

GIES Case Study on Zhushan Tea Northern Subtropical Low and Middle Mountains

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Abstract: Zhushan County in Hubei Province of China is located in Qinling-Daba Mountain and the north-south climate transition zone of China with thousands of years of tea planting history. Survey results show that 59.38% of Zhushan County is in low mountains at an elevation of 500–1,000 m, 65% of the area has a slope of less than 25°, the annual precipitation is 959 mm, and the average annual temperature is 16 °C. Except for July, the average daily sunshine duration over multiple years is less than 6 h. All soil and water quality indicators of the tea plantations meet

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[2] Liu, S. X., Fan, Q., Li, Y. Y., *et al.* GIES case dataset on Zhushan tea from northern subtropical low and middle mountains [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2025. <https://doi.org/10.3974/geodb.2025.04.06.V1>.

national standards, and no pesticide residues were detected. Zhushan tea is characterized by high water extract, high soluble sugar, high amino acids, selenium content, and a unique aroma. It includes both black tea and green tea: Zhushan green tea is high in tea polyphenols and catechins, while Zhushan black tea is high in theaflavins and relatively high in Theasinensins. By the end of 2024, the registered population of Zhushan County was 440,000, among which 200,000 were tea farmers. The comprehensive output value of Zhushan's tea industry exceeded 7 billion CNY, accounting for more than half of the county's GDP. The GIES case dataset on Zhushan tea from northern subtropical low and middle mountains includes case area boundary, physical geographic environment data (elevation classification, slope classification, climate, soil, water quality, vegetation), tea characteristics, social development, brand, and culture, etc. The dataset is archived in .shp, .xlsx, .tif, .docx, and .jpg formats, consisting of 56 data files with a total size of 548 MB (compressed into 1 file of 153 MB).

Keywords: Hubei Province; Zhushan County; tea; GIES; Case 23

DOI: <https://doi.org/10.3974/geodp.2025.04.08>

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.2025.04.06.V1>.

1 Introduction

Zhushan County was anciently called “Shangyong”, and was renamed “Zhushan” by Yuan Qin, the abolished emperor of the Western Wei Dynasty, because of its dense forests, tall bamboos, and beautiful landscapes. Located in the mountains of the northwestern Hubei Province, its north part evolves into the Wudang Mountains and the south part stretches into Daba Mountains. The verdant mountains of the Qinling-Bashan Mountains and the clean water flowing along the Du River have cultivated an excellent growth environment for tea trees, nourishing Zhushan County as a “national key tea-producing county” and making Zhushan tea uniquely sweet and refreshing. In the agricultural division of Hubei Province, Zhushan County is classified as the high-mountain famous tea production area in northwestern Hubei Province. In 2005, it was officially named as “Hometown of China's High-Aroma Ecological Green Tea” by the Organizing Committee of the China Special Product Hometown Recommendation and Promotion Activity. It has won the titles of “National County for Quality and Safety of Agricultural Products”, “National Demonstration County for Tea Assisted by Science and Technology”, “National Key Tea-Producing County” and “National Standardized Base County for Green Food Raw Materials (Tea)”, making the tea industry as a business card of Zhushan County.

2 Metadata of the Dataset

The metadata of the GIES case dataset on Zhushan tea from northern subtropical low and middle mountains^[1] includes dataset name, authors, geographical region, data formats and sizes, and dataset contents, etc. The detail is shown in Table 1.

3 Case Area

The case study area is in Zhushan County (Figure 1), Shiyan City, Hubei Province, between 109°32'E–110°25'E and 31°30'N–32°37'N. It is adjacent to Fangxian County in the east, Yunyang District in the north, Baihe County of Shaanxi Province in the northwest, Zhuxi County and Xunyang City of Shaanxi Province in the west, and Shennongjia Linqu and Wuxi County of Chongqing City in the south. The county is located 158 km southwest of Shiyan urban area and 638 km northwest of Wuhan. The total area is 3,586 km².

Table 1 Metadata summary of the GIES case dataset on Zhushan tea from northern subtropical low and middle mountains

Items	Description
Dataset full name	GIES case dataset on Zhushan tea from northern subtropical low and middle mountains
Dataset short name	ZhushanTeaCase23
Authors	Liu, S. X., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, liusx@igsnr.ac.cn Fan, Q., The People's Government of Zhushan County, Hubei Province, China, 903077405@qq.com Li, Y. Y., School of Tea Sciences, Anhui Agricultural University, lyy@ahau.edu.cn Ren, T. S., College of Land Science and Technology, China Agricultural University, tsren@cau.edu.cn Zhang, X. F., Tea Research Office, Shiyan Economic Crops Research Institute, 510561777@qq.com Meng, D., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, University of Chinese Academy of Sciences, Cher916@163.com Yao, T. T., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, University of Chinese Academy of Sciences, yaott.19b@igsnr.ac.cn Yang, L. H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, yanglihu@igsnr.ac.cn Ma, J. H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, majh@igsnr.ac.cn Xiong, Y. B., United Front Work office of Zhushan County Committee, 12936527@qq.com Ding, G., Office of Political Consultancy of Zhushan County Committee, 625237406@qq.com Zhou, Z. M., The Committee of Development and Reform of Shiyan City, China, 807196285@qq.com Gao, X. S., The Bureau of Agriculture and Rural Affairs of Zhushan County, China Yang, D. M., The Bureau of Agriculture and Rural Affairs of Zhushan County, 335264469@qq.com Chen, B. Q., The Bureau of Development and Reform of Zhushan County, 346187662@qq.com Wang, X. M., The Bureau of Agriculture and Rural Affairs of Zhushan County, 1050275352@qq.com Zhang, Y. Y., The Bureau of Agriculture and Rural Affairs of Zhushan County, 787917778@qq.com Li, J. Y., The Bureau of Agriculture and Rural Affairs of Zhushan County, 2238978@qq.com Shen, Y. F., Zhushan Tea Industry Group Corporation, 174663286@qq.com Chen, D. Q., The Hubei Shengshui Tea Plantation Limited Company/The Association of Tea of Zhuanshan County in Hubei Province, hbshengshui@163.com Lin, H., The Xingmeng Tea Limited Company, Zhushan County, Hubei Province, China, 511627395@qq.com Yang, S., The Youhua Tea Science and Technology Limited Company, 2263142056@qq.com Li, R., Shangyong Town, Zhushan County, 363286931@qq.com Guo, Y., Chengguan Town, Zhushan County, Zhushan 442200, 260253578@qq.com Li, M. H., The Agricultural Technology Extension Service Center of Desheng Town of Zhushan County, 138728165100@qq.com Zhang, J., The Agricultural Technology Extension Service Center of Baofeng Town of Zhushan County, 1793897168@qq.com Yang, C. H., The Agricultural Technology Extension Service Center of Shangyong Town of Zhushan County, 814630742@qq.com Cheng, W., The Bureau of Agriculture and Rural Affairs of Zhushan County, 1437744907@qq.com Zhang, C., The Center of Integrated Media Communication of Zhushan County, 782610092@qq.com Zhushan County, Shiyan City, Hubei Province
Geographical region	
Data format	.tif, .xlsx, .docx, .shp, .jpg
Data size	548 MB
Data files	Boundary data of case area; physical geographic environment data; tea quality and pesticide residue data; demographic, economic, managerial and cultural data, etc.
Foundations	Ministry of Science and Technology of P. R. China (2022YFF0801804); Shiyan Development and Reform Commission of Hubei Province (2024)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	(1) <i>Data</i> are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use <i>Data</i> subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute <i>Data</i> subject to written permission from the GCdataPR Editorial Office and the issuance of a <i>Data</i> redistribution license; and (4) If <i>Data</i> are used to compile new datasets, the 'ten per cent principal' should be followed such that <i>Data</i> records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset ^[2]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

