Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Assessment and Utilization of Shallow Geothermal Energy Resources in Tianjin Area

Tang Yong-Xiang[1], Yu Reng-An[2],Li Yuan-yuan[1], Zhao Na[1],Jin Bao Zhen[1] ,Ruan Chuan-xia[1]

[1]Tianjin geothermal exploration institute, 300250, China[2], China geological survey Tianjin Center, 300170, China

dry_tt@126.com

Keywords: Tianjin City, Shallow Geothermal Energy, Heat Capacity, Exploitation Direction, Countermeasure

ABSTRACT

Based on investigation of the shallow geothermal energy of Tianjin, shallow geothermal occurrence characteristics is closely linked with the Quaternary .The quaternary lithology is mainly composed of clay, silty clay, silt, fine sand and coarse sand, geological structure is clay, silty clay, silt, fine sand, coarse sand and mutual layer, thermal conductivity of rock and soil : 1.23 ~ 1.58W/ (m·℃), the specific heat capacity: 1898.52 ~ 2201.70 W/ (m ℃), underground water is 100 ~ 3000 (m^3/d), coefficient of hydraulic conductivity 50 ~ 300 (m^2/d), groundwater recharge is 30 ~ 80m^3/h, the single well recharge is 30 ~ 50% of output yield, The recharge is below 50 m^3/h, formation heat exhaustion is 32.32 ～ 126.1. the heat absorption is 17.73 ~ 66.8 (w/m). The shallow geothermal reserves and heat exchangers power of suitable areas are calculated aimed at the shallow geothermal energy used patterns (ground water source heat pumps, ground-source heat pump) in this area, and shows the economic and social value. The method of reduction groundwater source is used in heat pump and heat power calculation , The new calculation system of buried vertical tube heat power is created with FLUENT and EED software. Then propose the direction and measures of development and utilization to shallow geothermal energy in Tianji, and provide scientific basis for the realization of strategic objectives with saving energy and reducing emission, continued development and reasonable utilization.

1. INTRODUCTION

As a modern international port city and important economic center of the northern China, Tianjin have put forward higher requirements in the environmental function, air environmental quality and urban environmental sanitation. One important aspect is reducing environment pollution from the consumption of conventional energy and cleaning urban environment with making use of clean energy, then create "environmental protection model city." As a clean and green renewable energy, Shallow geothermal energy has rich reserves and advantages of low cost and conveniently used, brings great help to solve current problems of energy shortage, greenhouse gas emissions with comprehensive and efficient development(Yang rong and Li xiao zhao 2012).

Tianjin is rich in resources, convenient in mining facilities of shallow geothermal energy, rational development and utilization of the resources make contributions to alleviate the shortage of resources, to achieve energy-saving emission reduction and resource sustainable development and utilization. Based on the investigation of shallow geothermal energy project in Tianjin, this paper provide guidance for the development of shallow geothermal energy in research area with Assessment of shallow geothermal energy resources reserves and proposing the reasonable suggestions on development and utilization in the future .

2. OVERVIEW OF SHALLOW GEOTHERMAL ENERGY OCCURRENCE

Development and utilization of shallow geothermal energy Is closely related to its occurrence condition, and resources occurrence are mainly dependent on the local climatic conditions, geological conditions and rock soil thermal properties(Tang yong xiang and Li Yuan Yuan 2013).

2.1 Climate Overview

Tianjin is located in the east coast of the mid-latitude Eurasia, which mainly dominated by the monsoon circulation and is prevalent in East Asian monsoon region, its climate is warm temperate semi-humid continental monsoon and ocean transition. The main climatic characteristics are shown that: windy and drought in spring; hot and concentrated rainfall in summer; crisp and well-being moderate in autumn; cold, dry and less snow in winter. The annual average temperature is between 11.4 and 12.9 ℃. January is the coldest month, whose average temperature is between -3 and -5 ℃; July is the hottest month, whose average temperature is between 26 and 27 ℃. Overall Tianjin area that is suitable for exploitation of shallow geothermal energy for four seasons discernible.

2.2 Geology

Tianjin is located in I grade tectonic units in northern of North china platform, according to the distribution characteristics of Quaternary Tianjin city, northern mountain is not conducive to the occurrence of shallow geothermal energy, the working area is in the County plain south of Jixian piedmont fault zone (Figure 1) (after referred to as research area,) geological structure of the research area is complex, new structure motion control the deposition of the Cenozoic strata, and storage, recharge and discharge of the groundwater, distribution of temperature field ,control Quaternary geological structure of the area, strata distribution and hydrological geology characteristics. It have important effects on the reservoir of shallow geothermal resources.

