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Establishment of Evaluation Model for Shallow Geothermal Energy Resource Development Potential Based on Characteristic of Geotemperature

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ABSTRACT

The potential analysis of geothermal energy based on geothermal characteristics requires research of the regional shallow geothermal energy. Then, an evaluation model can be constructed. Taking Weinan City as an example, this paper studied the depth and temperature characteristics of the constant zone of subsurface temperature, the vertical variation characteristic of geotemperature, and the horizontal distribution characteristic of geotemperature in Weinan City. Based on the analysis of geotemperature characteristics, the analytic hierarchy process was used to construct the zoning evaluation system of the suitability of ground source, groundwater source, and surface water source. Then, the suitability of Weinan city was comprehensively zoned by the zoning evaluation system. The heat capacity and heat-exchange power of the heat pump system at the groundwater source were calculated based on the zoning results, and the heat-exchange power of the ground-coupled heat pump was obtained. According to the evaluation index, the development potential of shallow geothermal energy resources was evaluated. It can be seen that the heat pump system has great potential for heating in winter and cooling in summer through the experimental analysis model applied in this paper. The area is 50.79 km^2. The area of the potential middle region of the buried pipe heat pump is 135.74 km^2, and the potential of the pump system is low. The possible area of the ground source heat pump is 82.14 km^2. Upon comparing the model results with the current results, it was found that the consistency between the two is high.

Keywords: Geothermal characteristics; Shallow layer; Geothermal energy; Resource development; Potential evaluation; Model construction.

Establecimiento de un modelo de evaluación para el desarrollo potencial de recursos de energía geotérmica poco profunda con base en las características de la geotemperatura

RESUMEN

Con el fin de construir un modelo de evaluación del potencial de desarrollo de recursos de energía geotérmica poco profunda basado en características geotérmicas es necesario investigar la energía geotérmica superficial regional. Este estudio define la ciudad de Weinan como ejemplo para analizar las características de profundidad y temperatura constante del subsuelo de la zona, la característica de variación vertical de la geotemperatura y la característica de distribución horizontal de la geotemperatura. Con base en el análisis de la característica de geotemperatura se utilizó el proceso de jerarquía analítica para construir el sistema de evaluación de zonificación de la idoneidad de la fuente subterránea, la fuente de agua subterránea y la fuente de agua superficial. Luego, la idoneidad de la ciudad de Weinan fue zonificada por el sistema de evaluación. La capacidad de calor y la potencia de intercambio de calor del sistema de bombeo subterráneo se calcularon con base en los resultados de zonificación y se obtuvo la potencia de intercambio de calor de la bomba acoplada a tierra. Según el índice de evaluación, se evaluó el potencial de desarrollo de los recursos de energía geotérmica poco profunda. A través del análisis experimental, aplicando el modelo en este documento, se puede ver que el sistema de bomba de calor de fuente subterránea tiene un gran potencial para calentar en invierno y enfriar en verano. El área es de 50.79 km^2. El área de la región media potencial de la bomba de calor de tubería enterrada es de 135.74 km^2 y el potencial del sistema de bomba de calor de fuente subterránea es bajo. El área potencial de la bomba de calor de fuente terrestre es 82.14 km^2. Al comparar los resultados de la evaluación de este modelo con los resultados reales se encuentra que la consistencia entre los dos es alta.

Palabras clave: Características geotérmicas; Capa superficial; Energía geotérmica; Desarrollo de recursos; Evaluación potencial; Construcción de modelo.

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Introduction

Energy problems, environmental, and sustainable development issues always trouble all over the world. The extensive energy use consumes a large number of non-renewable energy sources such as coal and oil. But those resources are expensive. Energy has become a bottleneck restricting sustainable development (Liu & Nasr, 2019). People have paid more and more attention to energy conservation, new energy development, environmental pollution reduction, and sustainable development. All countries are trying to find and develop environmental, renewable energy. China is also facing the same problem (Wang et al., 2017). As a renewable, environmental, clean energy resource, the shallow geothermal energy resource has been gradually recognized, accepted and valued in recent years in China (Neupane et al., 2016). The shallow geothermal energy is a new member of the geothermal renewable energy family. It is also another form of solar energy, widely in the surface layer of the earth (thermostat layer). It can be recovered and renewable, and it is inexhaustible low-temperature energy (Zhang & Hu, 2018).

The shallow geothermal energy is a low-temperature geothermal resource in the rock and soil of the earth's surface; it is also an essential part of thermal energy. It is a clean, renewable resource with abundant reserves, wide distribution, and stable temperature. Its development and utilization play an essential role in energy saving, emission reduction, and environmental protection. Its development and utilization prospects are broad (Zhang et al., 2017). Currently, the development of technology is mature, which has been widely applied in heating and cooling. It is a good alternative energy and clean energy. With the gradual popularization of ground source heat pumps, the utilization of shallow geothermal energy has attracted more and more attention, which has become a new growth point of geothermal energy utilization. Due to the excessive growth of demand in the area where the ground source heat pumps are popularized, the application of this technology shows a blind and disorderly development trend, ignoring the hydrogeological condition of the application site to a large extent, leading to the waste of groundwater resource and the inefficiency of the heat pumps (Mihoub et al., 2016).

