

Comparison of hydrogeological characteristics between the Sanjiang Plain and the Amur River Basin

SU Chen^{1*}, XU Cheng-yun², CHEN Zong-yu¹, WEI wen¹

¹ Institute of Hydrogeology and Environmental Geology, Shijiazhuang 050061, China.

² Heilong jiang province pile foundation engineering corporation, Harbin 150036, China.

Abstract: Sanjiang Plain-Amur River Basin aquifer is the aquifer shared by China and Russia, which is of great significance to water sources management for both countries, acting as a focused area by China and Russia. In this paper, the hydrogeological characteristics of the Sanjiang Plain-Amur River Basin is studied, aiming at understanding the differences as well as similarities of aquifer classification, chemical characteristics of groundwater, quantity of groundwater and groundwater evaluation methods of two countries, which will lay a solid foundation to further holistic study of the trans-boundary aquifer in the Sanjiang Plain-Amur River Basin.

Keywords: Trans-boundary aquifer; Hydrogeology; Groundwater resource; Khabarovsk Territory

The trans-boundary aquifer, as a primary component of the global groundwater resources, plays a significant role in managing the precious water resources commonly shared by countries and in building a harmonious world, which has now drawn an extensive worldwide attention (PUR I S, 2001; Robert D H and Albert E U, 1989). With a vast territory, bordering on Russia, Kazakhstan, North Korea, Mongolia, Burma, Vietnam, *etc.* China contains multiple trans-boundary aquifers (HAN Zai-sheng and WANG Hao, 2001; NIU Lei, 2011), among which the Sanjiang Plain-Amur River Basin aquifer is commonly shared by China and Russia, stretching over two boundary rivers between China and Russia, namely the Heilong River in China (“the Amur River” in Russia) and the Ussuri River. The part of this aquifer distributed in China is called “Sanjiang Plain” aquifer while the other part in Russia is called “Amur River Basin” aquifer (HAN Zai-sheng *et al.* 2007) (Fig. 1). Although, multiple researches and studies have been conducted on the Sanjiang Plain-Amur River Basin aquifer by far (HAN

Zai-sheng, 2006; WANG Hao, 2006; Han Zai-sheng, 2010), the differences between China and Russia in terms of aquifer classification method, water resources evaluation method and the research degree of hydrogeology have restricted the integral research of the trans-boundary aquifer of both countries. Therefore, in this paper, contrastive analysis has been made specifically on the aquifer structure, hydrochemical characteristics of groundwater and the condition of groundwater resources of the “Sanjiang Plain” aquifer and “Amur River Basin” aquifer, laying a solid foundation for the holistic study on the trans-boundary aquifer.

1 Overview of physical geographical condition

The Sanjiang Plain-Amur River Basin covers an area of $10 \times 10^4 \text{ km}^2$, among which the Sanjiang Plain takes up $4.5 \times 10^4 \text{ km}^2$, formed under the alluviation of Heilong River, Songhua River and Ussuri River, while the Amur River Basin takes up about $5.5 \times 10^4 \text{ km}^2$, located in the middle-and-lower stream of Heilong River where is the

*SU Chen (1985-), male, from Taiyuan, Shanxi, researcher assistant, mainly engaged in research on groundwater resource evaluation and numerical simulation of groundwater. Email: camel_0072001@sina.com.

convergence area of Ussuri River and Heilong River (Kozlov C A, 2008) (Fig. 1). The research area presents landscape of three classes, namely piedmont tableland and monadnock, low plain and valley plain. The piedmont tableland and monadnock in China are mainly distributed in Kiamusze City area, Jixian County, Baoqing County, northern Luobei County and Fujin City, while the piedmont tableland and monadnock of the Amur River Basin is mainly distributed in southern Birobidzhan and the middle of Khabarovsk. The valley plain is mainly formed of high floodplain, low floodplain and bog and marsh distributed along the Heilong River and Ussuri River. The low plain is mainly gravel fan plain, formed of terrace of Class I and Class II. This area belongs to the continental monsoon climate. In the Sanjiang Plain, the average temperature is 21.9 °C in July and -18.1 °C in January and the average annual precipitation is 500-650 mm. In the Amur River Basin, the temperature is 14-21 °C in July and -14--28 °C in January and the average annual precipitation is 635-1 020 mm. In general, the annual average temperature of Amur River Basin is slightly lower than that of the Sanjiang Plain while the annual average precipitation of the former is slightly higher than that of the latter.

