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GIES Case Study on Huinan Rice Permanent Basic Farmland

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Abstract: Huinan County is under the jurisdiction of Tonghua City, Jilin Province, with a total area of 2,275 km^2, has 3 subdistricts, 10 towns, and 1 ethnic township. In 2023, Huinan County had a population of 214,100 and a GDP of 10.269 billion CNY. It is charactered by a temperate continental monsoon climate, volcanic ash-based soils, and irrigation supplied by pure mountain

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spring water, endowing it with distinctive habitat superiorities. It is also recognized as a permanent basic farmland area in Northeast China. Huinan rice varieties are high-quality rice varieties developed under local suitable climate and soil conditions, featuring rich trace elements, with pollutant concentration far below national standard limits. Benefiting from pristine water sources, fertile soil and unique climatic conditions, Huinan rice exhibits a long growth cycle and large diurnal temperature variation, which facilitates sufficient natural nutrient accumulation and contributes to its reputation as a naturally healthy and premium-quality ecological rice product. A complete industrial chain for rice cultivation and multi-stakeholder coordinated brand development mechanisms have been well established in Huinan County. This study scientifically verifies the quality advantages of Huinan rice and their correlation with local ecological conditions, thereby providing practical support for quality improvement and efficiency enhancement of the local rice industry. The dataset consists of data: case area boundary, physical geographic data, product characteristic data, operation and management data, socioeconomic and historical-cultural data, photographic materials. The dataset is archived in .shp, .docx, .tif, .jpg, and .xlsx data formats, and consists of 62 data files with data size of 73.0 MB (compressed into 1 file with 20.5 MB).

Keywords: Changbai Mountain; Huinan County; rice; permanent basic farmland; volcanic ash substrate; GIES; Case 37

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Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2026.04.02.V1.

1 Introduction

With the continuously growing pursuit of living standards and rising demand for high-quality agricultural products in the new era, premium agricultural commodities have become an indispensable part of people's daily life. To satisfy the urgent market demand for superior agricultural products, high-quality geographical indication products have emerged rapidly as the times require[1]. The Jilin Provincial Government have attached great importance to the ecological conservation and rational development of the Changbai Mt. region. With ecological conservation and high-quality development of the Changbai Mt. as the core orientation for the development of local characteristic resource-based food industries and the construction of Jilin regional brand series, a series of key development initiatives have been implemented successively.

Located in Tonghua City, Jilin Province, Huinan County lies at the western foot of the Changbai Mt., serving as a transitional zone between the Changbai Mt. Range and the Songliao Plain, and is characterized as a hilly and semi-mountainous area. The unique soil parent material formed by volcanic ash lays superior natural foundations for rice cultivation (Figure 1). In the context of the development and protection projects of geographical indication products in the Changbai Mt. region mentioned above, this paper further explores the cultivation pathways of geographical indications products, so as to provide a scientific basis and practical references for the high-quality development of regional characteristic agricultural products.

Figure 1 Huinan County rice

2 Metadata of the Dataset

The information including the name, authors, geographical region, year of the data, data files, data publication and sharing service platform, and data sharing policy of GIES case dataset

on Huinan rice permanent basic farmland[2] is shown in Table 1.

Table 1 Metadata summary of GIES case dataset on Huinan rice permanent basic farmland

Item	Description
Dataset full name	GIES case dataset on Huinan rice permanent basic farmland
Dataset short name	HuinanRiceCase37
Authors	Wang, P., School of Geographical Sciences, Northeast Normal University, wangp666@nenu.edu.cn He, J. W., People's Government of Huinan County, zhanghao1996@163.com Tian, C. Y., Huinan County Market Supervision and Administration Bureau, 1143866329@qq.com Wang, Y. F., People's Government of Chaoyang Town, Huinan, 1508042315@qq.com Zhao, L. L., People's Government of Huinan Town, Huinan, huinanzhen2415@163.com Wang, L., People's Government of Fumin Town, Huinan, umin8752472@163.comf Liang, L. L., People's Government of Yangzishao Town, Huinan, 451086176@qq.com Wang, S., People's Government of Shidaohe Town, Huinan, 16643509976@163.com Pan, X. M., People's Government of Shansonggang Town, Huinan, 19169178302@qq.com Gao, Z. H., People's Government of Huifacheng Town, Huinan, 1835215950@qq.com Li, P., People's Government of Jinchuan Town, Huinan, jinchuan8862003@163.com Xue, W., People's Government of Loujie Township, Huinan, 18743541922@163.com Li, J. N., People's Government of Qingyang Town, Huinan, 3516139302@qq.com Zhang, D., People's Government of Tuanlin Town, Huinan, 18243568052@163.com Ma, C. W., Dongfeng Sub-district Office, Huinan, 1169130040@qq.com Tong, L. S., Xifeng Sub-district Office, Huinan, xifengjiedaobangongshi@163.com Sun, X. J., Chaohui Sub-district Office, Huinan, 1169089796@qq.com Zhang, C. J., Huinan County Market Supervision and Administration Bureau, 2682806468@qq.com Zou, L. P., Huinan County Market Supervision and Administration Bureau, zouliping1125@163.com Meng, X. J., Jilin University of Finance and Economics, mengxj617@163.com Meng, W. R., Jilin Academy of Agricultural Sciences, mwr1104@126.com Ai, Z. G., Huinan County Agricultural Technology Extension Station, azg777@163.com Ni, X. J., Jilin Nishi Agricultural Technology Co., Ltd., 862610767@qq.com Zhang, J. X., Jilin Province Huinong Japonica Rice Science Technology Development Co., Ltd., 961506291@qq.com Guo, H. Y., Jilin Sanhe Farm Co. Ltd., 303700618@qq.com Shen, B. H., Jilin Changxing Grain and Food Co. Ltd., shenbaohua@126.com Shi, Y. H., Guanghui Village, Huifacheng Town, Huinan County, Jilin Province, 1438746701@qq.com Chen, Y., Jilin Agricultural University, 602563840@qq.com Zhao, L., Jilin Agricultural University, zhaol@jlau.edu.cn Zhao, G. Y., Jilin Agricultural University, zhaoguiyu@jlau.edu.cn Wang, H. Q., Jilin Agricultural University, wanghq921@126.com Yan, Y. X., Jilin Agricultural University, yanyunxian@126.com Che, X. C., Jilin Agricultural University, xiaocuic@jlau.edu.cn Tian, L., Jilin Agricultural University, tianlu-1982@163.com Sun, X., Jilin Agricultural University, 389099907@qq.com Lai, S. W., Jilin Agricultural University, 1084343694@qq.com
Geographical region	Huinan County, Tonghua City, Jilin Province
Year	2000–2024
Data format	.shp, .tif, .xlsx, .docx, .jpg
Data size	73.0 MB
Data files	Case area boundary, physical geographic data, rice product characteristic data, management data, photographs and images
Foundation	Jilin Provincial Administration for Market Regulation (2025)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101

