SPATIAL ANALYSIS TECHNIQUES BASED ON DATA FIELD AND ITS APPLICATION IN LAND GRADATION

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ABSTRACT:

Spatial analysis has being a hot issue in spatial information science. However, its lack of unified principles and systematic technology make its development lag behind applications' needs. This paper introduces field concept to spatial analysis, proposes the theoretical framework of spatial analysis based on data field, constructs land gradation data field, discusses spatial analysis techniques based on land gradation data field (including classification of data fields' sources, recognition of radiation pattern, determination of field strength, and attenuation model), and builds land gradation model. Research on urban commercial land gradation method based on land gradation data field is performed with case study in Wuhan, China. The gradation result is assessed to be reliable and authentic.

INTRODUCTION

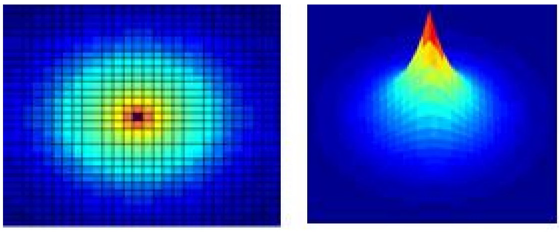
Spatial analysis, as the main analytical tool of geosciences, has received intensive discussions for many years. With the rapid development of spatial information technology, recent researches are focused on the recognition of spatial movement rules of natural and economical phenomena from spatial information, and ultimately its application in simulation, scientific predication and control. Principles and techniques of spatial analysis have been researched by geographers and cartographers from their own perspective, and three types of spatial analysis are formed[3]: spatial-graphical analysis (including spatial distribution, location, spatial morphology, spatial distance, spatial direction, topological and correlation relationship, etc) , spatial data analysis (which focuses on measures of attributes, including nominal, ordinal, interval and ratio attributes), and spatial model (which focuses on the analysis of spatial process and mechanism, including regional, linear and vocal processes). Goodchild[1,2] has discussed principles and techniques of spatial analysis from various aspects including spatial statistics, spatial mutual interactions, spatial reliance and spatial decision-making. Other relevant papers [3,4,5] have proposed principles and techniques of spatial analysis under GIS environment.

In general, current principles of spatial analysis are based on subjects like statistics, graph theory, topology, and computing geometry. Spatial objects and phenomena are analyzed mainly based on their locations and relationships, and quantitative descriptions focused on features are generated, which may answer questions like "what?", "Where?", "How much/many?", "How?", but not "Why?"[6,7].

Spatial analyses are performed on spatial phenomena and processes, and mathematical or geometrical methods are not sufficient to provide a deep understanding of these phenomena and processes. Therefore research objects' spatial movement rules should be recognized systematically and firstly. This paper discusses principles and techniques of spatial analysis from the perspective of spatial data field. The principles and techniques proposed are implemented with applications in land gradation.

FEATURES AND MEASURES OF DATA FIELD

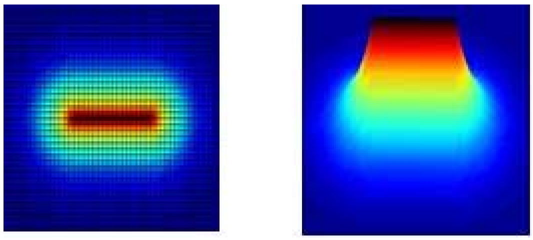
With the development of interdisciplinary researches between natural and socio-eco science, field concept and method have been widely applied in research area other than physics, e.g. sociology, economy and geography, i.e. concepts like social, economical and geographical field are proposed and extended. By introducing field concept to number fields, each data object may be deemed as a granule with certain weight in a n-dimensional space. Fields surrounding these granules exert forces on other granules without direct contact, and the total effects of these fields which extend throughout the space form a spatial data field (SDF). Similar to physical field, SDF also has the basic field features: 1) Activity; 2) Independence and distance decay; 3) Overlapping; 4) Homogeneity. Concepts like strength, potential and regions are also borrowed from physics to describe and measure the spatial data field: 1) Field strength and strength function. Spatial data objects form a virtual spatial data field by emitting data energy, and field strength is a quantitative expression of the intensity of this data energy at a particular position in the field. Strength functions provide mathematical descriptions of the distribution of data energy in the number field. 2) Field potential and potential function. Field potential is defined as the total amount of energy exerted on a particular position in the number field, i.e. field potential at a given position is the sum of the field strength calculated for this position. The sum here refers to the result of spatial overlapping. 3) Field region. Spatial data field has the property of distance-decay, i.e. field strength declines as the distance between field's source and object increases. The distance at which field strength becomes negligible may be deemed as the maximum range of data energy radiation. With the consideration of the homogeneity of data energy radiation, this range may also be defined as spatial data field's maximum radius of influence. Area within the radius is called as data object's field region 4) Interaction and overlapping. Spatial data fields interact with each other when they meet. i.e. exert forces on the same position, and the result of this interaction is the overlapping of spatial data field.