To solve these problems objectively and ensure the rational development and utilization of shallow geothermal energy, we not only normalize the heat pump market but also investigate and evaluate the shallow geothermal resource according to the hydrogeological conditions, regional development and energy demand. We should scientifically carry out the suitability zoning of ground source heat pumps' application and make reasonable development, and utilization plans to determine favorable development regions and appropriate development and utilization methods. All this to achieve orderly development, rational use and scientific management of shallow geothermal energy resources. These can provide a scientific basis for the macro decision-making on unified planning, improving energy efficiency and ensuring energy security (Michopoulos et al., 2016). Therefore, it is necessary to establish a model for evaluating the adaptability of ground source heat pumps. The standardized and systematic evaluation of shallow geothermal energy is critical. It is essential to organize them with various hydrogeological conditions for unified management. After considering the factors influencing the spatial distribution of shallow low-temperature energy, the standard way is challenging to achieve timely, effective management. Therefore, an evaluation model for shallow geothermal resources development potential should be constructed (Zhang et al., 2016).

Some relevant literature shows that many scholars have studied it. Liu Licai has divided the suitability of water source heat pumps in the planning area of Beijing. Wang Yabin has partitioned the suitability of hydrogeological conditions of the water source heat pump system in Tianjin. Wang Tao evaluated the suitability of shallow geothermal energy utilization in key cities along the Yellow River economic belt in Ningxia. Generally, China is still in the early stage due to its short development time. The unbalanced development and some problems need to be studied and solved urgently. Otherwise, it will directly affect the development and sustainable utilization of shallow geothermal energy resources. In conclusion, there are many complex methods for evaluating the suitability of shallow geothermal. There is no specific mature method theory. Some scholars directly use the method of artificial qualitative zoning to make the zoning intervals for the values of each element, and then corresponding suitability zoning is carried out. This method is too subjective, which is not scientific and reasonable enough. Some scholars use programming or software for the subarea. Although this method is efficient, it is not flexible enough. Meanwhile, the results are usually complex, and its practicability is too low. On this basis, this paper uses the analytic hierarchy process (AHP) to divide the suitability of development and utilization. After that, the evaluation model is used to evaluate the development potential of shallow geothermal resources based on the zoning (Alkhasov et al., 2016).

Material and Method

Geothermal Characteristic

Depth and Temperature of the Constant Cone of Subsurface Temperature

Because the geothermal characteristics of different regions are different, this paper takes Weinan City as an example to research. In order to analyze the relationship between the depth and temperature of the layer of constant temperature in Weinan, eight wells of different geomorphic units in this region (six of them are the engineering geological exploration holes, two of them are motor-pumped wells) are monitored numerically with the depth of water temperature (if the water temperature is close to the formation temperature, the measured water temperature is substitute for the ground temperature). In the thermal response test construction, a U-shaped pipe is embedded in the borehole, and water is injected to ensure the tightness. The U-tube can be used for future temperature tests, and the digital temperature measurement single cable multi-probe detection system is adopted. The actual construction proves that when the stratum temperature changes slowly, it is accurate in any depth (Zhou et al., 2017). The geothermal change curve and the scatter plot of the relationship between geo-temperature and depth in Weinan are obtained by corresponding technology. The geothermal change curve is shown in Figure 1. The scatter plot corresponding to the relationship between ground temperature, and depth is shown in Figure 2.

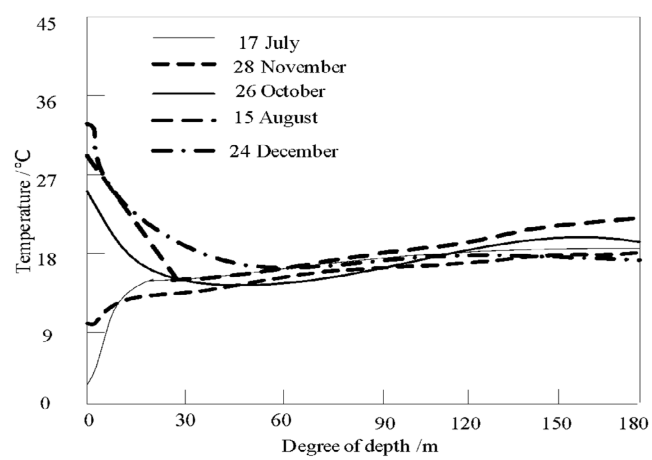

Figure 1. Map of ground temperature variation

From the variation curve of ground temperature, we can see that the ground temperature of each monitoring hole in the depth of 0m-15 m underground varies with the rise and fall of temperature in different seasons. The seasonal variation of ground temperature is evident. The ground temperature in the depth of 15 m-20 m underground is basically constant, and the ground temperature is 15°C-17°C. The ground temperature of each monitoring hole at the same depth does not change with the season when the depth is below 20 m. The ground temperature in different seasons is basically unchanged, and the temperature increases linearly with the increase of burial depth (Bisht & Rupenthal, 2016).

Geothermal Variation Characteristic at Vertical Direction

According to the data of eight geothermal monitoring points in different geomorphic locations, the geothermal field within the region generally increases with the depth at the vertical direction, but the geothermal changes vary in

