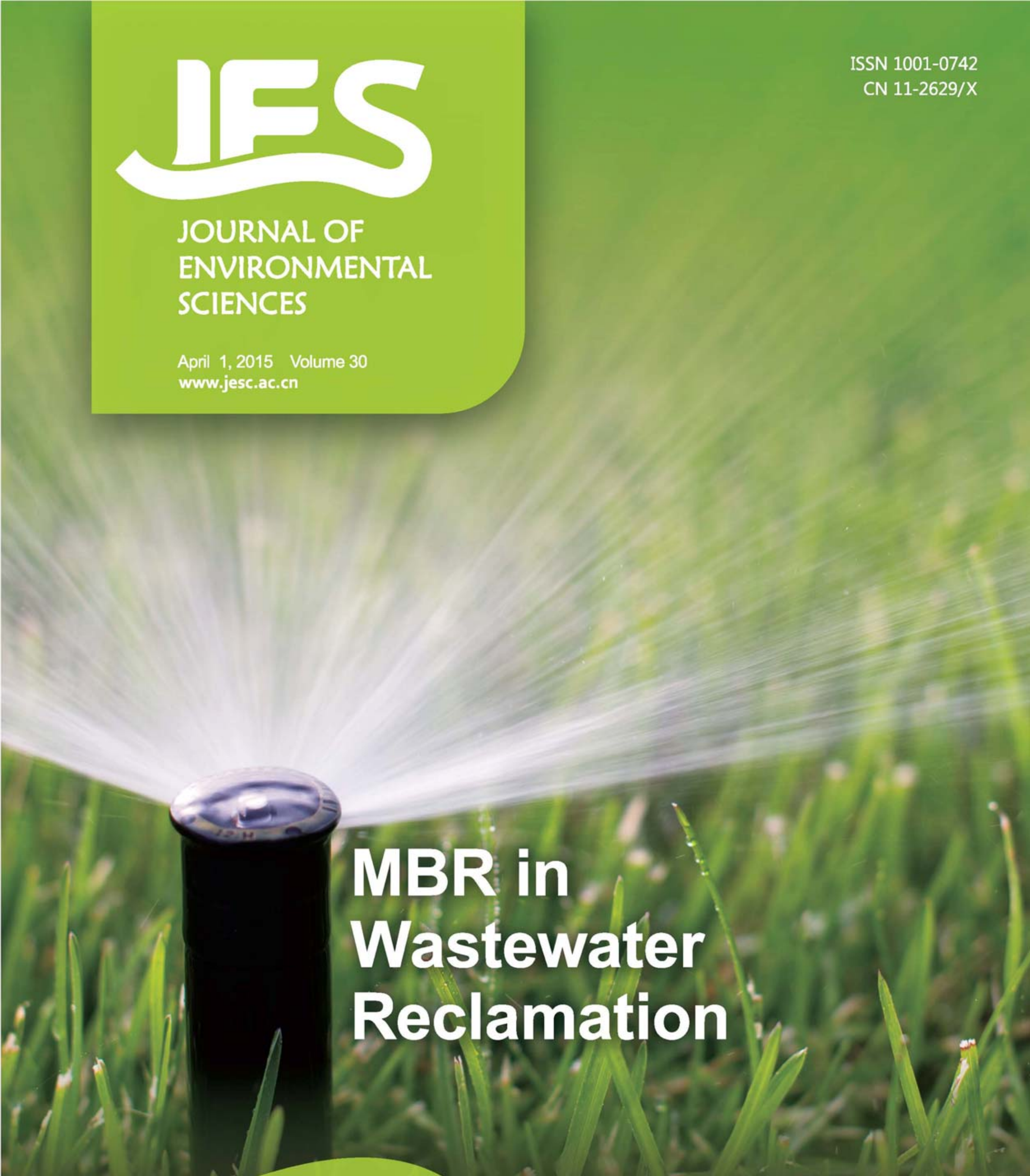
ISSN 1001-0742
CN 11-2629/X

JOURNAL OF ENVIRONMENTAL SCIENCES

April 1, 2015 Volume 30
www.jesc.ac.cn



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JOURNAL OF ENVIRONMENTAL SCIENCES 30 (2015) 129–131

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JOURNAL OF ENVIRONMENTAL SCIENCES

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Rice: Reducing arsenic content by controlling water irrigation

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ARTICLE INFO

Available online 17 March 2015

Keywords:
Arsenic
Cadmium
Rice
Food
Water irrigation
Metal contamination

Arsenic has long been recognized as a poison. Arsenic in water supplies that are used for both drinking and crop irrigation can expose many people chronically to elevated levels of arsenic.

