Study on the Solid Waste Properties and Disposal Methods of Island at Home and Abroad

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Abstract. In order to promote the rational development and utilization of the islands in China, the characteristics and disposal methods of the solid waste of the islands at home and abroad were summarized in this paper, and several proposals for island solid waste management and Chinese island development were mainly discussed in view of the problems. The results show that the island solid waste per capita output was generally higher than the mainland area, and the total output varied with seasons. The organic content of solid waste was higher in the island that mainly developed planting and breeding, while the paper and plastics content of solid waste was higher in the island that mainly developed tourism. Due to the remote location, the cost of solid waste collection and transportation was high. It was difficult to select landfill site because of the lack of land, and the incineration and compost on islands were not mature enough, and the technique of waste-to-biofuels was still under exploration. Based on the characteristics of island solid waste and the difficulties in the disposal process, solid waste reduction and treatment process improvement on islands were recommended. Three ways of island solid waste disposal were summarized so as to provide reference for sustainable development of Chinese islands.

1. Introduction
The island is a naturally formed land area surrounded by water which is above the water surface during high tide. There are more than 200,000 islands in the world, with a total area of 9,963,500 km², accounting for 6.6% of the total land area. The island is an important base point for coastal economic development, national defense construction and ecological construction. The island with surrounding environment has unique ecological resources and tourism resources. In recent years, large-scale development and construction on the island have led to a larger increase in the production of solid waste on the island, and unreasonable behavior such as random disposal and landfill have caused pollution to the island soil and the water area [1]. Due to the remote and isolated geographical location, transportation on the island is inconvenient and it is difficult for solid waste disposal. At present, there are few study on solid waste on islands in China, and the method of solid waste treatment on islands should be selected according to the economic and environmental conditions of the island. The characteristics, treatment methods and problems of island solid waste at home and abroad were briefly introduced, and some relevant suggestions for solid waste disposal were put forward in this paper.

2. Generation characteristics
Physical composition and production mode of solid waste are the important reference for treatment strategy, which are related to local natural conditions, climatic conditions, residents' customs, living habits, fuel structure and economic development [2]. Solid waste components present giant diversities
in different regions. The solid waste production and physical composition of the island present certain regular characteristics.

2.1. Production

In recent years, island solid waste production has increased significantly with economic development, population growth, and living standards improvement [3]. Per capita solid waste production of Mauritius in 1990 was 0.6 kg/d, which increased to 1.0 kg/d by 2010 [4]. Table 2 shows the solid waste production of some islands at home and abroad [4-14]. Compared with the mainland, the per capita output of solid waste on islands is generally higher. For instance, the per capita output of the Canary Islands is 1.86 kg/d, and that in Spain is only 1.37 kg/d; the per capita output of Puerto Rico Island is 2.45 kg/d, while the per capita output per capita is 2.04 kg/d. The main reasons for the high per capita output of solid waste in islands: (1) There is much waste by-product generated by aquaculture and planting on the island, such as the large amount of sugarcane and banana crop straw in the solid waste of Exuma Island [8]; (2) The living materials on the island are predominantly transported from the outside due to the limited resource, and the packaging of the goods generates extra garbage. For example, the plastic packaging box of Crete accounts for 37% of the total plastic content [6]. (3) The development of tourism has increased the production of solid waste. For example, Green Island has reached 350,000 visitors per year, and each visitor can produce 3.91 kg of garbage on average [5].

| Area    | Population | Land area (km²) | Distance (km) | Waste generation Rate (kg/d) | Population density (person/km²) |
|---------|------------|----------------|---------------|------------------------------|--------------------------------|
| Penghu  | 102000     | 126.9          | 61            | 0.904                        | 803.8                          |
| Matsu   | 13000      | 28.8           | 213           | 1.507                        | 451.7                          |
| Green   | 3804       | 15.0           | 33            | 1.233                        | 253.6                          |
| Crete   | 623065     | 8336           | 140           | 1.200                        | 74.7                           |
| Menorca | 81150      | 702            | 225           | 1.480                        | 115.6                          |
| Exuma   | 6928       | 187            | 155           | 1.813                        | 37                             |
| Malta   | 475000     | 316            | 100           | 1.616                        | 1503.2                         |
| Balearic| 760000     | 5014           | 230           | 1.295                        | 151.6                          |
| Canary  | 2117519    | 7493           | 100           | 1.860                        | 282.6                          |
| Mauritius| 1240000 | 1865           | 2000          | 0.968                        | 664.9                          |
| Puerto  | 3410000    | 8870           | 770           | 2.450                        | 394.4                          |
| Nanri   | 57150      | 44             | 10            | 1.030                        | 1298.9                         |