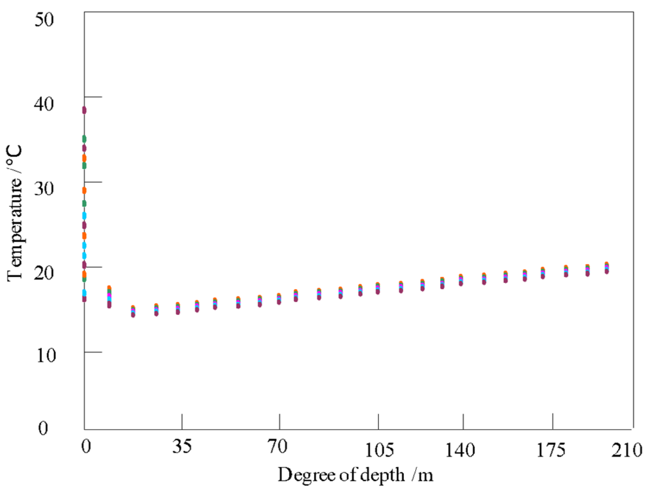

Figure 2. Scatter map corresponding to the relationship between ground temperature and depth

different depths. In the normal temperature zone (15 m-25 m), especially the near-surface area of 0 m-3 m, the ground temperature is affected by seasonal climate change, and the fluctuation is sensitive. Moreover, the influence of climate change on the ground temperature between 3 m and 15 m decreases gradually. Under the normal temperature zone of about 25 m, the ground temperature has not been influenced by local climate change. The temperature increases with depth. The ground temperature is19.8°C-22.0°C when the depth is 200 m. The average geothermal gradient is 1.18/100 m to 3.57/100 m. Based on the monthly average water temperature at different depths of eight long-term observation wells, the variation curves of ground temperature in various depths and different periods (the water temperature below groundwater level is the same as the ground temperature) with depth are drawn to analyze the vertical variation characteristics of ground temperature in natural state. According to the curve, the vertical geothermal distribution feature in the research area belongs to the linear gradual rising type. Under 20 m, the ground temperature of each observation hole at different depths does not change significantly with the seasons. With an increase of depth, the ground temperature increases linearly. The change of ground temperature in Qianlu Waterworks (WN178) is the largest, from 40m to 180m. As the ground temperature increases by about 5°C and the geothermal gradient is about 3.57°C/100 m. The changing trend of ground temperature in Zhang yicun (WG001) is relatively slow, from 30m to 100m. The ground temperature increases by about 0.81°C, and the geothermal gradient is 1.18°C/100 m. In the stratum warming zone, the geothermal temperature is controlled by deep geothermal warming, and the geothermal temperature gradually increases with depth. Due to the influence of geological structure, groundwater activity, and stratum rock characteristics, vertical geothermal warming varies from place to place. It is concluded that the geothermal temperature in the research area changes with depth. The features are mainly influenced by the geological structure and groundwater activity (Ruelle et al., 2016).

Geothermal Horizontal Distribution Characteristic

Generally, the ground temperature in 100 m buried depth is high in the south and low in the north. There is a geological fault in the front of the second terrace on the south bank of Weihe River. The ground temperature in the 100m buried depth of the third terrace on the south of fault can reach 19.1°C. The main reason is that the basement faults are mature in the area, conducive to the heat conduction from deep to shallow. The distribution direction of the third terrace in the south of Weihe River is consistent with the underlying fault structure. According to the contour maps of ground temperature and average geothermal gradient at 100 m depth, the geotemperature is abnormal if the geotemperature is higher than 17.5°C; and the average geothermal gradient is higher than 3°C/100 m. It can be seen that the geothermal anomaly regions are zonally distributed in the second and third terraces of Weihe River in the southern part of Weinan, and the average geothermal gradients are mostly concentrated in the range between 3.0°C/100 m-3.35 °C/100 m. The basement faults in the southern part of Weinan are mature (Czycholl et al., 2017), mainly influenced by the faults in the south bank of the F1 Weihe River. It is affected by the faults in front of the tableland of the F2 Weihe River and F3 Zero River faults. In addition, two ground fissures are developed in the southern part of Weinan and the trend is east-west, which are roughly parallel to the faults. The fault structure in this area is conducive to heat conduction from deep to shallow. The direction of geothermal anomaly is consistent with that of underlying fault structure. At present, the exploitation of shallow geothermal energy in Weinan is relatively low. No one wants to exploit and utilize the geothermal anomaly area.

Development and Utilization Suitability Zoning

Principle and Method of Suitability Zoning

The suitability zoning of shallow geothermal energy development and utilization runs through the research. Its purpose is to provide the basis for the selection of development and utilization mode, resource evaluation and development and utilization planning.

(1) Zoning principle is based on the geological and hydrogeological conditions. The geological conditions are the important basis for the occurrence of shallow geothermal energy, and the hydrogeological conditions are the main influencing factors for the occurrence of shallow geothermal energy. For the purpose of development and utilization of shallow geothermal energy, the reasonable development and utilization mode and the effective heat pump system are the important media. We need to focus on both economic benefits and environmental protection. Under the current technological and economic conditions, regions and ways with relatively good economic, environmental and energy-saving effects should be selected for the development and utilization of shallow geothermal energy. The plane division and vertical control should be combined. The range of plane zoning areas is the long-term planning area of urban construction in 2020. The overall evaluation control depth is 200 m.

(2) Zoning method: it is necessary to closely combine with the conditions of shallow geothermal energy in this area. Firstly, the necessary conditions of suitability are divided by key factor method, and then the suitability level is divided by analytic hierarchy process (AHP) and comprehensive index method respectively. The analytic hierarchy process (AHP) is a qualitative, systematic and hierarchical analysis method. It has practicality and effectiveness in processing complex decision-making problems. The comprehensive index method refers to the comprehensive evaluation index which uses the weight calculated by the analytic hierarchy process and the numerical value obtained by the fuzzy evaluation method to put forward the economic benefit index. The more influential factor on suitability division will be more important. By establishing the comparison matrix, we can check the consistency of comparison matrices and adjust the comparison matrix if necessary, so as to achieve acceptable consistency. According to the occurrence condition of shallow geothermal energy, it can be divided into three development and utilization modes: ground-source type (buried pipe), groundwater-source type and surface-water source type, and then we can divide them into different suitable areas. Ground source types can be divided into five types: favorable area, suitable area, general area, undesirable area and unsuitable area. Among them, suitable area can be divided into three sub-areas: loose rock subregion, semi-consolidated rock subregion and consolidated rock subregion (Winters et al., 2016). The groundwater source can be divided into three types: favorable area, suitable area and unsuitable area. The surface water source can be divided into two types: suitable area and unsuitable area.

