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GIES Case Study on Fusong Quanyang Mineral Water Basalt Lava Forestry

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Abstract: Quanyang Town, situated in Fusong County, is situated within the basaltic plateau and primeval forest hinterland of the Changbai Mt., Jilin Province, constitutes a representative area for the occurrence, extraction, and utilization of natural mineral water in the Changbai Mt. region. The study region covers approximately 589.84 km^2 and administratively includes 10 villages and 6 communities. In 2023, the total population is 26,372, with an urban population of 23,332. The Quanyangquan mineral water resource is notable for its abundant recharge, favorable hydrogeological occurrence conditions, and substantial resource volume. Environmental analyses reveal that the area is located within a north temperate continental monsoon climate zone. The distinctive basaltic geological structure, combined with extensive forest cover, weakly acidic soils rich in organic matter, and vigorous deep groundwater circulation, collectively promote precipitation infiltration and water-rock interactions, ensuring the stable formation of mineral water. The mineral water is primarily weakly alkaline (pH 7.2–7.5) and is characterized by low sodium content (4.28 mg/L), low mineralization, and elevated metasilicic acid concentrations (ranging from 18.3 to 28.1 mg/L, with 28.1 mg/L in the final product), fully complying with the China standard for drinking natural mineral water (GB 8537—2018). The hydrochemical facies are predominantly of the HCO_3^-–Ca·Mg type. Sustained by deep groundwater recharge, the water source demonstrates long-term stability in both yield and quality. Additionally, the surrounding aquatic environment exhibits a pristine hydrochemical background, marked by low salinity and minimal heavy metal concentrations, indicative of a favorable ecological condition. The quality of Quanyangquan mineral water derives from regional climate, geology, vegetation and soil, while source protection, spatial control and standardized production support its green brand and sustainability. The dataset is

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archived in .shp, .tif, .xlsx and .docx formats, and consists of 89 data files with data size of 110 MB (compressed into 1 file with 10.5 MB).

Keywords: Changbai Mountain; Quanyangquan mineral water; Quanyang Town; basaltic plateau; GIES; Case 34

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1 Introduction

Amid the ongoing transformation of consumer preferences and the intensifying emphasis on health-oriented hydration, natural mineral water has evolved from a traditional commodity into a valuable resource distinguished by its ecological integrity, quality standards, and brand identity. Recent national policies, including the "Healthy China" initiative and the promotion of "Ecological Civilization", have underscored the importance of high-quality utilization of regional specialty resources. These policies advocate for comprehensive, lifecycle-based management approaches encompassing upstream ecosystem preservation, rigorous quality assurance, brand development, and cross-industry collaboration. Within this framework, distinctive mineral water resources—shaped by pristine environmental conditions and stable natural endowments—serve not only as essential elements in premium drinking water supply chains but also as pivotal drivers for enhancing the value of ecological products and advancing sustainable regional development.

Fusong County constitutes one of the most concentrated and qualitatively representative regions for natural mineral water resources in China[1–3]. This concentration results from the synergistic interaction of volcanic geological structures, forest ecosystems, precipitation recharge dynamics, and minimal human interference, which collectively have given rise to numerous high-quality mineral water sources with considerable developmental potential. Preliminary studies indicate that Quanyang Town source exhibit stable recharge conditions, substantial resource volumes, and exceptional, long-term water quality stability. Nonetheless, prior existing research has primarily addressed the origin, hydrochemical properties, or resource exploitation assessments of mineral water in the Changbai Mt. area. Consequently, the comprehensive relationships among habitat conditions, environmental support mechanisms, and the foundational factors influencing product quality—factors that establish Quanyangquan as a distinguished geographical product—along with their implications for conservation management, remain insufficiently explored.

This study targets the mineral water of Quanyang Town in the Changbai Mt. as a representative case for analysis (Figure 1). By incorporating multiple dimensions—such as geological frameworks, geomorphological attributes, forest vegetation, soil conditions, hydrochemical properties, and conservation management practices—and utilizing empirical data obtained through field investigations, sample collection, and laboratory analyses, the research systematically characterizes the habitat features and their formative impact on mineral water quality. The aim is to establish an empirical basis for habitat conservation, quality assessment, and sustainable development of Quanyangquan, while offering strategic reference for the protection, utilization, and brand fortification of

Figure 1 Fusong Quanyang mineral water

premium mineral water resources throughout the Changbai Mt. area.

2 Metadata of the Dataset

The title, authors, geographic region, year of the data, dataset files, etc. for the GIES case dataset on Fusong Quanyang mineral water basalt lava forestry[4] are listed in Table 1.