(*To be continued on the next page*)

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Item	Description
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[3]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

3 Case Data Development

3.1 Case Area

Huinan County is situated in the northern part of Tonghua City, at the western foothills of the Changbai Mt. (Figure 2). It spans from 42°16′19″N to 42°49′15″N and 125°58′49″E to 126°44′39″E. The county administers 3 subdistricts, 10 towns, and 1 ethnic township, with a total area of 2,275 km^2. In 2023, Huinan County had a population of 214,100 and a GDP of 10.269 billion CNY, the rice planting area reached 32,536 ha, with a total rice output of 25.36×10^4 t.

Figure 2 Map of the geo-location and administrative divisions of Huinan County

3.2 Ecological and Environmental Data

3.2.1 Topography

Huinan County is situated at the western foothills of the Changbai Mt. and characterized as a semi-mountainous area. Ancient volcanic activities had shaped its distinctive topographic pattern with terrain gradually descending from southeast to northwest forming 4 landform types: low mountains, hills, tablelands and river valley plains. Based on the analysis of elevation and slope in Huinan County (Figure 3), the southeastern part is dominated by low mountains with an average elevation ranging from 500 m to 700 m. The central area is hilly and semi-mountainous, where the elevation is generally between 400 m and 500 m. Mountains and hills account for 67.9% of the total county area, forming a natural ecological barrier for the region[4]. River valley plains are distributed along rivers in the western and northwestern parts, with an altitude of 300–400 m and a slope gradient less than 2° (Figure 4). The open and flat terrain provides extensive arable land suitable for irrigation and large-scale rice cultivation. These geographic advantages have strongly supported the scaled development of volcanic ash soil substrate-based rice cultivation in Huinan County.

3.2.2 Land Use and Vegetation Cover

The total cultivated land area of Huinan County is 87,605.35 ha. Among all administrative towns, Yangzishao, Chaoyang, Huinan and Huifacheng possess relatively large cultivated land areas, collectively accounting for 48.02% of the county's total cultivated land. Rice cultivation is highly concentrated on irrigated farmland and paddy fields distributed across river valley plains. These areas are characterized by gentle terrain and convenient water

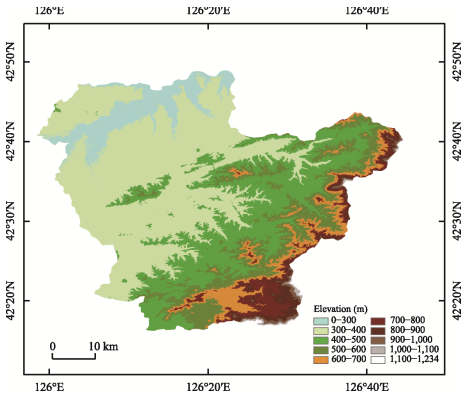

Figure 3 Elevation classification map of Huinan County

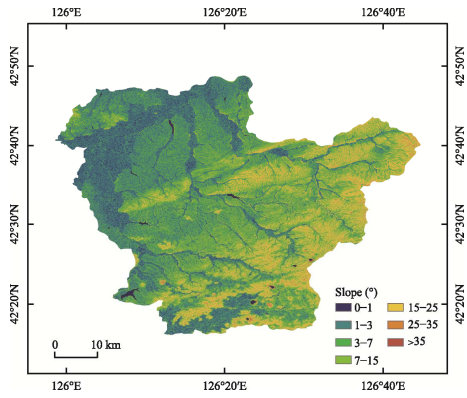

Figure 4 Slope classification map of Huinan County

irrigation, serving as the core base for large-scale production of high-quality rice. In contrast, the low mountains and hilly areas with steeper slopes are mainly covered by forest and dry farmland, with only limited rice cultivation. As shown in Figure 5, cultivated land patches are distributed in a belt-like pattern along river systems, which are closely associated to water bodies and irrigation infrastructures. This forms a spatial pattern integrating water systems and farmlands, providing inherent natural irrigation conditions for rice cultivation.

Based on Landsat-5 and Landsat-9 data[1] ,the Normalized Difference Vegetation Index (NDVI) for the case area was calculated (Figure 6). The results show that the overall vegetation coverage in the case area remains at relatively high level overall, with favorable vegetation conditions during the rice growing season, which preliminarily reflects the supporting effect of the superior ecological habitat on crop growth. Further pixel-scale linear trend analysis of NDVI medians from 2000 to 2025 reveals that statistically significant greening pixels ($p<0.05$) are widely and persistently distributed across the county, quantitatively confirming that the regional ecological environment has been in a stable and improving long-term trajectory. Significant greening pixels are mainly concentrated in paddy field areas within river valley plains, exhibiting a synergistic optimization pattern of "better land becomes even better", which strongly verifies the stable support of superior habitat conditions for rice growth. Benefiting from continuously improved vegetation coverage, abundant accumulation of soil minerals and clean irrigation water, local rice exhibits more sufficient nutrient accumulation, providing a solid and unique ecological guarantee for producing high-quality rice with excellent eating quality and stable product characteristics.

