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CHARACTERISTICS AND MANAGEMENT OF MUNICIPAL SOLID WASTE IN CHINA

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Abstract

This paper aimed to charaterize municipal solid waste (MSW) and examine problems existing in MSW management systems in China. MSW characteristics including generation rates, composition and heating values were respectively analyzed at three levels of provinces and major cities. Determining factors of MSW generation were made by multiple regression analysis and models of MSW collection rates were developed for the nation, a major city and for Shanghai. In addition, a concept model of MSW characteristic change was developed for major cities based on a cluster analysis. Existing MSW management systems need to improve their resource waste recovery systems , to anticipate strategies for waste electric appliance disposal, and to resolve the difficulties in collecting waste collection charges.

KEYWORDS: *municipal solid waste, characteristic,management, problems, China*

1. Introduction

In China, in light of the rapid economic development in recent years, and with the increase in urban population and expansion of the consumption activities of residents, municipal solid waste (MSW) has rapidly increased in the amount generated and has also remarkably changed in quality. Under the system that municipal solid waste is generally collected without classification, these changes have made municipal solid waste disposal more difficult. Although the government and individuals have paid more attention to municipal waste control, and the treatment rate has continued to increase over the past several years, in 1995, only 52% of the total municipal solid waste in China could be treated and disposed properly (Wang W., 1997). The garbage that could not be properly treated and disposed was transferred to suburbs and piled up in open dumps. Up to 1998, municipal

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solid waste dumped in open air had amounted to 6 billion tons, occupying 500 million m^2 of land, and causing over 200 cities to be almost surrounded by garbage (Zhu L.L., 1998). Pollution caused by municipal solid waste has become an urgent environmental as well as social problem in Chinese cities.

In October 1995, the Law of the People's Republic of China on the Prevention of Environmental Pollution of Solid Waste was issued and became effective from April 1996. This symbolizes the start of waste management under legal controls in China. How China controls municipal solid waste is increasingly attracting attention from researchers. Following the historic cycle of great production and great consumption already experienced by industrial countries, China will also become a society discarding great amounts of waste rapidly, as the country with one fifth of the world population and the highest development rate in the world. In waste reduction, reuse and recycling, China needs to construct a special waste control system combining its own social and economic characteristics with the environmental theories of the 21st century. For this, it is essential to make a current and predictive analysis of the exhaust characteristics of municipal solid waste. However, there is a shortage of literature quantitatively and systematically analyzing MSW in China. In this section, we aim to elucidate the exhaust characteristics of MSW, and clarify the current situation and problems of MSW disposal systems.

The following three points need to be noted in this section. One concerns MSW used as an object of analysis. Since garbage collection and disposal service in China is generally aimed at residents in urban areas, data for municipal solid waste supplied by statistical literature means the domestic waste produced in households, businesses and factories in urban areas. The second concerns the population generating MSW. In China, population of a city is divided into two parts being an urban population and the rural population in the city, in accord with the census registration of the two parts of non-agricultural population and an agricultural population according to career. Usually, the non-agricultural population, or the urban population in a city (non-agricultural population is smaller than urban population) is regarded as the generating population of MSW generation in a city; thereby, per capita generation rate is the calculated value of the total MSW collection rate and the non-agricultural population or urban population. The third concerns words such as garbage, waste etc used in this paper, which should be seen to be equal to MSW if there is no other explanation.

2. Characteristic of MSW at a National Level

MSW in China is defined as the solid waste generated in urban daily life or from the activities supplying services for urban daily life, and the solid waste ruled as MSW by law and administrative regulation (Technology and Policy of Municipal Solid Waste Disposal and Pollution Control, 2000). Figure 1 illustrates the sources of municipal solid waste in Shanghai and Guangzhou Cities. It was seen that municipal domestic waste in China includes domestic waste from households, road cleaning, offices, the catering trade, factories and hospitals, etc. Among these, households were the main source of MSW being 67% of the total MSW generated in Shanghai City in 1995 and 63% in Guangzhou City in 1997.

Figure 2 shows the changes in MSW generation, urban population and GDP in China from 1980 to 1999. During this period, the number of cities in China increased from 223 to 667, and the urban

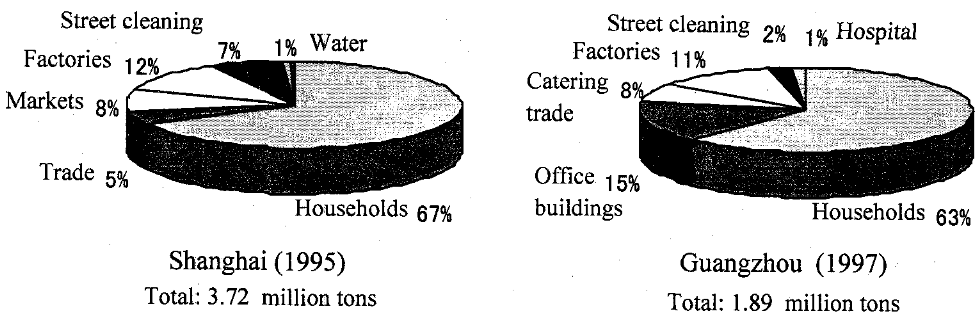

Figure 1. Resource of domestic waste in Shanghai and Guangzhou of China. Data Source: [Shanghai] Sen M., Nita Y. and Yokota, 1997; [Guangzhou] Chen B. L., 2000.

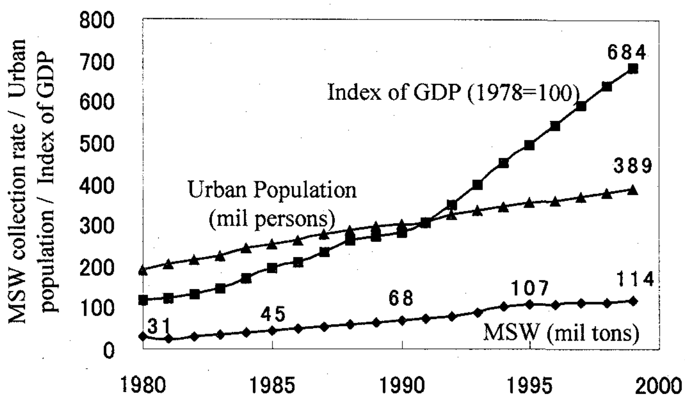

Figure 2. Change in MSW collection rate, urban population and GDP of China.
Data Source: China Statistical Yearbook,1981 to 2000.

population increased from 191 million in 1980 to 389 million in 1999, by an annual average increase rate of 9.8%, 5.8 times the figure 20 years ago. In such an economic development and urbanization process, the total generation rate of MSW in China increased rapidly to 114 million tons in 1999, an average annual increase of 7.1% from the 31.3 million tons in 1980.

Figure 3 illustrates the per capita MSW collection rates and total generation rates of MSW in 8 major countries. In 1996, urban residents, businesses, offices etc. in urban areas produced and discarded about 108 million tons of MSW, which is approximately 1.4 kilograms of waste per person per day. China exceeded Japan, U.K., Italy, France and Germany in per capita MSW collection rate and was the second in total MSW collection rate. Coal usage in portions of the urban households and increasing consumption activities were considered to be the main reasons for the relatively high per capita MSW generation. As to the increase of total MSW generation, the urban population increase accompanying with urbanization was an important factor.