Table 1 Metadata summary of the GIES case dataset on Fusong Quanyang mineral water basalt lava forestry

Items	Discription
Dataset full name	GIES case dataset on Fusong Quanyang mineral water basalt lava forestry
Dataset short name	QuanyangMineralWaterCase34
Authors	Bian, J. M., College of New Energy and Environment, Jilin University, bianjm@jlu.edu.cn Wang, D., People's Government of Fusong County, 236147070@qq.com Wang, F., College of New Energy and Environment, Jilin University, fanwang24@mails.jlu.edu.cn Li, Y. N., College of New Energy and Environment, Jilin University, yining24@mails.jlu.edu.cn Sun, X. Q., College of New Energy and Environment, Jilin University, sunxq13@jlu.edu.cn Li, Y. H., College of New Energy and Environment, Jilin University Wang, G., People's Government of Fusong County, 364899194@qq.com Gao, J. T., Fusong County Market Supervision and Administration Bureau, 84809029@qq.com Du, Y. C., Fusong County Market Supervision and Administration Bureau Zhang, J. M., People's Government of Quanyang Town, Fusong County Pan, X. H., Jilin Sengong Group Quanyangquan Beverage Co., Ltd. Liu, X. Y., Jilin Sengong Group Quanyangquan Beverage Co., Ltd. Huang, X. Y., Jilin Sengong Group Quanyangquan Beverage Co., Ltd. Liu, L. K., Fusong County Market Supervision and Administration Bureau Ding, Z. Y., School of Pharmacy, Jilin University Gao, H., Hydrogeological Survey Institute of Jilin Province Chen, S. B., College of Geoexploration Science and Technology, Jilin University, chensb@jlu.edu.cn Wang, Z. B., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, wangzb@igsnrr.ac.cn
Geographical region	Quanyang Town, Fusong County, Baishan City, Jilin Province
Year	2000–2025
Data format	.shp, .xlsx, .docx, .jpg
Data size	10.5 MB (compressed)
Data files	Case area boundary, physical geography data, product characteristic data, socioeconomic data, etc.
Foundation	Jilin Provincial Administration for Market Regulation (2025)
Data Publisher	Global Change Science Research Data Publication System, http://www.geodoi.ac.cn
Adress	No. 11A, Datun Road, Chaoyang District, Beijing100101, China
Data sharing policy	(1) *Data* are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use *Data* subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute *Data* subject to written permission from the GCdataPR Editorial Office and the issuance of a *Data* redistribution license; and (4) If *Data* are used to compile new datasets, the "ten percent principle" should be followed such that *Data* records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[5]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

3 Case Dataset Development

3.1 Case Area

The water source for the Fusong mineral water case is situated in Quanyang Town, Fusong County, Baishan City, Jilin Province (Figure 2), at geographic coordinates 127°32′46″E and 42°19′14″N. This source lies approximately 55 km in a straight line from Tianchi (Heavenly Lake) on Changbai Mt. and is located about 2 km from the Hun-Bai Railway in terms of transportation distance. Regional connectivity is enhanced by the proximity of the Heda

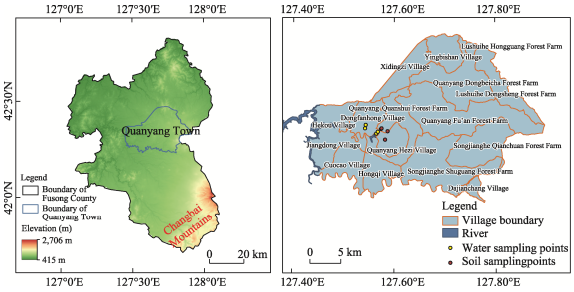

Figure 2 Geo-location map of the case area and sampling sites

Expressway (G11) and National Highway (G201), which run roughly 12 km to the north. Quanyang Town covers an administrative area of approximately 589.84 km^2. According to statistical data from 2023[6], the town administers 10 villages and 6 communities, comprising a total of 14,470 households and a population of 26,372, of whom 23,332 reside in urban areas. Fusong County, encompassing Quanyang Town, is characterized by an extensive hydrological network and functions as a significant zone for water conservation and mineral water resource concentration within the Changbai Mt. The area is distinguished by high forest coverage and an unspoiled ecological environment. The principal surface water bodies in the town include the Lazi and Quanyang Rivers, both tributaries of the Erdao Songjiang River system. The Quanyang River benefits from numerous spring inflows along its course, supporting a specialized industrial framework focused on the extraction and utilization of natural mineral water resources.

3.2 Climate Conditions

The case area is situated within a north temperate continental monsoon climatic zone[2]. Meteorological data from the Donggang Station spanning 2000 to 2024 indicate an average annual temperature of approximately 3.3 ℃[1], exhibiting marked seasonal variability with peak temperatures occurring in July and August and minimum temperatures in January. The mean annual precipitation is around 808.9 mm, with historical maximums reaching 1,071.3 mm; precipitation is predominantly concentrated between June and August. The average annual potential evaporation is 1,291.7 mm, accompanied by an annual sunshine duration averaging 2,315.77 h and a mean wind speed of 2.17 m/s. As depicted in Figure 3, temperature demonstrates a consistent unimodal annual pattern. Precipitation is primarily confined to the summer months, during which evaporation rates also increase, reflecting the characteristic features of a mountainous monsoon climate. This climatic regime significantly influences the genesis, recharge, and yield of Quanyangquan mineral water. Firstly, the temporal concurrence of peak precipitation and elevated temperatures— alongside the fact that summer precipitation substantially exceeds evaporation—promotes canopy interception by forest vegetation, regulation of soil moisture, and subsequent infiltration through basaltic pores and fractures, thereby facilitating effective recharge to the groundwater recharge. Secondly, although sub-zero winter temperatures and snow accumulation temporarily inhibit direct infiltration, cryospheric processes extend the recharge period via spring snowmelt, thereby enhancing the annual storage and discharge capacity. This climatic pattern—characterized by concentrated summer recharge and winter cryospheric modulation, serves as a buffer against short-term meteorological fluctuations, sustaining the stability of spring discharge and hydrochemical characteristics, and providing a conducive environment for the continuous production of mineral water.

