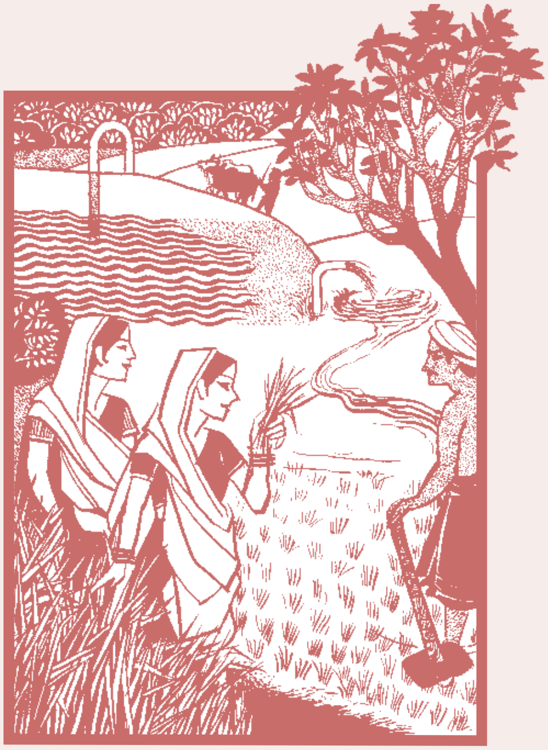

This Highlight reviews 34 papers that deal with interventions aimed at reducing negative impacts of irrigating with Arsenic (As) rich water. These studies show that there are six broad groups of interventions: deficit irrigation, soil fertilization, growing crops other than paddy, switching to As tolerant paddy cultivars, cooking methods to reduce As content in cooked rice and nutritional supplements. All these treatments are effective in reducing the uptake of As in grains and its accumulation in soil and increasing crop yields compared to control group, but the extent of these impacts vary. From a policy perspective, it is encouraging that these interventions are able to mitigate the negative impact of As in irrigation water to varying extent. This is because poor farmers in the Bengal delta are likely to continue to use groundwater for irrigation in the foreseeable future in the absence of any other viable options.

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HIGHLIGHT

Irrigating with Arsenic Contaminated Groundwater in the Bengal Delta

A Review of Mitigation Options

**Narmadha Senanayke and
Aditi Mukherji**

IRRIGATING WITH ARSENIC CONTAMINATED GROUNDWATER IN THE BENGAL DELTA A REVIEW OF MITIGATION OPTIONS[1]

Research highlight based on a paper with the same title[2]

INTRODUCTION

Literature on arsenic (As) contamination of groundwater is replete with studies about the impacts of drinking As contaminated water on human health as well as mitigation efforts in that context. Less is known, however, on the extent of use of As rich groundwater for irrigation and effectiveness of As remediation in agricultural contexts despite obvious implications for food and livelihood security (Dittmar et al. 2007) and the possible adverse health and crop impacts associated with As exposure via food chain contamination (Williams et al. 2006; Khan et al. 2009). In this study, we do a systematic review of all available evidence on the impact of mitigation measures aimed at reducing negative consequences of irrigating with As rich water.

While irrigation with As contaminated groundwater has emerged as a threat to health and livelihoods of poor people in the Bengal delta (Bangladesh and West Bengal), the scale and complexity of these threats as well as the tradeoffs involved are not very well understood. This is because of the multi-dimensionality of the problems involved. First, chronic exposure via contaminated crop consumption poses serious health risks such as stroke, cancers of the skin, bladder, lung, and liver (National Research Council 2001). However, unlike the risk of exposure via drinking water, the numbers affected by food-chain contamination are un-quantified. Second dimension 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 self-sufficient in the 1980s by using groundwater for irrigation (Pal et al. 2009:3349). Thus groundwater irrigation plays a crucial role in bridging shortfalls in water supply, stabilizing agricultural production and achieving food security in these regions and is also an effective vehicle of poverty alleviation (Palmer-Jones 1992; Hariss 1993). Third, dependence on groundwater for livelihoods and poverty alleviation means that the very farmers who are the targets of remediation policies often get negatively affected by mitigation efforts, unless those efforts also look at credible alternatives (Khan et al. 2010; Azad et al. 2009; Abedin et al. 2002; Panaullah et al. 2009).

