# Postprint: Water Resources Development Potential Assessment in the China-Mongolia-Russia Economic Corridor Based on Load Index

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**Date:** 2021-08-11T00:00:00+00:00

## Abstract

Using 2016 data on surface water resources, precipitation, population, and GDP from 43 provincial-level administrative units in the "China-Mongolia-Russia Economic Corridor" , this study systematically analyzes the distribution characteristics and development potential of water resources in the region through the water resource load index calculation method. The results indicate that surface water resources in the "China-Mongolia-Russia Economic Corridor" display a spatial pattern characterized as "more in the east and less in the west, more in the north and less in the south, and minimal in the central region" . Russia possesses abundant surface water resources, accounting for approximately 95% of the total surface water resources in the economic corridor. In addition to its small population and relatively low water demand, Russia exhibits low water resource utilization rates and substantial development potential. Northern Mongolia has relatively abundant surface water resources, with five administrative regions having water resource load indices below 1, suggesting certain development potential; however, the southern region faces severe surface water shortages. The three northeastern provinces of China and the Inner Mongolia Autonomous Region, due to their relatively high population densities and substantial water demands, all have water resource load indices exceeding 2, indicating low development potential. From the perspective of regional water resource optimal allocation, southern Mongolia and the four Chinese provinces (autonomous region) represent key areas requiring water resource optimization, while Russia possesses the conditions to alleviate water scarcity issues in certain regions of the "China-Mongolia-Russia Economic Corridor" . Nevertheless, as water resource development and utilization are intimately associated with socioeconomic development, the pathways for water resource cooperation within the "China-Mongolia-Russia Economic Corridor" require further in-depth investigation.

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# Full Text

## Evaluation of Water Resources Development Potential in the China-Mongolia-Russia Economic Corridor Based on Carrying Index

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### Abstract

This study utilizes 2016 data on surface water resources, precipitation, population, and gross domestic product for 43 provincial-level administrative units in the China-Mongolia-Russia Economic Corridor. Employing the water resources carrying index calculation method, we systematically analyze the distribution characteristics and development potential of water resources in this region. The results reveal that surface water resources in the China-Mongolia-Russia Economic Corridor exhibit a spatial pattern of "more in the east and north, less in the west and south, and least in the middle." Russia possesses abundant surface water resources, accounting for approximately 95.4% of the total surface water resources in the economic corridor. Benefiting from a small population and relatively low water demand, Russia also features low water resource utilization and substantial development potential. Northern Mongolia has relatively abundant surface water resources, with five administrative regions having a water resources carrying index less than 1.0, indicating certain development potential, while southern Mongolia suffers from severe surface water shortages. Due to relatively high population density and large water demand, the three northeastern provinces of China and the Inner Mongolia Autonomous Region all have water resources carrying indices greater than 2.0, indicating low development potential. From the perspective of regional water resources optimization allocation, southern Mongolia and the four provinces (autonomous regions) of China are key areas requiring water resources optimization, while Russia has the capacity to alleviate water scarcity issues in other regions of the China-Mongolia-Russia Economic Corridor. However, since water resources development and utilization are closely linked to socio-economic development, pathways for water resources cooperation within the China-Mongolia-Russia Economic Corridor require further in-depth research.

**Keywords:** China-Mongolia-Russia Economic Corridor; spatial pattern of water resources; water resources development potential; water resources carrying index

## Introduction

Freshwater scarcity [?] and water security issues [?] represent significant global challenges [?]. Since the 20th century, water shortages have become widespread across many regions in the Northern Hemisphere [?]. The United Nations World Water Development Report indicates that global water consumption will increase by 20-30% by 2050 compared to current levels, affecting the production and livelihood of over 5.7 billion people [?]. As a fundamental natural resource and strategic economic resource, water profoundly influences global ecological environments and sustainable development [?]. Russia' s water resources rank among the world' s largest, with river runoff accounting for 10% of the global total, primarily concentrated in sparsely populated Siberia [?]. Mongolia' s renewable inland freshwater resources total only $0.28\times10^{3}$ km$^3$, representing approximately 0.08% of the global total [?]. Due to water scarcity and severe pollution, Mongolia faces critical water security challenges [?]. China' s renewable inland freshwater resources amount to $2.8\times10^{3}$ km$^3$, but with climate change, drought issues have intensified in some regions, with inland river runoff decreasing and even experiencing flow interruption [?].

