

**Developing a GIS-Based Urbanization Prediction Method that Takes into Account
Neighborhood Relationship of the Unit of the “Block”:
A Look at the Environs of the Keihanshin Metropolitan Area in Japan**

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Abstract

On the outskirts of the metropolitan areas in Japan, the rapid development of urban areas and the improvement in transportation networks have brought various land use problems in their wake, including urban diffusion and the phenomenon of urban sprawl. There is a strong need for accurate predictions of land-use change and future urbanization, as well as investigation of the appropriateness of present land use controls and the land use controls that will be required in the future.

This study took as its object the outskirts of the Keihanshin Metropolitan Area, the second largest conurbation in Japan after the Tokyo Metropolitan Area, and using the digital maps and spatial analysis offered by GIS it aimed to: (1) develop an urbanization prediction model that takes into account the neighboring relationship of neighboring areas on a 100 m mesh unit; (2) apply this model to the study area and verify its validity regarding the conditions of present land use; (3) compare urbanization prediction results by this model with the present land use controls; and (4) make predictions for future urbanization and propose remedial measures for future land use controls.

1. Introduction

The lower cost of land in the outskirts of metropolitan areas in comparison with central metropolitan areas in Japan has meant that it has been comparatively easy to secure ground in these areas on which to construct offices and residences. Moreover, improvements in transportation networks in recent years have led to an improvement in accessibility to central metropolitan areas, which has encouraged the proliferation of urban areas on the outskirts of metropolitan areas. In many cases such urban areas have developed with extreme rapidity, and this has led to problems in land use such as urban diffusion and the phenomenon known as urban sprawl.

This has meant an exacerbation of problems related to competition between uses to which land is put, for example between urban areas, farmlands and forests, as well as the co-existence of these different types of land, long pointed out as a theme in land use plans. On the outskirts of the metropolitan areas, there is a disconformity between land use controls and actual land use, and this disconformity will only increase with the advance of urbanization. The need for land use adjustment is urgent.

It is thus essential to get an exact picture of the actual state of land use in a region in its entirety and verify whether appropriate land use controls have been implemented. It is also essential that we try to predict changes in land use that are likely to occur and the direction that is likely to be taken by future urbanization, examine whether the present land use controls are appropriate, and propose the kind of land use controls that will be required.

This study took as its object the outskirts of the Keihanshin Metropolitan Area, the second largest conurbation in Japan after the Tokyo Metropolitan Area. Based on its findings with regard to trends in urbanization it aimed to: (1) develop an urbanization prediction model that takes into account the correlation of neighboring areas on a 100 m mesh unit; (2) apply this model to the study area and verify its validity for present land use; (3) compare urbanization prediction results by this model with the present land use controls; and (4) make

predictions for future urbanization and propose remedial measures for land use controls.

A fair amount of accumulated research has been achieved regarding methods for predicting land-use change and future urbanization, mainly in the field of city planning. The main methods used have included the transition probability model and cellular automaton model. The former focuses on the land use composition of the entire study area, while the latter considers the influence of land use situations in environing areas mainly using a 500 m mesh unit. However, little use has been made of GIS with either of these models, and no account has been taken of the neighboring relationship of land use between neighboring areas using small area units.

On the basis of methods offered by previous studies, this study aims to use the digital maps and spatial analysis offered by GIS to develop an urbanization prediction model that can reflect the mutual influence and neighboring relationship of land use in neighboring areas using the unit of the block (in Japanese, *gaiku*, literally city or town block).

2. Study area description

The area for this study was Shiga Prefecture, located as shown in Figure 1 in the central part of the main island of Honshu. The first distinctive feature of this area is that it contains Lake Biwa, the largest lake in Japan, in the center of the prefecture; the reduction of the environmental load on Lake Biwa is thus an important policy issue. The second distinctive feature is the remarkable advance of urbanization, due to the location of this area on the outskirts of the Keihanshin metropolitan area: urbanization has occurred mainly in the southern lakeshore region where time distance to Osaka (the central city of the Keihanshin metropolitan area) is about an hour. Ever since the region was specified as an urban development zone, "the eastern Lake Biwa area," in the Kinki Bloc Development Act in 1963, it has played the role of receptacle for easing the over-concentration of population and

industries in the central parts of the Keihanshin metropolitan area. The third distinctive feature is the tremendous changes in land use that have occurred centering on the lakeshore region over the past roughly 30 years, due to the Lake Biwa Comprehensive Development Plan (LBCDP, 1972-1997) and the implementation of land development for recreational uses under the planning scheme called the Resort Necklace Plan (RNP, 1987-).

Accordingly, in Shiga Prefecture there is now a real need to take another look at land use plans, paying especial attention to attaining a balance between urbanization and conservation of the natural environment. In the Lake Biwa Comprehensive Conservation Plan (hereafter LBCCP; also known as Mother Lake 21 Plan, 2000-2020), which was initiated in 2000, land use is given particular priority as an important regional element with immense influence on water quality conservation, water resource cultivation, and natural environment and landscape conservation (Shiga Prefecture 2000).