The origin type of Quaternary area is alluvial, lacustrine and marine, strata structure is sand, sand and clay irregularly interbedded. Large variation of thickness, two depression zone thickness is more than 400m. The characteristics of stratigraphic structure is that

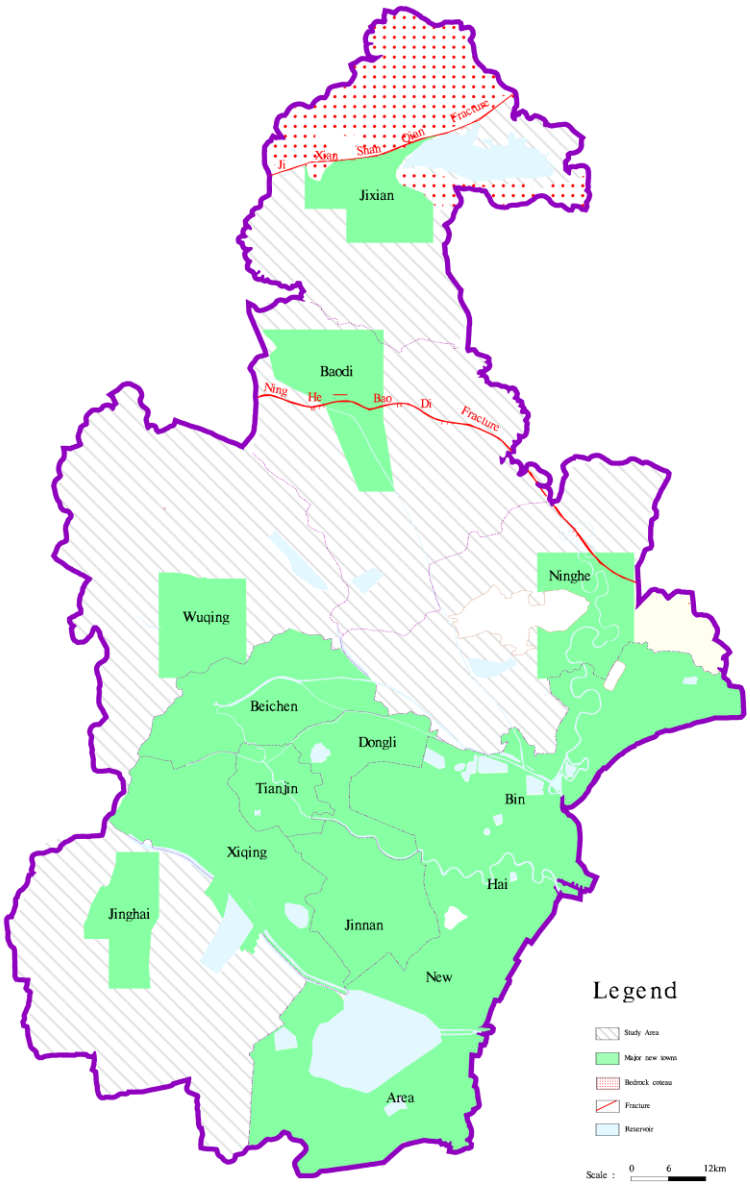

Figure 1 Regional map of studying area

underground water is abundant, especially better water bearing degree in the layer of coarse sand and gravel layer, to provides conditions for vertical recharge of surface water and horizontal mobile of layer water.

Quaternary shallow groundwater comprised of the first water (saline), group II (water + salt water group), group III water (freshwater) and Article IV group (fresh water), aquifer lithology is mainly silt, fine sand, fine sand, each aquifer thickness is different, generally 30 ~ 60m, water yield from south to North or northwest to the southeast gradually get worse (Wang guo liang 2006,Tang yong xiang and Li yuan yuan 2014).

2.3 Physical properties of rock and soil

Physical properties characteristics of Quaternary rock and soil have important affection in the occurrence of shallow geothermal energy resources, including rock mass rate, specific heat capacity and the characteristics of geothermal field et.al, which reflect thermal storage and heat capacity of rock soil. Rock and soil thermal properties in practical work usually is achieved from rock soil thermal response test.

The test results of the rock soil thermal response is known that thermal conductivity of the rock and soil in study area is 1.23 ~ 1.58W/ (m ℃), the specific heat capacity is 1898.5 ~ 2201.7J/ (kg • K), emission heat per drilling depth is 32.32 ~ 126.1 (w/m), absorption heat 17.73 ~ 66.8 (w/m), the average geothermal gradient value of shallow stratum above 200m is 1 ~ 4 ℃ /100m, temperature below 100m is 14.2 ~ 17 ℃, temperature of depth 120m is 14.6 ～ 18.8 ℃, increased to 16.6 ~ 22.6 ℃ to of depth 200m(Ruan chuan xia and Yu yan 2011) roof depth of Thermostat is 30 ~ 35m.