REVIEW METHODOLOGY

This review focuses on impact evaluation studies that look at remediation efforts for agricultural uses of As contaminated water. To examine the effectiveness of these mitigation efforts we used the methodology of systematic review (Higgins and Green (eds) 2008), which draws on 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. We also conducted searches of 'grey' literature to locate relevant conference proceedings, technical reports and other unpublished documents.

These searches returned over 1200 records. After reviewing titles and abstracts, we then limited our citations to those which were about mitigation strategies for agriculture in the Bengal delta; studies that used credible counterfactuals to measure impact of mitigation efforts; and where As uptake by crops and soils and yield of crop were used as outcome measures. According to this, 34 studies were included for review. We then coded studies on a range of methodological, descriptive and outcome/ impact related attributes. Though all studies were of high methodological quality, heterogeneity in intervention type and outcomes measured precluded

[1]This IWMI-Tata Highlight is based on research carried out with support from the International Water Management Institute (IWMI), Colombo. It is not externally peer-reviewed and the views expressed are of the authors alone and not of IWMI or its funding partners.

[2]This paper is available on request from p.reghu@cgiar.org

Table1 Different categories of interventions for mitigating impact of As in agriculture

Sr. No	Category of intervention	Focus of intervention	Number of studies
1	Changes in water management practices such as deficit irrigation, aerobic cultivation and intermittent ponding for paddy	To reduce uptake of As by soil and plant parts including grains and to reduce the impact of yield loss	13
2	Soil remediation including fertilization and bio-remediation	Same as above	11
3	Cooking methods for rice	To reduce human ingestion of As contaminated rice	3
4	Breeding As tolerant paddy or choosing suitable paddy cultivars	Same as above	2
5	Growing field crops other than paddy	Same as above	1
6	Nutritional supplements	To combat poor nutritional status and reduce susceptibility to As related diseases	1

quantitative meta-analysis. Therefore, we synthesize the existing evidence using narrative summaries and tables.

Interventions for mitigating impact of As on uptake by crops, soils and on crop yields: A review of effectiveness

A review of literature shows that interventions aimed at mitigating negative impacts of irrigating with As contaminated water may be summarized into six categories (Table 1).

Do water management practices like deficit irrigation reduce the burden of As?

The largest number of mitigation related studies focus on paddy and alternative irrigation methods to irrigate paddy. The overwhelming majority of these studies (Stroud et al. 2011; Li et al. 2009; Sarkar et al. 2012; Rahaman et al. 2011; Xu et al. 2008; Roberts et al. 2011; Huq et al. 2006; Hua et al. 2011; Das et al. 2008; Basu et al. 2010) show that deficit irrigation systems reduce As grain content when compared to conventional flood irrigation regimes. Duxbury et al. (2007) is the only key exception.

However, there is some debate over which type of deficit irrigation system: aerobic or intermittent ponding, results in the least grain accumulation. On one hand, Li et al. (2009) found growing rice aerobically during the entire rice growth duration resulted in the least grain As accumulation. Basu et al. (2010) and Xu et al. (2008) cite similar findings. On the other hand, Sarkar et al. (2012) found that while aerobic water regimes resulted in the lowest level of root As, the content of As in leaf and grain attained by imposition of intermittent ponding only during the vegetative stage of rice growth was optimum in terms of reducing As content in straw and grain (by 23 and 33 percent respectively).

The impacts of deficit irrigation on crop productivity are also contested and differ depending on the type of regime used. According to Duxbury et al. (2007), Xu et al. (2008) and Talukder et al. (2010) the yield of aerobically grown crops is less affected by As contamination than conventional flooded systems. On the other hand, Li et al. (2009), Peng et al. (2006) and Sarkar et al. (2012) find that the continuous cultivation of aerobic rice actually results in a substantial yield decline vis-à-vis other water management regimes.

