveys (reference 2). We excluded from the analysis the 250m² mesh-areas where within it more than 1($ha$) were sold. The undeveloped surface areas were obtained by adding the areas(pixels) classified as "Fields","Forests","Open Land","Waste Land" and "Wild Field" in Table 1.

Table.4 Results from Hayashi's Theory

| Heading | Predictor Factors (Item) | Categories | Samples | Category Scores | Ranges |
|---|---|---|---|---|---|
| Traffic Accessibility | time to center of city | 1 < 30 min. | 92 | 8.71 | 19.08 |
| | | 2 31 − 40 | 130 | 0.37 | |
| | | 3 41 − 50 | 128 | − 0.82 | |
| | | 4 51 − 60 | 98 | − 2.56 | |
| | | 5 61 − 70 | 67 | − 3.02 | |
| | | 6 71 =< | 28 | −10.37 | |
| Land-use | Landsat information | 1 'Fields' | 96 | −11.08 | 32.77 |
| | | 2 'Forests' | 80 | −10.24 | |
| | | 3 'Waste Land' | 181 | − 6.37 | |
| | | 4 'Urban Areas' | 44 | 21.69 | |
| | | 5 'Suburban Areas' | 142 | 14.66 | |
| Topographical Condition | maximum gradient | 1 =< 2° | 418 | 0.16 | 0.77 |
| | | 2 2° − 4° | 56 | − 0.43 | |
| | | 3 4° =< | 69 | − 0.61 | |
| | average altitude | 1 =< 20 m | 298 | − 0.12 | 0.31 |
| | | 2 21 − 40 m | 141 | 0.12 | |
| | | 3 41 m =< | 104 | 0.19 | |
| Land-use Restriction | Urban usage | 1 Areas Promoted for Urbanization | 318 | 5.96 | 20.65 |
| | | 2 Areas restricted from Urbanization | 134 | −14.69 | |
| | | 3 Areas Planned for Urbanization | 53 | 3.26 | |
| | | 4 undesignated | 38 | − 2.65 | |
| | Agricultural usage | 1 Areas promoted for Agricultural use | 118 | − 3.26 | 4.20 |
| | | 2 Unrestricted Agricultural Areas | 45 | 0.62 | |
| | | 3 undesignated | 380 | 0.94 | |
| | Forest usage | 1 Forest Areas | 62 | − 1.63 | 1.84 |
| | | 2 undesignated | 481 | 0.21 | |
| Constant term = 37.90 | | | R = 0.66 | | |

Some of the new areas' data may include, from land-use or residential development planning view point, unsuitable sites, due to lack of facilities or otherwise. However, as the above unsuitable sites' sale occurred under existing economic or social situations and land-use restrictions, the data gives us important information regarding demand for preferred housing development. In the above cases the *SI* means the potential of mesh-areas for housing site usages, in consideration of the trend or preference of demand.

Table 4 shows the scores estimated by the analysis. Though the correlation coefficient is as low as 0.66, it gives reasonable overall category scores. As can be seen from the ranges, land-use(32.77) strongly affects the *SI*-values. The urbane usage(20.65) and the traffic accessibility(19.08) have the same influences on them.

As the time-distances get longer, the category scores get reasonably lower. Under heading "land-use", the scores of 'Urban Areas' and 'Suburban Areas'(21.69,14.66) are high. Under urban usage, while the category score of "Areas Restricted from Urbanization"(-14.69) is the lowest. This reveals that their designation severely restrains the covered areas from residential development.

### 3.2 DIGITAL MAPPING

In the above analysis, we used the predictor factors obtained in 1979-1980. However, the opening of new subway and the abolition of two railway lines changed the traffic accessibilities. Land-use restrictions had also been revised in a part of the study area. We updated their digital data; extracted the land-use information from 1984 Landsat MSS data, and newly calculated 1984 *SI* using the above category scores.

Plate 2 shows a digital map for evaluating 250m² mesh-areas' suitability for residential purposes (Suitability Index Map) made by classifying the *SI* into various marked areas, shown below the map. Symbols "-" represent the areas more than the maximum gradient of 15° or the average altitude of 150m. Symbols "+" represent the mesh-areas classified as 'Urban Areas' in the "Areas Promoted for Urbanization". We eliminated the above two areas(-,+) from the evaluation, as nowadays new residential developments are rarely feasible.

In this map, symbols "@" correspond to the areas designated as "Areas Promoted for Urbanization " within traffic accessibility of 30-40 minutes, "#" to areas within 40-50 minutes. "&" to areas within 40 minutes (approx.), classified as 'Fields', 'Waste Land' or 'Forests'. They have not been developed in spite of them being suitable. We can evaluate their suitabilities, except for 'Forests', as well as the areas symbolized by "@" and "#" above, only from the view point of their effective investments in public-utilities.

Symbols "%" correspond to areas within 50 minutes and to most of the areas over 0.5(*ha*) approx.. They have potential, in the near future, for new residential developments, especially these areas adjacent to already developed ones. Symbols "*" and ":" correspond to the areas designated as "Areas Restricted from Urbanization".

We compared the Suitability Index Map of 1979 with a conventional map made by planning experts in 1978 (reference 3). In the latter map, they had used: land-use, traffic accessibility, gradient, soil and public facilities as predictor factors and classified their suitabilities into five stages. While, we obtained the *SI* as a continuous variable. We evaluated their findings by testing the correspondence of superiority of two random points, between both maps. The test revealed that 75% of the 800 trials were in agreement.

By using the Landsat data, the proposed method has the advantage of updating the land-use information which plays an important part in the evaluation. Therefore, the proposed method reduces effort and cost in digital mapping in assisting residential planning.