2 Hydrogeological characteristics

2.1 Hydrogeological zoning

In the studies on the Sanjiang Plain by China, this area is divided into two hydrogeological zones: bedrock mountainous area (I_1) and plain area (I_2). The plain area is considered as an integral part without hydrogeological subzones divided. In Russia, the Amur River Basin is also divided into two hydrogeological zones, namely bedrock mountainous area and plain area and the latter is further divided into several hydrogeological subzones (YANG Xiang-kui *et al.* 2008).

The Amur River Basin is located in the Sikhote-Alin fold hydrogeological area of Class I which accounts for 40% of the total area of Khabarovsk Territory, characterized by transition artesian basin (the valley between two fold systems), intermountain artesian basin and

volcanic hydrogeological zone (YANG Xiang-kui *et al.* 2008). The Amur River Basin is located southwest of this area, covering 4 hydrogeological zones of Class II, namely, V_6 -Vandansky, V_7 -Uldursky, V_8 -Khekhtsirsky and V_{10} -Amur River Artesian Basin Hydrogeological zone, among which the V_6 , V_7 and V_8 belong to mountainous area while V_{10} belongs to plain area which is further divided into 7 subzones (Sidorenko A B, 1971) (Fig. 1).

2.2 Classification of aquifers and water yield property

In the Sanjiang Plain and Amur River Basin, there are mainly distributed with aquifers of Quaternary System, but in the monadnock and piedmont tableland of this area, there are also distributed with volcanic rocks and sedimentary rocks of Mesozoic and earlier ages and granite of different ages. These rock stratum and rock mass form a large area of unevenly-distributed reticular weathering-fissured aquifer and linear tectonic-fissured aquifer, under the action of internal and external stress, storing bedrock fissure water.

Based on the geologic structure characteristics, the Sanjiang Plain is divided into 3 aquifers, namely, the Quaternary fissured aquifer (Q), the Paleogene-Neogene fissured aquifer (N+E) and the Pre-Quaternary bedrock-fissured aquifer (YANG Xiang-kui *et al.* 2008). Among these aquifers, the Quaternary fissured aquifer can be subdivided into 2 sub-aquifers: the Quaternary Holocene sub-aquifer (Q_4) and the Quaternary Pleistocene sub-aquifer (Q_{1-3}).

The Amur River Basin is mainly divided into 5 aquifers: the Quaternary modern fluvial aquifers (Q_4), the Quaternary Pleistocene fluvio-lacustrine deposits aquifers (Q_{1-3}), the Quaternary Pliocene unconsolidated sediments aquifers (N_2+Q_1), the Oligocene-Miocene loose detrital sediments aquifers ($E_{2-3}-N_1$) and the Mesozoic-Paleozoic sedimentary rock and magmatic rock aquifer (the fault zone of bedrock aquifer) (Han Zai-sheng, 2010).

Based on stratigraphic chronology and geologic structure, China and Russia divide the aquifers into several sub-aquifers. Though different division criteria taken by the two countries lead to different aquifer classification results, there is still

corresponding relation between the aquifer classifications of the two countries (Table 1).

The Sanjiang Plain-Amur River Basin is a large scale reservoir structure surrounded by mountains. Within this area, the monadnock fissured aquifer has limited amount of water resources but the plain loose rock fissured aquifer contains rich water. The northern part, eastern part, southern part and western part are hilly area formed of magmatic rock stratum with weak permeability which forms the confining boundary of the aquifer. The Tertiary aquifer is distributed with stable mudstone or complete bedrock at the bottom which works as the bottom confining boundary. Within the research area, the region near Khabarovsk in southern Russia and the east area of Tongjiang-Fujin-Youyi in China covered with claypan are confined water distribution area, while the central region of the research area in Russia and the west area of Tongjiang-Fujin-Youyi in China not covered with claypan or covered with island-

distributed claypan are phreatic water distribution area. The Tertiary Pliocene aquifer and the Quaternary sediment fissured aquifer have the richest water resources, which is exploited as the centralized water-supply source.