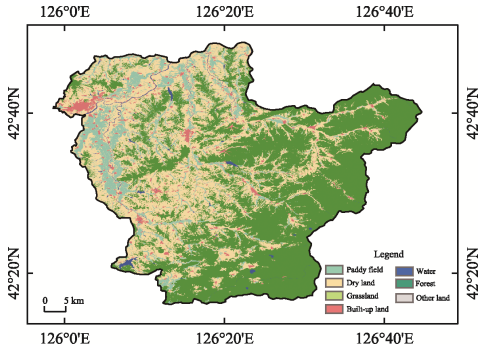

Figure 5 Land use map of Huinan County

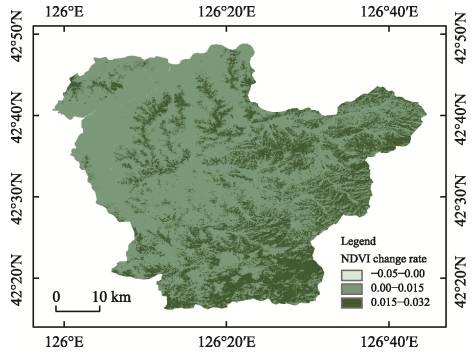

Figure 6 NDVI change rates map of Huinan County (2000–2025)

[1] EROS Data Center. https://earthexplorer.usgs.gov/.

3.2.3 Climatic Conditions

Huinan County features a temperate continental monsoon climate, which is further moderated by its transitional hilly and semi-mountainous terrain, resulting in four distinct seasons. It is windy and dry in spring, hot and rainy in summer, mild and cool in autumn, and long and cold in winter[5,6]. According to data from Huinan Meteorological Bureau, the regional mean annual temperature was 5.39 ℃ during 2005–2024, with an annual frost-free period of 148 d and a mean annual sunshine duration of 2,410.41 h. Precipitation is mainly concentrated from June to August, with an average annual total precipitation of 745.96 mm. The prevailing winds are southwest wind and westerly wind; wind speeds peak in spring and drop to the minimum in summer. The county averages 13 gale days per year with a mean wind speed of 2.19 m/s and an annual accumulated temperature exceeding 2,800 ℃ (Figure 7).

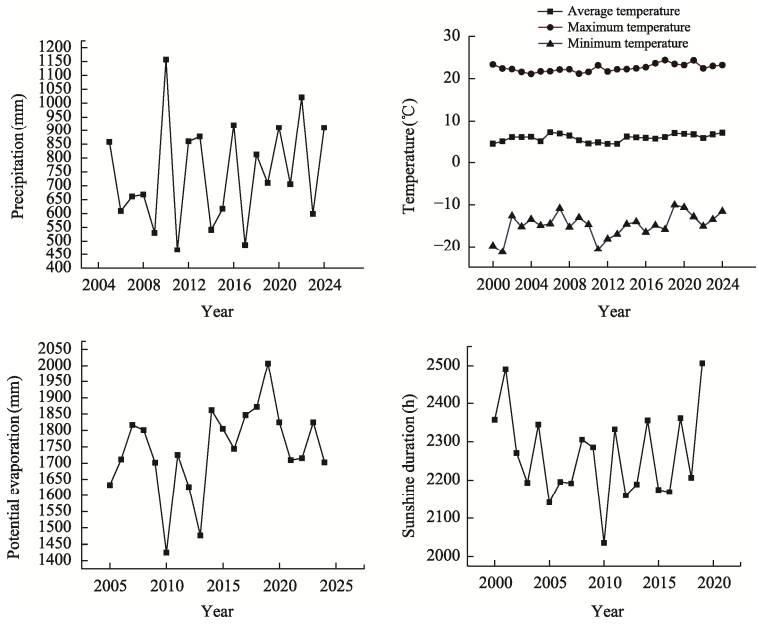

Figure 7 Climate characteristics change of Huinan County

As a typical thermophilic and water-demanding crop, rice has periodic demands for temperature and precipitation in producing areas. The climate of the case area is characterized by high temperature and abundant rainfall in summer, with a pronounced rain-heat synchrony that is highly consistent with the rice growth cycle and conducive to rice development. Statistical data indicate that the mean temperature from May to September remains above 14.5 ℃, fully meeting the thermal requirements for all critical growth stages of rice, including transplanting, tillering, heading and grain filling. The mean temperature of the hottest month (July) is merely 22.5 ℃, which coincides with the heading and flowering stage of rice. Such temperature conditions facilitate pollination and grain setting, and avoid the widespread "high-temperature forced ripening" phenomenon in other rice cultivating regions, thereby guaranteeing the stable production of high-quality japonica rice.

Meanwhile, affected by the continental monsoon climate, the region exhibits a large diurnal temperature range in summer, which benefits the accumulation of dry matter and flavor substances in rice. Sufficient sunshine, prominent day-night temperature variation and well-matched precipitation supply jointly optimize the growth environment of rice. The rational combination of light, heat and water resources extends the grain filling duration, restrains pest and disease outbreaks, and maintains the natural quality of rice, providing solid climatic support for the formation of high-quality rice.

3.2.4 Water Conditions

Surface water resources in Huinan County are primarily recharged by rainfall, and their seasonal variation is highly correlated with the temporal distribution of precipitation. In terms of hydrological regimes, the annual cycle can be divided into 3 seasons, which are spring flood season, dry season and main flood season. Meanwhile in view of flow conditions, it can be divided into open-water period and ice-covered period. Precipitation generally declines in winter and rivers froze over. During this period, surface water is mainly supplemented by groundwater, resulting in the first dry season. Surface water volume in this period accounts for 5%–10% of the annual total. Snowpack and river ice accumulated in the watershed during winter melt in March and April as temperatures rise, giving rise to spring floods, which contribute 10%–20% of the annual surface water resources. Scanty rainfall after spring floods leads to the pre-flood dry period. The main flood season starts in June, with concentrated rainfall occurring in July and August. Surface water runoff from June to September makes up approximately 70% of the annual volume[4]. Serving as the core water supply guarantee for local rice irrigation, reservoirs capture and store natural rainwater during flood seasons to fully meet water demands in critical rice growth stages such as tillering stage and grain-filling stage during dry periods. Major storage reservoirs in Huinan County include Hailong Reservoir, Shidaohe Reservoir, Dayishan Reservoir and Xiaoyishan Reservoir. Furthermore, mountain spring water from Sanjiaolongwan is diverted to reservoirs adjacent to rice cultivation areas including Xiaoyishan Reservoir. The diverted spring water is exposed to solar warming to increase its temperature before being applied to paddy field irrigation.

