The United Nations University

GEOTHERMAL TRAINING PROGRAMME
Orkustofnun, Grensásvegur 9,
IS-108 Reykjavík, Iceland

Reports 2003
Number 11

# ENVIRONMENTAL IMPACT OF GEOTHERMAL DEVELOPMENT IN HENAN PROVINCE, CHINA

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### ABSTRACT

Sustainable development is a key concept that has gained increasing international acceptance. Geothermal energy currently plays an important part in clean energy supply. The impacts of geothermal development are often positive. However, it is important that the environmental issues associated with development be addressed in a systematic way. A well-prepared Environmental Impact Assessment (EIA) can significantly minimize or eliminate the environmental impacts at an early planning stage. Henan Province is rich in low-temperature geothermal resources. More than 300 geothermal wells have been drilled since the 1980s, and are used for balneology, swimming, and space heating. In this report, the benefits of geothermal development, environmental impacts, mitigation methods, and measures to promote geothermal development in Henan Province are discussed.

## 1. INTRODUCTION

Henan Province is rich in low-temperature geothermal resources. The geothermal resources are employed for space heating, driving heat pumps, and heating greenhouses. Although geothermal energy is generally perceived as environmentally friendly, experience has shown that some potential environmental impacts are associated with it, for which mitigation is required. For a large populous province suffering from water resource scarcity, any forms of unsuitable geothermal development will enhance the imbalance.

To make proper decisions and apply appropriate mitigation measures, it is critical to understand the nature of geothermal resources, the types of development, and the possible effects on the environment. To these ends Environmental Impact Assessment (EIA), a systematic process to identify, predict and evaluate environmental effects of proposed projects, is generally deployed. The purpose of this paper is to study the environmental impacts of geothermal development with reference to the EIA process, and thus promote wiser use and development of geothermal resources in Henan Province. Although the impacts of geothermal development projects are often positive, different types of geothermal fields and geothermal development have varying impacts.

## 2. ENVIRONMENTAL IMPACT ASSESSMENT

### 2.1 Introduction

Sustainable development is a key concept that has gained increasing international acceptance in the world. Environmental Impact Assessment (EIA) is an important tool to promote sustainable development by integrating environmental considerations into a wide range of proposed actions. Simply defined, EIA is a systematic process to identify, predict, and evaluate the environmental effects of proposed projects. The purpose of EIA is to provide information for decision-making on the environmental consequences of proposed actions, and promote environmentally sound and sustainable development through the identification of possible impacts and mitigation measures.

### 2.2 The EIA process

Environmental Impact Assessment (EIA) has become a widespread and popular instrument in the environmental decision-making process. It started in the USA in the 1960s and spread thereafter to various other countries (Thors and Thóroddsson, 2003). Currently, most countries have set up their own EIA systems. The particular components, stages, and activities of an EIA process usually depend upon the requirements of the individual countries. However, most EIA processes have a common structure (Figure 1), and the application of the same main stages is a basic standard of good practice. Typically, the EIA process begins with screening to ensure that time and resources are directed to the proposals that matter environmentally; and ends with some form of follow-up on the implementation of the decisions and actions taken as a result of an EIA report. The EIA process highlights the following stages (taken from Sadler and Fuller, 2000):

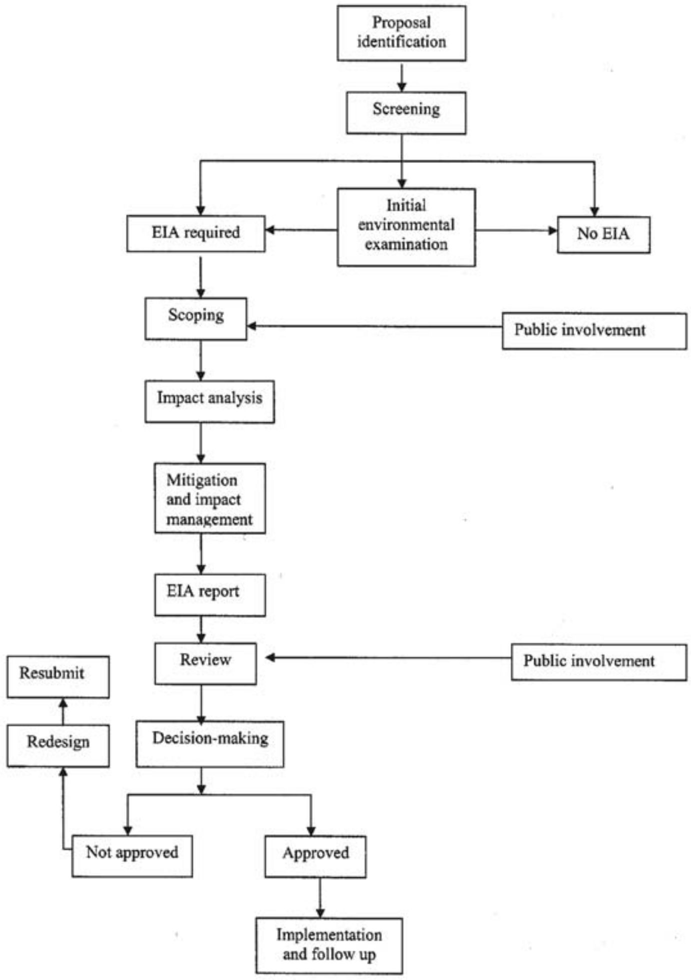


FIGURE 1: Generalised EIA process flowchart (Sadler and Fuller, 2002)

- **Public involvement:** To inform the public about the proposal and to obtain the inputs of those directly affected by or interested in the proposal. Public involvement in some form is possible throughout the EIA process, although it tends to focus on the scoping and review phases of EIA.
- **Screening**: To decide whether or not a proposal should be subject to the EIA process and, if so, in what detail.
- **Scoping:** To identify the key issues and impacts that are likely to require further investigation, and to prepare the terms of reference for the EIA study.
- **Impact analysis**: To identify and predict the likely environmental and social effects of the proposal and evaluate their significance.
- **Mitigation and impact management:** To develop measures to avoid, reduce or compensate for impacts, making good any environmental damage.

- **Reporting:** To describe the results of the EIA to decision-makers and other interested parties.
- **Review of EIA quality:** To examine the adequacy of the EIA report to see if it meets the terms of reference and provides the information necessary for decision-making.
- **Decision-making:** To approve or reject the proposal and set the terms and conditions under which it can proceed. The decision-maker also has the option to defer approval.
- **Implementation and follow up:** To check on the implementation of the terms and conditions of approval during the construction and operation phases; to monitor the impacts of the project and the effectiveness of mitigation measures; to take any actions necessary to ameliorate problems; and, as required, to undertake audit and evaluation to strengthen future EIA applications.

### 2.3 EIA in geothermal projects

Plans and projects that require an EIA are increasing in numbers. Geothermal development may have impact on the physical, chemical, biological, social, and economic aspects of the environment. It is necessary that geothermal development is associated with a well-defined EIA system.

Some countries, for example, Iceland, Italy, U.S., Philippines, and New Zealand have set up systematic geothermal regulations. With the continued development of geothermal resources, more countries have followed the U.S. and funding agencies, and adopted a recommendation of EIA for geothermal development.

### 2.4 Environmental Impact Assessment in China

EIA in China is based on foreign experience, combined with its own situation, and has been developed in several steps. At present, a practical EIA system for construction projects has been formed. However, there is still no regulation or law on EIA for geothermal development in China. The implementation of EIA in China started in the 1980s. In 1992, the Chinese government made it compulsory for construction projects to be evaluated before project takeoff, and thus to utilize EIA sufficiently as a decision-making tool.

On October 28, 2002, the People's Republic of China Environmental Impact Assessment Act, which took effect on September 1, 2003, was approved by the top legislature, the Standing Committee of the Ninth National People's Congress (NPC). The purpose of this Act is to provide China with a sustainable development strategy, and prevent the implementation of planning and construction projects from having an adverse impact on the environment. Projects to be carried out, that require an EIA, are those that are concerned with utilization of land, construction, development and utilization of regions, drainage, and sea areas. The law extends EIA procedures to government plans, and makes the environmental impact assessment of some government plans subject to comments by the public as well as by experts and by other interested parties.

## 3. OVERVIEW OF HENAN PROVINCE

### 3.1 Geographical setting and climate

Henan Province, which lies between 102˚ 21' E - 116˚ 39' E longitude and 31˚ 23' N - 36˚ 24' N latitude, is located in eastern central China, on the plain between the Yellow and Huaihe rivers, covering an area of over 160,000 km$^2$ (Figure 2). The Province is in a transitional area between the second and third steps of China's four-step terrain rising from east to west, with rolling mountains over 1,000 m a.s.l. in its western part and a plain area at 100 m or lower in the east. In its middle and eastern parts lies a vast fluvial plain created by the Yellow, Huaihe and Haihe rivers. Four rivers run across the Province, the

Yellow River, the Huaihe River, the Weihe River, and the Hanshui River, with the Huaihe River valley extending over up to 53 percent of the Province.

