OPTIMIZATION OF RURAL RESIDENTIAL AREA LOCATION BASED ON SCLP MODEL WITH A MAXIMUM FARMING RADIUS CONSTRAINT

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基于耕作距离约束下最小设施模型的村庄聚落区位优化

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***Abstract:** With an example of Xinfu District in Xinzhou, Shanxi Province, this article studies the change law of the farming radius and the farming inner radius in this area based on the data of the rural residential area, traffic network, cultivation block, and so on, and applies the set covering location problem (SCLP model) under the maximum farming radius to filter the minimum and best village location system as the planning target from the existing rural residential area location systems in Xifu District. The optimized results can be the foundation of the efficiency of land use and the construction of rural basic public service.*

***摘要:** 本文以山西省忻州市忻府区为例，采用村庄聚落、交通路网、耕作地块等数据，研究研究区境内村庄聚落耕作距离及农村居民点内部半径的特点，应用最大耕作距离约束下的最少设施模型，在将耕作距离控制在最大耕作距离的前提下，从研究区现有村庄聚落体系中筛选出数量最少、分布最优的村落体系作为村庄聚落区位优化目标，研究结果可为村镇规划、城乡统筹发展提供决策依据。*

***Keywords:** SCLP; rural residential area; farming radius; location-allocation*

***关键词:** 最少设施模型；村庄聚落；耕作距离；区位优化*

INTRODUCTION

The least facility problem is the Set Covering Location Problem (SCLP) [1, 2], attributing to set covering problem [1-3] of location-allocation basic problems, which was put forward by Berge [4]. Fulkerson, Ryser [5] and Edmonds [6], who gave the equation, and Church, Toregas [2, 7, 8] who discussed in detail the SCLP model and its applicability. SCLP is used widely in areas such as land and resources administration, urban and rural planning, national defense and military, public service facility layout, etc.

引言

最少设施问题是地理位置配置的集合覆盖模型 [1, 2]，属于区位优化基本问题中的集合覆盖问题 [1-3] 范畴。最初是由 Berge 详细提出 [4]，并 Fulkerson 和 Ryser [5]、Edmonds [6] 等人提出算式，Church，Toregas 等人 [2, 7, 8] 详细讨论最少设施模型及其适用性。最少设施问题在国土资源管理、城乡规划、军事国防、公共服务设施配置等诸多领域有着广泛用途。

MATERIALS AND METHOD

Theory of location distribution

Location distribution on a plane

Choose p ($1\leq p\leq K$) as the number of the facility. Each demand-point is supplied by one of the facility. This problem is a NP problem, which is expressed by mathematical model: the objective function of the two variables (the only variables are the two coordinates of the new facility) is:

材料与方法

区位布局理论

平面上的布局问题

它是在平面上选择 p 个设施（1≤ p ≤ K ），每个需求点由这些设施中的一个来满足，该问题是个 NP 难的问题，数学模型表示为：两个变量的目标函数是：

$$\mathrm{Min}Z=\sum_{i\in 1}d_i w_i=\sum_{i\in 1}w_i\sqrt{\left(a_i-x\right)^2+\left(b_i-y\right)^2} \tag{1}$$

where customers are located at (a_i, b_i), the facility is to be sited at (x, y), w_i is the known demand (or weight) of customer i; and I is the set of customers.The first-order conditions are first written in the form

其中消费者位于(a_i, b_i)，服务设施位于（ x, y ），w_i 是消费者 i 的已知需求（权重）；I 是消费者集合。一阶条件可先写为：

$$x=\frac{\sum_{i\in I}\dfrac{w_i a_i}{\sqrt{\left(a_i-x\right)w_i^2+\left(b_i-y\right)^2}}}{\sum_{i\in I}\dfrac{w_i}{\sqrt{\left(a_i-x\right)w_i^2+\left(b_i-y\right)^2}}} \tag{2}$$