Figure 1 Location of Shiga Prefecture in Japan

3. Framework and method

In Section 4 I explain how I developed an urbanization prediction model that takes into consideration the situation of the land use and the urbanization of Shiga Prefecture, based on the results of the above-mentioned precedence studies. In Section 5 I explain how I conducted an urbanization prediction for 1994 based on land use data taken in 1965, and then examined the validity of the model in comparison with land use data taken in 1994. I also explain how I performed a future urbanization prediction for after 1994 based on land use data taken in 1994. In Section 6, on the basis of these prediction results, I explain how I applied the urbanization prediction model developed in this study to make an evaluation of land use controls, mainly those in city planning areas. In this study, in order to offer information to aid policy judgments pertaining to LBCCP on the basis of findings, the analysis results are shown for the seven sub-basin units that are the regional classification as shown on maps for LBCCP.

In Japan, city planning areas are designated as areas in accordance with integrated and identifiable city zones, in keeping with the New City Planning Act of 1968. With the objective of preventing disorderly urbanization and enabling appropriate land use in each area of a city planning area as a whole, the land use plans are defined and land use controls are carried out for every area respectively. Within any city planning area, particular areas are given designations such as “urbanization promotion area,” “urbanization control area,” or “land use district,” while areas with no specification are referred to as “white areas.” Yamamoto (2001, 2002, 2003a and 2003b) and Yamamoto and Nakamura (2004) have already pointed out that land use problems accompanying urbanization have arisen in Shiga Prefecture specifically in city planning areas.

Areas designated as urbanization promotion areas are those where planned city area maintenance should be performed, while areas designated urbanization control areas are those where all development acts are in principle restricted. In a white area, restrictions apply to

any development activity that covers more than 3000m². Land use districts within any given city planning area can be divided into three kinds, those for residential, commercial or industrial use. In an urbanization promotion area the entire area will receive designations. In the six small-scale towns in the northwestern part of the area under study, however, no area was designated an urbanization promotion area. For these areas I therefore decided to consider land use district as the same as urbanization promotion area. After Section 5 I therefore carried out an analysis of land use districts.

4. Development of an urbanization prediction model

4.1 Creating a GIS database

In this study, the aim was to develop an urbanization prediction model to treat the diffusion phenomenon of urban areas using the small-scale unit of the block, paying attention to the fact that urbanization had advanced especially in the environs of the old urban areas in the past 30 years (from 1965 to 1994) in Shiga Prefecture.

The GIS used in this analysis were ArcGIS and ArcView, using a GIS database developed for the LBCCP in Shiga Prefecture. Specifically, I used data pertaining to land use (as of 1965 and 1994), land use control and traffic conditions.

Moreover, with the objective of efficiency of data management, I used GIS to process these digital data to a 100 m mesh unit on a spatial scale on the level of the block (for a total of 407,318 meshes in Shiga Prefecture) in order to use them for the analysis after Section 5.

4.2 Configuring a transition rule for urbanization and land use conversion

Firstly, a transition rule had to be configured that would determine whether the meshes where land that had uses other than urban areas, for example paddy fields, dry fields and forests, in t term (1965) had under the influence of urbanization in neighboring areas in $t+1$

term (1994) been converted into urban areas or remained in the original land use.

Regarding the conditions for neighboring relationship on the level of the block, as shown in Figure 2, consideration was given first to the proportion held by an urban area in a particular neighbor area of a nine-mesh unit (the main mesh in question and the eight meshes surrounding it). The proportions of various land uses were then computed for every nine-mesh unit, and where the proportion of one kind of land use was overwhelmingly large, the set-up was configured so that the entire nine-mesh unit could be converted to that land use. In addition, since based on this rule there were some meshes that had been urban area in the t term (1965) but appeared to have been converted to other land uses, they were extracted after the series of operations and corrected so that they could remain as urban areas.

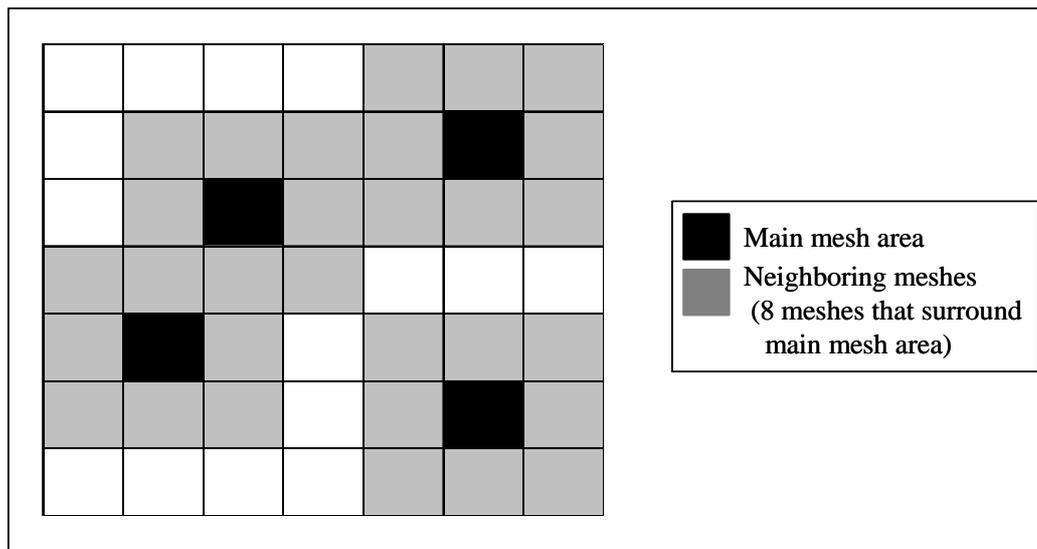


Figure 2 Conditions for neighboring relationships of the block

Moreover, if in the nine-mesh unit urban areas and other land use occupied a major proportion and were equal to each other in number, all the areas of the nine-mesh unit were converted into urban areas. The reason for this is that when conducting urbanization prediction based on land use data in 1965, the distribution of urban area is closer to the actual conditions in 1994 when it is presupposed that all the areas of a nine-mesh unit are converted

into urban areas than when it is presupposed that no land use changes at all have taken place.