In this section the relationships among MSW discharge amounts, generation populations, and

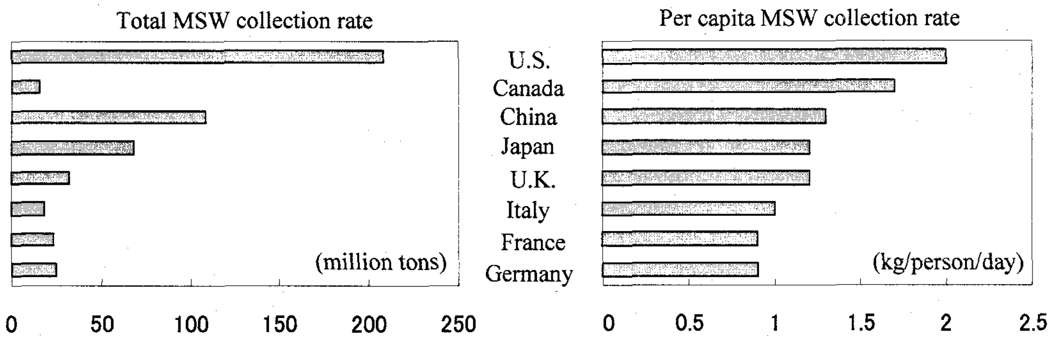

Figure 3. MSW collection by major countries (1995). Source: Zuo J., Matsumoto T. & Imura H., 2000.

income levels are analyzed at a whole nation level. Based on the data for MSW and the non-agricultural population of China from 1980 to 1998 (China Statistical Yearbook, 1981 to 1999; China Population Statistics Yearbook, 1999), the following approximate expression was obtained using the method of least squares.

$$W^N = 162.82 \exp (0.0055 P^N) \quad (1)$$
$$R^2 = 0.986$$

where W^N is the total collection of MSW of China (10^6 t) and P^N is the non-agricultural population of China (10^6). This expression indicates an exponential curve downwardly convex, which implies that the total collection of MSW increases at a faster speed than the urban population.

Moreover, to find the relationship between residential income levels and the MSW collection amount, data for per capita GDP and per capita MSW collection rate was analyzed using the method

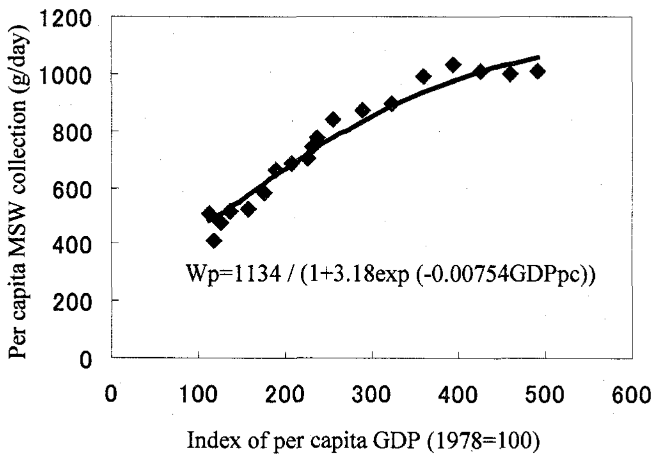

Figure 4. Correlation between per capita MSW collection rate and per capita GDP. Data Source: China Population Statistics Yearbook, 1999; China Statistical Yearbook, 1981 to 1999.

of least squares. As a result, the following logistic approximate expression was obtained.

$$Wp^N = 1134 / (1+3.18\exp(-0.00754\ Gp^N)) \quad (2)$$
$$R^2 = 0.965$$

where Wp^N is the per capita MSW collection rate (g/day), Gp^N is the index of per capita real GDP of China (1978=100). The index of GDP rather than GDP was used to reflect the economic level and to avoid disturbances of price fluctuations. Figure 4 shows the curve of this expression, showing that the increased rate of per capita MSW is slowing around the point of 1,100 g/day although per capita MSW increases with the increase of per capita GDP.

3. Characteristic of MSW Seen at a Provincal Level

For the most realistic view, ArcView GIS was used in this paper to describe the features of MSW generation in China. Thus, all collected data relating to MSW generation were integrated into the resource and environment database of China, which was developed by the Lab of Resource and Environment Information System (LREIS) of the Academy of Science of China.

Figure 5 shows the average per capita MSW collection rate in 27 provinces and the three major cites of Beijing, Tianjin and Shanghai, which are directly under the jurisdiction of the central

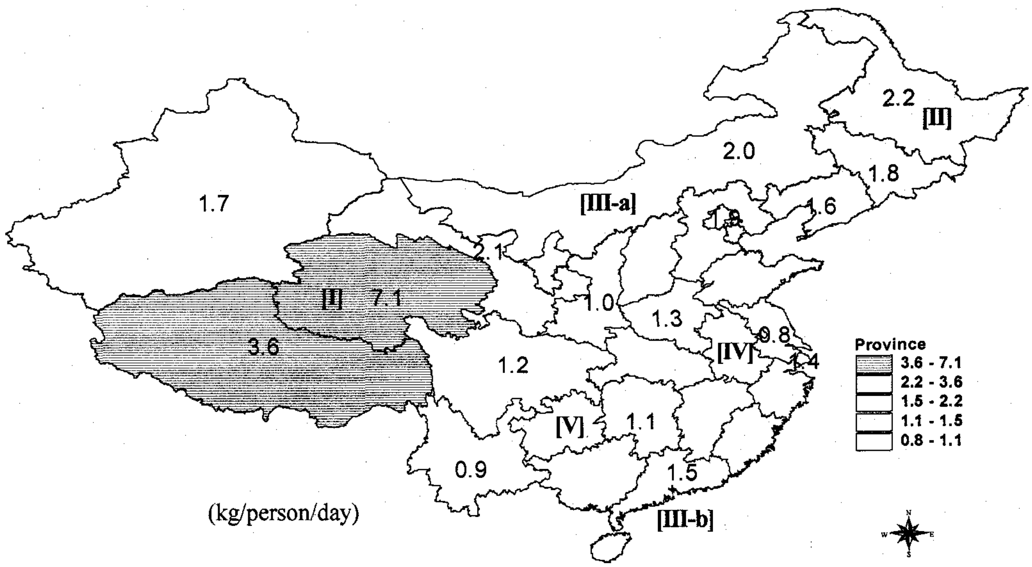

Figure 5. Per capita MSW collection rate by province (1996). Data Source: China Statistical Yearbook, 1997; Urban Statistical Yearbook of China, 1997.

government of China. Five classes of per capita MSW collection rates were determined using the method of natural breaks, which identifies breakpoints by looking for groupings and patterns inherent in the data. Compared with cities in the northern region, those in the southern region appeared to have relatively low values of per capita MSW collection rates. It could be explained that coal is still used as a household fuel by portions of urban families; cities in the northern region and highlands discharged more coal ash than cities in the southern region due to the relatively cooler weather. In detail, two provinces (Group I) in the highest highland of the world had the highest per capita MSW generation, twelve provinces and the two cities of Tianjin and Shanghai (Group IV and V) in the middle or southern areas were the lowest. Thirteen provinces (9 in the northern area, Group II, III-a; 4 in the southern area, Group III-b) and Beijing City ranged between the two extremes. It was noticed that Zhejiang and Guangdong provinces, locating in the south coastal area, were in the top position of the popularization rate of gas usage, 93.6% and 90.0% respectively, and that the average per capita MSW collection rate of the cities in the two provinces was higher than those in the surrounding provinces. The reason was considered to be that high consumption levels in the areas with rapid economic development rates stimulated an increase of MSW discharge, Zhejiang and Guangdong province were first and third in per capita GDP in 1996, $1,139 and $1,128 US Dollars, respectively.