Located between the northern sub-tropical and warm temperate zones, Henan Province has four distinctive seasons with complex weather conditions characterized by a hot and rainy summer, a dry and windy winter, and spring. Rainfall averages about 600-1000 mm/year, increasing from north to south. The annual temperature increases from about 12.8˚C in the north to 15.5˚C in the south, with the frost-free period lasting about 300 days.

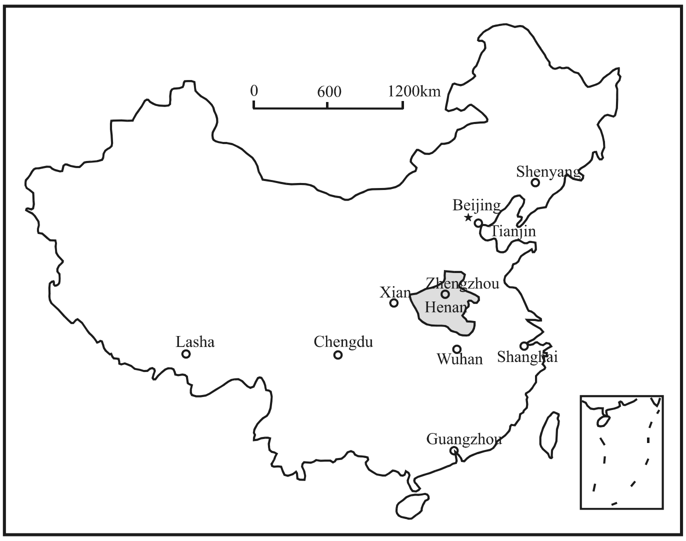


FIGURE 2: Location map of Henan Province in China

### 3.2 Social and economic aspects

Henan is an agriculture-based province with about 92.56 million people and with a population density of 554 persons per $km^2$. The distribution is uneven with fewer people in the western part and more in the eastern. The urban population is only 23.20% of the total population. The capital city, Zhengzhou serves as a bridge connecting east and west, south and north. It is also a centre of culture and economy, playing an important role as a centre for business and trade. It now has an urban population of 1.69 million. By the year 2005, the urban population is projected to be 2 million. In 2000, the Gross Domestic Product (GDP) of Henan was 514 billion Yuan, and the per capita gross domestic product was 5,444 Yuan. The total financial revenue of the local government was 24.65 billion Yuan, while the total expenditures were 44.55 billion Yuan, and the total investment in fixed assets was 147.57 billion Yuan. A large population puts great pressure on the environment, and thus aggravates environmental pollution.

### 3.3 Natural resources

Of the more than 150 types of exploitable minerals found on earth, 121 are available in Henan, of which, reserves of 78 have been identified; 61 have been mined and utilized. In terms of reserves, 48 of Henan's minerals are listed among the top 10 in China, of which molybdenum, blue asbestos, grit stone, natural alkali, perlite, sapper and andalusite are listed as No. 1, and bauxite, natural hone, and limestone for producing cement are assessed as No. 2. There are also rich reserves of minerals like wolfram, cesium, nickel and gold, and also of marble, coal, petroleum, and natural gas, (Zeng et al., 1992). There are 3,830 species of higher plants, and 418 kinds of animals in Henan. It is an important producer of China's wheat, corn, cotton, tobacco leaves, and oil plants.

### 3.4 Tourism

As one of the birthplaces of Chinese civilization, Henan has had several epoch-making archaeological discoveries, including the Peiligang culture site dating back 7,000 years, the Yanshao culture site some 6,000 years old, and the Dahe culture site that is more than 5,000 years old. In ancient China, more than 20 dynasties established their capitals in Henan. Three of China's seven great ancient capitals are located in Henan: Anyang of the Shang Dynasty, Luoyang of nine dynasties and Kaifeng of seven dynasties. The province numbers one in the whole country in terms of underground cultural relics, and numbers two in existing cultural relics on the ground. The Yellow River, with numerous ancient relics and scenic attractions, also provides Henan with a rich tourist resource.

# 4. GEOTHERMAL BACKGROUND

## 4.1 Introduction

The geothermal systems in Henan Province can be divided into two groups depending on the mode of heat transfer – convective and conductive. The former are mainly located in western mountain areas where there are lots of hot springs along the main deep faults (Figure 3), while the latter are in the eastern plain and the Nanyang basin.

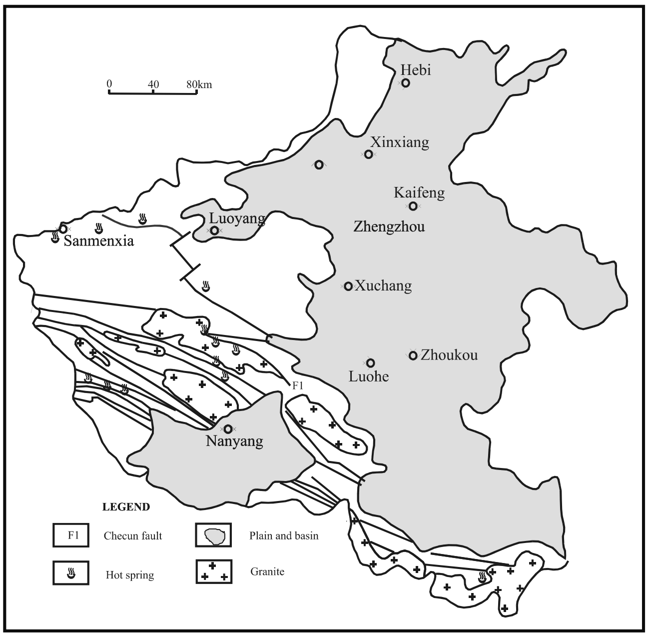

FIGURE 3: Distribution map of hot springs related to deep faults in Henan Province

Good permeability in thick layers causes the eastern basin to form a regional low-temperature reservoir. A series of small uplifts and depressions has formed due to uplift or subsidence of the Mesozoic and Cenozoic rocks (Figure 4). The uplifts include the Neihuang lift, the Tongxu lift, the Pingyu-Xiping lift, and the Luxi lift; while the depressions include the Tangyin depression, the Dongming depression, the Jiyuan-Kaifeng depression, the Zhoukou depression and the Zhumadian-Huaibin depression. In general, the geothermal reservoir conditions in depressions are better than in uplifts. The regional geothermal aquifers are composed of Mingzhen and Guantao groups of the upper Tertiary, the lower Tertiary, and Cambrian-Ordovician.

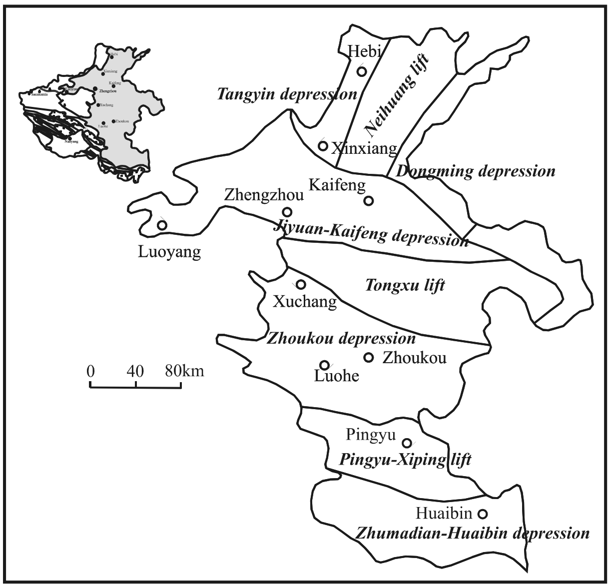

FIGURE 4: The distribution of uplifts and depressions in the eastern plain of Henan Province

The Mingzhen group is mainly situated in Kaifeng, Puyang, Luohe and Zhoukou. The depth to the geothermal reservoirs is in the range from 750 to 1200 m. The aquifer is composed of mealy sand and medium sand. Water production from a single well is 50-60 $m^3$/h in Kaifeng, 30 $m^3$/h in Luohe, Zhoukou and Puyang. The water in most places can be used as drinking water.

The Guantao group is mostly located in Zhengzhou, Xinxiang, Puyang and Zhoukou. The depth to the geothermal reservoirs varies from 700 to 2200 m. The aquifer is mostly composed of mealy sand and middle sand. In general, water production is 30-40 $m^3$/h. Water quality in Zhengzhou, Zhoukou and Puyang is relatively good, but worse in Kaifeng and Xinxiang where mineralization is higher than 3 g/l.

The lower Tertiary is mainly in the Jiyuan and Luoyang basins. The burial depth of the geothermal reservoirs varies from 800 to 1800 m. The aquifer is mainly composed of mealy sand. In general, water production is 10-20 $m^3$/h with mineralization higher than 2 g/l.

