The Research of Total Capacity of Jiaosi Hot Spring

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Abstract. Jiaosi hot spring has been the most famous tourist attraction of hot spring in Taiwan. In recent years, the amount of hot spring increases substantially due to the developing tourism of hot spring. To conserve hot spring resources and accomplish the perspective of sustainable development, using GIS as a studying tool, this study used both the volumetric and the elastic storage methods to estimate the total volume capacity of hot springs as the reference of management of hot springs.

1. Introduction

In recent years, due to the flourishing tourism industry, large numbers of hot spring hotels and condominiums were built in hot spring areas, resulting in a significant increase in the use of hot spring. In order to prevent excessive development and to conserve hot spring resources, the Yilan country government has been actively proposing relevant policies and regulations for the development and management of hot spring tourism. A management plan for hot spring areas was also developed in 2010 by the county government [1]. The contents of the plan include hot spring inspection and monitoring, maintenance and updating of management systems, estimation of total volume capacity of hot springs, and determination of the area of hot springs.

In 2015, one large hotel in the Jiaoxi hot springs used the well point method for excavation works in the basement. This resulted in neighboring residents being unable to draw hot spring water and a dramatic decrease in hot spring temperature. This has made the authorities alert whether the hot spring resources were depleted, which, together with the increase in hot spring water usage, and changes in hydrological conditions, made the capacity of hot springs the major issue.

2. Study Area

The study area was mainly based on Jiaoxi village of Yilan country. The reservoirs layer of Jiaoxi hot springs are distributed between the Szeleng-Ss plate and the alluvial layers, and the hot spring outcrop locations were distributed in the Tangweigou area. This area has water gushing out throughout the entire year, which has high water temperature, and obvious hot spring signs. Therefore in 2010, the government started management and planning operations. At that time, the total development potential for hot springs was estimated at up to14,326 CMD. However, due to excessive development of hot springs in recent years, it is required to reevaluate the total volume capacity of hot springs[2].

3. Estimation Model of Total Volume Capacity

Aimed to estimate the total hot spring capacity, this study is required to establish a formation mechanism model , including the area of the reservoir layer, characteristics, filling mechanisms and source of the hot springs [3].

With different geological conditions, hot springs of Yilan County have different storage and filling mechanisms but their formation was largely due to groundwater entering a heat source along underground fissures to form a hot water reservoir layer. When the replenishment and usage of

groundwater is balanced, the storage volume remains unchanged. However, when the replenishment amount decreases or when the usage amount increases, the storage volume would decrease. Hydrological and geological conditions were used as a basis for establishing a theoretical model and estimating relevant parameters of the rock layer and alluvial layer to estimate storage volume and replenishment volume.

This study used the following estimation models to estimate storage volume:

3.1 The Volumetric Methods

The volumetric method, expressed in the following formula, was used to calculate the volume of groundwater that could be stored in void spaces of aquifers (groundwater storage volume) under conditions of atmospheric pressure, where the volume of the hot spring area was multiplied by the effective porosity to obtain the storage volume. This calculation formula is expressed below [4]:

$$Q = V \times \eta \quad (1)$$

Q：Total Volume Capacity [m^3]

V：The Volume of Reservoir Layer [m^3]

η【ef】：Effective Porosity [%]

The total volume capacity of hot springs can be expressed by its area and thickness, and the formula (1) is changed to:

$$Q = A \times T \times D \times Ef \quad (2)$$

Q：Total Volume Capacity [m^3]

A：The Area of Reservoir Layer

T：Thickness[m]

D：Specific Gravity (Assume to 1)

Ef：Effective Porosity [%]

3.2 The Elastic Storage Method

The elastic storage method refers to the amount of water released after water level of a pressurized confined aquifer decreased. This is mainly through two types of mechanisms: (1) Effective stress compresses the reservoir layer; water release is controlled by reservoir compressibility (2) Fluids expand as pressure drops; water release is controlled by fluid compressibility. This calculation formula is expressed below (Freeze etc, 1979):

$$Q = V \times S = \rho g B(\alpha + \eta\beta) \times V \quad (3)$$

S：Storage Coefficient

B：Thickness of Reservoir Layer [m]

α：Compressibility of Reservoir Layer

β：Compressibility of Fluid

4. Estimation Results

The reservoir layer of the Jiaoxi region is divided into three parts: the Szeleng-Ss layer, the Kangkou-Fm layer, and the alluvial layer. The Szeleng-Ss layer is distributed in the western side of the mountain, and its thickness, counted from an elevation of -50 meters to -400 meters, is 350 meters. The Kangkou-Fm layer is distributed below the alluvial level, and its thickness, counted from an elevation of -200 meters to -400 meters, is 200 meters. The thickness of the alluvial layer, distributed between an elevation of 0 meters to -200 meters, was estimated by drilling data at around 200 meters,

selected, where the areas with an underground resistivity below 40Ω-m were selected [5]. The hot spring capacity was estimated at 192.76~229.72 million m3 (Table 1) [6].