The same transition rule applied in this study also for the period between t+1 term (1994) and t+2 term (2023). Since these 30 years are basically consistent with the period for LBCCP (2000-2020), by performing an urbanization prediction for this period we can provide information that pertains not only to the land use plans but also to this environmental plan.

5. Analysis and consideration of urbanization prediction result

5.1 Characteristics of urbanization and land use

Figure 3 shows a comparison of the land uses in 1965 and 1994 of Shiga Prefecture while Table 1 shows the changes in land use in Shiga Prefecture for the past 30 years, based on the GIS data of the land uses in both 1965 and 1994. In the present study, the urban areas which were already formed in 1965 are referred to as “old urban areas”, and the urban areas which have newly formed over the past 30 years (1965-1994) are referred to as “new urban areas.”

We can see from Figure 3 that new urban areas have increased for the most part in the southern and the southeastern parts. Moreover, the conditions of transformation in land use to urban areas shown in Table 1 shows that the proportion of urban areas has increased by 3.4% in the past 30 years throughout Shiga Prefecture. Among the new urban areas, the areas that have been converted from farmlands (mainly paddy fields and dry fields) occupy 2.3 % and the ones have been converted from forests occupy 1.2%.

It has already been pointed out by Yamamoto (2001, 2002 and 2003b) that the new urban areas converted from farmlands have expanded mainly around the old urban areas in the plains that stretch from southern regions across to the east in the lakeshore region. In contrast, in the southern inland areas, the new areas converted from the forests have increased

alongside the main roads.

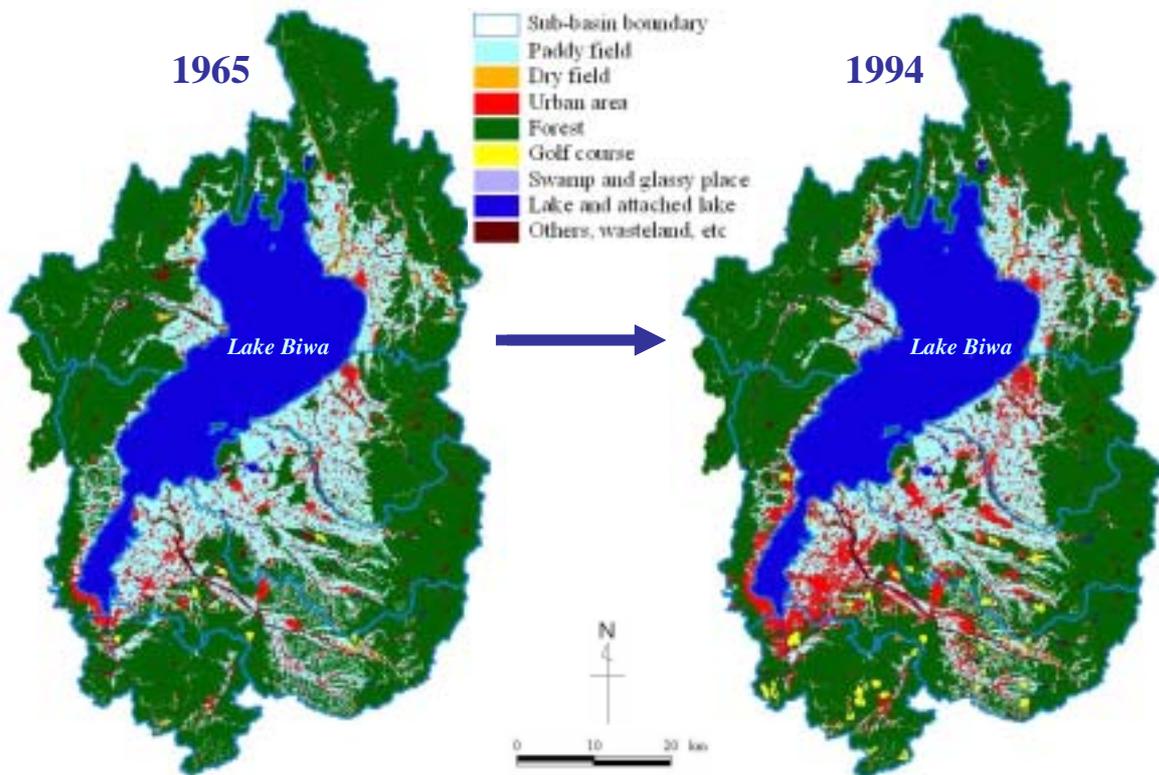


Figure 3 Land use in the Shiga Prefecture (1965, 1994)

Table 1 Land use transformation using 100 m mesh unit (1965-1994)