Suitability Zoning Evaluation System of Ground Source

The geological and hydrogeological conditions, construction conditions, thermophysical properties, topography, geomorphology, environmental geological problems are chosen as the attribute-level indexes for the evaluation of suitability zoning of development and utilization of geo-source type. Where, the thickness of the loose layer, the probability of geological hazards and the topography are the key factors. On the premise of determining the key factors, the method of analytic hierarchy process and the method of comprehensive index are used to divide the development and utilization suitability zoning of shallow geothermal energy of ground source type. As shown in Figures 3 and Figure 1:

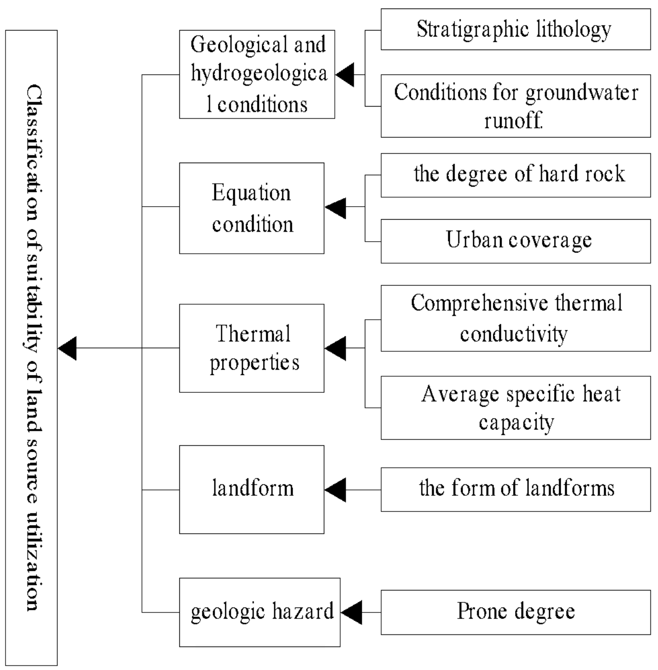

Figure 3. Structure diagram of suitability division for development and utilization of source type

Table 1. Selection table of crucial factors of suitability

Suitability	Partition key factor
Suitable area	An area with loose layer thickness greater than 100 m
lower area	Semi-consolidated rock area
General suitable area	Geological hazard (collapse, landslide, debris flow, karst ground collapse) low-prone area, and loose layer thickness of 30 m-50 m
Difference suitable area	Geological hazards (collapse, landslide, debris flow, Karst ground collapse) in prone areas, middle hills and above geomorphologic units
unconfined area	Geological hazard (collapse, landslide, debris flow, karst ground collapse) high-prone area

From Figure 3, we can see that the structure of suitability division of development and utilization of geo-source type is mainly based on the geothermal characteristic. By considering the hydrogeological condition, equation condition, thermal physical property, topography, geological hazards and other factors, we can divide the suitability of development and utilization of geo-source type. Meanwhile, it can be seen that the suitability can be divided into five categories (Yan & Xu, 2016).

Subarea Evaluation System for Suitability of Groundwater Source

The groundwater abundance and groundwater dynamic field conditions are selected as attribute-level indexes for the suitability evaluation of groundwater source. The six indexes such as single-well water inflow, effective thickness of aquifer, recharge capacity, water level burial depth, water level descent rate and recharge modulus are selected as element layers of the hierarchical analysis. Where, the groundwater richness, the recharge capacity and environmental geology are the key factors (Li et al., 2016). On the premise of determining the key factors, the method of analytic hierarchy process and the comprehensive index are used to divide the suitability of development and utilization of shallow geothermal energy of groundwater sources.

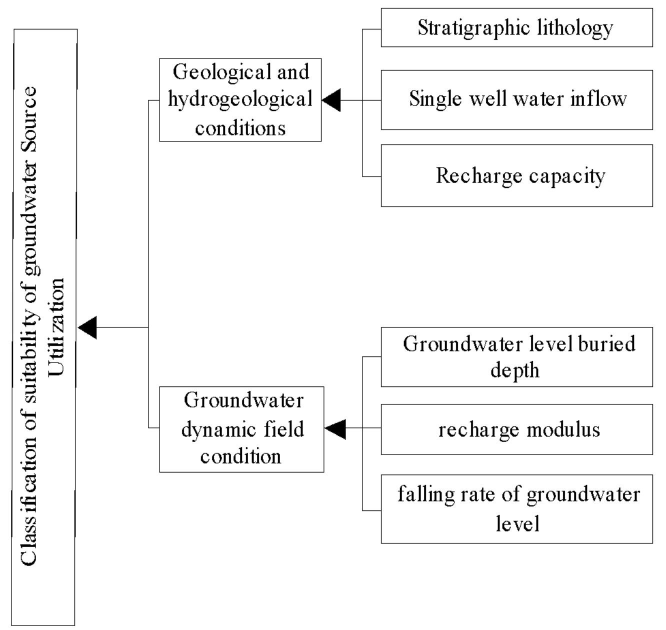

Figure 4. Structure diagram of suitability division for development and utilization of underground water source type

