Environmental Science and Pollution Research (2018) 25:10115–10125
https://doi.org/10.1007/s11356-017-1154-0

RESEARCH ARTICLE

The spatio-temporal dynamic pattern of rural domestic solid waste discharge of China and its challenges

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Received: 12 April 2017 / Accepted: 26 December 2017 / Published online: 30 January 2018
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Abstract

At present, construction of rural domestic waste treatment facilities is seriously lagging, and in many cases, treatment facilities do not yet exist in some villages of China. Serious rural waste pollution has not only impacted the quality of surface water and groundwater but also the atmosphere and the living environment of farmers of China. There are relatively few studies of rural domestic waste pollution, especially with respect to the spatio-temporal dynamic pattern of rural domestic waste discharge. Using survey data and income per capita, we calculated rural domestic waste discharge per capita per day. From this, we calculated provincial rural domestic waste discharge. According to our study, rural domestic waste discharge was 1.42×10^8 t/year in 2000. This number increased to 2.3×10^8 t/year in 2006 and to 2.47×10^8 t/year in 2010. Rural domestic waste increased dramatically while the actual rural population and the proportion of the rural population declined. When examining the eight regions, the rural domestic waste discharge of northeastern China, Qinghai-Tibet, middle China, and southwestern China had increased dramatically, while that of northern China, southern China, and eastern China increased relatively slowly. The economies of northern China, southern China, and eastern China are more developed; their rural domestic waste discharge has been high since 2000 and has continued to increase slowly. In northeastern China, Qinghai-Tibet, middle China, and southwestern China, rural domestic waste discharge was low in 2000; however, in the ten-year period from 2000 to 2010, their rural domestic waste discharge increased dramatically.

Keywords Rural China · Rural domestic solid waste discharge · Spatio-temporal dynamic pattern

Introduction

With rapid economic development, production and living standard have changed quickly and the capacity of the rural environment to self-purify has been seriously compromised. Furthermore, the Chinese government has focused more attention on industrial and urban pollution than on rural pollution (Fan et al. 2010; Geng et al. 2007; Wu and Du 2001; Wu et al. 2006). Most rural solid domestic waste has been heaped or dumped (Shi 2013; Wei et al. 2007). In the eastern developed regions, domestic pollution has become a major source of non-point source pollution, surpassing industrial pollution (Ding and Lai 2011; Li et al. 2003; Yao et al. 2009; Zhao et al. 2010).

Rural domestic solid waste is waste that is produced in rural areas from daily life or through the services necessary for daily life activities, including food waste, kitchen waste, livestock manure and other organic matter, cinder, tiles, and other solid wastes (Bian and Zhao 2005). Rural domestic waste discharge has increased with the development of the rural economy and the improvement of rural standards (Ehrlich and Holdren 1971; Fodha and Zaghdoud 2010; Grossman and Krueger 1994; Liu et al. 2015). Domestic solid waste pollution has become a serious concern due to the notable lack of rural living garbage treatment facilities.

With the development of urbanization, the rural population of China decreased from 8.08×10^8 to 6.71×10^8 from 2000 to

Responsible editor: Philippe Garrigues

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2010 (NBS 2001, 2011). Along with the development of the rural economy in China, the living standards of farmers are continually improving. Rural domestic solid waste in China has grown rapidly; in fact, its growth rate is greater than that of urban residents. It is estimated that total solid waste discharge was 1.42×10^8 t by 2000 (Li and Xu 2007). The total discharge of rural domestic solid waste was 2.34×10^8 t in 2010 (Huang et al. 2012), increasing by 67.1% over the ten-year period from 2000 to 2010; however, the solid waste discharge of urban residents has increased from 1.14×10^8 to 1.57×10^8 t (an increase of 37.7%) (Huang et al. 2012). This is notable because domestic solid waste from rural residents has increased more rapidly than that of urban residents.

The growth rate of rural domestic waste discharge is impacted by the per capita income growth rate of the farmers (Bruyn 2000; Dinda 2004). Due to lack of environmental awareness, substandard infrastructure, and the dispersed distribution of rural residents, pollution in rural areas is more serious than before (Liu et al. 2008; Lu et al. 2015; Mazzanti and Zoboli 2009). Therefore, there would be great benefits to improving the rural living environment and the quality of life within rural areas.

In 2015, the central government proposed "Guiding Opinions on Comprehensively Promoting Rural Garbage Treatment"; they suggested that to build a better society by 2020, the living environment of more than 90% of rural villages should be effectively governed. Because rural settlements are small and dispersed (Tian et al. 2007, 2012), these changes would increase the cost of rural solid domestic waste treatment. In turn, the central government hoped to gain a better understanding of the spatial and temporal dynamic patterns of rural domestic waste discharge from the previous ten years to make effective planning decisions.

The objectives of this study are as follows: (1) to examine the temporal dynamics of rural solid domestic waste discharge in China from 2000 to 2010; (2) to map the spatial patterns of the rural solid domestic waste discharge of every province, central municipality, and autonomous region; and (3) to compare rural domestic waste discharge per capita per day between the different regions.