A large area of Cambrian-Ordovician limestone is deeply buried in the eastern plain areas such as Hebi, Puyang, Xinxiang, Zhoukou and Luohe. The burial depth of the aquifer roof varies from 700 to 3000 m. Two wells more than 3200 m deep have been drilled in Hebi.

### 4.2 History of geothermal utilization and development in Henan Province

Geothermal springs have been used in Henan Province since the dawn of civilization mainly for healing, disease prevention, and bathing. An overall geothermal resource survey began in the 1960s. From 1980, geothermal prospecting and exploration have been conducted in over 20 cities/counties. Water temperature and production at 1000 m in the plains area were predicted with the aid of data from geothermal wells and oil wells. So far, more than 300 geothermal wells have been drilled within the whole province for the purposes of balneology, bathing, greenhouse growing, and space heating. Most hotels and sanatoria have drilled their own production wells as a supplementary service facility to attract more customers.

The main geothermal fields are located in cities of considerable population density, so there is a great potential and demand for geothermal space heating in Henan Province. However, due to lack of funds and advanced technology, the current exploitation depth is restricted between 600 and 1500 m depth. In most cities, such depths cannot provide high enough temperature for space heating. Kaifeng city, located to the east of Zhengzhou, was the first to install geothermal space heating. Following Kaifeng city, Zhengzhou has been developing space heating for the last few years. In addition, the use of heat pumps has started in some buildings in Zhengzhou city.

### 4.3 Characteristics of major fields mining heat by conduction (Tertiary aquifer)

The temperature gradient in the sedimentary basin is in the range 2.5-3.2˚C/100 m. In general, the temperature is 40-45˚C at 1000 m and 65-67˚C at 1500 m. An analysis of deep oil exploration wells shows that in the deeper aquifer 113˚C geothermal water can be expected at 3100 m depth.

The current production areas are mainly concentrated in several highly populated cities such as Zhengzhou, Kaifeng, Zhoukou, Xuchang, Nanyang, Luoyang, and Xinxiang. The geothermal water in most places is of good quality, and can even be used as potable water such as in Zhengzhou. Salinity is in the range from 0.8 to 6 g/l, and the tendency is for the salinity to increase with depth (Figure 5). Table 1 shows the main characteristics of the explored Tertiary geothermal fields in plains and basins, and Table 2 shows the chemical composition of some geothermal waters from the Tertiary fields in the plain area.

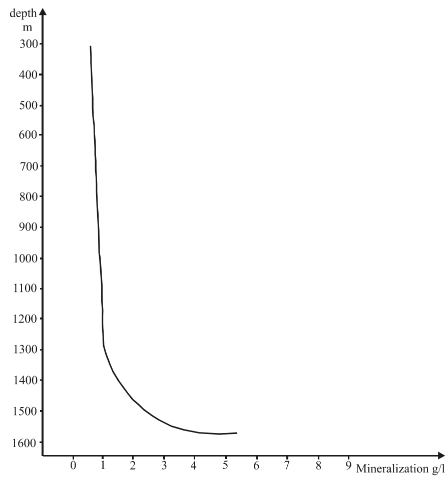

FIGURE 5: Mineralization of geothermal water vs. depth in the eastern plain (Zhu et al., 2002)

### 4.4 Characteristics of the Hebi field (Cambrian-Ordovician aquifer)

For the purpose of developing geothermal resources and attracting tourists to the city, two deep wells have been drilled in Qibin, a new district of Hebi, which is located in the Tangyin graben. The production strata is Cambrian-Ordovician limestone, with an area of about 188 km$^2$. This area has experienced many periods of tectonic activity, and the main faults have a north-northeasterly, northeasterly and easterly trend. The geothermal field is controlled by faults and the water quantity is large in the place near the fault belts.

In addition, there is a potential of rich $CO_2$ resources of high purity in this field. The gas-water ratio of well 1 is 14.2:1 and the $CO_2$ content of the gas can be as high as 99.93%. It is estimated that exploitable geothermal water is $1.39 \times 10^8$ m$^3$ and the $CO_2$ reserves are $16 \times 10^8$ m$^3$. Tables 3 and 4 show data on these two deep geothermal wells, and the chemical composition of geothermal water in Hebi, respectively.

TABLE 1: Main characteristics of explored Tertiary geothermal fields in plain and basins (Zhao et al., 2003)

| **City** | **Area ($km^2$)** | **Lithologic age** | **Reservoir depth (m)** | **Well flow rate ($m^3/h$)** | **$T_{max}$ (°C)** | **Water quality assessment** | **Annual available water volume ($10^6$ $m^3$)** | **Exploitation potential** | **Remark** |
|---|---|---|---|---|---|---|---|---|---|
| Zhengzhou | 400 | N | 1000-1200 | 55 | 52 | Good quality | 16 | E-O aquifer resources between 1500 and 2800 m not known; In the northeast part of the city, N aquifer resources between 1500 and 2500 m not known | In some places over-exploitaton leads to mixing with shallow groundwater |
| Kaifeng | 1600 | N | 1600-1800 | >60 | 75 | Below 1300 m depth high mineralization, $Ca^{2+}$, $Mg^{2+}$, $Cl^-$ | 64 | Resources below 1800 m not known. | In some places over-exploitation has led to drying up of some wells |
| Zhoukou | 600 | N | 1000-1600 | 40-50 | 50 | Good quality | 7.3 | E-O aquifer resources not clear | |
| Xuchang | 766 | N | 1100-1300 | | 60 | Mostly good quality, some places high $Cl^-$ and $SO_4^{2-}$ | 8.3 | Resources below 1200 m not known | |
| Nanyang | 820 | E | 600-2000 | 40-50 | 50 | High $F^-$ | 12.1 | Resources below 2000 m not known | |
| Luoyang | 275 | E | 1100-1700 | 20 | 65 | High $I^-$ | 4.2 | | |
| Hebi | 188 | $O_l$ | 2000-3500 | 77 | 74 | High $Cl^-$, $SO_4^{2-}$ | 3.24 | | High content $CO_2$ |
| Xinxiang | 72 | N | 800-1300 | 20-25 | 46 | High $F^-$ | 14.43 | $O_2$ aquifer resources at 1500-2500 m not known | |

N: Neogene; E: Eocene; $O_l$: Lower Oligocene

TABLE 2: Chemical composition of geothermal water from Tertiary fields in the plain area in Henan Province (Zhu et al., 2002)

| City | Depth (m) | pH | $Na^++K^+$ (mg/l) | $Ca^{2+}$ (mg/l) | $Mg^{2+}$ (mg/l) | $HCO_3^-$ (mg/l) | $SO_4^{2-}$ (mg/l) | $Cl^-$ (mg/l) | $H_2SiO_3$ (mg/l) | $Sr^{2+}$ (mg/l) | $F^-$ (mg/l) | Mineralization (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kaifeng | 600-800 | 8.10 | 189.75 | 8.22 | 4.25 | 385.64 | 70.60 | 43.00 | 26.00 | 0.23 | 0.69 | 407.64 |
| | | 8.43 | 201.47 | 4.50 | 2.50 | 434.20 | 50.48 | 38.04 | 23.26 | 0.23 | 0.92 | 504.01 |
| | | 8.20 | 214.13 | 4.01 | 3.64 | 476.57 | 48.51 | 33.32 | 26.00 | 0.23 | 0.99 | 543.05 |
| | 800-1600 | 8.59 | 236.80 | 5.53 | 1.98 | 507.95 | 49.00 | 41.66 | 27.90 | 0.22 | 0.30 | 589.05 |
| | | 8.20 | 237.70 | 4.01 | 2.43 | 473.52 | 81.17 | 45.00 | 20.60 | 0.21 | 2.40 | 607.58 |
| | | 8.40 | 302.20 | 3.01 | 2.43 | 640.10 | 88.38 | 35.10 | 31.20 | 0.20 | 0.99 | 753.77 |
| | | 8.32 | 275.17 | 4.40 | 1.50 | 604.30 | 57.96 | 32.61 | 31.23 | 0.24 | 2.00 | 675.02 |
| | | 7.90 | 645.50 | 9.82 | 3.77 | 546.76 | 287.71 | 469.71 | 32.50 | 0.51 | 1.22 | 1692.40 |
| | | 8.20 | 259.20 | 5.01 | 2.43 | 562.60 | 49.95 | 40.06 | 37.70 | 0.16 | 1.60 | 639.33 |
| | | 8.10 | 270.22 | 3.01 | 3.52 | 581.52 | 72.53 | 29.07 | 36.40 | 0.22 | 1.20 | 670.93 |
| | | 8.00 | 231.50 | 4.01 | 3.64 | 528.43 | 62.44 | 32.97 | 36.40 | 0.20 | 1.10 | 600.18 |
| | | 8.20 | 232.55 | 3.43 | 1.34 | 532.65 | 47.10 | 26.64 | 35.50 | 0.24 | 1.60 | 578.73 |
| | | 8.40 | 278.11 | 3.01 | 2.43 | 604.71 | 61.96 | 36.16 | 33.80 | 0.24 | 1.60 | 685.87 |
| | | 7.20 | 1625.00 | 101.80 | 27.36 | 236.76 | 44.67 | 2578.99 | 54.60 | 7.65 | 0.74 | 4544.32 |
| Zhoukou | 800-1300 | 8.32 | 311.65 | 25.28 | 12.30 | 613.56 | 126.34 | 30.39 | 30.84 | | 1.41 | 792.02 |
| | | 8.36 | 361.57 | 5.61 | 1.94 | 629.72 | 176.75 | 42.18 | 26.00 | 0.23 | 2.04 | 906.08 |
| | | 8.20 | 385.97 | 5.61 | 1.94 | 615.08 | 178.67 | 86.85 | 31.60 | | 2.25 | 996.15 |
| Luoyang | 1350 | | 711.7 | 188.58 | 61.11 | 223.33 | 1442.82 | 410.51 | 36.40 | 1.42 | 1.20 | 3076.92 |