In contrast, when the objective of the minimum weighted squared distances is differentiated with respect to the x and y coordinates of the facility,the resulting equations are separable and a simple closed-form solution exists, in which:

反之，当最小加权距离平方的目标有别于相对于该设施的 x 和 y 坐标时，所得到的方程是可分离的，存在简单的闭式解，其中：

$$\bar{x} = \frac{\sum_i w_i a_i}{\sum_i w_i} \text{ 和 } \bar{y} = \frac{\sum_i w_i a_i}{\sum_i w_i} \tag{3}$$

Where J is a set of facility locations, where the point(x_j, y_j) is the location of the facility for all $j Î J$. Defining u_{ij} as the proportion of customer i's demand that is served by the jth facility, the multifacility location problem can then be written as

其中 J 是服务设施区位集，点(x_j, y_j) 是第 j 个服务设施且所有的 $j Î J$ 。定义 u_{ij} 作为第 j 个服务设施服务消费者 i 的需求属性，这种多服务设施区位问题能被表示为：

$$\text{Min } z = \sum_{i\in I}\sum_{i\in I} w_i d_{ij} u_{ij}$$

$$\text{s.t. } \sum_{j\in J} u_{ij} = 1 \quad \forall i \in I \ , \quad u_{ij} \in \left|\forall i \in I, j \in J \ , \ x_i, y_j\right| \forall j \in J \tag{4}$$

Where the variables x_j and y_j, $j Î J$ appear only implicitly in the formulation in the guise of the distances d_{ij}.

上式中变量x_j 和 y_j , $j Î J$ 指代公式中的距离d_{ij} 。

Location distribution on network

ReVelle and Swain were the first to formulate the p-median as a zero-one programming problem. A variant of their original formulation is [9].

网络中的区位分布

ReVelle和Swain 首先提出将P-中位问题作为0-1规划问题，其原始公式如下：

$$\text{Min } z = \sum_{i\in I}\sum_{i\in I} w_i d_{ij} u_{ij}$$

s.t.

$$\sum_{j\in J} x_{ij} = 1 \quad \forall i \in I \ , \ x_{ij} \le y_{ij} \quad \forall i \in I \ , \ j \in J \ ,$$

$$\sum_{j\in J} y_j = p \ ,$$

$$x_{ij} = 0 \vee 1 \quad \forall i \in I \ , \ j \in J \ , \ y_i = 0 \vee 1 \quad \forall j \in J \tag{5}$$

where the locational variables y_i are one, if a facility is located at node j and zero otherwise. The allocation variables x_{ij} denote the proportion of the demand of the customer at node I that is assigned to a facility at node j. Finally, p denotes the number of facilities that are to be located; the remaining parameters are as defined above.

其中如果设施位于结点 j 处区位变量y_j为1，否则为0。优化变量x_{ij} 表示结点 I 处的消费者分配给结点 j 处的服务设施。p表示优化后的服务设施数量；其余变量同上。

Optimized model of rural residential location under the maximum farming radius

To formalize, denote again I as the set of demand nodes and let J symbolize all candidate sites at which facilities may be located. The model that allows locations only at the vertices of a network is referred to as the vertex-center problem and it can be formulated as follows:

最大耕作距离约束下的村庄聚落区位优化模型

模型定义 I 为需求结点集合， J 表示服务设施可能选址的位置。这种只允许选址位于网络结点上的模型是结点中心问题，其公式可表示如下：

$$\text{Min } z$$

$$\text{s.t. } \sum_{j\in J} y_{ij} = 1 \ \forall i \in I,$$

$$y_{ij} - x_j \le 0 \quad \forall i \in I \ , \forall j \in J \ , \ \sum_{j\in J} y_{ij} = p \ , \ z - \sum_{j\in J} d_{ij} y_{ij} \ge 0 \quad \forall j \in J \ ,$$

$$x_j \in \{0,1\} \quad \forall j \in J \ , \ y_{ij} \in \{0,1\} \quad \forall i \in I \ , \forall j \in J \tag{6}$$

