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Analysis of output, component characteristics and management status of municipal solid waste on the Tibetan plateau

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Abstract: This article describes the population of Xizang, the composition of municipal solid waste, and the distribution of municipal solid waste treatment facilities. With the development of Xizang's economy and tourism, the amount of municipal solid waste cleared and transported in Xizang has increased from 380,000 tons in 2003 to 692,200 tons in 2021, with an average annual growth rate of 4.56%. The proportions of kitchen waste, paper waste, and ash waste in the municipal solid waste components in Xizang have significantly decreased over the past 10 years. For example, the proportion of ash decreased from 22.83% in 2012 to 13.04% in 2021. Overall, recyclables such as paper, plastic rubber, textiles, glass, metal and wood and bamboo accounted for between 55.69% and 58.22% of the total municipal solid waste in Lhasa City. The disposal of municipal solid waste in Xizang was mainly through landfill. There are more than 130 landfill sites, 1 incineration plant, 5 pyrolysis pilot sites, 2 kitchen waste treatment plants, and more than 160 waste transfer stations for municipal solid waste disposal in Xizang. The designed daily disposal capacity of municipal solid waste is 3,768.4 tons per day.

Introduction

Xizang (Tibet) is located in the southwest of China on the Qinghai Xizang Plateau, with an average altitude of more than 4,000 meters, earning its nickname "Roof of the world". As of the end of 2022, the total permanent population of Xizang is 3.64 million. Xizang has 6 prefecture level cities and 1 region, with its capital being Lhasa. In 2022, Xizang's gross regional product (GDP) reached 213.264 billion CNY, with a per capita GDP of 58,438 CNY, marking an increase of 1.4%.

In Xizang, due to the economic and tourism development, as well as population increase in recent years, a large amount of domestic waste and tourism waste have been produced (Zhou et al. 2023a). The treatment and management of household waste is a huge challenge for a region, as there are necessary connections with the economy, natural environment, living habits, and population of the region (Duan et al. 2020, Wang et al. 2012). According to the National Bureau of Statistics, by 2021, the amount of urban municipal solid waste in Xizang reached 692,200 tons. The main methods for treating household waste include incineration, landfill, and composting. Incineration can effectively treat household waste, but the gases generated during the incineration process (such as acidic gases and dioxin like organic waste) can affect the surrounding environment and human health (Dan et al. 2022, Zhou et al. 2023b). The advantage of landfill treatment is that it is easy to operate, but it also generates a large amount of pollutants such as landfill gas and leachate during the treatment of household waste, which can have an impact on the surrounding environment, such as atmosphere, groundwater, surface water, and soil (Zhou et al. 2022a, Zhou et al. 2022b, Zhou et al. 2023b).

Therefore, in order to clearly understand the production, treatment scale and current situation of treatment facilities of urban solid waste in Xizang, we described the output, physical and chemical characteristics and treatment scale of urban solid waste in Xizang by literature review and field research.

Methods

Data sources

The data of the article mainly comes from several resource websites, including CNKI, Elsevier, China Xizang Tourism Network, National Bureau of Statistics, Xizang Autonomous Region Statistics Bureau, and other websites.

Method of investigation

The main targets are seven cities in Xizang, and the detailed list of the survey is listed in Table 1.

Calculation method

In the data search, as the data for municipal solid waste output of each city cannot be found, the waste output data for each

Table. 1. List of Proposed Designs.

1	2	3	4	5	6	7	8	9	10
Number	City	County or district	Latitude	Longitude	MSW treatment facilities (1 Incineration, 2 Landfill, 3 Others)	Number of processing facilities (seats)	Designed processing scale (tons/day)	Number of transfer facilities(seats)	Cost invested (10000 CNY)

city in Xizang in 2022 was calculated using the following formula in this article:

$$Y = P1 * D1 * 365 + P2 * D2 * 365 \quad (1)$$

In the formula, Y represents the annual output of MSW. P1 denotes the permanent urban population of cities in Xizang in 2022, while P2 represents the permanent non-urban population of cities in Xizang in 2022, as shown in Table 2. The number 365 corresponds to the total number of days in 2022. D1 stands for the daily output of urban municipal solid waste in Xizang, with a value of 1.37kg/day, while D2 represents the daily output of non-urban municipal solid waste in Xizang, with a value of 0.085kg/day. The data for D1 and D2 are sourced from Han et al. 2015.