TABLE 3: Data on geothermal wells in Hebi (Deng et al., 2003)

| **Well name** | **Depth (m)** | **Outflow temperat. (ºC)** | **Perforation** | **Production rate** | **Production type** | **Gas-water ratio** | **Gas composition** |
|---|---|---|---|---|---|---|---|
| 1 | 3276 | 74 | Ordovician | 1847 $m^3/d$ | Artesian | 14.2:1 | $CO_2$ 82.94~99.93%<br>$CH_4$ 0.07~17.56% |
| 2 | 3318 | 58 | Cambrian | 50 $m^3/h$ | Periodic artesian | | $CO_2$ 97.07%<br>$N_2$ 2.93% |

TABLE 4: Chemical composition of geothermal water in Hebi (mg/l) (Deng et al., 2003)

| | **Well 1** | | | | **Well 2** |
|---|---|---|---|---|---|
| Analysis date | 2002.5.19 | 2002.9.24 | 2002.12.29 | 2002.9.25 | |
| $K^+$ | 575.30 | 661.6 | 606.30 | 619.4 | 527 |
| $Na^+$ | 292.60 | 277.43 | 282.27 | 302.4 | 266.2 |
| $Ca^{2+}$ | 278.36 | 307.81 | 411.42 | 390.8 | 486.2 |
| $Mg^{2+}$ | 108.38 | 102.42 | 109.47 | 104.0 | 147.4 |
| $Cl^-$ | 38.64 | 38.64 | 39.35 | 39.21 | 586.4 |
| $SO_4^{2-}$ | 587.89 | 577.32 | 627.75 | 630.5 | 598.5 |
| $HCO_3^-$ | 2252.90 | 2409.07 | 2716.0 | 2555 | 2008 |
| TDS | 4187.2 | 4429.96 | 4857.8 | 4718.6 | 4699 |
| pH | 6.63 | 6.78 | 6.75 | 6.90 | 6.89 |
| Water type | $HCO_3$-K·Ca<br>$HCO_3$-Ca·K | $HCO_3$-K·Ca<br>$HCO_3$-Ca·K | $HCO_3$-K·Ca<br>$HCO_3$-Ca·K | $HCO_3$-K·Ca<br>$HCO_3$-Ca·K | $HCO_3$·Cl-Ca |

## 4.5 Characteristics of resources mining heat by convection

Geothermal resources mining heat by convection are mainly found in the western mountains. Rich hot springs are distributed there along deep faults (Figure 3). The most famous are the five hot springs along the Checun fault. The Checun fault is situated in the collision belt of the Yangtze plate and the North plate. The water temperature of the springs is 50-69˚C. Due to high fluorine, the water is used for medical treatment. Table 5 shows the chemical composition of hot springs in the Checun fault.

TABLE 5: Chemical composition (mg/l) of hot springs in Checun fault (Zhao and Liu, 2000)

| | **Shangtang** | **Zhongtang** | **Wentang** | **Xiatang** | **Jianchang** |
|---|---|---|---|---|---|
| Temperature (˚C) | 61 | 61 | 49 | 61 | 50 |
| Artesian yield ($m^3/h$) | 53.35 | 10.7 | 2.2 | 30.71 | 4.62 |
| pH | 8.20 | 8.20 | 7.80 | 8.20 | 8.10 |
| Alkalinity | 0.374 | 0.35 | 0.364 | 0.40 | 0.497 |
| $Cl^-$ | 24.70 | 2360 | 24.50 | 34.20 | 37.40 |
| $SO_4^{2-}$ | 115.30 | 90.80 | 93.70 | 98.50 | 178.00 |
| $HCO_3^-$ | 148.80 | 165.50 | 170.50 | 174.80 | 159.0 |
| $CO_3^{2-}$ | | | 0.00 | 0.00 | 0.00 |
| $F^-$ | 16.00 | 17.00 | 17.00 | 17.50 | 15.00 |
| $Na^+$ | 133.50 | 135.50 | 135.50 | 143.90 | 168.40 |
| $K^+$ | 1.20 | 1.20 | 1.70 | 4.80 | 4.40 |
| $Ca^{2+}$ | 7.80 | 4.80 | 7.00 | 10.00 | 11.20 |
| $Mg^{2+}$ | 0.00 | 0.00 | 0.00 | 0.00 | 1.20 |
| $As^-$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $SiO_2$ | 40.0-68.1 | 50.0-78.8 | | 40.0-86.9 | 97.5 |

## 5. ENERGY AND ENVIRONMENT

### 5.1 Current environmental problems

Henan is an overpopulated province coupled with fast economic growth over the past 20 years. Industrialization and urbanization, accompanied by inadequate infrastructure investment and management capacity, have caused serious environmental damage. Environmental problems such as water contamination, water scarcity, air pollution, soil degradation and erosion, land subsidence, industrial and mine solid disposal are quite serious.

The surface water system is very contaminated with raw sanitary wastes, industrial wastes and agricultural chemicals. Of the surface water, only 23.6% reached national Grade III standard. More than 55.1% of the surface water was among the most seriously polluted. Small-scale township and village enterprises, which are very difficult to monitor and regulate, routinely dump their untreated waste directly into streams and rivers. It is estimated that polluting enterprises discharge over 100 tons of waste water per day along the Huai river in Henan, and degradation and decrease of land resources cause 1.6 billion tons/yr of silt being dumped into the Yellow river in Henan and its neighbouring provinces.

Due to surface water contamination, the extraction of groundwater has been increased. As a result of over-extraction of groundwater, land subsidence and lowering of the water table occur in many cities, and cones of depression are becoming larger.

Due to fossil fuel energy, Henan Province suffers from severe air pollution. The heavy use of uncleaned coal leads to large emission of sulphur dioxide and particulates. At the same time, in the vast rural areas, soil degradation caused by chemical fertilizers and pesticides is widespread. Funding and efforts are urgently needed in curbing pollution and waste to stop any further environmental deterioration. Henan's local government has planned to invest 30,000 million Yuan on environmental improvement during the current Five Year Plan (2001-2005). The working emphasis is mainly on controlling water contamination and air pollution.

At present, there are 19 established nature reserves on 1.36% of the province's land, and three national geology parks. The forest cover is 19.83% of Henan Province.

### 5.2 Energy consumption and air quality

Energy consumption in Henan Province is rising with economic growth increasing by 42% from 1991 through 1999. The province depends on coal for 80% of its energy (in 1999), which is the ninth highest coal dependency rate among the 31 provinces in China. Coal is widely used in factories and power stations, as well as for home heating. Compared to Japan, the USA, and India, where energy from coal account for 14%, 22%, and 53%, respectively, coal consumption in China including Henan Province is quite high.

In Zhengzhou city, the capital of Henan Province, coal consumption is about 26-27 million tons per year, of which about 0.6 million tons are used for space heating in the city centre. This energy structure, with high dependence on coal brings about severe air pollution from emissions of sulfur oxides (SOx), nitrogen oxides (NOx), dust, and other pollutants. Total $SO_2$ emissions in 2000 reached 877,000 tons for the whole province.

Of the 18 cities in Henan Province, 14 have Total Suspended Particle (TSP) levels that exceed the National Atmospheric Environment Grade 2. The TSP production in Zhengzhou reaches approximately 27 tons/$km^2$ per month. Among the 113 air pollution controlling cities in China, 7 are in Henan Province: Zhengzhou, Kaifeng, Luoyang, Pingdingshan, Jiaozuo, Anyang and Sanmenxia. For about 50 days, the air quality in Zhengzhou was among the most deleterious in all the cities of China, Grade 4 in 2002. From 1997, Zhengzhou has been specified a smoke controlling zone, and from 2002 Zhengzhou and Gongyi cities have both been specified $SO_2$ controlling zones.

