Impact assessment of human diet changes with rapid urbanization on regional nitrogen and phosphorus flows—a case study of the megacity Shanghai

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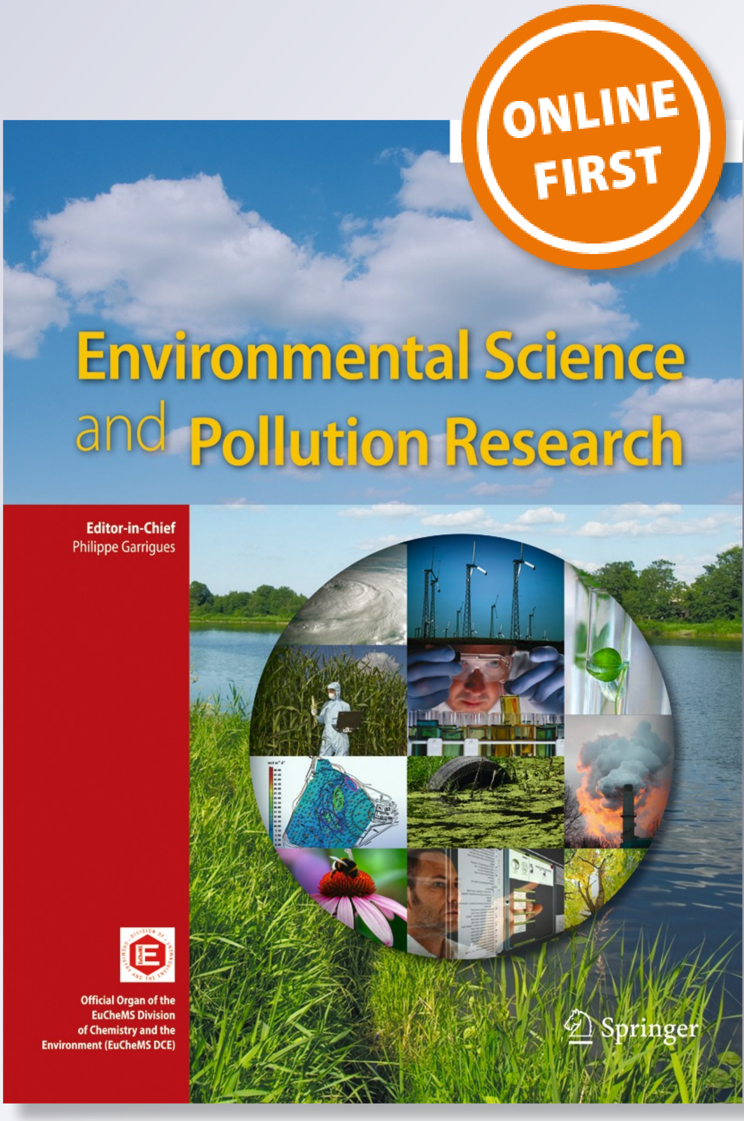

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RESEARCH ARTICLE

Impact assessment of human diet changes with rapid urbanization on regional nitrogen and phosphorus flows—a case study of the megacity Shanghai

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Abstract Regional material flows are strongly influenced by human diets. To diagnose and prevent environmental problems that threaten urban sustainability, the impact of human diet changes with rapid urbanization on the regional nitrogen (N) and phosphorus (P) flows were quantitatively evaluated. A survey of day-to-day activities was conducted of 450 individuals surveyed (adults over 18 years old) in three representative areas (the central district, the new district, and the suburban/rural areas) of Shanghai, a megacity which has attracted worldwide attention. The lifestyle (eating habits, domestic sanitation, drainage facilities, etc.) pattern was determined and the potential N and P loads from human diets on the environment were calculated. The daily potential nitrogen and phosphorus loads from human diets was 19.36 g-N, 1.80 g-P in the central district, 16.48 g-N, 1.52 g-P in the new district, and 13.04 g-N, 1.20 g-P in the suburban/rural areas of Shanghai. Respondents in all three areas, especially those in the suburban/rural areas reported a preference for increasing the intake of animal-derived as well as processed foods, which means that the potential N and P load from human diets to the environment will increase further. In addition, most respondents consider industrial wastewater discharge as the main cause of eutrophication of waterbodies, though in recent years water pollution caused by domestic wastewater has increased rapidly, but this has received much less attention. Environment-friendly eating habits and improvements in the environmental awareness will be required.

Keywords Urbanization · Human diet · Nitrogen and phosphorus flow · Water environment · Shanghai · Megacity

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Introduction

Nitrogen (N) and phosphorus (P) are essential elements in life activities, which are usually regarded as restricting factors in plant growth. Liebig found three indispensable elements (nitrogen, phosphoric acid, and potassium) for plant growth in 1841 and the Haber-Bosch process was developed in 1914, enabling changes in crop fertilizer production to inorganic from organic matter. Due to the wide use of synthetic nitrogen and phosphorus fertilizers, which are generally made by chemically fixing atmospheric nitrogen and processing rock phosphate, the global food production has increased dramatically, and the world population has also grown rapidly. However, more than half of the nitrogen and phosphorus in fertilizers flows into the environment, and this has caused many environmental problems, such as accelerated eutrophication of rivers, lakes, wetlands, reservoirs, and oceans, nitrate pollution of groundwater, greenhouse effects, changes to the biogeochemical cycle in ecosystems, loss of habitat, changes in biodiversity, and so on. Scientists from 28 countries identified nine planetary boundaries (such as climate change, ocean acidification, stratospheric ozone, global freshwater use, etc.) within what humanity may continue living safely, and which were published by Nature in 2009 (Rockström et al. 2009). According to that paper, humanity