The Sanjiang Plain is located in the piedmont alluvial-proluvial fan or upstream area, where the sediments in the aquifer is formed of coarse particles, with water yield of a single well at 500-5 000 m³/d. The Class-I and Class-II terrace area approaching the watercourse are mainly distributed with Middle Pleistocene aquifer and Lower Pleistocene aquifer with large thickness, where the water yield of a single well of most regions can reach at least 2 000 m³/d. Under the valley plain area of some major rivers including the Songhua River and the fossil river course area, the sand-gravel aquifer with large thickness is buried, formed of coarse particles, with water yield of a single well reaching at least 5 000 m³/d (ZHOU Yu-bo, 2011) (Fig. 2).

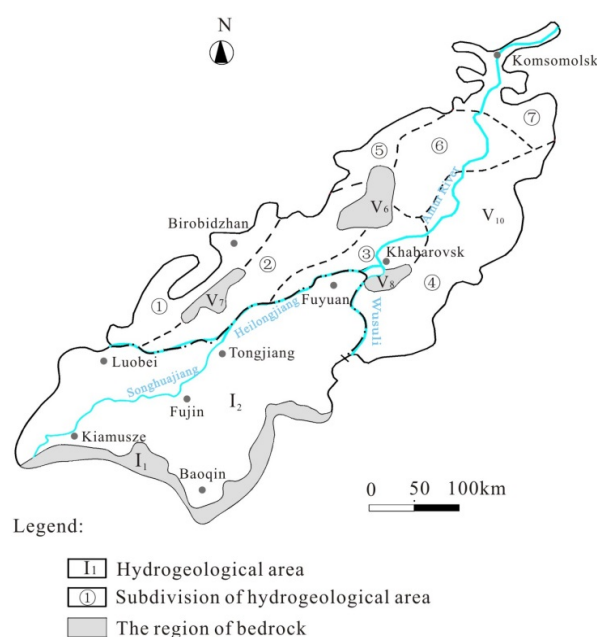


Fig. 1 Study area and hydrogeological divisions

Table 1 Aquifers in the Sanjiang Plain and the Amur River Basin

Amur River Basin aquifers in Russia	Sanjiang Plain aquifers in China
Quaternary Holocene aquifer (Q ₄)	Quaternary Holocene aquifer sub-aquifer (Q ₄)
Quaternary Pleistocene aquifer (Q ₁₋₃)	Quaternary Pleistocene aquifer sub-aquifer (Q ₁₋₃)
Quaternary Pliocene unconsolidated sediments aquifer	Paleogene-Neogene fissured aquifer (N+E)
Oligocene-Miocene sediments aquifer (E ₂₋₃ -N ₁)	