The China-Mongolia-Russia Economic Corridor, situated in the mid-to-high latitudes of the Northern Hemisphere, encompasses diverse landscapes including forests, grasslands, deserts, Gobi, and permafrost. Water resources are extremely unevenly distributed spatially, with multiple issues including mid-latitude hydrological drought, high-latitude flooding, surface water quality deterioration, and transboundary water disputes [?]. Against this backdrop of climate warming, China, Mongolia, and Russia face varying degrees of challenges in rational water resources development and utilization, necessitating urgent transnational cooperation and scientific research. This study focuses on the China-Mongolia-Russia Economic Corridor, analyzing its water resources distribution characteristics, influencing factors, and development potential to provide a scientific basis for promoting rational water resources development and ecological environmental protection in the region.

## 1. Study Area Overview

According to the National Science and Technology Basic Resources Survey Special Project "Multidisciplinary Joint Investigation of the China-Mongolia-Russia International Economic Corridor," the "China-Mongolia-Russia Economic Corridor" in this study covers a total area of approximately $9.20\times10^{6}$ km$^2$, including $7.6\times10^{5}$ km$^2$ in China, $1.99\times10^{6}$ km$^2$ in Mongolia, and $6.45\times10^{6}$ km$^2$ in Russia. The study area extends from east to west across the Northeast China Plain, East Siberian Mountains, Mongolian Plateau, Central Siberian Plateau, West Siberian Plain, and East European Plain [Figure 1: see original paper]. The climate gradually transitions from temperate monsoon to temperate continental, temperate semi-arid, temperate arid, and back to temperate continental. The average annual temperature ranges from -5 to 15°C, and average annual precipitation ranges from 50 to 1000 mm.

Russia's portion has the most abundant surface water resources, featuring major rivers such as the Lena, Yenisei, Ob, and Volga, as well as Lake Baikal, the world's largest freshwater lake [?]. Mongolia has numerous endorheic rivers and lakes with significant seasonal runoff variation, experiencing high flow during summer and flow interruption or freezing in winter. The Selenga River, originating south of Lake Khövsgöl in Mongolia, flows north into Russia and eventually drains into Lake Baikal, while the Kherlen River, originating from the eastern slopes of the Khentii Mountains, flows east into Hulun Lake in China. Surface water resources in China's three northeastern provinces and eastern Inner Mongolia mainly come from summer precipitation, which accounts for 55-74% of the annual total, with rivers exhibiting distinct wet/dry season variations and inter-annual fluctuations [?]. Major rivers include the Liao River and the transnational Amur River.

### 2.1 Data Sources

The study area comprises 7 provinces (autonomous regions) in China, 21 provinces (municipalities) in Mongolia, and 15 border regions (republics, oblasts) in Russia. China' s surface water resources data were obtained from the Ministry of Water Resources' 2016 *China Water Resources Bulletin* (http://www.mwr.gov.cn/zzsc/tjgb/szygb/2016/mobile/index.html#p=8). Russia' s surface water resources data came from the 2016 *State Water Cadastre: Surface and Groundwater Resources, Their Use and Quality* [?]. Due to missing water resources data for Mongolia in 2016, we used 2012 surface water statistics for each province (municipality) [?]. Precipitation data were obtained from the Global Precipitation Climatology Center (GPCC) 0.25° gridded monthly precipitation reanalysis dataset (https://opendata.dwd.de/climate_{environment}/GPCC/html/fulldata-monthly_{v2018}*{doi}*{download}.html), which shows good consistency with meteorological station observations in the mid-to-high latitudes of the Northern Hemisphere [?]. Population and GDP data for Chinese provinces were sourced from provincial statistical yearbooks (Liaoning: http://www.ln.stats.gov.cn/tjsj/sjcx/ndsj/otherpages/2017/indexch.htm; Jilin: http://tjj.jl.gov.cn/tjsj/tjnj/2017/ml/indexc.htm; Heilongjiang: http://www.hlj.stats.gov.cn/tjsj/tjnj/201801/t20180105_{62314}.html; Inner Mongolia: http://tj.nmg.gov.cn/Files/tjnj/2017/zk/indexce.htm). Russian and Mongolian data were obtained from the Russian Federal State Statistics Service (https://rosstat.gov.ru/) and the Mongolian National Statistics Office (http://www.1212.mn/), respectively. All monetary values were converted to US dollars using 2016 exchange rates (USD 1 = CNY 6.65 = RUB 67.0 = MNT

2145).