The main health concern for chronic exposure to arsenic is the development of cancer. Although the World Health Organization (WHO) recommends that total arsenic in drinking water should be under 10 μg/L (or 10 ppb), (WHO, 2011), some regions around the world have water arsenic concentrations as much as a thousand times higher than the WHO guideline value (NRC, National Research Council, 1999; Nordstrom, 2002).

Another significant source of arsenic is rice. Arsenic tends to concentrate in rice at higher levels than other crops, such as wheat (Schoof et al., 1993; Williams et al., 2007). There have been many studies focusing on rice physiology and arsenic uptake (Meharg and Hartley-Whitaker, 2002; Ma et al., 2008; Zhu et al., 2008; Rahman and Hasegawa, 2011; Zhang et al., 2011; Zhao et al., 2009 and 2013), but there is still no common consensus on the underlying mechanism for the higher arsenic uptake by rice.

An option to reduce arsenic exposure can be the restriction of rice consumption. However, because rice is such a major staple food of many populations, restricting rice consumption is not a practical solution. This issue is further exacerbated in Southeast Asia, where rice is a staple food and arsenic concentrations in drinking water may also be high (Meharg et al., 2009). Therefore, those who are exposed to arsenic from both drinking water and rice could be at risk of arsenic-induced health effects.

These concerns have motivated organizations to attempt regulating arsenic in rice. For example, the Codex Alimentarius Commission (2014), an international body coordinated by WHO and the Food and Agriculture Organization of the United Nations, has proposed a maximum level of 0.2 mg/kg (or 200 μg/kg) for inorganic arsenic in white (or polished) rice. However, regulation is not easy and not without issues (Schmidt, 2015). It is challenging to regulate arsenic in rice because the amount of rice consumed varies throughout the population (Muthayya et al., 2014) and because different types of rice contain different arsenic species (Abedin et al., 2002). For example, dimethylarsinic acid (DMA) is the predominant arsenic species found in rice grown in North America, whereas inorganic arsenic species are predominant in rice grown in India (Williams et al., 2005; Meharg et al., 2009). Because of these challenges, there is extensive research aimed at reducing the uptake of arsenic by rice and minimizing the total concentrations of arsenic in rice grains (Abedin et al., 2002; Ma et al., 2008; Wang and Duan, 2009; Rahaman et al., 2011; Pan et al., 2014; Zhang et al. 2011; Schmidt, 2015).

Addressing the many concerns on arsenic in rice, a recent paper by Hu et al. (2015) is an effort towards controlling arsenic contamination in rice cultivation. They investigated which crop-watering regimen (minimal water, intermediate amounts of water, or flooding) resulted in the lowest arsenic concentrations in brown rice. Using Brazilian upland rice grown on arsenic and cadmium contaminated soils, they compared arsenic and cadmium in pot-grown rice and field-grown rice. Because rice cultivation requires copious amounts of water, naturally it depletes reservoirs that can be used otherwise as drinking water. Since Brazilian upland rice is bred to thrive in minimal watering conditions (Cheng et al., 2000), less water is needed, which saves both resources and time.

Hu et al. (2015) showed that arsenic concentrations and speciation both varied with each water irrigation regimen. With increasing amounts of water used to irrigate the rice crops, an increased level of total arsenic was detected in the rice. Flooding of rice crops yielded the highest total arsenic

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http://dx.doi.org/10.1016/j.jes.2015.03.001

concentration in the rice grain. Rice grown using the minimal amount of water showed the least concentration of arsenic. This is consistent with other studies (Xu et al., 2008; Pan et al., 2014); however, rice grown with minimal water is not always successful in producing good plant yields, and growing Brazilian upland rice may not always be easy.