However, in all reviewed studies As accumulation in soils was the least in aerobic conditions. According to Sarkar et al. (2012), the highest value of soil As was attained under continuous ponding followed by intermittent ponding, saturated and aerobic regimes. Similarly, Talukder et al. (2010) and Xu et al. (2008) argue aerobic cultivation reduced the amount of As deposited to the soil.

Taken together, the evidence suggests that the remediation potential of deficit irrigation is promising in terms of reducing As content in grains and soils. However, the positive impacts of deficit irrigation for crop productivity are contested. This may be a cause for concern from a policy perspective since it will be difficult to convince farmers to move to deficit irrigation regimes if their crop yields go down on account of this.

Do measures like artificial fertilization and bio-remediation help?

A large number of studies explore the mitigation potential of soil amendments such as application of inorganic fertilizer or organic manure which can immobilize, adsorb, bind or co-precipitate As *in situ*. The overwhelming majority of studies found that fertilization (irrespective of type) reduces As concentrations in grains. Li et al. (2009) for instance found silicon (Si) fertilization decreased the total As concentration in straw and grain by 78 and 16 percent, respectively. Talukder et al. (2010) and Pigna et al. (2010) show significant reductions of As content in rice grain at higher phosphorous amendments. Huq et al. (2011) found that the total accumulation of As in three rice varieties BR 29, BR 35, and BR 36 was reduced by 227, 229, and 397 percent, respectively when balanced NPK fertilizers were added to the medium.

Several studies also investigate the potential of organic matter to remediate As accumulation in grains. Rahman et al. (2011) found that combined applications of various types of organic manure reduced the As content by 33.47 percent and 36.87 percent in whole grains and milled grains respectively, compared to control soils where no such manure was applied. Similarly, Huq et al. (2008) reported that organic matter application was able to reduce As accumulation by as much as 75 percent in the vegetative part of the plant.

Overall the impact of fertilization on crop yields is positive. Li et al. (2009) found the addition of Si fertilizer increased grain and straw yield significantly. Huq et al. (2008) found yield differences could be avoided by balance fertilization. Huq et al. (2011) also found that the effect of balanced fertilization on the total and grain yield of rice was highly significant. Pigna et al. (2010) found that for plants grown without phosphorous addition there was a decrease in biomass production of 15 percent, 52 percent, and 67 percent as As concentration in the irrigation water increased, but this reduction was less severe when phosphorous was added to soils. Finally, Huq et al. (2008) found that organic-matter application had a more positive effect on yields than no application at all levels of As spiking.

A commonly cited drawback of fertilization, however is that it has not proven to be effective in remediating As accumulation in agricultural soils. Li et al. (2009) for instance found the addition of Si fertilizers increased As concentration in the soil solution. Huq and Joardar (2008) record similar results for balanced fertilization, and Huq et al. (2011) observed that higher amounts of As were found to remain in the soils treated with balanced fertilizers compared to non-fertilized soils. However, Das et al. (2008) and Mukhopadhyay et al. (2000) found that the As content in soil markedly decreased, especially with farmyard manure application.

Bio-remediation of soils using algae and fungi has been tried and shown to be successful. Huq et al. (2007) observed that algae could reduce accumulation of As in rice plants by as much as 71 percent and was also found to depress As accumulation in soil. In a related study, Srivastava et al. (2010), evaluated the As removal efficacy of ten fungal strains and found five out of these strains were very effective with high rates of bioaccumulation.

Does switching to alternative field crops have any impact?