### 2.2 Research Methods

The water resources carrying index establishes relationships between regional water resources, population, and socio-economics to reflect water utilization levels and assess development difficulty [?]. Due to its computational simplicity and readily available data requirements [?], this index has been widely applied in water resources development studies across various scales, from China' s three-tier river basins [?] to countries along the "Belt and Road" initiative [?]. The index is typically calculated using population, gross domestic product, and water resources data as follows:

$$C = K \times \frac{P + G}{W}$$

where $C$ is the water resources carrying index; $P$ is population ($10^4$ persons); $G$ is gross domestic product ($10^8$ USD); $W$ is water resources volume ($10^8$ m$^3$); and $K$ is a precipitation-related coefficient calculated as:

$$K = \begin{cases} 1.0 - 1.2, & 800 < R \leq 1600 \\ 1.2 - 1.4, & 400 < R \leq 800 \\ 1.4 - 1.6, & 200 < R \leq 400 \\ 1.6 - 1.8, & R \leq 200 \end{cases}$$

where $R$ is precipitation (mm). A higher $C$ value indicates higher water resource utilization and lower development potential, while a lower $C$ value indicates lower utilization and greater development potential. Referencing water resources development potential classification for "Belt and Road" countries [?], we adopt a similar classification system for the water resources carrying index (Table 2).

Surface runoff depth ($r$, mm) is defined as the ratio of regional annual water resources volume ($W$, $10^8$ m$^3$) to corresponding area ($S$, $10^4$ km$^2$), calculated as:

$$r = \frac{W}{S} \times 10^5$$

### 3.1 Spatial Distribution Characteristics of Surface Water Resources

Surface water resources in the China-Mongolia-Russia Economic Corridor display a pattern of "more in the east and north, less in the west and south, and least in the middle" [Figure 2: see original paper]. Russia' s portion is the most abundant, accounting for 95.4% of the corridor' s total surface water resources. Among Russia' s 15 administrative units, 6 have surface water resources exceeding 1.0$\times10^{10}$ m$^3$, 5 have annual runoff depths between 500-1000 mm (primarily in the East Siberian Mountains), and 4 have depths less than 189 mm (mainly in the Central and West Siberian Plateaus).

All 21 administrative units in Mongolia have surface water resources less than 1.00$\times10^{9}$ $m^3$, making it the most water-scarce region in the corridor. The administrative unit with the highest annual runoff depth is Ulaanbaatar (164 mm). Northern Mongolian Plateau areas have annual runoff depths exceeding 20 mm, while southern and western regions have less than 20 mm, with some areas (e.g., South Gobi Province) receiving less than 5 mm. Annual runoff depths in China' s three northeastern provinces range from 104-151 mm, while Inner Mongolia has the lowest depth (approximately 34 mm).

The uneven spatial distribution of water resources in the China-Mongolia-Russia Economic Corridor will lead to a series of water-related problems and risks as climate warming continues. In the short term, major river runoff in northern and central-southern Russia will continue to increase. In the long term, climate change will cause extreme hydrological events such as mountain floods and debris flows to become more frequent [?]. Studies show that since the 1990s, runoff in some Mongolian rivers has significantly decreased, with corresponding reductions in lake water levels. In recent decades, over 500 rivers in Mongolia have dried up, increasing spatiotemporal disparities in water distribution and exacerbating the polarization between drought and flood trends, posing more severe challenges to ecological environments [?].

### 3.2 Analysis of Water Resources Development Potential

**3.2.1 Water Resources Utilization Degree in the China-Mongolia-Russia Economic Corridor** Among Russia' s 15 administrative units, only Moscow Oblast has a water resources carrying index ($C$) > 2.0. Russia' s abundant water resources primarily benefit from favorable natural geographic and climatic conditions. Combined with the region' s characteristic low population density and minimal socio-economic water demand, overall water utilization remains low, preserving substantial development potential.

