

Prediction on Optimum Population Capacity Determined by Facility Density



メタデータ	言語: English 出版者: 公開日: 2023-06-27 キーワード: 作成者: Yisu, Wang, Riken, Homma メールアドレス: 所属:
URL	http://hdl.handle.net/2297/00070434

This work is licensed under a Creative Commons
Attribution-NonCommercial-ShareAlike 3.0
International License.



Prediction on Optimum Population Capacity Determined by Facility Density

A case of residence attraction areas in Kumamoto

Yisu Wang^{1*}  and Riken Homma² 

¹ Graduate School of Science and Technology, Kumamoto University.

² Faculty of Advanced Science and Technology, Kumamoto University.

* Corresponding Author, Email: wys15558199325@163.com

Received: Sept. 24, 2021; Revised: Dec. 01, 2022; Accepted: Jan. 09, 2023

Keywords: Residence Attraction Areas, Facility Density, Optimum Population Capacity, Random Forest Regression, Population Prediction

Abstract: In the context of population decline and urban sprawl, based on “The Location Optimization Plan” to promote the sustainable structural transformation of city to compact city, the residential attraction areas in Kumamoto, Japan are taken as the research area. And the prediction model of optimum population capacity is used to measure the balance between people and urban environment by Random Forest regression, so as to grasp the residential development of residence attraction areas with sufficient population capacity. From the whole residence attraction areas, future population development trends will not exceed the region's optimum population capacity, but there are problems in maintaining the population in the urban inducing areas, mainly reflected in the Suizenji-Kuhonji, Kengun and Nagamine regional hubs.

1. INTRODUCTION

For recent urban development, doughnut phenomenon and sprawl are becoming common. The term sprawl first appeared in a 1955 Times article as a negative expression of the current situation of London suburbs ([Audirac, Shermeyen et al., 1990](#)). [Batty, Besussi et al. \(2003\)](#) defined sprawl as "chaotic growth", which was kind of unplanned and incremental urban growth was generally considered unsustainable. [Bhatta, Saraswati et al. \(2010\)](#) raised the issue that sprawl leads to inefficient use of resources. [Chin \(2002\)](#) also pointed out that sprawl would lead to low-density suburban development, resulting in waste of land resources, reduced coverage and utilization of facilities, and increased management costs.

In the case of Japan, urban sprawl is proceeding more rapidly in the context of population reduction and aging. According to the report "Land Use Issues under Population Reduction", areas with less than half of the population account for more than 60% of the current residential areas, and uninhabited areas account for 20% of the residential areas. In addition, the continuous conversion of farmland land to urban land in the face of population reduction



@ Licensee SPSP Press

This open access article is published under a Creative Commons [Attribution-NonCommercial-NoDerivatives 4.0 International] license.

<https://creativecommons.org/licenses/by-nc-nd/4.0/>

has led to inefficient land use and the increase of residential vacancy and unutilized land. And it is also important to respond to the demand for medical and welfare services and maintain the vitality of the region in the face of population decline and aging ([Ministry of Land, Infrastructure, Transport and Tourism, 2016](#)).

Therefore, in order to make concentrated and efficient use of limited resources and realize sustainable development of cities and society, the Japanese Ministry of Land, Infrastructure, Transport and Tourism began to issue plans related to compact cities in 2015 ([Ministry of Land, Infrastructure, Transport and Tourism, 2015](#)). The plan related to compact cities called “The Location Optimization Plan” was issued, so as to seek the transformation of urban structure to sustainable development in the future. The purpose of the plan is to enable people of all ages to enjoy a convenient, healthy, comfortable and vibrant life, while realizing efficient urban management, low-carbon urban structure and strong disaster resistance urban construction.

In terms of the characteristics of “The Location Optimization Plan”, it mainly includes three points from urban environment and people: (1) The urban master planning including urban functional planning of housing, medical care, welfare, commerce, public transportation and other urban functions. (2) The urban construction of "compact city + network" based on the combination of residence and multifunctional facilities through public transportation. (3) Residential attraction areas are set up in urbanized area, while countermeasures against residential vacancy and unutilized land will be taken as new options to maintain population density and prevent hollowing-out of central urban area, as shown in *Figure 1*.

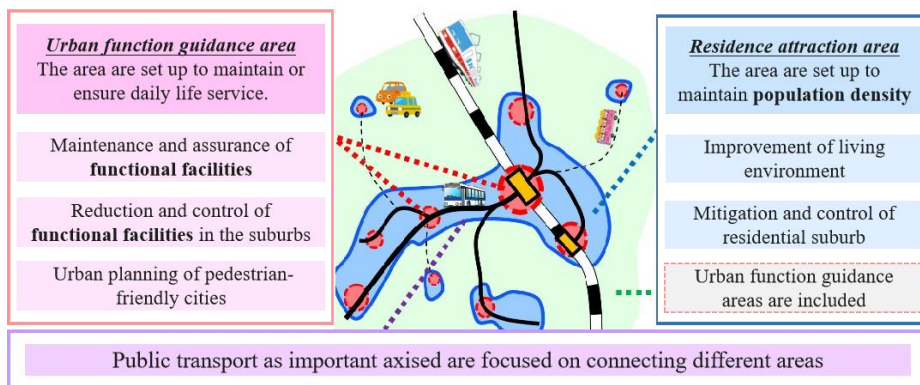


Figure 1. The main points of “The Location Optimization Plan”

Source: [Urban Planning Bureau of Kumamoto City \(2016\)](#)

Then, the important goal of “The Location Optimization Plan” is to maintain population density, but lots of scholars mainly focus on the rationality of policy formulation, evaluation of residential attraction area, policy implementation and the impact of compact urbanization on urban development. Hosoya grasped the concerns and problems of Hokkaido's “The Location Optimization Plan”, as well as the positive and negative impacts of the implementation of the plan through questionnaire surveys ([Hosoya, Mori et al., 2019](#)). [Sugihara, Ikaruga et al. \(2018\)](#) used expert system to construct compact city structure model, and studied the designation method of residential attraction area and the evaluation of life convenience in Shonan, Shimamatsu and Hikari. [Yoshida, Ikaruga et al. \(2018\)](#) analyzed the urban structure of Shunan City according to the human settlement evaluation index

system of Portland city. In these current studies, it can be seen that there is a lack of research on population density and the relationship between population and urban environment.

While, population density, as the target value, is related to birth rate, death rate and transfer rate, and lacks connection with urban environment, which is not enough to promote the "The Location Optimization Plan", so the focus of this research has shifted to what population density is appropriate as a target value. From our aspect, it is the upper limit of population that balances the resources and environment closely related to people's life as a constraint, so that people can also live conveniently under the premise of full utilization of resources, which is more suitable as the target value of population density. Then the "upper limit of population in balance with the environment" is often referred to as carrying capacity in previous studies.