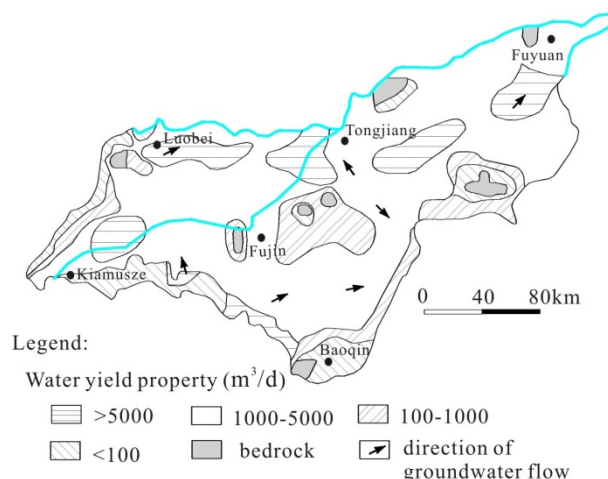


Fig. 2 Water yield property of the Sanjiang Plain

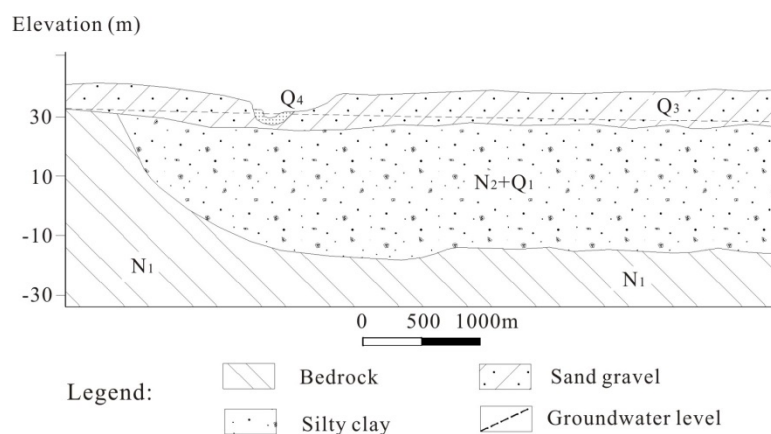


Fig. 3 Sedimentary deposit of Fedorovskoe in Khabarovsk

The Amur River Basin aquifer is formed in modern times, distributed with alluvial sediments and alluvial-lacustrine sediments from bottom to top which are mainly Pliocene-Quaternary loose detrital sediments. Under the condition of drawdown at 5-10 m, the aquifer can provide a pumping flow of 10-20 L/s ($864-1\,728\text{ m}^3/\text{d}$). The bottom of Basin (Miocene-Paleogene sediments) is distributed with aquifer formed of terrigenous alluvial-lacustrine sediments with poor water yield property, with pumping flow as low as 1-3 L/s ($86.4-259.2\text{ m}^3/\text{d}$) in general (Caravans K P and Terekhov L D, 1999). Fig. 3 shows the profile of the Fedorovskoe sediment near Khabarovsk in the south of the Basin, where the aquifer are formed of sand deposits and sand gravel stratum of Pliocene and Early Pleistocene epoch, with rich water resources and water table at over 30 m in general.

The Sanjiang Plain and Amur River Basin is

different in their respective aquifer division and their respective calculation condition of water yields. But in general, the major aquifer like the Pliocene-Pleistocene aquifer has a water yield of about $2\,000\text{ m}^3/\text{d}$, the water yield property of the aquifers showing little difference between the two countries.

2.3 Groundwater hydrochemical characteristics

For the bedrock-fissured water of monadnock and piedmont tableland within the Sanjiang Plain area, the groundwater hydrochemical characteristics are $\text{HCO}_3\text{-Ca}$ and $\text{HCO}_3\text{-Na}\cdot\text{Ca}$, with Fe less than 0.28 mg/L and TDS less than 0.40 g/L . For the Quaternary loose rock fissured water in the plain area, the hydrochemical characteristics are $\text{HCO}_3\text{-Ca}\cdot\text{Mg}$. Additionally, there are also $\text{HCO}_3\text{-}$

Ca type and $\text{HCO}_3\text{-Na}\cdot\text{Ca}$ type. Little regularity is found during the varying of the negative ions and positive ions in groundwater and no crosswise zoning is found evidently in the groundwater chemical types. The content of primary iron ions and manganese ions exceeds the standard generally. The acidic and weak acidic reducing environment together with the weak alternating action of the groundwater make the iron ions and manganese ions enrich abundantly in the groundwater (YANG Xiang-kui *et al.* 2008).

The Quaternary loose rock fissured water of the Sanjiang Plain is usually water with little mineral substance and weak acidity, with TDS less than 0.5 g/L in general. In vertical direction, the groundwater in the upper segment has higher TDS and total hardness but lower pH value than the lower segment does. The Quaternary loose rock fissured water is generally of the same type, with major ion content varying little, which indicates that infiltrating and storing are the major moving pattern for water in the mountain front, showing nearly no migration characteristics. The groundwater in the mountain front has relatively good flow conditions, so the groundwater circulates fast, showing a relatively low degree of mineralization and featuring $\text{HCO}_3\text{-Ca}$ type water. The content of iron and manganese in the groundwater does not exceed the standard severely in the mountain front. However, in the Quaternary aquifer system in plain area, the groundwater has a relatively high content of iron and manganese due to the slow flow and thus the leaching action and enrichment of mineral elements. Additionally, the degree of minerali-

zation and hardness of the groundwater increases gradually, which results in a large variety of chemical types of groundwater and the $\text{HCO}_3\text{-Ca}$ type is no longer the dominant type.

In the Amur River Basin loose sediment fissured aquifer and the Cenozoic fault aquifer, the chemical type of the natural water changes from $\text{HCO}_3\text{-Na}$ type and $\text{HCO}_3\text{-Mg}\cdot\text{Na}$ type in the basin edge to the $\text{HCO}_3\text{-Ca}$ in the basin center gradually. The aquifer is enriched with iron and manganese generally, resulting in the change of chemical constituents of groundwater. The change of major constituent of the groundwater in the Pliocene-Quaternary aquifer ($\text{N}_2\text{-Q}$) is mainly owing to ferrous ion (Kozlov C A, 2008).