Spatial variation in $C$ values across the 43 administrative units is significant, generally showing a pattern of "high in the south, low in the north." Five administrative units have $C$ values less than 1.0, all concentrated in northern Russia. Six units have $C$ values between 1.0 and 2.0, located along the China-Mongolia border. Mongolia' s uneven regional development results in relatively developed economies and larger populations in some provinces, and combined with slightly higher surface runoff depths in northern areas, southern regions generally have higher $C$ values than northern areas. Ulaanbaatar City has the highest $C$ value at 6.8, while Orkhon Province reaches 5.2. China' s Heilongjiang, Jilin, Liaoning, and Inner Mongolia all have high $C$ values exceeding 2.0, primarily due to rapid economic development and high water resource utilization [Figure 3: see original paper].

**3.2.2 Zoning of Water Resources Development Potential** Based on the water resources carrying index for the 43 administrative units in the China-Mongolia-Russia Economic Corridor, we classify them into zones of very large, large, moderate, small, and very small development potential. Notably, no administrative units have $C$ values between 2.0 and 3.0, indicating a "polarized" development potential characterized by low utilization and high potential in northern regions, and low potential in southern regions.

**(1) Zones with large development potential** ($C < 1.0$)
These zones cover most of Russia and northern Mongolia. In Russia' s East European Plain, Novgorod Oblast, Mari El Republic, Tatarstan Republic, Kirov Oblast, Udmurt Republic, and Tyumen Oblast in the West Siberian Plain feature flat terrain, major rivers including the Volga and Ob, and temperate continental climates with annual precipitation exceeding 400 mm (up to 937 mm in Novgorod Oblast), resulting in abundant surface water resources and large development potential. Additionally, the Republic of Tuva, Republic of Khakassia, Republic of Buryatia, and Irkutsk Oblast in the southern Central Siberian Plateau; Jewish Autonomous Oblast, Primorsky Krai, Amur Oblast, Zabaykalsky Krai, and Khabarovsk Krai in the southern East Siberian Mountains; and Mongolia' s Khentii and Selenge provinces in the upper Selenga River basin all have $C$ values less than 1.0, indicating large development potential.

**(2) Zones with moderate development potential** ($1.0 \leq C < 2.0$)
Russia' s Moscow Oblast, Mongolia' s Sükhbaatar Province, and China' s Heilongjiang Province exhibit moderate water utilization but still possess considerable development potential. The dominant factors differ by region: Russia' s potential is primarily constrained by socio-economic development levels, while for water-scarce Mongolia and China, relatively abundant surface water volumes significantly enhance development potential.

**(3) Zones with small development potential** ($2.0 \leq C < 5.0$)
These zones are mainly distributed in central-southern Mongolia (Dakhan-Uul Province) and China' s Jilin Province and Inner Mongolia Autonomous Region. Despite large economic development disparities, water scarcity is the most fundamental cause of low development potential. For example, Mongolia' s Gobisümber Province has surface water resources of only $0.03\times10^{8}$ m$^3$ and average annual precipitation of just 104 mm. Continued industrial development will exacerbate water shortages and further reduce utilization potential.

**(4) Zones with very small development potential** ($C \geq 5.0$)
These include Mongolia' s Orkhon Province and Ulaanbaatar City, and China' s Liaoning Province. Orkhon Province has a medium-level socio-economy but the highest $C$ value in the study area (5.2) due to extremely scarce surface water resources ($0.08\times10^{8}$ m$^3$), far insufficient to support socio-economic development. As Mongolia' s capital, Ulaanbaatar City has a population of $1.44\times10^{6}$ (the largest among Mongolian administrative units) and high socio-economic development, creating enormous water demand and minimal development potential. Liaoning Province, as a traditional industrial base in

China, faces severe water shortages despite moderate surface water resources, due to large production and domestic water demands, resulting in minimal development potential.

**3.2.3 Typical Regional Analysis** Under the combined influence of water resources, population, and economic factors, development potential follows certain patterns: regions with higher water resources generally have greater potential, while economically developed regions show higher utilization. However, some areas require special attention due to unique natural or socio-economic characteristics.