Carrying capacity was originally applied to the ecological field, which was measured as the maximum load of an environment, in which the population limit could mainly be expected to depend on physical factors like food, water, competition, etc. (Hui, 2006). Then the optimum theory of population was propounded by Edwin Cannan in his book *Wealth* published in 1924 (Gupta, 2010), and popularized the use of the words to describe the number of people the earth can support in the 1950s (Sayre, 2008). The optimum theory in 1888s is different from the Malthusian theory, which showed the carrying capacity was the kind of ideal population level that socioeconomic environment can support (Seidl and Tisdell, 1999). While in terms of optimum population capacity, Fred Singer proposed using the quality of life as a reference standard for evaluating optimum levels of population (Singer, 1972).

On the basis of the previous study, the environmental population capacity pays more attention to economic and social factors support, basic goal, capacity limits. Yandri mentioned that the concept of "triple bottom lines" (economic, social, and environmental) are influential in sustainability, and developed 51 SRA (Sustainability residential area) indicators grouped into economic, social, environmental, infrastructure, technology, and governance parameters (Yandri, Priyarsono et al., 2021). The basic goal is that the environmental capacity can meet people's high quality production and living environment. Finally, the population size that meets the above requirements must have a capacity limit, so that the population cannot expand without limit (Tong and Qi, 2009; Wei, Dai et al., 2016). Therefore in this study, the optimum population capacity is a kind of environmental population capacity which focused on the population size based on social factors support.

The selection of urban environmental factors and how to use urban environmental factors to infer the appropriate population density is a topic of this study. Most of the previous studies used urban density to evaluate the urban environment, and right relationship between people and environment plays an important role in sustainable development. Teller (2021) indicated that based on the driving factors of urban transformation such as demographic change, facility agglomeration, transport projects, many cities need to try to optimize land use, improve facilities and services, and seek a new balance between city and population. From the perspective of Dovey and Pafka (2014), it was not the density in itself that is sought after, but rather the quality that the dense urban environment provides, such as the way people relate to work, activities, living services, parks, recreation, and so on. And Tsuang and Peng (2018) also indicated the convenient and comprehensive life function and adequate medical and educational resources play important role in community livability development.

Then urban density is mainly related to people's living environment and life service guarantee. From perspective of living environment, quantifiable "residential land density", "residential population density", "floor area ratio" (Chen, T.-H. K., Qiu et al., 2020). In terms of life services, POIs (Point of Interest), which reflects the spatial coordinates (X,Y) of urban facilities, is highly correlated with population distribution in small areas (Alahmadi, Atkinson et al., 2014; Bakillah, Liang et al., 2014). While, Dong, Yang et al. (2016) also proposed that population distribution is highly correlated with factors such as land use and POI data. Therefore, the prediction of optimum population capacity in terms of facilities can better guarantee the basic living needs of people and realize the optimal and intensive use of urban resources.

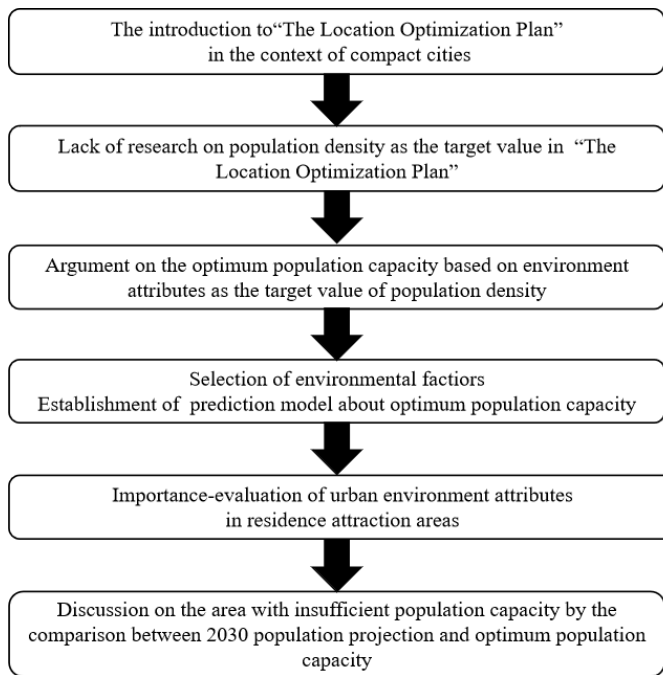


Figure 2. Research framework

2. METHODS

2.1 Research area

Kumamoto City is located in Kumamoto Prefecture, Japan. It accounts for 5.3% of the total area of the Kumamoto prefecture and is home to about 740,000 citizens, accounting for 42.7% of the prefecture's population. In April 2012, Kumamoto City became the third designated cities by the government decree of Kyushu. In Kyushu, it is the third most populous city after Fukuoka and Kitakyushu.

Kumamoto City began to prepare relative plan in 2015s and issued a formal "The Location Optimization Plan" in 2016s. Kumamoto City is the first city in Japan to actively respond to the national urban regeneration policy and to draft and implement the "The Location Optimization Plan" (Urban Planning Bureau, 2021). The basic consideration for Kumamoto City to promote "The Location Optimization Plan" is from the perspective of population outlook. The population is expected to remain at 700,000 for the next few years. However, in the long term, the population is predicted to drop

to 642,000 by 2050s and the aging process will continue. This outcome is undesirable and needs to be stopped ([Urban Planning Bureau of Kumamoto City, 2019](#)).

Further, according to the status quo of Kumamoto, related topics were sort out ([Urban Planning Bureau of Kumamoto City, 2019](#)). Among them, topics related to daily life service functions catch my attention. Due to the decrease of the population surrounding daily life services, the number of users is decreasing. And from the perspective of facilities related to daily life service, the coverage rate is decreasing, while management cost is increasing, thus urban facilities utilization environment needs to be improved.

Therefore, these main questions need to be solved in the residence attraction areas mentioned in “The Location Optimization Plan of Kumamoto City”.