Table 2. Selection of key factors

Key evaluation factor	Suitability		
	Suitable area	More suitable area	unconfined area
Single well water inflow/(m3/d)	>3000	1000-3000	<1000
Groundwater irrigation and production ratio/%	>80	50-80	<50
Recharge capacity	Best	secondary	difference
(1) The area with land subsidence > 500 mm is an unsuitable area of groundwater source type.			
(2) Land subsidence 0 mm-500 mm area, take down a suitability level			

From Figure 4, the division structure of suitability of development and utilization of groundwater source is mainly based on the geothermal characteristic. After considering the geological condition, hydrogeological condition and groundwater dynamic field condition, the suitability of groundwater source can be divided by above factors. Meanwhile, the key evaluation factors of suitability division of groundwater source development and utilization mainly include the number of single well users, groundwater irrigation-production ratio and recharge capacity. According to above evaluation factors, the suitability evaluation of groundwater source development and utilization can be achieved.

Zoning Assessment System for Suitability of Surface Water Source

The development and utilization of surface water source shallow geothermal energy can be divided into two types: separated type and closed type. The evaluation indexes of suitability of surface water source type mainly include the recyclable amount of surface water, water depth, water temperature, water quality and distance from the project.

Table 3. Classification of suitability for development and utilization of surface water source types

Utilization mode	open	closed
Volume during dry season/(×104m³)	>20	>20
water quality	Meet the requirements of the specification	Meet the requirements of the specification
Water depth in dry season/m	>3	>3
Coldest monthly mean water temperature	>10	>5
Distance between utilization engineering and water source/km	<0.5	<0.5
Comprehensive evaluation standard of suitability	It is appropriate to meet the five indicators	

From Table 3, we can see that the evaluation indexes of development and utilization of surface water resource mainly include five evaluation indicators: volume, water quality and depth in dry season. The suitability of surface water resources development and utilization can be divided by the degree of conformity of development and utilization of surface water resources to these indicators (Wen & Fang, 2018).

Evaluation of Tap Potential of Shallow Geothermal Energy Resource

The evaluation for development potential of shallow geothermal resources includes the evaluation of shallow geothermal capacity and heat-exchange power. Based on the zoning results, the evaluation index of shallow geothermal resource development potential is selected at first, and then the development potential of shallow geothermal resource is evaluated by the evaluation index.

Heat Capacity

The shallow geothermal energy capacity is the unit temperature difference heat stored in shallow rock, soil and groundwater. The thermal storage method is adopted. The depth range is 200 m. The calculated area is the suitable area.

$$Q_R = Q_S + Q_W + Q_A \tag{1}$$

In the formula, Q_R is the geothermal energy capacity. Q_S is the energy capacity in rock and soil. Q_W is the energy capacity of water contained in rock and soil (Sowizdzal, 2016). Q_A is the energy capacity of air contained in rock and soil. The formula for calculating the energy capacity of rock and soil is as follows:

$$Q_S = \rho_s C_s (1-\phi) Md \tag{2}$$

In the formula, ρ_s is the density of rock and soil. C_s is the specific heat capacity. ϕ is the porosity. M is the area. d is the thickness of rock and soil are considered (Al-Samari & Ali, 2018). The formula for calculating the energy capacity of water in rock and soil are as follows:

$$Q_W = \rho_W C_W \omega Md \tag{3}$$

In the formula, ρ_W is the water density. C_W is the specific heat capacity. ω is the water content of rock and soil. The formula for calculating the energy capacity of air in rock and soil are as follows:

$$Q_A = \rho_A C_A (\phi - \omega) Md \tag{4}$$

In the formula, ρ_A is the air density. C_A is the specific heat capacity of air. According to the main rock character of the aquifer, the depth of the Quaternary base boundary and the depth of shallow groundwater, this region is divided into 148 sub regions. According to the difference of area conditions, the sub regions are merged into 18 evaluation units. According to the main rock character of aquifer, they are divided into three areas, and then we calculate them.

Heat-exchange Power of Groundwater Source Heat Pump System

The heat-exchange power of groundwater heat pump systems is calculated by groundwater demand conversion method. The calculation process is as follows:

$$Q_q = Q_h \times n \times \tau \tag{5}$$

In the formula, Q_q is the heat-exchange power of shallow geothermal energy in the evaluation area. Q_h is the heat-exchange power of shallow geothermal energy of a single well. n is the number of drillable holes in the calculation area. τ is the land usage rate. The formula for calculating the heat-exchange power of shallow geothermal energy of single well is as follows:

$$Q_h = q_w \Delta t \rho_w C_w \times 1.16 \times 10^{-5} \tag{6}$$

In the formula, Q_h is the heat-exchange power for a single well. q_w is the amount of groundwater recycling utilization. Δt is the difference in temperature for groundwater utilization. ρ_w is the density of water, 1000 kg/m³. C_w is the specific heat capacity of water, 4.18 kJ/(kg·°C).

Heat-exchange Power of Buried Tube Heat Pump System

According to the heat-exchange power of the ground-coupled heat pump, the unit heat transfer method (Fu, 2018) is adopted. The calculation process is as follows:

$$Q_K = q_k M \times 10^{-3} \tag{7}$$

In the formula, Q_K is the heat-exchange power of shallow geothermal energy, and q_k is the heat-exchange power of shallow geothermal energy per unit area. M is the calculation area.

