Urbanization affects water and nitrogen use in the food chain in China

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ABSTRACT

Urbanization and agriculture are highly coupled. However, the impacts of urbanization(e.g. transformation in urban and rural population and change in diet) on water and nitrogen (N) use remain poorly understood. The objectives of this study are to quantify water flows in the food chain of China, to analyze the complex relationship between urbanization and water and N use efficiency, and to project water and N demand in China via various scenarios, using a combination of water footprint approach and the food chain model NUFER. In 2006, China consumed in total about 857 km^3 of water and 49 Tg of N, in which 132 km^3 of water (15%) and 15 Tg of N (31%) were imported (as feed and food) , and 21 km^3 of water (2.4%) and 5 Tg of N (10%) were exported (as feed and food). Besides that, if Chinese diet increases, especially with animal protein intake, to current European (EU-27) level, water and N use will have to increase to approximately 1600 km^3 and 70 Tg, respectively. We concluded that urbanization plan in China must consider its impacts on water and N uses in the food chain, as ignoring these effects will lead to biased interpretations and unsustainable development.

INTRODUCTION

Urbanization and agriculture are highly coupled and dependent on the availability of natural resources and the capacity of ecosystems (Foley et al. 2005, Glaeser 2011, Satterthwaite et al. 2010). Urbanization can be defined as the growth of urban areas and population as a result of global change. The level of urbanization is commonly presented as the proportion of total population living in urban areas. Globally, Cities are growing and more food needs to be provided with limited of land and water. This pressure becomes even more serious for countries as China with rapid economic growth and increasing water shortage (Liu et al. 2008, Piao et al. 2010), and severe environmental degradation . Hence, there is a pressing need to use water and nitrogen (N) more efficiently in order to feed the growing human population and to prevent large scale ecosystem degradation. (Vitousek et al. 1997, Smil 2000, Tilman et al. 2002, Sachs 2008, Guo et al. 2010, Ju et al. 2009).

Water and N are two most important crop yield limiting factors in agriculture (De Wit 1958, Marschner 1995). Modern agriculture with high water and N supply has greatly contributed to the global food security but also led to severe environmental problems such as soil acidification, pollution of water bodies and greenhouse gas emission (Sutton et al. 2011, Guo et al. 2010, Ju et al. 2009). Water and N interactions are fairly understood at the plant and field levels but not yet at the regional level, which is partially due to different research interests, in part is also because of the complexity of the large system. Therefore, the impacts of urbanization(e.g. transformation in urban and rural population and change in diet) on water and nitrogen (N) use and environment have not yet been quantified and analyzed systematically. Lack of coherent understanding of water and N use at the regional level may lead to incomplete analyses and inaccurate recommendations for management strategies (Allan 2003, Gleick 2003, Mosier 2004, Sachs et al. 2010, Galloway et al. 2008).

Hence, the objectives of this study are to quantify water flows in food chain of China, to analyze the complex relationship between urbanization and water and N use efficiency, and to project water and N demand in China via various scenarios, using a combination of water footprint, N footprint approach and the food chain model NUFER (Hoekstra 2008, Ma et al. 2010).

METHODS

Quantifying water flows in food chain requires following information: Agricultural production, rainfall and irrigation water in year of 2006. These are statistical data that can be derived from online database of National Bureau of Statistics of China (NBSC) http://219.235.129.58/welcome.do#. Therefore these data are not listed in this paper. We use water footprint approach to quantify water flow in the food chain of China in year 2006. The water footprint approach was fairly documented in (Hoekstra 2008). The most important concept in water footprint approach is the virtual water content, which represents the amount of water that are used to produce a unit of agricultural products (Table. 1). For agricultural products, especially for crop products, most of water (>95%) was consumed by evapotranspiration (Hoekstra 2008). Therefore, the water that stay in the food item itself can be neglected. However, unlike water, quite a proportion of N stay with in food items as protein. Therefore the quantification of N need a slightly different approach comparing to water. We differentiate the N that is in the food item as Ne, and the total N used to produce a unit of food as Nt (Table. 1).

A food chain (Fig. 1) is described as a “pyramid” shape that consists of four main compartments, namely crop, animal production, food processing, and food consumptions in the households (Ma et al. 2010). By quantifying the flows of food/feed in terms of water and/or N, we can provide an overview of water and N use, import and export throughout the food production-consumption chain.

For scenarios, we use year 2006 as the baseline with population of 1.3 billion and 40% urbanization. We distinguish the diet for urban and rural dwellers. The diet of Chinese people in different year are listed in Table 2. In three scenarios, we project for the year 2050 when Chinese population is predicted as 1.5 billion. In scenario 1 (S1), we consider only the effects of increasing population from 1.3 to 1.5 billion with the same urbanization rate (40%) and the same diet intake as year 2006. In scenario 2 (S2), we use 1.5 billion population with 50% urbanization rate and keep the same diet as year 2006. In scenario 3, we assume that the rural dwellers have the same diet as urban ones. In scenario 4, we assume that the Chinese have the same diet as European (EU-27).