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has already transgressed three planetary boundaries: for climate change, rate of biodiversity loss, and changes to the global nitrogen cycle, especially the biogeochemical nitrogen cycle; nitrogen, which reached the safety limits (35 million t $year^{-1}$) in the early 1970s and which is now exceeded by more than four times. As these factors are interdependent, transgressing one may both shift the position of other boundaries and cause them to be violated. Further, according to the global model, Asia has become to a hotspot (heavy environmental load) due to its increases in reactive nitrogen (Galloway et al. 2008).

Although Asia has more than 60 % of the population of the world, there are only 36 % of cultivated land and water resources, supporting the lives with few resources (FAOSTAT 2013). In addition, due to rapid economic growth, urbanization, and globalization, social systems in Asia have changed significantly since the late of 20th century, and the human dietary changes is shown to be shifting toward a diet dominated by higher intakes of animal and partially hydrogenated fats and lower intakes of fiber (Popkin 2006). In particular, China has about 20 % of the world population but only 7 % of cultivated land, here diet changes may cause food problems and effect material cycles at the regional and the global scale. For example, with the high economic growth in the late 1970s, the human diet changed from grain-derived foods to animal-derived food. The consumption of beef, dairy products, aquatic products, and marine products increased exponentially in China (FAOSTAT 2013). Due to the increases in animal-derived foods, nitrogen and phosphorus discharged from human excreta increased, and this may increase the nitrogen and phosphorus load drained through sewers into waterbodies. Meat product consumption increases result in increases in grain feed production and livestock waste, and the nitrogen and phosphorus load discharged into waterbodies increases. In addition, nitrogen and phosphorus transferred through food and grain imports and exports and via water and atmosphere cycles has a widespread impact. Many studies have been carried out from nutrition and heath viewpoints (e.g., Popkin 2006), but few studies from the relationship between humans and nature and material cycling viewpoints. In recent years, the Twin Cities Household Ecosystem Project started a project to quantify fluxes of carbon, nitrogen, and phosphorus at the scale of individual households in the Minneapolis–Saint Paul metropolitan area in Minnesota, USA (Fissore et al. 2011). And the authors, based on a day-to-day activities survey, have quantified and clarified the impact of human activities (human diet, sanitation, and farming methods, etc.) on the nitrogen flow in six typical ecosystems in China in 2006 (Liu et al. 2008, 2009, 2012: a northern metropolis agro-ecosystem, a southern metropolis agro-ecosystem, an oasis agro-ecosystem in the temperate continental desertification zone of Northwest China, an irrigation agro-ecosystem in the northern Huang-Huai River plain, a decentralized paddy agro-ecosystem, and a concentrated paddy agro-ecosystem in the Changjiang river basin), but we have not so far looked at the phosphorus flow in the research.

China's rate of urbanization, meanwhile increased from 10.6 % in 1949 to 46.59 % in 2009. And the number of areas designated as cities increased from 132 in 1949 to 655 in 2009, and it is forecast that there will be 50 % in 2020, and 75 % in 2050 of the population living in cities. The rapid urbanization is causing pressure on the environment and that is becoming an important factor in environmental issues in China. Therefore, it is a compelling need to gain a better understanding of how activities in urban areas affect the fluxes of major elements such as nitrogen and phosphorus (Kaye et al. 2005, Grimm et al. 2008).

As the first step to achieve this, we chose the megacity Shanghai as a case study. We quantitatively evaluated the impact of human diet changes on the regional nitrogen (N) and phosphorus (P) flows to diagnose and describe environmental problems that threaten urban sustainability with the rapid urbanization.

Methods

Content of the questionnaire and interview survey

A field survey (including a questionnaire and interview) of day-to-day activities was conducted to establish the parameters (consumption of N and P per capita, potential N and P load from human waste to the soil and water, etc.) for the regional nitrogen and phosphorus balance model, since no reliable statistical data could be obtained about food consumption situation/changes and the discharge routes of waste in urban or rural areas from existing statistical data.

The field survey was conducted in the Shanghai central district, the new district (The Pudong new downtown since large-scale development, 1992) and the suburban/rural areas from October 2009 to March 2010, with the cooperation of the East China Normal University in Shanghai. The locations of the investigation are as follows: Central district (including the Huangpu, Luwan, Xuhui, Changning, Jingan, Putuo, Zhabei, Hongkou, and Yangpu districts); New district (Pudongxinqu districts); Suburban/rural areas (including the Minhang, Baoshan, Jiading, Jinshan, Songjiang, Qingpu, Fengqian, and Chongming districts), which showed in Fig. 1. In order to make survey results representative, samples were chosen randomly in each location. For a 95 % confidence level and a 10 % margin of error (or confidence interval), the minimum sample size is estimated to be 97 (Hamburg 1985). Also considering the response rate, we selected 150 samples (adults over 18 years old) at each location (450 in total). All of the responses were obtained by personal interviews conducted by previously trained investigators.