Results and Discussion

Production of waste

The permanent resident population, tourist population, GDP, and the amount of urban municipal solid waste in Xizang within the study area were shown in Figure1. Figures (1), (2), (3) and (4) respectively illustrate the permanent population, tourist population, GDP and waste clearing and transportation volume of Xizang. Data regarding Xizang's permanent population, GDP, and waste removal volume in the figure were sourced from the National Bureau of Statistics, while the data concerning the tourist population are from Xizang Tourism Network of China and Xizang Autonomous Region Statistics Bureau. The permanent resident population increased from 2.72 million in 2003 to 3.64 million in 2022. The tourist population rose from 928,600 in 2003 to 30.0276 million in 2022, with an average annual growth rate of 164.92%. GDP increased from 18.6 billion CNY in 2003 to 2132.6 billion CNY in 2022, reflecting an average annual growth rate of 55.08%. Notably, population growth outpaced GDP growth, indicating a direct relationship between population and GDP, as well as urban solid waste (Duan et al. 2020). The amount of urban solid waste cleared and transported increased from 380,000 tons in 2003 to 692,200 tons in 2021, with an average annual growth rate of approximately 4.56%. Moreover, the impact of tourist population was evident, such as the capacity of municipal solid waste in Lhasa City in 2020, which was 299.18kg/m3 in the dry season and 418.703kg/m3 in the rainy season. The higher capacity of municipal solid waste in the rainy season may be attributed to it being the peak season for tourism in the Qinghai Xizang Plateau region, resulting in a greater generation of tourism waste.

Table. 2. Urban and non-urban population data for each city.

City	Urban population (10000 people)	Non urban population (10000 people)
Lhasa	60.5511	26.238
Shigatse	18.4323	61.383
Shannan	11.3048	24.0987
Nyingchi	9.7675	14.1261
Nagqu	11.603	38.8808
Ngari	5.3839	7
Qamdo	13.3017	62.7949
Notes:The population data is from the National Bureau of Statistics.		

Physico-chemical characterization of Xizang wastes

Xizang, situated on the Tibetan plateau, experiences unique climatic conditions such as extreme cold, high altitude, low pressure and lack of oxygen. These conditions significantly influence the physical composition of household waste. Figure 2 displays the results of a composition investigation of household waste in five functional areas of Lhasa City. The study reveals distinct patterns: the commercial area of the highland city exhibits a higher proportion of paper waste, while the residential area contains more ash and residue. In contrast, the business area displays a prevalence of papers waste, while both the cleaning and special areas show increased amounts of plastics and rubbers. These findings underscore substantial differences in wastes categories among the various functional areas.

Over the past ten years, Lhasa has witnessed a notable reduction in kitchen waste, paper, and ash waste proportions in its municipal solid waste, as depicted in Table3. The decline in kitchen waste can be attributed to the implementation of segregated waste collection practices. Economic development, accelerated urbanization, and improved urban road construction in the Xizang region have contributed to the decrease in ash and dirtproportions in municipal solid waste. On the other hand,