3.3 Geological Structure

The case area is located within the volcanic province of the Changbai Mt., where the regional tectonic frameworks is defined by multi-directional fault systems, predominantly

[1] National Meteorological Science Data Center, Donggang Station: 54284.

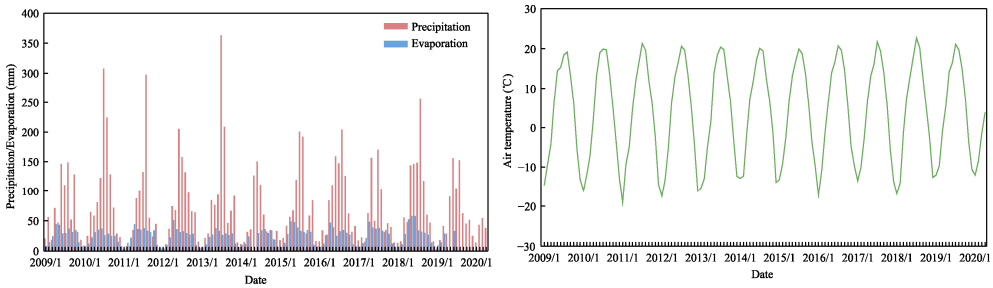

Figure 3 Statistical of average precipitation, evaporation, temperature in Fusong County (2000–2024)

oriented east-west and northeast. Extensive Cenozoic volcanic activity has led to the widespread deposition of basaltic sequences. The primary outcrops correspond to the Junjianshan Formation (Lower Pleistocene, Quaternary), which is chiefly composed of massive and vesicular basalts. The presence of well-developed primary vesicles and contraction joints within these units offers substantial storage and conduits for groundwater movement. Simultaneously, the regional fault networks function as preferential pathways facilitating deep groundwater circulation and mineral water discharge. The regional topography exhibits a northwestward descending stepped physiography originating from the Changbai Mt. volcanic massif. This interplay between basaltic plateaus and topographic gradients establishes favorable hydrodynamic conditions that promote groundwater flow through pores, fractures, and fault zones. Consequently, groundwater emerges as prolific spring clusters at topographic depressions or lithological barriers. Mineralogically, the basalts are predominantly composed of plagioclase and pyroxene. These rocks are characterized by elevated concentrations of SiO_2, Al_2O_3, and TFe[3], and are enriched in components such as CaO, MgO, Na_2O, and K_2O. The incongruent weathering of these primary minerals supplies a continuous influx of Ca^{2+}, Mg^{2+}, Na^{+}, and HCO_3^- ions to the soil-groundwater system.

Mineral spring recharge in Fusong County is primarily controlled by atmospheric precipitation[3], with a considerable fraction of the groundwater undergoing extended deep circulation that enhances water-rock interactions. Throughout its migration, the groundwater persistently leaches silicate minerals from the basaltic host rock; this process, driven by the involvement of CO_2 involvement and carbonate dissolution, progressively leads to the formation of metasilicic acid mineral water characterized by low mineralization and a dominant HCO_3^-–Ca·Mg (calcium-magnesium bicarbonate) hydrochemical facies[7]. As a major mineral water source in Fusong County, Quanyangquan is notable for its stable recharge regime, consistent hydrochemical characteristics, and substantial resource capacity, making it a highly representative example of the region's mineral water resources.

3.4 Topography

The case area is located on the volcanic lava plateau of the Changbai Mountain[3]. The regional topography generally slopes downward from east to west, with geomorphological features predominantly comprising basaltic plateaus, mid-mountain slopes, and river valleys. Within this region, the plateau surfaces are relatively level, punctuated by localized volcanic cones. River valleys exhibit a trough-shaped morphology, while the edges of the plateau margins are marked by significant fluvial incision. Consequently, the area demonstrates a distinct physiographic gradient transitioning from elevated plateaus to slopes and valleys. Utilizing 12.5-m resolution ALOS PALSAR DEM data[2], the elevation and slope characteristics of the case area were classified and analyzed (Figure 4). Findings reveal that elevations predominantly range between 700 and 1,000 m, encompassing 87.03% of the total area. Slope

[2] NASA ASF DAAC. https://search.asf.alaska.edu/.

analysis indicates that the terrain is mainly gentle and flat; with slopes under 7° accounting for 80.70% of the region; notably, the 3°–7° represents the largest proportion at 35.82%. The Quanyangquan spring is located at approximately 750 m elevation, situated within a mid-to-low elevation zone characterized by relatively gentle topography. This geomorphological context facilitates effective capture of upgradient recharge and convergence of groundwater flow, thereby supporting stable spring discharge.