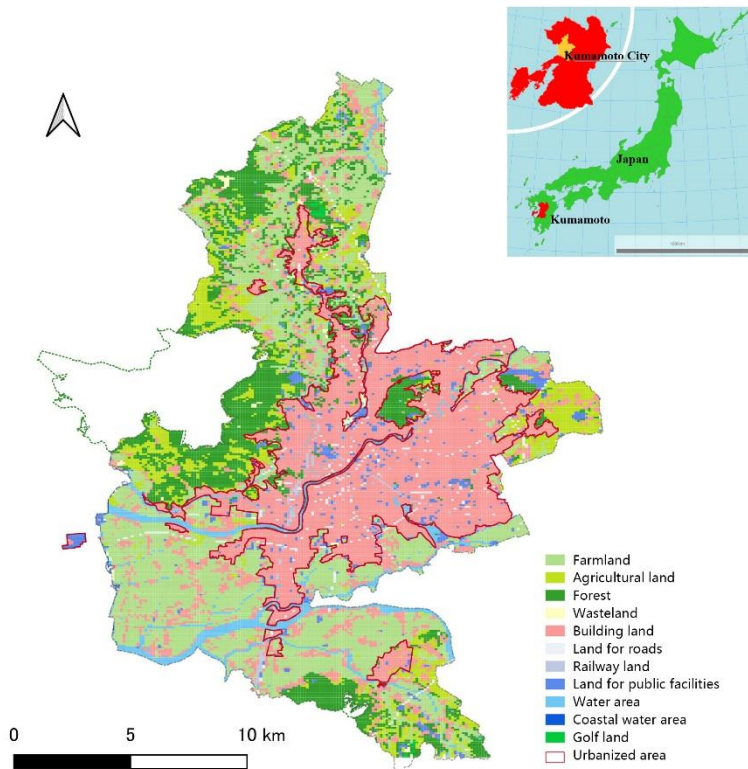
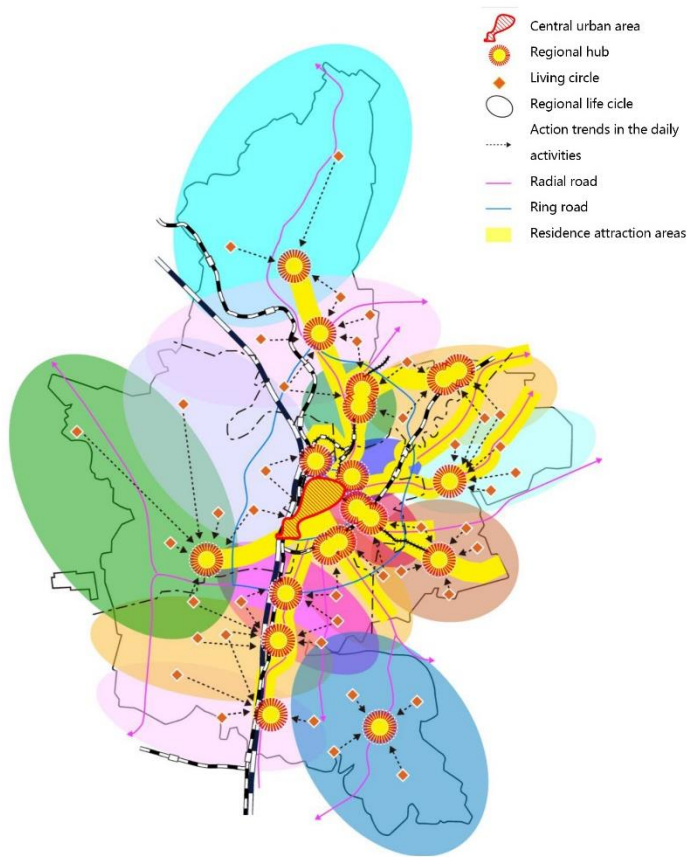


Figure 3. The land use map of Kumamoto City



*This figure dose not mainly show location,but the connection between living circle and regional hubs

Figure 4. Spatial structure image of Kumamoto's compact city master plan
 Source: [Urban Planning Bureau of Kumamoto City \(2019\)](#)

The residential attraction areas in Kumamoto City are mainly composed of the urban function guidance area, the public transport service areas, and the area near the public transportation axis, the area near the public transport axis, and setting rules of residence attraction areas are as shown in *Table 1*. In addition, the progress schedule of residence attraction areas is monitored by population density, with a target value of 60.8 people per hectare ([Urban Planning Bureau of Kumamoto City, 2019](#)).

Table 1. Setting rules of residence attraction areas

Area	Rule
Urban function guidance area	Central area ^{*1} : 415ha Regional center ^{*2} : 800m walking circle
Public transportation service area	Railway station , tram stop: 500m walking circle Bus stop: 300m walking circle
Area along the public transport axis	Rail transit: 500m walking circle Bus route that runs more than 75 times a day: 300m walking circle

Note:*1:The central area is about 415 hectares from the surrounding area of Kumamoto Castle and the municipal government to Kumamoto Station.

*2:Regional centers refer to the core areas in the regional life circle, and their locations are set at 15 in the master plan.

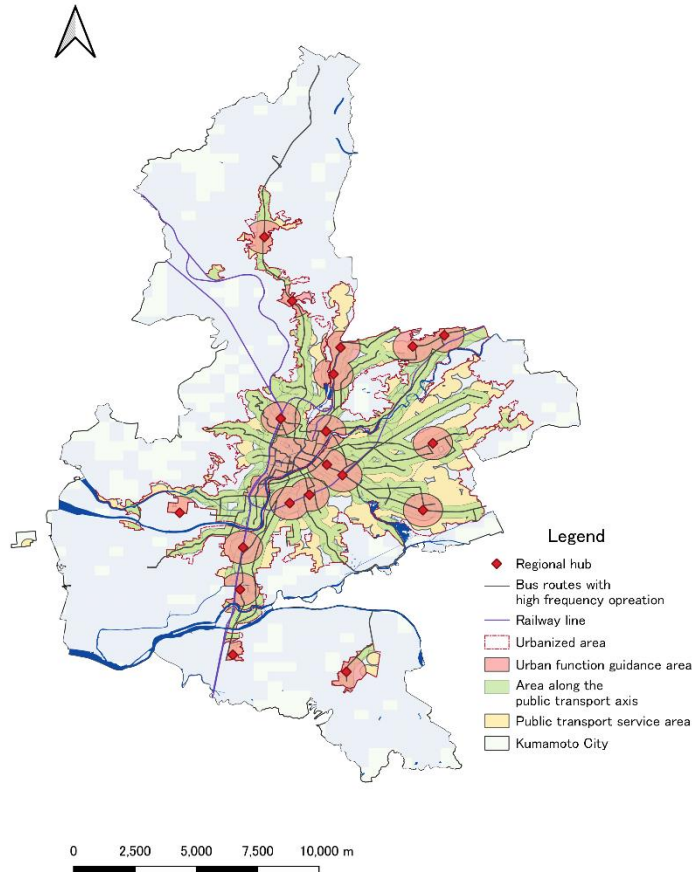


Figure 5. The residence attraction areas in Kumamoto City

2.2 Prediction model of population capacity

2.2.1 Relevant indexes of urban environment

Based on “The Location Optimization Plan”’s concern to urban facilities, and urban density is mainly to ensure life services and transportation related to people’s living quality. Therefore, urban facilities are mainly selected to explore the relationship between urban facilities and population and its impact on population. And in terms of basic necessities of life, welfare facilities, medical facilities, catering facilities, schools, convenience stores, park facilities, and public transit facilities are selected as the influencing factors to measure urban density.