4. Characteristics of MSW at the Major Cities Level

In this section, situations concerning MSW collection rates, composition and heating values for major cities in China were analyzed and compared with major cities in Japan. In addition, deciding factors of MSW generation were analyzed by using multiple linear regression analysis. Based of these results, a conversion rule of exhaust characteristics of MSW in Chinese cities was then discussed.

4.1 Changes in MSW Generation, Composition and Heating Values

(1) MSW Generation

Figure 6 displays total MSW collection rates and per capita MSW collection rates in 46 major cities in 1991 and 1995.

In total MSW collection rates, Beijing, Shanghai, Shenyang, Tianjin, and Harbin were the highest in order from high to low. All, except Shanghai, are located in the northern region of China. In 1995, Xining city, located in the cool Qingzhang highland, and the new cities with the highest economic increase rates, for example, Zhuhai, Beihai and Wenzhou, also appear with relatively high per capita MSW collection rates. Among 46 major cities, 22 cities produced below 0.5 million tons of MSW a year, 15 citeis ranged from 0.5 to 1.0 million tons a year, and 9 cities were over 2 million tons in total MSW collection rates.

During the period from 1991 to 1995, 20 of the 46 major cities experienced decreases in per capita MSW collection rates, while 26 cities experienced increases in per capita MSW collection rates. Although 20 cites showed decreases in per capita MSW collection rates, only 11 cities had

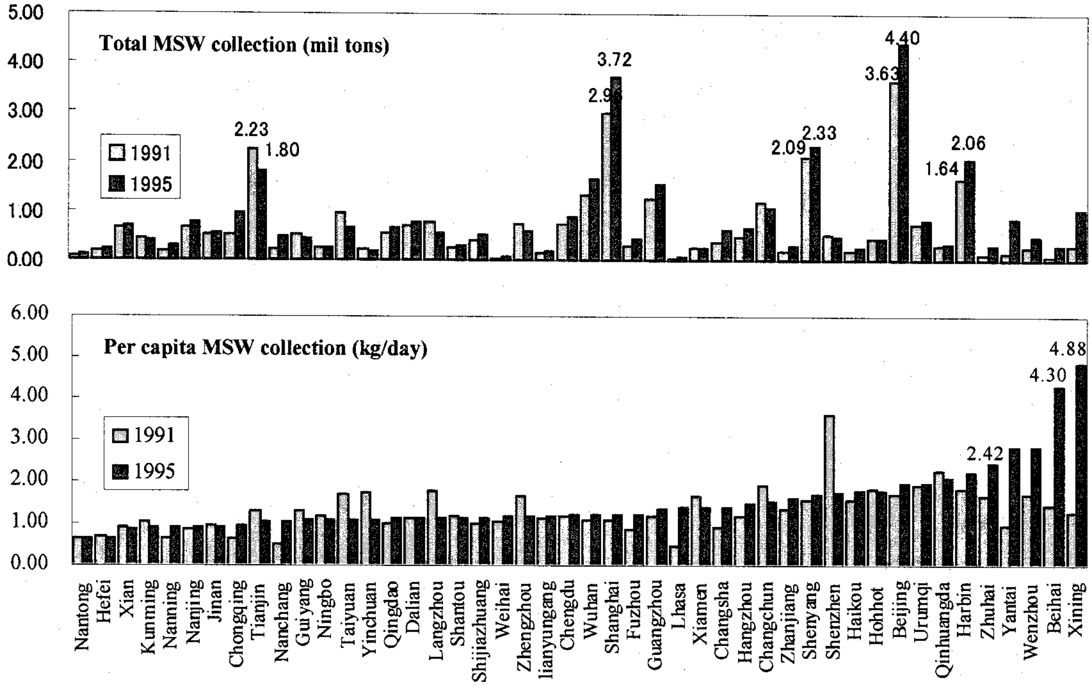

Figure 6. Per capita and total MSW collection in 46 major cities (1991 and 1995). Data Source: China Statistical Yearbook, 1992, 1996; Urban Statisticl Yearbook of China, 1992, 1996.

decreases in total MSW collection rates, and 35 of the 46 major cites showed increases in total MSW collection rates. Expansion of administrative areas and accompanied increases of urban population in most of the cities showing decreases in per capita MSW collection rate could be considered to be the reason for the fact that the number of cities showing decreased total MSW generation rates was less than the number of cities showing decreased per capita MSW collection rates. It was noticed that in all of the 5 cities with the highest per capita MSW collection rates in 1995, there appeared a sharp rise in per capita MSW collection rates during the 4 years. In cities, increase trends and decrease trends in per capita MSW collection rates existed at the same time, which respectively resulted from the improvement of consumption levels and the popularization of gas usage in households. In cites with a high popularization of gas usage, MSW collection rates appear as an increased trend with improving economic consumption levels.

Next, changes in MSW generation in China's major cities were compared with Japan's major cities. Figure 7 shows changes of 6 cities in China (Beijing, Tianjin, Shanghai, Shenyang, Xi'an and Guangzhou) and 4 cities in Japan (Tokyo, Osaka, Nagoya and Fukuoka) in total per capita MSW collection rates. In Beijing and Shanghai, total MSW collection rates increased rapidly from the 1980s, now almost reaching the same level in MSW collection rate as Tokyo. In Shenyang and Tianjin, located in the northern region of China, total MSW collection rates tended to increase again in recent years though they decreased in past periods. In Tianjin, the per capita MSW collection rate decreased by 21% from 1.27 kg/day to 0.99 kg/day during the 6 year period from 1990 to 1996, while

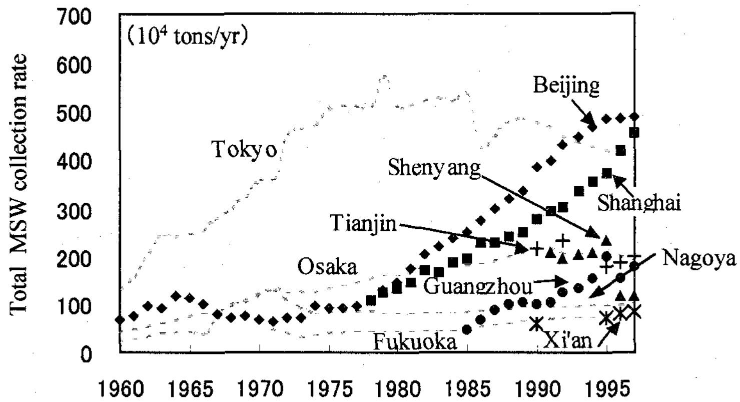

Figure 7. Change in MSW collection rate in several major cities in China and Japan. Data Source: [Japan] Fact Book of Waste Management & Recycling in Japan, 1999; [Guangzhou] Zhao Q.H., 1998; [Other Chinese cities] Statistical Yearbook of each City.

the percentage of population using gas for household use increased from 57.3% to 90.8% and per capita GDP increased from 3,621 to 12,270, 3.4 times that in 1991.In Guangzhou, located in the southern region of China, MSW generation has kept increasing during the past years, reaching the same level as Osaka in total MSW collection rate. In Xi'an, located in inland China, the total MSW collection rate tended to increase gradually, and now is at the same level as Fukuoka City.