Problems arise due to huge quantities of sulfur and nitrogen oxide emissions. In moist air, sulfuric and nitric acids are formed. The acids which are spread by the wind and precipitated by rain cause damage to forests, affect aquatic ecosystems and corrode railway tracks, roads, and most historic buildings. The high concentration of smoke and soot particles causes poor visibility and results in an increase in respiratory diseases. This situation prompted the Henan provincial government to take measures against air pollution in its 10th Five-Year Plan. Targets included 10% reductions in $SO_2$, NOx, and TSP emissions, compared to year 2000 levels; and 20% reduction in $SO_2$ emissions in cities designated as $SO_2$ pollution control zones, in compliance with the National Atmospheric Environment Grade 2. The Henan provincial government plans to pursue policies such as transition to clean energy, use of clean coal, closure of key pollution sources, and wider use of collective heating systems in order to meet its targets for improving the atmospheric environment.

## 6. BENEFITS OF GEOTHERMAL DEVELOPMENT

### 6.1 Environmental benefits of geothermal compared to fossil energy

Combustion of fossil fuels such as coal, oil, and gas have negative effects on the environment. The burning of any of these resources leads to atmospheric pollution. Coal is by far the dirtiest of these nonrenewable resources. The combustion of coal releases large amounts of carbon dioxide, nitrogen oxides, and sulfur dioxide, and small amounts of highly toxic uranium, lead, cadmium, mercury, rubidium, thallium, and zinc.

The use of oil for energy also releases carbon dioxide and nitrogen oxides. Emissions of both chemicals contribute to the formation of smog. Because of its unique distribution, much of the oil extracted from the ground must be transported by pipe to main cities. Occasionally, transported oil is spilled into the environment where it takes its toll on wildlife. Natural gas is the cleanest fossil fuel to burn. Burning it produces an amount of carbon dioxide per unit of energy released that is 50 % less than coal and one-third less than oil. In addition, burning natural gas does not cause sulfur dioxide emissions.

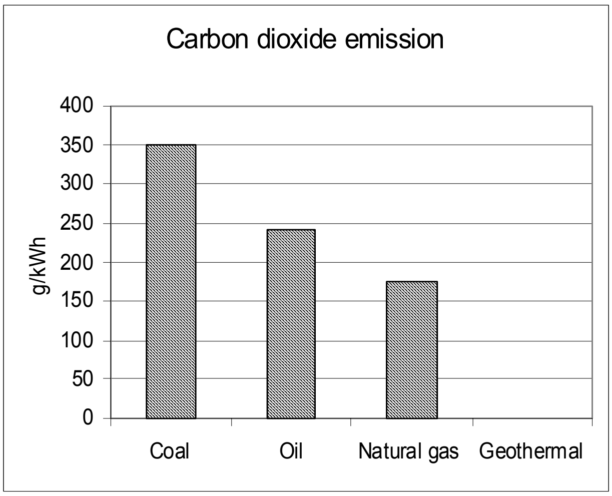


FIGURE 6: Diagram of carbon dioxide emissions from district heating systems (Data from Henan Environmental Protection Bureau, 2003)

Zhengzhou and Kaifeng’s urban population are 1.69 million and 800 thousand, respectively. Space heating is needed 120 days per year. In Zhengzhou city centre, 0.6 million tons of coal are used for space heating every year. In Figure 6, carbon dioxide emissions from district heating systems using low-temperature geothermal resources and fossil fuels based on the experience from Zhengzhou and Kaifeng are compared.

Compared to coal, oil, and natural gas, geothermal energy causes almost no pollution in terms of particulate matter, sulfur dioxide, nitrogen oxides or aromatic hydrocarbons. Moreover, geothermal energy provides an additional advantage stemming from the fact that it produces almost no carbon dioxide.

### 6.2 Comparison of economical benefits from the use of geothermal and fossil energy

Compared to conventional heating systems using solid fuel, gas fuel, or liquid fuel, geothermal water is economically competitive. Based on the experience from Tianjin, four heating systems using coal, natural

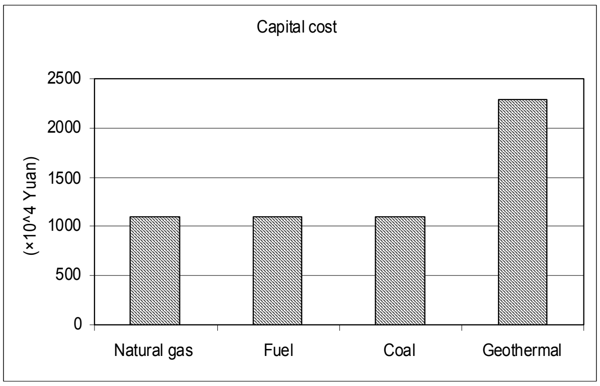


FIGURE 7: Comparison of capital costs of natural gas, fuel, coal, and geothermal energy (Zhang et al., 2000)

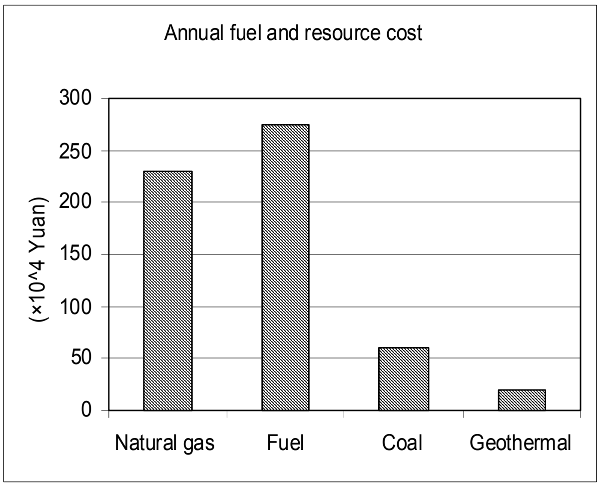


FIGURE 8: Comparison of annual fuel and resource costs of natural gas, fuel, coal, and geothermal energy (Zhang et al., 2000)

gas, fossil, and geothermal water are compared, with reference of a district heating system supplying a residential area of $12 \times 10^4$ $m^2$ floor space. The capital cost of the four approaches is shown in Figure 7. The capital cost takes into consideration the heat source, transmission and distribution network, and consumer facilities. As can be seen, the capital cost of the heating systems using coal, natural gas and fossil fuel are fairly close, and are all lower than that of the geothermal system. However, based on the current market energy cost, the geothermal system has the lowest fuel/resource cost and lowest per unit heating energy cost - only 8.9% that of diesel fuel, 10.7% of natural gas, and 45% of coal (Figures 8 and 9). The result of the comprehensive calculation reveals that the fossil fuel approach has the highest operating cost (Figure 10). The coal approach has the lowest operating cost; however, it has a fatal problem in its severe air pollution. The approach of using geothermal water has the highest capital cost, yet the lowest operating cost and the best energy utilization efficiency (Zhang et al., 2000).

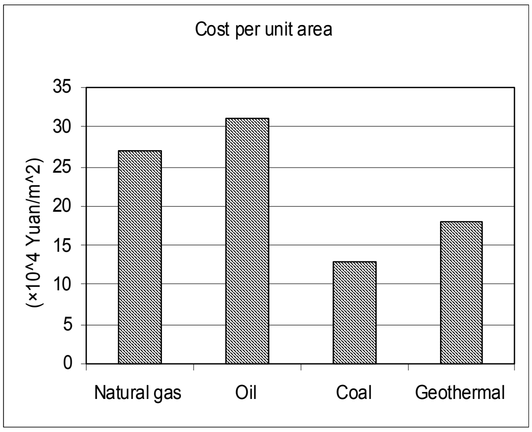


FIGURE 9: Comparison of cost per unit area of natural gas, fuel, coal, and geothermal energy (Zhang et al., 2000)

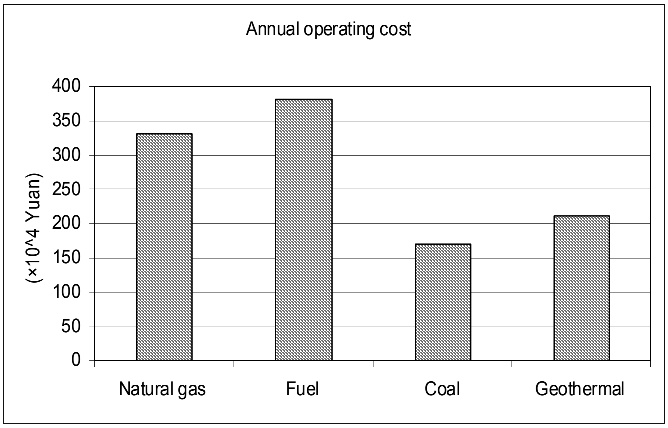


FIGURE 10: Comparison of annual operating costs of natural gas, fuel, coal, and geothermal energy (Zhang et al., 2000)

### 6.3 Health benefits for the public

Geothermal energy offers indirect benefits to the public by reducing the combustion of fossil fuels and local atmospheric pollution. Direct benefits are numerous, particularly for recreational purposes. The widespread hot springs have been associated with health and recreation, and have led to the development of resorts with spas; not only leading to the establishment of long term tourism, but also therapeutic uses, notably balneology.