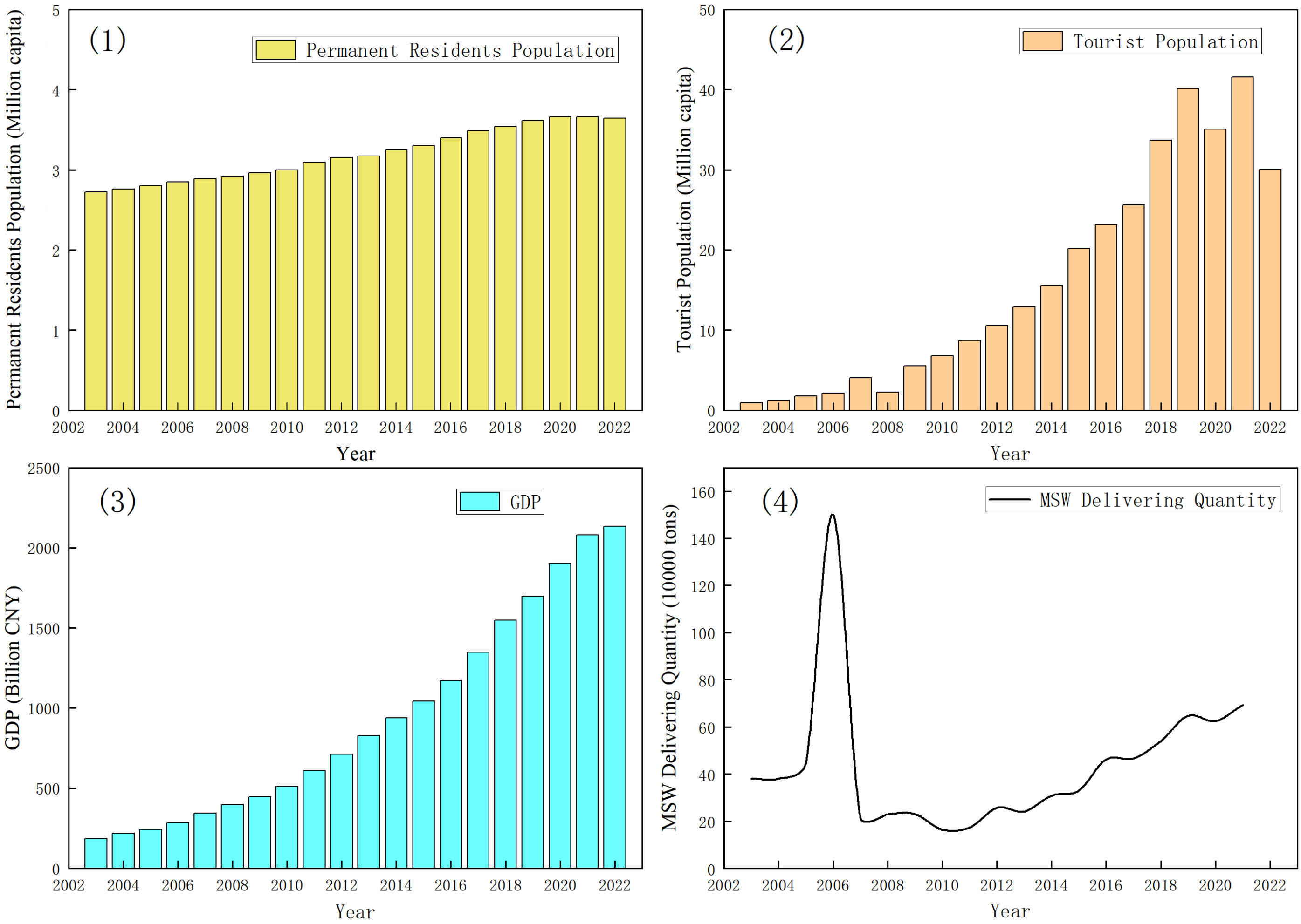

Figure 1. Xizang's permanent population, tourist population, GDP and municipal solid waste clearing and transportation volume from 2003 to 2022.

there has been a significant increase in plastic, textile, wood and bamboo, glass and metal waste proportions, likely due to the region's economic growth and improved living standard, leading to higher rates of disposal of these recyclable materials. Overall, recyclable materials such as paper, plastic rubber, textiles, glass, metal and wood and bamboo now constitute between 55.69% and 58.22% of Lhasa City's total municipal solid waste. Organic materials, particularly kitchen waste (both animal and vegetative), account for between 20.45% and 28.63% of the total municipal solid waste.

Figure 3 presents the results of a comparison of municipal solid waste fractions between Lhasa, a plateau city, and 19 other cities in China, sourced from various references including Xiao et al. 2015, Chen et al. 2016, Han et al. 2019, Liu et al. 2006, Ko et al. 2009, Zhang et al. 2010, Zhao et al. 2009, Zhou et al. 2023a, Zhuang et al. 2008. The graph highlights that each city exhibits the highest percentage of kitchen-based waste in its municipal solid waste. However, Lhasa's food waste percentage is lower than that in other Chinese cities, possibly due to differences in eating habits on the Xizang Plateau. Conversely, the percentage of metallic waste in Lhasa is significantly higher than in other cities in the China. In addition, Lhasa demonstrates a high percentage of paper, plastic and rubber waste in its municipal solid waste, indicating a relatively high proportion of recyclables. These findings underscore the unique waste composition and recycling potential of urban municipal solid waste in Lhasa.

Figure 4 displays the composition of domestic waste in Lhasa City compared to 21 foreign places, with data sourced from various references including Dolezˇalová et al. 2012,

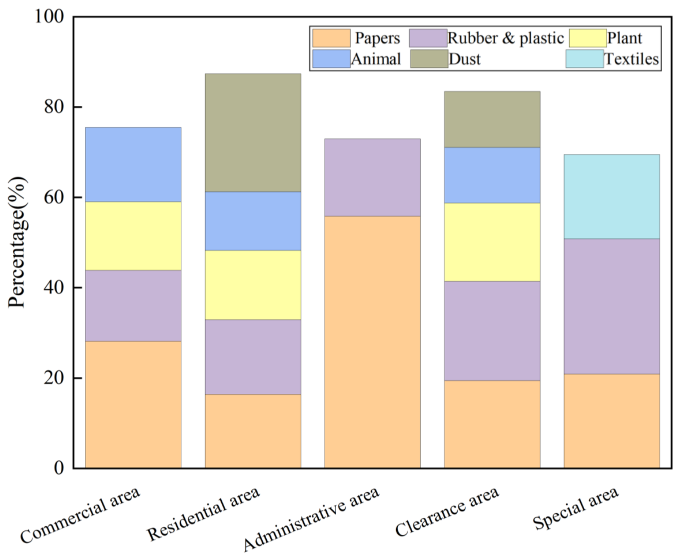

Figure 2. Percentage of main municipal solid waste physical components in each functional area of Lhasa City.