Methodology

Kitchen waste was the major source of domestic solid waste (He et al. 2010; Gu et al. 2008; Li et al. 2012). In each region with different economic and development levels, rural domestic waste discharge per capita differed. The living standards and consumption models were different in each of the regions. China can be divided into northeastern China (Heilongjiang, Jilin, and Liaoning), northern China (Beijing, Tianjin, Hebei, Henan, Shandong, Shanxi, and Inner Mongolia), eastern China (Shanghai, Jiangsu, Zhejiang, and Anhui), middle China (Hubei, Hunan, and Jiangxi), southern China (Fujian, Guangdong, Guangxi, and Hainan), northwestern China (Shaaxi, Ningxia, Gansu, and Xinjiang), southwestern China (Yunnan, Guizhou, Sichuan, and Chongqing), and Qinghai-Tibet (Qinghai and Tibet) (Fig. 1). We studied the rural domestic waste discharge per capita in these different regions.

Data on rural domestic solid waste discharge was collected from relevant literature. We calculated rural domestic solid waste discharge for the years 2000, 2006, and 2010.

Rural domestic solid waste discharge in 2000

In 2000, it is estimated the rural domestic solid waste discharge reached 1.42×10^8 t (Li and Xu 2007). Rural domestic solid waste discharge was 0.48 kg per person in one day (Li et al. 2012). We used 0.48 kg per person in one day as the mean value of rural domestic solid waste discharge in China for the year 2000. The income per capita is correlated positively with rural domestic solid waste (Huang et al. 2012; Liu et al. 2005). Because per capita income has a great impact on rural domestic solid waste, rural income per capita was used to calibrate the figures for rural domestic solid waste for the different provinces. We can get the equations as follows:

$$NRDSW_{\mathrm{pi}} = NRDSW/\mathrm{NI} \tag{1}$$

where $\mathrm{NRDSW_{pi}}$ is the national rural domestic solid waste per person in one day per income, NRDSW is the national rural domestic solid waste per person in one day, and NI is the national per capita income.

$$PRDWS_{\mathrm{pi}} = NRDSW_{\mathrm{pi}} \times \mathrm{PI} \tag{2}$$

where $\mathrm{PRDWS_{pi}}$ is the provincial rural domestic solid waste per capita in one day per income and PI is the provincial income per rural capita.

$$PRDWS = PRDWS_{\mathrm{pi}} \times \mathrm{PR} \times 365 \tag{3}$$

where PRDWS is the total provincial rural domestic solid waste discharge and PR is the provincial rural population.

Rural domestic solid waste discharge in 2006

Rural domestic waste discharge was 0.86 kg per person in one day, based on data obtained from China's drinking water and sanitation status quo survey from 31 provinces in 2006 (Yao et al. 2009). According to the survey, rural domestic waste discharge was 0.96, 0.88, 0.77, and 0.81 kg per person in one day in eastern China, middle China, western China, and northeastern China. For this survey, China was divided into eastern China, middle China, western China, and northeastern China (we had not studied Taiwan, Hong Kong, and Macau in this paper). Eastern China included Beijing, Tianjin, Hebei,

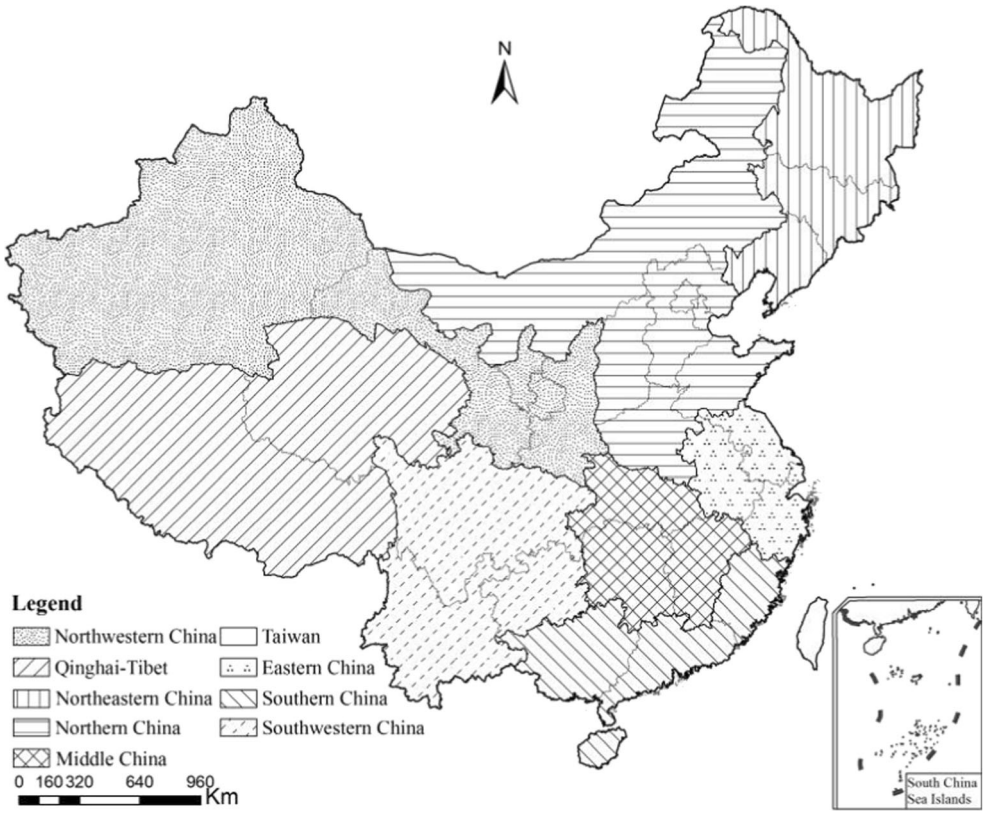

Fig. 1 The regionalization of China

Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan. Middle China included Shanxi, Henan, Hubei, Hunan, Anhui, and Jiangxi. Western China included Inner Mongolia, Ningxia, Shaanxi, Chongqing, Guizhou, Guangxi, Yunnan, Gansu, Qinghai, Sichuan, Xinjiang, and Tibet. Northeastern China included Liaoning, Jilin, and Heilongjiang. From the data, we found that rural domestic waste discharge per capita per day in eastern China was greater than those in middle and western China.