(a) Data field of point source

(b) Distance-decay of point source

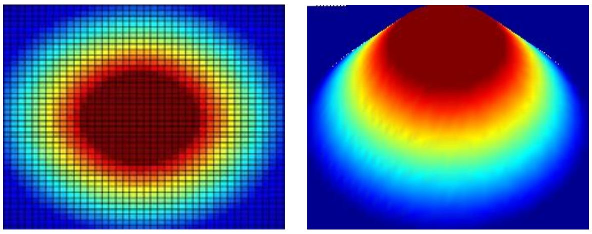
Figure 1. Data field of point source



(a) Data field of linear source

(b) Distance-decay of linear source

Figure 2. Data field of linear source



(a) Data field of planar source

(b) Distance decay of planar source

Figure 3. Data field of planar source

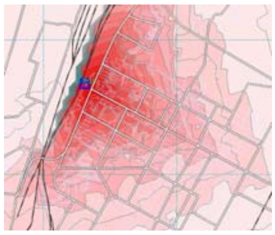


Figure 4. Example of heterogeneous data field

SPATIAL ANALYSIS TECHNIQUES BASED ON DATA FIELD

When analyzing spatial objects and their relationship in the spatial data field, different types of fields may be classified according to the geometrical types of sources, i.e. point, line and area.

3.1 Spatial analysis based on homogeneous data field

3.1.1 Field of point sources

Point object emits data energy in much the same way as a point charge in the electromagnetic field. Data field of point object is illustrated in Fig 1 with the consideration of homogeneity and distance-decay: field lines are concentric circles with point object as their center; they are spaced more closely near the object and vice versa

3.1.2 Field of linear sources

Data field around linear objects is similar to the gradient field along electrical wires, i.e. field strength declines as the distance from wires/linear objects increases. The data field around linear objects and its attenuation model are demonstrated in Fig 2. The endpoints of lines are usually crucial points, e.g. intersections of roads. Hence the field of linear objects may be distorted at these endpoints due to the overlapping of different fields and become spindle-shaped.

3.1.3 Field of planar sources

Homogeneous planar objects have similar radiation pattern and features of data energy with point objects, which lead to a similar data field as shown in Fig 3.

3.2 Spatial analysis based on heterogeneous data field

Spatial data field may confront with obstacles during the emission of data energy, and become heterogeneous, i.e. its spatial pattern and attenuation model need to be modified on the basis of data field shown in Fig1, 2 and 3. Example of heterogeneous data field is illustrated in Fig 4, in which railway station serves as point source of data field and railway serves as obstacle.

3.3 Features of spatial data field

Graphical representations (Fig 5) including equipotential line, gradient line, field region, equilibrium point, equilibrium line, competition line and effective range are adopted to describe the pattern of spatial data field.

3.4 Overlapping of spatial data field

Overlapping of data energy happens when spatial data fields meet, and the main types of overlapping are competition and aggregation. Competitive overlapping is based on maximum potential energy principle, whereas aggregate overlapping follows certain functions.

DATA FIELD FOR LAND GRADATION AND ITS APPLICATION

4.1 Data field for land gradation

Gradation of land quality is synthesis of social, economical, and natural factors, which also constitute spatial data field for land gradation. With spatial analysis techniques based on data field, land quality's regional difference and distribution pattern may be revealed, and applied in land gradation

4.2 Quantitative analysis of land gradation factor

Land gradation factors may be classified as point, linear and planar factors according to their order. From spatial data field's point of view, land gradation deals mainly with the radiation pattern of data energy, field region, field strength, attenuation and interaction of point, linear and planar data field.