The facility data are mainly from National Numerical Intelligence, and some of data such as catering facility, shopping service facility, convenience stores are crawled by python from Map Fun.

Table 2. Collected data

Category	Data	Data source
Welfare facility	Density of facilities	National Land Information
Medical facility	Density of facilities	National Land Information
Catering facility	Density of facilities	Map Fun
Shopping service facility	Density of facilities	Map Fun
School	Density of facilities	National Land Information
Convenience stores	Density of facilities	Map Fun
Park facility	Density of facilities	National Land Information
Public transit facility	Density of facilities	Urban planning basic survey

Category	Data	Data source
Population	Population density	E-stat population census
Population 2030	Population density	National Land Information

2.2.2 Data Preprocessing

The POI data, land use data and 500-meter population mesh data are imported into ArcGIS for processing. Firstly, three kinds of data can be spatially matched through Spatial Join. Then density of facilities can be calculated by Kriging with the number of facilities in each population mesh. While in order to distinguish the impact of facilities on demographic more clearly, categories of POIs that may related to population distribution were selected through correlation analysis. The density of each facility in mesh can be taken as the characteristic quantities.

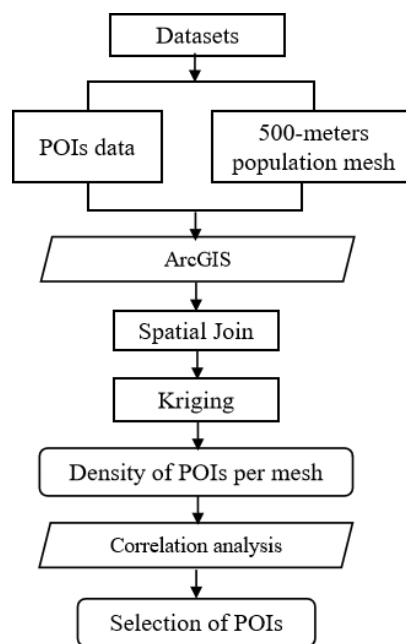


Figure 6. Flowchart of data preprocessing

2.2.3 Random Forest regression

There are many variables for prediction of carrying capacity of human population based on urban environment, and the quantitative relationship among them is complex. Therefore, it is necessary to use a method that can handle the high-dimensional data set composed of many variables. Random Forest is a machine learning algorithm that can process high dimensional data sets with high reliability and low time computation. Several studies have successfully used Random Forest for population prediction, the relationship between environmental factors such as and population distribution can be deeply analyzed, so as to obtain a high precision optimum population determined by urban environment (Yang, X., Ye et al., 2019). In this study, Random Forest was used to evaluate the optimum population capacity in residential attraction areas.

Random Forest regression is a nonlinear regression method in machine learning. The mechanism is to select data by bootstrap sampling. For a large number of learning data sets formed by repeated such sampling, decision trees

are constructed respectively. The decision tree is a learning method that divides data based on conditions, so as to build a prediction model by repeating the process "for a certain variable, the prediction result branches at a certain threshold". In the case of regression, divide by the variable threshold that minimizes the sum of squares of the error between each data and the average. By repeating this, a regression model is finally created.

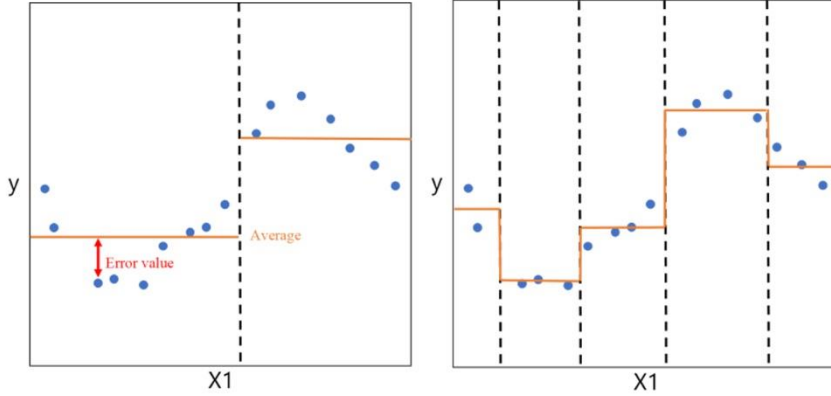


Figure 7. The operation diagrammatic drawing of Random Forest regression

Source: <https://funatsu-lab.github.io/open-course-ware/machine-learning/random-forest/>

Then the prediction model of carrying capacity of human population determined by urban environment can be built by Random Forest regression. The proportion of each land use type and the density of POIs regarded as the characteristic quantity of model, and the population density is taken as the dependent variable. Data is divided into test data and training data by Random Forest regression to build the training mode. Finally, based on the accuracy assessment of the training model, the influencing factors highly related to optimum population capacity can be determined, and prediction model can also be established well.

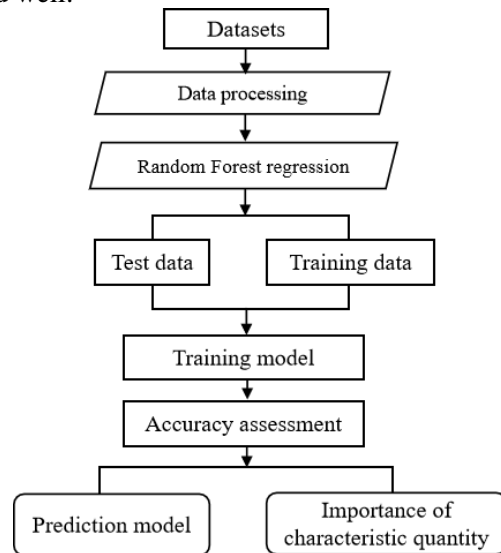


Figure 8. Flowchart of Random Forest regression

3. ANALYSIS AND RESULTS

3.1 Determination of characteristic quantity

In terms of facility, in urbanized area of Kumamoto City, the correlation coefficient of welfare facility, medical facility, convenience stores, park facility, public transit facility is over 0.500, which shows that they can be characteristic quantity of prediction model. Then the coefficient of determination (R²) of the prediction model for optimum population capacity is 0.894, and the accuracy is 73.31%.