From the above definition, we infer the SCLP under the maximum service radius [9-11]. That is, on the premise of the given traffic network and that the all studied farming cultivation blocks are within the maximum farming radius, to solve the minimum rural residential location and its distribution. The equation is as follow:

有上述定义，我们可以推导出最大服务半径约束内的最少设施[9-11]，即在给定道路交通网络和保证研究区全部耕作地块均在村庄聚落最大耕作半径之内的前提下，求解能覆盖整个耕作地块的最少的村庄聚落数量及其区位结构，其公式如

$$\text{p} = \min \mathop{å}_{jÎ J} x_j \tag{7}$$

Constraints:

$\sum_{j\in N_i} x_j \ge 1 \quad i \in I$ (there is at least one rural residential point in the maximum farming radius) ;

$x_j = (0,1) \quad j \in J$ (when the rural residential is located on *j* , it is 1. If not, it is 0) ;

N_i is the farming block; *i* is the maximum farming radius; the total number of the rural residential points within d_{max} is:

约束条件为：

$\sum_{j\in N_i} x_j \ge 1 \quad i \in I$ (此处至少有一个耕作半径) ;

$x_j = (0,1) \quad j \in J$ (当自然居住是j, 它是1. 如果不是, 则0) ;

N_i 是耕作地块, *i* 是最大耕作半径; d_{max} 内的村庄聚落总数为：

$$N_i = (j \in J \mid d_{ji} \le d_{max}) \quad i \in I$$

Among them: *p* is the number of the chosen rural residential points: *i* is the encode of the farming blocks ($i \in I$, *i* = 1,2 , … , m) ; *j* is the encode of the candidate rural residential points ($j \in J$, *j* = 1,2 , … , n) ; d_{ji} is the shorted route distance from the rural residential point *j* to the farthest point of the farming block *i* ; d_{max} is the maximum of the farming radius.

其中：*p* 是要选取的村庄数目；*i* 是耕作地块编码（ $i \in I$ ，i = 1,2，…，m）；*j* 是候选村庄编码（ $j \in J$ ，*i* , *j* = 1,2，…，n)；d_{ji} 为从第 *j* 个村庄到第 *i* 块耕作地块最远处的最短路径距离；d_{max} 是最大耕作半径。

RESULTS

Data and analysis

Analysis on the maximum of the farming radius

The farming radius is the spatial distance from the rural residential point to the farming block. There is rural residential radius in the rural residential point, which is the radius of a circle which center is the center of gravity of the rural residential point and which area is equal to the area of the rural residential point. In this article, the farming radius in SCLP model is the sum of the distance from the edge of the rural residential point to the farming block and the inner radius of the rural residential point.

Using Path Distance Model, the study first calculates the Path distance from the farming block in the study area to the nearest rural residential point (fig 1), and then figures out the rural residential radius in the study area (fig 2) according to the areas of each rural residential point. The result is that the maximum farming radius from the edge of the rural residential point to the farming block is 2647m, and the maximum rural residential radius is 650.88m. with the sampling, the maximum farming radius is finally determined to 3500m.

结果

数据与分析

最大耕作距离分析

耕作距离是指从村庄聚落到耕作区的空间距离。村庄聚落内部还存在村庄聚落半径，它是指以村庄聚落重心为中心划圆，当圆面积等于村庄聚落建设用地规模时的半径。本文最小设施模型中的耕作距离是指包括村庄聚落边缘至耕作地块的距离与村庄聚落内部半径之和。

研究首先使用 Path Distance Modler 计算研究区各田块与最近村庄聚落的路径距离（如图 1 所示），之后通过村庄聚落面积计算出研究区各村庄聚落半径（如图 2 所示）。结果显示，村庄聚落边界至耕作田块最大耕作距离为 2647m，最大村庄耕作距离为 650.88m，并结合抽样实地调将最大耕作距离确定为 3500m。