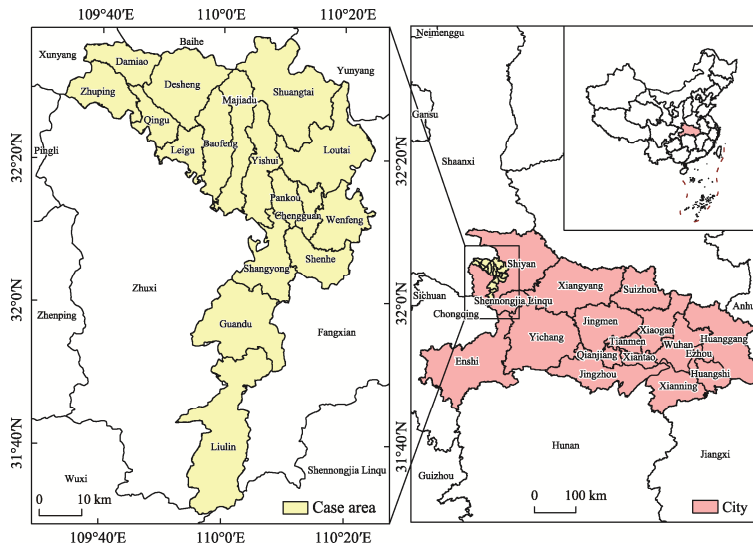


Figure 1 Map of geo-location of Zhushan County

Covering 16 of 17 towns, Zhushan tea is distributed in 3 major tea-growing zones around Dagan Mountain, Nvwa Mountain and Daquan Mountain respectively. Dagan Mountain tea-growing zone consists of 4 towns (Zhuping, Damiao, Qingu and Desheng); Nvwa Mountain tea-growing zone consists of 4 towns (Leigu, Baofeng, Majiadu and Yishui); and Daquan Mountain tea-growing zone consists of 8 towns (Pankou, Chengguan, Wenfeng, Shangyong, Shuangtai, Loutai, Shenhe and Guandu). The main tea processing bases and warehousing & logistics bases are located in Xuanguzhou Village of Pankou Township, Xiaoyan Village of Baofeng Town, Shengshui Village of Desheng Town, Chenjiahe Village of Zhuping Township, Jingquan Village of Shenhe Township, Daquanshan Village of Shangyong Town and Xizhuang Village of Qingu Town, respectively. The main quality inspection services, electronic sales platforms, tea and agricultural products cold storage base, cold chain transportation base, tea wholesale markets, and Wudang Mountain Tea Museum are located in Shangyong Tea Center in Pankou Township.

The case area covers 3 major tea-growing zones in Zhushan County, with the sampling conducted at Guoyingchachang Tea Garden and Hejiaba Tea Garden in Shengshui Village of Desheng Town belonging to the Dagan Mountain tea-growing zone, Qingquan Tea Garden in Baofeng Town belonging to the Nvwa Mountain tea-growing zone, Liujiashan Tea Garden in Chengguan Town and Daquanshan Tea Garden in Shangyong Town belonging to the Daquan Mountain tea-growing zone (Figure 2). In addition, physical geography, population and economic data at the whole of the county level were also investigated.

4 Geographical and Environmental Data

4.1 Topography

Zhushan County is located in the hinterland of the Qinling-Daba Mountains in northwestern Hubei Province. The territory is surrounded by overlapping mountains, and the landform consists of 3 major terrain areas: northern, central, and southern parts. The overall terrain is high in the west and low in the east, steep in the south and gentle in the north, with a river valley plain in the middle. It is surrounded by mountains, sloping from the boundary to the

center, forming a basin. Based on the ASTER GDEM 30-m DEM data¹, a classify analysis to the elevation and slope of Zhushan County was conducted. The altitude ranges from 181 m to 2,604 m (Figure 3). About 59.38% of the area is low mountains with an elevation of 500–1,000 m; areas below 500 m account for 15.34%, mostly being rivers and riparian zones; and areas above 1,000 m account for 25.28%, classified as middle mountains. Additionally, 65% of the county has a slope of less than 25°, which is consistent with the distribution of low-middle mountainous areas (Figure 4). Tea plantations are mostly distributed in the areas with an elevation below 1,800 m and a slope of less than 25°. The vast low mountain area and gentle slopes below 25° provide an excellent growth environment for Zhushan tea.

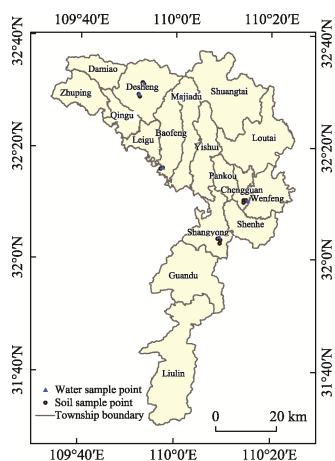


Figure 2 Distribution map of the sampling points

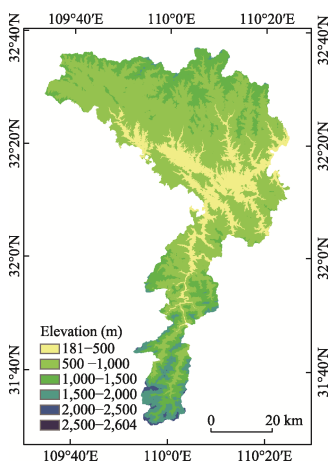


Figure 3 Map of elevation in Zhushan County

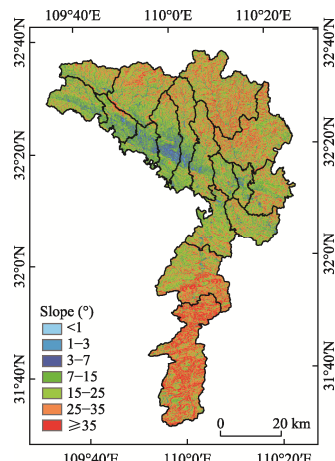


Figure 4 Map of land slope in Zhushan County

4.2 Climatic Data

Zhushan County is situated in the transitional zone between northern and southern climates, belonging to the northern subtropical monsoon continental climate. The entire region enjoys sufficient heat, with an average annual temperature of 16.1 °C (2015–2023). The temperature rises rapidly in early spring with July and August being the high-temperature period. The temperature decreases gradually in autumn, and there is no significant extreme low temperature in winter (Figure 5).