The questionnaire consisted of four parts. The first part was for basic information about the respondents, such as sex, age, height, weight, occupation, income, type of household registration (agricultural or non-agricultural), and educational level. The second part included the current state and future preferences related to diets. In this part, food products were

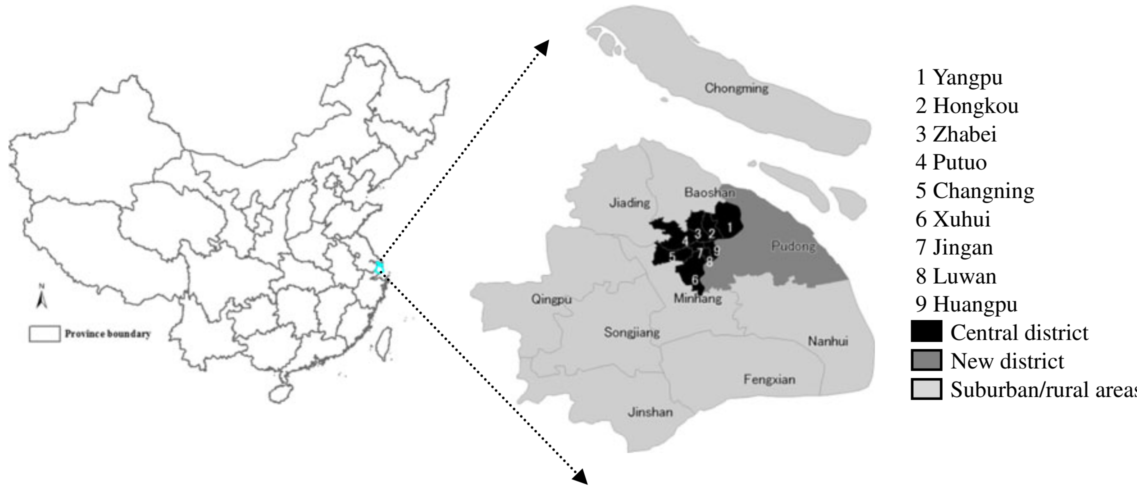

Fig. 1 Study area

categorized into 47 items in 9 groups according to the China Food Composition Database (Yang 2004), and the respondents were asked to fill in a form recalling what and how much they had eaten in the last 24 h (breakfast, lunch, and dinner). The third part comprised questions pertaining to human waste disposal. These questions included the specifications of the home toilet facilities, sewage situation, and discharge routes. The fourth part was about the understanding of the respondents as to the main causes of the eutrophication of local lakes and rivers.

The 24-h dietary recall method used in this study is an established dietary evaluation method for determining actual food intake, which is often used in national health and nutrition surveys and in ongoing national food consumption and individual food intake research studies in the USA (see Briefel 1994; Guenther 1994). This method has several shortcomings: one such is its dependence on respondent short-term memory or diets not representative of the typical daily intake. However, if the focus of a study is on average values of identified groups, then the 24-h dietary recall method is arguably sufficient (National Research Council 1986). In the current study, the survey method was improved by distributing the questionnaires from Sunday to Saturday (with average numbers on each day) to cover the differences in food intake on week days and weekends. Also, experienced and trained field-workers were chosen and recruited for administering the questionnaire to increase the accuracy of the survey data.

Interviews for the rate of process and removal of N and P had been done by visiting centralized treatment facilities for urban areas and distributed processing facilities for rural areas.

Data analysis

The database is built based on statistics and survey data. Based on the database, the main analysis consists of the N and P intake from food per capita per day, the N and P load from human waste to rivers and soil, and the consumption trends. The N and P quantities in the food estimated according to the China Food Composition Database (Yang 2004) was added to the database. In addition, the N and P load induced by the human diet in Shanghai city was assessed by integrating population and wastewater treatment rates.

Results and discussion

Attributes of respondents

The questionnaire response rate was over 90 % (Table 1) as the responses were obtained by personal interview. The proportion of women in Shanghai central district was about 52 %, but 65 % in the new town and suburban/rural areas. This arises from the reason that women often answered questions for the whole family when the field-worker visited the family. Characteristics of the respondents are listed in Table 2. The average age of all the respondents was 40 years in the Shanghai central district, 37 years in the new district, 48 years in the suburban/rural areas, and a statistically significant difference was observed ($p<0.05$). About the education level, the rates of “college graduate or higher” in the central district and the new district were highest, and the rate of “middle school graduation” in the suburban/rural areas was highest. Based on the responses, the main type of family was a three person family in all three areas. The annual income of households was 42,600 Chinese yuan in the central district, 38,400 Chinese yuan in the new district, and 24,000 Chinese

Table 1 Response rate of questionnaire survey

	Central district	New district	Suburban/rural area
Investigation	150	150	150
Respondent	140	140	135
Valid respondent	120	120	124

Table 2 Characteristics of the respondents

		Central district	New district	Suburban/ rural area
Sex	Male	58	41	44
	Female	62	79	80
Age (years)	18–29	19	40	14
	30–39	50	45	17
	40–49	39	26	45
	50–59	11	6	32
	≥60	1	3	16
Household registration	Rural residents	7	20	116
	Non-rural residents	111	96	8
Education level	Elementary school	0	11	18
	Middle school	7	24	74
	High school	24	23	19
	College and higher	89	60	4
	Others	0	0	9
Household members (persons)	1	7	5	2
	2	22	19	24
	3	61	64	66
	4	13	14	16
	5	12	16	15
	≥ 6	3	2	1
Household income per year (Chinese yuan)	<10,000	1	0	30
	10,000–20,000	9	11	36
	20,000–50,000	13	37	39
	50,000–100,000	32	27	17
	≥100,000	65	43	2

yuan in the suburban/rural areas with a statistically significant difference ($p<0.05$).