Table 1, Total Volume Capacity Estimation of Jiaoxi Hot Springs
(Yilan hot spring management plan, 2017)

Potential Area	Potential Range (Km^2)	Thickness (m)	Effective Porosity (%)	Temperature (℃)	Capacity×10^6 m^3
Szeleng-Ss	3.21	350	8% ~ 9%	55	89.88 ~ 101.12
Kangkou-Fm	2.66	200	4% ~ 5%	40	21.28 ~ 26.60
Alluvium	2.04	200	20% ~ 25%	40	81.60 ~ 102.00
Total					**192.76 ~ 229.72**

This calculation result was compared with that from the 2010 Yilan hot spring region management plan (Table 2) [1]. It was found that the Jiaoxi hot spring capacity decreased by 10~12 million m3 and temperature decreased by about 5°, indicating that the flourishing tourism industry has a huge impact on hot spring resources. How to maintain the sustainable development of hot spring resources is an important issue that the government needs to carefully evaluate and ponder.

Table 2, Total Volume Capacity Estimation of Jiaoxi Hot Springs
(Yilan hot spring management plan, 2010)

Potential Area	Potential Range (Km^2)	Thickness (m)	Effective Porosity (%)	Temperature (℃)	Capacity×10^6 m^3
Consolidated	2.614	600	8% ~ 9%	60	125.2 ~ 141.1
Alluvium	1.988	200	20% ~ 25%	45	79.5 ~ 99.4
Total					**204.8 ~ 240.5**

Besides understanding the current situation of hot spring resources, estimation of hot spring capacity is an important basis for approving hot spring development. This estimation could be used for the delineation and modification of the area of the Jiaoxi hot springs when used in combination with relevant data such as the safe yield (Table 3) of the hot springs, constituent elements of the hot spring area, development direction and urban planning of hot spring areas, and other modification condition. After the area of hot springs is revised (Fig.1), overlaying urban planning map by GIS can be used (Fig. 2) as a reference source for planning of public water supply pipelines.

Table 3 , Safe Yield of Jiaosi Hot Spring (Yilan hot spring management plan, 2017)

Hot Spring	Water Balance Method Safe Yield (CMD)	Water Table Fluctuation Annual Recharge(mm)	Annual Recharge Zoning Ratio	Zoning Safe Yield(CMD)
Jiaosi	15,306	Monitor Station 1：1,852	55.4%	8,479
		Average Station 2-3：747	22.4%	3,429
		Monitor Station 4：743	22.2%	3,398

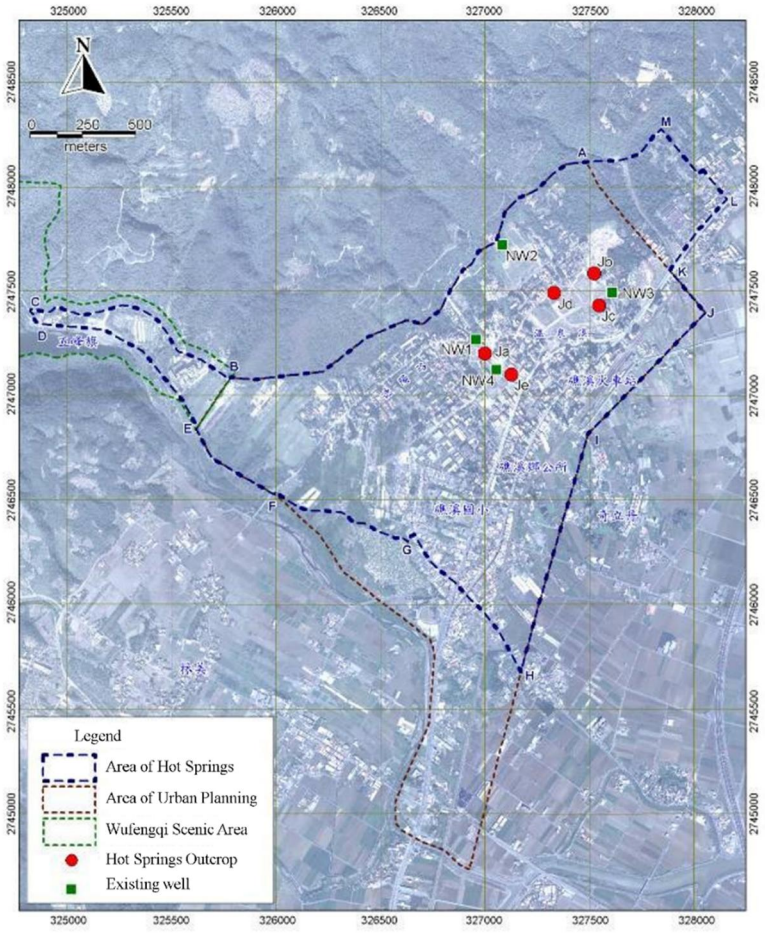

Fig. 1, Area of Jiaosi Hot Springs (Yilan hot spring management plan, 2017)