Affected by the development of tourism and climate change, the total solid waste production of islands varies seasonally. For instance, the solid waste output of Menorca in August is twice the average of winter [8]. The solid waste output of Wailing ding and Dong’ao Island is shown in Figure 1, which also shows the regulation that waste output in summer and autumn is higher than that in winter and spring.
2.2. Component
The development of the island industry affects the component of solid waste by affecting the production mode and life style of residents. Due to its unique geographical location and climatic conditions, the island generally develops planting, aquaculture and tourism, and the composition of solid waste presents a fixed pattern. Six typical islands at home and abroad were selected as research objects, and the components of solid waste are shown in Table 2.

Table 2. Solid waste compositions of several islands

| Area         | putrescible | paper | plastic | metal | glass | others |
|--------------|-------------|-------|---------|-------|-------|--------|
| Mauritius [5]| 68          | 12    | 13      | 1     | 1     | 5      |
| Green [7]    | 39          | 27    | 5       | 2     | 6     | 21     |
| Crete [8]    | 39.15       | 19.94 | 16.85   | 4.95  | 5.33  | 13.78  |
| Langkawi [15]| 41.68       | 18.15 | 33.45   | 3.7   | 2     | 1.02   |
| Wailingding  | 45.4        | 12.75 | 13.01   | 4.34  | 2.11  | 22.29  |
| Dong’ao      | 42.29       | 18.53 | 12.9    | 3.93  | 3.05  | 19.3   |

The putrescible of solid waste on the islands take up the highest proportion, including leftovers, by-products of agriculture and garden leaves. The putrescible content in Mauritius is much higher than that on other islands, which is directly related to Mauritius’s main economic structure. Mauritius has a large number of sugarcane, and it produces much putrescible waste such as bagasse in the process of sugar manufacturing. Nanri Island mainly develops aquaculture, and the content of livestock manure and algal residue account for 17.2% and 12.7% of the total waste respectively [14]. The content of paper and plastic waste in Crete and Langkawi, which is mainly based on tourism development, is higher than that on other islands. This is because tourists consume a large amount of goods and produce more paper packaging, plastic bags and bottles around the scenic spots. Research on Crete Island shows that human social activities have a strong correlation with the composition of garbage. In the tourist areas, aluminium bottles, glass bottles, paper and plastic packaging are much higher than other places [7].

3. Status of island solid waste management
At present, there are three types of solid waste disposal mode on the island: The first is rough treatment including simple landfill and open burning, such as the treatment process on Bahrain Island [16] and Nanri Island [14]; The second is comprehensive treatment, which is well applied on Miyakojima [17]; The third is that solid waste is transported to the mainland for treatment, which is the main treatment mode on Estonian Islands [18], Wailingding Island and Dongao Island. The entire management process for solid waste includes collection, transfer and end treatment.
3.1. Collection and Transfer
Collection is the primary part of the solid waste management. Insufficient collection will affect the normal operation of the subsequent transport and treatment. Due to the lack of solid waste collection facilities on many islands, the producers have no choice but to randomly pile up solid waste or incinerate on the spot, which seriously endanger the surroundings and residents' health [16]. The collection and transshipment costs generally account for a relatively high total cost of solid waste management. For instance, the solid waste collection fee on the Malaysian Islands accounts for 75% of the total municipal expenditure [15]. Many islands garbage can only be stacked on site because of the incapability of affording collection and transportation costs [19]. To remedy this, classification collection can reduce waste collection costs [20]. In addition, some islands waste are transported to the mainland for disposal by ship on account that the scale of garbage is very small or treatment station site selection is difficult. The Wanshan Islands are the first area in China to transfer solid waste outside the islands. The biggest obstacle of outside disposal is the high transportation cost. The cost of shipping solid waste to mainland in the Wanshan Islands can reach to 1500-2000 RMB/ton.