(2) MSW Composition

Besides changes in generation rates, in light of economic development it is easily concluded that MSW also has changed in composition and quality with lifestyle changes. The share of coal ash keeps decreasing with continuous popularization of gas usage in urban households, while the amounts and share of waste such as paper, plastic and metal keeps increasing with improvement of

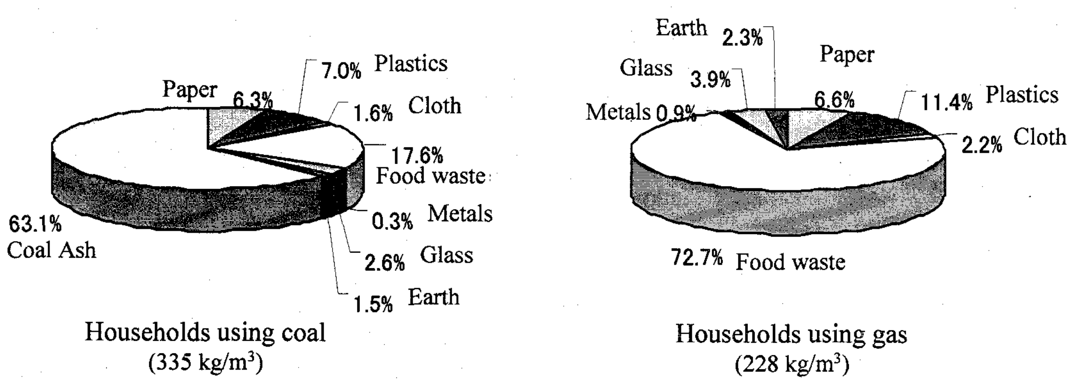

Figure 8. Composition of household solid waste by households using coal and gas in Shanghai. Data Source: Sen M., Nita Y. and Yokota, 1997.

living standards and consumption levels.

Figure 8 shows the composition of waste produced by households using gas and households using coal, respectively, in Shanghai, which was used to explain the difference in waste composition due to different fuels. Organic materials accounted for 93% of the total waste from households using gas and 33% of the total waste from households using coal. The difference in waste composition made waste density very different. The density of waste produced by households using gas weighed 228 kg/m^3, while that using coal weighed 335 kg/m^3.

During the past twenty years, gas usage in urban households has been greatly popularized; the percentage of urban population with access to gas in China was 81.7% (667 cities) in 1999, up from 22.4% (317 cites) in 1985. The physical characteristics of MSW greatly changed accompanying with this change.

Figure 9 shows MSW composition changes in Korea, Japan and in 5 major Chinese cities. Although MSW composition and its changes were very different in the five cities, increases of organic waste such as paper, clothing and plastic and a distinct decrease of coal ash and earth were common. The share of waste plastic to total MSW increased to 15% in Beijing in 1998 and 17.5% in Guangzhou in 1997, and has come into line with the mean value of 16.5% in cities in Japan in the 1980s. At the same time, the share of waste paper and clothing reached 24.1% in Beijing in 1998 and 10.7% in Guangzhou in 1997, it was still lower compared with the mean value of 40% in 1975 and 55% in 1998 in Japan.

Figure 10 shows compositional changes of MSW by different generation sources in Beijing. It was seen that the share of waste paper and plastic increased in all MSW discharge resources, and composition ratios of coal ash and surplus decreased in houses with gas and heating systems, high

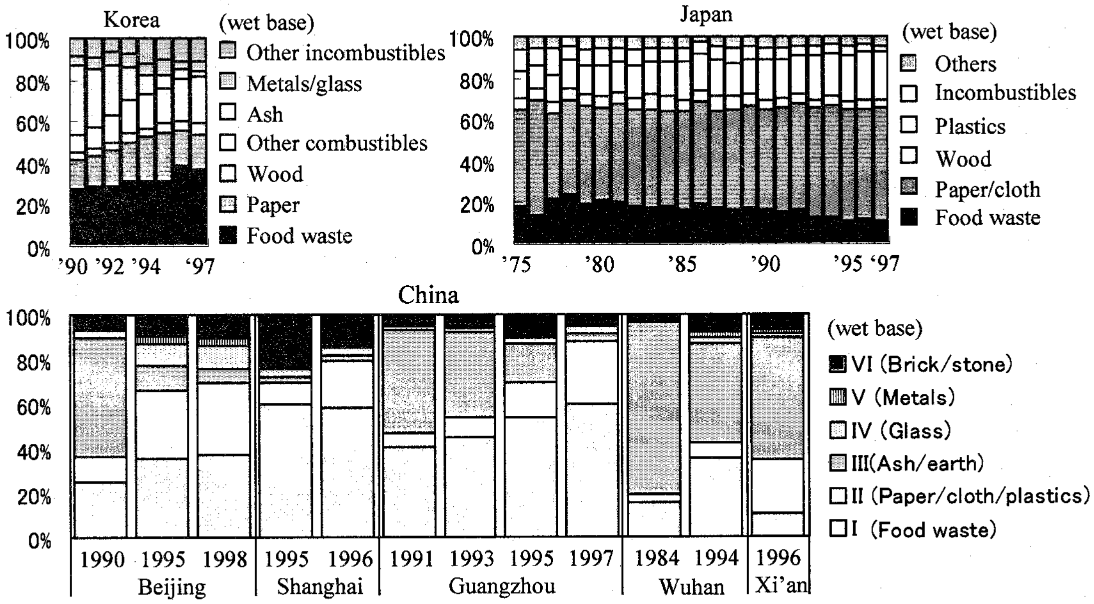

Figure 9. Compositional change of MSW in Korea, Japan and China. Data source: [China] Jiang Y. & Kang M.Y., 2001; [Japan] Fact Book of Waste Management & Recycling in Japan, 1999; [Korea] Municipal Statistics of Korea, 1990 to 1998.