	Paddy field	Dry field	Urban area	Forest	Golf course	Swamp and glassy place	Lake and attached lake	Others, wastland, etc
Paddy field	16.3	0.1	0.1	0.3	0.0	0.0	0.0	0.1
Dry field	0.2	0.7	0.0	0.2	0.0	0.0	0.0	0.1
Urban area	2.2	0.1	4.9	1.2	0.0	0.0	0.1	0.2
Forest	0.4	0.1	0.1	52.7	0.0	0.0	0.0	0.3
Golf course	0.1	0.0	0.0	0.5	0.1	0.0	0.0	0.0
Swamp and glassy place	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lake and attached lake	0.1	0.0	0.0	0.0	0.0	0.0	17.0	0.1
Others, wastland, etc	0.3	0.0	0.0	0.4	0.0	0.0	0.1	1.0
Land use (1965)	19.5	1.0	5.1	55.3	0.1	0.1	17.2	1.6
Land use (1994)	16.9	1.2	8.5	53.6	0.7	0.1	17.2	1.8

5.2 Analysis and consideration of urbanization prediction result

Urbanization prediction for 1994 was performed based on land use data in 1965, and the predictive values were computed by comparing them with the land use data in 1994. Figure 4 shows the predictive values of each municipality, and Figure 5 shows the urbanization prediction results compared with the actual distribution of the urban areas in 1994.

The predictive value of the urbanization prediction model developed in this study was found to be 58.7% for Shiga Prefecture in its entirety. The predictive values are as high as 67.7% and 69.2% respectively in the white areas and areas outside city planning areas where there is little possibility for the advancement of urbanization. On the other hand, the predictive value is 57.8% in urbanization promotion areas and land use districts, and 54.4% in urbanization control areas. Moreover, as shown in Figure 4, the predictive values are low in areas in the south that have shown an especially remarkable increase in urban areas over the past 30 years. The predictive values are high especially in the northeastern and northwestern areas which have not seen any particular transformation in land use.

Figure 5 shows the situation in Shiga Prefecture in more detail, and as we can see from this there is the most remarkable difference between the prediction results and the distribution of the urban areas in 1994 in the city of Kusatsu and its neighboring municipalities, where in recent years there has been advance in the construction of new towns and the accumulation of cultural facilities such as universities and libraries. The difference between the prediction result and the actual distribution of the urban areas in 1994 is also conspicuous in the western lakeshore region in Otsu city and in the southern inland area. These areas have lately seen brisk new towns development and housing development.

Thus we can say that the urbanization prediction model developed in this study is useful for prediction only for urbanization that takes the form of urban areas diffusing around an old urban area. There are limits as to its predictive usefulness regarding intensive urbanization in areas distant from old urban areas, such as new towns development.