Zhushan experiences distinct 4 seasons, with synchronized rainfall and heat. The average annual precipitation is 958.5 mm, which is concentrated from March to October, accounting for 92% of the annual total (Figure 6). The average daily sunshine duration in the months other than in July is less than 6 h (Figure 7), and the average annual sunshine duration is 1,428 h, providing an excellent environment to conduct the photosynthesis for shade-loving tea plants.

Zhushan County exhibits unique radiation conditions. Based on the documented study^[3], Zhushan County has weak direct radiation. The average annual global radiation in Zhushan from 1981 to 2012 was 3,800–4,100 MJ/m²/year, which is close to that of the Yunnan-Guizhou Plateau (less than 3,800 MJ/m²/year)—the region with the lowest global radiation in China—and much lower than that of the upper reaches of the Yarlung Tsangpo

¹ NASA, METI. ASTER GDEM. <https://www.earthdata.nasa.gov/>.

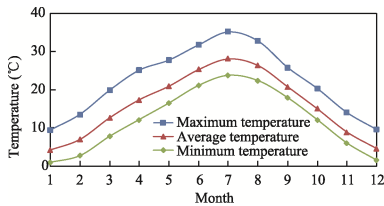


Figure 5 Monthly average temperature of Zhushan County (2015–2023)

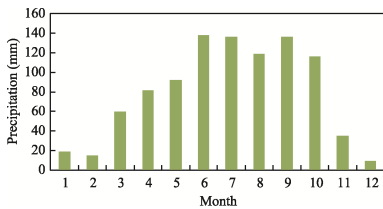


Figure 6 Monthly average precipitation of Zhushan County (2015–2023)

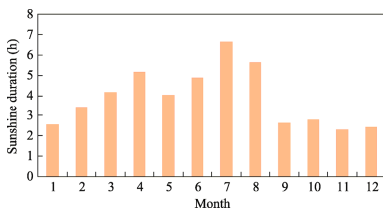


Figure 7 Monthly average daily sunshine duration of Zhushan County (2015–2023)

River in the Qinghai-Xizang Plateau (more than 6,800 MJ/m²/year), the region with the highest global radiation in China. The average annual diffuse radiation from 1981 to 2012 was 2,350–2,450 MJ/m²/year, which is highly suitable for the production of high-quality tea.

4.3 Soil Conditions Data

The main soil types in Zhushan County are yellow-brown earths and mountain brown earths^[4]. The soil exhibits a vertical zonal distribution pattern: below an elevation of 800 m, the soil is generally fluvo-aquic soil and yellow-brown earths; between 800–1,500 m, it is yellow-brown earths; and above 1,500 m, it is mountain brown earths^[5].

Soil samples were collected from Shengsui-Guoying-chachang, Daquanshan, Liujiashan, Shengsui-Hejiaba, and Qingquan Tea Garden. Samples were taken every 20 cm from the surface down to the gravel layer. The soil pH and heavy metal content were tested by the Physical and Chemical Analysis Center of the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (IGSNRR, CAS). The average pH was 5.1, indicating acidic soil (Table 2). The test results for heavy metals are shown in Table 3. The heavy metal content at all sampling points in the case area was lower than the risk screening values (RSV) defined by the national standard for soil contamination of agricultural land^[6].

Table 2 Statistical results of soil pH tests collected from sampling points

Sampling point	Longitude (°E)	Latitude (°N)	pH	Sampling point	Longitude (°E)	Latitude (°N)	pH
P1	109.89	32.52	5.4	P8	110.24	32.17	5.1
P2	109.88	32.52	5.6	P9	110.25	32.18	5.2
P3	109.88	32.53	6.5	P10	109.87	32.49	5.8
P4	110.15	32.06	4.4	P11	109.87	32.48	6.1
P5	110.16	32.05	4.5	P12	109.96	32.27	4.3
P6	110.16	32.06	4.8	P13	109.95	32.27	4.2
P7	110.24	32.18	4.1				

The soil fertility of Zhushan County was tested in accordance with the soil nutrient classification standards of the Second National Soil Survey. The results showed that the soil organic matter content ranged from 6.18 to 31.8 g/kg, and the total nitrogen content ranged from 0.388 to 1.99 g/kg. According to Du, *et al.* (2023)^[7], Zhushan County is located in a northwest-southeast selenium-rich soil belt within Shiyan City. The average soil selenium content in Baofeng Town, Yishui Town, and Qingu Town was 0.91 mg/kg, which is higher than the soil selenium background value in national A horizon (0.29 mg/kg), classifying it as a selenium-rich region^[8]. In 2025, the Geological Society of China recognized Baofeng Town, Leigu Town, and Qingu Town in Zhushan County as naturally selenium-rich areas, with an average soil selenium content of 1.105 mg/kg.

Table 3 Statistical results of heavy metal content in soil samples

Sampling point	Cd (mg/kg)	Hg (mg/kg)	As (mg/kg)	Pb (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Zn (mg/kg)
P1	–	1.1	8.2	28.2	117.4	41.5	46.0	99.3
P2	–	0.9	2.4	28.2	112.8	46.1	55.5	153.6
P3	–	0.3	6.9	24.3	113.7	54.3	57.8	128.8
P4	–	0.0	–	21.8	101.5	56.8	46.8	129.3
P5	–	0.0	6.5	18.7	114.3	59.2	48.0	113.4
P6	–	–	–	17.8	120.1	80.5	56.2	158.5
P7	–	0.5	2.5	24.6	104.2	45.4	58.8	117.3
P8	–	0.7	0.0	27.1	127.3	46.2	60.0	128.2
P9	–	0.9	1.5	26.3	124.0	40.3	57.8	95.6
P10	–	0.7	14.8	15.8	49.4	25.5	23.5	154.3
P11	–	0.5	6.4	13.7	51.9	25.5	22.3	158.6
P12	0.2	0.6	13.9	22.7	95.2	22.6	36.7	113.0
P13	–	0.3	–	9.2	42.8	9.6	16.6	45.7
Limit (pH≤5.5)	0.3	1.3	40	70	150	150	60	200
Limit (5.5<pH≤6.5)	0.3	1.8	40	90	150	150	70	200

Note: “–” indicates that the substance was not detected (hereinafter the same).