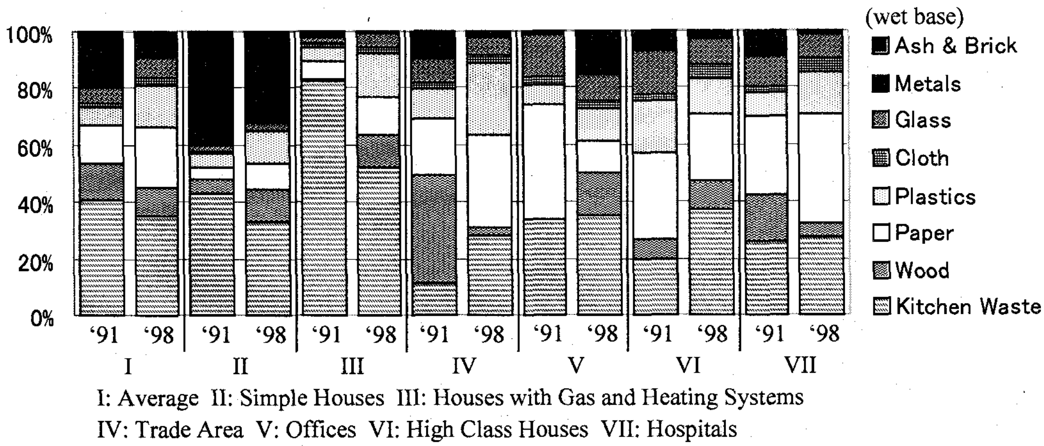

Figure 10. Compositional change of domestic solid wastes by different generation sources in Beijing. Data Source: [Year 1991] Li Guoxue, 1999; [Year 1998] Target and Strategies for Beijing's Solid Waste Pollution Control from 1998 to 2002, 1999.

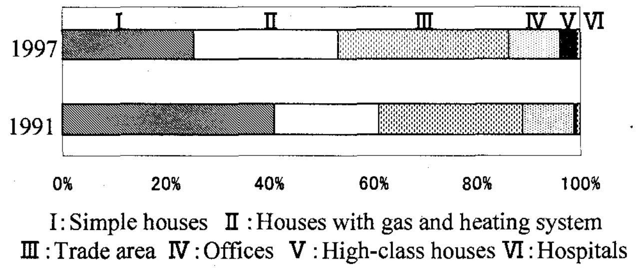

Figure 11. Proportional change of MSW by different sources in Beijing (1991 and 1997). Data Source: Li G.X., 1999.

class houses, hospitals and trade areas. With the change in MSW composition in each discharge resource, the proportion of waste generation amounts by different sources changed accordingly.

Figure 11 shows the distribution of waste weight by different generation sources in 1991 and 1997 in Beijing. It was found that the share of waste from simple houses decreased from 41% to 25%, the share of waste from trade areas increased from 28% to 33%, and the share of waste from houses with gas and heating systems increased from 20% to 28% during the period between 1991 and 1997.

In general, compositional change of MSW in Chinese metropolitan areas appeared to decrease in inorganic waste and increase in organic waste.

(3) MSW Heating Values

Because of regional diversity in life style, economic activity situations etc, MSW heating values in different regions appeared very different. For example, the average lower heating value of domestic waste in Beijing was about 1,000 kcal/kg in 1996; in Guangzhou, it was 880 kcal/kg in 1991 and 1,500 kcal/kg in 1997.

Table.1 Heating value of MSW in Beijing by generation sources (1996)

Heating Value	Higher Heating Value	Higher Heating Value	Lower Heating Value	Water Content
(kcal/kg)	(dry base)	(wet base)	(wet base)	(%)
Common Residential Area	1,729	921	485	53.9
Exclusive Residential Area	2,486	1,690	1,353	33.2
School and Institute Area	1,865	1,175	824	36.2
Downtown	2,807	1,937	1,571	34.6
Hotels	2,773	2,121	1,913	10.3
Hospitals	2,121	1,294	934	39.4
Parks	1,913	1,428	1,119	26.0

Data Source: supplied by Chinese Research Academy of Environmental Science, 2000.

Table 1 gives heating values of MSW in Beijing by different discharge sources. The difference in heating values manifests the influences of lifestyles on MSW heating values. The lower heating values of domestic waste discharged from exclusive residential areas, trade areas, hotels and parks were over 1,000 kcal/kg, higher than those discharged from common residential areas, hospitals, schools and institutional areas.

Figure 12 shows the positive correlation between MSW heating value and economic level by using data for seven major cities in Japan, and Beijing and Shanghai in China. It is also shown that the correlation level between MSW heating values and economic levels is comparable between China's and Japan's cites when values of per capita GDP are converted into purchasing power parity. That is to say, it is possible to predict MSW heating values in China's cities by using the experience of Japan's cities. If MSW lower heating value in Guangzhou changes in the Tokyo model (Figure 12) and economic activity increases keep an annual increase of 8% before 2010 and 5% between 2010

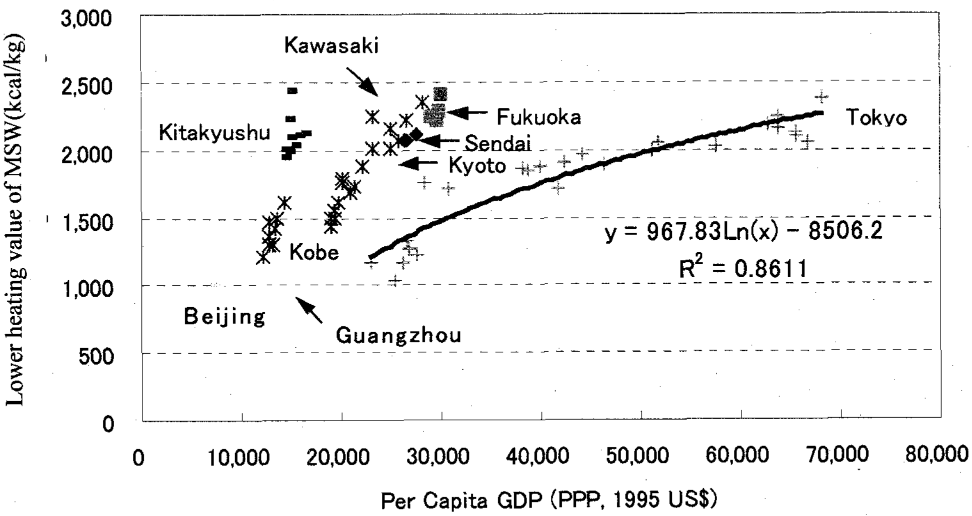

Figure 12. Relation between MSW heating value and per capita GDP in several major cities of China and Japan. Data Source: [Japan] Fact Book of Waste Management & Recycling in Japan, 1999; Statistical Yearbook of Big Cities, 1960 to 1997; [China]Urban Statistical Yearbook of China, 1995 to 98; Zhao Q.H., 1998; Chen B.L., 2000.

and 2020, the MSW lower heating value in Guangzhou will reach about 1,900 kcal/kg in 2010, equal to the same level in Tokyo in the later 1980s, and reach 2,200 kcal/kg in the late 2020s, equal to the current level in Tokyo.

Figure 13 shows the historic changes in lower heating values of MSW in Japan and China's cities. It was found that the current lower heating value of MSW in China's metropolitan areas with remarkable economic development, like Beijing and Shanghai, has exceeded 1,000 kcal/kg, and is equal to be the average level of Japan's major cities in the 1970s, or current average levels of Japan's middle and small cities. For these metropolises, the incineration method has become feasible for MSW disposal, for 1,000 kcal/kg of lower heating value is the lower limit for keeping waste burning continuously without auxiliary fuel.