Table 3. Importance of each influencing factor in urbanized area

Facility	Importance
Welfare facility	0.1642588
Medical facility	0.55875088
Convenience stores	0.08756383
Park facility	0.12860667
Public transit facility	0.06081983

Welfare and medical facilities have the greatest impact on population density. It's shown that they are closely related to quality of daily life service, and are an important reference for people when they choose to live. While park facilities are able to improve the living environment, and they also have a positive impact on the population density.

3.2 Discussion on the optimum population capacity in residence attraction areas

3.2.1 The schedule management based on population density

In order to carry on the schedule management to the “The Location Optimization Plan”, the population density as target value is set, and the target population density is based on the 2015 census in order to maintain the population density of the residential attraction areas in 2015 by 2030 in the context of population decline. In order to grasp the progress of maintaining population density in the residence attraction areas, the residence attraction areas can be divided into three areas: urban function guidance area, public transport service area and area along the public transport axis, and density management is carried out respectively.

Table 4. Schedule management about population density of residence attraction areas

Area	Image	Optimum population density by Random Forest	Predicted population density by 2030 Cohort method	Predicted population density by 2015 census
Urban function guidance area	An area of high density of population and functional facilities	73.4 people per hectare	71.0people per hectare	72.9 people per hectare

Area	Image	Optimum population density by Random Forest	Predicted population density by 2030 Cohort method	Predicted population density by 2015 census
Public transport service areas	The surrounding area of a major transportation hub with certain functional facilities gathering.	59.5 people per hectare	57.6 people per hectare	57.4 people per hectare
Areas near the public transport axis	The area where it is easy to reach the urban function guidance area by using nearby bus lines with high frequency and urban function concentration.	60.6 people per hectare	58.5 people per hectare	58.1 people per hectare
Residence attraction areas	A concentrated residence with a certain population density	63.6 people per hectare	58.9 people per hectare	60.8 people per hectare (Target value)

In terms of schedule management about population density, The population density of the entire residence attraction areas will not exceed the carrying capacity of the urban environment until 2030, and that the urban environment will satisfy people's lives for the next 10 years. However, from the viewpoint of the urban function guidance areas, it can be seen that it may be difficult to maintain the population density until 2030. The population density in urban function guidance areas shows a tendency to decline, positive and effective measures such as utilization of scattered land and vacant lot, as well as supplement of facilities should be taken so that more people can live in areas where facilities gather. In addition, the public transportation service areas and the areas along the public transportation axis where population is expected to increase, should be taken active measure on further improvement of the service level of public transportation, as well as pedestrian space, bicycle running space, and other public vacant lots, which can contribute to creating favorable living environment and improving residential quality.

3.2.2 The comparison between optimum population capacity and 2030 predicted population by Cohort

The predicted population by the Random Forest regression is the optimum population capacity supported by the situation of land use and facilities. While, the estimated population by the Cohort method is mainly determined by two factors related to the population itself, "natural increase/decrease" and "movement rate". The population difference by comparing the two predicted population shows unchanged, positive and negative, which can be used to determine whether the environment can support people's lives in 2030s.

In areas where population difference is positive, it is sufficient for the urban environment to support people's living services. In areas where population differences remain unchanged, people's livelihoods can be

maintained in urban environments, but further consideration is needed in the long run. In areas where the population difference is negative, priority is given to the overall planning of facilities and land use to make it more comfortable for people to live. And according to the entire residence attraction areas, the proportions of the number of meshes with positive, negative, and unchanged population differences are 46.43%, 40.64%, and 12.93 %.

In terms of the urban function guidance areas, the regional hubs with insufficient population capacity are the Kengun, Nagamine, Suizenji-Kuhonji regional hub. It turns out that it is not enough to support the estimated population in 2030s, and coordination and arrangement of facilities and vacant lot should be planned positively. While the population capacity of other regional hubs is still left, with the largest remaining 20 percent of the population in the Ueki regional hub, as shown in *Table 5*.

Table 5. Schedule management about population of regional hubs

Regional hub	Average population by 2015 census	Predicted population by Cohort method in 2030s	Optimum population by Random Forest	Population difference
Central area	1653	1668	1741	73
Ueki area	619	614	759	145
Hokubu area	415	415	432	17
Kusunoki-Musashigaoka area	1511	1484	1528	44
Hakenomiya-Shimizukamei area	1237	1225	1253	28
Kamikumamoto area	1587	1561	1653	92
Kokai area	1944	1952	1991	39
Nagamine area	2352	2420	2368	-52
Suizenji-Kuhonji area	2361	2404	2394	-10
Kengun area	2154	2150	2134	-16
Heisei-Minamikumamoto area	2016	2075	2081	6
Shiroyama area	1000	999	1130	131
Karikusa area	1292	1320	1329	9
Kawajiri area	950	931	996	65
Tomiai area	312	334	359	25
Jonan area	555	542	601	59

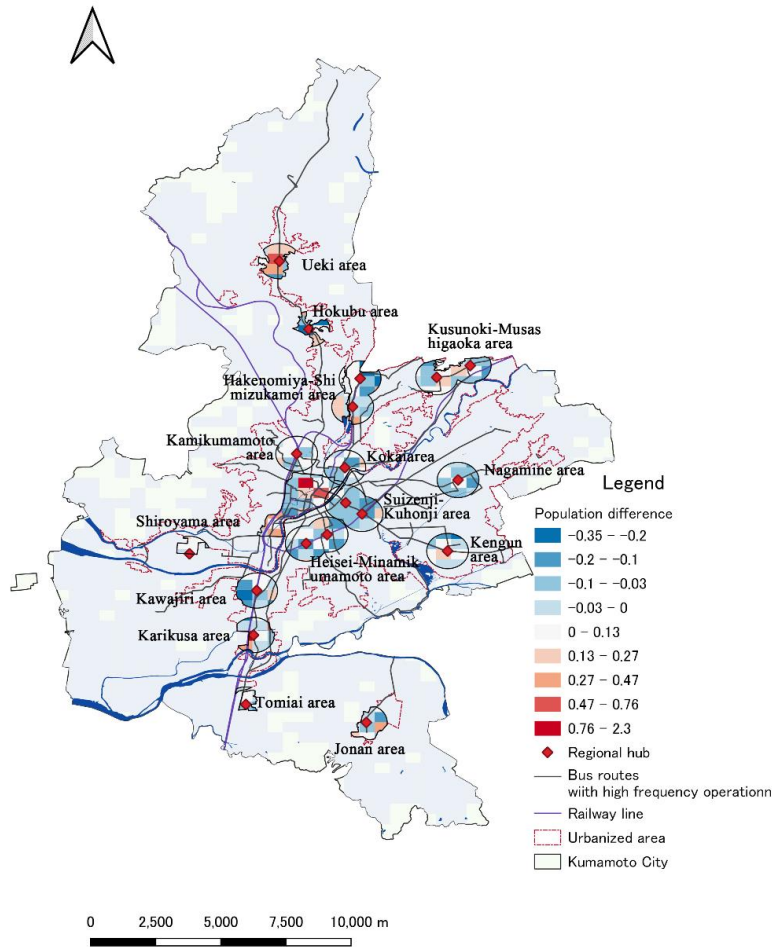


Figure 9. The population difference (predicted population by Cohort in 2030s compared to optimum population capacity)