4.4 Land Use and Biodiversity Characteristics

With reference to the 2020 Global 10-m Land Cover Product produced by the European Space Agency (ESA) using Sentinel-1 and Sentinel-2 multi-source satellite data combined with machine learning², the interpretation and reclassification were performed to obtain the distribution map of major land use types in Zhushan County (Figure 8). It is seen that forest land is the dominant land use type in Zhushan County, accounting for 89.10% of the total area and distributed across most regions except the plains. Non-forest land accounts for 10.90%, including cropland (4.75%), grassland (3.99%), built-up land (0.82%), and water areas (1.34%).

With a thousand-year history of tea cultivation, tea farmers in Zhushan County mostly adopt an intercropping pattern where tea gardens are interspersed with forest lands and croplands (Figure 9). In recent years, with the promotion of ecological and low-carbon tea garden agricultural technologies, attention has been paid to the configuration of secondary plants in tea gardens, with the target ecological land being not less than 10%. Those plants which are beneficial to the tea garden ecosystem, such as osmanthus, ginkgo, cherry, and metasequoia, are more and more planted around tea gardens, in open spaces, and along roadsides, at

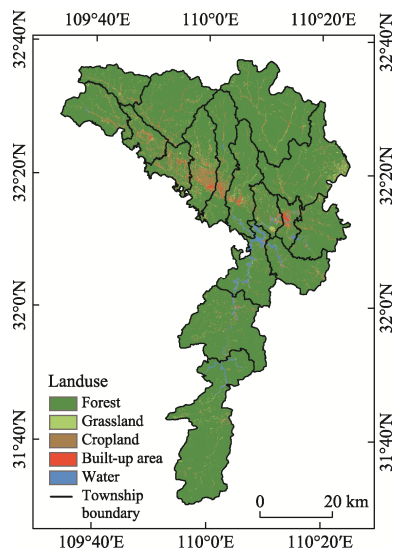


Figure 8 Land use map of Zhushan County

² <https://worldcover2020.esa.int/>.

approximately 225 plants per hectare. This has effectively improved soil and water conservation efficiency, increased and maintained biodiversity, with pests and diseases prevented to the greatest extent.



Figure 9 The tea-forest-agriculture intercropping biodiversity landscape in Zhushan County

4.5 Water Conditions Data

Zhushan County is by the Du River, the largest tributary of the Hanjiang River, which is the longest tributary of the Yangtze River. It received water flowing from Zhenping County of Shaanxi Province, Zhuxi County of Hubei Province, and parts of Fangxian County and Shennongjia Linqu. The county features overlapping mountains, deep valleys, large river water surface gradients, and abundant water and hydropower resources. The clean water flowing in the Du River nourishes the tea-growing mountains, making Zhushan County a core water source area for the South-to-North Water Diversion Project. There are no large-scale factories in the area, and thus no wastes discharge from it to the air, soil and water. According to monitoring record by the Zhushan County Environmental Monitoring Department, the surface water in Zhushan County meets the Class II standard specified in the Environmental quality standards for surface water (GB 3838—2002)^[9]. The water quality is excellent, being colorless, odorless, tasteless, and transparent, with a pH range of 5.5–7.5, arsenic (As) content ≤ 0.05 mg/L, cadmium (Cd) content ≤ 0.005 mg/L, and lead (Pb) content ≤ 0.05 mg/L.

Water samples were collected from a stream in Shengsui-Guoyingchachang Tea Garden, a pond in Shengsui-Hejiaba Tea Garden, a stream in Daquan Mountain tea-growing zone, a stream in Qingquan Tea Garden, and the Huohe Reservoir near Liujiashan Tea Garden. These samples were tested by the Physical and Chemical Analysis Center of IGSNRR, CAS, with the results presented in Table 4. The content of elements and ions in the water samples well meets the national surface water quality standards^[9]. It also meets national drinking water standards^[10]. Notably, the selenium content in the water samples from Daquan Mountain tea-growing zone (0.012 mg/L) and Liujiashan Tea Garden (0.014 mg/L) is slightly higher than the national drinking water standard (0.01 mg/L). As previously mentioned, Zhushan County is located in a selenium-rich geological unit in China. The relatively high selenium content in the water samples reflects the geological background of

Table 4 Statistics of element and ion content in water samples Unit: mg/L

Items	Shengshui-Guoyingchachang	Daquanshan	Liujiashan	Qingquan	Shengshui-Hejiaba	GB3838—2002	GB 5749—2022
Al	—	0.003	—	0.022	—		0.2
As	0.004	—	—	—	—	0.1	0.01
B	0.017	0.001	0.004	0.003	—	1	1
Ba	0.048	0.001	0.097	0.088	0.021		0.7
Ca	27.823	15.695	42.150	17.410	34.665		
Cd	—	0.001	0.001	0.001	0.000	0.01	0.005
Co	—	0.000	0.000	0.001	0.000		
Cr	0.001	0.001	0.001	0.000	0.001	0.1	0.05
Cu	0.000	0.002	0.002	0.003	0.001	1	1
Fe	0.004	0.001	0.001	0.027	0.000		0.3
K	2.981	0.393	1.351	0.859	0.301		
Li	0.000	0.011	0.002	0.001	0.001		
Mg	7.875	5.086	12.840	5.562	5.512		
Mn	0.002	0.000	0.001	0.006	0.000		0.1
Mo	0.001	0.010	0.014	0.010	0.009		0.07
Na	5.271	12.400	4.782	6.288	5.305		200
Ni	0.001	—	0.000	0.000	—		0.02
P	—	0.008	0.000	0.009	0.007	0.02	
Pb	—	0.002	0.001	0.001	0.003		0.01
Se	0.001	0.012	0.014	0.008	0.003	0.2	0.01
SiO ₂	11.880	15.410	5.460	0.615	8.723	0.02	
SO ₄ ²⁻	35.640	3.067	23.365	12.940	14.005		250
Sr	0.095	0.107	0.221	0.137	0.259		
V	—	—	—	—	—		0.01
Zn	—	0.001	0.001	0.076	0.007		1

Zhushan County. In accordance with the National food safety standard—drinking natural mineral water (GB 8537—2018)^[11], the lower limit of selenium content for selenium-type mineral water is 0.01 mg/L, and the upper limit is 0.05 mg/L. Selenium is an essential trace element for the human body. The slightly higher selenium content in the natural water in Zhushan County helps the growth of selenium-containing tea, which is beneficial to individuals in need of selenium supplementation.