In the tourist season and the typhoon season, the island's solid waste production is highest and the sanitation personnel and transport vehicles should be increased. Menorca has the highest solid waste production in summer, employing 17% more sanitation personnel than in other seasons, and the frequency of garbage trucks is twice than that in winter [8]. Wailingding Island and Dong'ao Island had the highest solid waste production in August. Due to the limited sanitation workers and facilities, the solid waste on the two islands could not be collected and transported in time, and the stacking phenomenon was serious. The effective collection of solid waste on the island requires not only a complete infrastructure, but also the cooperation of local residents and tourists. In Mauritius, despite that rural garbage are collected at least once a week and urban garbage are collected three times a week by door-to-door, there still are 12% of the waste dumped in wasteland or waters [4]. Therefore, government should also strengthen environmental protection propaganda for island residents and tourists while improving the solid waste collection facilities.

3.2. End treatment
3.2.1. Landfill and incineration. The traditional solid waste treatment methods include landfill, incineration, composting and recycling. The landfill plays a major role in the past solid waste management of the island due to its simple method and low cost. As the number of populations increases and landfills become saturated, landfills are gradually decreasing in islands. Due to the rapid increase in waste production, the service life of sanitary landfills in Mauritius has been shortened from 19 years to 8 years, and other methods have to be explored [4]. Wanshan Islands in China began to transport waste to mainland for treatment in 2010 because of the overload use of landfills. The incineration of solid waste has a high degree of reduction, and the generated heat energy can also be recycled. In Mauritius, the amount of electricity generated by the burning of sugarcane bagasse reached 59.8 billion kWh a year, accounting for 17.2% of total electricity production [21]. However, insufficient incineration could produce carcinogenic harmful substances such as dioxins and polychlorinated biphenyls, and the ash has the risk of heavy metal pollution. 20.8% of POPs in Mauritius derived from the incineration of hospital hazardous waste [22]. Therefore, it is necessary to optimize and improve the treatment process to decrease the pollutants for incineration treatment of solid waste of the island.

3.2.2. Compost and recycling. Solid waste containing much perishable matters could be disposed by composting, and the recyclable matters such as paper boxes, plastic bottles and metal can be reused so as to reduce other resources usage. In Mauritius, 45.4 tons of solid waste is used for composting every year due to the large amount of bagasse generated by sugar production. Grenada is famous for exporting tropical crops such as nutmeg, banana and cocoa, and plant waste compost is common on this island [23-24]. In addition, the fertilizer produced by composting can be recycled in agriculture, which could increase the yield and quality of agricultural products and improve the natural landscape of the island.
Miyako Island in Japan used cow dung and bagasse for composting, and the fertilizer produced was used in agricultural land to maintain soil fertility [17]. However, the composting process will produce volatile malodorous substances such as methyl mercaptan. If not treated reasonably, they will do harm to the health of inhabitants. Solid waste recycling is also common in the world. Of the 52 island countries or regions in the world, 83% choose to recycle metals, 65% recycle plastics, 56% recycle glass, 50% recycled paper, and 10% recycled textiles [15]. Sealey proposed “zero solid waste” model, which is that the island waste is not disposed of by landfill and incineration, but used for composting and recycling [25]. The “zero solid waste” treatment mode can improve environmental quality of island and attract more tourists. It is a suitable solid waste treatment mode for island development.

3.2.3. Bioenergy manufacture. The biodegradation of organic matter to produce energy such as ethanol, biodiesel, and hydrogen has become a frontier topic in the treatment of solid waste on islands. Many islands have landfills, and the landfill methane can be used as an energy resource. The main component of the solid waste landfill gas in the Canary Islands is methane (50-70%), the calorific value reaches 8900 kcal/Nm3, and the main products of combustion are CO2 and water vapor, which can be used as a clean fuel [12]. Based on that 88.5% of the greenhouse gases produced by the Malta Island Landfill are methane, the government of Malta is planning to replace fossil fuels with methane [10]. Khadoo-Jeetah has successfully use sugar cane skin, grassy grass and coconut shell coming from solid waste in Mauritius to develope bioethanol [26]. Using bagasse to produce bioethanol and biodiesel in under development in Fiji [27]. The solid waste to energy can reduce the island's solid waste pollution reduce and provide clean energy, so it is promising to solve the problem of energy shortage in island. However, the technology of waste to energy is not mature enough at present. Many island areas such as Fiji, Cuba, and Jamaica have been making bioethanol from organic solid waste only at the stage of research, and cannot manufacture it in large quantities.