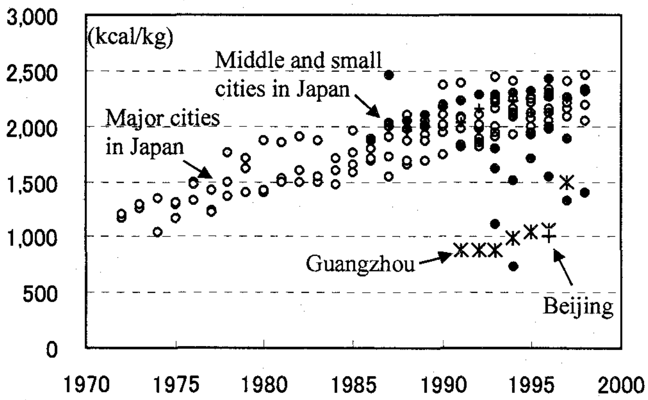

Figure 13. Trends in lower heating values of MSW in cites of Japan and China. Data Source: [Fukuoka] Enterprise Outline of Fukuoka Environmental Bureau, 1998; [Other cities in Japan] Fact Book of Waste Management & Recycling in Japan, 1999; [Guangzhou] Zhao, Q.H., 1998; [Beijing] Supplied by Chinese Research Academy of Environment Science, 2000.

4.2 Determining factors and models for MSW generation

Among the 46 major cities mentioned above, only 35 cities had all the data regarded to be necessary for analysis of determining factors of MSW generation. Therefore, the factors deciding MSW generation were analyzed by using multiple-regression analysis based on data for these 35 major cities in 1995 (Urban Statistical Yearbook of China, 1996), where the per capita MSW collection rate at a major city level was destination variable, and per capita GDP, urbanization ratio, percentage of population with access to gas and annual mean temperature were extracted as explaining variables by using the stepwise selection method. The following formula for per capita MSW collection rate at a major city level was obtained.

$$Wp = 710.8\ Gp^{0.25}\ Purb^{0.43}\ Pgas^{-0.49}\ T^{-0.52} \qquad R^2=0.807 \qquad (3)$$

(2.17*)(2.69*)(2.28*)(3.78**)

(*significant at 0.05 level, **significant at 0.01 level) where Wp is per capita MSW collection rate (g/day); Gp is per capita GDP (Yuan, 1995 price, T-value=2.17). Purb is urbanization ratio (%, T-value=2.69) that is the ratio of non-agricultural population to total population of the city, Pgas is percentage of population accessing gas (%, T-value=2.28) and T is the annual mean temperature (℃, T-value=3.78). This formula indicates that per capita MSW collection rate is defined in terms of increase factors of economic levels, urbanization rates and decreased rates of climate conditions and dissemination degrees of gas usage in households.

Based on data for Shanghai during the period from 1978 to 1997 (Statistical Yearbook of Shanghai), the following formula for the per capita MSW collection rate in Shanghai was obtained by multiple-regression analysis.

$$Wp_{-sh}=10.86Gp_{-sh}^{\ 0.81}\ Pgas_{-sh}^{\ -0.37} \qquad R^2=0.984 \qquad (4)$$

(9.85**) (2.05)

(**significant at 0.01 level)

where Wp_{-sh} is per capita MSW collection rate (g/day), Gp_{-sh} is per capita real GDP index (1952=100, T-value=9.85), and $Pgas_{-sh}$ is percentage of population with access to gas (%, T-value=2.05) in Shanghai. This formula shows that the per capita MSW collection rate in Shanghai can be defined in terms of the increasing factor of economic level and the decreasing factor of degree of dissemination of gas usage in households.

4.3 Conversion of MSW Characteristics

In China, coal as a household fuel had been widely used in urban households until several years ago. During that period, inorganic materials such as coal ash and earth were the main component of MSW compared with organic materials. However, during the past several years, urban households using gas as their household fuel have increased rapidly with the further building of urban gas systems. In 1999, among 27 provinces and 4 cities under the direct control of the central government, 11 provinces and 3 cities have exceeded the value of 80% (China Statistical Yearbook, 2000). Now, in cities with high percentages of the population using gas for household fuel and heating, the share of organic materials has become higher than that of inorganic. However, in cities with low percentages of the population using gas for household use, the share of inorganic materials is relatively high; this situation is especially remarkable in northern cities because heating that consumes a lot of coal is common in the cool winter. In addition, with improvements in living standards attributing to increased income, organic waste such as kitchen garbage, paper, plastic etc has increased year by year. In other words, economic conditions are taking the place of geographic conditions to become the contributing factor of difference in per capita MSW collection rates.

To understand the pattern of change of MSW characteristics in China's cities, 35 major cities were classified by groups using cluster analysis based on six classes of data from the 35 cities, which included data for per capita MSW collection rate, 4 classes of data relating to MSW generation and data for population. Table 2 shows the analysis results and characteristics of each group. It was found that the 35 cities could be divided into four groups according to MSW characteristics. In cities in

Table 2. Classification of major cities in terms of MSW generation and related factors (1995)

Factors \ City Type	Group 1 (7 cities)	Group 2 (17 cities)	Group 3 (10 cities)	Group 4 (1 cities)	Average (35 Cities)
Per Capita MSW Collection (g/day)	1,285	778	1,340	1,753	1,068
Percentage of People with Access to Gas (%)	87	79	76	52	79
Annual Mean Temperature (°C)	18	16	8	22	15
Urbanization Rate (%)	62	34	59	76	48
Per Capita GDP (yuan/year)	15,750	8,034	7,511	80,373	11,494
Total Population (million)	6.85	6.21	3.11	0.99	5.30

Note: [Group 1] all the indices of the cities were higher than the average levels; [Group 2] the cities were at the average level in percentage of people using gas and lower level in per capita MSW collection rate, urbanization rate and per capita GDP compared with the average values; [Group 3] the cities were at lower level in annual mean temperature and percentage of people using gas for household use compared with the average values; [Group 4] cities were at lower level in percentage of people using gas and higher level in per capita MSW collection rate, annual mean temperature, urbanization rate and per capita GDP compared with the average values. Data Source: Urban Statistical Yearbook of China, 1996.

Group 1 it could be seen that economic development, concurrent urbanization, and population increases caused increases in MSW collection rates. Beijing, Tianjin, Shanghai etc belonged to this group. Cities in Group 2 were thought to be accessing to Group 1 when per capita MSW collection rates will increase with the process of future economic development and urbanization. Cities in Group 3 approached the situation of cities in the group where decreases of coal ash caused by popularization of gas usage and an increase of garbage caused by economic development existed at the same time. Urumqi, Lanzhou, and Xining are included in this group. Group 4 only has one city, Shenzhen, which is situated next to Hong Kong and is one of China's special economic zones. Because of its special economic development and urbanization pattern, Shenzhen showed different MSW characteristics compared with the other cities.