5 Zhushan Tea Product Quality Data

5.1 Zhushan Tea Planting History

Zhushan has a long-standing tea-planting tradition. In the Eastern Jin Dynasty, Chang Qu wrote in the book of Huayang Guozhi: Ba Zhi: “When King Wu in Zhou Dynasty attacked the last King Zhou in the Shang Dynasty (around 1066 BC), he actually received military support from the states of Ba and Shu, as documented in the Book of Shang.... Products such as cinnabar, lacquer, tea, and honey... were all offered as tributes.” This passage records that more than 3,000 years ago, local tea from the Ba and Shu region was used as a tribute. There is a famous Chinese idiom “People living in the state of Yong always disturb themselves”,

referring those mean people who always trouble themselves. The story behind this idiom occurred in 611 BC when the ancient people at the State of Yong, where current Zhuanshan County located, overestimated its strength, attempted to conquer the State of Chu, but was ultimately defeated by a coalition of the States of Chu, Ba, and Qin. From another perspective, this idiom provides evidence that the tea-farming in Zhushan County had already achieved prosperous as early as 2,600 years ago.

Over the long course of tea planting and production, tea farmers in successive dynasties have gradually selected and bred local tea varieties that are highly adapted to the ecological conditions for tea-growing in Zhushan County. These varieties have leaf areas of less than 40 cm², belonging to small-to-medium leaf tea varieties. Among them, the “Zhushan Black Large Leaf” variety obtained the Registration Certificate for Non-Major Crop Varieties from the Ministry of Agriculture and Rural Affairs of P. R. China (Certificate No.807) in 2024.

5.2 Zhushan Tea Quality Data

By employing gas chromatography/mass spectrometry (GC/MS) analysis, Ding, *et al.* (2014)^[12] found that Zhushan tea contains 54 aroma components in which geraniol, nerolidol, linalool and its oxygenated derivatives, juniperol and phytol are main components; the tea from Shengsui Village, Desheng Town, exhibited the highest aroma components. The combination of these aroma substances gives Zhushan tea its unique quality, characterized by an aroma described as “chestnut fragrance with a hint of floral aroma”. The product is rich in soluble solids, boasting a strong aroma, tender color, mellow taste, and elegant shape.

The sensory and physicochemical qualities of Zhushan green tea and black tea samples were tested by the Key Laboratory of Tea Science of the Ministry of Education and the National Engineering and Technology Research Center for Plant Functional Components Utilization, both of which are affiliated with Hunan Agricultural University. The evaluation methods included sensory quality assessment, colorimetry, high-performance liquid chromatography (HPLC), gas chromatography (GC), and GC/MS, with reference to relevant national standards and classic scientific literature. The results are presented in Table 5.

In terms of sensory quality, Zhushan green tea features tight and uniform strips, a relatively lustrous green color, a yellowish-green and bright tea soup color, a fresh and lasting aroma, a mellow and refreshing taste, and a tender and bright color for the leaf after infusions. It is characterized by high water extract content (reaching 44.08%, compared to the national standard for ordinary green tea^[13] of greater than 34%) and high tea polyphenol content (reaching 21.75%, compared to the national standard of greater than 11%). Its catechin content is as high as 13.92% (exceeding the national standard for ordinary green tea of greater than 7%), imparting a fresh and refreshing taste without bitterness. This is attributed to the low content of epigallocatechin gallate (EGCG), an ester-type catechin that contributes to bitterness, at only 2.95%. Alkaloids in Zhushan green tea are dominated by caffeine, with a content ranging from medium to high. The L-theanine content reaches 1.83%, which is another source of the fresh and refreshing taste of Zhushan tea, as the taste threshold of L-theanine for the general green tea is merely 0.06%^[14]. Additionally, the soluble sugar content is high (reaching 7.45%), equivalent to that of Grade 1 pan-fried green tea^[15].

In terms of sensory quality, Zhushan black tea exhibits tight and slender strips, a relatively lustrous black color, an orange-red and bright tea soup's color, a sweet and lasting floral aroma, a mellow taste, and a red and uniform soft leaf after infusions. In terms of physicochemical quality, Zhushan black tea has a high water extract content (reaching 35.77%), which is higher than the national standard^[16] for Grade 1 small-to-medium leaf black tea. It is high in free amino acids (reaching 5.29%) and L-theanine (reaching 0.91%), which contribute to its fresh and refreshing taste. The tea polyphenol content is relatively

Table 5 Statistics of sensory and physicochemical quality tests of Zhushan tea

No.	Item	Zhushan green tea	GB/T 14456.1—2017	Zhushan black tea	GB/T 13738.2—2017
1	Tea soup color	Yellowish-green and bright		Orange-red and relatively bright	
2	Aroma components	Mainly esters and terpenes		Mainly phenols and aromatic hydrocarbons	
3	Water extract (%)	44.08	≥34	35.77	≥32 (Grade 1, small-to-medium leaf variety)
4	Soluble sugar (%)	7.45		4.06	
5	Selenium (μg/kg)	29.77		81	
6	Free amino acids (%)	5.23		5.29	
6.1	L-theanine (%)	1.83		0.91	
7	Theaflavins (%)	—		0.89	
8	Tea polyphenols (%)	21.75	≥11	4.51	≥7
8.1	Catechins (%)	13.92	≥7	3.11	
8.1.1	Simple catechins (%)	4.31		0.37	
8.1.1.1	Epigallocatechin (EGC) (%)	2.23		0.36	
8.1.1.2	D-Catechin (C) (%)	0.16		—	
8.1.1.3	Epicatechin (EC) (%)	1.85		0.01	
8.1.2	Ester-type catechins (%)	≥9.61		≥2.74	
8.1.2.1	Epigallocatechin Gallate (EGCG) (%)	2.95		0.98	
8.1.2.2	Gallocatechin Gallate (GCG) (%)	3.01		0.14	
8.1.2.3	Epicatechin Gallate (ECG) (%)	3.35		1.63	
9	Theasinensins (%)	—		1.26	

low, and the alkaloid content is also low, resulting in a mild taste for Zhushan black tea. One of the reasons for the low tea polyphenol content is the oxidation of tea polyphenols into theaflavins. The theaflavin content of Zhushan black tea reaches 0.89%, which is superior to that of domestic small-to-medium leaf black tea (typically ranging from 0.36% to 0.6%)^[17]. High theaflavin is the main contributor to the “brightness” of the tea soup and the fresh taste, and also plays a key role in forming the “golden rim” of black tea soup. Similarly, in black tea, catechins are oxidized into polymeric catechins. Zhushan black tea has a relatively high Theasinensins (TSs) (1.26%), which is generally ranges from 1.0% to 1.5%^[18,19] for ordinary black tea. The soluble sugar content in Zhushan black tea reaches 4.06%.