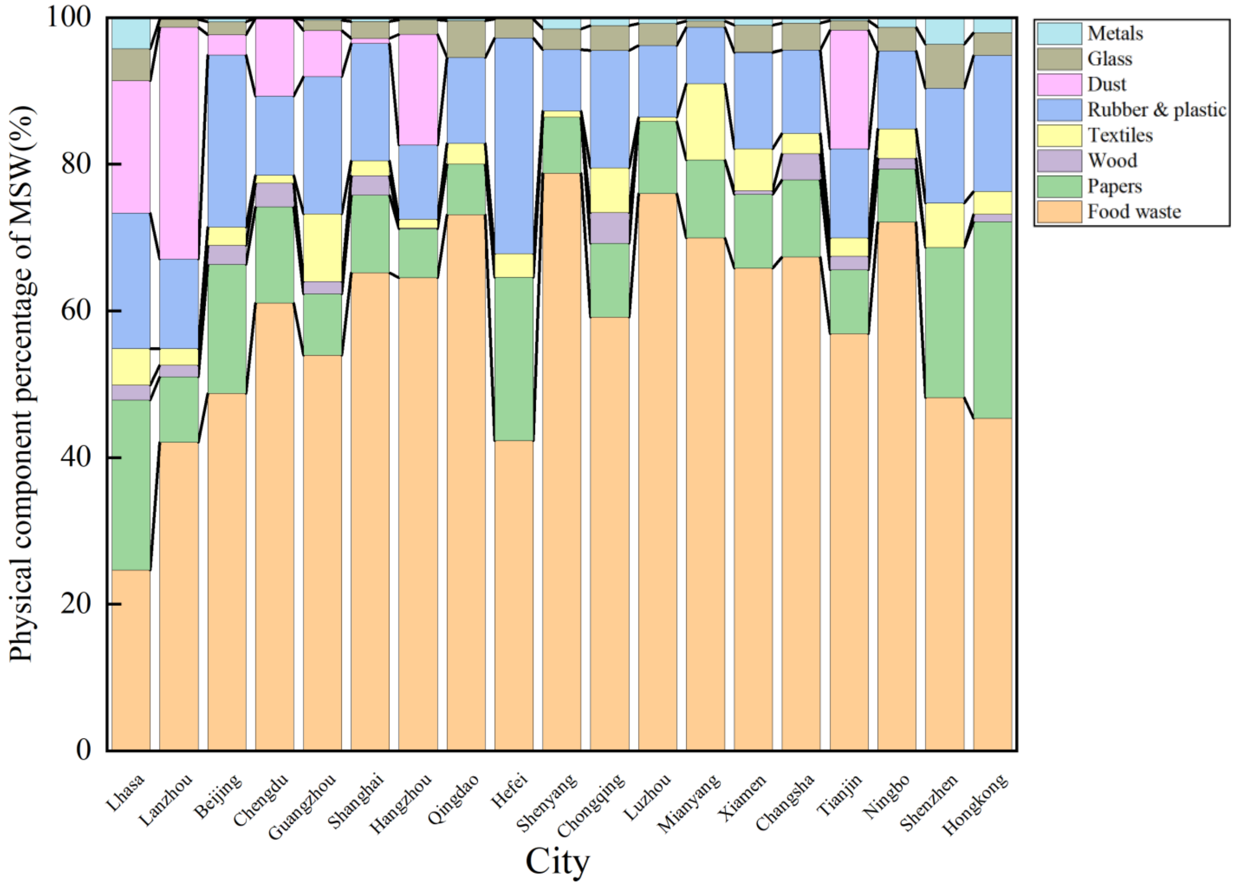

Figure 3. Percentage of physical components of municipal solid waste in Lhasa and different cities in China.