The daily calorie, nitrogen, and phosphorus intake from each food item

The daily calorie, nitrogen, and phosphorus intake from each food is shown in Table 3 as follows. Energy intake per capita per day is 2,582 kcal in the central district, 2,316 kcal in the new district, and 2,121 kcal in the suburban/rural areas. Nitrogen intake is 19.36 g in the central district, 16.48 g in the new district, and 13.04 g in the suburban/rural areas. Phosphorus intake is 1.80 g in the central district, 1.52 g in the new district, and 1.20 g in the suburban/rural areas. In all three areas, most of the energy intake comes from grain, 41, 44, and 57 % in the central district, the new district, and the suburban/rural areas, respectively. Second largest energy source is meat, 21, 21, and 17 % in the three areas. For the nitrogen, intake most comes from meat: in the central and the new district, more than 25 %, and from grain 22–23 % in both the central and new districts. While, the intake from grain is the highest in the suburban/rural area, 33 %, here 19 % is from meat. Nitrogen intake from fish is about 20 % in Shanghai while the China average is only 10 %. Although the nitrogen intake from beans is the fourth in all the food, intake from "dougan", a bean processed product, is very high in the central and new districts while intake from soybeans is the highest in the suburban/rural areas. For phosphorus, the intake ranking by decreasing order is grain (24 %), meat (18 %), fishery (17 %), and bean products (13 %) in the central district, grain (25 %), meat (19 %), fishery (18 %), and dairy product (8 %) in the new district, and grain (31 %), bean products (16 %), fishery (15 %), the meat (14 %) in the suburban/rural areas.

Respondents in urban areas like the central and new districts show a higher intake of meats, eggs, fish, fruit vegetables, and other luxury foods, like meat and its processed products, dairy food, fish, and cakes, desert, and less intake of traditional foods like grain and soybeans. And the diets in urban areas have more diversity than diets in suburban/rural areas.

Table 4 shows the mean values and the confidence intervals of the energy, nitrogen, and phosphorus intakes from foods in Shanghai city, with respect to sex, age, and household annual income. The t test was used for gender, and

Table 3 The daily amount of energy, nitrogen, and phosphorus from each food in Shanghai regions

		Crops	Meats	Eggs	Fish	Legumes	Milk	Tubers and starches	Vegetables and fruits	Others	Total	Confidence interval (confidence level: 95 %)	
												Lower	Upper
Energy (kcal person^{-1} day^{-1})	A	1070	532	53	178	150	97	110	121	271	2582	2445	2720
	B	1024	489	57	155	82	121	70	104	214	2316	2120	2524
	C	1216	366	30	115	145	19	39	87	104	2121	1963	2215
N (g person^{-1} day^{-1})	A	4.33	5.10	0.74	3.94	2.51	0.77	0.16	0.65	1.16	19.36	18.1	20.7
	B	3.80	4.44	0.80	3.43	1.37	1.01	0.11	0.52	1.00	16.48	14.6	18.4
	C	4.26	2.48	0.40	2.55	2.31	0.14	0.05	0.57	0.28	13.04	11.5	13.5
P (g person^{-1} day^{-1})	A	0.43	0.33	0.07	0.30	0.23	0.12	0.02	0.20	0.10	1.80	1.69	1.91
	B	0.37	0.28	0.08	0.27	0.12	0.16	0.02	0.14	0.08	1.52	1.32	1.73
	C	0.40	0.17	0.04	0.18	0.20	0.02	0.01	0.15	0.03	1.20	1.07	1.24

A Central district; *B* new district; *C* suburban/rural area

ANOVA was used for age and household annual income to test for statistically significant differences among groups (with 5 % as the significance level). There was a significant difference between males and females with respect to energy and nitrogen, and among age groups and household annual income groups with respect to energy, nitrogen, and phosphorus. As for the age, the most amount of energy intake is the group of 40–49 years old, and the most amount of nitrogen and phosphorus intake is the group of 30–39 years old. In addition, as for the household annual income, the most amount of energy intake is the group of 50–100 thousand Chinese yuan and the most amount of nitrogen and phosphorus intake is the group of equal to or more than 100 thousand Chinese yuan.

According to the Japan Eating Intake Standard (edition 2010, HP of Ministry of Health, Labour and Welfare 2013), the requirements for energy, protein (about 6.25 times that of nitrogen), and phosphorus for ages 30–49, is 2,650 kcal/day, 60 g/day, 1,000 mg/day for males and 2,000 kcal/day, 50 g/day, 900 mg/day for females, respectively. The intake of nitrogen and phosphorus per capita in Shanghai city is far above the standard, even twice that in the central and new districts.

