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Impacts of soil and water pollution on food safety and health risks in China

Yonglong Lu [a,*], Shuai Song [a,1], Ruoshi Wang [a,b,1], Zhaoyang Liu [a,b], Jing Meng [a,b], Andrew J. Sweetman [c,d], Alan Jenkins [d], Robert C. Ferrier [e], Hong Li [c,d], Wei Luo [a], Tieyu Wang [a]

[a] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK
[d] Centre for Ecology & Hydrology, Wallingford, OX10 8BB, UK
[e] The James Hutton Institute, Aberdeen AB15 8QH, Scotland, UK

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ABSTRACT

Environmental pollution and food safety are two of the most important issues of our time. Soil and water pollution, in particular, have historically impacted on food safety which represents an important threat to human health. Nowhere has that situation been more complex and challenging than in China, where a combination of pollution and an increasing food safety risk have affected a large part of the population. Water scarcity, pesticide over-application, and chemical pollutants are considered to be the most important factors impacting on food safety in China. Inadequate quantity and quality of surface water resources in China have led to the long-term use of waste-water irrigation to fulfill the water requirements for agricultural production. In some regions this has caused serious agricultural land and food pollution, especially for heavy metals. It is important, therefore, that issues threatening food safety such as combined pesticide residues and heavy metal pollution are addressed to reduce risks to human health. The increasing negative effects on food safety from water and soil pollution have put more people at risk of carcinogenic diseases, potentially contributing to 'cancer villages' which appear to correlate strongly with the main food producing areas. Currently in China, food safety policies are not integrated with soil and water pollution management policies. Here, a comprehensive map of both soil and water pollution threats to food safety in China is presented and integrated policies addressing soil and water pollution for achieving food safety are suggested to provide a holistic approach.

1. Introduction

China's per capita arable land area is less than half of the world average and per capita arable water is about one quarter of the world average (UNESCO, 2012). As a result, the country simply cannot afford to lose any more available land or water due to increasing problems with pollution. Historically soil and water pollution have been considered separately by environmental policy makers. It is imperative, however, that integrated policies, addressing both soil and water pollution, are formulated for the protection of agricultural production and human health.

Water availability is essential for agriculture, and ensures the sustainable increase of grain yield. The largest threat to food production in China may be the impending water shortage due to the highly uneven distribution of surface water resources, and rising demands from irrigation, population increase, and rapid urbanization (Liu and Diamond, 2005; Li, 2010). Moreover, serious surface water pollution in China not only aggravates the water shortage risk but also leads to grain quality degradation. Most research papers to date have focused on the relationships between crop yield and water resources (Y. Wang et al., 2008; Piao et al., 2010; Peng, 2011), water use efficiency (Deng et al., 2006; Fan et al., 2011), infrastructure (Lohmar et al., 2003), agricultural management (Hu et al., 2006) and climate change (Piao et al., 2010; Grassini and Cassman, 2012; Wei et al., 2014), while few studies have investigated the effects of surface water pollution on grain quality at the national scale. There are clear implications for sustainably managing available water supplies, understanding the nature and magnitude of demands, analyzing the factors affecting water quality, and developing policies to ensure continued growth in agricultural production.

Pesticides have been playing an important role in the success of modern food production since the 1950s (Beddington, 2010; Rahman, 2013). Numerous studies have demonstrated that fertilizer and pesticide use have contributed greatly to improved grain production. However, inefficient use of pesticides can also lead to considerable human risks. Inadequate management of pesticide application in food production constitutes potential occupational hazards for farmers and environmental risks for agricultural ecosystems (Lake et al., 2012; Thuy et al.,

* Corresponding author.
E-mail address: yllu@rcees.ac.cn (Y. Lu).
[1] S.S. and R.W. contributed equally to this work.

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2012). Pesticide residues in grain can directly influence public health via food consumption, and diet-related diseases can result in negative public health consequences (James, 2001; Li et al., 2008). The World Health Organization has reported that unintentional occupational poisoning by pesticides has resulted in several million cases worldwide and provided evidence that pesticides were responsible for severely affecting many aspects of human health (WHO, 1990). Although the current use of pesticides poses potentially less threat to the environment and to humans than before, these adverse impacts are still a major and long-term concern.