The Sanjiang Plain-Amur River Basin, where the water shows a generally low degree of mineralization, the terrain is flat, and the groundwater alternates relatively weakly, is suitable for the enrichment of iron ions in the water. At the same time, with the increase of depth, the condition for the groundwater to alternate weakens relatively, which leads to the increasing of the content of iron ions in the groundwater. The total iron content increases with the increase of ferrous ion content. The abundance of ferrous ion existed in water indicates that the water is in a reducing environment. The acidic, weakly acidic reducing environment and the weak alternating action of the groundwater make the iron ion and manganese ion enrich in the groundwater and, with content increasing from the basin edge to the basin center (Table 2).

Table 2 Hydrochemical features and resources assessment of groundwater

Type	Sanjiang Plain	Amur River Basin
Area (10^4 km^2)	5.5	4.5
Chemical type of groundwater	$\text{HCO}_3\text{-Ca}\cdot\text{Mg}$; $\text{HCO}_3\text{-Na}$; $\text{HCO}_3\text{-Ca}$	$\text{HCO}_3\text{-Ca}\cdot\text{Mg}$; $\text{HCO}_3\text{-Na}$; $\text{HCO}_3\text{-Ca}$
TDS (g/L)	<0.5	0.1-0.4
Concentration of iron ions (mg/L)	0.3-24, Max. 40	0.1-0.4
Concentration of manganese ions (mg/L)	0.2-0.4, Max. 12	0.3-30
PH	6.5-7.65	0.1-1.4
Vertical zoning of water chemistry	mineralization zone; hardness zone	Iron ion zone; manganese ion zone
Exploitable resources ($10^8 \text{ m}^3/\text{a}$)	40.21	37.12

2.4 Groundwater recharge, runoff and discharge characteristics

The aquifer in the left bank of Songhua River on the Sanjiang Plain is recharged by meteoric water directly. In the western and southern part of the research area, the groundwater is recharged by the lateral runoff from the mountainous area. In addition, the surface water body from the Ussuri River can also recharge the groundwater on seasonal base. The groundwater flows from the piedmont area toward the confluent region of Heilong River and the Songhua River. The Sanjiang Plain groundwater system is largely affected by human activities, resulting in groundwater depression cones in some parts of this area. Artificial exploitation, vertical evaporation and discharging to the river are major routes for discharge of groundwater in this area. With the increase of exploitation degree of groundwater, the proportion of artificial exploitation in the total discharge will increase gradually.

The groundwater in the Amur River Basin is mainly recharged by meteoric water. Additionally, the lateral runoff from the mountainous area in the south and north and the surface water in this area are also important recharge sources. The groundwater flows from the piedmont to the Amur River in the basin center and discharge into the Amur River finally. Due to the relatively low degree of development and utilization, the major discharge route for this area at present is not artificial exploitation but vertical evaporation and river discharging.

The Sanjiang Plain-Amur River Basin groundwater is mainly recharged by meteoric water, running from the piedmont to the rivers in

the basin center and discharging into the Heilong River and the Amur River at last. The recharge, runoff and discharge conditions for the Sanjiang Plain aquifer and for the Amur Basin aquifer are similar. However, due to the different degrees of development and utilization in the two countries, the discharge quantity of different discharge routes varies in these two countries and so do the surface water recharge conditions.

3 Groundwater resources characteristics

3.1 Classification and comparison of groundwater resources

In the local groundwater resources evaluation of Russia, the exploitable resource is also called the groundwater resource potential, which is classified into the exploited reserves and predicted reserves.

The exploited reserves refer to the groundwater resources via technically and economically rational water intake projects under the comprehensive exploitation conditions, and the quality of the groundwater shall meet the standards for specified uses in the national economy within the calculated time limit of water utilization; and based on the quality standards, the groundwater can be classified into 4 classes: Class A, Class B, Class C_1 and Class C_2 . The predicted resources are put forward based on the local evaluation data and are classified as Class P (Fig. 4) (Minister of Natural Resources of the Russian Federation, 1997; SE Qiao-fu, 1998).