Establishment of Shallow Geothermal Energy Potential Evaluation Model

According to the heat-exchange power of ground source heat pump system and the indexes of heating in winter and cooling in summer, the area for heating and cooling of suitable and more suitable regions of groundwater ground source heat pump in winter and summer was further calculated, and then the resource potential of ground source heat pump system (Zhang et al., 2018) is obtained. The detailed formulas are as follows:

$$m = \frac{1000Q_q}{q} \tag{8}$$

$$Q_{zq} = \frac{m}{M} \tag{9}$$

In formulas, m is the heating/cooling area of groundwater/buried pipe ground source heat pump system. Q_q is the heat-exchange power in the suitable region and the more suitable region of groundwater/buried pipe ground source heat pump system. q is the heating index in winter and the refrigeration index in summer. Q_{zq} is the resource potential of groundwater/buried pipe ground source heat pump system. m is the heating/refrigerating area of groundwater/buried pipe ground source heat pump system. M is the area of the calculation region. Through the above formulas, the index table of potential evaluation zoning is obtained.

Table 4. Potential Assessment Division

Evaluation project	Divisional indicators		
Unit area heating area/($\times10^4$ m^2/km^2)	>32	20-32	<20
Refrigerable area per unit area/($\times10^4$ m^2/km^2)	>40	28-40	28
The land use coefficient is 100% of the heating area per unit area./($\times10^4$ m^2/km^2)	>162	<162	
The land use coefficient is 100% refrigerable area per unit area/($\times10^4$ m^2/km^2)	>204	<204	-
Potential zoning	High potential area	Central potential area	Low potential area

On the basis of the above analysis, the development potential of shallow geothermal energy resources can be evaluated by the above table.

Results

In order to verify the validity of the evaluation method, the proposed method is used to analyze the occurrence condition of shallow geothermal energy in Weinan city and the characteristic of geotemperature in Weinan city. It evaluates the suitability of development and utilization and the heating/cooling potential of groundwater ground source heat pump system and buried pipe ground source heat pump system. The heat capacity of shallow geothermal energy is calculating. The environmental benefits and economic benefits of shallow geothermal energy development are discussed. The detailed analysis process is shown below.

Suitability Zoning of Groundwater Ground Source Heat Pump

In order to research the suitability zoning effect of groundwater ground source heat pump of the proposed method, a practical experiment is carried out. The results of the practical adaptability zoning are shown in Figure 5. The area and percentage of each region after the zoning are shown in Table 5.

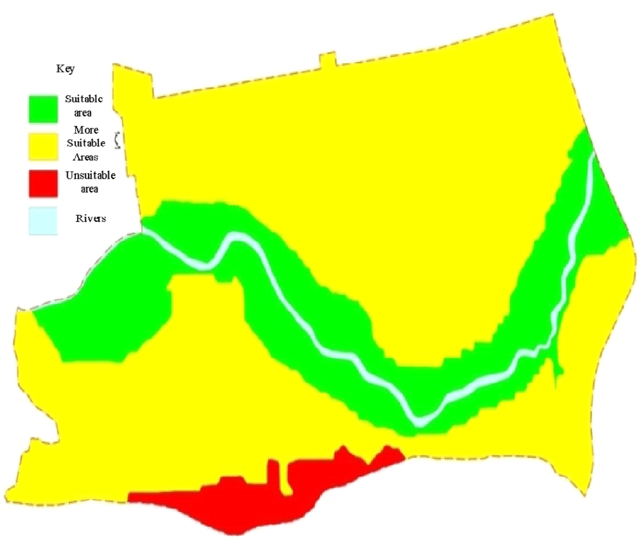

Figure 5. Suitability zoning of groundwater ground source heat pump in Weinan City

From the charts, we can see that the suitability of groundwater source heat pumps is obviously different due to the difference of hydrogeological characteristics. The suitability can be divided as follows. The suitable region of groundwater source heat pump: it is distributed in the mid-Weihe floodplain of the evaluation region. The rock character of aquifer is composed of gravel,

Table 5. Statistical table of suitability zoning and area of groundwater ground source heat pump

Suitability zoning	Real area /km^2	Percentage
Suitable area	36.49	11.69
More suitable area	153.61	49.24
General suitable area	95.48	30.61
Difference suitable area	10.62	3.4
Unconfined area	12.56	4.03
Unevaluated area	3.21	1.03
Total	311.97	100

gravel-bearing medium-coarse sand and silty clay. The stratum has good water conductivity, including double-layer phreatic water-confined water. The water-abundance is good. The unit water inflow is 10 m^3/h·m-30 m^3/h·m. Therefore, it is suitable for groundwater pumping. The area of this region is 61.14 km^2, accounting for 22.23% of the total area of the evaluation area. The suitable region of groundwater source heat pump: it is distributed in the first terrace on the north bank of Weihe River, the terrace on the south bank of Weihe River and the alluvial-proluvial fan region. The rock character of aquifer is Quaternary Holocene Alluvion, including the gravelly sand, medium sand, coarse sand, silt and silty clay. The groundwater pumping condition in this area is relatively good, the water abundance is medium-weak, the unit inflow is 1 m^3/h·m-10 m^3/h·m. The area is 196.60 km^2, accounting for 71.48% of the total area of the evaluation area. The unsuitable region of groundwater source heat pump: it is mainly distributed in the third terrace covered by loess in the south evaluation region. The stratum lithology is mainly Pleistocene Aeolian Loess and silty clay with little thin sandy soil. The water abundance of groundwater in this region is weak, and the water conductivity is poor. The unit water inflow is 1 m^3/h·m-5 m^3/h·m, which is not suitable for the project of groundwater source heat pump. The unsuitable area of groundwater source heat pump is 10.93 km^2, accounting for 3.98% of the total area of the evaluation area. The unevaluated area is Weihe River, namely the existing river in the evaluation area, with an area of 6.37 km^2, accounting for 2.32% of the total area of the evaluation region.