3. THE CALCULATION OF SHALLOW GEOTHERMAL RESOURCES RESERVES AND HEAT POWER

The scale of Shallow geothermal reserves is referred to be geothermal energy reserves whose depth buried generally less than 200m in the study area and economic conditions can be developed in the current technical

3.1 Calculation of static reserves

For the groundwater level in the region is 1 ～ 2m, while roof depth of the thermostat is 30m, the shallow geothermal energy which is stored in the vadose zone does not have developmental value, the heat capacity in vadose zone is ignored. According to the analysis of geological situation in the region, combined with the use of ground source heat pump system construction characteristics, the volumetric method is used to measure the area 200m shallow geothermal formations contain static reserves. When calculating the area is 10707km^2 which remove the reservoir and parts of the ocean, shallow geothermal capacity is about 5590 × 1012kJ / ℃.

3.2 Heat power calculation (heating and cooling of depicting 120 days)

3.2.1 The heat capacity calculation of groundwater source heat pump

It uses groundwater Conversion method. Expression is:

$$Q_q = Q_h \times n \times \tau \quad (1)$$

Where: Q_q , Q_h , n, τ ,are evaluate the shallow geothermal heat power, Shallow geothermal heat to power a single well, the number of the calculation area can be drilled and Land use ratio, respectively.

groundwater Conversion method is used to calculate the heat power of single well(table 2) ,According to the suitability of groundwater source heat pump district (table 1), and the policy of irrigation set mining, to determine the actual amount of water each partition single well. the heat power of the suitable and Less- suitable area (table 3) is calculated according to the number of wells pumping irrigation cloth per unit area, multiplied cloth wells area (suitable, Less- suitable area multiplied by the factor of 14.66% of land use) and single well heat power.

Table 1: scope and size of the groundwater source pump suitability

Suitability partition	distribution range			area（km^2）			Major survey area（km^2）		
	grouph Ⅱ Aquifer	grouph Ⅲ Aquifer	grouph Ⅳ Aquifer	grouph Ⅱ Aquifer	grouph Ⅲ Aquifer	grouph Ⅳ Aquifer	grouph Ⅱ Aquifer	grouph Ⅲ Aquifer	grouph Ⅳ Aquifer
Suitable	Baodi northeastern, Ninghe northern and Jinghai western	Baodi mideastern and Jinghai western	Baodi mideastern, Ninghe northeastern, Jinghai midwestern	1186	1440	1240	163	142	237
Less -Suitable	Baodi and Ninghe southwest most of Wuqing, Jinghai Central	most of Ninghe, Wuqing and Beichen, Baodi western	Most of Xiqing, Jinghai, Wuqing and Ninghe	4247	4840	4409	824	1454	1108
Unsuitable	most of Beichen, Dongli Xiqing and Jixian center city, Jinnan, Binhai and Jinghai south-central	most of Dongli ,Jinnan and center city	most of Beichen,Dongli Jinnan and Binhai	6091	3547	4008	3308	2674	3281

Table 2: calculation of the heat capacity for single well

Area	Water output of single well q_w (m^3/d)			Q_h Heat power of single well winter / summer (kW)					
	grouph Ⅱ Aquifer	grouph Ⅲ Aquifer	grouph Ⅳ Aquifer	grouph Ⅱ Aquifer		grouph Ⅲ Aquifer		grouph Ⅳ Aquifer	
Center City	320	500	1000	77.581	155.16	121.22	242.44	242.44	484.88
Beichen	320	1200	480	77.5808	155.1616	290.928	581.856	116.3712	232.7424
Xiqing	320	1200	480	77.5808	155.1616	290.928	581.856	116.3712	232.7424
Jinnan	320	600	320	77.5808	155.1616	145.464	290.928	77.5808	155.1616
Dongli	320	600	320	77.5808	155.1616	145.464	290.928	77.5808	155.1616
Binhai north	800	1200	1200	193.95	387.90	290.93	581.86	290.93	581.86
Binhai south	150	150	150	36.366	72.732	36.366	72.732	36.366	72.732
Wuqing	1000	1200	1200	242.44	484.88	290.928	581.856	290.928	581.856
Baodi	900	1540	1540	218.196	436.392	373.3576	746.7152	373.3576	746.7152
Jinghai	1750	2100	1750	424.27	848.54	509.124	1018.248	424.27	848.54
Jixian	450	1400	0	116.3716	232.7422	339.4166	678.8322	0	0
Ninghe	1540	1540	1540	373.3572	746.7154	373.357	746.715	373.3576	746.7152