Figure 14 is a concept model drawn based on the above analysis, showing trends of the changes

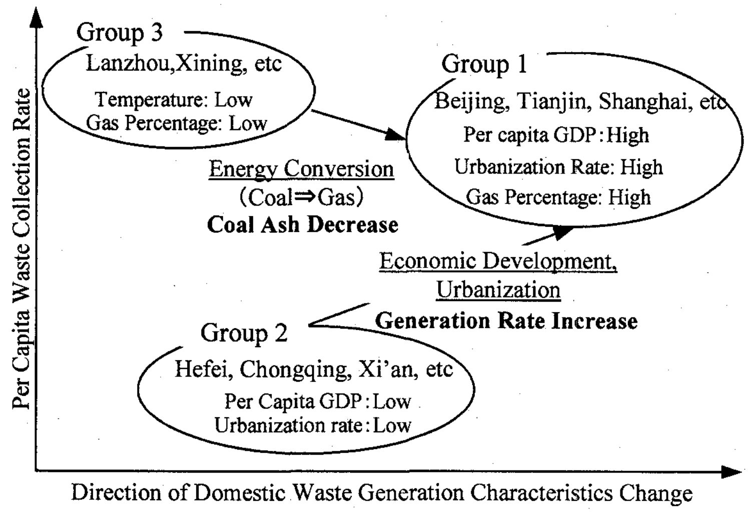

Figure 14. Model of MSW characteristic changes in cities of China

in per capita MSW collection rates and it's the relevant factors in China's cities. When Group 4 is left out, due to its special differences, the trend for Groups 2 and 3 to access to Group 1 in light of future predicted MSW characteristic changes can be seen. It can be said that the change of direction of MSW characteristics in cities of Group 1 in rapid economic development and urbanization processes will determine MSW disposal in China's cities in the future.

5. Mangement of MSW

In this section, a survey of MSW disposal systems was made concerning three aspects of MSW disposal - history, methods and expense. On this basis, the existing problems were explored.

5.1 Overview

(1) History

MSW disposal history in China can be divided into three stages. The first stage is before the middle of the 1970s when MSW generation amounts were not very great and the MSW components were relatively simple. Disposal was mainly by transferring to country areas around the city and being used for composting. The second stage is between the middle of the 1970s and the middle of the 1980s. In 1978, China carried out a reforming and opening policy and began to experience rapid processes of economic development and urbanization. With these changes, MSW generation amounts increased rapidly, and the MSW components became complicated. Due to the system of unsorted MSW collection in China's cities, collected MSW increasingly included plastic, metals etc. These changes made MSW composting disposal difficult and the quality of obtained compost degraded. In addition, the popularization of fertilizer usage decreased the need for compost.

The third stage is after the middle of the 1980s. In order to resolve the serious problems of MSW, China really began to institute MSW disposal systems in urban areas and greatly augmented investment in disposal facilities. During the period from 1979 to 1986, the total construction and maintenance expenses for urban environment and sanitation systems was about 9.3% of the total construction and maintenance expenses of cities in China. The share of construction investment to total construction and maintenance expense of urban environment and sanitation systems increased from 5.2% in 1979 to 25.6% in 1986. Beijing, now with a 6.60 million non-agricultural population, increased its MSW disposal rate from 2.0 % in 1990 to 22.1% in 1995 and 81.5% in 2000. Guangzhou, now with a 3.30 million non-agricultural population, began to build its first landfill site, and now has three landfill sites with a total disposal capacity of 4.60 million cubic meters.

(2) Method

Currently in China landfill is considered the main method, and that recovery for composting and recycling is an assistant method for MSW disposal. Incineration methods used for MSW disposal in

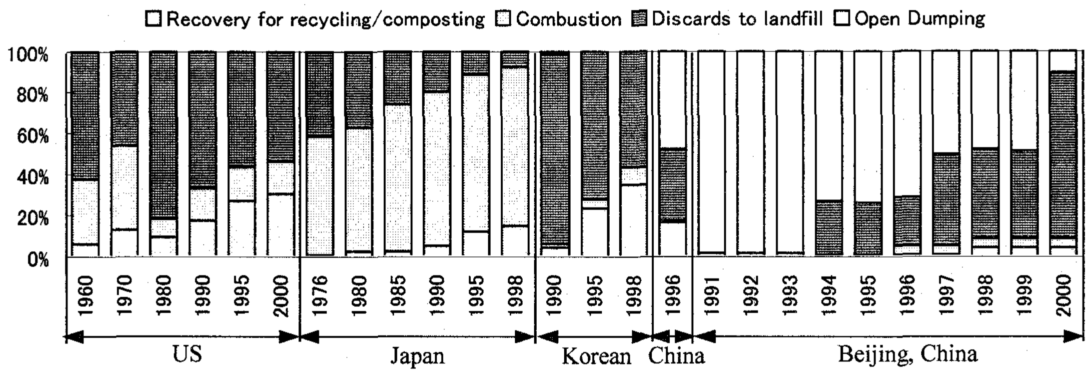

Figure 15. Trends in MSW Management in US, Japan, Korean, China and Beijing, China. Data Source: [China] Wang W. and Murase H., 1997; [Beijing, China] supplied by Municipal Administration Committee of Beijing, 2000; [Korean] Municipal Statistics of Korean, 1990 to 1998; [US] Characterization of MSW in the US, 1996; [Japan] Fact of Waste in Japan, 2000.

China are still in the research and planning stage. Figure 15 shows changes in MSW management methods by the U.S., Japan, Koran, China and Beijing City. The rapid increase in disposal rate of MSW in Beijing has been obtained mainly by landfill methods. In 2000, Beijing disposed 89.8% of its collected MSW, with 88% disposed by landfill, 7% by composting and 6% by combustion.

In the metropolitan areas of China, MSW disposal projects by combustion and recovery are being intensively planned because suitable landfill sites are become difficult to find and incineration methods become feasible for increasing heating values of MSW. Table 3 shows the MSW disposal projects in recent years of Beijing and Guangzhou. It is seen that Beijing has plans to build four combustion facilities with a total capacity of 3,600 tons per day, which is close to half of the current MSW collection rate per day (compared with a real but statistical value in 2000), and Guangzhou is planning to build 2 combustion facilities with a total capacity of 1,100 tons per day which is equal to be about 20% of the MSW collection rate per day of 1997. The Gaoantun MSW combustion and

Table 3. MSW Disposal Projects of Beijing and Guangzhou in Recent Years

City Name	Project and Disposal Capacity (ton/day)	
Beijing	Incineration Plant I	1,300
	Incineration Plant II	1,000
	Incineration Plant III	1,000
	Incineration Plant IV	300
	Waste Disposal Plant	1,000
	Reclamation and Recycling Plant I	300
	Reclamation and Recycling Plant II	500
Guangzhou	Incineration plant I	900
	Incineration Plant II	200
	Composting Plant	1,000
	Reclamation and Recycling Plant	1,000
	Reclamation and Recycling Plant	500

Data Source:[Beijing] Targets and Strategies for MSW Pollution Control in Beijing (1998 to 2002), EPA of Beijing, 1999; [Guangzhou] Chen B. L., 2000.

power generation project now building and planned to be in operation in 2002 has an investment of 84 million US Dollars.