4. Suggestions
Due to the special geographical location and climatic conditions of the island, solid waste disposal mainly faces the following problems:

(1) Limited availability of suitable land on islands for solid waste disposal such as landfill.
(2) Remoteness of many SIDS, resulting in high costs for consumables used in typical waste management operations that must be imported.
(3) Small and sometimes spare populations that limit any potential economies of scale, and the high cost on solid waste collection and transportation.
(4) Pollutions of present solid waste treatment methods such as POPs produced by incineration and odor produced by composting, damaging inhabitants’ health.

The main solution to improve solid waste disposal on the island depends on the reduction of the source and the improvement of the treatment process.

4.1. Source reduction
The source reduction of solid waste on the island can reduce the pressure of subsequent collection, transshipment and end treatment. The following measures can be taken: First, choosing lightweight, reusable packaging materials to reduce the solid waste produced in the process of transportation, and import processed food replace of raw items to reduce kitchen garbage. Second, encouraging inhabitants to buy and save food less, reducing the amount of garbage produced due to items overdue. Third, increasing the utilization rate of solid waste recycling through separate collection. Fourth, improving the construction of solid waste collection and transportation, and making relevant laws and propagandized about hazard of solid waste pollution in every community to change the custom of littering at random.
4.2. Technology selection

The treatment process determines the effect of island solid waste disposal and the impact on the life quality of residents on island. The selection of island solid waste treatment technology should focus on the following aspects: First, choosing the treatment method with high degree of solid waste reduction, such as incineration or packaging to mainland for disposal. Second, improving the solid waste treatment process to reduce pollutant emissions. The incineration is mainly needed to dispose tail gas. Reducing the environmental and human hazards of pollutants such as nitrogen oxides and dioxins, and the leachate produced during the composting process may cause nitrogen and phosphorus in the island water body. And heavy metal pollution, it should be discharged after treatment. Third, deepen the development of island solid waste resource utilization technology to make up for the tightness of island resources; such as microbial degradation of organic solid waste to prepare clean biofuels, combustible solid waste to prepare derivative fuels.

5. Enlightenment for the solid waste disposal of Chinese islands

Based on the characteristics of solid waste at home and abroad and the problems in the management process, three disposal methods for island solid waste are summarized as shown in Figure 2. The first one is to package and transport solid waste to the mainland for disposal, which can avoid the accumulation and pollution of solid waste on the island and minimize the impact of solid waste on the island environment. It is suitable for islands which are close to the mainland. The high freight charge is the biggest challenge and the island with poor economic scale maybe can’t afford it. The second is the treatment technology of clean composting and harmless incineration, which is suitable for islands with both development of crop and tourism. What should be noted are the requirement of foul odor control.
in composting yards and decontamination of tail gas and ash in incineration plants. On the basis of
classification collection, the third is the method of waste recycling and biofuel manufacture through
biodegradation, maximizing the utilization of solid waste resources characteristics, making up for the
lack of island energy shortage, which is the most optimal disposal method for island solid waste.

The number of islands at a distance of less than 10 km to the mainland in China account for more
than 68% [18], thus the method of waste packaged to mainland is more implementable in China. The
islands far away from mainland could adopt the second solid waste disposal method. And with the
development of biofuel technology, the third disposal method are supposed to put into use extensively.

6. Conclusion
Due to the particularity of geographical location and lifestyle, the average per capita yield of solid waste
is higher than that of mainland. The total output in summer and autumn is generally higher than that in
winter and spring. The most three components are putrescible, paper and plastic, and the islands that
mainly develop planting and breeding contain more perishable waste, while the islands that mainly
develop tourism contain more perishable waste.

Because of the remoteness and inconvenient transportation, the solid waste treatment on island is
difficult and the cost is high. The disposal methods mainly include landfill, incineration, composting
and recycling based on the variety of solid waste characteristics and geographical environment, and the
promising technique is still under research and development. Facing the problems at present, effective
source reduction and proper treatment selection are the main solving method.

(3) Most Chinese islands could transport solid waste to the mainland for treatment, and the islands
far away from mainland could adopt compost and incineration under the premise of removing odor,
harmful gas and heavy metal in ash. With the development of technology, recycling and biofuel
manufacture are the most promising waste disposal method.

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