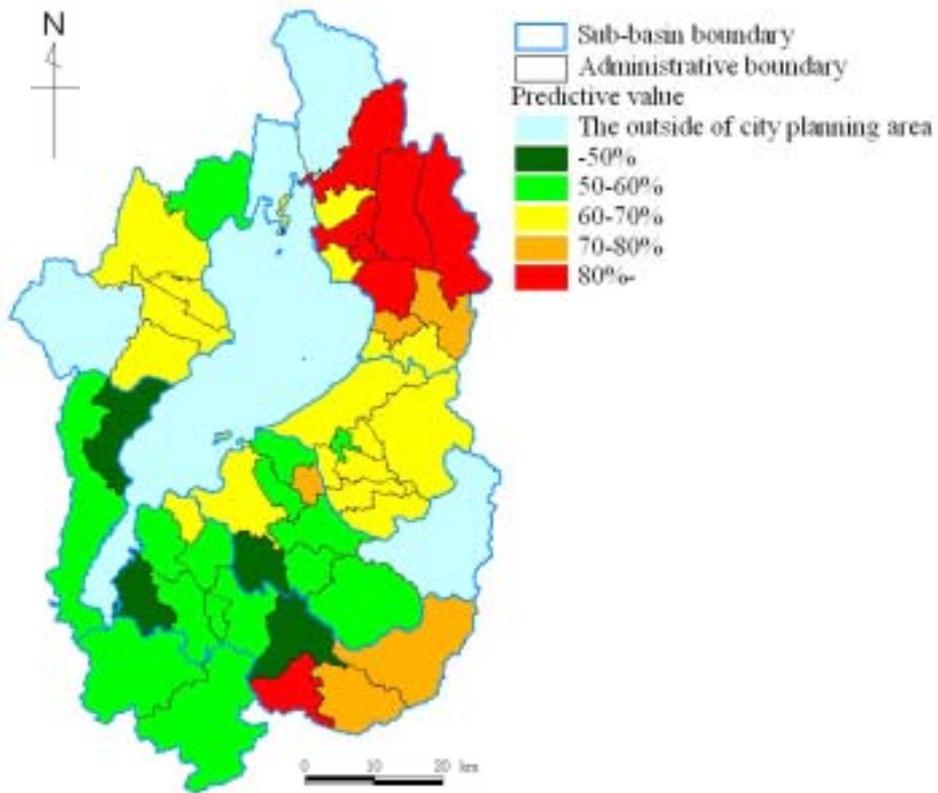


Figure 4 Predictive values in each community

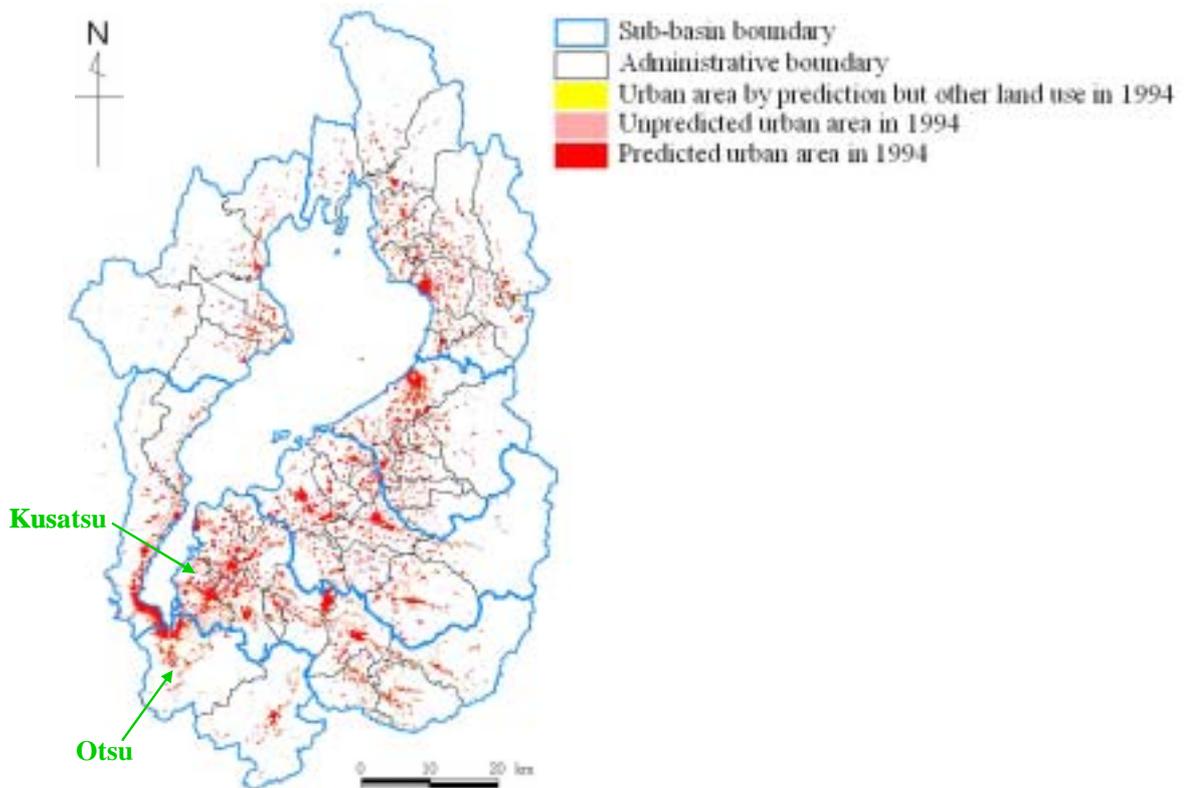


Figure 5 Urbanization prediction results compared with actual distribution of urban areas in 1994

5.3 Future urbanization prediction

Assuming that urbanization during 1994-2023 advances under the same sort of conditions as during 1965-1994, further urbanization prediction for the period from 1994 to 2023 was then conducted based on the land use data taken in 1994. According to the urbanization prediction model developed in this study, the proportion of the urban area out of the total area of Shiga Prefecture will increase by about 1.3%, and about 0.8% of farmlands and 0.3% of forests will be converted into urban areas and decrease respectively. In most of the areas, it was predicted that land use transformation would mainly occur with farmlands becoming urban areas. However, the land area of urban area that will be converted from forests is only about 1% out of all of the cities and towns.

Figure 6 shows the proportion by which urban areas are seen as likely to increase during 1994-2023 over what they were in 1994, per municipality. On the basis of Figure 6, the proportion of increased urban areas during 1994-2023 will be more than 115% in relatively numerous cities and towns in the southeastern part of the prefecture, and less than 110% in some cities and towns in the eastern and northern parts.

From the above, if urbanization during 1994-2023 advances under the same sort of conditions as during 1965-1994, we can predict that up until 2023 it will be farmlands that decrease rather than forests and land put to other uses. Therefore, attention should be given to the necessity of adopting a mitigation system for reducing the load on Lake Biwa that will increase with future urbanization, in addition to the refurbishment of Shiga Prefecture's legal systems to protect farmlands. Particularly in the southern part of the prefecture, where the increase in urban areas during 1994-2023 looks set to be remarkable, there is a strong necessity for these things.