Source: Based on data from <https://nlftp.mlit.go.jp/ksj/>

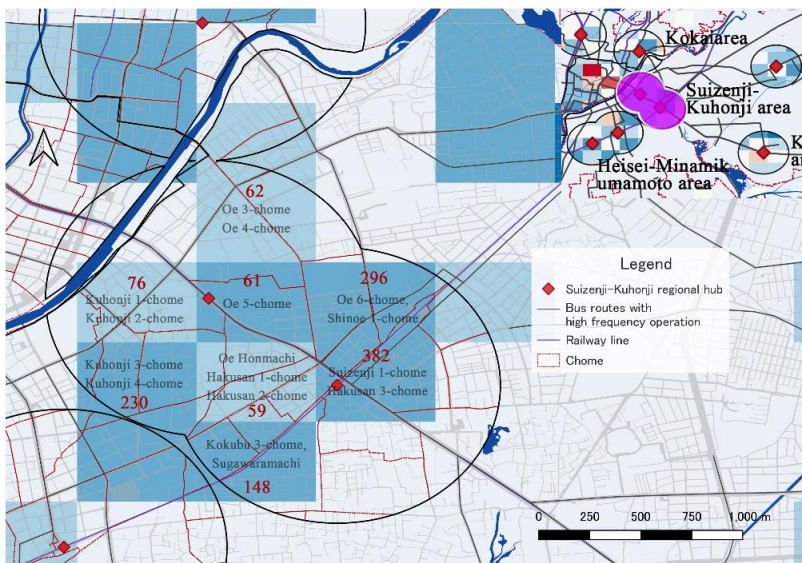


Figure 10. Insufficient population capacity of Suizenji-Kuhonji regional hub

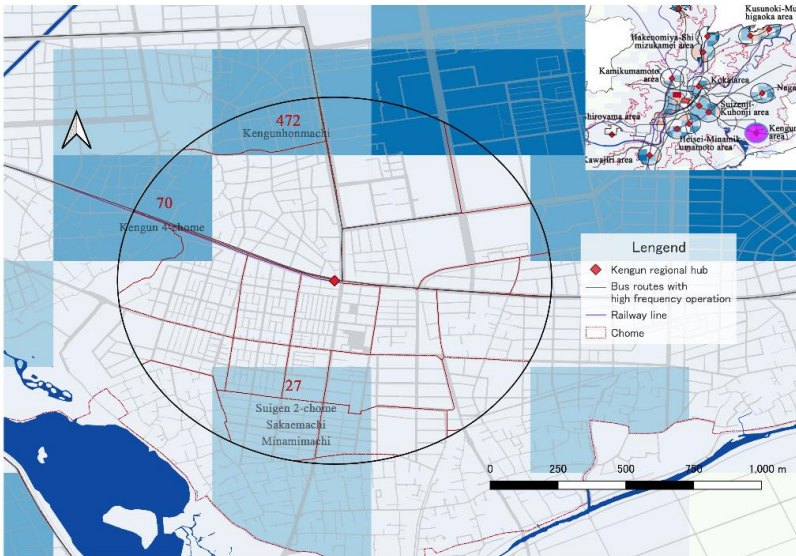


Figure 11. Insufficient population capacity of Kengun regional hub

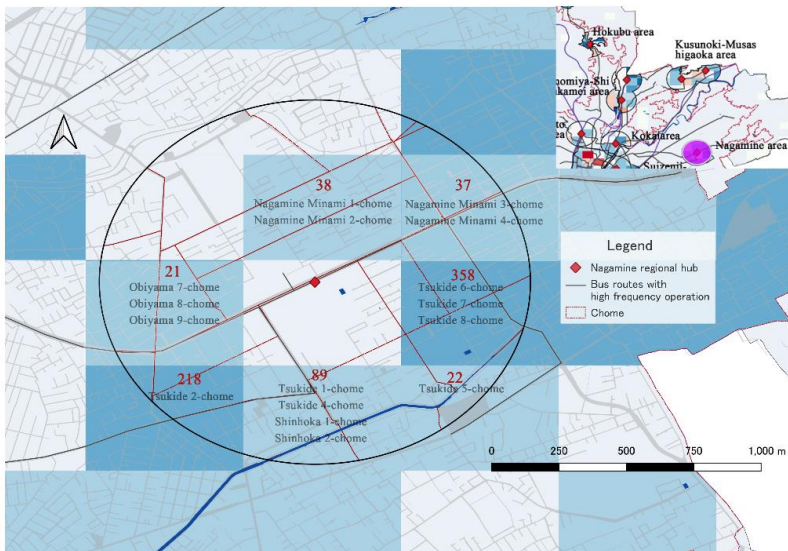


Figure 12. Insufficient population capacity of Nagamine regional hub

4. DISCUSSION AND CONCLUSION

In this study, we mainly focuses on the goal of maintaining population density in the residence attraction areas of “The Location Optimization Plan” proposed by Japan for compact city development, and then studies the optimum population capacity in the area. In Japan, most of studies related to residence attraction areas mainly focus on the rationality of policies, implementation effects, or the convenience of residence attraction areas and other directions, while quantitative studies are very lacking (Kurata and Okai, 2020). And population density, as the target value of residence attraction areas, is the key point to quantitatively promote compact sustainable development. But pure population projections based on natural growth rates are not what we expect. Population distribution is the result of the comprehensive effect of natural factors and social environmental factors, a deeper understanding of man-earth relationship, and the balance between

urban and people have important guiding significance for the sustainable development of the city ([Jiang, Yang et al., 2002](#)). Therefore, we actively explore the population capacity that can make the urban and population balanced.

Research on population prediction based on the urban environment, lots of scholars chose a machine learning method of Random Forests. Wang and Kan scholars through the use of Random Forests regression and multiple linear regression method to study the population distribution in Tibet, the results show that Random Forest regression method is more effective. ([Wang, C., Kan et al., 2019](#)). Of course, population prediction is a very complex issue, and the effect of each influencing factors on it also needs to be further studied, which is also needed to be deeply considered for my further study ([Wang, L., Feng et al., 2015](#)).