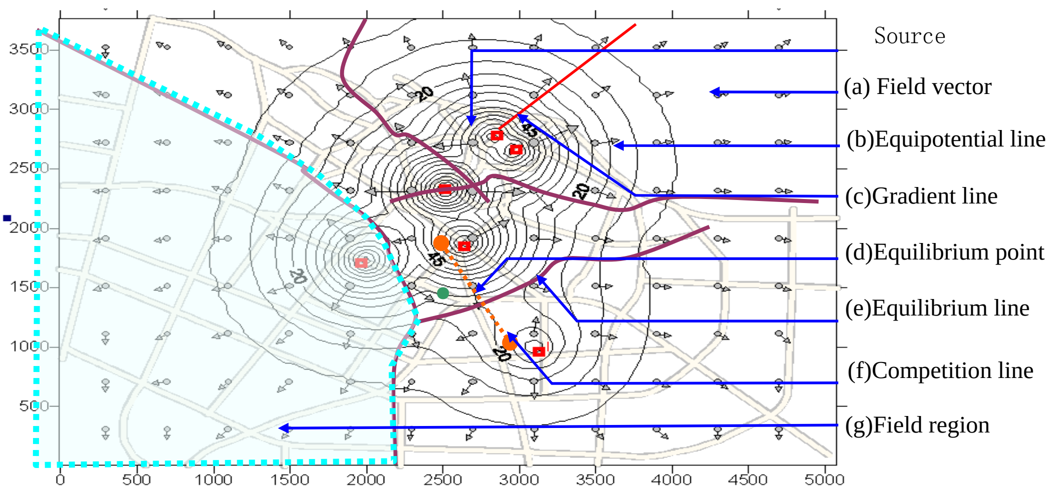


Figure 5. Graphical representation of data field

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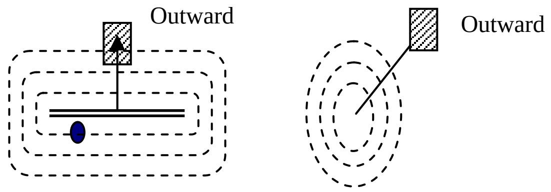
4.2.1 Quantitative analysis of point impact factor

Point factors are those may be deemed as points in the context of the whole region. Their influence on land gradation correlates with the scale of facilities related to the factor, e.g. local business centers, parks, harbors, bus stops, etc, and the distance from these facilities.

(1) Radiation pattern of data energy

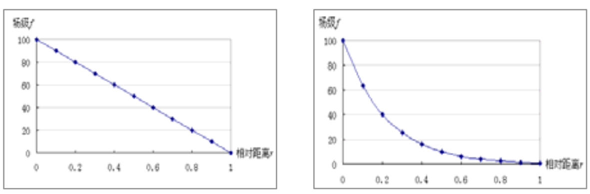
Data energy radiation pattern of point factor is usually spatial distance-dependent field:

Spatial data object exert influence on land use through land gradation data field. Since potential energy is closely related to 'distance' i.e. field's strength at a given position declines as its distance from the object increase, its distribution is usually homogeneous (Fig 6(b)).



(a) Linear field source (b) Point field source

Figure 6. Spatial distance-dependent field



(a) Linear decay (b) Exponential decay

Figure 7. Distance decay of field strength

(2) Strength function and attenuation model

i) Strength function

Strength function of data field for land gradation has two types: linear and exponential attenuation function, which are explained as followed:

$$f_i = F_i(1 - r_i) \quad \text{(Linear attenuation function)}$$

$$f_i = F_i^{(1 - r_i)} \quad \text{(Exponential attenuation function)}$$

and

$$r = \begin{cases} d/D \ (d \le D) \\ 1 \ (d > D) \end{cases}$$

Where

d_i represents the distance between field source i and assessment unit;

F_i represents the effect of field source i, i.e. the data energy of land gradation data field's source;

D represents the radius of influence, i.e. field region.

Fig 7 illustrates the attenuation models of both linear and exponential attenuation functions.

ii) Attenuation model

d_i in strength function may be computed in various ways according to different types of data energy emitted by impact factors in land gradation. Euclidean distance between evaluation unit and field source is usually adopted for distance-dependent field. Distance computation with consideration of obstacles is elaborated in [11].

(3) Field region

Field region in data field for land gradation is comparable to the impact factors' influence range in traditional land evaluation. The potential at a particular position decays as its distance from point-source of data field increases, and thus the equipotential lines form concentric circles with point-source as their centers. The furthest euqipotential line from point-source of data field, i.e. equipotential line represents zero potential, indicates the field boundary.