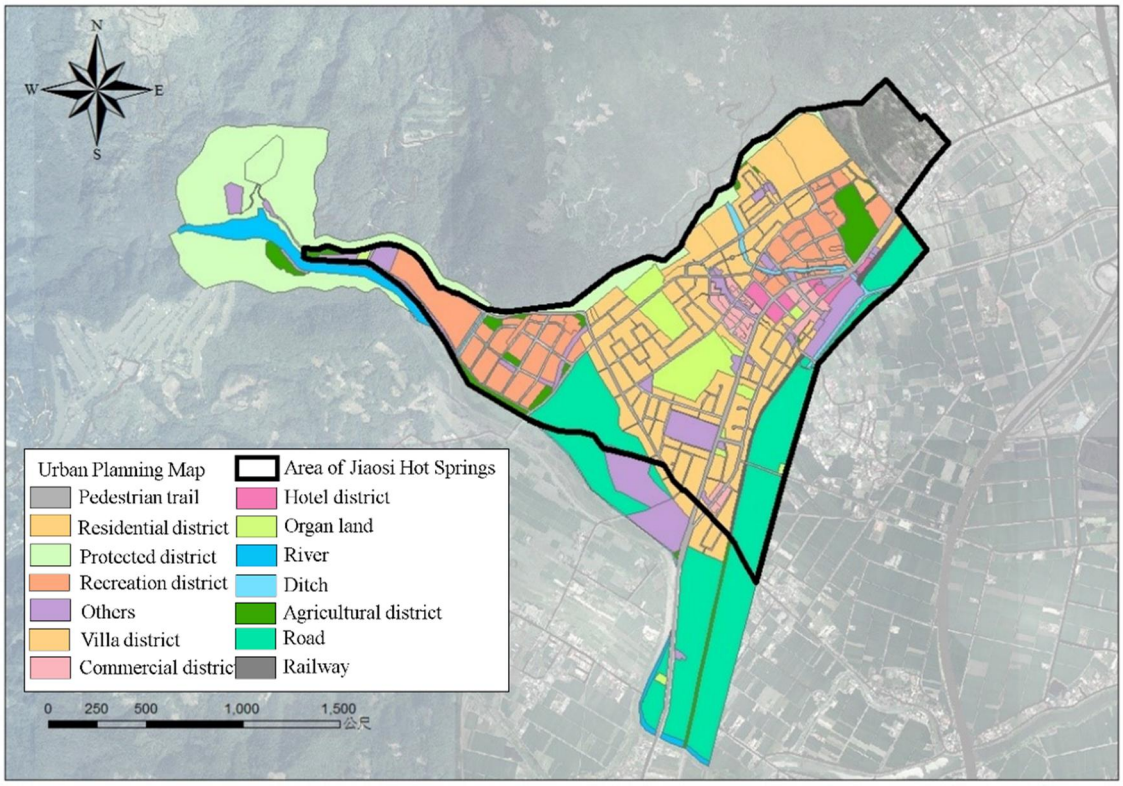

Fig. 2, Map Overlay with Area of Jiaosi Hot Springs and Urban Planning Map

5. Conclusion and Recommendations

With the estimation results of the total volume capacity, conclusions and recommendations were listed below.

(1) The capacity were estimated at 192.76–229.72 million m3 using the volumetric and elastic storage methods.
(2) The total capacity of Jiaoxi hot spring decreased by 10–12 million m3 from 2010 to 2017.
(3) Comparison of the water temperature of the various rock layers in Jiaoxi hot springs showed that the overall water temperature decreased by 5° from 2010 to 2017.
(4) The evaluation methods for capacity showed differences with the depth of different strata; hot spring capacity could be estimated using different depths in the future.
(5) Excessive development imposed a huge impact on hot spring resources and government agencies should carefully evaluate and ponder the feasibility of current policies.
(6) Results of map overlay with area of Jiaosi hot springs and urban planning map could be used as a reference for planning and setting up public hot spring pipelines in the future.

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