Estimation of the potential nitrogen and phosphorus loads from human waste to rivers and soil

With regard to the nitrogen and phosphorus metabolism in healthy adults under standardized metabolic conditions, the amount of nitrogen and phosphorus consumed is equal to that discharged (FAO/WHO/UNU 1985). Thus, if we ignore the intra-annual variations, the amount of nitrogen and phosphorus estimated to be released annually into the environment as human waste is approximately 7.07 kg-N /per capita/per year,

Table 4 The mean value and the confidence interval (confidence level: 95 %) of the energy, nitrogen and phosphorus intakes from foods in Shanghai city, with respect to sex, age, and household annual income

		Energy (kcal person^{-1} day^{-1})	N (g person^{-1} day^{-1})	P (g person^{-1} day^{-1})
Sex	Male	2,646 (2,498–2,794)	17.6(16.1–19.0)	1.60(1.47–1.73)
	Female	2,139 (2,023–2,256)	15.4(14.3–16.6)	1.44(1.31–1.55)
Age (years)	18–29	2,148 (1,853–2,443)	15.3(12.5–18.2)	1.43(1.08–1.77)
	30–39	2,392 (2,221–2,564)	17.3(15.6–18.9)	1.59(1.44–1.74)
	40–49	2,461 (2,309–2,613)	17.0(15.6–18.4)	1.57(1.44–1.70)
	50–59	2,319 (2,115–2,523)	15.2(13.4–17.0)	1.38(1.24–1.52)
	≥60	1,860 (1,559–2,161)	10.5(8.25–12.8)	1.03(0.80–1.26)
Household income (Chinese yuan year^{-1})	<10,000	2,027 (1,716–2,338)	11.7(9.30–14.2)	1.14(0.92–1.35)
	10,000–20,000	2,066 (1,878–2,255)	13.5(11.9–15.1)	1.27(1.12–1.43)
	20,000–50,000	2,410 (2,216–2,603)	16.3(14.4–18.3)	1.48(1.31–1.64)
	50,000–100,000	2,440 (2,259–2,621)	16.9(15.2–18.7)	1.59(1.42–1.76)
	≥100,000	2,407 (2,216–2,597)	17.9(16.2–19.6)	1.64(1.44–1.83)

6.01 kg-N /per capita/per year, and 4.75 kg-N /per capita/per year for nitrogen; and 0.65 kg-P /per capita/per year, 0.56 kg-P /per capita/per year, and 0.44 kg-P /per capita/per year for phosphorus in the central district, the new district, and in the suburban/rural areas, respectively.

The results of field survey in each area investigating the state of home toilets (Fig. 2), and discharge routes for human waste (Fig. 3) revealed that flushing toilets were common in all areas. And instead of being used as fertilizer, most of the human waste is flushed away by the drainage since the urban drainage system was common in the central built-up and new district. Over 70 % of human waste is used as fertilizer in the suburban/rural areas, about 20 % is treated by small-scale distributed sewage-treatment facilities.

The human waste stored in "septic tanks" and "manure storage" as well as the residue of "biomass toilets" is returned to the soil as fertilizer; while that discharged into "direct drainage" and "sewage" runs into waterbodies (ponds, rivers, and oceans) eventually. From this, we have defined the human waste that is collected in "septic tanks", "manure storage" and the residue of "biomass toilets" as "returned to the soil", and that discharged into "direct drainage" and "sewage" as "discharged into rivers". According to the result of the discharge route of human waste survey, the rate of human waste "returned to the soil" is 5, 1, 73 % in the central district, the new district, and the suburban/rural areas, and the rate of "discharged into rivers" is 95, 99, 27 % in these areas, respectively.

According to the interview results of centralized and distributed sewage-treatment facilities in Shanghai, the removal ratio of nitrogen and of phosphorus is 50 and 80 % in the distributed septic tanks, and 60 and 70 % in the centralized septic tanks. This is quite a high level in China, though improvements are still needed to prevent eutrophication of waterbodies.

In addition, according to the Shanghai statistical yearbook, among the 1.92×10^7 permanent residents in Shanghai, there are 6.53×10^6 residents in the central district, 4.19×10^6 residents in the new district, and 8.49×10^6 in the suburban/rural area. With the assumption that the central area and new district uses centralized sewage treatment while the rural area uses distributed sewage treatment, the amount of nitrogen and phosphorus discharged from household diets is 2,308 t-N, 214 t-P discharged to soil, and 19,620 t-N, 1,501 t-P discharged to waterbodies in the central area; 252 t-N, 23 t-P discharged to soil, and 9,063 t-N, 627 t-P discharged to waterbodies in the new district; 29,532 t-N, 2,707 t-P discharged to soil, and 6,473 t-N, 512 t-P discharged to waterbodies in the rural areas. Thus, the total amount of nitrogen and phosphorus discharged to soil is 3.21×10^4 t-N, 2.94×10^3 t-P, and to waterbodies it is 3.52×10^4 t-N, 2.64×10^3 t-P.