4.2.2 Quantitative analysis of linear factor

Linear factors are mainly linear-distributed facilities, e.g. roads, and bus lines. Their influence on land gradation is similar to those of point factors, i.e. depends on both the scale of and distance from facilities.

(1) Radiation pattern of data energy

Data field of linear impact factor and its radiation pattern is usually treated as spatial distance-dependent field in implementations due to the simplification of calculation.

(2) Strength function and attenuation model

Linear field-source's strength function is selected from linear function or exponential function according to actual condition in practice. Its strength function also has the property of distance-decay as demonstrated in Fig 7(b).

(3)Field region

There is an inverse relationship between the potential energy at a particular position in the data field of linear impact factor and its distance from the linear factor; Equipotential lines (isopotentials) are spindle-shaped and with linear factor their center lines; Again, the furthest euqipotential line from the linear object, i.e. equipotential line represents zero potential, indicates the field boundary.

4.2.3 Quantitative analysis of planar impact factor

Planar impact factors are usually homogeneous and cover a certain area, e.g. air pollution, noise. Their impact on land gradation merely depends on their values.

(1) Radiation pattern of data energy

Planar field-source exerts influence on evaluation unit with its coverage, therefore planar field-source may be treated as homogeneous in land gradation and its emission of data energy outside its coverage may be negligible.

(2) Strength function and attenuation model

Under the condition that planar field-source emits no energy outside its coverage, its strength function equals to its own data energy and is homogeneous within the field i.e. there is no energy decay.

(3)Field region

Since data field of planar impact factor emit no energy outside its coverage, data field's region coincides with planar impact factor.

4.3 Land gradation model based on overlay of data field for land gradation

Differences in land grade stem from the overlapping of data energy radiation of all impact factors, and are represented as the differences in potentials in the land gradation data field. Functional relationship between potential and grade mentioned above exists, and can be identified by sample statistics (similar to the identification of functional relationship between land grade and integrated effective degree in traditional land gradation). Therefore land gradation model based on data field may be built as followed:

$$G(c) = g\left(P(c)\right) = g\left(\bigcup_{i=1}^{n} \lambda_i f_i(x, y)\right)$$

Where

$G(c)$ is the land grade of evaluation unit c;

$P(c)$ is the potential at c in land gradation data field;

λ_i is weight of impact factor i;

$f_i(x, y)$ is strength function of impact factor i.

According to the different features of data field, the overlapping of land gradation field may be classified into: 1) overlapping of homogeneous data fields i.e. overlapping of data fields of the same type; 2) overlapping of heterogeneous data fields i.e. overlapping of data fields of different types.

4.3.1 Overlapping of homogeneous data fields

Competitive overlapping refers to the process that potential in the land gradation field at a particular position will be set to be the maximum value in potentials at the same position in different impact factors' data field during the overlapping and merging of these multiple impact factors' data field due to the exclusiveness and homogeneity of potential propagation. Competitive overlapping is showed in Fig 8 (a)-(b) where

$f = \max(f_i)$ in the overlapping area.

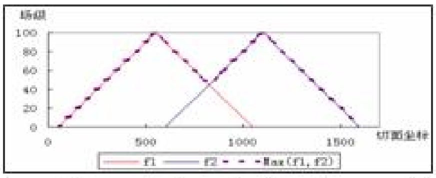
Aggregate overlapping means that the effect of multi-impact factors is reflected by potential aggregation since these factors exert influence on evaluation units independently. Aggregate overlapping is showed in Fig 8 (c)-(d) where $f = \sum(f_i)$ in the overlapping area.

4.3.2 Overlapping of heterogeneous data fields

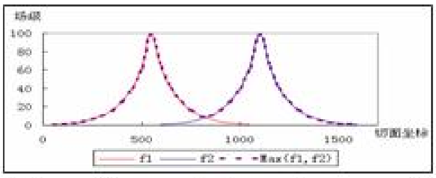
Considering relationship between data fields of different impact factor and their influence outside the evaluation units, overlapping of heterogeneous data fields is usually aggregate and shown as followed.

$$G(c) = \sum\left(P(c)\right) = \sum_{i=1}^{n} \lambda_i f_i(x, y)$$

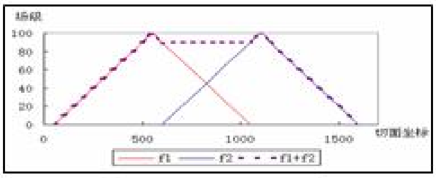
Where $G(c)$, λ_i, $f_i(x, y)$ and $P(c)$ have the same meaning as mentioned above