RESULTS & DISCUSSION

In 2006, China consumed in total about 857 km^3 of water, in which 132 km^3 of water (15%) were imported (as food and/or feed), and 21 km^3 of water (2.4%) and 5 Tg of N (10%) were exported (as food and/or feed) (Fig 1A.). In crop production, China used in total 746 km^3 of water, in which 78% was from rainwater and 22% was from irrigation water. Domestically, 61% of water was used to produce feed for the animal and 39% went directly to the household consumption. These quantification was done by water footprint approach. Interestingly, for N flows, where Ma *et al.* (2010) used mass flow approach to quantify, China consumed in total about 49 Tg of N, out of which 15 Tg of N (31%) were imported (as food and/or feed), and 5 Tg of N (10%) were exported (as feed and food). The methods used in these two studies are rather different. For example, water footprint approach focus more on the share of the “virtual” water use for each sector whereas mass flow approach focus on the partition of “real” the N use in each sector. This is in part due to the different nature of water and N in the food chain, in part is also because of limitation for both water footprint approach and mass flow approach. Therefore, the interpretation of these results requires understanding of both approaches. It is also a challenge to combine and integrate these two approaches to make the results and analysis more comparable in the future.

We developed an conceptual model to demonstrate the relationships between urbanization and water use efficiency and N use efficiency for each sector (Fig 1B). Take crop production (Fig 1B-I) as an example, Low urbanization counties often refer to low accessibilities to advanced technologies, knowledge, irrigation system and fertilizer. Accordingly yield was rather low in crop productions and therefore low WUE and NUE. Such cases can be found in many extreme poor countries in the world (<10% urbanization rate). When the society further developed, more cities and populations need to be fed by limited of land and water, WUE will increase but with high cost of N losses to the environment. This is especially true for countries as China(40% urbanization rate) with huge population and rapid economic growth where the food security was still the first priority. When people are more concerned about the environment, such as EU countries that are mostly characterized with high urbanization rate(70-80%), WUE and NUE will be improved to an acceptable level (Sutton et al. 2011, Ma et al. 2010, Guo et al. 2010, Ju et al. 2009). Therefore, in crop production sector, WUE will increase gradually along with the urbanization development but NUE will drop down at some stage and increase again in the end.

Similarly for animal production sector (Fig 1 B-II), for example, the Netherlands can produce milk and meat much more efficiently than other developing countries in the world, meaning high production efficiency. However, due to the limitation of land to reuse/recycle animal manure, the reuse/recycle efficiency is low. Therefore, how to improve NUE at the whole system has become a huge challenge for these high animal production countries in Europe (Sutton et al. 2011).

For the food processing sector (Fig 1 B-III), European people, for example, are much more selective for food, rather part of the food is considered as offal/not eatable therefore not entering the household consumption sector(Fig 1B-IV). Moreover, people in rich countries also waste a large amount of food at the household consumption sector(Fig 1B-IV), which further lower WUE and NUE at these sectors. Therefore, a quantification of water and N flows throughout the food chain can be an useful tool to reveal these possible relationships and trade-offs.

According to our calculation, increasing population and further urbanization has various impacts on water and N use in the future. More strikingly, if Chinese diet increase, mainly in animal protein intake, to current European (EU-27) level, water and N use will be increased to about 1600 km^3 and 70 Tg, respectively (Fig 2.).

Apart from that, there are also some other social-economic aspects that could affect WUE and NUE. For example, many farmers (120 million), especially young farmers, work full time in the city. The remaining farmers are either old or do not have the ability to learn novel management techniques, which further decrease WUE and NUE. Further, an increasing number of landless animal production farms are situated near urban environments, rely largely on imported animal feed and do not have the land-base for utilizing the nutrients contained in animal manure. Hence, a large fraction of the manure is simply discharged into surface waters, with or without previous treatment (Ma et al. 2010).

CONCLUSIONS

Urbanization in China has huge impacts on its future water and N use, depending on its increasing population, transformation in urbanization and change in diet. Current development pattern has contributed to a high food security and sufficiency however with compromises of high environmental cost. We concluded that urbanization plan in China must consider its impacts on water and N uses in the food chain, as ignoring these effects will lead to biased interpretations and unsustainable development.