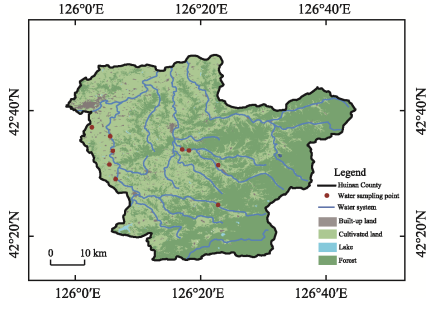

Figure 8 Water sampling sites distribution map of Huinan County

Considering the physical geographical conditions of the case area and the fact that reservoirs serve as the main irrigation water sources, the irrigation water samples were collected to further explore the superior habitat advantages (Figure 8). A total of 11 water samples were collected and analyzed by the Institute of Agricultural Quality Standards and Testing Technology, Jilin Academy of Agricultural Sciences (Northeast Innovation Center of Chinese Agricultural Science and Technology). The test results (Table 2) indicate that the local irrigation water is weakly alkaline. Electrical conductivity, an indicator reflecting the total concentration of dissolved salts in water, ranged from 105 to 317 μS/cm with a mean value of 178.09 μS/cm, representing an overall low-salinity level that avoids soil salinization. In addition, the unique mountain spring water is enriched with a variety of trace elements, particularly magnesium and calcium, both of which exhibit notably high concentrations and may contribute positively to habitat quality.

The concentrations of heavy metals and metalloids in all water samples were far lower than the threshold values specified in the national Standard for irrigation water quality (GB 5084—2021)[7] (Table 3). Notably, cadmium was not detected in all tested samples. As one of the heavy metals most prone to enrichment in rice grains and posing severe hazards to human health, especially to kidneys and bones, the non-detection of cadmium fundamentally eliminates potential cadmium contamination risks of rice cultivated on volcanic ash soil, which constitutes an essential safety advantage of local rice products. These findings fully guarantee the safety of irrigation water and lay a solid foundation for the quality and safety of rice.

In conclusion, the case area boasts superior water quality with extremely low pollutant

concentrations. It not only reflects the well-preserved ecological environment of Huinan County, but also supplies abundant trace elements for rice growth to further improve the nutritional quality of rice. It serves as one of the core cornerstones for building the brand image of volcanic ash-cultivated rice which emphasizes green production, organic attributes, food safety and health benefits.

Table 2 Statistical testing results of trace element concentration (nutrient) in water of Huinan County

Sample	pH	Total water-soluble salt content (electrical conductivity at 25 ℃) (μS/cm)	Mg (μg/L)	P (μg/L)	K (μg/L)	Ca (μg/L)	Mo (μg/L)	Mn (μg/L)	Fe (μg/L)
W (3)	7.27	198	5,948	42.4	1,221	17,996	0.91	0.572	109
W (4)	7.12	173	4,942	23.6	1,646	16,266	0.58	0.506	45.8
W (5)	9.15	187	10,570	29.1	1,355	11,025	1.12	1.40	28.7
W (11)	6.88	169	5,754	45.8	1,066	15,922	1.16	1.06	85.5
W (12)	7.02	153	4,896	81.3	922	14,176	0.70	8.92	636
W (13)	7.14	127	4,576	59.9	934	9,390	0.45	1.63	128
W (14)	6.97	105	3,445	31.3	659	11,799	0.46	1.77	224
W (15)	7.05	190	6,492	32.2	1,365	23,124	3.04	2.07	65.7
W (16)	7.03	226	6,196	76.6	479	26,357	0.89	1.40	142
W (17)	7.33	317	8,599	82.7	2,245	27,563	1.86	4.22	462
W (18)	7.35	114	3,414	66.2	1,001	9,744	0.52	4.07	815
Average value	7.30	178.09	5,893.81	51.91	1,172.09	16,669.27	1.06	2.51	249.24

Note: Water samples in this study were collected in multiple batches. Each batch was numbered independently according to the sampling time, resulting in discontinuous serial numbers. This numbering method exerts no influence on statistical data analysis and the reliability of research conclusions.

Table 3 Statistical testing results of water heavy metal contents in Huinan County Unit: μg/L

Sample	Cr	Ni	Cu	As	Zn	Se	Cd	Hg	Pb
W (3)	0.179	1.02	0.86	ND	1.15	0.113	ND	0.161	0.074
W (4)	0.053	0.45	0.77	ND	0.84	0.175	ND	0.123	ND
W (5)	0.109	0.59	1.03	ND	1.45	0.113	ND	0.125	ND
W (11)	0.092	1.14	1.10	ND	1.81	0.287	ND	0.111	0.008
W (12)	1.13	1.51	1.96	ND	0.89	0.983	ND	0.107	0.265
W (13)	0.300	0.91	0.97	ND	0.32	0.150	ND	0.097	0.005
W (14)	0.289	0.82	1.35	ND	0.96	0.335	ND	0.097	0.065
W (15)	0.373	0.76	1.68	ND	1.51	0.222	ND	0.097	ND
W (16)	0.165	0.92	1.20	ND	1.35	0.149	ND	0.093	0.023
W (17)	0.898	2.29	3.37	0.669	1.88	0.806	ND	0.095	0.445
W (18)	1.03	2.07	2.27	0.856	1.47	0.754	ND	0.091	0.632
Average value	0.42	1.13	1.50	0.76	1.23	0.37	ND	0.11	0.19
Limits[7]	≤100	≤200	≤500	≤2,000	≤50	≤20	≤10	≤1	≤200

Note: ND indicates Not Detected.