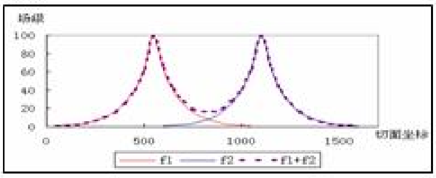
(a) Competitive overlapping under linear decay model



(b)Competitive overlapping under exponential decay model



(c) Aggregate overlapping under linear decay model



(d) Aggregate overlapping under exponential decay model

Figure 8. Overlapping of homogeneous data field

CASE STUDY

5.1 Study area

Commercial land use in Wuhan central districts is researched in the experiment on land gradation based on data field. Wuhan is situated in the middle of Hubei Province of China, East Longitude 113° 41′ -115° 05′ , North Latitude 29° 58′ -31 ° 22′ . It lies in the east of Jianghan Plain, and the confluence of the middle reaches of the Yangtze River and Han River. Wuhan is comprised of seven urban districts, six suburban districts and two development districts, and occupies a land of 854908.83 hectare.

5.2 Selection and quantification of gradation factor

The selection and construction of factor system for commercial land gradation in study area is through Delphi method and under the guidance of principles including dominance, difference, suitability, prediction, benefit, etc. The strength function of data field formed by each factor is chosen from linear and exponential functions according to conditions in practice. The overlapping rules and definition of field regions are shown in Table 1.

Factor type	Name	Strength function	Radiation pattern	Overlapping of homogeneous data fields	Field region
Point factor	Business service center	Exponential	Inside: homogeneous; Outside: distance-decay	Among centers of the same level: competitive(Max); Among centers of different levels: aggregation	$d=\sqrt{\frac{S}{n\pi}}$
	Harbor		Distance-decay from its geometrical center	Competitive overlapping	
	Long-haul bus station				
	Railway station				
	Bus convenience level	Linear			
	Park				
Linear factor	Road planning	Exponential	Distance-decay from linear objects within serving area	Competitive overlapping	$d=\frac{S}{2L}$
	Road accessibility				
	Water supply				
Planar factor	Noise pollution	Constants	Homogeneous within planar factors	Competitive overlapping	Planar factors' coverage
	Drainage condition				
	Land use planning				
	Green space coverage				
	Population density				
	Geological condition				
	Terrestrial condition				
	Air pollution				

Table 1 Factor system for commercial land gradation.

d represents radius of impact factor's data field, S represents land gradation area, and L is length of linear impact factor.

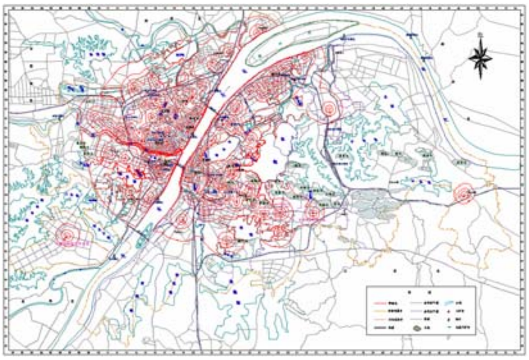


Figure 9. Equipotential line in data field of point impact factor

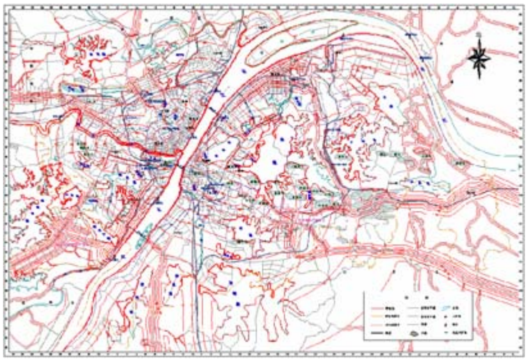


Figure 10. Equipotential line in data field of linear impact factor

Data fields of point impact factor (with business service center as example) and linear impact factor (with road accessibility as example) are depicted in Fig 9 and Fig 10 respectively.