And the current research on environmental population capacity mainly aims to explore the total population and its distribution in a large area, and rarely goes into the medium and micro level of the city ([Yang, J. B., Chen et al., 2010](#)). Research results are often limited to population prediction, lacking guidance on the reality and practicality of the interaction between people and the urban environment. Therefore, the research area of my study is narrowed and accurate to the residence attraction areas as the medium and micro level area, so as to carry out more realistic research.

[Fang, Yin et al. \(2021\)](#) took the 11-1 area of Yihe Road in Nanjing city as an example to further explore the population capacity at the medium and micro level of the city. The space capacity, traffic capacity, facilities capacity and the capacity of four dimensions of social psychology were used to predict the population capacity, the result obey "buckets effect", which was determined by the minimum capacity of these four dimensions. This study provided a great reference for the diversity and comprehensive of the indicators selection for my further study ([Fang, Yin et al., 2021](#)). Meanwhile the area of each land use is used as important indicators in Europe and America ([Roni and Jia, 2020](#)), the enrichment of characteristic quantity to build a model with higher accuracy can be realized.

This study mainly discussed whether urban environment can support the population capacity in the future by comparing the population prediction result of Cohort method with the population capacity based on facilities by Random Forest regression. [Chen, J. and He \(2021\)](#) have put forward the necessity of effective control and reasonable distribution of building capacity, which is similar concept to the control and maintenance of population density in the "The Location Optimization Plan". Meanwhile, the population capacity based on residential buildings and the planned population capacity were compared to discuss whether the population capacity was optimum, which should also prove the correct directionality of this study. Compared with the comparison between the population based on building capacity and the population of planning capacity, the comparison between the population based on natural growth rate and the population based on facilities in this study highlights the impact of urban environment on population capacity.

Besides, highlight of this study is that it focuses on the positive and negative cases of population differences. According to the population difference based on the prediction results of urban facilities and natural growth rate, and determines whether city can provide high-quality life for these people in the future through the positive and negative population difference, which has made a breakthrough in practical significance in quantifying the balanced relationship between people and cities. While, it can effectively guide the allocation and tilt of urban resources. This study has identified that population

capacity of Suizenji-Kuhonji, Kengun, Nagamine regional hub is insufficient, but the specific need what facilities support did not study. Saito's research on comparison of increase or decrease in population and surrounding buildings for three years, beneficial to the regional population growth building function and characteristics were evaluated (Saito, 2021). Then Soltani confirms meaningful differences between cases with the same density but different spatial design characteristic (Soltani, Gu et al., 2020). On the basis of these studies, the future research may focus on increasing or decreasing in population and surrounding facilities, which assesses what kind of facilities for the lack of population capacity area need resource configuration and priority support, and what spatial design is more attractive when the building density is fixed.

From the whole residence attraction areas, future population development trends will not exceed the region's optimum population capacity. However, there are some problems in maintaining the population in the urban function guidance area, mainly reflected in the Suizenji-Kuhonji, Kengun and Nagamine regional hubs. The population of the surrounding radiation area of public transport tends to increase, and the interactive development of transportation and surrounding areas is particularly important.

AUTHOR CONTRIBUTIONS

Conceptualization, W.Y. and H.R.; framework, W.Y. and H.R.; methodology, W.Y.; resources, W.Y. and H.R.; data curation, W.Y.; writing—original draft preparation, W.Y.; writing—review and editing, W.Y. and H.R. All authors have read and agreed to the published version of the manuscript.

ETHICS DECLARATION

The authors declare that they have no conflicts of interest regarding the publication of the paper.

REFERENCES

- Alahmadi, M., Atkinson, P. M., et al. (2014). "A Comparison of Small-Area Population Estimation Techniques Using Built-Area and Height Data, Riyadh, Saudi Arabia". *IEEE Journal of Selected Topics in Applied Earth Observations Remote Sensing*, 9(5), 1959-1969. doi: <http://doi.org/10.1109/JSTARS.2014.2374175>.
- Audirac, I., Shermeyen, A. H., et al. (1990). "Ideal Urban Form and Visions of the Good Life Florida's Growth Management Dilemma". *Journal of the American Planning Association*, 56(4), 470-482. doi: <https://doi.org/10.1080/01944369008975450>.
- Bakillah, M., Liang, S., et al. (2014). "Fine-Resolution Population Mapping Using Openstreetmap Points-of-Interest". *International Journal of Geographical Information Science*, 28(9), 1940-1963. doi: <https://doi.org/10.1080/13658816.2014.909045>.
- Batty, M., Besussi, E., et al. (2003). "Traffic, Urban Growth and Suburban Sprawl". (1467-1298), *University College London Centre for Advanced Spatial Analysis Working Papers Series 70*. London: Centre for Advanced Spatial Analysis, University College London. on
- Bhatta, B., Saraswati, S., et al. (2010). "Urban Sprawl Measurement from Remote Sensing Data". *Applied geography*, 30(4), 731-740. doi: <https://doi.org/10.1016/j.apgeog.2010.02.002>.
- Chen, J. and He, X. F. (2021). "Analysis of Population Capacity Based on Land Use and Residential Buildings". *Urban Geotechnical Investigation & Surveying*, (1), 27-31.