3.2.5 Soil Conditions

Located in the volcanic belt at the western foot of the Changbai Mt., Huinan County is dominated by volcanic ash soils which exhibit the typical characteristics of the northeastern China black soil region. In terms of physical properties, volcanic ash soils are characterized by a loose texture, high porosity, favorable permeability and air permeability, which facilitate the extension and respiration of rice root systems as well as the efficient absorption

of water and nutrients. In terms of chemical composition, weathered volcanic ejecta release abundant minerals and trace elements. Meanwhile, the overlying black soil and humus layers supply sufficient organic matter and basic nutrients (nitrogen, phosphorus, potassium, etc.). Consequently, the local soil possesses excellent water and fertilizer retention capacity as well as desirable aeration performance. Particularly distinctive are the stone plate lands formed by solidified volcanic lava, which are covered by fertile soil of 10– 30 cm thickness formed through thousands of years of weathering and humus accumulation with extremely high mineral content. Given the low heat capacity of stone plates, large diurnal temperature differences occur, which further promote nutrient accumulation in the rice during the grain-filling stage. In addition, various paddy soil types are distributed across the region, such as albic paddy soil, alluvial paddy soil and peat soil, providing diverse and fertile conditions for rice growth.

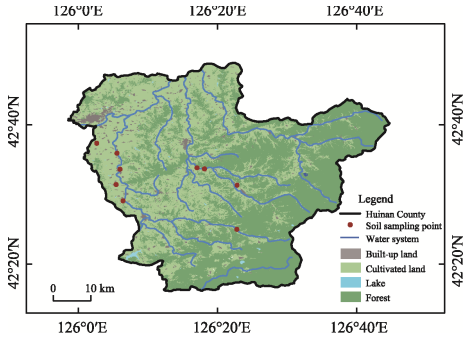

Figure 9 Soil sampling sites distribution map of Huinan County

To further explore the soil characteristics of the case area, surface soil samples were collected from different towns and townships, and the mineral element concentrations of these samples were determined by the Institute of Jilin Academy of Agricultural Sciences (Northeast Innovation Center for Agricultural Science and Technology of China). The spatial distribution of sampling sites is shown in Figure 9. The magnesium concentration in soil samples ranged from 6,509 mg/kg to 21,197 mg/kg, with a mean value of 9,804.33 mg/kg. As an essential element for photosynthesis in rice, magnesium directly affects photosynthetic efficiency and nutrient metabolism, and plays a vital role in yield formation and quality improvement. The soil calcium concentration varied from 3,127 mg/kg to 20,273 mg/kg, averaging a relatively high 7,037.44 mg/kg. During rice growth, calcium contributes greatly to maintaining stable cell structure, balancing nutrient uptake and enhancing stress and disease resistance of rice plants. In summary, the unique volcanic ash-derived soil in Huinan County is rich in essential secondary elements such as magnesium and calcium, which create superior edaphic conditions for local rice cultivation. In addition, the soil in the case area is also abundant in other trace elements (Table 4).

Table 4 Statistical testing results of soil nutrient in Huinan County

Sample	pH	OM (g/kg)	TN (g/kg)	TP (g/kg)	TK (g/kg)	Mg (mg/kg)	Ca (mg/kg)	Mn (mg/kg)	Fe (mg/kg)
S (1)	5.54	39.20	1.74	0.61	21.59	8,088	5,951	317	30,499
S (2)	6.24	29.10	2.86	1.45	17.00	9,522	3,867	511	54,864
S (11)	6.26	16.80	1.27	0.64	20.48	7,481	4,261	477	30,410
S (12)	5.75	30.50	1.72	1.29	17.33	21,197	20,273	1,423	63,584
S (14)	5.48	45.10	1.41	0.9	21.02	11,774	11,552	918	39,710
S (15)	5.91	33.60	2.06	0.89	21.55	7,356	3,710	529	33,159
S (16)	5.56	24.30	3.12	0.93	18.59	9,434	6,295	641	37,511
S (17)	5.57	16.90	1.51	0.71	20.55	6,878	3,127	646	32,163
S (18)	5.91	23.80	2.04	0.7481	20.17	6,509	4,301	468	30,652
Average value	5.80	28.81	1.97	0.91	19.81	9,804.33	7,037.44	658.89	39,172.44

Note: Soil samples in this study were collected in multiple batches. Each batch was numbered independently according to the sampling time, resulting in discontinuous serial numbers. This numbering method exerts no influence on statistical data analysis and the reliability of research conclusions.

The iron concentration ranges from 30,410 mg/kg to 63,584 mg/kg, with an average of 39,172.44 mg/kg; manganese, from 317 mg/kg to 1,423 mg/kg, averaging 658.89 mg/kg; zinc, from 72.7 mg/kg to 125 mg/kg, averaging 99.248 mg/kg. Though rice requires these trace elements in small quantities, their deficiency will cause distinct physiological disorders and impair rice yield and grain quality. The abundant reserves of various trace elements in the soil of Huinan County further highlight its superior edaphic conditions for rice cultivation.

The concentrations of 8 soil pollution elements in the case area, including chromium, nickel, copper, zinc, arsenic, cadmium, mercury and lead, are all far below the risk screening values set in Soil environmental quality risk control standard for soil contamination of agricultural land (Trial) (GB 15618—2018)[8] (Table 5). The test results demonstrate that the soil in the case area is not contaminated, providing a fundamental basis for the production of safe and high-quality rice grown on volcanic ash soils.

Table 5 Statistical testing results of soil heavy metal content in Huinan County Unit: mg/kg

Sample	Cr	Ni	Cu	Zn	As	Cd	Hg	Pb
S (1)	206.4	37.8	22.6	78	6.78	0.271	0.0398	22.5
S (2)	157.3	52.5	28.6	125	6.71	0.313	0.0356	21.4
S (11)	72.8	28.0	21.6	72.7	8.33	0.241	0.0345	23.8
S (12)	101.0	34.9	39.9	125	6.70	0.345	0.028	18.3
S (14)	243.4	42.6	25.9	95.8	8.67	0.278	0.0438	25.4
S (15)	128.5	32.2	23.7	88.6	7.35	0.288	0.0432	26.0
S (16)	89.6	41.8	26.7	106	8.22	0.320	0.0357	26.8
S (17)	93.7	28.3	23.7	82.5	10.5	0.241	0.0398	30.6
S (18)	138.8	31.0	25.1	79.2	9.98	0.226	0.0412	30.4
Average value	136.83	41.60	26.42	94.76	8.14	0.280	0.0379	25.02
Limits[8]	≤250	≤70	≤50	≤200	≤30	≤0.4	≤0.5	≤100

Note: Soil samples in this study were collected in multiple batches. Each batch was numbered independently according to the sampling time, resulting in discontinuous serial numbers. This numbering method exerts no influence on statistical data analysis and the reliability of research conclusions.

