Agricultural Water Management 135 (2014) 90–99

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Review

Irrigating with arsenic contaminated groundwater in West Bengal and Bangladesh: A review of interventions for mitigating adverse health and crop outcomes

Nari Senanayake[a,*], Aditi Mukherji[b,1,2]

[a] International Water Management Institute, Colombo, 127, Sunil Mawatha, Pelawatta, Battaramulla, Sri Lanka
[b] International Centre for Integrated Mountain Development (ICIMOD), GPO Box 3226, Kathmandu, Nepal

ARTICLE INFO

Article history:
Received 14 June 2013
Accepted 27 December 2013
Available online 28 January 2014

Keywords:
Groundwater irrigation
Agriculture
Arsenic mitigation interventions
Systematic review
West Bengal
Bangladesh

ABSTRACT

There is a rich body of literature on arsenic (As) contamination of groundwater and its consequences for human health via drinking water. Less is known however, on the impacts that flow from the use of arsenic rich groundwater for irrigation or the effectiveness of arsenic remediation in agricultural systems. To partially fill this gap, we review 29 studies that examine the consequences of irrigating with arsenic contaminated groundwater and 28 studies which evaluate interventions aimed at reducing its negative impacts on human health and crops. These studies are geographically limited to West Bengal and Bangladesh (Bengal plains) as these regions constitute hubs of concerns for groundwater contamination. These studies show that there are six broad categories of interventions: deficit irrigation; soil fertilization; growing alternative field crops (other than paddy); switching to arsenic tolerant paddy cultivars; cooking methods to reduce arsenic content in rice and nutritional supplements. Importantly, these efforts target different stages of the agri-food system, some intervene in production processes and balance concerns for crop yields and human health while others focus on consumption practices and only mitigate health risks. Despite this diversity in focus, our results indicate that all treatments have positive effects, either in reducing As content in grains, its accumulation in soil and/or increase crop yields compared to control groups. However, the extent of these impacts varies as do their implications for long-term agricultural sustainability. From a policy perspective, these interventions offer promising alternatives to the extremes of restricted groundwater use on the one hand, and unregulated extraction on the other, but are yet to be integrated into mainstream extension services.

Contents

* Corresponding author. Current address: University of California, Davis, CA 95616, USA. Tel.: +1 5302204792.
E-mail addresses: nsenanayake@ucdavis.edu (N. Senanayake), amukherji@icimod.org (A. Mukherji).
[1] Tel.: +91 9775003222x254.
[2] Current address: International Centre for Integrated Mountain Development (ICIMOD), GPO Box 3226, Kathmandu, Nepal.

0378-3774/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agwat.2013.12.015

1. Introduction: Setting the context

Literature on arsenic contamination of groundwater is replete with studies about the health impacts of drinking arsenic contaminated water as well as assessments of mitigation efforts in that context. Less is known however, on the use of arsenic rich groundwater for irrigation particularly its extent, its impact on crop health, as well as the effectiveness of arsenic remediation efforts in agricultural contexts. This is despite obvious implications for food and livelihood security (Dittmar et al., 2007) and the possible adverse health and crop impacts associated with arsenic exposure via food chain contamination (Williams et al., 2006; Khan et al., 2009).

While, irrigation with arsenic contaminated groundwater has emerged as a threat to the health and livelihoods of people in the Bengal plains (Bangladesh and West Bengal), the scale and complexity of these threats as well as the trade-offs involved in their mitigation are not yet well understood. This is due to the complex and sometimes contested nature of the problems involved. First, chronic exposure via contaminated crop consumption poses serious health risks such as cancers of the skin, bladder, lung, and liver, and of stroke (National Research Council, 2001). However, unlike the risk of exposure via drinking water, the numbers affected by food-chain contamination are un-quantified. A second dimension of the problem is that groundwater is often the *only* source of irrigation in these regions and plays an important role in livelihood and food security. Consider, Bangladesh, which achieved food self-sufficiency and rapid poverty alleviation in the 1990s thanks to intensive use of groundwater (Karim, 2001), and West Bengal which became rice self-sufficient in the 1980s by using groundwater for irrigation (Pal et al., 2009). Thus, groundwater irrigation plays a crucial role in bridging shortfalls in water supply, stabilizing agricultural production, achieving food security in these regions, and is also an effective vehicle of poverty alleviation (Palmer-Jones, 1992; Harriss, 1993). Finally, dependence on groundwater for livelihoods and poverty alleviation often means that remediation efforts which limit water supply in the short term can have adverse consequences for participating farmers and pose serious and immediate threats to food and livelihood security in the region. Thus, the very farmers who are the targets of remediation policies are often negatively affected by mitigation efforts, especially when those efforts fail to offer credible irrigation alternatives.