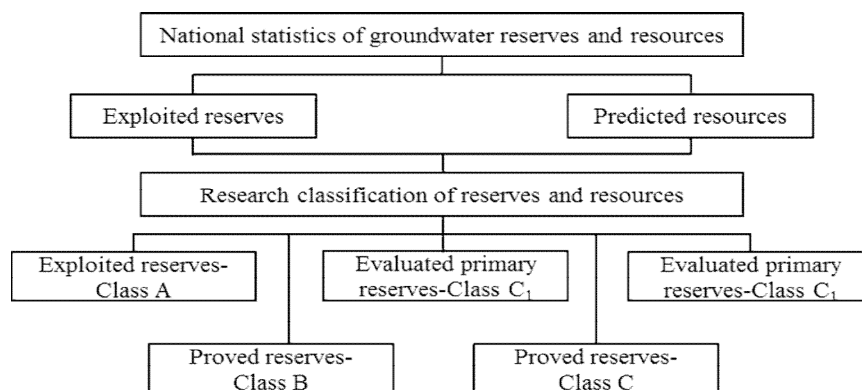


Fig. 4 Division of the exploitable groundwater in Russia

The exploitable groundwater resources (m^3/a) of China refer to the amount of groundwater that can be exploited from the aquifer per unit time under certain technical conditions on the premise that the exploitation will not cause severe environmental and geological problems. Thus, the concept of exploitable groundwater resources put forward by China and the concept resources potential by Russia have the same meaning, both referring to the exploitability of the local groundwater.

3.2 Exploitable groundwater resources of the Sanjiang Plain-Amur River Basin

3.2.1 Estimation of exploitable resources of the Sanjiang Plain

The exploitable groundwater resource of the Sanjiang Plain is figured out by means of numerical simulation and equalization method. In accordance with the Investigation and Assessment of the Potential of Groundwater Resources and Eco-Environmental Geology of the Sanjiang Plain, the exploitable groundwater resource of this area is $37.12 \times 10^8 \text{ m}^3/\text{a}$, and the storage capacity of the groundwater under years of equilibrium condition is in an equilibrium state (YANG Xiang-kui *et al.* 2008).

3.2.2 Estimation of exploitable resources of the Amur River Basin

The Amur River Basin is located in the Far East of Russia, including small parts of Khabarovsk Territory and most parts of Yevreyskaya (EAO). The overall Far East is divided into 18 regions based on the administrative division (Shikhalev V M. 2012). Except for the 0 region (Khabarovsk) that is adjacent to the Bolshoy Ussuriysky Island, all of the other regions can provide groundwater-related information figured out by means of equalization method and analytical method (Davydenko L V. 2010). The Amur River Basin covers 8 of the 18 regions: 0, 1, 6, 7, 8, 9, 17 and EAO regions (Fig. 5). Except for the 0 region where the information is not available, the exploitable underground resources of the other 7 regions can reach $57 \times 10^8 \text{ m}^3/\text{a}$ (Table 3). By analyzing the distribution and flow characteristics, it suggests that the groundwater of this area mainly flow from the mountainous area to the plain area and the exploitable groundwater resources are mainly distributed in plain area. Thus, the exploitable resources of Amur River Basin take up most of the total exploitable quantity of these administrative regions.

Table 3 Exploitable groundwater of regions containing the Amur River basin ($10^3 \text{ m}^3/\text{d}$)

Classification	Region 1	Region 6	Region 7	Region 8	Region 9	Region 17	Region EAO	Total
Exploitable resources	1 365	355	1 711	1 774	2 205	3 330	4 930	15 670
Predicted resources	1 222.3	354.98	734.61	1 772.57	2 205	3 021.63	4 165.08	13 476.16
Exploited reserves	142.7	0.02	976.39	1.43		308.37	764.93	2 193.84

The research by Kozlov in 1999 found that the exploitable groundwater resources of Amur River Basin is $10\ 363 \times 10^3 \text{ m}^3/\text{d}$ ($37.82 \times 10^8 \text{ m}^3/\text{a}$) (Kozlov C A, 2008) with the captured river water $1\ 008 \times 10^3 \text{ m}^3/\text{d}$ included. With the increase of rain water in this area in recent years, the exploitable groundwater tends to increase.