4 Product Characteristics Data

4.1 Rice Varieties

4.1.1 Hongke Series

The rice varieties independently developed in Huinan County are mainly the Hongke Series, including Hongke 728, 785, 825, 87, 880 and other cultivars. Consistent with the habitat characteristics of Huinan County described above, these varieties feature a compact plant type, strong tillering ability, erect and upward-pointing flag leaves. Their required accumulated temperature ranges from 2,620 ℃ to 2,800 ℃, which is highly compatible with the local climate conditions (annual accumulated temperature exceeding 2,800 ℃) mentioned in previous sections, as well as being well adapted to the local soil conditions. With high-quality rice as their core advantage, these varieties are characterized by high head rice yield, low gelatinization temperature, high gel consistency, and moderate amylose content. All of these meet the national high-quality rice standards, and ensure superior cooking and eating quality. Meanwhile, they also exhibit favorable resistance to major diseases such as rice blast and sheath blight, boasting comprehensive advantages including strong planting adaptability, high yield, and excellent taste of cooked rice products.

4.1.2 Wuyoudao 4

Huinan County lies within the monsoon climate zone of Northeast China. When warm currents pass through the region, the wind direction shifts to southwest-to-northeast, triggering the backflow of the warm current. This results in 2–3 ℃ higher active accumulated temperature in the case area compared with adjacent regions, which helps meet the active accumulated temperature demand of high-quality rice from April to September and guarantees the sound growth of rice.

Meanwhile, benefiting from the unique geographical and climatic conditions of the producing area, Wuyoudao 4 achieves abundant dry matter accumulation, with moderate amylose content and relatively high amylopectin content. The large diurnal temperature difference during the rice grain-filling and maturity stage promotes the accumulation of rapidly soluble disaccharides in Wuyoudao 4 rice, which is highly beneficial to human health. The cultivated rice features uniform grain size, bright and glossy appearance, as well as a rich, lingering flavor and intense fragrance.

4.1.3 Zhongkefa 5

Zhongkefa 5 is one of the principal cultivars for high-quality and stable yield of Huinan rice. It has a whole growth duration of about 150 d, suitable for single-cropping rice cultivation in the medium-maturity rice growing region of Huinan. It requires an active accumulated temperature (≥10 ℃) of 2,700–2,750 ℃, which is highly compatible with the climatic conditions of Huinan County. This cultivar exhibits a plant height of about 102.8 cm and strong tillering ability, producing approximately 18,200 effective panicles per ha. It has an average of 118.3 total grains per panicle, a seed setting rate of 79.9%, and a 1,000-grain weight of 26.9 g, with outstanding lodging resistance. In terms of quality traits, it achieves a head rice yield of 70.1%, chalky grain rate of 6.0%, chalkiness degree of 1.8%, amylose content of 16.1%, gel consistency of 70 mm, and a length-width ratio of 3.0, meeting the Grade 2 high-quality rice standard of the agricultural industry. It produces slender, translucent rice grains with minimal white belly; the cooked rice is elastic, moist and fragrant, with no starch retrogradation even after cooling. The volcanic ash-derived soils in Huinan are rich in potassium, calcium, selenium and other trace elements. Combined with the unique local conditions including mineral spring water irrigation (with a water temperature of 6–9 ℃), a growth duration of 138–145 d, and a diurnal temperature difference of about 11 ℃, these factors facilitate the accumulation of flavor-related compounds in Zhongkefa 5, and improve the performance of chalkiness degree and head rice yield. This cultivar also features cold tolerance and lodging resistance, which can reduce losses caused by early frost, wind and rain disasters, and ensure stable yield. With the comprehensive advantages of high yield, superior quality and strong stress resistance, Zhongkefa 5 has become a key cultivar for achieving simultaneous improvement in both yield and quality of Huinan rice. Its ecological synergy with volcanic rock fields and mineral spring water irrigation not only ensures food security, but also enhances brand value, serving as a representative model of green and efficient japonica rice production in Northeast China.

4.2 Rice Quality

The collected Huinan rice samples were subjected to trace element analysis by the Institute of Agricultural Product Quality and Safety, Heilongjiang Academy of Agricultural Sciences. As shown in Table 6, the concentrations of calcium, phosphorus and magnesium in Huinan rice are generally high, reflecting the enrichment effect of mineral elements in the volcanic ash-derived soil. In addition, trace elements including zinc, manganese, iron and selenium were all detected in the samples, demonstrating the advantage of volcanic ash substrate rice in terms of trace element nutrition.

The analytical results showed that the concentrations of contaminants, including lead, cadmium, arsenic and mercury, in the Huinan rice are far below the maximum limit values of each element specified in the National food safety standard—maximum levels of contaminants in food (GB 2762—2022) (Table 7)[9]. These comparative results demonstrate that the pollutant content in Huinan rice is extremely low, fully complying with national standards, and even far superior to the standard requirements. This also demonstrates the rice cultivation advantages of Huinan County: the region boasts an excellent planting environment, and the produced rice features outstanding quality.

Table 6 Statistical testing results of rice trace element and nutrients in Huinan County Unit: mg/kg

Test item	Huinan rice	Control group	Test item	Huinan rice	Control group
Ca	73.6	62.2	Co	0.00422	0.00631
K	890	888	Se	0.034	0.051
P	884	880	Cu	1.50	2.16
Mg	210	185	Mo	0.413	0.512
Mn	8.10	11.2	Ti	0.167	0.155
Fe	3.13	3.81	Si	64.2	54.2
Zn	12.8	12.5			

Table 7 Statistical testing results of food safety indicator for rice in Huinan County Unit: mg/kg

Test item	Huinan rice	Limits[9]	Test item	Huinan rice	Limits[9]
Pb	ND	0.2	Ni	ND	/
Cd	0.0115	0.2	As	0.0862	0.35
Cr	0.143	1	Hg	0.00543	0.02

Note: ND indicates Not Detected; / indicates no corresponding standard limit.