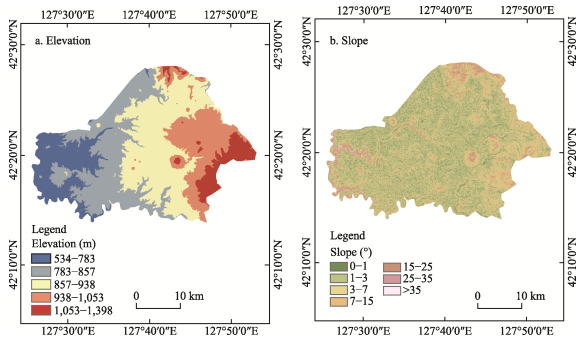

Figure 4 Elevation and slope classification maps of Quanyang Town

Concerning the hydrogeological conditions conducive to mineral water formation, the case area is predominantly characterized by lava plateaus and gently sloping terrains within low to mid-elevation mountainous areas. This physiographic setting promotes the gradual infiltration of atmospheric precipitation, a process moderated by the buffering effects of dense forest cover and topsoil—thereby facilitating effective groundwater recharge. Additionally, the topographic gradient provides the gravitational force necessary for groundwater migration through basaltic pores, fractures, and fault zones, channeling flow toward zones of concentrated discharge at mid to lower elevations. This topographic progression—encompassing recharge in higher elevations, subsurface migration along gentle slopes and structural discontinuities, and stable discharge in lower-lying areas—constitutes a fundamental framework supporting the sustained recharge, consistant yield, and extensive water-rock interactions characteristic of the Quanyangquan mineral water system.

3.5 Vegetation Conditions

The case area is characterized by well-established vegetation, predominantly comprising forested land. It borders the Changbai Mountain Nature Reserve along its eastern edge and encompasses a diverse range of forest types. Natural secondary young- and middle-aged stands constitute a significant portion of the vegetation, with coniferous-broadleaf mixed forests representing the principal natural forest type, while coniferous forests predominate among plantation types. Analysis based NDVI data (Figure 5) reveals a sparse distribution of low-value zones, indicating that vegetation cover within the case area is both continuous and stable. Bare soil and anthropogenic disturbances constitute only a minor component of the landscape. The high forest density and uninterrupted vegetation layers contribute to effective precipitation interception, reduction of surface runoff, and improved soil water retention[7]. These processes collectively facilitate the gradual infiltration of precipitation and enhance the region's water conservation capacity, thereby establishing a strong ecological barrier and creating a conducive environment for the recharge and formation of mineral water.

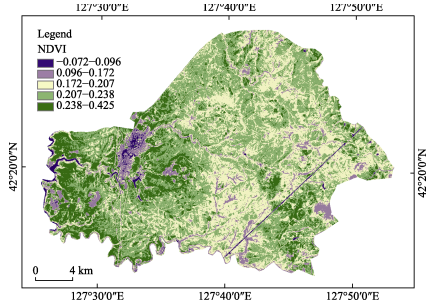

Figure 5 NDVI classification map of Quanyang Town

3.6 Soil Conditions

The predominant soil type within the case area is Albic soil, characterized by a clay loam to

clay texture and a compact structure. The authors selected 3 representative sites for soil analysis: forested land adjacent to the water source, forested land within Quanyang Town, and local agricultural land. At each site, 3 replicate samples were collected and stratified into surface (0–20 cm) and subsurface (20–40 cm) layers (Figure 2). These samples were physically homogenized in equal proportions by layer and subsequently submitted to the Jilin Provincial Institute of Geological Sciences for detailed analysis. Analytical results indicate that the soil exhibits a generally weakly acidic, with pH ranging from 5.09 to 5.65 (Table 2). Soil organic matter (SOM) content in the forested topsoil is notably elevated, reaching a maximum of 93.523 g/kg, whereas the subsurface layer exhibits a minimum SOM concentration of 20.5 g/kg. In contrast, SOM concentrations in the farmland layers are 38.13 g/kg and 46.74 g/kg for the surface and subsurface horizons, respectively. This high SOM content within a weakly acidic pedological environment effectively increases soil CO_2 and facilitates the release of low-molecular-weight organic acids. Such conditions enhance the chemical weathering of plagioclase and pyroxene minerals in the basaltic bedrock, thereby promoting the mobilization of Ca, Mg, Na, HCO_3^-, and H_2SiO_3 into the groundwater system. This biogeochemical process forms the essential habitat foundation that characterizes Quanyangquan mineral water as a low-mineralization, calcium-magnesium bicarbonate type. Moreover, the concentrations of heavy metals, including Zn, Cu, and Pb, remain well below the thresholds established by the national standard Soil environmental quality risk control standard for soil contamination of agricultural land (Trial) (GB 15168— 2018)[8], confirming that the soil in the case area is uncontaminated and maintains a pristine condition.