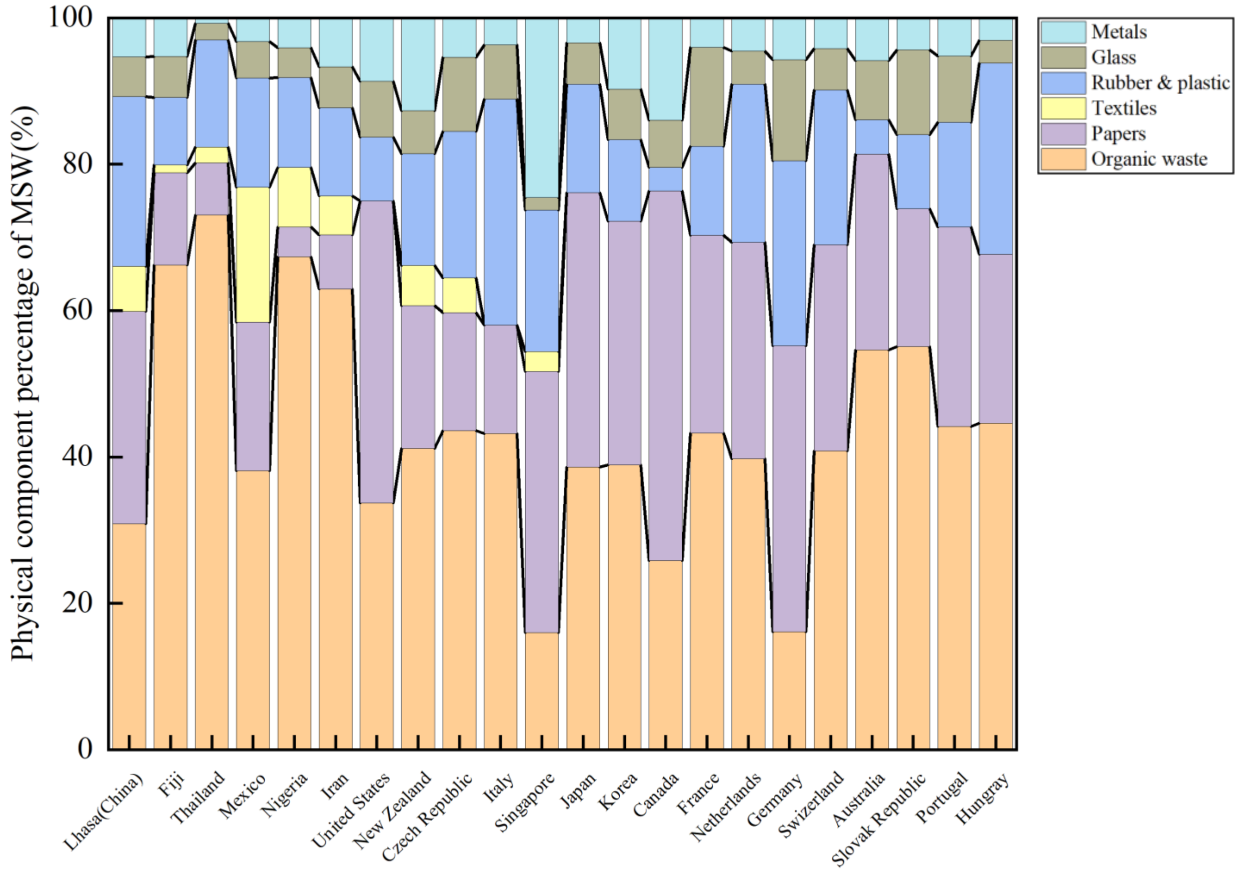

Figure 4. Comparison of Physical Components of Municipal Solid Waste between Lhasa City and Other Foreign Places.

Table. 3. Comparative analysis of different municipal municipal solid waste components.

City	Year	Physical components (%)								
		Kitchen waste	Papers	Plastics and rubbers	Ash and dirt	Textiles	Wood and bamboo	Glass	Metals	Other
Lhasa	2012	20.45	23.74	14.84	22.83	4.5	2.76	4.73	5.12	1.03
	2021	28.63	22.33	21.95	13.04	5.35	1.34	3.9	3.35	0.11
	Average	24.54	23.04	18.40	17.94	4.93	2.05	4.32	4.24	0.57
Note: The data in the table are from reference (Dan et al,2022, Zhou et al. 2023a).										

Fabrizio et al. 2011, Han et al. 2019, Hiramatsu et al. 2009, Paúl et al. 2010, and Zhang et al. 2010. Analysis of the figure reveals that Lhasa's organic waste proportion surpasses only Singapore, Canada, and Germany, but falls below that of other countries. In contrast, paper waste in Lhasa exceeds that of developing countries such as Fiji, Thailand, Mexico, Nigeria, and Iran, with marginal differences compared to developed countries. While some countries lack data on textile waste, Mexico exhibits a substantially higher proportion compared to other places. Lhasa's plastic component proportion ranks relatively high, only trailing behind Italy, the Netherlands, and Germany, and surpassing other countries. Glass proportion is lower than France and Germany, with similar proportions to other countries. Metal proportion lags behind countries like the United States, New Zealand, Singapore, and Canada, with slight variations compared to other countries. Overall, developing countries exhibit a relatively high proportion of organic waste, while developed countries show higher proportions of paper, glass, and metals. These disparities are closely linked to local economic levels and living habits.