- Chen, T.-H. K., Qiu, C., et al. (2020). "Mapping Horizontal and Vertical Urban Densification in Denmark with Landsat Time-Series from 1985 to 2018: A Semantic Segmentation Solution". *Remote Sensing of Environment*, 251, 112096. doi: <https://doi.org/10.1016/j.rse.2020.112096>.
- Chin, N. (2002). "Unearthing the Roots of Urban Sprawl: A Critical Analysis of Form, Function and Methodology. (Casa Working Papers 47)". (1467-1298), London: Centre for Advanced Spatial Analysis (UCL).
- Dong, N., Yang, X., et al. (2016). "Research Progress and Perspective on the Spatialization of Population Data". *Journal of Geo-Information Science*, 18(10), 1295-1304. doi: <http://doi.org/10.3724/SP.J.1047.2016.01295>.
- Dovey, K. and Pafka, E. (2014). "The Urban Density Assemblage: Modelling Multiple Measures". *Urban design international*, 19, 66-76. doi: <https://doi.org/10.1057/udi.2013.13>.
- Fang, Y., Yin, M., et al. (2021). "Research on the Renewal of Historical and Cultural District Based on Environmental Population Capacity with a Case of Block11-1, Yihe Road, Nanjing (in Chinese)". *Modern Urban Research*, 1-10.
- Gupta, R. (2010). *S. Chand's Elementary Geography*. S. Chand Publishing, Uttar Pradesh.
- Hosoya, J., Mori, S., et al. (2019). "Analysis of an Impact on Machizukuri by the Introduction of Location Optimization Plan :Focusing on the Actual Situations of Municipalities in Hokkaido (in Japanese)". Paper presented at the Architectural Institute of Japan Conference Academic Lecture Summary, Ishikawa. Architectural Institute of Japan.
- Hui, C. (2006). "Carrying Capacity, Population Equilibrium, and Environment's Maximal Load". *Ecological Modelling*, 192(1-2), 317-320. doi: <https://doi.org/10.1016/j.ecolmodel.2005.07.001>.
- Jiang, D., Yang, X.-h., et al. (2002). "Study on Spatial Distribution of Population Based on Remote Sensing and Gis (in Chinese)". *Advances in Earth Science*, 17(5), 734. doi: <http://doi.org/10.11867/j.issn.1001-8166.2002.05.0734>.
- Kurata, K. and Okai, Y. (2020). "A Study on the Designation Policy of the Residential Instruction Area-Focused on Maizuru City, Kyoto Prefecture (in Japanese)". *Architectural Institute of Japan Conference Academic Lecture Summary*. Tokyo: Architectural Institute of Japan.
- Ministry of Land, Infrastructure, Transport and Tourism. (2015). "The Transition to Compact Cities". Retrieved from <https://www.mlit.go.jp/common/001083358.pdf> on Oct. 01, 2021.
- Ministry of Land, Infrastructure, Transport and Tourism. (2016). "Land Use Issues under Population Reduction". Retrieved from <https://www.mlit.go.jp/common/001120157.pdf> on Oct. 01, 2021.
- Roni, R. and Jia, P. (2020). "An Optimal Population Modeling Approach Using Geographically Weighted Regression Based on High-Resolution Remote Sensing Data: A Case Study in Dhaka City, Bangladesh". *Remote sensing*, 12(7), 1184. doi: <https://doi.org/10.3390/rs12071184>.
- Saito, E. (2021). "Analysis on the Changes and Causes of Low Unutilized Land in Local City: A Case Study of Regional Hubs in 'the Location Optimization Plan'". (Master), Kumamoto University, Kumamoto City.
- Sayre, N. F. (2008). "The Genesis, History, and Limits of Carrying Capacity". *Annals of the Association of American Geographers*, 98(1), 120-134. doi: <https://doi.org/10.1080/00045600701734356>.
- Seidl, I. and Tisdell, C. A. (1999). "Carrying Capacity Reconsidered: From Malthus' Population Theory to Cultural Carrying Capacity". *Ecological economics*, 31(3), 395-408. doi: [https://doi.org/10.1016/S0921-8009\(99\)00063-4](https://doi.org/10.1016/S0921-8009(99)00063-4).
- Singer, S. F. (1972). "A Study of Optimum Population Levels—a Progress Report". *Proceedings of the National Academy of Sciences*, 3839-3848. doi: <https://doi.org/10.1073/pnas.69.12.3839>.
- Soltani, S., Gu, N., et al. (2020). "Spatial Configuration and Density How Building Density Affects Spatial Arrangement of a Neighbourhood". *International Review for Spatial Planning Sustainable Development*, 8(3), 87-100. doi: https://doi.org/10.14246/irspsda.8.3_87.
- Sugihara, R., Ikaruga, S., et al. (2018). "Study on the Specified Method of Residence Instruction Areas in Combined Statistical Area, Using Expert System (in Japanese)". Paper presented at the Architectural Institute of Japan Conference Academic Lecture Summary, Miyagi. Architectural Institute of Japan.
- Teller, J. (2021). "Regulating Urban Densification: What Factors Should Be Used?". *Buildings & Cities*, 2(1). doi: <http://doi.org/10.5334/bc.123>.

- Tong, Y. F. and Qi, M. Z. (2009). "Analysis on the Main Restrictive Factors, Existing Problems and Countermeasures About the Population Carrying Capacity in Beijing (in Chinese)". *Social Science of Beijing*, (6), 25-31.
- Tsuang, H.-C. and Peng, K.-H. (2018). "The Livability of Social Housing Communities in Taiwan: A Case Study of Taipei City". *International Review for Spatial Planning Sustainable Development*, 6(3), 4-21. doi: https://doi.org/10.14246/irpspd.6.3_4.
- Urban Planning Bureau. (2021). "The Main Efforts on the Location Optimization Plan of Each City".
- Urban Planning Bureau of Kumamoto City. (2016). "2nd Kumamoto City Master Plan". Retrieved from https://www.city.kumamoto.jp/common/UploadFileDsp.aspx?c_id=5&id=14791&sub_id=3&flid=114841 on Nov.12, 2021.
- Urban Planning Bureau of Kumamoto City. (2019). "The Location Optimization Plan of Kumamoto City". Retrieved from https://www.city.kumamoto.jp/common/UploadFileDsp.aspx?c_id=5&id=9398&sub_id=4&flid=80022 on Nov. 09, 2021.
- Wang, C., Kan, A. K., et al. (2019). "Population Distribution Pattern and Influencing Factors in Tibet Based on Random Forest Model". *Acta Geographica Sinica*, 74(4), 664-680.
- Wang, L., Feng, Z., et al. (2015). "The Change in Population Density from 2000 to 2010 and Its Influencing Factors in China at the County Scale". *Journal of Geographical Sciences*, 25, 485-496. doi: <https://doi.org/10.1007/s11442-015-1181-z>.
- Wei, C., Dai, X., et al. (2016). "Prediction Analysis Model of Integrated Carrying Capacity Using Set Pair Analysis". *Ocean coastal management*, 120, 39-48. doi: <https://doi.org/10.1016/j.ocecoaman.2015.11.011>.
- Yandri, P., Priyarsono, D. S., et al. (2021). "Formulating and Validating Sustainable Residential Area Indicators in Suburban Metropolitan Jakarta". *International Review for Spatial Planning Sustainable Development*, 9(3), 82-102. doi: https://doi.org/10.14246/irpspd.9.3_82.
- Yang, J. B., Chen, Q. H., et al. (2010). "Environment Capacity of Population and Its Spatial Guidance on County Level, a Case Study of Cangnan County in Wenzhou City (in Chinese)". *Urban Planning*, 34(5), 82-87. doi: <http://doi.org/10.22146/IJG.2382>.
- Yang, X., Ye, T., et al. (2019). "Population Mapping with Multisensor Remote Sensing Images and Point-of-Interest Data". *Remote Sensing*, 11(5), 574. doi: <https://doi.org/10.3390/rs11050574>.
- Yoshida, Y., Ikaruga, S., et al. (2018). "Evaluation of Location Optimization Plan by Portland Compact City Model ". Paper presented at the Architectural Institute of Japan Conference Academic Lecture Summary, Ishikawa. Architectural Institute of Japan.