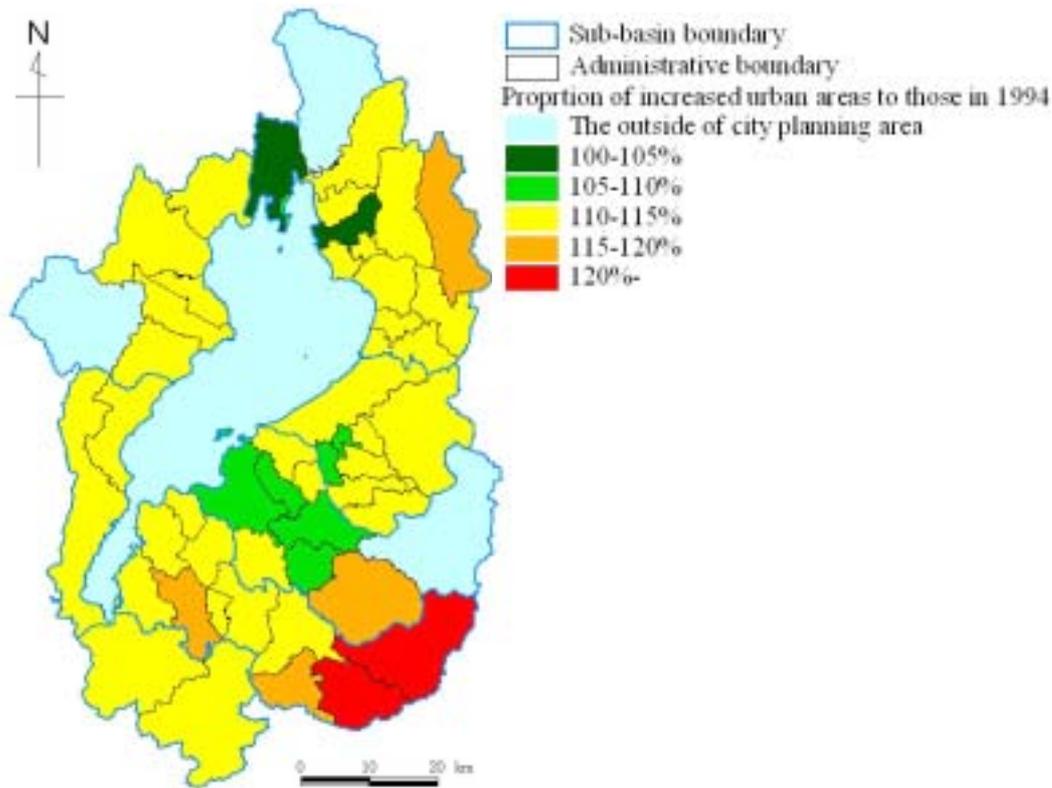


Figure 6 Proportion of increased urban areas in 1994-2023 as against 1994

6. Application of urbanization prediction method to the evaluation of land use controls

6.1 Evaluation in urbanization control areas and white areas

By comparing the prediction result in 1994 based on land use data in 1965 and the land use plan, an examination can be made of the effectiveness of present land use controls in urbanization control areas and white areas. In urbanization control areas and white areas, development activity is restricted and yet the reduction of farmlands and forests with the expansion of urban areas has become a serious land use problem.

As of 1994 the proportion of urban area to total land area is roughly 10% in urbanization control areas and about 8% in white areas. However, of these urban areas about 4% in urbanization control areas and about 3% in white areas are areas where urbanization had not been predicted. For urbanization control areas and white areas where the advance of urbanization must be prevented, grasping the distribution of unpredicted urban areas will

make possible an examination of the problem of urbanization that advances in intensive fashion in areas that are distant from old urban areas.

Figures 7-1 and 7-2 show the proportion of unpredicted urban areas in urbanization control areas and white areas respectively in 1994, per municipality. In Figure 7-1 we can see that although the proportion of urban areas not predicted in urbanization control areas is less than 5% in most cities and towns, it is strikingly high, more than 50%, in four cities and two towns in the southern part of the prefecture. In Figure 7-2 we can see that the proportion of urban areas not predicted in white areas is more than 30% in six towns in the eastern part and five towns in the northwestern part of the prefecture.

From this we can conclude that most of the urban areas that increased over the past 30 years in urbanization control areas in the southern part and in white areas in the eastern and northwestern parts expanded in areas distant from old urban areas, and this is where the problems in land use controls arise. Moreover, since the expansion of such urban areas may give even more environmental load than foreseen to the water quality of Lake Biwa, it will be necessary to consider this point for LBCCP and in land use plans.