Table 3: The heat capacity of groundwater source heat pump in suitable area

Area	Well cloth area (km^2) (= Suitable area *land-use factor)			Heat power winter / summer (kW)					
	grouph Ⅱ Aquifer	grouph Ⅲ Aquifer	grouph Ⅳ Aquifer	grouph Ⅱ Aquifer		grouph Ⅲ Aquifer		grouph Ⅳ Aquifer	
Baodi	80.712	105.83	54.488	7924.975	15849.95	17781.43	35562.85	9154.627	18309.25
Jinghai	37.115	97.819	85.158	4251.599	8503.198	13446.52	26893.04	9755.15	19510.3
Ninghe	56.067	7.5089	42.174	10466.55	20933.1	1401.743	2803.487	7872.971	15745.94
Total	173.89	211.16	181.82	22643.13	45286.25	32629.69	65259.38	26782.75	53565.5

The heat capacity of groundwater source pump is 40.15 × 10^{4}kW/80.3 × 10^{4}kW (winter / summer) in Study area. The total size of No Ⅱ aquifer groundwater source heat pump systems in suitable and less-suitable area is 5433km^2,with heat power is 11.1 × 10^{4}kW/22.2 × 10^{4}kW (winter / summer); the total size of No Ⅲ aquifer suitable and less-suitable area is 6280 km^2, with heat power is 16.7 × 10^{4}kW/33.4 × 10^{4}kW (winter / summer) ; The size of No Ⅳ aquifer in suitable and less-suitable total area is 5649 km^2, with heat power is 12.35 × 10^{4}kW/24.7 × 10^{4}kW (winter / summer).

Table 4: The heat capacity of groundwater source heat pump in less- suitable area

Area	Well cloth area (km^2) (= Suitable area *land-use factor)			Heat power winter / summer (kW)					
	group Ⅱ Aquifer	group Ⅲ Aquifer	group Ⅳ Aquifer	group Ⅱ Aquifer		group Ⅲ Aquifer		Group Ⅳ Aquifer	
Center City	0	11.888	15.582	0	0	1412.218	2824.435	3702.173	7404.346
Beichen	25.678	65.41	25.315	2171.449	4342.898	20742.26	41484.52	3211.057	6422.114
Xiqing	3.9655	52.448	70.836	292.2665	584.5331	14495.56	28991.11	7831.069	15662.14
Jinnan	0	2.5054	3.2149	0	0	619.5559	1239.112	424.0097	848.0194
Dongli	6.899	5.2131	0	749.3215	1498.643	1061.645	2123.29	0	0
Binhai New	23.584	16.501	0.538	3887.964	7775.928	4080.586	8161.171	133.0468	266.0936
Jixian	17.35	1.3165	0	10499.08	20998.15	2323.518	4647.035	0	0
Wuqing	218.69	224.71	206.47	27570.42	55140.85	33995.14	67990.28	31235.08	62470.17
Baodi	127.64	80.123	112.85	12532.76	25065.53	13461.5	26923	18959.25	37918.5
Jinghai	82.929	87.139	113.93	9499.722	18999.44	11978.44	23956.87	13050.7	26101.4
Ninghe	115.91	162.25	97.571	21638.63	43277.26	30288.55	60577.1	18214.46	36428.91
Total	622.65	709.51	646.3	88841.62	177683.2	134459	268917.9	96760.84	193521.7

3.2.2 The heat capacity calculation of buried pipe ground-source heat pump power

It is suitable for the development and utilization of underground pipe ground source heat pump in the study area calculating with new evaluation system of vertical buried pipe heat power. It is based on the underground thermal parameters, and load standard of typical meteorological conditions of buildings on the premise of long-term sustainable exploitation (controllable temperature, heat pump COP not reduced),

Base on the three-dimensional mathematical model of heat transfer, the numerical software of FLUENT and EED are applied, by adjusting group layout characteristics of the tube determination, to establish the heat exchange capacity of ground coupled heat pump system by sustainable development and utilization. Not only the method takes into consideration the underground thermal balance, but also consider the economy of the heat pump system

Heat power of buried ground-source heat pump system is 67 × 106kW/100.6 × 106kW (winter / summer) in the study area by calculation. Including that the total size of suitable area (grade Ⅰ area) and less-suitable areas (Ⅱ grade zone) area is $4721km^2$,with heat capacity is 29.87×10^6kW/44.81×10^6kW (winter / summer); size of generally suitable area (Ⅲ grade zone) is $5986km^2$,with heat capacity is 37.2×10^6kW/55.8×10^6kW (winter / summer).