**(1) Extremely water-scarce region: Orkhon Province, Mongolia**
Mongolia is extremely water-scarce overall, with Orkhon Province being the most water-deficient area in the study region. Its surface water resources are the lowest ($0.08\times10^{8}$ $\mathrm{m}^3$), yet its population ranks second among Mongolian administrative units, resulting in the highest $C$ value (5.2). Under current conditions, water resources are the decisive factor limiting local potential. With severe water shortages and high utilization, socio-economic development is already severely constrained, making this a key area of concern for "Belt and Road" economic corridor construction.

**(2) Regions with relatively high water resources but low development potential: Four provinces (autonomous regions) of China**
China's four provinces (autonomous regions) have generally higher annual runoff depths than Mongolia, but their water resources development potential is significantly lower than water-scarce northern Mongolia. With dense populations exceeding $1.0\times10^{7}$ persons each and a combined GDP about 10 times that of Russia and Mongolia, water resources are not the sole determinant of development potential in these rapidly developing regions. Human consumption and production impacts on water utilization are substantial, requiring coordinated development between society, economy, and water resources.

**(3) Regions with limited water resources but development potential: Northern Mongolia**
Mongolia's economic center is in the capital Ulaanbaatar, accounting for approximately 40% of the study area's Mongolian population. Except for Ulaanbaatar, other regions have relatively underdeveloped economies. Although total surface water resources in northern Mongolia are not high, low consumption creates development potential despite limited water availability. Therefore, these regions are temporarily not constrained by water resources, allowing priority development of urban areas and optimized water allocation systems.

### 3.3 Prospects and Recommendations for Water Resources Cooperation

Russia's Siberian region is rich in water resources with substantial development potential. Russian scholars have proposed increasing freshwater utilization to meet domestic needs while transferring Siberian water resources to water-scarce Central Asian regions [?] to stimulate economic growth [?]. However, high technical costs and ecological risks have stalled such plans. Currently, Russia primarily exports water resources through virtual water and bottled water [?]. In recent years, global warming has significantly increased precipitation in Siberia [?], with river runoff showing upward trends [?]. Trilateral cooperation among China, Mongolia, and Russia could leverage Siberian freshwater resources to alleviate drought in Mongolia and other regions [?]. However, transnational water cooperation faces challenges including differences in water use patterns [?], basin water culture divergences, high hydraulic engineering costs, long economic cost recovery periods, ecological damage from overexploitation, and technical deficiencies [?].

The "Belt and Road" initiative provides favorable opportunities for trilateral cooperation, establishing platforms for rational water resources development and fostering political, economic, and cultural consensus. Technically, China' s South-to-North Water Diversion Project has accumulated valuable experience. Consequently, China, Mongolia, and Russia have broad prospects for cooperative water resources development. While balancing water resources and regional development in northern China, attention should focus on water issues in Mongolia' s water-scarce provinces (Orkhon, Dakhan-Uul, Gobisümber, and East Gobi) during development processes. Priority should be given to developing economically lagging but water-unconstrained northern Mongolian regions, while utilizing Russia' s abundant water resources through regional allocation to alleviate water shortages and promote sustainable economic development along the corridor.

## 4. Conclusions

The China-Mongolia-Russia Economic Corridor exhibits a spatial pattern of "more in the east and north, less in the west and south, and least in the middle" for surface water resources. Russia and northern Mongolia have relatively large development potential, while southern Mongolia and China' s four provinces (autonomous regions) have smaller potential. Water resources development potential primarily depends on both water availability and socio-economic development levels. Russia' s abundant water resources and sparse population provide conditions for alleviating water shortages in other corridor regions. Southern Mongolia and China' s four provinces (autonomous regions), with dense populations and relatively developed economies, have substantial water demands and represent key areas for water resources optimization allocation in the China-Mongolia-Russia Economic Corridor. Trans-regional water cooperation and rational development will contribute to overall economic development in the corridor. Therefore, against the backdrop of the "Belt and Road" initiative, China, Mongolia, and Russia are expected to strengthen scientific and technological cooperation to jointly promote regional water resources optimization allocation and water trade development.

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*Note: Figure translations are in progress. See original paper for figures.*