Among all types of pollutants reported, heavy metals are considered to present the greatest risk to food safety in China (MEP&MLR, 2014). The main sources of heavy metals in farmland soils include mining and smelting, sewage irrigation, sludge reuse and fertilizer application (Chen et al., 1999). Due to extensive and nonstandard production processes of some mining and smelting enterprises, large quantities of heavy metals affect farmland through wastewater irrigation, waste transportation, sludge application and atmospheric deposition which has been shown to be particularly important in southern China with abundant mineral resources (Hu et al., in press; Xu et al., 2014). Extensive irrigation with poorly treated water from sewage in China has been employed since the 1950s, with the affected area increasing from 115 km^2 in 1957 to 36,000 km^2 in 1998 (Huang and Wang, 2009), remaining above 30,000 km^2 since then. Sewage irrigation refers to the use of sewage outflow for irrigation purposes without any treatment or with simply solids removed, frequently containing toxic and hazardous substances. In some areas, untreated sewage outflow from small cities has been applied directly to farm fields. Sewage irrigation is an effective method to alleviate the shortage of water resources, however, according to an official survey in the 1980s, 86% of the area receiving sewage irrigation did not meet the standards for irrigation water quality, and 65% of sewage irrigation area was contaminated by heavy metals, of which mercury (Hg), lead (Pb) and cadmium (Cd) were the most serious heavy metal pollutants (Wang and Zhang, 2007; Xin et al., 2011). A recent official nationwide survey also reported that 39 of 55 sewage irrigation areas were contaminated by Cd, arsenic (As) and polycyclic aromatic hydrocarbons (PAHs) (MEP&MLR, 2014). The accumulation of heavy metals is rapidly increasing especially in farmlands with intensive agriculture and large irrigation systems (Chen et al., 2008; Zhang and Shan, 2008). Meanwhile, waste materials from intensive livestock production, which contain high concentrations of As, zinc (Zn) and copper (Cu), are becoming important pollution sources with the expansion of the animal husbandry industry (Zeng et al., 2013).

Water and soil pollution not only has negative effects on food safety but can also result in increased health risks, and has been implicated in the rise of 'cancer villages'. The term 'cancer village' commonly refers to a village in which the morbidity rate of cancer is significantly higher than the average level, most probably caused by environmental pollution (Liu, 2010). In this paper, we use the systematic data on cancer villages collected with clear description of village name, location, main diseases, water quality, and pollution sources. These data suggest that cancer villages tend to cluster in the eastern China, the most important grain producing region. Widespread environmental pollution, especially water pollution is proposed as a key factor in the occurrence of cancer villages (Liu, 2010; Gong and Zhang, 2013).

2. Methods

2.1. Systems approach

In this paper, a multifactorial approach was used to define a comprehensive spatial analysis of water and soil pollution threats to food safety. Food safety and security are mostly about that of staple food in China. Rice, wheat and maize are staple food, while fish is consumed as subsidiary in some parts of China but not as staple food in China. Besides that, because of serious river pollution, fish production in China is mostly through aquaculture and mariculture mainly in some regions of eastern China. In cancer villages located near seriously polluted rivers, fish is barely caught locally, so fish consumption is not considered in this paper.

Within the administrative boundary of China, more detailed analyses were undertaken at the provincial and major river basin levels to define 31 discrete areas, excluding Hong Kong, Macao, and Taiwan because of unavailability of suitable data. Statistical analyses were performed with SPSS Statistics V20.0 (SPSS Inc. Quarry Bay, HK). Multiple regressions were used to determine the relationships between application of fertilizer, pesticide and grain yield in past two decades. Spatial distributions of water resources, water and soil pollution, and cancer villages were performed with the Arcmap module in ArcGIS V10.0 software (ESRI, Redland, CA). Life cycle analysis was made of policy evolution process for chemicals and heavy metals management since the 1950s, and social network analysis was made of the relationships among the relevant governing bodies.

2.2. Dataset

Data were collected from the following sources: (1) a number of national and provincial statistical databases, including "China Statistical Yearbook," "China Agricultural Statistical Yearbook," "China Environmental Status Bulletin"; and "China Water Resources Bulletin"; (2) national or provincial environmental survey such as the latest Nationwide Soil Pollution Survey Report, and Environmental Quality Report; and (3) the existing research results and methodologies described in respective tables or figures.

3. Water quality and food production

3.1. Water availability for irrigation

The highly uneven distribution of surface water resources and areas of agricultural production between the North and the South, the East and the West are shown in Fig. S1. Some 40% of the grain yield is produced in the Yangtze River, Pearl River, southeast and southwest river basins, while there is more than 70% water resource in these regions. Songhua, Liaohe, and Haihe River Basins in northern China have 20% of the water resources, but provide nearly 50% of the country's grain production. Agricultural water use is a major part of all water used annually, sourced from glaciers, surface water, and groundwater. The share of irrigation in total water use has declined from 80% in the 1980s to 61% in 2010 in China (NBS, 2013). Figs. S2 and S3 show a significant correlation between effective irrigation area and crop yield which suggests that irrigation plays an essential role in ensuring food production although it is clear that there is an uneven distribution of water resources, especially in the North with extremely scarce water resource. Effective irrigation area is not simply the area that is irrigated, but refers to the total farmland area where water is available with reasonable access to irrigation facilities. The correlation coefficients between surface water for irrigation and grain yield also demonstrate that surface water irrigation is essential to grain yield (Wang et al., 2013) in Huaihe, Songhua and Liaohe River Basins (Figs. S4, S5). The low correlation coefficients were influenced by the water transfer for irrigation in the Yellow River Basin and Haihe River Basin, low surface water irrigation ratio in the Yangtze River Basin and variations of water use efficiency in the North China Plain. The most serious water shortage in the main grain production areas is located in the North China Plain with 33.8% of the national arable land but only 3.85% of the national water resources. As a result, the water table has fallen steadily due to intensive agriculture and industry uses over the past 40 years (Li, 2010; Fan et al., 2011).