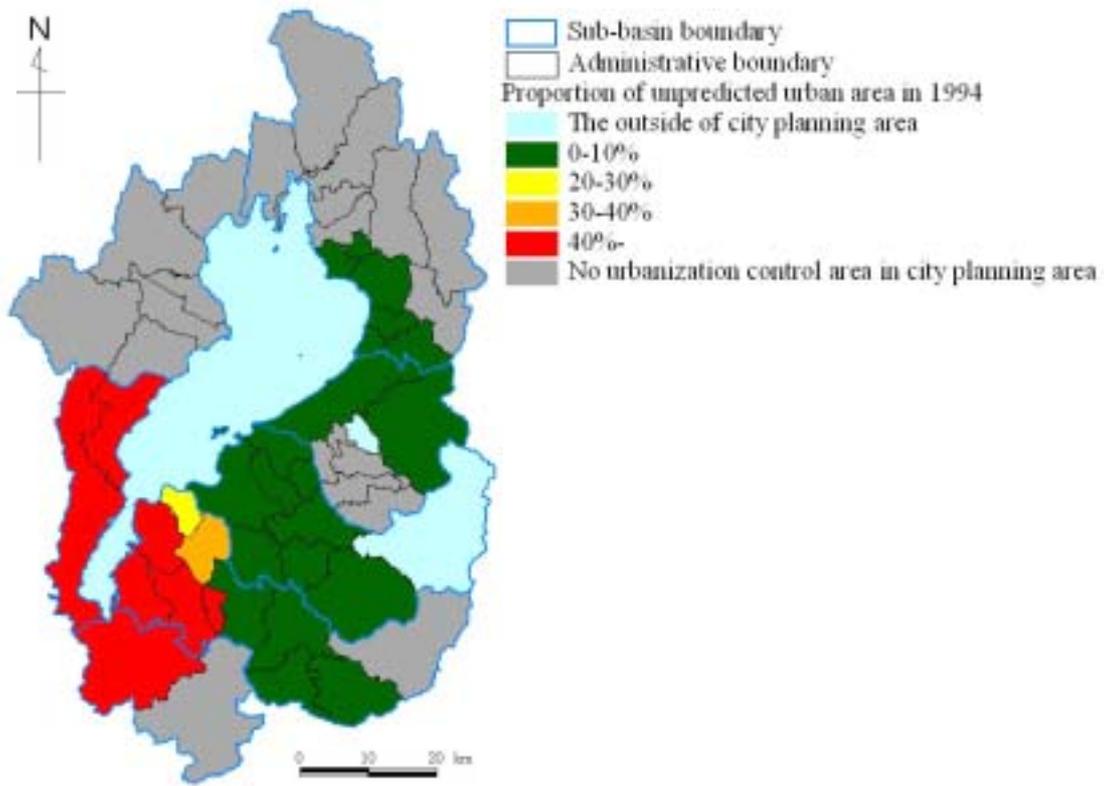


Figure 7-1 Unpredicted urban area in urbanization control areas in 1994

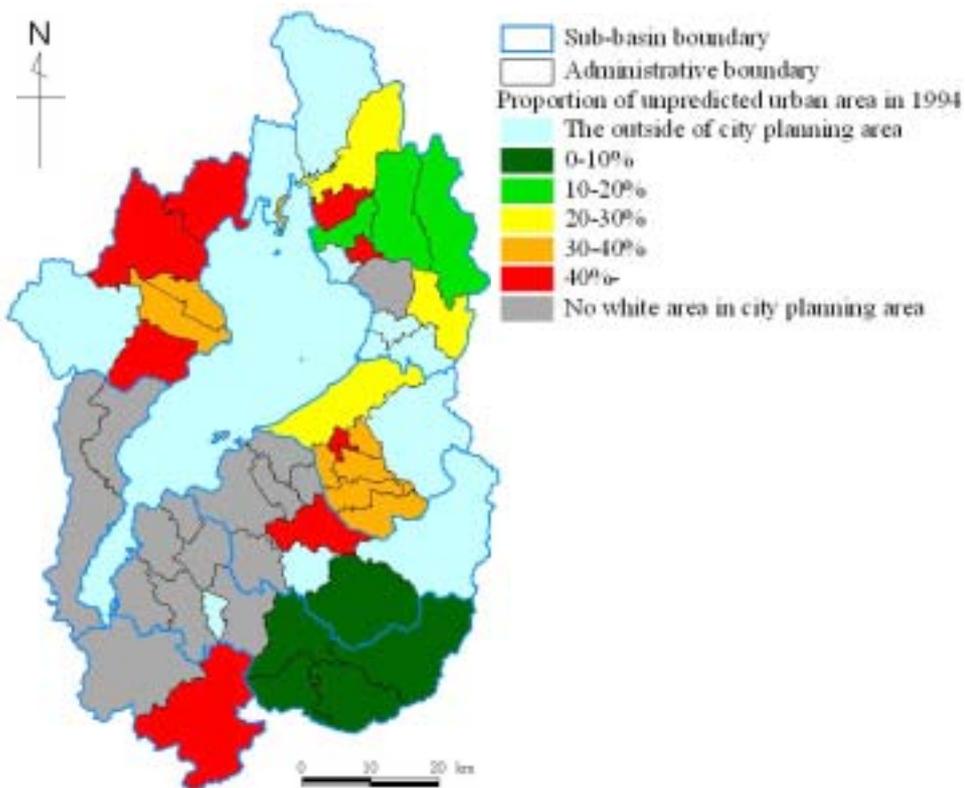


Figure 7-2 Unpredicted urban areas in white areas in 1994

6.2 Evaluation in urbanization promotion area and land use district

A comparison of the prediction results for the period 1994-2023 based on land use data in 1994 and land use plans enables an examination to be made of the present land use controls in the urbanization promotion areas and the land use districts. Assuming that urbanization during 1994-2023 advances under the same sort of conditions as during 1965-1994, we can then consider whether the urbanization promotion areas and the land use districts have been designated appropriately.

The prediction results show that the proportion of urban area throughout Shiga Prefecture taken as a whole will probably increase by about 6% during 1994-2023, which for urbanization control areas and land use districts will mean an increase to about 81%. Figure 8 shows the proportion of urbanization in urbanization promotion areas and land use districts during 1994-2023 based on these urbanization prediction results: we can see that it is only in cities and towns in the southern areas that the proportion of urban area in urbanization control areas and land use districts will increase to more than 90%; the proportion of urban area will remain less than 50% in small-scale towns in the northeast part. Moreover, in most small-scale towns, even if urban area does increase as predicted, the proportion of urban area in urbanization promotion areas and the land use districts will remain less than 70%. From this, it can be said that in Shiga Prefecture in all but the southern and southeastern parts that adjoin the central part of the Keihanshin metropolitan area where urbanization can be expected to keep advancing, there are many cities and town where excessive designation has taken place of urbanization promotion areas and land use districts.