Disposal analysis of waste in Xizang

(1) Number and distribution of municipal solid waste disposal facilities in Xizang

Based on data gathered from surveys of municipal solid waste treatment facilities and transfer stations across the Xizang

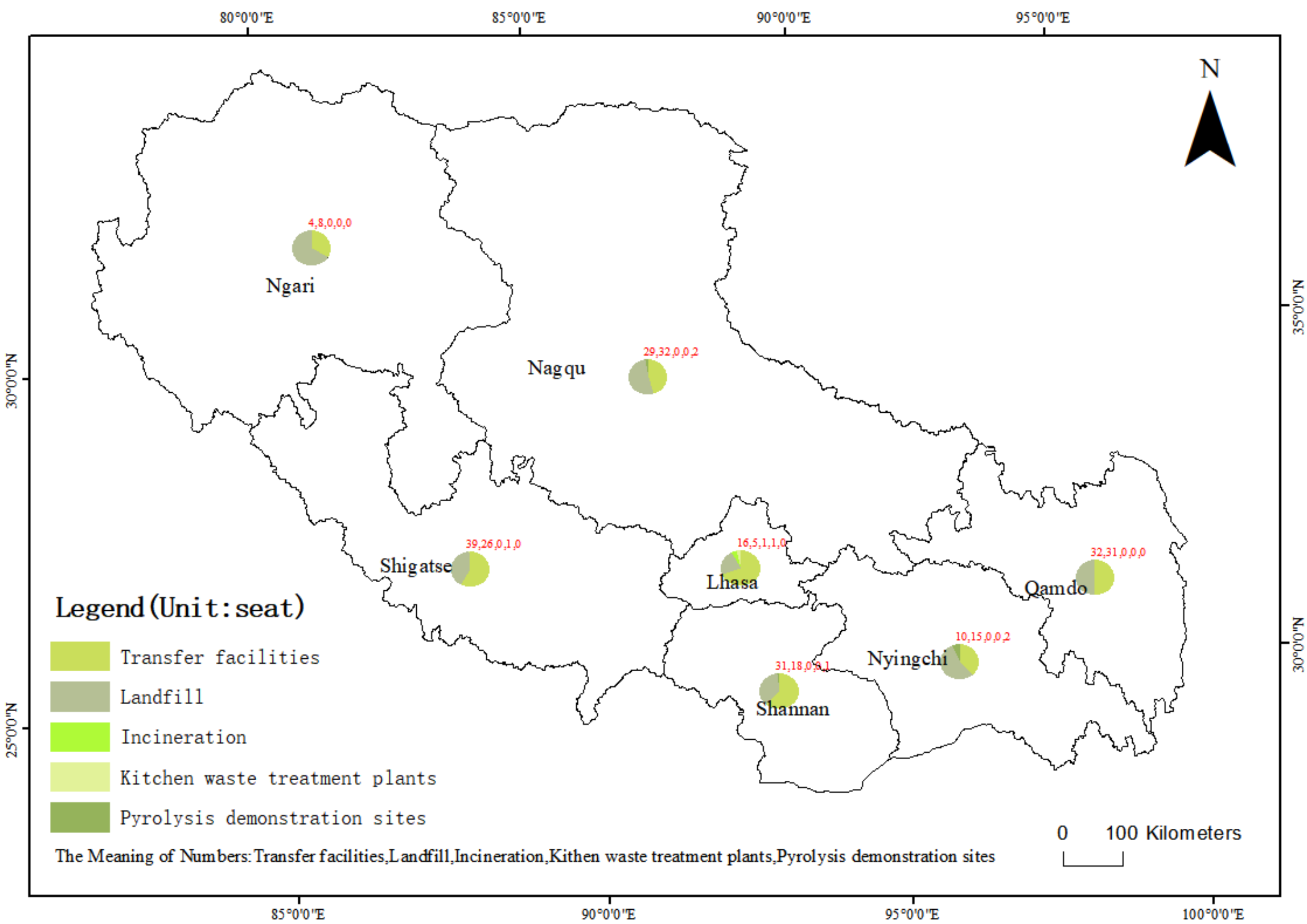

Figure 5. Number and distribution of waste treatment facilities by city in Xizang.

Table. 4. Municipal solid waste Production and Designed Daily Treatment Scale in Various Cities in Xizang.

City	Permanent resident population (10000 people)	Population density (per person/km^2)	Projected municipal solid waste production in Xizang in 2022 (10000 tons)	Designed treatment capacity (tons/day)
Lhasa	86.7891	27.16	31.09	1566
Shigatse	79.8153	4.34	11.12	411
Shannan	35.4035	4.39	6.40	354.2
Nyingchi	23.8936	1.98	5.32	283
Nagqu	50.4838	1.35	7.01	578.6
Ngari	12.3	0.39	2.91	195.6
Qamdo	76.0966	6.9	8.60	380
Total	364.7819	46.51	72.45	3768.4

Note: 1. Population data was from the National Bureau of Statistics. 2. The production of municipal solid waste in 2022 was calculated according to Equation (1). 3.Designed daily capacity was based on field research.