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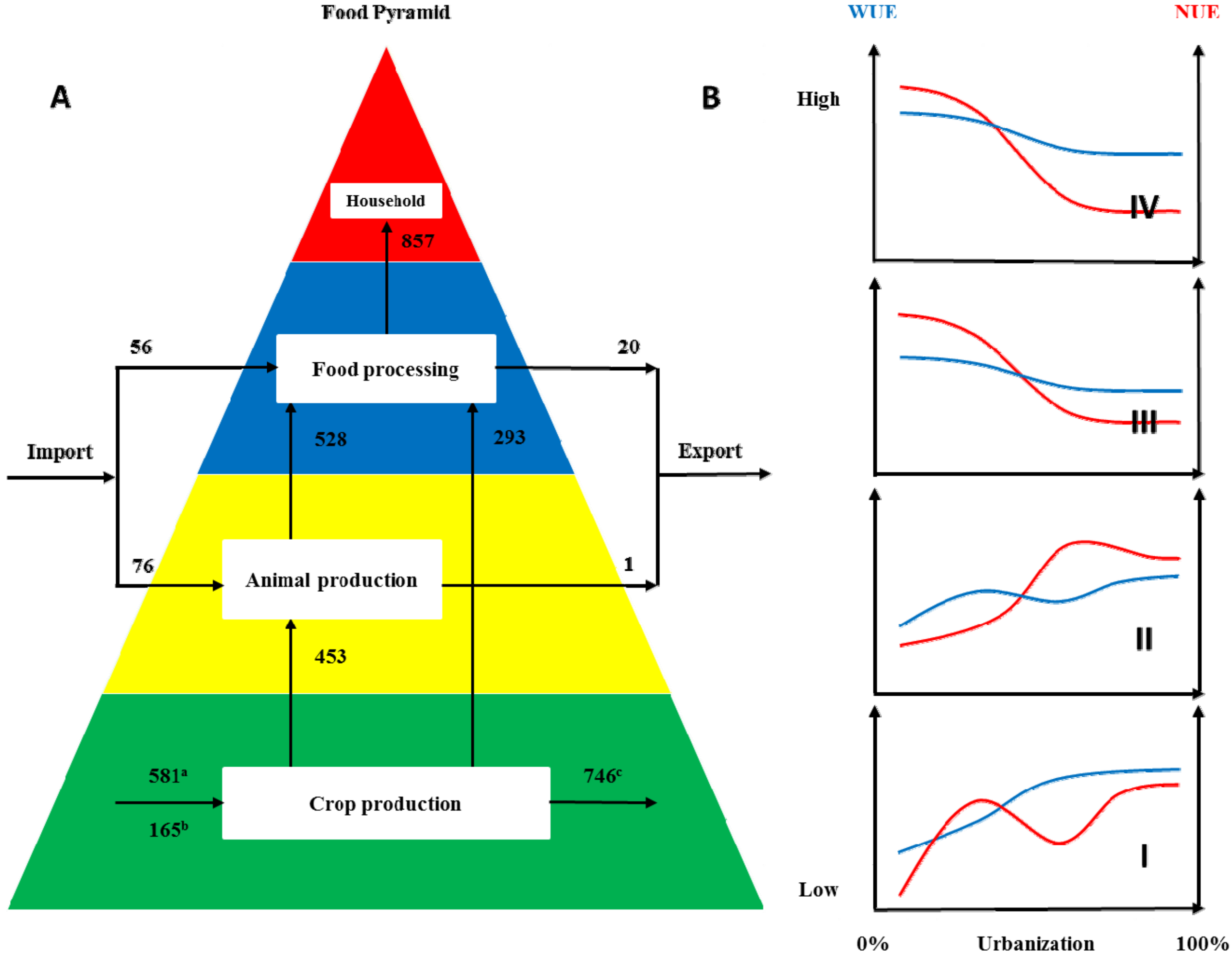

Figure 1. Conceptual model of urbanization's effects on water and N use efficiencies in the food chain.

On the left side, the Fig. 1A represents the food chain that consists of four main compartments, namely crop, animal production, food processing, and food consumptions in the households. Arrows in the food pyramid represent the flows of food (in terms of water) between compartments. The numbers represent the amount of water, in unit of km3. 581[a] represents amount of rainwater, 165[b] represents irrigation water and 746[c] are the sum of rainwater and irrigation water.

On the right side, in the Fig. 1B, we provide a conceptual model of urbanization's effects on water and N use efficiencies for the four compartments of the food chain. Accordingly, Fig 1B-I refers to crop production, Fig 1B-II refers to animal production, Fig 1B-III refers to food processing and Fig 1B-IV refers to household consumption. The blue line represents WUE and the red line represents NUE along with the urbanization rate at the horizontal axis.