In this research, we draw a modulus zoning map for groundwater exploitation (Fig. 6) based on the “Hydrogeological map of Khabarovsk Territory” (Marnie H A and Reichlin A B, 1968) and

estimated the exploitable groundwater resource ($40.21 \times 10^8 \text{ m}^3/\text{a}$) of the Amur River Basin, with exploitation modulus at $2.31 \text{ L/s} \cdot \text{km}^2$. Considering all the calculation results above, we found that this value accounts for 70% of the total exploitable groundwater resources of the 8 administrative regions, which is a little higher than the calculated amount of 1999 and is consistent to the variation law of the actual resources amount. Therefore, the calculated value $40.21 \times 10^8 \text{ m}^3/\text{a}$ as the exploitable groundwater resources of the Amur River Basin is

reasonable.

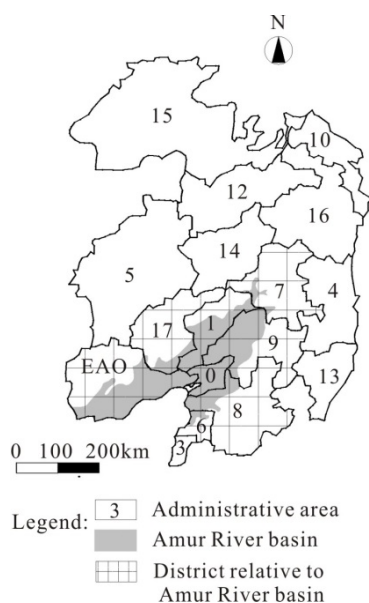


Fig. 5 Administrative divisions in Khabarovsk Territory

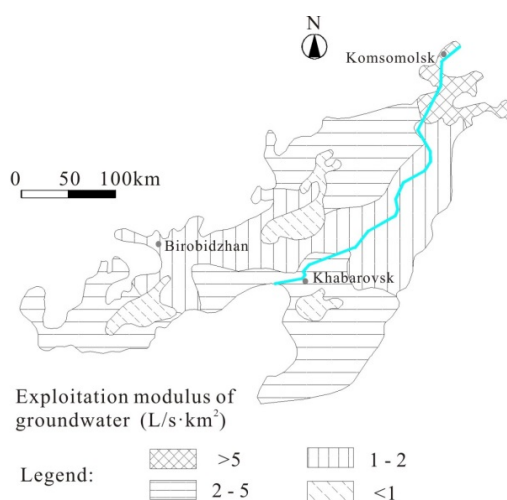


Fig. 6 Exploitation modulus of groundwater in the Amur River basin

The respective evaluation result of the exploitable groundwater resources of the Sanjiang Plain and the Amur River Basin shows that the exploitable groundwater resource of Sanjiang Plain-Amur River Basin is $77.33 \times 10^8 \text{ m}^3/\text{a}$, among which the Sanjiang Plain contributing $37.12 \times 10^8 \text{ m}^3/\text{a}$ and Amur River Basin taking up $40.21 \times 10^8 \text{ m}^3/\text{a}$ (Table 2). Based on the respective area on each side of boundary, the exploitable groundwater resource amount of the Sanjiang Plain relatively equals to that of the Amur River Basin.

4 Conclusions

(1) Both the Sanjiang Plain and the Amur River Basin are fluvial plain formed under the alleviation of Heilong River, Ussuri River and some other rivers, possessing similar depositional conditions. As a result, they have similarities in terms of the aquifer structure, hydrochemical characteristics of natural water, recharge runoff discharge characteristics of groundwater and the exploitable resource amount. However, due to the different aquifer classification criteria taken by China and Russia and the difference of the hydrogeological analytical method, there are some differences in the interpretation of some concepts by both countries. When conducting research on the overall trans-boundary aquifer, contrastive analysis shall be carried out on these differences and uniform criteria shall be applied to the study on the trans-boundary aquifer.