region, Figure 5 illustrates the current distribution of transfer facilities, landfill sites, incineration plants and pyrolysis pilots for municipal solid waste treatment. The map reveals that there are over 130 landfills and more than 160 waste transfer stations operating throughout Xizang. The predominant method of municipal solid waste treatment and disposal in Xizang is maily landfill-based, encompassing sanitary landfills and simple landfills in urban and county cities (Dan et al. 2022, Zhou et al. 2023a). Notably, the first waste-to-energy plant on the Tibetan plateau is located in Qushui County, Lhasa (Dan et al. 2022, Zhou et al. 2023a). In addition, demonstration sites for waste pyrolysis have been constructed in plateau cities such as Nyingchi, Shannan, and Nagqu, comprising a total of five pilot sites. Additionally, two kitchen waste treatment facilities have been established, primarily in Lhasa and Shigatse.

(2) Scale of municipal solid waste treatment in cities in Xizang
Table 4 presents key information regarding the population, municipal solid waste production, and design treatment scale of each city in Municipal Xizang. The projected production of municipal solid waste in Xizang for 2022, calculated based on Equation 1, reveals that Lhasa tops the list with 310,900 tons, followed by Shigatse with 111,200 tons, Qamdo with 86,000 tons, Nagqu with 70,100 tons, Shannan with 64,000 tons, Nyingchi with 53,200 tons, and Ngari with 29,100 tons. Overall, municipal solid waste production in Xizang was estimated to reach 725,000 tons in 2022, a figure closely matching the 692,200 tons of municipal solid waste removal reported in 2021 by the National Bureau of Statistics, indicating the reliability of the calculation method. The field survey also revealed the design treatment capacity of waste incineration power plants in each city. In Lhasa, the design treatment capacity was 750 tons/day, resulting in an overall municipal solid waste treatment scale of about 1,566 tons/day, directly correlated with the city's population and economy. Other cities also demonstrated significant treatment capacities, with Shigatse at approximately 411 tons/day, Shannan at 354.2 tons/day, Nyingchi at 283 tons/day, Qamdo at 380 tons/day, Nagqu at 578.6 tons/day, and Ngari at 195.6 tons/day. The collective design daily treatment capacity of municipal solid waste in Xizang reached approximately 3,768.4 tons/day.

Based on data surveyed by the National Bureau of Statistic on the daily municipal solid waste treatment capacities of 31 provinces in 2021, Figure 6 illustrates key findings. The statistics primarily include daily amounts of municipal solid waste disposed of, incinerated, and landfilled, with composting data unavailable and Hong Kong, Macao, and Taiwan excluded. The figure reveals that in 2021, Xizang's daily municipal solid waste disposal capacity stood at 2,355 tons, nearly equivalent to Qinghai Province's capacity of 2,296 tons per day. In Qinghai Province, municipal solid waste is predominantly disposed of in a single landfill. Comparing Xizang's disposal capacity with that of other provinces, the lower capacity is primarily attributed to factors such as population, economy, and waste production. Coastal regions of the country, being more populous and economically developed, exhibit larger municipal solid waste production and daily treatment capacities. For instance, Guangdong Province boasts a daily municipal solid waste treatment capacity of 176,736 tons (Figure 6)'

Problems and recommendations

Problems

Field research has revealed concerning issues regarding municipal solid waste management in Xizang. Some existing landfills are currently overfilled, yet no plans for new treatment facilities have been proposed. Moreover, certain counties face various problems with their landfills, including lax management, irregular operations, inadequate leachate treatment, waste surpassing the height of the landfill dam, and insufficient groundwater monitoring. Furthermore, landfill disposal poses significant challenges due to the fragile ecological environment of the Tibetan plateau. The method requires vast areas of land and can lead to environmental degradation, impacting both land resources and the ecological