First, we obtained survey data on rural domestic waste discharge per capita per day from eastern China, middle China, western China, and northeastern China. We then calculated the regional rural domestic solid waste per capita in one day per income using Eq. (4). If the individual province belonged to the region in question, the regional rural domestic solid waste per income would be represented by provincial rural domestic waste discharge. We calculated the provincial rural domestic solid waste per capita in one day using Eq. (5) and the total provincial rural domestic waste discharge using Eq. (3).

$$RRDSW_{\mathrm{pi}} = RRDSW/\mathrm{RI} \tag{4}$$

where $\mathrm{RRDSW_{pi}}$ is the regional rural domestic solid waste per capita in one day per income, RRDSW is the regional rural domestic solid waste per capita in one day, and RI is the regional per capita income.

$$PRDWS_{\mathrm{pi}} = RRDSW_{\mathrm{pi}} \times \mathrm{PI} \tag{5}$$

where $\mathrm{PRDWS_{pi}}$ is the provincial rural domestic solid waste per capita per day and PI is the provincial income per rural capita.

Rural domestic solid waste discharge in 2010

There are two major studies that investigated rural domestic waste discharge per capita in one day in China in 2010. Huang et al. (2012) surveyed 123 villages in seven provinces (Beijing, Jilin, Hebei, Zhejiang, Anhui, and Yunnan). Daily discharge of rural domestic waste per capita was 0.95 kg, based on data obtained from seven provinces (Huang et al. 2012). Li et al. (2012) obtained 1118 survey responses from farmers in six provinces (Jilin, Hebei, Anhui, Zhejiang, Sichuan, and Yunnan). Rural domestic solid waste discharge per capita was 1.07 kg based on 1118 sampled households in six provinces in 2010 (Li et al. 2012). Of note is the fact that rural domestic waste has increased dramatically over this ten-year span.

Using data from the two surveys, we calculated the rural domestic waste discharge per capita in one day for every province. For Beijing, data were available from Huang's survey only. For Hebei, Jilin, Anhui, Zhejiang, Sichuan, and Yunnan, data were available from both Huang and Li's

surveys. We used mean data from the two surveys. For the regions without survey data, we used regional rural domestic waste discharge to represent provincial rural domestic waste discharge. First, we calculated regional rural domestic solid waste per income using Eq. (4). We then calculated the provincial rural domestic solid waste per capita using Eq. (5). Lastly, we calculated the total provincial rural domestic solid waste discharge using Eq. (3).

Results and analysis

Rural domestic waste discharge in China from 2000 to 2010

We calculated the rural domestic waste discharge in China from 2000 to 2010. Over these ten years, rural domestic waste discharge increased dramatically (Table 1, Fig. 2). In 2000, rural domestic waste discharge was 1.42×10^8 t/year; this increased to 2.3×10^8 t/year by 2006 and to 2.47×10^8 t/year by 2010 (Table 1). Hence, rural domestic waste discharge increased dramatically by 1.05×10^8 t/year over the ten-year period. However, the rural population decreased from 8.08×10^8 to 6.71×10^8 over the same ten years (Fig. 2). The rural population accounted for 63.91% of the national population in 2000 and decreased to 50.32% of the national population in 2010. Although the rural population had declined steadily, rural domestic waste discharge in China still increased by 7.4% each year.

Rural domestic waste discharge increased over the ten-year period from 2000 to 2010 but not in a linear manner. From 2000 to 2006, rural domestic waste discharge increased by 8.8×10^7 t and accounted for 83.8% of the ten-year increment (Table 1, Fig. 2); for six years, rural domestic waste increased dramatically. From 2006 to 2010, rural domestic waste increased by 1.7×10^7 t and accounted for 16.2% of the ten-year increment (Table 1, Fig. 2). By the way, rural domestic waste discharge increased slowly over the last four years of this decade.

Regional differences in waste discharge in China from 2000 to 2010

With a large area and great regional disparity, there are big differences in rural domestic waste discharge in China. From 2000 to 2010, rural domestic waste discharge in northeastern China showed the most dramatic increase (144.3%), due to the living habits of the rural people in this region (Tables 2, 3, and 4, Fig. 3). Qinghai-Tibet, middle China, and southwestern China also showed sharp increases in their discharge of 129.3, 86.1, and 77.4%, respectively. However, northern China (45.7%), southern China (27.3%), and eastern China (19.5%) showed more gradual discharge increases over the same time period.

The rural domestic waste discharge of Qinghai-Tibet, middle China, and southwestern China increased dramatically because per capita income of the rural population remained low. Rural domestic waste discharge in Beijing, Jiangsu, and Zhejiang declined. Their rural domestic waste discharge was high in 2000, but over the following ten years, the rural population moved to the cities and townships and, in turn, the rural population declined. As a result, rural domestic waste discharge has declined.