@ >= 60 # >= 50 & >= 40 % >= 30 * >= 20 : >= 10 ^ < 10

" + " = Mesh-areas classified as 'Urban Areas' in "Areas Promoted for Uabanization"

" - " = Mesh-areas eliminated from evaluation

Plate.2 Suitability Index Map for Residential Purposes

### 3.3 SUITABILITY OF AREAS PLANNED FOR URBANIZATION

Zoning within each administrative district(the study area consists of 16 local administrative districts) consits of drawing the boundary within lands restricted from use, considering complicate circumstances of the particular locality.

Plate 3 shows a Suitability Index Map for evaluating the suitabilities of "Areas Restricted from Urbanization". Symbols "+" represent "Areas Promoted for Urbanization " and symbols "-" represent mesh-areas classified as 'Fields', 'Waste Land' and 'Forests'. They occupy approximately 40% of "Areas Promoted for Urbanization ".

In the "Areas Restricted from Urbanization", A and B districts have relatively large *SI*-values. It may be required for A district, as an airport is located in it, to be developed for public usages rather than residential purposes. While, from the view point of the public-utilities investment, it is well to incorporate the B district into "Areas Promoted for Urbanization ".

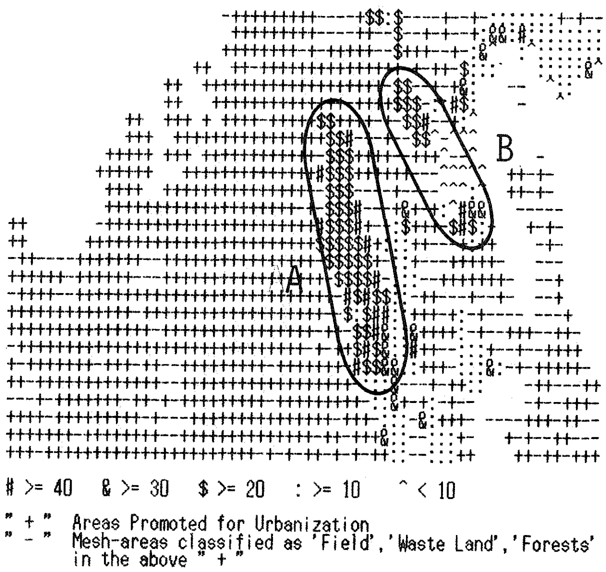



Plate.3 Suitability Index Map of "Areas Restricted from Urbanization"

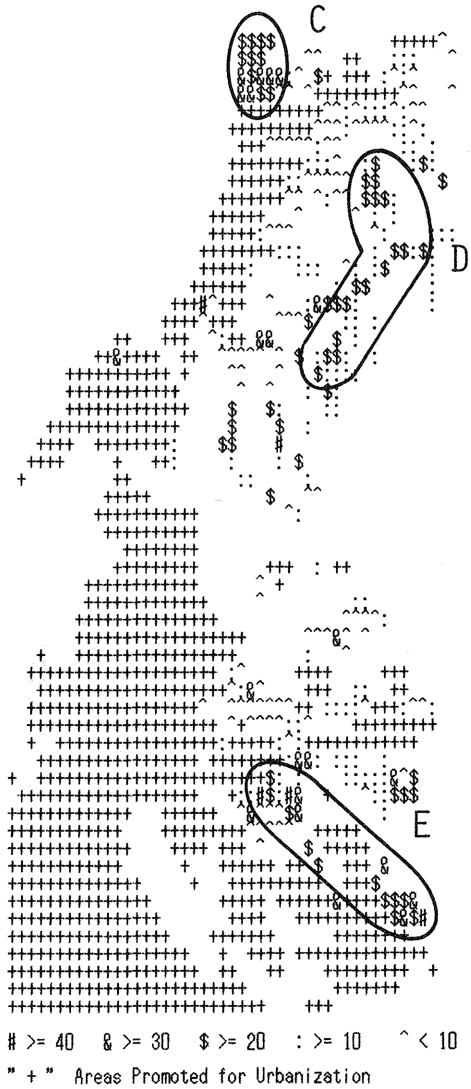



Plate.4 Suitability Index Map of "Unrestricted Agricultural Areas"

### 3.4 SUITABILITY OF UNRESTRICTED AGRICULTURAL AREAS FOR URBANIZATION

As "Unrestricted Agricultural Areas" are allowed for development, not only for agricultural, but also for urbane usages, planners face the difficulty in harmonizing both usages, especially within "Areas Planned for Urbanization".

Plate 4 is Suitability Index Map of the "Unrestricted Agricultural Areas". C, D and E districts have relatively large values of *SI*. As C and D are already near developed areas, they face less problem for residential development rather than for agricultural purposes. While, D district is away from existing "Areas Promoted for Urbanization". More residential developments in this district require a large amount of public-utilities' investment. As shown in Plate 1, 'Fields' of lower altitudes lie to its western region. This discourages planners from further developments and they would designate it as "Area Restricted from Urbanization", having the lowest score(-14.69) as shown in Table 4.

Digital maps give us basic information to assist in designation of land-use restrictions and reveal some of the problem areas that should be restrained from developments.

## 4. CONCLUSION

The characteristics of the digital mapping proposed and the results are summarized as follows:

1)Hayashi's theory rationally gave us the predictor factors' importance in evaluating the 250m² mesh-areas' suitability for residential purposes.

2)The land-use information derived from Landsat data played an important part of the evaluation.

3)The digital map gave us reasonable evaluation of the overall suitability, same as the conventional manually-made one by experts.

4)From the digital maps, we can derive basic informations to assist in designations of land-use restriction and planning for residential development.

## REFERENCES

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3)Development Planning Department of Fukuoka Prefecture : Evaluation Map for Possibilities of Residential Development, 1978.