Heat Exchange Power and Potential of Groundwater Ground Source Heat Pump

In order to study the validity of calculation and evaluation for the heat-exchange power and potential of groundwater ground source heat pumps in Weinan City, it is necessary to carry out practical analysis. The analysis results are shown in Table 6.

From Table 6, the total area of suitable and more suitable regions of groundwater source heat pump in this area is 145.22 km^2, and the total heat transfer power of groundwater source heat pump system is 1.17×10^6 kW (winter)/ 3.58×10^6 kW (summer). When using the groundwater ground source heat pump system to develop and utilize the shallow geothermal energy, the average heating potential in winter is 1.48×10^5m^2/km^2, and the average refrigeration potential in summer is 2.13×10^5 m^2/km^2.

Heat Exchange Power and Potential of Buried Tube Ground Source Heat Pump

In order to study the validity of this method in calculating and evaluating the heat-exchange power and potential of ground source heat pump, it is necessary to take the average temperature of fluid in the buried pipe of Weinan City in winter and summer as 6°C and 32°C respectively. The heat-exchange power potential of the ground source heat pump system in Weinan City is calculated and evaluated by the proposed method. The results obtained by the proposed method are as follows.

Table 6. Heat transfer power and potential of groundwater ground source heat pump

Zoning and numbering	Zhao Zhai-Li Jia Wan	Longjiang Town-Hantai District-Pu Zhen	Liangshan town	Zhongsuo town-Dahekan town	Sujiashan Village	Total
Zonal area/km^2	21.95	94.37	15.33	13.24	0.33	145.22
Suitability	More suitable	Suitable	Suitable	Suitable	More suitable	
Winter heat transfer power/kW	8.83×10^4	1.21×10^6	2.67×10^5	2.32×10^5	1.16×10^3	1.17×10^6
Summer refrigeration power/kW	1.76×10^5	2.42×10^6	5.34×10^5	4.62×10^5	2.32×10^3	3.58×10^6
Winter heating potential/(m^2/km^2)	5.39×10^4	1.72×10^5	2.33×10^5	2.35×10^5	4.68×10^4	1.48×10^5
Summer Refrigeration Potential/(m^2/km^2)	7.77×10^4	2.48×10^5	3.36×10^5	3.38×10^5	6.74×10^4	2.13×10^5

Table 7 shows that the heat-exchange power in winter and summer is 1.04×10^7 kW and 1.26×10^7 kW respectively. The average heating potential in winter is 9.64×10^5 m^2/km^2 and the average refrigeration potential in summer is 1.18×10^6 m^2/km^2 when using the ground source heat pump system to develop and utilize shallow geothermal energy.

Analysis of Resources Development Potential

In order to verify the accuracy of the proposed method in evaluating the development potential of shallow geothermal energy, it is necessary to carry out actual experimental analysis. Weinan City is divided into three regions. Finally, the evaluation results as shown in Table 8.

From Table 8, we can see that land use coefficient has a great influence on the potential of ground source heat pump systems. Meanwhile, most of the floodplain areas in Weinan are high potential areas of ground source heat pumps. The water level in the area is shallow and the effective aquifer is thick. The comprehensive heat transfer coefficient is high and single-hole heat exchange power is large. The ground source heat pump system has large heating/cooling potential in winter and summer. The area is 50.79 km^2, accounting for 18.47% of the total area. The first-order region of Weihe River within the zoning area is the middle potential area of ground source heat pump, with an area of 135.74 km^2, accounting for 49.35% of the total area. The built area of Weinan has small land use coefficient and low potential of ground source heat pump system, which belongs to the low potential area of ground source heat pump. The area is 82.14 km^2, accounting for 29.86% of the total area. Through actual investigation and analysis, we can see that the evaluation results of the proposed method are in good agreement with the actual results. Therefore, the evaluation accuracy of the proposed method is higher.

Discussions

There are many ways to exploit the shallow geothermal energy resource. The groundwater ground source heat pump and buried pipe ground source heat pump are the two main ways. The groundwater source heat pump system consists of groundwater heat-exchange system, computer room system and terminal system. The working principle of the ground water source heat pump system is to pump groundwater and exchange heat through a ground source heat pump unit or plate heat exchanger. In winter, all the low-temperature water pumped from underground water after heat exchange through a ground source heat pump unit is recharged into the same aquifer, and the heat quantity is used for the building heating and domestic hot water. In summer, all the high-temperature water is recharged into the same aquifer after the heat exchange of pumped groundwater through a ground source heat pump unit or plate heat exchanger. At the same time, the high-temperature water can be exchanged through a heat pump unit to provide domestic hot water. The characteristics are as follows: at suitable sites for sinking a well, a certain number of pumping and irrigation wells are drilled, and heat is absorbed or discharged from groundwater by recycling, so that the number of wells and the area are few. The heat-exchange way of the underground heat-exchange system is mainly the

Table 7. Calculation table of heat transfer power meter potential of a ground source heat pump with buried pipe