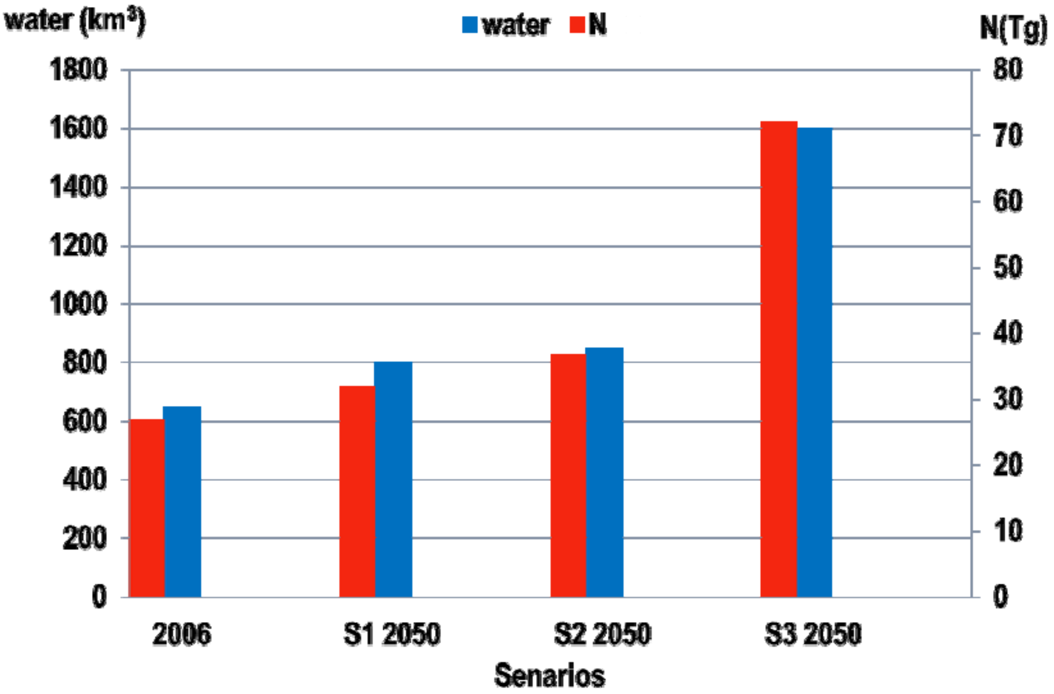

Figure 2. Water and N demands in China in 2050 with different population size and diet scenarios.

For scenarios, we use year 2006 as the baseline with population of 1.3 billion and 40% urbanization. In three scenarios, we project for the year 2050 when Chinese population is predicted as 1.5 billion. In scenario 1 (S1), we consider only the effects of increasing population from 1.3 to 1.5 billion with the same urbanization rate (40%) and the same diet intake as year 2006. In scenario 2 (S2), we use 1.5 billion population with 50% urbanization rate and keep the same diet as year 2006. In scenario 3, we assume that the rural dwellers have the same diet as urban ones. In scenario 4, we assume that the Chinese have the same diet as European (EU-27).

Appendixes

Table1. Virtual Water Content (VWC), embedded N (Ne) and total N (Nt) of food items in China.

Food item?	VWC[a] (m^3/kg)	Ne[b] (g/kg)	Nt[b] (g/kg)
Rice	1.31	13	50
Wheat	0.98	23	63
Maize	0.84	19	52
Potatoes	0.23	3	44
Beans	3.20	53	63
Vegetables	0.19	11	15
Fruits	0.50	30	46
Pork	4.46	15	359
Beef and mutton	8.50	25	515
Poultry	2.39	27	178
Eggs	3.55	22	54
Sea food	5.00	27	332
Milk	1.00	5	44
Vegetable oils	5.08	*	*
Animal fats	4.00	*	*
Sugar	1.02	8	60
Alcohol	0.18	*	*

* means no data
[a] from (Liu and Savenije 2008)
[b] based on NUFER model calculations (Ma et al. 2010).

Table 2. Diets in 1980, 2006 and 2050 for the rural and urban households in China

	Urban diet (kg/capita/year)			Rural diet (kg/capita/year)		
	1980	2006	2050	1980	2006	2050
Rice	79	114	114	79	94	94
Wheat	80	80	80	65	55	55
Maize	9	8	8	50	10	10
Potatoes	24	13	13	83	21	21
Beans	5	8	8	5	6	6
Vegetables	115	158	158	123	113	113
Fruits	25	28	28	9	14	14
Pork	14	38	38	5	17	17
Beef and mutton	3	8	8	1	4	4
Poultry	6	14	14	2	8	8
Eggs	6	14	14	1	8	8
Sea food	8	21	21	3	10	10
Milk	4	27	27	3	4	4
Vegetable oils	8	21	21	3	13	13
Animal fats	2	2	2	2	5	5
Sugar	4	3	3	1	2	2
Alcohol	1	1	1	1	1	1

Data of 1980 and 2006 are derived from The China Health and Nutrition Survey (CHNS) http://www.cpc.unc.edu/projects/china.
Data of 2050 are assumed data for the calculation in scenarios.