Compared to other energy sources, geothermal energy is extremely well suited to large baseload heating applications such as swimming pools. Moreover, the relative abundance of energy often allows spas to be heated to higher temperatures than other conventionally heated facilities, which enhances their attraction for swimming and their suitability for clinical treatment of diseases.

### 6.4 Employment benefits

At present, urbanization has become a truly global phenomen whose increase in rate and scale is catastrophic. It is estimated that by the year 2005, the urban population of Zhengzhou will reach 2 million. The gigantic concentration of people will result in a multiple increase in the supply of water and energy to cities and a huge need for job creation.

The number of individuals directly employed in geothermal energy utilization is difficult to quantify with any degree of accuracy. Firstly, many service and specialist development companies as well as consultancies that work in this field, also work in related industries notably oil and gas exploration and groundwater management. The demand for specific services also tends to be cyclical. Equipment suppliers, such as turbine and pump manufacturers, pipe fabricators, and control hardware companies will also supply items for geothermal schemes but only as a part of their product range. These estimates exclude people employed in recreation facilities, tourism, spas, greenhouse horticulture, processing industries, and fish farming which use geothermal energy. These activities tend to be labour-intensive and therefore it can be said that geothermal development could be highly beneficial to the local economy and a tool for job creation.

## 7. ENVIRONMENTAL IMPACTS AND PROPOSED MITIGATION

### 7.1 Impacts on groundwater systems

Henan, being an agriculture-based province, more than 50% of its water consumption is concentrated in farm irrigation. Due to severe contamination of surface water, over-exploitation of groundwater in some places has caused severe land subsidence and falling water levels. For the past years, intensive geothermal exploration has been carried out in most cities. In the process of geothermal development, what needs to be considered first is the groundwater system. Any unsuitable water development will intensify the groundwater imbalance. So, it is quite important to treat all groundwater as one system and integrate the water use plan and to combine management and utilization of shallow groundwater and geothermal water. Utilization of the thermal water reserves must not be regarded in isolation, but should be related to use of other water such as drinking water, irrigation water etc., due to the fact that these are a much greater load on the water reserves.

The utilization of previously spent geothermal water for commercial, industrial and irrigation uses will help to minimize withdrawal of potable water. Geothermal water is in most places of good quality, with salinity in the range 0.8 to 6 g/l. The water's salinity is a little high only in a few places such as at the Hebi and Checun fault. Based on the chemical composition, the geothermal water in most places is suitable for irrigation. So the water used for space heating can be reused for city virescence, farm irrigation, and industry.

In order to build a tourist city in Hebi, an integrated utilization plan has been put forward. Tables 6 and 7 show that the geothermal water in Hebi cannot be used as drinking water, but after cooling, it may be suitable for irrigation. Besides, utilizing warm wastewater for fish breeding has made it possible to achieve a faster and larger body mass growth than in natural conditions. The breeding season can be expanded from 150 to 300 days a year. Table 8 shows that fluoride, copper, zinc, and chromium contents of the geothermal water in Hebi are a little high, but after dilution it can be used in fish industry.

TABLE 6: Assessment of geothermal water as drinking water in Hebi (Deng et al., 2003)

| Item | National drinking water standard | Well 1 | Well 2 |
|---|---|---|---|
| pH | 6.5 - 8.5 | 6.32 - 6.9 | 6.89 |
| Soluble Fe | ≤ 0.3 mg/l | 0.14 - 3.0 | 0.097 |
| Total manganese | ≤ 0.1 mg/l | 0.22 - 0.5 | <0.01 |
| Total copper | ≤ 1.0 mg/l | 0.03 - 0.22 | <0.02 |
| Total zinc | ≤1.0 mg/l | 0.02 - 0.60 | 0.09 |
| Volatile phenol | ≤ 0.002 mg/l | <0.002 | <0.002 |
| Sulfate | ≤ 250 mg/l | 577 - 630.5 | 598.5 |
| Chloride | ≤ 250 mg/l | 38.6 - 39.4 | 586.4 |
| Fluoride | ≤ 1.0 mg/l | 2.30 - 3.0 | 1.4 |
| Cyanide | ≤ 0.05 mg/l | <0.001 | <0.001 |
| Total arsenic | ≤ 0.05 mg/l | 0.02 | 0.05 |
| Selenium | ≤ 0.01 mg/l | <0.0001 | 0.0012 |
| Total mercury | ≤ 0.001 mg/l | <0.0001 | <0.0001 |
| Total cadmium | ≤ 0.01 mg/l | <0.01 | <0.005 |
| Total chromium | ≤ 0.05 mg/l | <0.001 | <0.004 |
| Total lead | ≤ 0.05 mg/l | <0.01 | <0.001 |
| Total silver | ≤ 0.05 mg/l | 0.03 - 0.04 | <0.001 |
| Nitrate | ≤ 20 mg/l | | |

TABLE 7: Assessment of geothermal water as irrigation water in Hebi (Deng et al., 2003)

| Item | National irrigation water standard | Well 1 | Well 2 |
|---|---|---|---|
| Water temperature | ≤ 35 | 73 | 63 |
| pH | 5.5 - 8.5 | 6.32~6.90 | 6.89 |
| Total salinity | ≤ 1000 mg/l (non-salinization area)<br>≤ 2000 mg/l (salinization area) | | |
| Chloride | ≤ 200 mg/l | | |
| Sulphide | ≤ 1 mg/l | | |
| Mercury and its compounds | ≤ 0.001 mg/l | <0.0001 | <0.0001 |
| Cadmium and its compounds | ≤ 0.005 mg/l | <0.01 | <0.005 |
| Arsenic and its compounds | ≤ 0.05 mg/l (irrigated field)<br>≤ 0.1 mg/l | <0.002 | 0.05 |
| Chromium and compounds ($Cr^{+6}$) | ≤ 0.1 mg/l | <0.004 | <0.004 |
| Lead and its compounds | ≤ 0.1 mg/l | <0.01 | <0.001 |
| Copper and its compounds | 1.0 mg/l | 0.03~0.22 | <0.02 |
| Zinc and its compounds | 2.0 mg/l | 0.02~0.60 | 0.089 |
| Selenium and its compounds | ≤ 0.02 mg/l | <0.0001 | 0.0012 |
| Fluoride | ≤ 2.0 mg/l (high F concentration region)<br>≤ 3.0 mg/l (general region) | 2.40~3.0 | 1.40 |
| Cyanide | ≤ 0.5 mg/l | <0.001 | <0.001 |
| Oil type | ≤ 5.0 mg/l (slightly polluted region)<br>≤ 10.0 mg/l | | |
| Volatile phenol | ≤ 1.0 mg/l | <0.002 | <0.0015 |
| Benzene | ≤ 2.5 mg/l | | |
| $CCl_3CHO$ | ≤ 0.5 mg/l (wheat)<br>≤ 1.0 mg/l (rice, corn, soybean) | | |
| Propylene aldehyde | ≤ 0.5 mg/l | | |
| Boron | ≤ 1.0 mg/l (tomato, potato, winter squash, Chinese chives, onion, cucumber, citrus)<br>≤ 2.0 mg/l (wheat, corn, eggplant, green pepper, scallion, Chinese cabbage) | | |
| Colon bacillus | ≤ 1000/l | | |

TABLE 8: Assessment of geothermal water as water for fish industry in Hebi (Deng et al., 2003)

| Item | National fisheries water standard | Well 1 | Well 2 |
|---|---|---|---|
| pH | 6.5 - 8.5 | 6.32 - 6.90 | 6.89 |
| Mercury | ≤ 0.0005 | <0.0001 | <0.0001 |
| Cadmium | ≤ 0.005 | <0.01 | <0.005 |
| Lead | ≤ 0.05 | <0.01 | <0.001 |
| Chromium | ≤ 0.1 | <0.004 | <0.004 |
| Copper | ≤ 0.01 | 0.03 - 0.22 | <0.02 |
| Zinc | ≤ 0.1 | 0.02 - 0.6 | 0.089 |
| Nickel | ≤ 0.05 | <0.03 | <0.03 |
| Arsenic | ≤ 0.05 | <0.002 | 0.05 |
| Cyanide | ≤ 0.005 | <0.001 | <0.001 |
| Sulphide | ≤ 0.2 | | |
| Fluoride | ≤ 1 | 2.4 - 3.0 | 1.40 |
| Benzene | ≤ 0.005 | <0.002 | <0.005 |

### 7.2 Land subsidence, lowering of water level, depletion of groundwater

Sustained use of a particular geothermal reservoir can lead to gradual and extensive land subsidence and lowering of the water table. Land subsidence will cause consequential damage to railroads, highways, and particularly, the pipelines through which the geothermal fluids are pumped from the wells to the users. It can also cause the formation of ponds and cracks in the ground and, further will lead to instability in buildings (Hunt, 2001).