(3) Expense

During the past decade, China greatly increased construction expenses for MSW disposal facilities. For example, China invested 1.04 billion US Dollars in 1998 and over 1.20 billion US Dollars in 1999 for new landfill construction. In Beijing, construction expenses invested in MSW disposal systems at 1995 prices were 17 million US Dollars in the five year period from 1986 to 1990, 45 million US Dollars in the five year period from 1991 to 1995, and rapidly increased to 133 million US Dollars in the five year period from 1996 to 2000.

In China, capital sources for construction of MSW disposal facilities changed from single to multiple sources with the increasing need for construction expenses. For example, before 1990, all construction capital for MSW disposal systems in Beijing came from the central government budget. But, among the 131 million US Dollars of construction expenses during the period from 1990 to 2000, 80% was from local government sources, 17% from gratuitous financial aid of foreign governments (Germany, 39 million marks) and 3% from loan from the World Bank (4.50 million dollars). As to operation expenses, the Environmental Sanitary Agency of Beijing, responsible for MSW and human waste treatment, spent 60 million US Dollars in 1999, of which about one third was personnel cost. Under the current situation of the MSW disposal systems mainly adopting landfill, cost of MSW collection, transportation and disposal is about 9.6~12 US Dollars per metric ton. It is notable that over half of the cost is for MSW transportation.

5.2 Problems

(1) Collapse of Resource Waste Recovery Systems

In China, recovery systems for resource waste have existed for a long time and had been effectively operated over a relatively long time. Waste recovery stations widely located in residential districts successfully recovered resource wastes such as paper, books, glass, cloth and metals by using a purchasing method. Whereas, accompanying speedy economic development, the recovery price for resource waste went down respective to the economic growth, that is to say, the incentive for sorting to recycle resource waste was reduced. As a result, the recovery system of resource wastes declined. For example, the historic maximum number of waste recovery stations in Shanghai reached about 5,000, but in 1998 the number was down to about 100. For now, a more effective recovery system for resource wastes that could replace the existing systems has not been formed. This fact not only decreases resource waste recovery but also directly increases pressure on landfills due to the increased amounts of garbage and the complicated garbage composition.

Moreover, as population migrating from the countryside increase and publicly owned recovery systems for resource wastes decline, the numbers of scavengers rise in urban areas. It might be considered that this disorderly collection may increase the pollution risks from hazardous wastes.

(2) Diversification of MSW

With the enhancement of living standards, MSW composition in China has become diversified. As analyzed in 4.1, garbage composition was simple before, composting was effective for MSW disposal; however, under the current conditions of unsorted garbage collection, composting has become difficult due to the interfusing of various unsuitable materials.

Furthermore, there is no suitable system for waste electric appliances. Figure 16 shows the trend in the numbers of electric appliance owned per 100 urban households from 1985 to 1999. Urban households owned 112 color television sets, 91 refrigerators and 78 washing machines per 100 households on average in 1999. It can be predicted that problems from electric appliance waste will become serious with the increasing discard of electric appliances in the near future. As to waste batteries, there is a similar problem of a lack of a suitable disposal system. In order to resolve current and potential dangerous waste problems, it is necessary to push ahead with disposal systems for waste electric appliances and batteries as soon as possible.

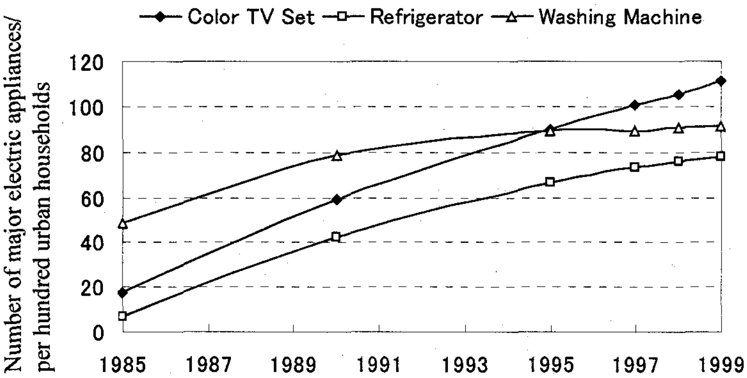

Figure 16. Trends in number of major electric appliances year-end owned by per 100 urban households. Data Source: China Statistical Yearbook, 2000.

In addition, with the rapid urbanization process and urban building, construction waste has become an important problem. In 1997, Shanghai produced 4.54 million tons of domestic waste and 3.01 million tons of construction waste. Because both domestic and construction waste were discarded in the same landfills, the duration of usage of landfills has been greatly shortened.

(3) Difficulty in Collection of Waste Disposal Charges

In Beijing, urban residents are charged two types of waste disposal fees. One is a sanitation charge of 2 yuan/month (about 0.24 US Dollar) per person, which is used for the salaries of workers collecting garbage. Another is a waste disposal charge, which began from Sept.1, 1999. For different objects the charge is different. Table 4 shows details of these two types of charges.

Nevertheless, MSW disposal charge collections have really only been executed in 6 of the 18 districts and counties of Beijing until Aug. 2000. During a period of one year from Sept. 1999 to

Table 4. MSW disposal charges in Beijing (2000)

Name of Charge	Object	Price
Sanitary Charge	Urban Households	2 yuan/month/person (about 0.24 USD)
Garbage Diposal Charge	Resident Population	3 yuan/month/household (about 0.36 USD)
	Nomadic Population (staying over half a year)	2 yuan/month/person (about 0.24 USD)
	Employers*	25 yuan/ton (about 3.01 USD)

Data Source: provided by Municipal Administration Committee of Beijing, 2000. Note: 1USD=8.3 yuan

Aug.2000, only 0.7 million US Dollars, about one twentieth of the expected MSW disposal charges, was collected.

Two problems are considered to exist in garbage disposal charge collection. One is that actual addresses of residents are different from their registered addresses, which makes charge collection difficult. Another is that a portion of residents refuse to pay the MSW disposal charge. The reasons for the later phenomena are complicated; a relatively high rate of the garbage disposal charge to income, resistance toward assuming a burden of the garbage disposal costs and difficulties in payment due to increases of unemployment and so on could be considered to some of the reasons.

6. Summary

In this paper, the characteristics of municipal solid waste in China were analyzed at the three levels of national, provincial and major city. Especially, factors deciding MSW generation rates were analyzed and models for MSW collection rates developed by multiple regression analysis. Moreover, 35 major cities were classified in terms of MSW characteristics and related social, economic and geographic conditions. A concept model for cities' MSW characteristic changes was examined and MSW disposal systems were investigated in respect to MSW disposal history, management, expenses and existing problems.

In the future, a study on the predicted future needs of MSW disposal considering MSW amounts and quality is expected. In detail, it will include the possibility of MSW disposal changing towards combustion based on MSW heating value predictions and needs prediction of combustion and landfill facilities based on MSW collection rate predictions. Besides this, it will also be necessary to clarify the need for the establishment of waste electric appliance policies by predicting the generation rates for electric appliance waste. In addition, as MSW disposal needs in the future are predicted and the gap between need and supply of current disposal facilities is clarified, it will become necessary to predict the greater needs for the necessary capital and resources, and to anticipate strategies for fundraising mechanisms and an early transition to a recycling society.

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