4 THE ECONOMIC AND SOCIAL VALUE OF SHALLOW GEOTHERMAL ENERGY

4.1 Economic

The economic value of commonly is calculated using analog conventional energy (coal) method for conversion. Available reserver of Shallow geothermal energy resources is 17481×10^{14}J / a, standard coal equivalent 579 743 400 t / a, annual utilization of shallow geothermal energy resources amounting to the value of 418.21×10^8 yuan / a, development and utilization of shallow deduction geothermal resources can replace the energy consumption caused by the annual number of standard coal 44,807,500 t (Table 5). The size of urban building heating area to solve Shallow geothermal resources to develop all the available resources is $13.49 \times 10^8m^2$, the size of cooling area in study area is $12.68 \times 10^8m^2$.

4.2 Environmental benefits

Based on the evaluation results of shallow geothermal resources, annual reserves of replacing standard coal to develop the entire shallow geothermal energy resources is 5,974,3400ton, deduction energy consumption caused by the exploitation of shallow geothermal, with replacing standard coal is 4,480,7500 ton, it can reduce emissions of ash which is 11,842,1800 ton including nitrogen oxides, sulfur dioxide, carbon dioxide into the atmosphere, and reduce environmental management costing 130,601,170,000 yuan, Dioxide(2.386t)、sulfur dioxide(1.7%)、coal ash（0.8%） is produced by coal of 1t combustion (Table 6)(Yang fan and Li feng lin 2011).It plays an important role in Cities “energy saving”.

Table 5 shallow geothermal resources available economic capacity analysis

Items	heat pumps		Total
To heating / cooling area ($\times10^6m^2$)	8.04/10.05	1341.37/1257.53	1349.41/1267.58
The amount of available geothermal resources ($\times10^{16}J$)	1.25	173.56	174.81
Can replace standard coal（$\times10^4t$）	42.68	5931.66	5974.34
The value of geothermal resources (billion yuan)	0.0299	4.1522	4.1821

Table 6: Data tables of the environmental benefits generated from the developed resources (one year)

Project	Natue of emission reduction (million ton)	price(yuan/ton)	Saving fees of treament (million yuan)
The amount of ash	31.37	800	25096
The amount of nitrogen oxides	33.16	2400	79584
Sulfur dioxide	38.09	1100	41899
Carbon dioxide	11739.58	1100	12913538
Total	11842.18		13060117

5 EXPLOITATION

Development and utilization of shallow geothermal energy is influenced and restricted by the social productive, technology, hydrogeological conditions and other aspects of political factors and so on. The occurrence conditions of shallow geothermal resources is controlled by the factors of Quaternary geological structure, lithology, facies, sedimentary environment, hydrogeological characteristics, physical properties and shallow hot rock geothermal field characteristics, environmental geological conditions and others.

Maximized development and utilization of shallow geothermal energy will be carried according to the system planning of social elements which are the characteristics of shallow geothermal resources, within the area of energy consumption structure and economic technology(Hu cai ping and Pan yong jun 2012,Yang hong liang and Zheng kang bin 2010)。

5.1 Exploration principle

⑴ Groundwater source heat pump exploration must be carried in suitable or less suitable area, considering the impact of geological environment, it′s prohibited to develop and utilize groundwater source heat pump in the trend of increased land subsidence area, high-speed rail along each side of 500m, the core area of nature reserves, the surface water protection area, the core area of the groundwater source, high-rise buildings intensive areas, and the port industrial etc.

⑵ Buried pipe ground- source heat pump is fit to be used in the study area. When developing in suitable area (grade Ⅰ district), pipe depth is less-than 120m, we do not need to consider the impact of brackish water interface; while pipe depth is less-than 100m in the more suitable area (grade Ⅱ district), we also do not to consider the effect of water backplane salty, but when pipe depth is greater than 100m, the salt water body should be treated in the course of construction to prevent brackish string layer; when developing in the general suitable area (grade Ⅲ district), we must pay attention to the existence of brackish water interface and take effective measures to prevent brackish string layers.

5.2 Direction and program of exploitation

5.2.1 Exploitation direction

There are mainly two aspects in the study area while Exploitation of shallow geothermal resources

(1) Geothermal air conditioning

The area of shallow geothermal energy resource development and utilization are carried mainly in winter heating and summer cooling, whose area including enterprises, institutions, shopping malls, exhibition halls, schools, hospitals, hotels and restaurants and so on. With the guidance of the national energy policy, many construction projects have adopted geothermal air conditioning systems, application scale showed a rapid increasing trend (Wang song tao and Wang hua jun 2012).

(2) Health care

Underground water has medical value, It can be used in bathing, convalescent care under the guidance of a doctor, then promote the level of local economic development and people health(Lv chun hai and Li qing chao 2013).