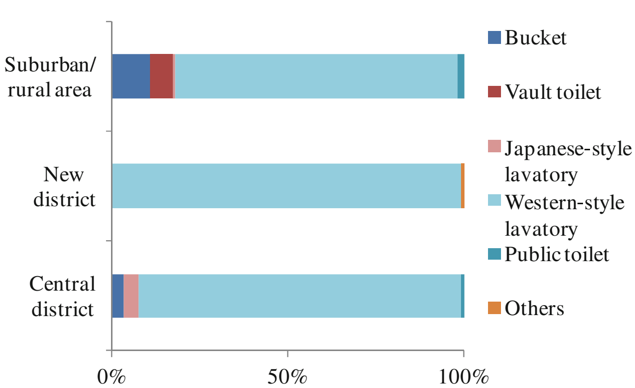

Fig. 2 State of home toilets

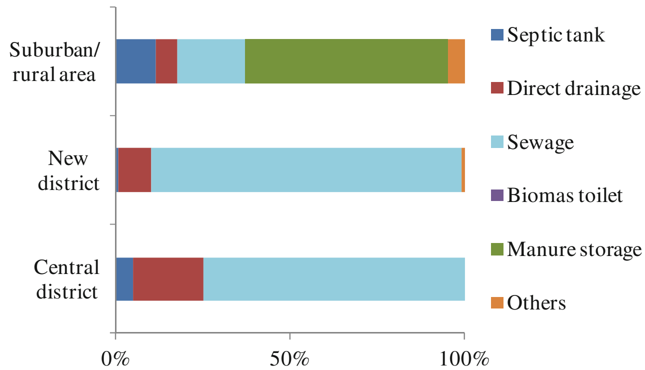

Fig. 3 Discharge routes for human waste

It should be noted that the amounts of nitrogen and phosphorus loads calculated here are the potential amounts from human excrement that are discharged directly into the environment, without considering excrement storage, denitrification during transfer, and dumping in rivers, deposition, and volatilization. Since the start of heavy use of chemical fertilizers in the 1980s, nitrogen and phosphorus in the soil is probably close to saturation. Therefore, it is possible that most of the organic fertilizer will be discharged into rivers from the soil through leaching and runoff. According to the interviews, 50 % of the waste (excess sludge) in sewage-treatment plants will be incinerated after dehydration, while what is left will be placed in landfills. The excess sludge left is organic, which contains lots of nitrogen and phosphorus. Thus, there is a high risk of secondary pollution from the landfill sites. Since this situation is very complex, we did not consider it in this study.

Main changes in food intake in 1980–2010

Based on the collected statistical data from the Shanghai Statistical Yearbook of main foods purchased per capita in general households in the years 1980–2010 (the eight classifications include cereals, meats, eggs, fish, vegetables, fruits, milk, and oils), we analyzed the changes in household diets (see Fig. 4) in rural and urban areas of Shanghai. It must be noted that the data is the amount of purchased food, which

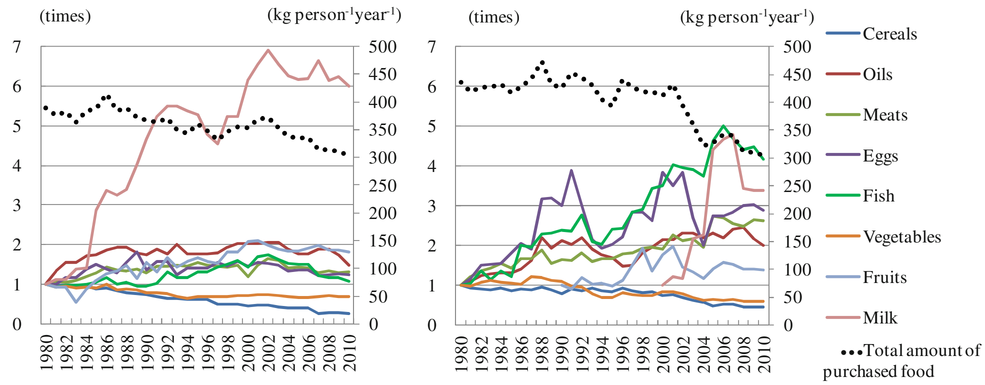

Fig. 4 Changes of purchased foods in general households in urban and rural areas of Shanghai in the years 1980–2010. The *left graph* is for urban areas and right graph is for rural areas; the *left vertical axis* is the ratio (purchased food in each year/ purchased food in 1980), and the *right vertical axis* is the total amount of purchased food

is consumed directly, not including processed foods, such as bread and eating out. It is not the total food intake per capita, but represents the state of household food consumption.

In the urban area, the total food consumed per capita was 390 kg in 1980, reached a peak at 414 kg in 1986, then decreased gradually, and became 304 kg in 2010. In rural areas, it was 436 kg in 1980, reached a peak at 453 kg in 1991, decreased gradually thereafter, and in 2010 it became to 305 kg. It was found that the amount of grain purchased in rural areas was far larger than in urban areas, whereas the amount of fruits purchased in urban areas was far larger than in rural areas. Oils, meats, eggs, and fish purchases in rural areas are lower than in urban areas in 1980, however, it reached almost the same level as in urban areas around 2010. Moreover, the consumption of cereals and vegetables, which account for a large part of the diet in rural areas continued to decline. For urban areas, the cereal consumption declined greatly from 149 kg in 1980 to 40 kg in 2010; vegetables consumption from 146 kg in 1980 to 103 in 2010. In rural areas, the cereal consumption declined from 303 kg in 1980 to 136 kg in 2010; vegetables from 109 kg in 1980 to 65 kg in 2010. While oils, fruits, meats, eggs, and milk tended to increase. Especially milk consumption, in urban areas has increased more than seven-fold during 1980–2000, while in rural areas it has increased by about five times since the beginning of the 21st century. However, there were no further increases since a series of infant fatalities occurred from a large amount of milk powder mixed with toxic substances called melamine. The consumption of oils, meats, eggs, fish, and fruits increased until the early 2000s, and then decreased, maintaining a relatively stable state. However, compared with a modest change in urban areas, the change that occurred in rural areas was significant, particularly for fish, eggs, and meats, which have increased by more than twice.