5 Socioeconomic Development and Industrial Management

5.1 Overview of Socioeconomic Development in Huinan County

According to data from the Huinan County Statistical Yearbook, Huinan County had a total population of 213,100 in 2023, of whom 100,700 resided in rural areas. The county's gross domestic product (GDP) reached 10.269 billion CNY, with a year-on-year growth of 6.0%. The industrial structure ratio of the primary, secondary and tertiary industries was 24.1:23.6:52.3. The local fiscal revenue totaled 880 million CNY, a year-on-year increase of 85.8%; fixed asset investment amounted to 3.46 billion CNY, rising by 5.9% year on year. The per capita disposable income of rural permanent residents was 19,849 CNY, representing a year-on-year growth of 5.7%, while that of urban permanent residents reached 30,331 CNY, with a year-on-year increase of 4.3% (Table 8).

5.2 History and Heritage of Huinan Rice Production

Huinan County has a long-standing rice production history, and its rice cultivation tradition can be traced back to the late Ming and early Qing dynasties. According to the Huinan County Annals, during 1570–1640, a Korean immigrant settlement of more than 200 residents was established at the foothills of Bingwu Mt. in the Longgang Mt. in the Changbai Mt. area (present-day Qingyang Town, Huinan County). The tribe settled here, reclaimed wasteland, and cultivated rice along the Jiaohe River, introducing the earliest japonica rice cultivation and rice processing technologies to Huinan, and thus initiating the history of rice planting in the county.

Table 8 Statistical of socioeconomic conditions of Huinan County (2020–2023)

Year	Total population (10^4 persons)	GDP (10^8 CNY)	Per capita GDP (CNY)	Added value of primary industry (10^8 CNY)	Grain cultivated area (ha)	Grain yield (10^7 kg)	Rice cultivated area (ha)	Rice yield (10^7 kg)
2020	31.96	88.47	27,464	22.75	75,300	51.616	31,333	22.66
2021	23.00	92.95	39,927	22.76	75,347	53.14	32,149	24.65
2022	22.01	98.52	43,777	25.24	76,894	54.45	32,312	24.93
2023	21.41	102.69	47,300	24.7	77,160	55.56	32,536	25.36

In the 35th year of the Wanli reign of the Ming Dynasty (1607), Nurhachi, the founder of the Qing Dynasty, conquered the Huifa tribe. During a hunting trip, he tasted the local rice and was impressed by its excellent eating quality. He then set up an imperial hunting ground along the Huifa River, appointed officials to supervise the rice cultivation and production, and listed Huinan rice as a tribute rice for the imperial court. Since then, the superior quality of Huinan rice has been officially recognized.

Following the founding of P. R. China in 1949, the cultivation and production of Huinan rice entered a stage of rapid development. In the 1960s, local authorities experimented with and promoted seedbed-based rice seedling raising and film seedling raising technologies, improving the standardization level of rice cultivation. In the 1980s, rice cultivation technology achieved great breakthroughs, with significant improvements in planting efficiency and yield.

5.3 Rice Cultivation and Management

5.3.1 Land Arrangement

Land arrangement involves autumn or spring ploughing combined with paddy flooding and harrowing to achieve a level field surface. Integrated with full straw returning and high stubble conservation tillage measures, these practices effectively improve soil fertility as well as soil water storage and moisture retention capacity.

5.3.2 Seed Selection

Certified japonica rice varieties with strong low-temperature tolerance, salt-alkali resistance and disease resistance are selected for cultivation. Relevant standard tests including seed vigor determination, salt-alkali resistance identification and sterile line identification are implemented to guarantee seed quality, genetic purity and stress resistance.

5.3.3 Seedling Raising

Unified seedling raising techniques are popularized throughout the county, including the usage of simple plastic cell-tray seedling cultivation, straw-based substrates and wood-ear mushroom residue substrates media. Standardized sowing rate, seedling age and seedbed management procedures are strictly implemented, together with quality evaluation standards for seedling trays and operational specifications for seed sowers. Priority is given to temperature and humidity regulation in seedling greenhouses. The greenhouse temperature is maintained at 30–32 ℃ during the seedling emergence stage following the principle of lower temperature in daytime and higher temperature at night, with the nighttime bed surface temperature kept no less than 10 ℃. In terms of water management, dry nursery cultivation criteria are strictly followed. Sufficient water is irrigated before emergence, and supplementary water is supplied according to requirement after seedling sprouting. Meanwhile, targeted prevention and control measures are carried out against damping-off and bacterial wilt. Standard and robust seedlings with strong stress resistance are cultivated with a seedling age of 35 to 40 d, which provides high-quality seedlings for both mechanical

and manual rice transplanting operations.

5.3.4 Rice Transplanting

Rice transplanting is generally concentrated from mid-to-late May. Considering the climatic characteristics of the eastern hilly and semi-mountainous areas in Huinan County, cultivation practices designed to enhance canopy light interception are prioritized for promotion. In particular, ridge direction is adjusted to 18°–20° west of south to optimize the light receiving conditions of rice canopy to enhance the utilization of solar radiation. Mechanical transplanting serves as the major planting mode, alongside the wide usage of mechanical direct seeding including both dry direct seeding and water direct seeding. The transplanting density is strictly regulated according to the field fertility conditions, that is, 9×6 inches (approximately 185,000 hills per ha) for high-fertility farmland and 9×5 inches (approximately 222,000 hills per ha) for medium-fertility farmland. The conventional planting density is controlled within 106,000 to 133,000 hills per ha with 2 to 3 seedlings per hill, so as to achieve optimum plant density.

5.3.5 Fertilization

Fertilization practices follow the specifications of soil test-based formula fertilization, combined application of organic and inorganic fertilizers, as well as chemical fertilizer reduction with efficiency improvement. Well decomposed organic fertilizers are increased as base fertilizer, and targeted topdressing is applied during tillering and booting stages according to seedling growth status, so as to raise fertilizer utilization efficiency and reduce non-point source pollution. In accordance with the regulations on low-temperature resistant water and fertilizer regulation and high-quality safe dry farming, the cyclic irrigation mode of "shallow water-wetting-drying" is adopted in water management. Deep water is retained to protect seedlings during low temperature periods, which achieves water saving, cold resistance maintenance and root activity cultivation simultaneously.