5.2.2 Exploitation program

In order to make the shallow geothermal green-energy serving in the area of economic development research ,we analysis the comprehensive development and utilization solutions of shallow geothermal energy based on the principle of the development and utilization of major new towns in the study area(Figure 2 and 3).

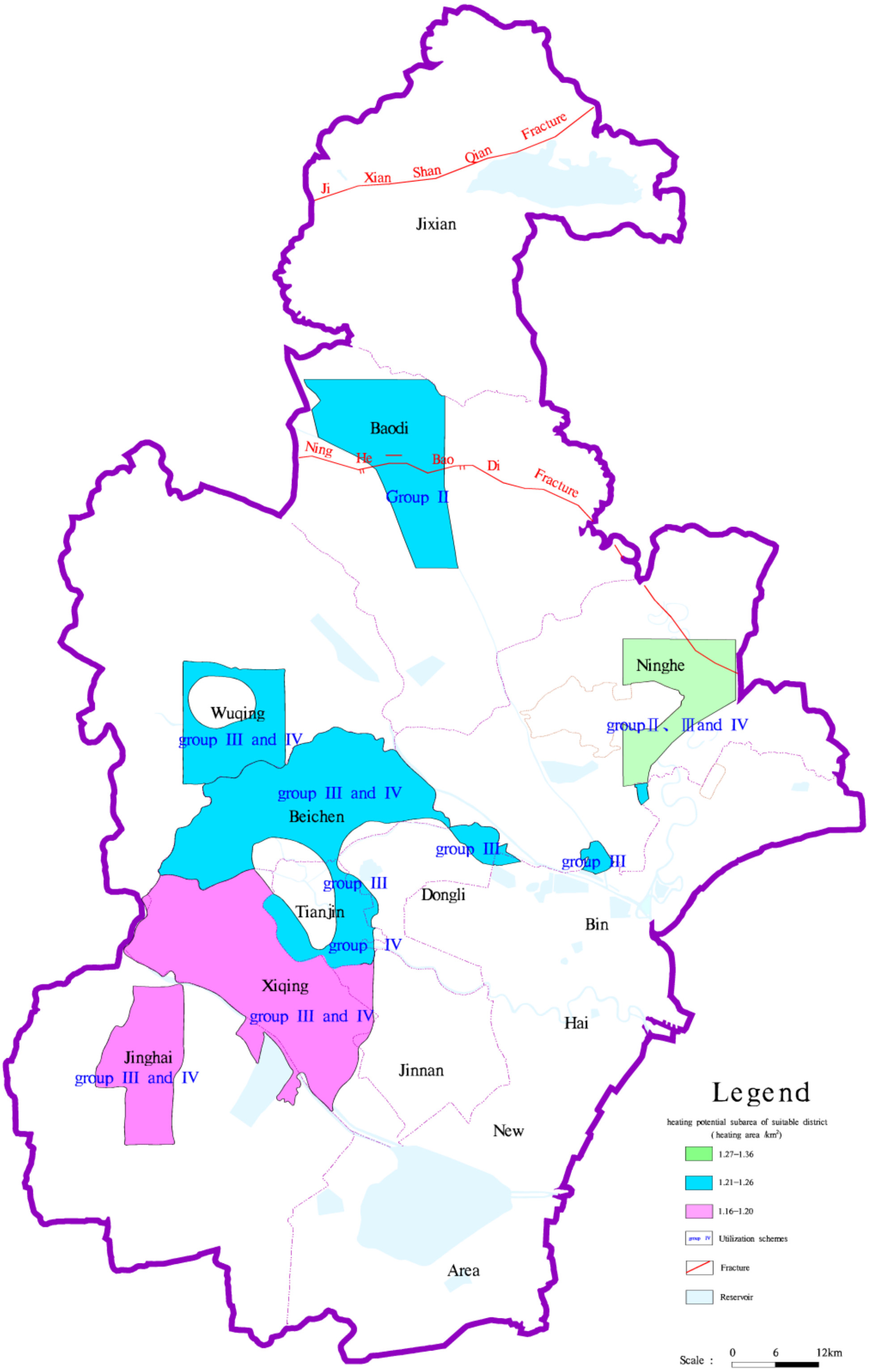

Figure 3: Exploitation map of major new towns groundwater source heat pump system in the study area