In light of the above, this paper provides an overview of the impacts of irrigating with contaminated groundwater on soil quality, grain uptake, and crop productivity. It then draws on the methodology of systematic review to analyze and compare the findings of 28 distinct mitigation efforts in the Bengal plains. We focus on a variety of interventions, ranging from deficit irrigation regimes and fertilization to improved cooking methods and hyper-accumulation of arsenic in soil through algae. A core goal of this study is to examine whether or not these interventions work and to what extent. In all cases we measure remediation potential and success based on changes in arsenic grain content, yield, and/or soil accumulation. Finally, we discuss some implications of our findings for future research.

2. Review questions and methodology

The emerging literature on arsenic and irrigation is quite broad in scope. It includes several strands of inquiry including: studies which document the extent of contaminated water use in agriculture (Dittmar et al., 2007; Ahmed, 2009); the chemical and bio-physical mechanisms of arsenic uptake by different crops (Williams et al., 2005; Bhattacharya et al., 2009, Bogdan and Schenk, 2009) and fish (Das et al., 2004; Chen and Liao, 2012); the possible health impacts of ingesting arsenic through human food chain contamination (Huq et al., 2006a; Pal et al., 2009; Kar et al., 2012); the impacts of irrigating with arsenic contaminated water on soil and crop productivity and finally, mitigation measures for reducing negative impacts of irrigating with arsenic contaminated groundwater. Of interest to us in this paper are the last two strands of literature. Specifically, our review addresses two questions:

1. What is the impact of irrigating with arsenic contaminated groundwater on soil quality, crop productivity, and uptake of arsenic by crops?
2. What are the impacts of various mitigation measures on reducing arsenic accumulation in soil, grain, and crop productivity?

To answer these questions, we draw on the methodology of systematic review (Higgins and Green, 2008). Systematic reviews utilize methodical search and data collation techniques to synthesize evidence across all available studies. To locate as comprehensive a set of studies as possible, we searched all major academic databases, including Water Resources Abstract, CAB Direct, Econ Lit, Sociological Abstracts, Web of Science, Scopus, World Bank Publications, FAO's AGRIS database, ProQuest Central, EVA Environmental Abstracts, Ingenta Connect, Ovid Databases, JSTOR, Sage Journals, Science Direct, IWMI's catalogue, and Google Scholar search engines. We also conducted searches of 'grey' literature to locate relevant conference proceedings, technical reports, and other unpublished documents.

To answer our first question, we limited our citations to studies that document impacts of irrigating with arsenic contaminated water in the Bengal plains. In particular, these studies measure arsenic concentration in topsoil, arsenic uptake by various types of crops, and the impacts of irrigating with arsenic rich water on crop productivity. We review 29 such studies which use credible controls. The findings of these impact assessments are examined through narrative summaries. While arsenic contamination of aquaculture products (where agricultural fields are also used for fish farming) is an important pathway of entry of arsenic into the human food chain, we do not review evidence on this issue because no studies dealing with arsenic and aquaculture meet our review criteria.

To answer our second question we limited our citations to those which examined mitigation strategies for agriculture in the Bengal plains; studies that used credible counterfactuals to measure impact of mitigation efforts; and studies where As uptake by crops and soils and crop yields were used as outcomes measures. Based on these criteria, 28 studies were included in