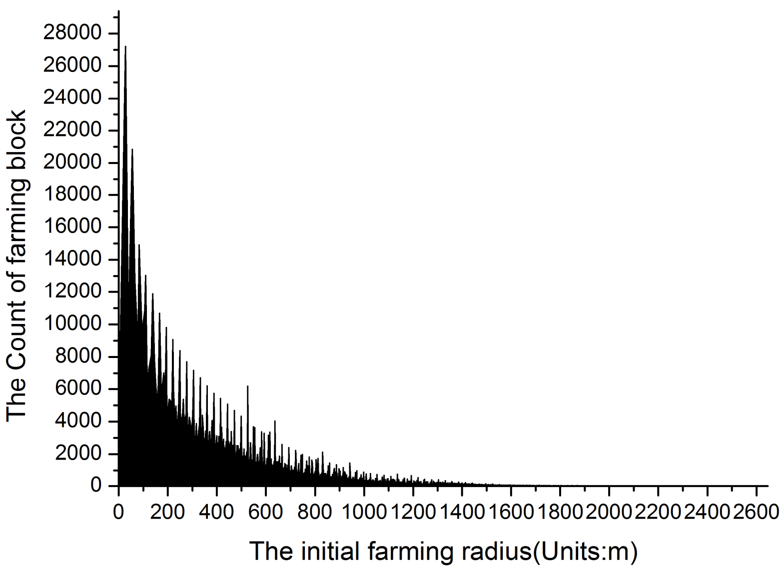

Fig. 1 - The distribution of initial farming radius in Xinfu District / *忻府区初始最初的农业耕作半径*

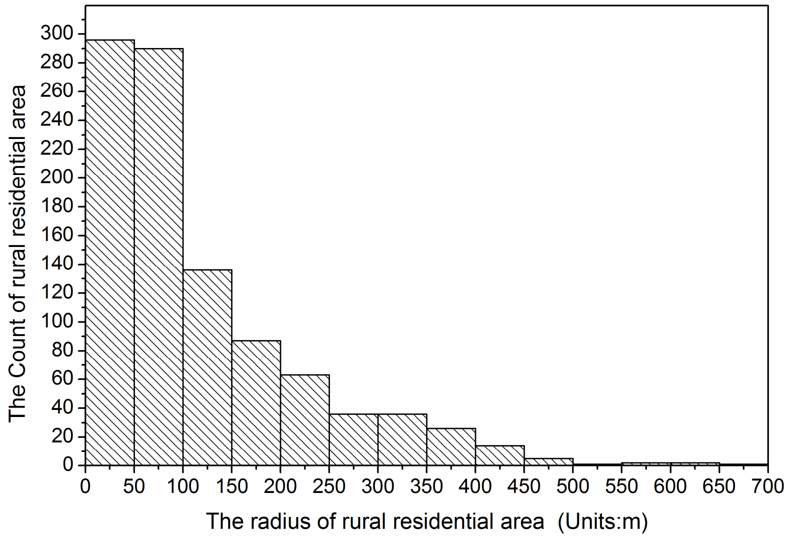

Fig. 2 - The distribution of rural residential area radius in Xinfu District / *忻府区分布的农村住宅区域半径*

Analysis on optimization of rural residential location

In the model, the centers of gravity of the patches of the 8140 rural residential points sized 100×100m^2 serve as service facility level. The centers of gravity of the patches of the 79157 pieces of farming blocks sized 100×100m^2 serve as demands level. Impedance conversion is Linear, impedance is length (m), the way direction is Facilities to Demand, U-turn is allowed, and the output pattern type is straight line. To optimize the rural residential location in Xinfu District by SCLP model under maximum farming radius, the existing 995 rural residential points in Xinfu District can be optimized to 370 central villages ensuring the maximum farming distance within 3500m (fig 3). The network distance from any farming block sized 100×100m^2 to the nearest central village is under 3500m (fig 4). According to the best plan, to divide the 71563 pieces of farming blocks to the central villages, the least number is 1, the largest number is 969, the average number is 193, the middle number is 93, and the standard number is 216.