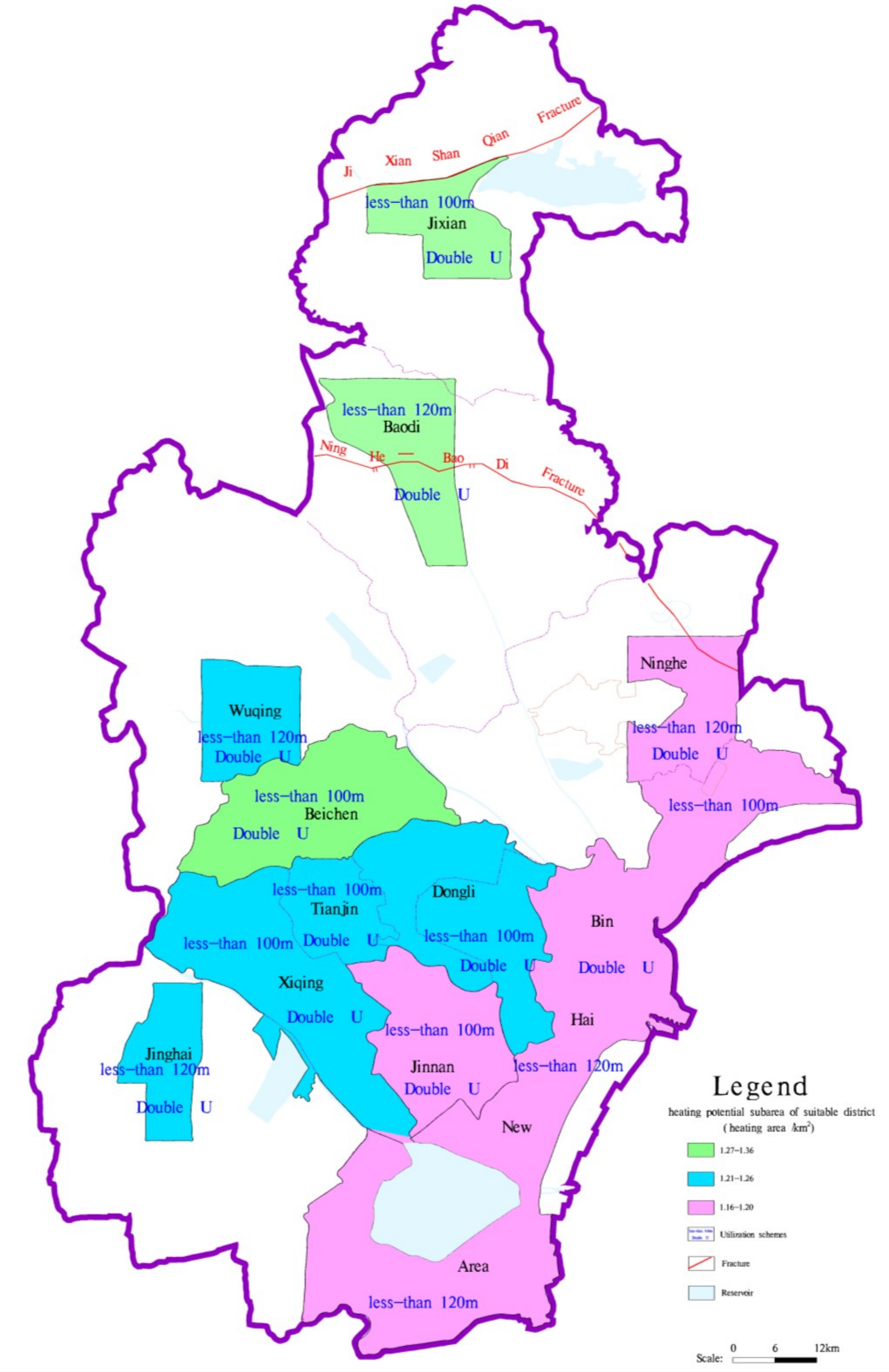

Figure 4: Exploitation map of major new towns buried pipe ground-source heat pump in the study area

Overall, the groundwater source heat pump is mostly suitable for development and utilization of water in different groups in addition to the Binhai New Area and Jixian Metro area, but it needs to do recharge work.

While the double U buried pipe depth of ground-source heat pump appropriate buried is more than 100m in the central city, Xiqing, Jinnan and Dongli, it is needed to treat bottom boundary of salt water; and the appropriate buried depth of double U is less-than 120m in North Star, Wuqing, Baodi, Jinghai and Ninghe district, it is also needed to treat bottom boundary of salt water and spacing of hole is 5m; but the appropriate buried depth of double U is more than 120m in southern of Binhai New Area, it is needed to treat bottom boundary of salt water; but the appropriate buried depth of double U is less than 120m in northern of Binhai New Area, it is needed to treat bottom boundary of salt water.

6. EXPLOITATION MEASURES

In order to make the shallow geothermal energy serve the study area's economic construction, and solve its presence in the development and utilization, we provide the protection measures of shallow geothermal resources in the sustainable and rational development and utilization.