5.3 Safety Indicators

Tea leaves were sampled in accordance with the national standard^[20] and sent to Jiangsu Anshun Technical Service Co., Ltd. to test the pesticide residues. The residual of mancozeb (a fungicide), malathion (an insecticide), bentazone (a herbicide), and fenobucarb (an insecticide) were tested in accordance with the National food safety standard—maximum residue limits for pesticides in food (GB 2763—2021)^[21]. Residues of other pesticides were tested in accordance with the National food safety standard—maximum residue limits for 112 pesticides in food (GB 2763.1—2022)^[22], covering a total of 111 items. The test results indicated that no pesticide residues exceeding the maximum limits were detected in either the green tea or black tea, as detailed in Table 6.

Table 6 Test results of pesticide residues in Zhushan tea

	Index	Test result	Limit (mg/kg)
1	Etofenprox, Tolfenpyrad, Zineb	–	50
2	Diflubenzuron, Dinotefuran, Flufenoxuron, Cartap, Cypermethrin and Beta-cypermethrin, Chlorfenapyr, Fluvalinate, Permethrin, Picoxystrobin	–	20
3	Cyhalothrin and Lambda-cyhalothrin, Etoxazole, Fenazaquin, Hexythiazox	–	15
4	Pyraclostrobin, Clothianidin, Thiacloprid, Thiamethoxam, Acetamiprid, Buprofezin, Difenoconazole (Difenoconazole-1 and Difenoconazole-2), Deltamethrin, Endosulfan, Chlorothalonil	–	10
5	Diafenthiuron (Mitrazon), Carbendazim, Indoxacarb, Carbaryl (Sevin), Bifenthrin, Fenpropathrin, Pyridaben	–	5
6	Imidaclothiz	–	3
7	Chlorpyrifos	–	2
8	Nitenpyram, Azadirachtin, Cyfluthrin and Beta-cyfluthrin, Glyphosate	–	1
9	Imidacloprid, Emamectin, Benzoate, Profenofos, Fenitrothion, Malathion, Glufosinate	–	0.5
10	DDT, HCH, Ivermectin, Pymetrozine, Trichlorfon, Methomyl, Phoxim, Paraquat	–	0.2
11	Atrazine, Fenvalerate and S-Fenvalerate, Bentazon	–	0.1
12	Simazine, Chlorobenzilate, Chloroneb (Chloromethoxybenzene, Chlorophenyl Methyl Ether), Acephate, Dimethoate, Fluorodifen, Methidathion (Supracide), Mevinphos, Batrachotoxin, Methamidophos, Omethoate, Vernolate, Isocarbophos, Fenobucarb, Ethoprophos (Mocap), Demeton, Cycloate, Binapacryl	–	0.05
13	Phosfolan, Methylphosfolan	–	0.03
14	Methyl Bromide, Carbofuran (Furadan), Chlorsulfuron, Methyl Parathion, Chloropropylate, Ethametsulfuron (Methyl Ethametsulfuron), Metsulfuron-methyl	–	0.02
15	Chloramben, Chlorophthalic Acid, Chlorfenson, Nitrofen, Cyhexatin, Pentachloronitrobenzene, Fluorodifen, Ethylene Dichloride, Endosulfan, Dinocap, Dinoseb, Dalapon, Carbosulfan (Marshal), Dicofol, Phorate, Isazofos, Terbufos, Chlorfenvinphos, Chlorothalonil (Chlorophthalate Methyl Ester), Heptenophos, Indanofan, Chlorquinox, Dinoterb	–	0.01

6 Management of Zhushan Tea Industry

6.1 Socio-economic Development of Zhushan County

According to statistical data from the Zhushan County government, the GDP of Zhushan County has increased steadily from 1.084 billion CNY in 2002 to 15.24 billion CNY in 2023 (Figure 10). As a key economic crop of Zhushan County, Zhushan tea has played a significant role in driving the county's economic development. Since the late 1990s, Zhushan County has identified tea as a leading agricultural specialty industry. Since 2017, large-scale tea plantation development has been carried out, with an annual increase of about 666.67 ha of tea plantations. By the end of 2024, according to statistics from the Zhushan County Bureau of Agriculture and Rural Affairs, nearly all suitable areas in 220 out of 242 villages across 16 townships in the county have been planted with tea. The total area of tea plantations in Zhushan County is nearly 200 km², with an annual output of nearly 20,000 t of dry tea. The average price of dry tea is 60 CNY/kg, while the most premium pre-Qingming Festival tea is priced at 900 CNY/kg. The comprehensive output value of the tea industry has exceeded 7 billion CNY, accounting for more than half of the county's GDP, indicating that the tea industry has become the largest and highest value-added competitive industry in Zhushan County.

The registered population of Zhushan County showed an upward trend from 2002, peaked in 2010, and subsequently exhibited a downward trend. In recent years, this downward trend

has slowed (Figure 11). Currently, the county's registered population is 440,000, with a permanent population of 340,000. Tea plantations cover 45,000 households in the county, and more than 200,000 people are closely engaged in the tea industry chain, with an average annual income increase of 7,600 CNY per person derived from the tea industry.

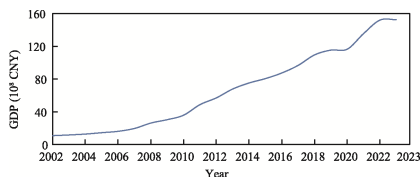


Figure 10 Annual GDP change of Zhushan County

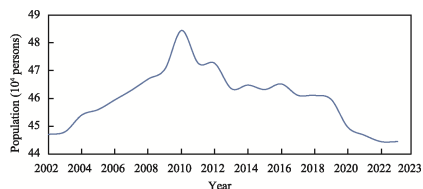


Figure 11 Annual population change of Zhushan County

6.2 Cultivation and Management

Traditionally tea trees in Zhushan County are planted between mid-to-late October to early-to-mid November or mid-to-late February. Improved tea varieties were carefully selected to adapt to Zhushan County's climate among early, mid, and late-maturing types, to avoid of overly overlapping of tea picking and processing. For young tea plantations, pruning is conducted in March: the first topping pruning is performed at a height of 15 cm above the ground, and subsequent pruning is carried out annually with the height increased by 10 cm. After 3 rounds of pruning, a high-yield tea canopy is supposed to be achieved. Canopy renovation for mature tea plantations includes minor pruning, deep pruning, heavy pruning, and stumping. Following pruning, enhanced fertilizer and water management are implemented, along with regular pruning and maintenance of the tea trees.