村庄聚落区位优化分析

模型以忻府区8140个100×100m²大小的村庄聚落图斑的重心作为服务设施图层，以79157个100×100m²大小的耕作地块图斑的重心作为需求图层，阻抗变换为Linear，阻抗为长度(m)，路途方向为Facilities to Demand，允许U-turn，输出图形类型为直线。通过最大耕作距离约束下的最小设施模型优化忻府区区农村居民点区位布局，经过运算，忻府区现有的995个农村居民点在保障最大耕作距离不超过3500m的情况下可以优化为370个中心村（忻府区现有的995个自然农村居民点及优化后的370个中心村的分布情况详见图3所示），任何100×100m²的耕作田块距离最近的中心村的网络距离均小于3500m（耕作田块的距离中心村路网耕作距离情况可详见图4所示）。按照最优方案将71563块耕作田块分配给中心村，最少的中心村可分的1块，最多的可以分到969块，平均为193块，中值为93块，标准分布为216块。

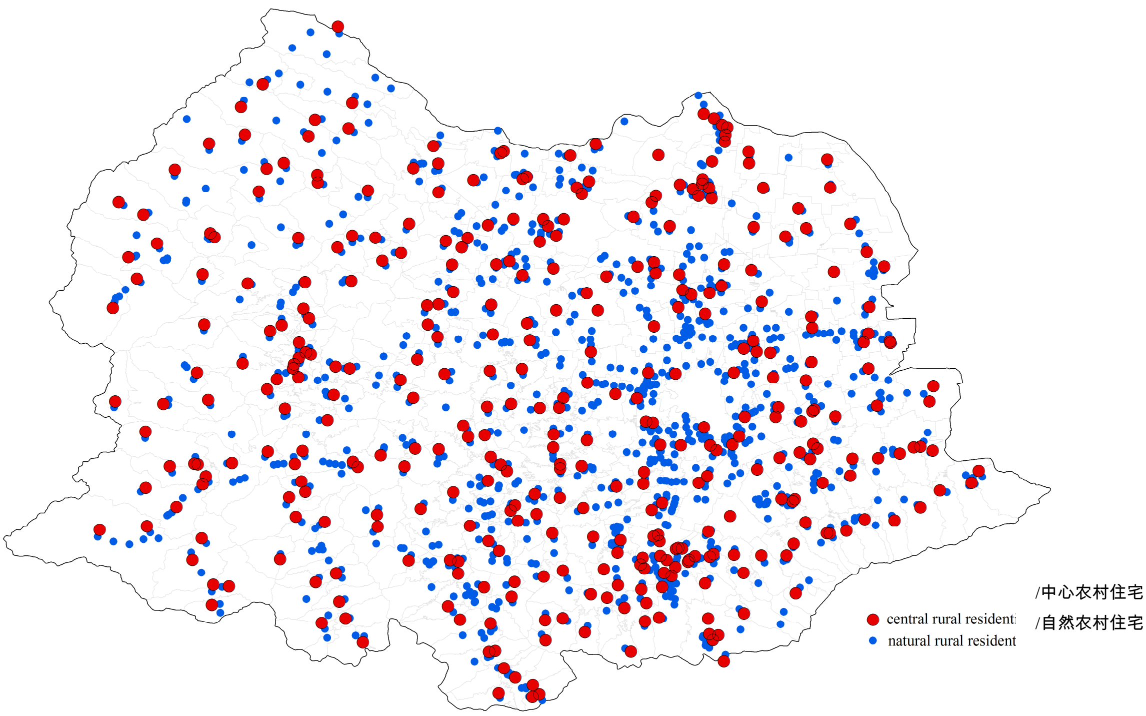

Fig. 3- The distribution of central rural residential in XinFu District / *中心农村住宅分布在忻府区*