From 2000 to 2006, rural domestic discharge was concentrated in southwestern China, with this region accounting for 19.4% of the national rural domestic discharge; this was attributed to its rapidly developing economy and its large rural population. Qinghai-Tibet's discharge increased the least over the same time period, accounting for only 0.9% of the national rural domestic discharge due to the region's low economic development and small rural population.

Table 1 The rural domestic waste discharge per capita per day of China in 2000–2010

Years	The net income of the farmers per capita in China (Yuan/year)	The rural domestic waste discharge per capita per day in China (kg/person·day)	National rural population ($\times 10^8$)	The rural domestic waste discharge ($\times 10^8$ t/year)
2000	2253	0.48	8.08	1.42
2001	2366	0.53	7.96	1.55
2002	2476	0.59	7.82	1.70
2003	2622	0.66	7.69	1.86
2004	2936	0.74	7.57	2.04
2005	3255	0.82	7.45	2.23
2006	3587	0.86	7.32	2.30
2007	4140	0.89	7.15	2.32
2008	4761	0.92	7.04	2.37
2009	5153	0.95	6.89	2.40
2010	5919	1.01	6.71	2.47

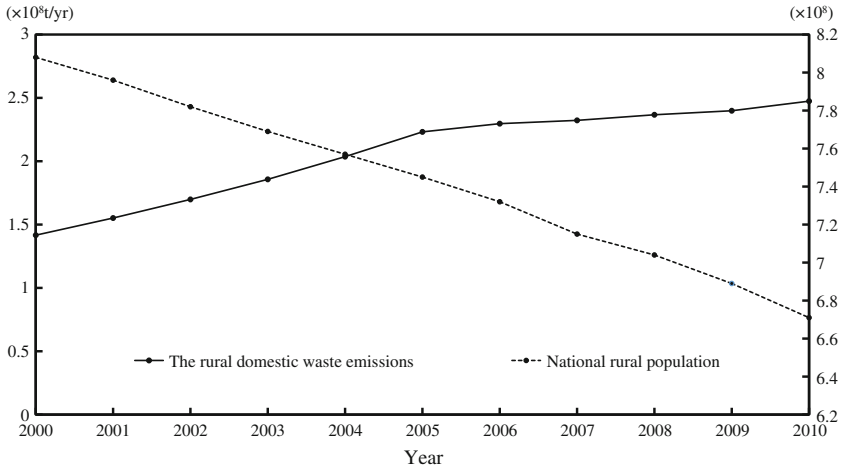

Fig. 2 The rural population and domestic waste discharge in China

From 2006 to 2010, rural domestic discharge was concentrated in northeastern China. Rural domestic discharge in northeastern China accounted for 39.3% of the total rural domestic discharge in China due to the improvement in living standards and fuel use in the winter. However, rural domestic discharge declined in southwestern China; discharge started out high, but then declined from 2006 to 2010 (Tables 3 and 4).

Table 2 The rural domestic waste discharge of every province in 2000

Region	Urban population ($\times 10^8$)	Rural population ($\times 10^8$)	The net income of the farmers per capita (Yuan/year)	The rural domestic waste discharge per capita per day (kg/(person·day))	The rural domestic waste discharge (t/year)
National total	4.59	8.08	2253	0.48	1.42×10^8
Beijing	0.11	0.03	4605	0.98	1.11×10^6
Tianjin	0.07	0.03	3622	0.77	7.89×10^5
Hebei	0.18	0.50	2479	0.53	9.61×10^6
Shanxi	0.12	0.21	1906	0.41	3.18×10^6
Inner Mongolia	0.10	0.13	2038	0.43	2.16×10^6
Liaoning	0.23	0.19	2356	0.50	3.55×10^6
Jilin	0.14	0.14	2023	0.43	2.16×10^6
Heilongjiang	0.19	0.18	2148	0.46	2.99×10^6
Shanghai	0.15	0.02	5596	1.19	8.53×10^5
Jiangsu	0.31	0.44	3595	0.77	1.22×10^7
Zhejiang	0.23	0.24	4254	0.91	7.94×10^6
Anhui	0.17	0.43	1935	0.41	6.50×10^6
Fujian	0.14	0.20	3230	0.69	5.09×10^6
Jiangxi	0.11	0.30	2135	0.45	4.97×10^6
Shandong	0.35	0.56	2659	0.57	1.16×10^7
Henan	0.21	0.71	1986	0.42	1.10×10^7
Hubei	0.24	0.36	2269	0.48	6.36×10^6
Hunan	0.19	0.45	2197	0.47	7.73×10^6
Guangdong	0.48	0.39	3654	0.78	1.10×10^7
Guangxi	0.13	0.32	1865	0.40	4.68×10^6
Hainan	0.03	0.05	2182	0.46	7.99×10^5
Chongqing	0.10	0.21	1892	0.40	3.04×10^6
Sichuan	0.22	0.61	1904	0.41	9.04×10^6
Guizhou	0.08	0.27	1374	0.29	2.87×10^6
Yunnan	0.10	0.33	1479	0.31	3.78×10^6
Tibet	0.01	0.02	1331	0.28	2.19×10^5
Shanxi	0.12	0.24	1444	0.31	2.74×10^6
Gansu	0.06	0.19	1429	0.30	2.16×10^6
Qinghai	0.02	0.03	1490	0.32	3.92×10^5
Ningxia	0.02	0.04	1724	0.37	5.09×10^5
Xinjiang	0.07	0.13	1618	0.34	1.60×10^6