In terms of fertilization, through the rational combination of base fertilizers and topdressings, ecological and efficient fertilization technologies are promoted, such as intercropping ecological manure, soil testing and formulated fertilization, integrated water and fertilizer management, and partial replacement of chemical fertilizers with organic fertilizers. Base fertilizers primarily consist of oil cake fertilizer, cattle and sheep manure, and commercial organic fertilizers, with an application rate at over 4,500 kg/ha, supplemented by 600 kg of special tea fertilizer per ha.

In terms of weeding and pest control, Zhushan County adheres to the principle of "prevention first, control comprehensively", based on ecological prevention and control as well as ecological regulation. Priority is given to agricultural practices, physical control, and biological control measures, reducing the use of chemical pesticides to 0. Measures such as inter-row mulching, weed suppression using native weeds, and mechanical mowing are adopted to control weed growth. The occurrence of pests and diseases is closely monitored, with a focus on the ecological control of major pests and diseases such as tea green leafhoppers, tea geometrids, mites, and tea cake disease. Lime-sulfur mixture is used for winter disinfection of tea plantations to ensure a safe and environment-friendly tea products.

In terms of tea plantation management, efforts are made to promote emission reduction and carbon sequestration in tea plantations. Practices such as mulching inter-rows with tea straw and pruning waste are advocated to enhance the soil water retention capacity. Roads within the plantation areas are centered on tea processing sections, connecting to tea plots in various locations to facilitate transportation, mechanical access, and tea plantation management activities such as picking and fertilization. The integration of agricultural machinery and agronomic techniques is strengthened, with the selection of appropriate machinery for tea plantation operations. Mechanized production technologies, such as mechanical pruning, picking, tillage, and pest control in tea plantations, are promoted in

accordance with local conditions. Mechanized picking improves the efficiency of tea harvesting while minimizing energy consumption as much as possible.

Zhushan tea picking follows clear standards regarding picking time, picking parts, and picking methods to ensure the quality of fresh tea leaves. Fresh leaf picking is typically mainly in spring, while efforts are also made to utilize summer and autumn tea resources to enhance overall benefits.

New tea is picked as “one bud and one leaf”. The traditional picking method is manual harvesting. In recent years, Zhushan County has vigorously promoted mechanical tea picking. A single tea-picking machine can harvest 100 kg of fresh tea leaves per hour, which is equivalent to the efficiency of 10 manual workers. Through the introduction of high-efficiency tea-picking machines, the picking of summer and autumn tea, once characterized by a low input-output ratio when done manually, has now attracted greater attention from tea farmers, increasing the income of tea plantation by 30,000 to 45,000 CNY per ha. When picking fresh leaves, natural containers such as bamboo products are used as much as possible to avoid the use of plastic products.

There are two processing modes for picked fresh tea leaves. In mode one, tea farmers first send fresh leaves to cooperatives (or bases) for initial processing. The processed leaves will then be further processed by tea farmers and become tea to be sold in the market by tea farmers themselves. In mode two tea farmers sell the fresh leaves to the enterprises or cooperative bases, where the fresh leaf will be processed and sold in the market by the enterprises instead by farmers.

Processing procedures include withering, sun-drying (for black tea), fixation, rolling, and roasting, all of which adhere to strict technical standards to ensure the quality of color, aroma, taste, shape of the tea. Food safety and quality control are emphasized throughout the processing process to meet the demands of both domestic and international markets. The equipment in tea processing factories is kept clean and hygienic, and the entire production process is designed to prevent tea from coming into contact with the ground. The process flow is optimized for rationality and efficiency, emphasizing continuous and intelligent production, with processing strictly carried out in accordance with standards.

6.3 Brand Value

Zhushan County is located to the south of Wudang Mountain in Shiyuan City. Wudang Mountain, renowned as “the unparalleled scenic spot since ancient times and the top fairy mountain in the world”, is a well-known World Cultural Heritage site. In the early stage, Shiyuan City launched the “Wudang Dao Tea” brand, aiming to infuse the tea with the cultural charm of Wudang Mountain. However, while the “Dao Tea” label endowed the tea with profound cultural attributes, it also alienated certain customer groups, resulting in not ideal market performance. Since 2021, Shiyuan City has made concerted efforts to build the regional public brand of “Wudang Mountain Tea”. Compared with “Wudang Dao Tea”, “Wudang Mountain Tea” has broader inclusiveness, providing greater development space for tea in Shiyuan City, including Zhushan tea, which belongs to the broader Wudang Mountain region.

Within the total tea plantation area of 56,567 ha in Shiyuan City, Zhushan County accounts for nearly 20,000 ha, making it a key tea-producing county in Shiyuan City. To better protect the regional brand, guarantee the sustainable development of regionally branded tea, and implement the vision of “Wudang Mountain Tea originates from fragrant Zhushan, and high-quality Zhushan tea is enjoyed worldwide”, Zhushan County has established a range of county-level public brand under Wudang Mountain Tea represented by “Zhushan Selenium Tea”, “Shengsui Green Tea”, and “Zhushan Black Tea”. It developed a series products including “Shixing Black Tea”, “Shengshui No.1”, “Zhujingya” and “Youhua Tea with

Orchid Fragrance”. These products cover multiple categories, including green tea, black tea, dark tea, white tea, yellow tea, scented tea, tea beverages and tea wine. The local Hubei provincial standard for “Shengsui Maojian” has been approved, and “Shengsui Green Tea” has been recognized as a National Agro-product Geographical Indications by the Ministry of Agriculture of China. Zhushan tea products have obtained multiple quality certifications, such as the ISO9001 Quality Management System, QS Food Quality and Safety, and OTRDC Organic Tea, ensuring that the products meet both national and international standards.