Due to over-exploitation of groundwater and geothermal water, the water table keeps falling. In most cities, regional cones of depression are becoming larger and larger. In Zhenghou and Kaifeng cities, where geothermal resources are developed to a high degree, the total land subsidence has reached 96 cm and 113 cm, respectively (Zhao et al., 2003). Usually a cold ground water zone overlies the geothermal systems. If exploitation of the system results in a large pressure drop in the reservoir, cold water may flow downward into the system, leading to a mixture of cold water and geothermal water. In the city centre of Zhengzhou, high nitrate concentrations are found in some geothermal water implying mixing of shallow and deep zone waters.

Most of these environmental problems can be avoided by means of reinjection of the spent thermal water into the aquifer. It is important that reinjection water should be similar in quality and properties to the subsurface water in the aquifers. An important restriction is that the biological material content should not exceed 1 mg/l and the water should not be subject to bacteriological and biological contamination. So spent bath water cannot be used as reinjection water, unless it is purified. The only action which can be taken is to try to maintain the pressure in the reservoir. Wastewater reinjection can help to reduce pressure drop and hence subsidence. However, it is quite vital to choose the right location for a reinjection well at a safe distance to avoid lowering of the temperature of the production well by cooler water. On the other hand, the distance should be short enough to maintain a pressure connection.

### 7.3 Thermal pollution

The water temperature being higher than that of the surroundings promotes biological processes. As a result of this warmer water, solubility of oxygen in water decreases. The amount of oxygen dissolved in the warmer water could become exhausted leading to the death of aquatic living organisms. To meet the demands of space heating, the cooled geothermal water's temperature is still high and the amount is large in a bitter, cold winter. The multiple use of the water is a way to solve the problem. This will entail use of heat pumps, hot water cultivation, etc.

### 7.4 Chemical impact

The geothermal water in Henan Province can be divided into 9 types (Table 9). In general, the geothermal water is of good quality. However, in some places, e.g. in Xinxiang and Nangyang, the fluorine concentration is quite high. In the Checun fault, the fluoride concentration is in the range from 10.4 to 24.85 g/l, which is much higher than specified in the national drinking water standard, (1 g/l). High fluoride concentration has been shown to be very poisonous to humans. Too high concentrations cause teeth and bone diseases. High fluorine water cannot be reused for fish farming or irrigation.

High mineral content can also be hazardous for irrigation. In irrigation water with high salt content, the process of ion-exchange starts resulting in calcium ions changing places with sodium ions. Because the sodium ions have a higher bond energy, this process is practically irreversible leading to soil sodification. The ideal irrigation water contains less than 500 mg/l dissolved minerals (Camp, 1963).

TABLE 9: Types of geothermal water in Henan Province, China (Zhao et al., 2003)

| Water type | pH | Mineralization (g/l) | Main occurrences | Remarks |
|---|---|---|---|---|
| Na - $HCO_3$ | 7.4 - 7.6 | 0.915 - 1.084 | Hot springs | High $F^-$, 9.5 - 13 mg/l |
| Ca- $HCO_3$,Ca-Mg- $HCO_3$ | | 0.3 - 0.4 | Zhengzhou, Luoyang | |
| Ca - Na- $HCO_3$ | | | Zhengzhou | Deplet. of groundwater |
| K-Ca - $HCO_3$ | 6.32 - 6.90 | 5.2 | Hebi | Ordovician limestone water, high $CO_2$ gas |
| Na - $SO_4$ | 8.35 | 0.661 | Hot springs | High $F^-$, 10 mg/l |
| Na - Cl | | 10 - 30 | Nanyang, Kaifeng | High $Br^-$, $I^-$ |
| Na - Ca-$HCO_3$-$SO_4$ | 7.2 - 9.04 | 0.355 - 0.707 | Hot springs | $F^-$ 15 - 18 mg/l |
| Na-Cl-$SO_4$ | 7.2 - 7.88 | 1.33 - 3.32 | Luoyang, Xinxiang | |
| Na- $HCO_3$-Cl | 7 - 8.65 | 2.334 - 3.051 | Nanyang | |

### 7.5 Landslides

Landslides occur mainly in the western mountains. Recent geologic surveys show that about 1581 landslides have occurred in the whole province, and many have been recently. Landslides pose serious threats to highways and structures that support villages, mining, and energy production, as well as general transportation (Zhao et al., 2002).

In the development of geothermal resources in the western mountains, landslides risk places severe constraints on the placement of both wells and other facilities. The developer should locate well pads on islands of stable bedrock and drill one or more slant holes from a single site (Crittenden, 1981).

### 7.6 Gas emissions

In low-temperature geothermal fields, there are almost no gas problems. But in the Hebi Cambrian-Ordovician geothermal field, a large quantity of pure $CO_2$ has been discovered, where $CO_2$ content of the gas can be as high as 99.93%. The $CO_2$ emanations are not a major environmental problem for geothermal development, but the utilization of these gases for other industrial processes can improve the use of the resource as well as the environmental conditions. The $CO_2$ recovery process can be very simple compared to that in other geothermal fields, due to the simple gas composition, including compression-cooling, drying, final purification and condensation. It is expected that $16 \times 10^8$ $m^3$ $CO_2$ can be recovered from Hebi geothermal field. The $CO_2$ can be used in soft drink production and for recharging fire extinguishers.

### 7.7 Visual impact

Direct use installations for space heating have no visual impact. Other uses of geothermal energy such as horticulture and fish farming tend to have relatively minor visual effects, depending on the scale of development and the nature of the terrain in which these activities take place.

Environmental and visual impacts and land use will be most prevalent during drilling, testing and construction of geothermal installations, mostly in the form of noise, traffic movement and dust. These effects are obviously temporary.

### 7.8 Noise

Being a populous province, urban noise pollution from households and traffic is serious. For low-temperature geothermal development, well-drilling/testing will aggravate the noise problem being close to residential areas. It can be speculated that the noise effects will be serious, but the impacts from drilling and well testing are temporary and will diminish when all the wells have been drilled and tested.

The potential impact of noise depends not only on its level but also on the proximity of residential areas to the site. Noise is attenuated with distance (by about 6 dB every time the distance is doubled), although lower frequencies (e.g. noise from drill rigs) are attenuated to a smaller extent than higher frequencies (Brown, 1995). On the site itself, workers can be protected by wearing ear mufflers during drilling and testing.

### 7.9 Corrosion

Corrosion problems are very common in geothermal utilization systems. The salinity of geothermal water in Henan ranges from 0.8 to 6 g/l (Zhu et al., 2002). In geothermal water, some substances are favourable to the health of human beings. However, excessive concentration of ions such as chloride and sulphate are harmful to the utilization system.

The chloride ion causes breakdown of the passive films that provide some protection to the substrate metals. This will result in pitting corrosion. Chlorides also form relatively stable complex ions or coordination compounds that can result in accelerated corrosion. Sulfate is the primary ion in some geothermal fluids. It is not, however, as aggressive as chloride. Oxygen present in low concentrations in geothermal fluids can be neglected. However, the intrusion of oxygen into hot geothermal fluids will lead to greatly accelerated corrosion. The combination of oxygen and chloride is especially bad and may lead to catastrophic failures if there is a danger of stress corrosion cracking (Miller, 1979). Two solutions are considered. One is adding corrosion inhibitor to the geothermal water and the other is using geothermal water indirectly through a heat exchanger. From technical, economical, environmental, and energy utilization points of view, the indirect heating system with heat exchangers can serve as foundation for the geothermal system, with fossil fuel energy used for peak loads.

## 8. RISK ASSESSMENT

### 8.1 The risk in well drilling

Geothermal exploitation is capital-intensive, with large initial investment costs that are difficult to predict accurately due to the uncertainties of drilling costs and reservoir yields. Depending on the hydrological and geological data, the water output or temperature can deviate from the predicted situations in the finished well. The risk is greater for deep geothermal wells because of limited hydrological and geological data.

### 8.2 The risk of declining production

The size, and therefore production capacity, of a geothermal reservoir provides another significant risk in geothermal development. A complete understanding of the reservoir can only be obtained by withdrawing fluids from the reservoir over a sustained period, with subsequent computer modelling to assess the possible future performance. It can take several years of production from a field to obtain sufficient data to assess reservoir performance with confidence because the reservoir rate of decline is frequently exponential in nature with initial high rates of decline (Axelsson, 2003).

Assessment of resource size and production capacity is a critical part of any geothermal development project. In the absence of long-term production data, resource assessments at the feasibility stage mainly relies on the extent of the reservoir, as defined by drilling and geophysical anomalies, and a knowledge of reservoir fluid temperatures. Such assessments may contain large errors.

### 8.3 The risk of contaminating drinking water

The fresh water aquifers are located above the geothermal reservoirs, and thus drilling operations may lead to groundwater contamination. Drilling fluids are usually the greatest potential threat to the environment. The drilling process damages the environment, as the deep well will unavoidably pass through some underground water aquifers and there is a possibility of contamination by the drilling fluids. For the purpose of protecting shallow groundwater, both production and injection wells should be cemented and lined with proper casing pipes; and solid waste from the drilling operation should be deposited in suitably controlled landfills.