Table 3 The rural domestic waste discharge of every province in 2006

Region	Urban population ($\times 0^8$)	Rural population ($\times 10^8$)	The per capita net income of the farmers in China (Yuan/year)	The rural domestic waste discharge per capita per day (kg/person·day)	The rural domestic waste discharge (t/year)
National total	5.83	7.32	3587	0.86	2.30×10^8
Beijing	0.13	0.02	8275	1.37	1.24×10^6
Tianjin	0.08	0.03	6228	1.03	9.80×10^5
Hebei	0.27	0.42	3802	0.63	9.73×10^6
Shanxi	0.15	0.19	3181	0.85	5.99×10^6
Inner Mongolia	0.12	0.12	3342	1.00	4.49×10^6
Liaoning	0.25	0.18	4090	0.88	6.63×10^6
Jilin	0.14	0.13	3641	0.78	5.67×10^6
Heilongjiang	0.20	0.18	3552	0.77	4.96×10^6
Shanghai	0.16	0.02	9139	1.51	1.13×10^6
Jiangsu	0.39	0.36	5813	0.96	1.27×10^7
Zhejiang	0.28	0.22	7335	1.21	9.58×10^6
Anhui	0.23	0.38	2969	0.80	1.12×10^7
Fujian	0.17	0.19	4835	0.80	5.39×10^6
Jiangxi	0.17	0.27	3460	0.93	9.02×10^6
Shandong	0.43	0.50	4368	0.72	1.32×10^7
Henan	0.31	0.63	3261	0.87	2.03×10^7
Hubei	0.25	0.32	3419	0.92	1.07×10^7
Hunan	0.25	0.39	3390	0.91	1.29×10^7
Guangdong	0.59	0.34	5080	0.84	1.05×10^7
Guangxi	0.16	0.31	2770	0.83	9.32×10^6
Hainan	0.04	0.05	3256	0.54	8.85×10^5
Chongqing	0.13	0.15	2874	0.86	4.69×10^6
Sichuan	0.28	0.54	3002	0.90	1.76×10^7
Guizhou	0.10	0.27	1985	0.59	5.90×10^6
Yunnan	0.14	0.31	2250	0.67	7.65×10^6
Tibet	0.01	0.02	2435	0.73	5.37×10^5
Shanxi	0.15	0.23	2260	0.68	5.61×10^6
Gansu	0.08	0.18	2134	0.64	4.18×10^6
Qinghai	0.02	0.03	2358	0.71	8.57×10^5
Ningxia	0.03	0.03	2760	0.83	1.04×10^6
Xinjiang	0.08	0.13	2737	0.82	3.80×10^6

From 2000 to 2010, rural domestic discharge in northern China, middle China, southwestern China, northeastern China, southern China, eastern China, northwestern China, and Qinghai-Tibet accounted for 17.1, 15.5, 13.7, 11.9, 5.6, 5.0, 4.9, and 0.7%, respectively, of national rural domestic discharge. Northern China produced the largest proportion of rural domestic discharge with the largest population.

Regional differences in waste discharge per capita in one day in China from 2000 to 2010

Nationally, rural domestic waste discharge was 0.48 kg per person in one day in 2000. However, discharge increased to 0.86 kg per person in one day by 2006. Moreover, it increased to 1.01 kg per person in one day by 2010 (Table 1). Over these ten years, rural domestic waste discharge per capita per day increased dramatically.

Additionally, over this time period, the net income of farmers per capita in China increased dramatically. In 2000, the net income of farmers per capita in China was 2253 Yuan/annum (NBS 2001). It increased to 3587 Yuan/year in 2006 and 5919 Yuan/year in 2010 (NBS 2007, 2011) (Table 1). Net farmer income per capita increased by 9.75% between 2000 and 2006. However, it increased by 13.34% between 2006 and 2010. This increase in income stimulated an increase in rural domestic waste discharge.

Among the eight regions, rural domestic waste discharge per capita per day increased the most in northeastern China 0.79 kg per person in one day over the ten years studied (Fig. 4). Demand for fuel was higher, and more household garbage was produced in this region (Li et al. 2012). Therefore, rural domestic waste discharge per capita per day in northeastern China showed the most dramatic increase. Rural domestic waste discharge per capita per day in southern China increased the least (0.29 kg per person in