Table 2 Statistical testing result of principal soil indicators in Quanyang Town

Test item	Unit	Forest soil S1 (20 cm)	Forest soil S1 (40 cm)	Forest soil S2 (20 cm)	Forest soil S2 (40 cm)	Farmland soil S3 (20 cm)	Farmland soil S3 (40 cm)	Limits[8]
pH	–	5.53	5.09	5.65	5.52	5.59	5.60	/
TN	g/kg	3.32	2.71	5.34	1.52	2.51	2.96	/
AP	mg/kg	22.0	12.6	24.4	13.5	32.9	24.6	/
AK	mg/kg	129	70.0	155	56.2	167	181	/
SOM	g/kg	54.1	41.8	93.5	20.5	38.1	46.7	/
Si	%	29.10	29.61	29.33	32.02	30.72	30.01	/
Cd	mg/kg	0.159	0.127	0.229	0.092	0.192	0.200	0.3
Hg	mg/kg	0.061	0.052	0.086	0.040	0.052	0.057	1.8
As	mg/kg	9.04	9.32	9.94	11.1	12.4	13.0	30
Pb	mg/kg	27.8	27.1	27.8	28.5	29.7	33.0	90
Cr	mg/kg	75.6	73.1	78.6	74.3	81.3	85.3	200
Ni	mg/kg	32.5	33.3	23.5	28.7	28.9	29.2	100
Cu	mg/kg	26.8	26.8	20.5	22.0	24.0	24.0	50
Zn	mg/kg	112	111	95.4	92.8	102	114	200

Note: – indicates no corresponding data; / indicates no corresponding standard limit.

3.7 Surrounding Water Conditions

In May 2025, water samples were collected by authors from multiple sites, including the Quanyang River, Erdao Songjiang River, Quanyang Lake, the stream traversing the Quanyang Spring water source area, and local tap water (Figure 2). These samples were subsequently analyzed at the Jilin Provincial Institute of Geological Sciences, with the results presented in Table 3. The pH across all sampling sites ranged from 6.77 to 7.16, suggesting that the water was predominantly neutral to slightly alkaline. TDS concentrations varied between 60 and 145 mg/L, indicative of low mineralization levels. HCO_3^- emerged as the dominant anion, with concentrations spanning from 29.3 to 65.2 mg/L; notably, higher concentrations were observed in the Erdao Songjiang River, while other sites exhibited comparable levels. Cl^- concentrations were notably low (0.72–3.84 mg/L), and fluoride levels were measured

between 0.10 and 0.12 mg/L. These findings collectively suggest a low salinity baseline in the regional water bodies and minimal influence from anthropogenic pollution sources. H_2SiO_3 concentrations ranged from 18.3 to 26.4 mg/L, with the stream and tap water from the source area reaching 25.3 mg/L and 26.4 mg/L, respectively. The elevated bicarbonate and low chloride concentrations, alongside consistent pH and metasilicic acid levels, reflect a stable hydrochemical environment in the surrounding waters. Importantly, all key parameters in the surface water samples complied with the national Class I water quality standards[9]. These results indicate that the area surrounding the water source maintains a favorable natural hydrochemical background and a pristine ecological environment, thereby providing conducive external conditions for the formation and preservation of the natural quality of Quanyangquan mineral water. Furthermore, the data imply that water source protection measures and regional environmental management practices are generally effective.

The concentrations of trace elements such as Mn, Fe, As, Se, and Sr in water samples collected from the case area were all markedly below the regulatory thresholds established for corresponding surface water (GB 3838—2002)[9] or drinking water standards (GB 5749—2022)[10]. Additionally, heavy metals such as Cd, Pb, and Cr were found to be below the detection limits. Considering that agricultural activities in Quanyang Town are predominantly rain-fed and self-sustaining, coupled with the absence of heavy industrial operations or large-scale high-risk pollutant discharge facilities in the region, it can be concluded that the baseline water quality in the vicinity of the case area is of a high standard.

Table 3 Statistical testing result of surrounding water quality in Quanyang Town

Test item	Unit	Tap water (W1)	Erdao Songjiang River (W2)	Quanyang Lake (W3)	Quanyang River (W4)	Source stream (W5)	Limits[9]	Limits[10]
pH	–	7.13000	6.77000	6.91000	7.09000	7.16000	6-9	6.5–8.5
TDS	mg/L	60	145	62	60	63	/	≤1,000
Cl^-	mg/L	1.07000	3.84000	0.99000	0.82000	0.72000	≤250	≤250
HCO_3^-	mg/L	32.60000	65.20000	32.60000	32.60000	29.30000	/	/
H_2SiO_3	mg/L	26.40000	19.60000	18.30000	25.50000	25.30000	/	/
Sr	mg/L	0.03880	0.09970	0.03720	0.03840	0.03560	/	/
Se	mg/L	0.00200	0.00300	0.00100	0.00090	0.00200	≤0.01	≤0.01
Mn	mg/L	0.00098	0.00108	0.00986	0.00086	0.00115	≤0.1	≤0.1
Fe	mg/L	0.03040	0.02170	0.14300	0.00170	0.05810	≤0.3	≤0.3
F^-	mg/L	0.12000	0.11000	0.10000	0.11000	0.12000	≤1.0	≤1.0
Cd	mg/L	<0.00006	<0.00006	<0.00006	<0.00006	<0.00006	≤0.001	≤0.005
Pb	mg/L	<0.00007	<0.00007	<0.00007	<0.00007	<0.00007	≤0.01	≤0.01
Hg	mg/L	<0.00007	<0.00007	<0.00007	<0.00007	<0.00007	≤0.00005	≤0.001
As	mg/L	0.0003	0.0009	0.001	0.0004	0.0003	≤0.05	≤0.01
Cr	mg/L	<0.00009	<0.00009	<0.00009	<0.00009	<0.00009	≤0.01	≤0.05

Note: – indicates no corresponding data; / indicates no corresponding standard limit.