In addition, assuming that urbanization during 1994-2023 advances under the same sort of conditions as during 1965-1994, a similar comparison was also made of the urbanization prediction results for 1994-2023 and land use controls in urbanization control areas and white areas. It was found that in the urbanization control areas, the proportion of urban area will probably increase by 1.6% throughout Shiga Prefecture as a whole, while the proportion for

the area taken up by actual cities and towns will probably be less than 5%. Similarly the proportion of urban area will probably increase by 1.2% throughout Shiga Prefecture as a whole in the white areas after 1994, and the proportion of urban area for cities and towns will be less than 4%. This suggests that there is little likelihood that urbanization will advance on a large scale in urbanization control areas and white areas purely through urban area diffusion during 1994-2023.

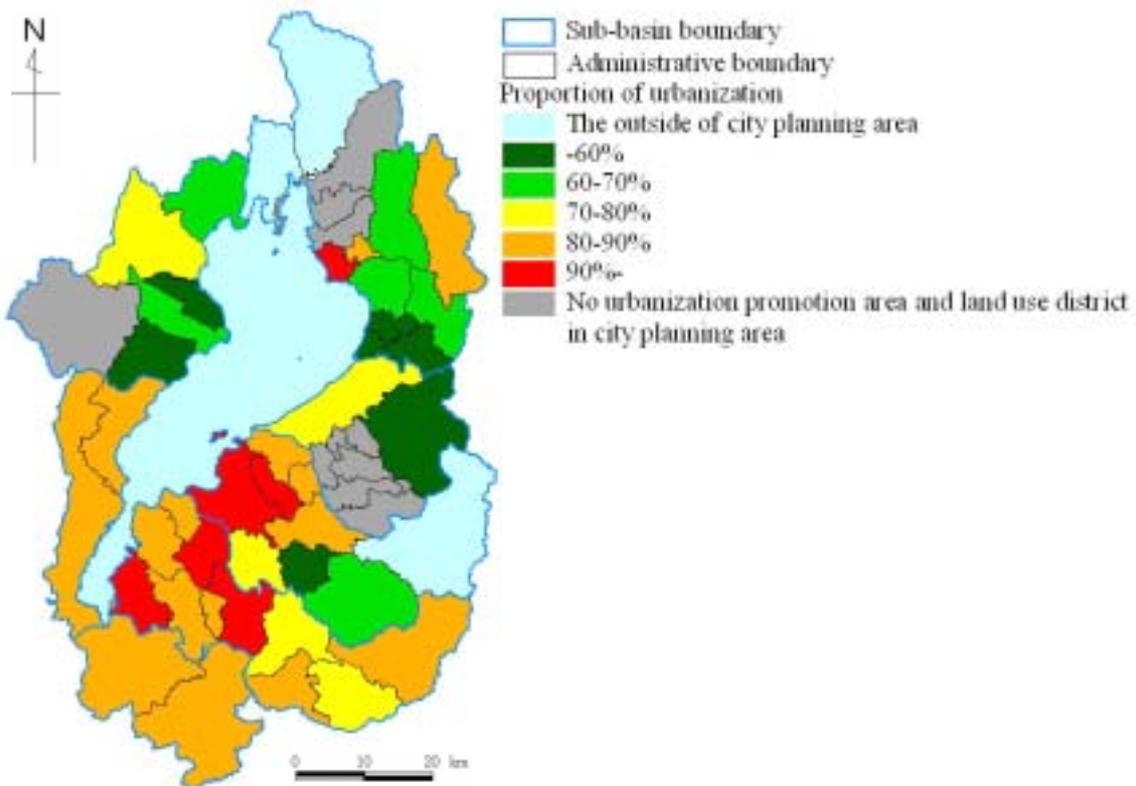


Figure 8 Prediction of proportion of urbanization in urbanization promotion areas and land use districts during 1994-2023

7. Conclusion

This study aimed to develop an urbanization prediction model using the level of the block, and using the results obtained in this model in order to evaluate the present land use controls in Shiga Prefecture as a region that bordered the Keihanshin metropolitan area. The findings of this study can be summarized as follows:

(1) The predictive value of the urbanization prediction model developed in this study was 58.7% for the study area in its entirety, and in northern areas where urbanization is less advanced more than 80%.

However, while this model does basically enable predictions regarding the phenomenon of diffusion in urban areas, there are limits to its suitability for predictions regarding intensive urbanization in regions distant from old urban areas.

(2) Comparison of the urbanization prediction results with present land use controls revealed that many of the urban areas that expanded in the last 30 years in urbanization control areas and white areas occurred in concentrated fashion in areas that were distant from old urban areas. However, these areas are the areas where urbanization should be restricted.

Further, the urbanization prediction results also indicate that an excessive designation of urbanization promotion areas and land use districts has taken place in every area apart from areas in the south conveniently located to the center of the Keihanshin Metropolitan Area. These are areas where urban area management should be promoted in planned fashion.

In future research, it will be necessary to develop an urbanization prediction model that can take into consideration various other factors pertaining to urban conglomerations including regional traffic conditions, land use controls, and geographical conditions, regarding the plains in the southern area of Shiga Prefecture where expansion of urban areas cannot be explained only by urban diffusion. Also, in this study, restrictions in the GIS database meant that use could only be made of the two time frames of the existing digital data for an interval for 30 years. However, if and when an urbanization prediction model can be

developed that will take into consideration the conditions mentioned above, it will be necessary to devise a model with a much greater level of accuracy, using for example digital data taken at ten-year intervals at three points in time.

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