Table 4 The rural domestic waste discharge of every province in 2010

Region	Urban population ($\times 10^8$)	Rural population ($\times 10^8$)	The per capita net income of the farmers in China (Yuan/year)	The rural domestic waste discharge per capita per day (kg/person·day)	The rural domestic waste discharge (t/year)
National total	6.70	6.71	5919	1.01	2.47×10^8
Beijing	0.17	0.03	1 3262	1.46	1.47×10^6
Tianjin	0.10	0.03	1 0075	1.33	1.30×10^6
Hebei	0.32	0.40	5958	1.09	1.58×10^7
Shanxi	0.17	0.19	4736	0.63	4.25×10^6
Inner Mongolia	0.14	0.11	5530	0.73	2.94×10^6
Liaoning	0.27	0.17	6908	1.34	8.11×10^6
Jilin	0.15	0.13	6237	1.21	5.66×10^6
Heilongjiang	0.21	0.17	6211	1.20	7.48×10^6
Shanghai	0.21	0.02	1 3978	1.63	1.47×10^6
Jiangsu	0.48	0.31	9118	1.07	1.22×10^7
Zhejiang	0.34	0.21	1 1303	1.01	7.67×10^6
Anhui	0.26	0.34	5285	0.94	1.16×10^7
Fujian	0.21	0.16	7427	1.03	5.94×10^6
Jiangxi	0.20	0.25	5789	1.08	9.82×10^6
Shandong	0.48	0.48	6990	0.93	1.63×10^7
Henan	0.36	0.58	5524	0.73	1.54×10^7
Hubei	0.28	0.29	5832	1.09	1.14×10^7
Hunan	0.28	0.37	5622	1.05	1.42×10^7
Guangdong	0.69	0.35	7890	1.09	1.41 × 107
Guangxi	0.18	0.28	4543	0.63	6.35×10^6
Hainan	0.04	0.04	5275	0.73	1.16×10^6
Chongqing	0.15	0.14	5277	0.94	4.63×10^6
Sichuan	0.32	0.48	5087	0.88	1.55×10^7
Guizhou	0.12	0.23	3472	0.62	5.18×10^6
Yunnan	0.16	0.30	3952	0.73	7.95×10^6
Tibet	0.01	0.02	4139	0.73	6.22×10^5
Shanxi	0.17	0.20	4105	0.65	4.79×10^6
Gansu	0.09	0.16	3425	0.54	3.23×10^6
Qinghai	0.03	0.03	3863	0.69	7.79×10^5
Ningxia	0.03	0.03	4675	0.74	8.89×10^6
Xinjiang	0.09	0.12	4643	0.73	3.33×10^6

one day). Rural domestic waste discharge per capita per day in middle China, southwestern China, Qinghai-Tibet, northern China, eastern China, and northwestern China increased by 0.6, 0.44, 0.41, 0.48, 0.34, and 0.33 kg per person in one day, respectively (Fig. 4).

Rural domestic waste discharge per capita per day was dramatically different for each of the 31 provinces. Over the ten-year period, rural domestic waste discharge per capita per day in the Liaoning province increased the most (0.84 kg per person in one day) (Tables 2, 3, and 4, Fig. 4). Discharge in the Zhejiang province showed only a gradual increase (0.1 kg per person in one day) (Fig. 4). Because the living habits and energy structure of the two regions vary, rural domestic waste discharge per capita per day was dramatically different as well.

From 2000 to 2006, rural domestic waste discharge per capita per day in Inner Mongolia, Sichuan, Xinjiang, Jiangxi, Ningxia, and Chongqing increased by more than 0.46 kg per person in one day (Tables 2 and 3, Fig. 4). In these regions, economic development was rapid and living standards improved; as a result, rural domestic waste discharge grew. However, rural domestic waste discharge per capita per day in Guangdong increased by only 0.06 kg per person in one day, which was the lowest increase of all these regions.

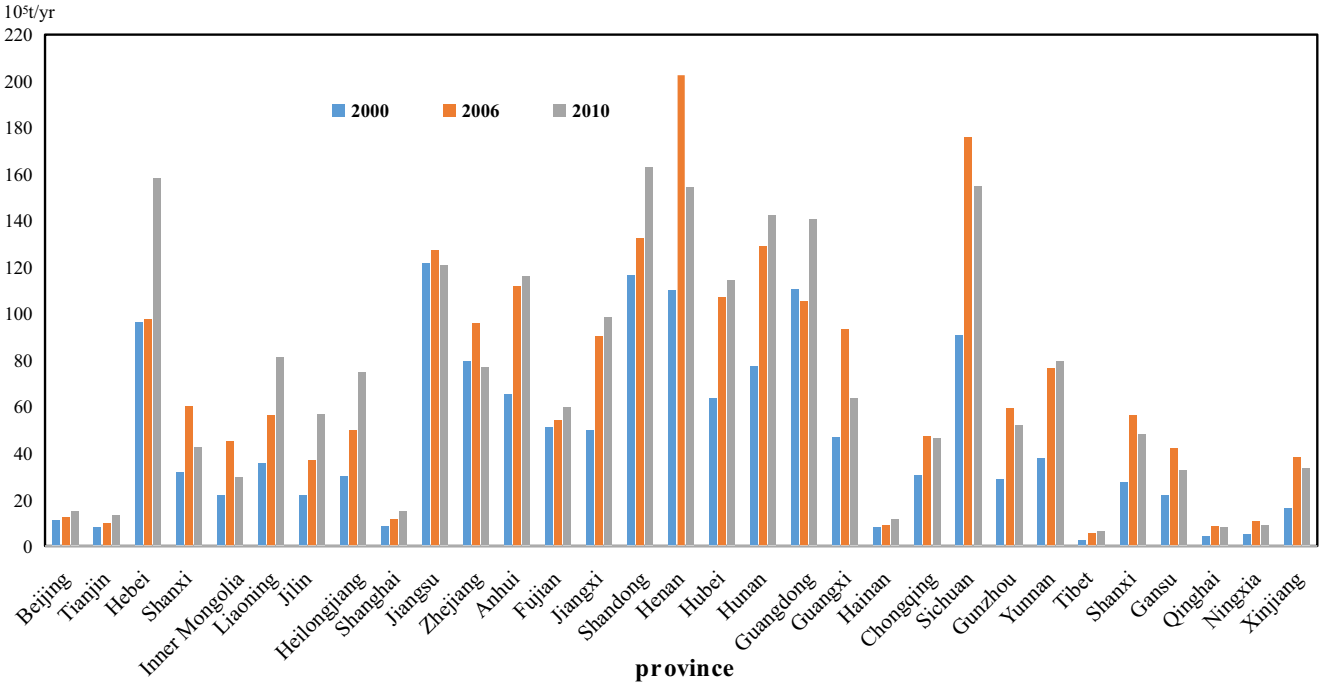

Fig. 3 The rural domestic waste discharge in China

Rural domestic waste discharge per capita per day in Guangdong had been high in 2000 and remained comparatively stable for the following six years.