4 Mineral Water Quality Data

4.1 Mineral Water Quality

Historical data[11] indicate that the pH of the raw water from Quanyangquan generally ranges between 7.25 and 7.66, indicating midly alkaline conditions. TDS concentrations are approximately 54–88 mg/L, categorizing the water as a low-mineralized mineral water. The ionic composition is predominantly characterized by HCO_3^- as the main anion, Ca^{2+} and Mg^{2+} serving as the primary cations. The hydrochemical profile demonstrates considerable stability, with the water classified within the HCO_3^-–Ca·Mg hydrochemical facies. Molar fraction analysis shows that HCO_3^- constitutes roughly 74% of the total anions, while Ca^{2+} and Mg^{2+} together account for approximately 66% of the total cations.

Raw water samples collected from Quanyangquan were subjected to analysis by the

Baishan Product Quality Inspection Institute and the National Drinking Water Product Quality Supervision and Testing Center. The results (Table 4) indicate that the H_2SiO_3 concentration is 28.1 mg/L, which satisfies the threshold requirements stipulated in the National food safety standard—drinking natural mineral water (GB 8537—2018)[12], underscoring its significance as a key diagnostic component of Quanyangquan mineral water. Concurrently, the Na^+ concentration was measured at 4.28 mg/L, while Cl^- and SO_4^{2-} concentrations were notably low, at 0.80 mg/L and 3.70 mg/L respectively, reflecting a minimal saline background. F^- (0.22 mg/L) and NO_3^- (4.96 mg/L) concentrations remain at minimal levels.

Concerning heavy metals and other contaminants, concentrations of As, Hg, Cd, Pb, Cr, Sb, Ni, Ba, bromides, borates, volatile phenols, cyanides, nitrites, and other parameters were all well below regulatory limits[12], thereby conforming to the relevant quality standards.

Table 4 Statistical testing result of key indicators of Quanyangquan mineral water

Test item	Unit	Testing result	Limits[12]	Test item	Unit	Testing result	Limits[12]
pH	–	7.48000	/	Br^-	mg/L	<0.005	0.01
Na^+	mg/L	4.28000	/	BO_2^-	mg/L	0.03000	5
K^+	mg/L	1.55000	/	Sb	mg/L	<0.00007	0.005
Ca^{2+}	mg/L	5.06000	/	Mn	mg/L	0.00040	0.4
Mg^{2+}	mg/L	2.28000	/	Ni	mg/L	<0.00007	0.02
Fe^{2+}+Fe^{3+}	mg/L	0.04000	/	Ba	mg/L	0.00200	0.7
HCO_3^-	mg/L	33.00000	/	Cr	mg/L	0.00020	0.05
CO_3^{2-}	mg/L	<3	/	Cu	mg/L	<0.00009	1
Cl^-	mg/L	0.80000	/	Ag	mg/L	<0.00003	0.05
SO_4^{2-}	mg/L	3.70000	/	Volatile phenols	mg/L	<0.0020	0.002
NO_3^-	mg/L	4.96000	/	CN^-	mg/L	<0.0020	0.01
H_2SiO_3	mg/L	28.10000	≥25.0	As	mg/L	0.00020	0.01
Co	mg/L	<0.00003	/	Hg	mg/L	<0.0001	0.001
V	mg/L	0.00200	/	Cd	mg/L	<0.00006	0.003
Al	mg/L	0.08000	/	Pb	mg/L	<0.00007	0.01
F^-	mg/L	0.22000	≤1.5	NO_2^-	mg/L	<0.0033	0.1
Se	mg/L	0.00100	0.05	BrO_3^-	mg/L	<0.005	/

Note: – indicates no corresponding data; / indicates no corresponding standard limit.

4.2 Product Feature Comparison

Based on comparisons with internationally renowned mineral waters, the mineral water produced in Quanyang Town is of exceptional quality (Table 5)[13–16].

Table 5 Comparison of the water quality of Quanyangquan mineral water with the world-renowned mineral waters Unit: mg/L

Brand name	Origin	K^+	Na^+	Mg^{2+}	Ca^{2+}	HCO_3^-	SO_4^{2-}	H_2SiO_3
Quanyangquan	Fusong, China	1.55	3.31	3.13	7.13	33.41	3.13	26.79
Volvic	Auvergne, France	6.2	11.6	8	11.5	371	8.1	41.2
Evian	French Alps	1.1	7	27.6	82	375	12	18
Vittel	France	4.9	7.5	20.6	95.9	267	122	10.9
Perrier	Southern France	0.4	10.6	3.6	159	430	32	13.1
Gerol	Eifel Volcanic, Germany	2.8	11.1	49.5	137	427	45	17.1