Arsenic speciation patterns also varied with each water irrigation regimen. Speciation is necessary because different arsenic species have different toxicities and can be found in varying concentrations in food and water. Inorganic arsenic is several orders of magnitude more toxic than organic arsenic when the inorganic and organic arsenic species of the same oxidation state are compared (Charoensuk et al., 2009; Shen et al., 2013). Hu et al. (2015) detected three arsenic species in rice: inorganic arsenate (As(V)), inorganic arsenite (As(III)), and DMA. In rice grown aerobically (with minimal water), 88% was inorganic arsenic and 11% DMA. Interestingly, while rice grown under flooding conditions had the highest total arsenic concentration, a smaller fraction (38%) was present as inorganic arsenic and the rest (62%) was in the form of DMA. Since DMA generally has lower toxicity than inorganic arsenic, the predominant arsenic species in rice as DMA may seem to be less of a concern. However, precautions should still be taken to reduce its presence in rice because the reduced trivalent form of this dimethylarsenical is highly toxic (Styblo et al., 2000).

In addition to arsenic, crops can also take up cadmium. Cadmium is highly toxic and can lead to many chronic toxicity diseases, including increased risk of atherosclerosis and hypertension, both leading to heart disease (Revis et al., 1981). Hu et al. (2015) demonstrated that the lowest cadmium concentrations were found in rice grown by flooding. This pattern differs from total arsenic, which showed the highest levels of total arsenic in rice grown by flooding. These opposing trends suggest that care must be taken when choosing irrigation regimes to minimize the uptake of arsenic and cadmium in rice grains if the soil is polluted with both elements. In this regard, the use of phosphate fertilizers is cautioned, as some phosphate fertilizers have high concentrations of cadmium and repeated applications of phosphate fertilizers could result in significant increases in soil cadmium (Mulla et al., 1980).

Since controlling the arsenic intake from rice is difficult with many complications, minimizing the arsenic content in rice is the next best option. Hu et al. (2015) have shown that growing rice in an environment with minimal water irrigation results in the least amount of total arsenic in rice. Further research on understanding the mobility of arsenic in water and soil, plant uptake and translocation into the rice grain, and transformation of arsenic through abiotic (reduction–oxidation) or biotic (methylation) processes can contribute to achieving the goal of minimizing arsenic levels in rice. Rice cultivation is also an important aspect of controlling arsenic in rice. This can include irrigation management, utilizing different species of rice, or potentially genetically modifying the rice (Jia et al., 2012). By incorporating an arsenic methyltransferase enzyme from algae (Qin et al., 2009), scientists hope to achieve arsenic volatilization out of the rice crop, resulting in less arsenic present in the plants (Meng et al., 2001; Jia et al., 2012). Overall, continued research in these areas contributes to the effort of reducing arsenic in rice, and can greatly help to reduce overall arsenic intake in regions prone to arsenic problems.

Photo by Dr. Baodong Chen, Research Center for Eco-Environmental Science, Chinese Academy of Sciences.

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Journal of Environmental Sciences (Established in 1989)
Volume 30 2015

Supervised by	Chinese Academy of Sciences	**Published by**	Science Press, Beijing, China
Sponsored by	Research Center for Eco-Environmental		Elsevier Limited, The Netherlands
	Sciences, Chinese Academy of Sciences	**Distributed by**	
Edited by	Editorial Office of Journal of	Domestic	Science Press, 16 Donghuangchenggen
	Environmental Sciences		North Street, Beijing 100717, China
	P. O. Box 2871, Beijing 100085, China		Local Post Offices through China
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Editor-in-chief	X. Chris Le	**Printed by**	Beijing Beilin Printing House, 100083, China

CN 11-2629/X **Domestic postcode: 2-580** **Domestic price per issue RMB ¥ 110.00**

ISSN 1001-0742