6.1 Strengthen the key technologies research and development

Whether the rock and soil thermal parameters is accurate or not and how to promote the quality of ground source heat pump, etc. are key factors to improve the development and utilization of shallow geothermal energy, thus we strengthen the domestic institute testing equipment and self-developed ground source heat pump technology, then improve development and utilization levels of light layer while investigation and evaluation of geothermal energy.

6.2 Compilation of shallow geothermal energy resource development and utilization program

According to exploration and evaluation work of shallow geothermal resources in the research area, combined with the current status of the development and utilization, development and utilization programs of geothermal energy resource are complied, the development and utilization of resources and effective protection and rational utilization of shallow geothermal resources are strengthen macro-controlled, resource development and environmental coordination are promoted, the development and utilization levels can be enhanced, then provide evidence of shallow geothermal energy resources when management in accordance with the law.

6.3 Establish improved monitoring system

Combining demonstration projects on shallow geothermal resources research, we monitor the operational status of ground source heat pump engineering, ground engineering system formation and the water temperature variation, and deal with the monitoring data when digital processing .Then predict the environmental geological effects of development and utilization of shallow geothermal energy resources, put forward corresponding prevention measures and provide technical support for the rational development and utilization of shallow geothermal energy .

6.4 Establish improved database system of development and utilization of shallow geothermal energy resource

Establish survey database of shallow geothermal, provide a platform for effectively organization, management and use of these data. Then provides an important basis of development and utilization of shallow geothermal energy when more systems of government decision-making departments, intuitive grasp of research occurrence of shallow geothermal energy resources, utilization, more scientific and rational planning, management and guide.

6.5 Establish new incentives of the relevant government departments and coordination mechanisms

Shallow geothermal energy have development potential, involving a number of different departments in the development and utilization management, which establishing in accordance with the relevant government departments who suggest the division of responsibilities interrelated and mutually reinforcing coordination mechanisms. At the same time the introduction guidance of relevant policies should be strengthen and the promotion and application of shallow geothermal energy should be encouraged.

7. CONCLUSION

There are some problems in the application of shallow geothermal resources in the study area Currently, but I believe that this clean green Energy will play a greater role in economic development and environmental protection in the study area with the help of the government and related departments, relying on continuous improvement of policies and regulations, rules, norms, and technological progress and innovation.

REFERENCES

Hu, C.P., and Pan, Y. J. :Study on Geothermal Resources Development and Protection and Administrative Safeguards in Dongying City ,*Shandong Land and Resources*,**28**,(2012),77-79.

Lv, C, H., and Li, Q.C.: Evaluation and Utilization of Geothermal Resources in Weifang, *Science & Technology Vision*,**3**,(2013),80-91.

Ruan, C, X., Yu, Y., and Tian, X. M.: Shallow Geothermal Resources Survey and Evaluation in Tianjin Binhai New Area, *Report.* Tianjin Geothermal Exploration and Development Institute, Tianjin ,China. (2011), 56-60.

Tang, Y. X., Li ,Y.Y., Yu, R.A., Liu, J. L., Ruan, C.X., and Jin, B. Z.: Analysis on the Occurrence Conditions and Prospects of the Shallow Geothermal Energy in Tianjin area, *Tianjin Institute of Geology and Mineral Resources*, **36**,(2013),213-220.

Tang, Y. X., Li ,Y.Y., and Yu, R. A.: Assessment of Suitability Partition of Shallow Geothermal Energy Utilizationg modes in Binhai New Area, *GAS & HEAT*,**34**,(2014),21-25.

Wang, S. T., Wang, H. J., and Wang, Z. J.: In-Situ thermal Conductive Test of Rock Soils for Shallow Geothermal Energy Utilization in Weifang *,Hydrogeology and Engineering Geology*,**39**,(2012),134-138.

Wang, G. L., Bai ,J. F., and Li, G., L.: Annual Report 2005 of the Dynamic Monitoring of Groundwater Levels in Tianjin Binhai Area,Tianjin Institute of Environmental Geology,TJ(2006).

Yang, R., Li, X.Z., Wu ,W.B., Xiong , Z.Y., Cao ,L., and Yu, X.: Assessment of Application Potential of Shallow Geothermal Energy in Suzhou City, *Renewable Energy Resources*,**30**,(2012),74-77.

Yang, F., Li, F, L.,and Zhang, S. G.:Development and Utilization of Shallow Geothermal Energy in Baoding City, *Hydrogeology and Engineering Geology*,**39**,(2011),134-138.

Yang, H. L., Zheng, K. B., and Zheng, K. L.: State of Shallow Geothermal Energy Development and Utilization of Large-scale. Chinese Geothermal Achievements and Prospects - China Geothermal Development Symposium, *Beijing, Geological Publishing House*,BJ(2010).