Basaltic fissure and pore-water systems are extensively distributed throughout the Fusong area of the Changbai Mt., with the aquifers in Quanyang Town demonstrating notably high water-yielding capacities[17,18]. The hydrochemical profile of Quanyangquan mineral water closely resembles that of the internationally recognized Volvic brand from the French Alps; however, its metasilicic acid concentration is markedly higher than that of other well- known mineral waters[13]. The overall mineralization remains at a low level, distinguished by an exceptionally low sulfate concentration, which mitigates the bitternesstypically associated with elevated sulfate content. High-quality mineral water must meet both physiological health standards[19] and sensory acceptability. In this investigation, the palatability of

Quanyangquan was quantitatively evaluated using the O Index developed by Hashimoto[20,21]. The analysis produced an O Index of 5.8, significantly surpassing the criterion for "delicious water" (O Index≥2.0). Furthermore, the ^{17}O-NMR full width at half maximum (FWHM), an indicator of water cluster structure, was determined to be 78 Hz. This measurement aligns closely with the cluster structure observed in Evian mineral water and falls well within the recognized range for natural premium drinking waters (70–90 Hz). Accordingly, the taste quality of Quanyangquan is classified as "excellent".

5 Socioeconomic Development and Industrial Development

5.1 Socioeconomic Development

In 2023, Fusong County reported a GDP of 11.519 billion CNY[6], reflecting a year-on-year increase of 5.5% at constant prices. The value added by the primary, secondary, and tertiary sectors was 2.616 billion CNY, 1.755 billion CNY, and 7.148 billion CNY, respectively. This distribution corresponds to a sectoral composition ratio of 22.7:15.2:62.1, indicating a predominantly tertiary-sector-driven economy characterized by the integrated development of ecological resource utilization and the service industry. The township recorded a total of 14,470 households and a population of 26,372 in 2023, of which 23,332 were urban residents, demonstrating a notably high urbanization rate within the township.

Leveraging its advantageous forest ecological environment and resource endowments within the hinterland of the Changbai Mt. hinterland, Quanyang Town has adopted a strategic development focus on forest-based foods products, mineral water extraction, and ecological services. The Jilin Provincial Government has officially recognized "Quanyang Forest Food Town" as a provincial-level characteristic industrial township. Consequently, Quanyang Town benefits from a solid industrial foundation and favorable policy support, positioning it well for the sustainable development of regional specialty resources and the promotion of green industrial sectors.

5.2 History and Culture

The Fusong mineral water, situated in Quanyang Town, lies at the core of the volcanic lava plateau within Changbai Mt. The nomenclature of this water source derives from extensive long-term observations of the natural habitat; specifically, the Quanyang River— historically known as the Quanyan River—is formed by the confluence of 8 major mineral spring clusters. Due to the consistent discharge and stable temperature of these springs throughout the year, the river remains unfrozen even during the harshest winter months, thereby creating a distinctive landscape characterized by the juxtaposition of "white mountains and black waters". Upon the establishment of the Quanyang Forestry Bureau was established in 1959, the area was officially designated as "Quanyang", reflecting the bureau's location north of the Quanyan River and adhering to the traditional Chinese convention whereby the northern side of a river is termed as "Yang". A local proverb encapsulates this phenomenon: "In the depths of winter, the mountains are blanketed in white, while the spring river flows black". This adage vividly illustrates the unique properties of the water source: wherein the the river remains unfrozen and exhibits a deep black hue, resembling a dark ribbon winding meandering through the snow-laden forest. This is not only a natural wonder of the Changbai Mt. but also reflects the earliest observations by local residents regarding the water's high stability and exceptional quality. Moreover, the water source area region substantially overlaps with the Changbai Mt. ginseng cultivation area, thereby providing an unpolluted and pristine environment conducive to the growth of ginseng and other rare medicinal plants.

5.3 Mineral Water Resources Development

Recent data from 2024 reveal that the annual runoff of Fusong mineral water in Quanyang

Town amounts to 1.93×10^6 t (calculated on a 365-day basis). Currently, Jilin Sengong Group Quanyangquan Beverage Co., Ltd. has largely attained continuous year-round production. The company's mining permit authorizes an annual extraction capacity of 8×10^6 t, representing the highest approved volume among mineral water enterprises in the Changbai Mt. region. Actual annual extraction approximates 7×10^6 t, with total water usage for production reaching 7.89×10^6 t during the most recent operational period (June 2023 to May 2024). Thus, the permitted extraction volume constitutes only 41.42% of the total annual runoff, indicating considerable potential for expansion in both extraction and production. Within the broader context of mineral water development in Fusong County, the Quanyang Town source area exhibits a distinct competitive advantage in production capacity. Its authorized extraction volume is 12 times greater than that of the Xiagu Spring and 6 times that of the Xianren Spring, accounting for 78.4% of the company's total capacity within Fusong County. This substantial resource endowment underpins supply stability, facilitates capacity enhancement, and supports market growth, thereby affirming the site's status as a representative core sample area.

5.4 Sustainable Development of Quanyangquan Mineral Water

According to the Quanyang Town territorial space and urban planning, construction activities are predominantly concentrated within established urban centers and along transportation corridors. Conversely, areas adjacent to mineral water sources retain a substantial proportion of forested land and ecological connectivity, creating a spatial configuration that effectively separates development and construction from water source protection zones. Simultaneously, the town's industrial composition is largely characterized by low-pollution sectors, including forestry, service industries, and mineral water extraction, while agricultural practices are mainly reliant on rain-fed methods. This combination contributes to a relatively low level of anthropogenic disturbance overall. Such a spatial arrangement—marked by the dominance of ecological spaces alongside concentrated human activities—fosters favorable environmental conditions that support stable groundwater recharge and ensuring long-term water quality safety.