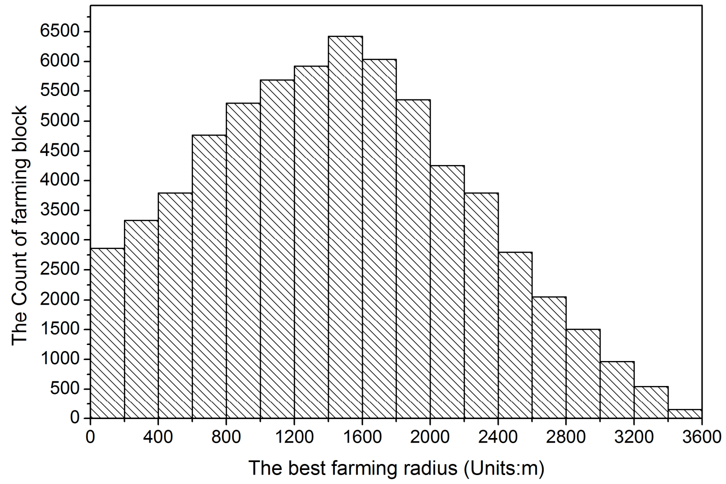

Fig. 4- The best farming radius distribution of farming block in XinFu District / *耕作田块的距离中心村路网耕作最优距离*

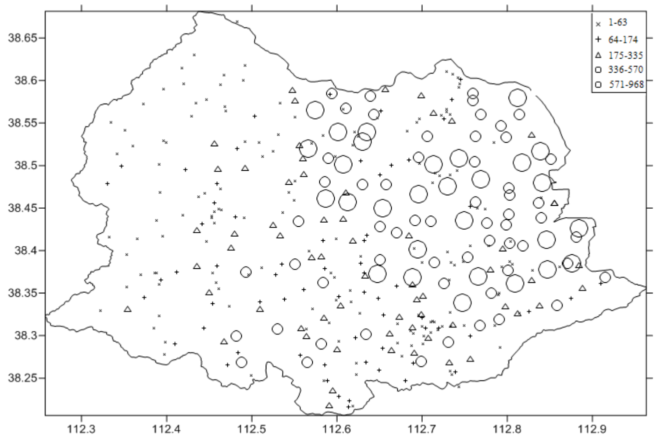

Fig. 5- The distribution of central rural residential farming block number in XinFu Distric t / *府区中心村耕作田块分布情况*

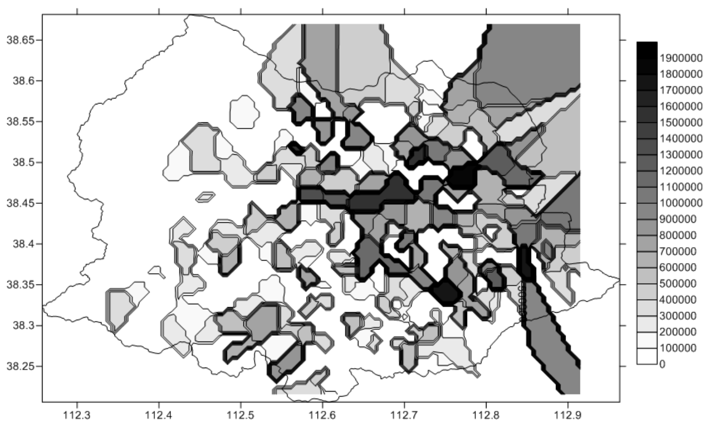

Fig. 6 - The total farming radius of central rural residential farming block in XinFu District / *忻府区各中心村的分配得到耕作总距离图分布情况*