5.3.6 Pest and Disease Management

Huinan County has established the integrated system of monitoring, early warning and prevention and control based on standardized data collection protocols for monitoring, investigation and risk early warning of major rice pests and diseases such as striped stem borer and rice blast. Green-oriented priority and comprehensive management are adhered to in pest management. Biological control measures, including the release of trichogramma wasps and usage of sex pheromone traps, are adopted to suppress pest populations. Low-toxicity and low-residue pesticides are used with strict compliance with pesticide safety intervals. Supporting detection criteria such as rice blast resistance identification and borer resistance grading are implemented to enhance variety resistance and control precision. Such practices reduce chemical pesticide input, and guarantee rice quality and safety, as well as the ecological health of farmland.

5.4 Rice Industry Development and Brand Building

In recent years, both the rice cultivation area and total rice production in Huinan County have increased steadily, accompanied by significant improvement in average yield per ha. These trends reflect the robust and sustained development of the local rice industry. The scale of standardized planting bases has been continuously expanded. A National Standardized Green Food Rice Production Base covering 10,000 ha has been established, and the Santonghe Organic and Green Rice Industrial Park has been recognized as a provincial modern agricultural industrial park. The number of certified green and organic rice products keeps growing, which lays a solid industrial foundation for follow-up research.

To promote high-quality industrial development, the government of Huinan County has

continuously strengthened policy guidance and service support. It has established industrial associations, fostered leading enterprises and built market linkage platforms to advance the upgrading of rice processing capacity and extend the industrial chain. Meanwhile, in-depth cooperation with scientific research institutions has been carried out to promote elite rice cultivars and green production technologies, so as to consolidate the foundation for industrial development.

Huinan County has gradually established a rice branding system characterized by a dual-brand development model integrating a regional public brand and enterprise-owned brands. Huinan Rice serves as the regional public brand, while "Jizhen" brand, owned by leading enterprise, Jilin Province Huinong Japonica Rice Scientific Technology Development Co. Ltd., has been recognized as one of the "Top Ten Platinum Brands of Jilin Rice". Huinan Rice was certified as a Geographical Indication product in 2013, and successively won gold awards at the 15th, 16th and 17th China Green Food Expositions from 2014 to 2016. Furthermore, Huinan County was designated as one of the first National Standardized Planting Bases for Green Rice by the China Ministry of Agriculture and Rural Affairs. Local enterprises have progressively obtained organic and green food certifications, with the total certified area exceeding 2,000 ha. As a result, the market reputation, the brand visibility and the consumer recognition of Huinan rice have continued to rise steadily.

5.5 Ecological Environment Traceability for Huinan Rice

To enable full traceability of rice cultivation environment and the entire production process, ensure the quality, safety and authenticity of rice products, and support the promotion of Huinan rice's distinctive quality attributes and regional branding strategy, Huinan County has built a GIES ground station for rice growing environments. Equipped with low-power Internet of Things (IoT) sensor networks, these stations can automatically identify and record 10 environmental monitoring parameters including real-time field imagery, air temperature, air humidity, air quality, wind speed and wind direction. They enable real-time environmental monitoring and long-term data storage and management, providing accurate data support for rice quality traceability and environmental management and optimization. Furthermore, the monitoring system improves the farm to table quality control framework, and enhances the credibility and quality assurance mechanisms underpinning the development and protection of Geographical Indication product "Huinan Rice" (Figure 10).

Figure 10 QR code and field image captured by the GIES ground station (21/6/2026)

6 Conclusion

The case area possesses a unique combination of favorable agroecological conditions, superior grain quality and profound agricultural heritage that collectively support the

development of Huinan rice. The distinctive terroir conditions lay a natural foundation for the excellent quality of Huinan rice. Independently developed rice varieties and government-led industrial organization mechanisms constitute two key pillars underpinning the branding development of Huinan rice.

Located in the river valley plain of the Changbai Mt. region, Huinan County features a temperate continental monsoon climate with coincident precipitation and thermal conditions during the growing season as well as large diurnal temperature variation. The volcanic ash-derived soils are rich in essential mineral nutrients and free from detectable heavy metal contamination, while irrigation with pure mountain spring water contributes to natural mineral replenishment within the agroecosystem. The synergistic effect of the above three conditions makes this area an ideal place for high-quality rice cultivation and forms the defining terroir attributes that distinguish Huinan rice from other rice products. Well-adapted cultivars and superior product quality further enhance the competitiveness of this geographical indication product. Relevant studies show that locally suitable rice varieties perform well here. Locally independently developed Hongke series, as well as Wuyoudao 4 and Zhongkefa 5, are characterized by high yield and fine grain quality. Product quality assessment revealed that local rice products are abundant in trace elements, with pollutant concentrations and heavy metal contents far below national standards, presenting a high level of food safety and prominent quality advantages that conform to the core quality attributes of geographical indication products. Supported by a comprehensive quality traceability system, an integrated production and management framework suitable for geographical indication products has been established, which provides vital support for the development and protection of geographical indication brands.

Despite these advantages, several challenges remain, including limited brand recognition, incomplete coverage of standardized production systems, and relatively low value addition along the rice industrial chain. Addressing these constraints through subsequent industrial upgrading, technological innovation, and value chain enhancement will be essential for strengthening market competitiveness. Meanwhile, it puts forward definite optimization directions for agroecosystem protection and sustainable development of geographical indication products in the future.

Author Contributions

Wang, P. was responsible for the overall design of the study, conducting investigations, sampling, data collation, and manuscript writing. He, J. W. provided overall guidance. Zhao, L. participated in field investigation and manuscript writing. Meng, X. J. offered guidance on ecological environment analysis. Meng, W. R. and Ai, Z. G. supervised the rice production and management analysis. Sun, X. generated the spatial maps. Chen, Y. and Lai, S. W. collected and processed samples. Tian, C. Y., Zhang, C. J. and Zou, L. P. coordinated the investigations Zhao, G. Y., Yan, Y. X., Che, X. C. and Tian, L. were responsible for the investigation, sampling, and data collection. Wang, H. Q. was responsible for video production. The other authors participated in data collection. All authors contributed to the discussion and revision of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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