In December 2024, Zhushan County issued the Ten policies for supporting the high-quality development of the tea industry in Zhushan County and the Implementation plan for the high-quality development of the tea industry in Zhushan County, aiming to guide the high-quality development of the Zhushan tea industry with high standards. Efforts are being made to shift from “scattered distribution” to “concentrated and contiguous” development of tea plantations, and to transform the growth model from “traditional extensive” to “modern intensive”, so as to improve the quality and efficiency of the tea industry and drive the long-term income growth of tea farmers. Tea plantations were mainly planted and managed by tea farmers. Currently through the “cooperative+base+farmer” model, enterprises are organized to sign price guarantee agreements with farmers, ensuring that all fresh leaves picked by farmers are purchased. Led by leading enterprises, the tea industry drives tea farmers to increase their income and achieve prosperity, promotes the development of the tea industry, and meets the needs of consumers in different regions. To promote the brand and popularization of Zhushan tea, members of this case study, including leaders from the Zhushan County government, members from tea associations, scientists, and entrepreneurs, have participated in numerous international and domestic conferences. Examples include the event “Water from Shiyang Nourishes Beijing, Premium Products Enter Thousands of Households: Zhushan Theme Day” held in Beijing on October 18, 2024, the “GIES New Year Fair” held in Beijing on January 10, 2025, and the “Beijing-Shiyang Counterpart Cooperation and 2025 Shiyang Advantageous Industry Promotion Conference” held in Beijing on May 8, 2025. By integrating the characteristics of tea with social development, brand building, and cultural elements, Zhushan County promotes the development of tourism, optimizes the agricultural structure, strengthens brand building, and contributes to sustainable development and the dissemination of tea culture.

6.4 Culture Development

Through the integration of tea and tourism, Zhushan County has transformed its tea plantations into tourist attractions, attracting a large number of tourists for sightseeing, tea-picking, and leisure activities. Efforts are being made to upgrade the industrial system from a “single business type” to the “integration of primary, secondary, and tertiary industries”, with continuous efforts focused on the integration of tea and tourism. The county is exploring an integrated development model of “tea plantation with cultural and creative products, research, study, tours, health and wellness activities”, holding the Wudang Mountain Tea Tourism and Culture Month for 3 consecutive sessions already, promoting a tea tourism brand of “Ten Miles of Tea Fragrance · Encounter in Zhushan”, and injecting new vitality into rural revitalization and the transformation and upgrading of the tea industry. Zhushan County has launched the annual “Top Ten Most Beautiful Tea Plantations” selection activity. In 2024, tea plantations such as Shengsui Organic Tea Demonstration Plantation in Desheng Town, Liujiashan Tourist Tea Plantation in Chengguan Town, and Daquanshan Tea Garden in Shangyong Town were awarded the honor of “Top Ten Beautiful Tea Plantations”, from which Daguan Mountain tea-growing zone affiliated with Hubei Shengshui Tea Limited Company has been awarded as one of the Top Ten Most Beautiful Tea Gardens and Top Ten Premium Tea Tourism Routes in Hubei Province, and

Liujiaoshan Village in Chengguan Town has been recognized as a National Beautiful Leisure Village.

6.5 GIES Ground Station for Zhushan Tea

On September 15, 2024, IGSNRR, CAS established an automatic ground habitat station for Zhushan tea's Geographical Indications Environment and Sustainability (GIES) in the Liujiaoshan Tea Garden of Zhushan County (Figure 12). This station is used for real-time monitoring of various location-based variables, including precipitation of 5 mm or more, total radiation, air temperature, humidity, atmospheric pressure, wind speed, PM_{2.5}, PM₁₀, atmospheric CO₂ concentration, noise, and soil moisture and temperature at depths of 20 cm and 40 cm below the surface. On September 16, 2024, officials from the Food and Agriculture Organization (FAO) of the United Nations visited Zhushan County and attended the International Capacity Building Workshop on GIES for Special Agricultural Products (SAPs) Shiyang Zhushan Session. The case study underwent a special international review, and Zhushan tea received high praise from international experts³.



Figure 12 Zhushan tea GIES ground station

7 Discussion and Conclusion

Through this case, it is clear that Zhushan tea owes its origin to the suitable weather, beautiful mountains and clean water in Zhushan County. The natural endowments that nurture the excellent characteristics of Zhushan tea can be attributed to its northern subtropical features of Zhushan County. It includes extensive low mountainous areas with gentle slopes (less than 25°), abundant annual precipitation of nearly 1,000 mm, average annual temperature of 16 °C, daily sunshine duration of less than 6 h except in July, and the low total solar radiation in China with suitable diffuse radiation. These scientific data acquired from this case study support the already high-quality development of Zhushan tea and offers a new path for leveraging technology to drive the high-quality development of the local economy.

The detailed data from this study demonstrated the excellent characteristics of Zhushan tea, including high water extract content, high soluble sugar content, high amino acid content, selenium enrichment, a unique aroma, high tea polyphenol and catechin contents in Zhushan green tea, and high theaflavin and relatively high theasinensins contents in Zhushan black tea. In recent years, Zhushan County has vigorously promoted ecological and low-carbon tea plantation technologies, with 20,000 ha of ecological tea plantations covering 16 townships across the county, an annual output of 20,000 t of dry tea, and a comprehensive output value of 7 billion CNY. In particular, through policy support and industrial guidance, impoverished households have been assisted in escaping poverty by engaging in tea planting, and the tea industry in Zhushan County is closely integrated with poverty alleviation efforts. The development of the tea industry has driven the value addition of related industrial chains, including tea processing, packaging, logistics, and sales. It has

³ Beijing Daily APP. <https://baijiahao.baidu.com/s?id=1811394876080182916&wfr=spider&for=pc>.

also provided a large number of employment opportunities for local residents, with over 300 tea-related business entities in the county. Many impoverished households have increased their family income and improved their living conditions by participating in tea planting, processing, and sales. A total of 45,000 households had increased their income through the tea economy, and those who have escaped poverty have secured a stable source of income from the tea industry. Zhushan tea has driven the local people toward prosperity, is deeply loved by customers, and has won numerous national and provincial honors. The tea industry has thus become a key means for Zhushan County to transform its “lucid waters and lush mountains” into “mountains of gold and silver”.

Author Contributions

Liu, S. X. was responsible for the overall design of the study, conducting investigations, sampling, data collation, and manuscript writing. Fan, Q. provided overall guidance. Li, Y. Y. offered guidance on tea-related expertise. Ren, T. S. offered guidance on the analysis of the soil data. Zhang, X. F. offered guidance on the analysis of tea garden management. Meng, D. created the spatial maps. Yao, T. T. collected and processed soil and water samples. Yang, L. H. was responsible for the development and installation of the GIES ground station. Xiong, Y. B., Ding, G., Zhou, Z. M., Gao, X. S. and Chen, B. Q. coordinated the investigations and supported data collection. Yang, D. M., Wang, X. M., Zhang, Y. Y. and Li, J. Y. were responsible for investigations, sampling, and data collection. The other authors participated in data collection. All authors contributed to the discussion of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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