From 2006 to 2010, rural domestic waste discharge per capita per day in Liaoning, Hebei, Heilongjiang, and Jilin had increased by more than 0.43 kg per person in one day (Tables 3 and 4). The rural people of northeastern China were producing more domestic waste in households due to the energy structure in this region (Li et al. 2012). Rural domestic waste discharge per capita per day in Liaoning was the highest over those four years. The rural people of Inner Mongolia, Shanxi, Zhejiang, Guangxi, Henan, Gansu, Ningxia, Xinjiang, Shaanxi, Qinghai, and Sichuan decreased their rural domestic waste discharge.

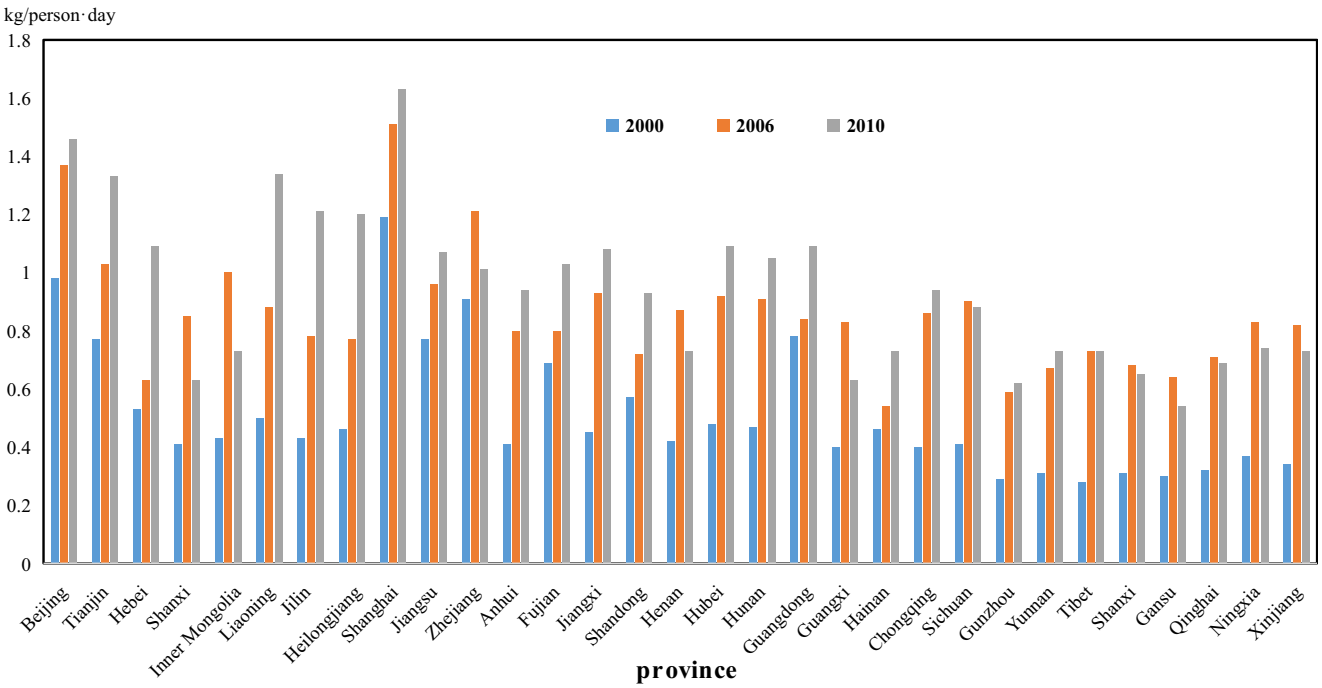

Fig. 4 The rural domestic waste discharge per capita per day in China

Rural domestic waste discharge was impacted by economic development. As economic conditions improved, especially in the early stages of economic development, the consumption capacity of farmers grew, which resulted in greater waste discharge. At a certain level, however, waste discharge actually decreased with further economic growth.

Discussion

There is no national and provincial data of rural solid waste discharge in China owing to the previous neglection. Most studies were based on the small-scale survey. There was few deep studies on the relationship between rural solid waste discharge and the social and economic development.

It calculated the rural solid waste discharge for the national and provincial scale in 2000–2010 using the survey studies (Li and Xu 2007; Li et al. 2012; Yao et al. 2009; Huang et al. 2012). For 2000, it used the estimation of total rural domestic solid waste discharge and rural domestic solid waste discharge per capita per day by Li and Xu (2007). For 2006, it used the survey data of rural domestic solid waste discharge per capita per day of the four regions (Yao et al. 2009). For 2010, it used two survey data to calculate the provincial rural domestic solid waste (Huang et al. 2012; Li et al. 2012).

The results showed that rural domestic waste discharge in China increased dramatically from 2000 to 2010. Discharge is likely to continue to increase at an annual rate of 10% (Huang et al. 2012; Li and Xu 2007). However, there is wide variability in the growth rates among these provinces over the different time periods.