### 8.4 The risk of management and market

The drilling and operating costs of low-temperature wells are fairly stable. A large number of residences are multi-users in a network district heating system. The market situation is unlikely to change and the risk is very small. Far greater risks are involved in industrial utilization leading to marketable products. The extent of the risk is then decided by product sales, not geothermal in nature.

## 9. FOLLOW-UP AND MONITORING

Once a resource has been developed, regular monitoring of production data, water temperature, water chemistry of reservoir, land subsidence and groundwater level should be undertaken, accompanied by simultaneous studies to better predict the future behaviour of the reservoir in order to maximize production and minimize premature reservoir decline.

### 9.1 Monitoring land subsidence

Subsidence has been observed in groundwater reservoirs and petroleum reservoirs in Henan Province. The subsidence has a number of implications for geothermal production and also other effects on the surrounding places. It is difficult to mitigate against land subsidence. However, it can be minimized by means of reinjection of the spent geothermal water back into the aquifer.

### 9.2 Monitoring of groundwater level, temperature and chemistry

Generally, the groundwater quality in Henan Province is acceptable for drinking and other domestic uses. Discharge of geothermal water will cause changes in the groundwater system. By monitoring the groundwater level, temperature, and chemistry, changes can be detected. There are several indicator species such as TDS, $SO_4^{2-}$, $F^-$, and nitrate that should be closely monitored to avoid future problems.

### 9.3 Monitoring of reservoir production, temperature and chemistry

For the sustainable development of a geothermal field, it is necessary to analyze its long-term exploitation stability. Monitoring chemical changes in geothermal fluids from the production wells is very useful to estimate various kinds of changes in reservoir conditions. With increasing production rate the reservoir pressure declines, gradually leading to changes in geothermal water recharge, thermal water component, local water-rock equilibrium, and temperature. These effects can be determined with the aid of fluid chemistry changes during production (Hunt, 2001).

The changes in isotopic and chemical composition in geothermal water often precede cooling of the geothermal reservoir, and data obtained by chemical monitoring of fluids may therefore give a warning in time for preventive action. Even with their inherent uncertainties, geothermometers can be very useful in estimating approximate temperatures in geothermal systems, and for investigating effects of water-rock partial re-equilibration during upflow. Increased Mg concentration, in general, and decreases in K/√Mg and Li/√Mg are very sensitive indicators of high and low temperature water mixing. If there is a connection between shallow groundwater and geothermal water, water withdrawals may affect both water supplies and water quality. Monitoring and proper management of groundwater pumping can prevent or minimize any potential depletion of groundwater. Geothermal waste-water disposal has potential impact on both surface and groundwater supplies.

## 10. PROMOTING GEOTHERMAL DEVELOPMENT

### 10.1 Funding projects

The main barrier to geothermal development in Henan Province is lack of funds. In view of this, some financing sources are discussed.

Funding can often be obtained from host governments, international assistance agencies, and foreign aid agencies. A variety of international and country-specific agencies provide assistance to entities pursuing development projects overseas, such as the World Bank Group and the Nordic Finance Group. The Global Environment Fund (GEF), and other global funds such as the Prototype Carbon Fund (PCF), have provided grants to various geothermal projects. The policy of these funds is to grant a specific amount for each ton of $CO_2$ not released to the environment.

**The World Bank Group**: During the last two decades, the World Bank Group, in close cooperation with GEF, has supported a series of geothermal projects. The World Bank and the United Nations Development Programme (UNDP) are now preparing complementary programmes to assist China to strengthen renewable energy development with partial financing from the Global Environment Facility.

**The Nordic Finance Group**: The Nordic Group of geothermal investors includes the Nordic Investment Bank (NIB), the Nordic Development Fund (NDF), the Nordic Environment Finance Corporation (NEFCO), and the Nordic Project Fund (NOPEF), all of which have contributed to the development of geothermal projects.

During the last decade, the NIB has supported 4 geothermal projects, one of which is in Tanggu of China. The projects focused on direct use. In the same period, the NDF and the NEFCO have supported 2 and 3 geothermal projects, respectively, focused on direct use. Finally, the NOPEF has supported 6 geothermal projects focused on combined uses.

**UNEP and GEF**: The UNEP/GEF Sustainable Alternatives Network (SANet) is based on GEF's knowledge and communication network to cultivate growing momentum in emerging markets for cleaner technology. GEF funding (grants) has so far provided for geothermal projects in Poland. Further geothermal projects in Poland are currently under consideration for GEF funding.

Within the geothermal energy sector, SANet intends to bring together interested public and private players to discuss the best ways to level the playing field in specific markets and countries. SANet wants to facilitate joint market visions that can form the basis for market development coalitions.

**The Geothermal Energy Development Fund (GeoFund)**: The concept of a World Bank-GEF Geothermal Development Fund (GeoFund) was first endorsed by World Bank ECA management in June 2001, and again in October 2002. It is a novelty and it will be established. It is expected that the majority of its projects (well over 60%) will involve district heating (facilities). Most projects will involve a combination of district heat provision and other applications.

Many countries have approached the World Bank, GEF and other donor agencies, such as UNDP and UNEP, with requests to help support geothermal development in a systematic manner. Expanded international support for Henan's geothermal energy development is particularly important, as the government is beginning to adapt its economic development to a market system.

### 10.2 Introducing advanced technologies to promote geothermal development

Henan Province has identified its indigenous geothermal potential over the past 20 years. However, development has been limited. The extent of geothermal resources below 1500 m depth has not been well established with the current technology and available investment. A large proportion of geothermal reservoirs needs to be confirmed by drilling of deep exploration wells. It is urgent to import advanced technology from abroad, and strengthen geothermal development cooperation with foreign countries. Localities should seize the opportunity to attract domestic and foreign high technology, raise the geothermal utilization efficiency, and set up a geothermal heating industry to attain environmental and economic benefits.

The largest potential use of geothermal energy is for geothermal heat pumps (GHP). The GHP is the highest efficiency heating and cooling system (Rybach, 2003). Heat pump technology should be more widely used in the geothermal community and a service system set up.

### 10.3 Strengthening management

There are more than 300 geothermal wells in production in the whole province now. In Zhengzhou and Kaifeng, there are 183 and 67 wells, respectively. Many wells belonging to different owners produce from the same geothermal reservoir. The well owners produce geothermal water in any quantities they like with a relatively low cost leaving large quantities of waste. As expected, this has caused various problems. The most serious is that the water level goes down too fast. In Kaifeng, some geothermal wells cannot produce water any more. Mitigation measures are urgently needed to get control over this hazardous situation, or the geothermal resources will be wasted and destroyed.

As a kind of mineral resource, geothermal resources belong to the nation. Obviously, only the government has the authority to control and administer the geothermal resources. It is necessary to strengthen management, and make and amend necessary rules and regulations on geothermal exploitation and development. The Tianjin government has established such a department, the Tianjin Geothermal Administration Office to control and administer the geothermal resources, and issued a detailed regulation to provide terms and conditions for geothermal administration.

To manage and control the geothermal fields, and to alleviate problems related to geothermal development, an administrative department and suitable legislation are urgently required based on Tianjin's experience.

## 11. CONCLUSIONS

Henan Province is rich in low-temperature geothermal resources. The geothermal water is suitable for direct use. There is a great potential for geothermal water to be used in space heating and agricultural greenhouses. Compared to traditional energy resources, geothermal resources are competitive environmentally and economically. Environmental impacts of geothermal development in Henan Province include: impacts on groundwater systems, land subsidence, decline of water level, depletion of groundwater, landslides, thermal pollution, chemical contamination, gas emission, visual impact, noise, and corrosion. Negative impacts are minimal and temporary, and can be mitigated by effective methods.

Development of geothermal energy resources is expected to play a major role in developing the local economy, enhancing environmental conditions, and serving the people. In order to promote geothermal energy development in Henan Province, more focus will be needed on the creation of international funding sources, introduction of advanced technologies, and strengthening management of geothermal resources.

## ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to Dr. Ingvar Birgir Fridleifsson, director of the UNU Geothermal Training Programme, for offering me the opportunity to participate in this special training; Mr. Lúdvík S. Georgsson, deputy director, for his helpful guidance; and Mrs. Gudrún Bjarnadóttir and Mrs. Maria-Victoria Gunnarsson for their efficient help and kindness during the six months' stay in Iceland. I sincerely thank my supervisor, Dr. Halldór Ármannsson, for providing me with his sound instruction, advice, and guidance during preparation of the report, and also his generous hospitality. Great thanks are addressed to Mr. Zhao Yunzhang for supporting me by providing domestic data. My deepest thanks to my husband Yang Zhibing for his caring during the six months. All glory and honour to God for the wonderful arrangement and successful completion of the entire programme.

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