Zoning and numbering	Praise canal	Longjiang Town-Qili Town-Paving Town	Liangshan Town-Belt floodplain on the South Bank of Hanjiang River	Floodplain on the east bank of Lianshui River	Floodplain east of Dahekan town on the south bank of Hanjiang River	The first - class terrace south of Liangshan Town	Huilong Temple-Yuying Village	Total
Zonal area/km^2	3.36	112.69	6.04	1.26	2.36	9.29	9.94	144.94
Suitability	More suitable	Suitable	Suitable	Suitable	Suitable	More suitable	More suitable	
Winter heat transfer power/kW	2.75×10^5	7.93×10^6	4.60×10^5	1.02×10^5	1.98×10^5	6.98×10^5	7.54×10^5	1.04×10^7
Summer refrigeration power/kW	3.34×10^5	9.61×10^6	5.59×10^5	1.23×10^5	2.41×10^5	8.48×10^5	9.12×10^5	1.26×10^7
Winter heating potential/(m^2/km^2)	1.09×10^6	9.44×10^5	1.01×10^6	1.09×10^6	1.12×10^6	1.03×10^6	1.02×10^6	9.64×10^5
Summer Refrigeration Potential/(m^2/km^2)	9.59×10^5	8.24×10^5	8.92×10^5	9.47×10^5	9.83×10^5	8.83×10^5	8.89×10^5	1.18×10^6

Table 8. Evaluation of Development Potential

Partition number	I	II	III	Average
Zonal area/km^2	143.02	114.76	10.89	268.67
Suitability	Both land source and water source are suitable or more suitable	Both land source and water source are suitable or more suitable	Only the ground source is suitable or more suitable.	
Considering the heating potential of Land use coefficient in Winter/(m^2/km^2)	2.68×10^5	2.04×10^5	1.54×10^5	2.36×10^5
Consider the potential of land use coefficient for summer refrigeration/(m^2/km^2)	3.43×10^5	2.62×10^5	1.95×10^5	3.03×10^6
Heating potential in winter when land use efficiency is 100%/(m^2/km^2)	1.37×10^6	1.48×10^6	1.55×10^6	1.43×10^6
Summer Refrigeration potential when Land use efficiency is 100%/(m^2/km^2)	1.75×10^6	1.88×10^6	1.96×10^6	1.82×10^6
Potential division	Central potential area	Low potential area	Low potential area	

thermal convection, and the temperature of groundwater is basically constant throughout the year. The initial cost is lower than that of a buried pipe ground source heat pump system. Under appropriate groundwater depth, COP is higher and the operation cost is lower.

The buried-pipe ground source heat pump system is similar to the groundwater ground source heat pump system. It consists of a heat exchange system with buried pipe, computer room system and terminal system. The working principle of the buried-pipe heat exchange system: the heat transfer medium circulates in the sealed vertical or horizontal buried pipe, and then the temperature difference among the heat transfer medium, the underground rock and soil and the groundwater is used to exchange heat, so that the purpose of utilizing the shallow geothermal energy can be achieved. Meanwhile, the heating and cooling of buildings and domestic hot water through heat pump technology can be realized. The features are as follows: the project needs to drill many boreholes according to the cold load and heat load, and sets a closed circulating pipe with certain strength, corrosion resistance and good heat transfer performance, and then uses the circulating liquid to exchange heat, so as to connect all circulating pipes. Finally, it enters the computer room and main engine. The buried-pipe ground source heat pump (GSHP) system is based on the fact that the temperature of underground rock and soil and groundwater remains constant throughout the year. If the vertical buried tube heat exchanger is used to conduct and absorb heat between underground rock and soil and groundwater, the heat exchange efficiency is lower than that of groundwater ground source heat pump systems. Compared with traditional air-conditioning systems and groundwater ground-source heat pump systems, the main disadvantage of buried-pipe ground-source heat pump systems is high initial investment of ground-source heat exchangers. The heat exchanger of a ground source heat pump system with a buried pipe occupies a larger area than that of the pumping well of an underground water source heat pump system. The ground source heat pump system does not draw water from the ground. Theoretically, the ground source heat pump system with buried pipe has less impact on the environment of underground space than that of groundwater source heat pump, and its procedure is simpler. Therefore, the ground source heat pump system with buried pipe has the characteristics of green environmental protection, high efficiency and energy saving, low operation cost, mature technology, wide application range (it is applicable to any stratum and building). In addition, it does not need to pump the groundwater.

Conclusions

The evaluation of shallow geothermal energy development potential is an effective technology for rational planning of urban layout, protection of shallow geothermal resources and sustainable development and utilization of shallow geothermal resources. Based on the analysis of the geotemperature characteristic in Weinan, this article achieves the suitability zoning of comprehensive development of groundwater source heat pump, buried pipe ground source heat pump and shallow geothermal energy according to the requirements of analytic hierarchy process. Meanwhile, this article uses the shallow geothermal capacity, heat-exchange power and resource potential to quantitatively evaluate the research region. The total area of suitable and more suitable regions of groundwater ground source heat pump in Weinan is 145.22 km^2. When using groundwater ground source heat pump systems to develop and utilize the shallow geothermal energy, the average heating potential in winter is 1.48×10^5 m^2/km^2, and the average refrigeration potential in summer is 2.13×10^5 m^2/km^2. The potential middle area of ground source heat pump in Weinan is 135.74 km^2, accounting for 49.35% of the total area, while the potential low area of ground-source heat pump in Weinan is 82.14 km^2, accounting for 29.86% of the total area. The result and the amount of available resources directly reflect the prospects and potential of shallow geothermal energy development and utilization in Weinan.

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