The Quanyang Town Wastewater Treatment Plant has maintained stable operational performance, consistently producing effluent that complies with Class 1 A standards. In 2023, the facility treated a total volume of 2.384×10^6 m^3 of wastewater, achieving effluent concentrations of COD at 10.3 mg/L and NH_3–N at 0.95 mg/L. Furthermore, all generated sludge, amounting to 80.89 t disposed in 2023, was disposed of safely, resulting in a 100% disposal rate. This comprehensive sludge management effectively mitigates the potential leaching hazards associated with sludge accumulation along the riverbank.

5.5 Industry and Brand Development

Capitalizing on the superior mineral water resources of Changbai Mt., Fusong County, in recent years, consistently prioritized the mineral water industry as a strategic focus within its green food sector and distinctive resource-based economy. The county has advanced this sector by intensifying efforts in resource exploration and assessment, safeguarding water sources, attracting and nurturing projects, and developing industrial parks. This comprehensive approach has facilitated the gradual establishment of an industrial development model characterized by leading enterprises and coordinated supply chain collaboration. By October 2021, the county's mineral water beverage production reached 9.47×10^5 t, 830 million CNY, and 150 million CNY, respectively. In 2023, these figures increased substantially, with production rising to 1.42×10^6 t, output value to 1.5 billion CNY, and combined profits and taxes totaling 267 million CNY[6]. Among the prominent enterprises in the region, Quanyangquan stands out as leading brand in Jilin Province, having received accolades such as the "China Famous Brand" and "China Well-Known Trademark", as well as being designated the inaugural "Changbai Mt. Ecological Food"

brand. Through sustained efforts in market expansion, channel development, and brand promotion, Quanyangquan has transformed from a regional drinking water brand into a nationally recognized high-quality natural mineral water brand rooted in Northeast China.

5.6 Ecological Environment Traceability for Quanyangquan Mineral Water

In order to facilitate near-real-time monitoring of the mineral spring habitat, the Fushong Quanyangquan mineral water GIES ground station was established in May 2025 at the the water source in Quanyang Town, Fusong County (Figure 6). This station employs a low-power IoT sensing system designed to continuously monitor and record various regional meteorological variables—including air temperature, precipitation, wind speed and direction, relative humidity, and atmospheric pressure—alongside habitat specific parameters such as soil temperature, soil moisture content, and soil electrical conductivity. The collected data are transmitted in real time for ongoing analysis.

Figure 6 GIES ground station in Quanyang Town

6 Discussion and Conclusions

The Fusong mineral water located in Quanyang Town originates within the basaltic plateau of the Changbai Mt. and is influenced by the integrated effects of multiple environmental factors. Precipitation, topography, geological structures, and vegetation cover collectively facilitates deep groundwater circulation and ensures stable spring discharge. Additionally, the presence of organic-rich soils promotes ion release and the accumulation of distinctive chemical constituents. The water exhibits an HCO_3^-–Ca·Mg hydrochemical facies, characterized by weak alkalinity, low mineralization, low sodium, and high metasilicic acid content, maintaining superior and stable quality. Water source protection, spatial management, and standardized production are the essential pillars for its sustainable development.

Although this study has elucidated the synergistic contributions of precipitation, vegetation, soil, and geological substrates to mineral water formation, the context of global climate change and frequent extreme weather events underscore the necessity for establishing a long-term dynamic monitoring network. This will provide a more robust scientific foundation for precise water resource assessments. The Fusong mineral water source area in Quanyang Town currently holds a significant advantage in production capacity, with authorized extraction volumes substantially surpassing those of adjacent sources. As production scales up, it is imperative to continuously monitor anthropogenic activities within and surrounding the case area, adhere to green production practices, and promote ecological conservation in tandem with corporate growth. The economic benefits derived should be reinvested into ecological protection initiatives, low-carbon technological advancements, and public science education. By deepening the exploration of the water source's historical-cultural heritage and promoting healthy drinking water concepts, the natural environmental assets can be transformed into high-value-added green brand capital, positioning Quanyangquan as a benchmark for ecological product development.

Author Contributions

Bian, J. M., Wang, F., Li, Y .N., Li, Y. H., Sun, X. Q. and Chen, S. B. designed the dataset and drafted the paper; Bian, J. M., Wang, F. and Li, Y .N. collected soil and water samples and conducted the tests; Wang, D., Wang, G., Gao, J. T., Du, Y. C., Zhang, J. M., Pan, X. H., Liu, X. Y., Huang, X. Y., Liu, L. K. and Gao, H. provided and processed critical monitoring data related to the survey, development, and production of the Quanyang Spring, as well as

socioeconomic and demographic data for Quanyang Town; Ding, Z. Y. provided feedback on the water quality and health sections of the data paper. Wang, Z. B. oversaw the study design, team coordination, and quality control.

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Conflicts of Interest

The authors declare no conflicts of interest.

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