DISCUSSION AND CONCLUSIONS

Discussion

Apply Surfer 10 software to make the distribution of central rural residential farming block number in XinFu District (fig 5). In the figure, it is clear that the central villages in Xinding Basin in East Xinfu District are given more farming blocks, while the central villages in western mountain areas are given less farming blocks, among which, the North Taiping Village has 968 pieces of farming blocks, and the Shiti Village and South Gao Village in Qicun Town, Yaokuan Village in Yangpo Township, Wen Village in Wencun Township, Xiashagou Village in Houhebao Township, Liujiazhuang Village in Xinjian Road Subdistrict Office, Longfengpo Village in Lancun Township, Xinbao Village and Xiangyang Village in

讨论和结论

讨论

应用 Surfer 10 软件制作忻府区中心村耕作田块分布情况散点图（详见图 5 所示），图中可以看出在忻府区东部忻定盆地内的中心村分配的耕作田块普遍较多，西部山区分配的耕作田块普遍较少，其中：最多北太平村可达 968 块耕作田块，最少的奇村镇石梯村、阳坡乡窑宽村、奇村镇南高村、温村乡温村、后河堡乡下沙沟村、新建路街道办事处六家庄村、兰村乡龙凤坡村、豆罗镇新堡村、豆罗镇向阳村、

Douluo Town, Zhuangmo Village in Zhuangmo Town have only 1 piece of farming block respectively.

Apply Surfer 10 software to make the total farming radius of central rural residential farming block in XinFu District (fig 6) by nearest natural neighbor. In the figure, it is noted that the total farming distance of the rural central villages surrounding the central city in Xinding Basin is the longest. The total farming distance of the central villages located in the plain areas such as outer central city, southwest hilly and mountainous areas, river valley and floodplain, with relatively centered farming blocks is shorter. The total farming distance of the central villages in hills and low mountainous areas is shorter than the former. The total farming distance of the central villages in the north, west and south mountainous areas is the shortest.

CONCLUSIONS

Applying SCLP model under the maximum service radius, we can calculate accurately in the study area the minimum rural residential location under the fixed farming radius, to optimize the existing rural residential location efficiently. According to SCLP model under the maximum farming radius, we can provide accurately the future optimizing direction and location of the rural residential location, and the scientific basis for identifying rural construction location, improving use efficiency of rural constructional land, and is beneficial to the intensive economy land use capability. Practically, considering the secondary and ternary industry location and historical and cultural situation, identifying redundant rural residential points, combining land reclamation and efficiency land use, we can move the peasants in the redundant rural residential points to the pointed central villages, and change the left land to the farming land step by step, to release the construction land potential and optimize the construction land location.

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庄磨镇庄磨村仅为 1 块耕作田块。

应用 Surfer 10 软件，采用最近邻点插值法制作忻府区各中心村的分配得到耕作总距离图分布情况图（详见图 6 所示），图中可以看出忻定盆地内环绕中心城区城市近郊区中心村耕作总距离最远，中心城区近郊外围及西南丘陵山区河谷漫滩等地势平坦处、耕作地块相对集中地区的中心村耕作总距离次之，丘陵及低山区中心村耕作总距离再次之，北部、西部、南部山区中心村耕作总距离最小。

结论

应用最大服务距离约束下的最小设施模型可以在保持最大耕作半径约束的前提下，精确计算出研究区内维持额定耕作半径条件下数量最少的村庄聚落区位分布情况，有效优化现有村庄聚落布局。根据最大耕作距离约束下的最小设施模型可以精确地提出村庄聚落未来的优化方向和位置，为明确农村建设位置，提高农村建设用地使用效率提供科学依据，有利于土地的集约节约利用，提高土地利用率。实践中可在考虑二三产业布局和历史文化情况的基础上，鉴别冗余的村庄聚落，结合土地整治、城乡建设用地增减挂钩等工作，逐步将布局冗余的村庄聚落中的农民搬迁至所定中心村内，将冗余村庄聚落内的土地改造为耕地或者其他农业用地，逐步释放建设用地潜力，优化城乡建设用地空间布局。

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