The structure of household diets in Shanghai, especially in rural areas, has diversified from being centered on cereals and vegetables. In addition, the proportion of food that contains animal protein, such as meats, eggs, fish, and milk increased from 14 % in 1980 to 29 % 2010 in urban areas; while it increased from 5 % in 1980 % to 22 % in 2010 in rural areas.

From the obtained data from the questionnaire and interviews carried out on daily life, it is clear that the eating habits of Shanghai's residents have changed significantly in both quantity and quality. People surveyed in the Shanghai central district and the new district consumed more kinds of food, but less traditional food, such as rice, soybeans, and fresh vegetables than people in rural areas, while the consumption of newly introduced items, such as bread for the breakfast, noodles for lunch (approximately equal to the consumption of rice),meat (chicken or beef), yogurt and milk (consumed little before), cheese (almost all imported), processed meat, bean products, luxury seafood (shrimps, crab, shellfish etc.), cakes, dessert, alcohol, and drinks were higher than that in the rural areas. Further, "Breakfast has changed to 'bread&ham&milk' from the previous 'pickles&porridge'" answered in the question of dietary changes in the interviews; and more kinds of processed foods, drinks, and fruits were consumed as side dishes for lunch and dinner compared with the pork, bean products, pickle, and Chinese cabbage before. Moreover, the volume of household food consumption decreased since 2000 in both urban and rural areas as shown in Fig. 4. According to the obtained data, the causes for this reduction can be considered as the development of the food processing industry and expansion of the catering industry, and an increase in eating out (especially lunch) for urban areas; while for rural areas, it is mainly due to the spread of modern agriculture causing reductions in labor needed, thus a reduced food intake.

Therefore, due to the rapid growth of urbanization in Shanghai, the diet has changed from a traditional staple food centered diet to more side dishes and animal protein food, and it has progressed to "diversification", "westernization", "up-grading", and "simplification".

Future consumption trends

Figure 5 shows the survey results of consumption trends for the future in the central district, the new district, and the

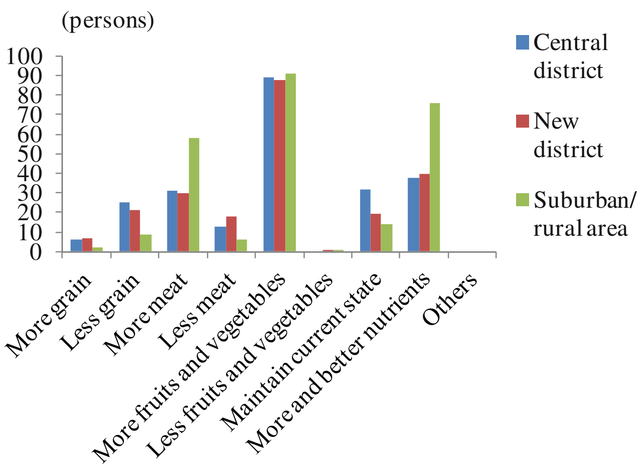

Fig. 5 Results of respondents nominated future food consumption relative to their current consumption (multi-choice)

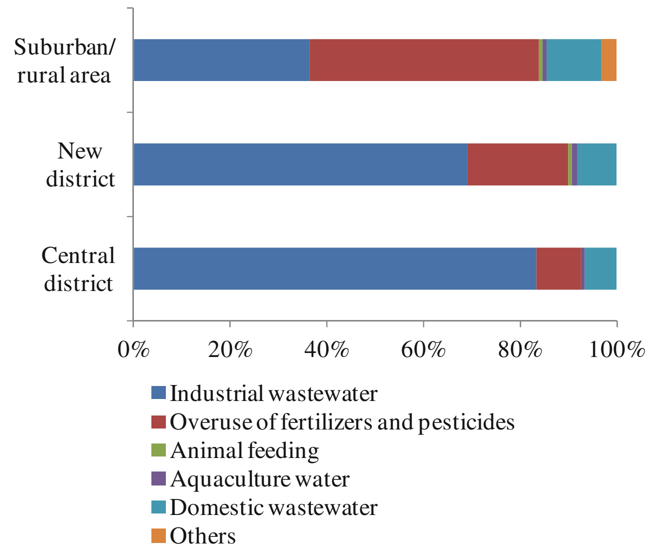

Fig. 6 Results of respondent nominated causes of eutrophication of waterbodies

suburban/rural areas. In all three areas, nearly 40 % of answers express "want more fruits and vegetables" in the future. And the trend of "want more animal-derived foods like meat", and "want less grain" could be observed. Here, 13 % of answers show "want more animal-derived foods like meat" in the central and new districts, 6 % of answers show "want less animal-derived foods like meat" in the central district with 8 % in the new district. Further, 23 % of answers show "want more animal-derived foods like meat" and 2 % of answers show "want less animal-derived foods like meat" in the suburban/rural areas. The tendency towards animal-derived foods is going to increase in the food consumption structure in Shanghai city, especially in the suburban/rural areas. Also the trend to a better nutritional balance could be observed since there are so many people who "want more and better nutrients".