(2) The Sanjiang Plain-Amur River Basin aquifer is classified into 3 groups: Quaternary Holocene aquifer (Q_4), Quaternary Pleistocene aquifer (Q_{1-3}), and Paleogene-Neogene fissured aquifer (N+E). The exploitable groundwater resource of the whole area is $77.33 \times 10^8 \text{ m}^3/\text{a}$. Analyzing from the area of the two sides of the boundary, the Sanjiang Plain and Amur River Basin share the nearly equal exploitable groundwater resources, respectively $37.12 \times 10^8 \text{ m}^3/\text{a}$ and $40.21 \times 10^8 \text{ m}^3/\text{a}$. The major groundwater chemical types of this area include $\text{HCO}_3\text{-Ca}\cdot\text{Mg}$, $\text{HCO}_3\text{-Na}$ and $\text{HCO}_3\text{-Ca}$. Most of groundwater is fresh water with degree of mineralization less than 0.5 g/L. The groundwater has a high content of iron, which is the major impacting factor that makes the groundwater exceed the quality standard.

(3) Due to the limited information about the trans-boundary aquifer, this research only made contrastive analysis on part of the hydrogeological characteristics of the Sanjiang Plain-Amur River Basin trans-boundary aquifer. The research on the trans-boundary aquifer requires joint efforts and cooperation between countries, which is of great significance for purchasing a deep knowledge of the state of aquifer and making full use of the aquifer.

(4) The trans-boundary aquifer is related to the interests of both countries and the capture and pollution of water resources may bring about

severe effects. Therefore, focused research on the three-dimensional hydrogeological structure of the Sanjiang Plain-Amur River Basin is required, in order to get knowledge of the interaction between groundwater and surface water and between different groundwater bodies in both countries from different aspects, so as to provide guidance for rational utilization of water resources.

Acknowledgements

Geological investigation project “the investigation of the trans-boundary aquifers in China” (No. 1212011220941).

References

- Caravans K P, Terekhov L D. 1999. Underground water in far east as a source of water. Ministry of Railways of the Russian Federation Far Eastern State University.
- Davydenko L V. 2010. Public accounting of groundwater far eastern federal district in 2009. Ministry of Natural Resources and Environment of the Russian Federation.
- HAN Zai-sheng. 2006. Trans-boundary aquifers in Asia with special emphasis to China. UNESCO.
- Han Zai-sheng. 2010. Trans-boundary aquifers in Asia-a preliminary inventory and assessment. UNESCO.
- HAN Zai-sheng, WANG Hao. 2006. A study of the problem on trans-boundary aquifers. *Hydrogeology & Engineering Geology*, 33(5):80-84.
- HAN Zai-sheng, WANG Hao, *et al.* 2007. Trans-boundary aquifers on the Sino-Russia Border-a case study of the Middle Heilongjiang-Amur River Basin. *Geology in China*, 34(4): 697-701.
- Kozlov C A. 2008. The groundwater resources and quality of the Amur River basin. *Mineral Resources Exploration and Protection*, 77(10): 51-55.
- Marnie H A, Reichlin A B. 1968. Hydrogeological map of the Amur Region. Khabarovsk: Khabarovsk Territory.
- Minister of Natural Resources of the Russian Federation. 1997. Classification of operating reserves and projected groundwater resources, 40(7).
- NIU Lei. 2011. Research on trans-boundary aquifers based on map of groundwater resources and environment in Asia. Beijing: China University of Geosciences.
- PUR I S. 2001. Internationally shared (trans-boundary) aquifer resources management-a framework document. IHP-VI Non Serial Documents in Hydrology. Paris: UNESCO, 9-36.
- Robert D H, Albert E U. 1989. Trans-boundary groundwaters: the bellagio draft treaty. *Natural Resource Journal*, 29(3): 663-722.
- SE Qiao-fu. 1998. Classification of operating reserves and projected groundwater resources. *Geological Science and Dynamic*, 10(5): 24-26.
- Shikhalev V M. 2012. Report on the environmental situation in the Khabarovsk Territory in 2010. Ministry of Natural Resources of the Khabarovsk Territory.
- Sidorenko A B. 1971. Soviet hydrogeological-volume XXIII, Moscow: Moscow subsoil publishing.
- WANG Hao. 2006. Research on Trans-boundary aquifers based on Asia part of world groundwater resource map. Beijing: China University of Geosciences.
- YANG Xiang-kui, YANG Wen, *et al.* 2008. Investigation and assessment of groundwater resource potential and eco-environment geology in Sanjiang Plain. Beijing: Geological Publishing House.
- ZHOU Yu-bo. 2011. Research on evolution of groundwater circulation environment in Sanjiang Plain. Changchun: Jilin university of China.