5.3 Gradation result and analysis

5.3.1 Gradation result

Land gradation model mentioned above is applied to process the overlapping of data fields of all impact factors. Frequency histogram of potentials in land gradation data field is generated and Nature Break method is used to classify different land grades. The result of gradation is displayed in Fig 11.

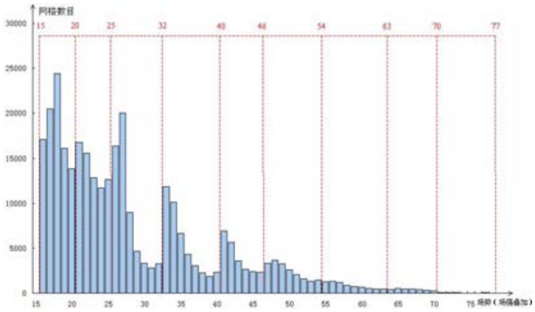


Figure 11. Frequency histogram of potentials in land gradation data field and classification

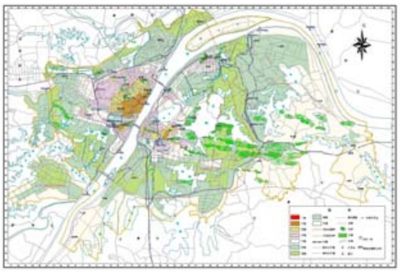


Figure 12. Commercial land gradation in study area

The gradation result is assessed by data on retail space's renting which is sensible to commercial land uses' location: sampled land values are used to evaluate the reasonability of corresponding land grade. The assessment result serves as guidelines in modification of land gradation, and Fig 12 demonstrates the final result of land gradation.

5.3.2 Interpretation and analysis

The distribution of commercial land grades in Wuhan coincides quite well with the distribution of business service centers in Wuhan: land grades decay from high level business service centers in central districts i.e. Hankou, Hanyang, and Wuchang, and form ring structures. The land grade range in Wuhan is from Ⅰ to Ⅸ. The highest land grade lies in Hankou district which is the mostly-developed area in central China, and the lowest land grade distributes in suburban districts on city boundary.

The resultant land gradation is further assessed by the 'Wuhan Urban Commercial Land Gradation" which is generated by traditional method and applied in practice. The result of comparison is listed in Table 2.

The interpretation of Table 2 is as followed:

1. For land grade Ⅰ to Ⅳ, experiment results are very closed to practical values, i.e. absolute differences are smaller than 1 km^2 and relative ratios of difference are less than 5%;

2. For land grade Ⅴ to Ⅸ, relative ratios of difference are still less than 5%, although absolute differences between experiment result and practical values range from two to seven square kilometers.

The overall result comparison indicates a high level of similarity between practical values and result generated in this research, which proves land gradation based on data field to be reliable and authentic.

CONCLUSION

With the consideration of spatial data features, this paper discusses spatial analysis techniques based on data field with applications in urban land gradation. Land gradation data field is analyzed and urban land gradation method based on this data field is proposed. The main content of this research contains:

1. Constructing the framework of spatial analysis based on data field. The introduction of field concept into spatial analysis brings new principles and research perspectives.

2. Specializing spatial analysis principles and techniques based on data field for urban land gradation. Systematic analysis on land gradation data field and its application in urban land gradation are performed, which includes the quantification (strength function, attenuation model, radiation pattern, region determination, etc) of point, linear and planar impact factor, the sample statistics based on data field, and land gradation model based on overlapping of data field.

3. Proposing urban land gradation method based on land gradation data field. Urban commercial land gradation is generated and assessed with Wuhan a case study. The comparison between experiment result and land grades in practice indicates authenticity and reliance of this method. Experiments also show that this method may not only generate satisfactory land gradation, but also may display the impact mechanism of different impact factors and explain the formation of different land grades.

Land grade	Practical value (m^2)	Experiment result(m^2)	Difference(m^2)	Ratio of difference (%)
Ⅰ	476966	478253	1287	+2.7
Ⅱ	6715721	6700421	-15300	-2.3
Ⅲ	16536391	16509398	-26993	-1.6
Ⅳ	43353357	43418351	65000	+1.5
Ⅴ	54382958	57216310	2833352	+5.2
Ⅵ	98422390	96040568	-2381822	-2.4
Ⅶ	140664378	135755191	-4909187	-3.5
Ⅷ	160108387	157226436	-2881951	-1.8
Ⅸ	229839963	237155577	7315614	+3.2
Total	750500505	750500505	0	0

Table 2

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