Causes of eutrophication

For the causes of water eutrophication, 83 % of answers show "industrial wastewater" in the central district and 69 % in the new district. Only 9 % of answers show "overuse of fertilizers and pesticides" in the central district and 21 % in the new district; 8 % show "domestic wastewater" in the central district and 10 % in the new district. In the suburban/rural areas, 48 % of answers show "overuse of fertilizers and pesticides", 36 % "industrial wastewater", and 11 % "domestic wastewater" (Fig. 6). However, according to the Shanghai Statistical Yearbook, the amount of "domestic wastewater" has exceeded "industrial & other wastewater" since 1996, and comprised 80 % of the total effluents in 2008 (Fig. 7). Also the amount of the chemical oxygen demand of "domestic wastewater" in 2008 was 239,100 tons while for "industrial & other wastewater" it was 27,600 tons. As a conclusion, pollution causes have changed from "industrial pollution" to "urban pollution" based on the population concentration and mass consumption since the industrial structure has been changing in Shanghai city. The first main factor in this is the change in the industrial structure. The service sector has exceeded secondary industry since 1998 and it comprised almost 60 % of the whole of GDP in 2009. In particular, the share of creative industries is increasing in the service sector. The industrial wastewater and contamination have decreased rapidly since industry with serious pollution (like paper industry, chemical industry, etc.) has transferred to the surrounding areas according to policies which control the sources of industry or adjust the industrial structure. The second main factor is the updating of industrial technology. The industrial water recycling rate was improved from 41 % 1992 to 58 % 2005 due to the introduction of new

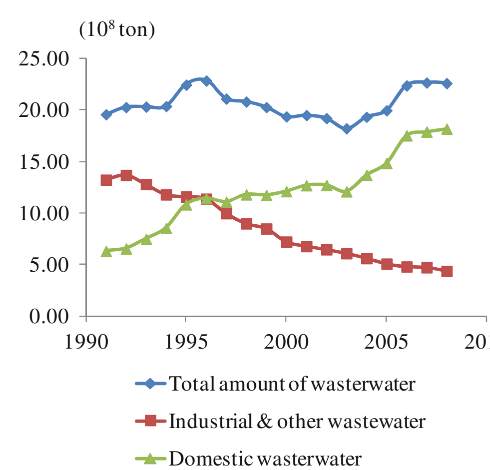

Fig. 7 Temporal change of wastewater in Shanghai

technology, which leads to a decrease in industrial wastewater. In 2008, more than 90 % of the industrial wastewater had achieved the emission standards since advanced wastewater treatment facilities had been introduced and this was accomplished by the tightened industrial source restrictions. The third main factor is the increasing population caused by rapid urbanization and the increase of the water consumption per capita caused by the urbanizing lifestyle. In Shanghai city, water environmental problems, rather than industrial pollution problems such as water pollution caused by industry, urban type pollution has become more and more serious. However, according to the investigation asking what is the cause of eutrophication, most respondents show a lack of recognition of urban/life type water pollution. Related lessons about causes of environmental problems and other environmental problems will arise in the future.

Summary

The everyday diet (what and how much we eat) has a significant impact on a regional material cycle. This study showed lifestyle (eating habits, domestic sanitation, drainage facilities etc.) changes with rapid urbanization and estimated the nitrogen and phosphorus intake from food per capita per day, and the potential nitrogen and phosphorus load discharged to the water and soil as human waste in the case of Shanghai, a megacity which attracts worldwide attention.

The results show the nitrogen and phosphorus intake from food per capita per day is as follows: N, 19.36 g in the Shanghai central district, 16.48 g in the new district, and 13.04 g in the suburbs/rural areas; P, 1.80 g in the Shanghai central district, 1.52 g in the new district, and 1.20 g in the suburbs/rural areas. The "soil reduction rate" from human waste is 5 % in the Shanghai central district, 1 % in the new district, and 73 % in the suburbs/rural areas. The potential nitrogen and phosphorus load from human waste to the environment annually per capita is 0.35 kg-N and 0.03 kg-P to the soil, 6.72 kg-N and 0.62 kg-P to rivers in the Shanghai central district, 0.06 kg-N and 0.006 kg-P to the soil, 5.95 kg-N and 0.55 kg-P to rivers in the new district, and 3.47 kg-N and 0.32 kg-P to the soil, 1.28 kg-N and 0.12 kg-P to rivers in the suburbs/rural areas. In Shanghai city, especially in the suburbs/rural areas, a preference was shown for increasing the intake of animal-derived foods as well as vegetables and fruits, which means that the potential N and P load from the human diet to the environment will increase. Water pollution has changed from industrial pollution to urban/life types of pollution, but there is still a lack of recognition of the causes of water pollution among residents. Environment-friendly eating habits and improvements in environmental awareness should be required.

There are many further issues that need to be addressed. In this study, a quantitative evaluation has been made of lifestyle impacts on regional nitrogen and phosphorus flows. However, the evaluation is only for the elements related to the diet. Other nitrogen and phosphorus sources, such as domestic non-fecal wastewater (gray water), service sectors, manufacturing sectors and agricultural sectors also have significant impacts on regional material circulation and still require elucidation.

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