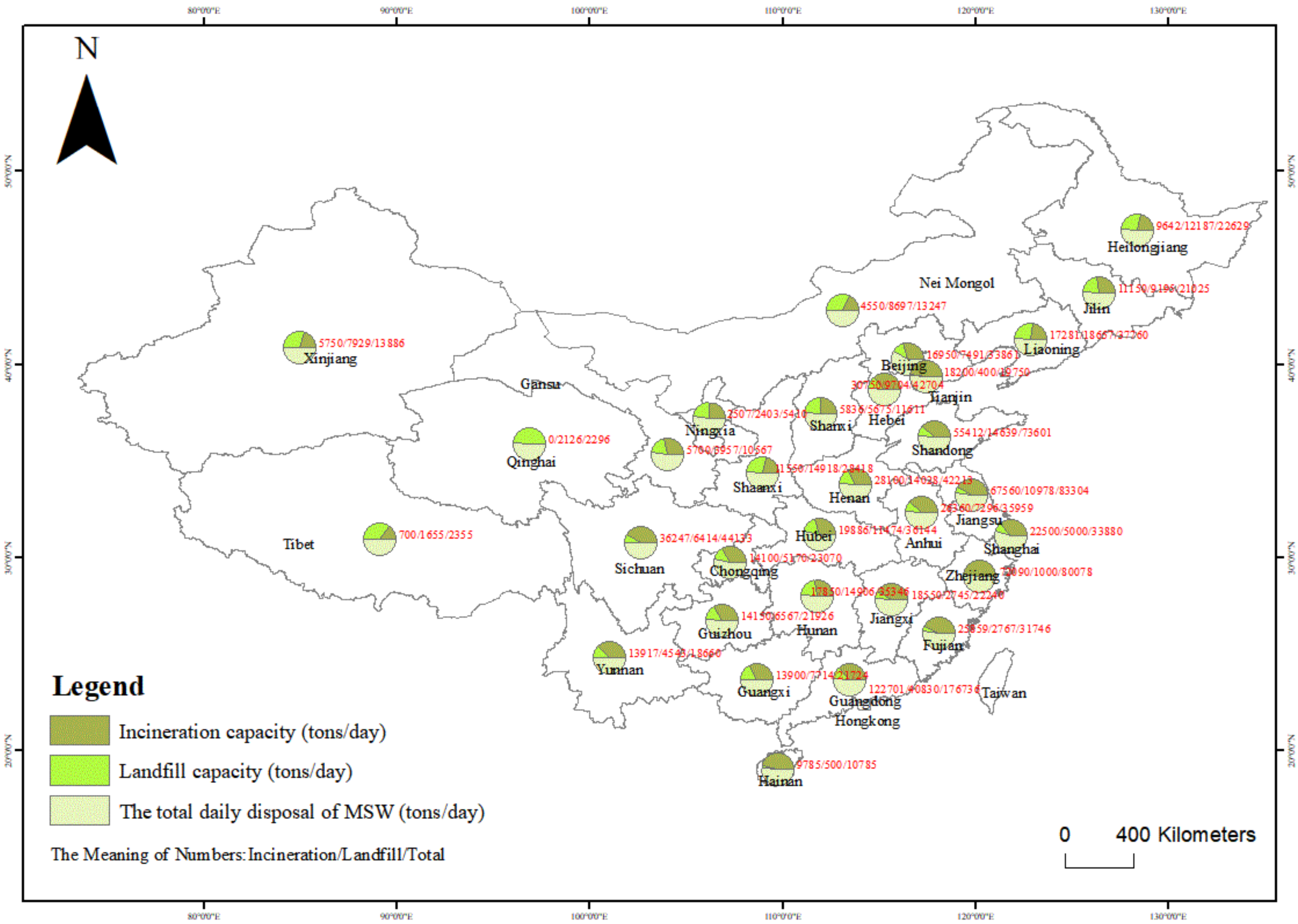

Figure 6. Daily municipal solid waste treatment capacity by province in China.

balance irreparably. These issues underscore the urgent need for comprehensive and sustainable solutions to address municipal solid waste management challenges in Xizang.

Recommendations

By means of field research and literature review, two recommendations are therefore made regarding the treatment and management of municipal solid waste in Xizang.

(1) Management

The corresponding management department of each city in Xizang should actively increase the supervision of landfill sites in accordance with the Technical Guidelines for the Disposal of municipal solid waste in the Xizang Autonomous Region. Problems should be considered the focal point in the management process, allowing for the integration of inspection, rectification, improvement and supplementation.

(2) Classification aspects

Each city in the Xizang region should strictly follow the Implementation Plan for the municipal solid waste Classification System of the Xizang Autonomous Region in the work of municipal solid waste classification. The old waste transportation vehicles should be replaced with closed transportation vehicles, providing clear reminders for waste sorting, optimizing the recycling system, regulating recycling outlets, and encouraging entrepreneurial operation.

Conclusions

The capacity of municipal solid waste in Xizang was lower in the dry season than in the rainy season, and the physical components of municipal solid waste under the change of the last decade have a larger proportion of reduction in kitchen waste, paper and ash waste. However, the percentage of recyclables in Xizang was higher compared to the percentage of recyclables in other cities in China. Municipal waste disposal in Xizang primarily relies on landfilling. The region boasts over 130 landfills for municipal solid waste and more than 160 waste transfer stations. In addition, there is one waste incineration plant, two kitchen waste treatment plants, and five waste pyrolysis demonstration sites. The designed daily treatment capacity of municipal solid waste in Xizang is 3768.4 tons/day, but the actual daily treatment capacity in 2021 was 2,355 tons/day. This figure falls below the daily waste treatment capacity observed in other provinces across China.

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Conflict of interest The authors declare that they have no conflict of interest.

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