Rural domestic waste is mainly composed of kitchen waste, waste paper, waste plastics, waste batteries, broken pottery, porcelain, glass, and other daily use articles (Li 2014). Li et al. (2012) confirmed that kitchen waste was the major component of household waste in the Zhejiang, Jilin, Anhui, Hebei, Sichuan, and Yunnan provinces. In general, the rhizomes and peels of fruits, vegetables, and aquatic products are more likely to form kitchen waste rather than grain and meat products (Li et al. 2012). The data in this study showed that higher rural domestic waste discharge appeared in relatively developed rural areas where farmers could acquire higher income per capita. Fruits and vegetables are considered an important food source for people in these regions due to their higher living standard. Hence, their rural domestic waste discharge was affected by their improved living standards.

The environmental Kuznets curve (EKC), put forth by Kuznets in 1955, best represents this phenomenon (Kuznets 1955). The EKC hypothesis postulates that an inverted "U"-shaped relationship exists between different environmental contaminants and per capita income, and after reaching a peak, the curve declines (Dinda 2004). According to the theory, rural domestic waste discharge is impacted by economic development. As economic conditions improve, the consumption capacity of farmers grows, which results in higher waste discharge. But at a certain level, waste discharge actually decreases with further economic growth. From 2000 to 2010, this trend was visible in the developed areas we examined, such as the Zhejiang province. Rural domestic waste discharge increased rapidly from 2000 to 2006, but slowly from 2006 to 2010. At present, this region is approaching the peak of the EKC and rural domestic waste discharge may decrease in the future. Therefore, the data presented in this study are in line with previous reports and research on this topic (Bruyn 2000; Dinda 2004; Kuznets 1955; Li et al. 2012).

Rural domestic waste discharge of the eight regions increased from 2000 to 2006. Rural domestic waste discharge in northeastern China, Qinghai-Tibet, middle China, and northern China increased, while those in southwestern China, northwestern China, and eastern China decreased from 2006 to 2010. These regions showed negative growth from 2006 to 2010. Based on the EKC hypothesis, rural domestic waste discharge will decline when economic development reaches a certain level. However, southwestern China and northwestern China have not yet reached sufficiently high levels of economic development.

Although the ratio of the rural population has declined over the past few years, rural domestic waste discharge is still increasing. Besides improving their environmental awareness, farmers and local governments have several important roles in improving the rural environment. Local governments should improve regulatory frameworks for rural waste management and establish more waste recycling points. There are obvious regional characteristics of rural domestic waste discharge in China. If China is divided into northern and southern regions, traditionally by the Qinling and Huai Rivers, the daily discharge of household garbage per capita in the northern provinces is 1.28 kg while those in the southern provinces are 0.72 kg (Li and Xu 2007). When making waste management decisions, different measures should be used for different regions. The rural environment can be ameliorated effectively at the same time as the economics of these regions grows, if waste is managed effectively.

According to the "Guiding Opinions on Comprehensively Promoting Rural Garbage Treatment" published in 2015, rural livestock and poultry manure should be utilized as a resource. The crop straw comprehensive utilization rate is expected to exceed 85%. The plastic recycling rate should reach more than 80%. The disposal and utilization rate of industrial hazardous waste should reach 95%. By the objective, more than 90% of villages' domestic waste should be effectively disposed. However, only 36% of the rural domestic waste discharge had been disposed in 2013 according to the ministry of housing and urban-rural development of China. Therefore, rural solid waste should be collected in villages, transported to towns, and processed in the county townships. Moreover,

rural villages should have facilities, equipment, modern technologies, cleaning teams, and long-term effective financial support and supervisory systems in place.

Conclusion

Based on the spatio-temporal dynamic patterns of rural domestic solid waste discharge in China, we put forward three conclusions:

(1) National rural domestic waste discharge in China has increased from 2000 to 2010. Over the first six years, rural domestic waste discharge increased dramatically. Over the last four years, it increased more slowly.
(2) In the eight regions of China, rural domestic waste discharge in northeastern China, Qinghai-Tibet, middle China, and southwestern China showed the most dramatic increase, while those in northern China, southern China, and eastern China increased relatively slowly. Economic development in northern China, southern China, and eastern China was greater and their rural domestic waste discharge was high in 2000. From that point on, their rural domestic waste discharge increased slowly. However, for northeastern China, Qinghai-Tibet, middle China, and southwestern China, their rural domestic waste discharge was low in 2000; going forward, their rural domestic waste discharge increased dramatically over the ten-year period.
(3) Rural domestic waste discharge per capita per day in northeastern China, middle China, southwestern China, and Qinghai-Tibet increased dramatically while that of northern China, eastern China, and northwestern China increased relatively slowly.

Using survey data and income data, we calculated rural domestic waste discharge per person in one day for every province, municipality, and autonomous region. We explored the spatio-temporal pattern of rural domestic waste discharge in China. This will benefit future environmental protection policy development. Rural domestic waste discharge should be a greater focus for the central government and for local governments. With increased urbanization, more rural people will move to the townships and cities. However, 6.03×10^8 people currently live in rural villages in 2015 (NBS 2016). Rural villages should, therefore, add the facilities and equipment needed to manage waste effectively in these regions.

Funding information This research was funded by the National Basic Research Program of China (Grant 2015CB953602), National Social Science Fund of China (Grant 17BGL256), and Crossing-discipline Open Grounds, School of Government, Beijing Normal University. The results, discussion, and conclusions of this paper do not necessarily represent the views of the funding agencies.

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