Substituting dry land crops such as maize or wheat for rice also has the potential to reduce As accumulation in both soils and food crops (Brammer 2009). Dry-land crops are less water-intensive than paddy and as such can reduce soil As content and crop uptake using the same mechanisms as aerobic cultivation. Indeed, Duxbury et al. (2007) found that 'wheat and maize grain contained approximately 7 and 25 times less As than rice grain.' Williams et al. (2007) produced similar results in their study of 173 individual sample sets of commercially farmed rice, wheat, and barley. Finally, Su et al. (2010) found that regardless of the As form supplied to plants [arsenite or arsenate], rice accumulated more As in the shoots than wheat or barley. However, Brammer (2009) raises important questions about the feasibility of substituting field crops, such as wheat, barley and maize for rice on a large scale; given that rice has always been the preferred crop of the farmers in the region.

Does breeding As tolerant paddy cultivar help?

Limitations of crop substitution have led scholars such as Norton et al. (2009) to advocate breeding As tolerant rice cultivars. To date, research in this area shows that As uptake, accumulation, and phytotoxicity differ significantly depending on the cultivar used (Rauf et al. 2011; Hua et al. 2011). For example, in a comparative study of As uptake in three different rice cultivars, Hua et al. (2011) found Rondo and Cocodrie varieties were more susceptible to elevated soil As levels, while Zhe 733 was less susceptible. Similarly, Rauf et al. (2011:1678) found that the As contents in grain and husk of rice variety BR 11 were higher than those of BRRI Dhan 33. Another study (Huq et al. 2011) found total accumulation of As in the rice variety BR 35 to be less than BR 29 and both to almost 50 percent less than BR 36. Thus, the remediation potential of breeding As tolerant rice varieties is promising in terms of reducing grain content and yield losses. However, such mitigation solutions have no impact on the rate of soil-As accumulation.

Do cooking methods of rice have an impact on As ingestion by humans?

The potential of cooking methods to reduce As content in rice grains is shown by Pal et al. (2009) who found that, up to 57 percent of As can be removed from As contaminated rice using cooking methods traditional to the Indian subcontinent (wash until clear, cook rice in excess water and finally discard excess water). These results are consistent with those obtained by Sengupta et al. (2006:1823) and Mihuez et al. (2007:1722). However, the remediation potential of traditional cooking methods depends on the As content of the cooking water. This again underlines the need for providing As free water for drinking and domestic purposes to all rural households in Bengal.

Can nutritional supplements play any role in reducing susceptibility to As induced diseases?

A very different set of studies investigate the links between poor nutritional status and increased susceptibility to As related diseases (Mitra et al. 2004; Maharjan et al. 2006) and highlight the potential of nutritional supplements to reduce the risk of As related health outcomes. Gamble et al. (2006) in a randomized, double-blind, placebo controlled folic acid supplementation trial in a rural region of Bangladesh found that folic acid supplementation to participants enhances As methylation. Because persons whose urine contains low proportions of dimethyl arsinate (DMA) and high proportions of monomethyl arsonate (MMA) and inorganic (unmethylated) As have been reported to be at greater risk of skin and bladder cancers and peripheral vascular disease, these results suggest that folic acid supplementation may reduce the risk of As-related health outcomes.

Conclusion

As contamination of groundwater and its consequences for drinking water and remediation measures thereof has been an area of intense focus and study since the early 1990s. However, as this paper highlights, the debate on impact of irrigation with As contaminated water is much more complex than the drinking water debate.

What is encouraging however is that search for solutions has already begun and it is recognized that agriculture and irrigation with groundwater are central to the livelihoods of millions of poor people in the Bengal delta. We found as many as 34 high quality papers that used credible counterfactuals to measure the impact of six broad categories of treatments. Our review shows that all these methods have some positive impact by reducing uptake of As by plant and its accumulation in the soil and preventing yield reduction in crops, though all interventions are not equally effective, some are better than others and effectiveness depends on a large number of other factors. Here, the area for future research is to understand the combined effect of all these interventions. For example, Das et al. (2008) studied the interaction between zinc fertilization and deficit irrigation. While these studies and experiments are going on, it is equally important to create awareness among farmers and extension officials about several mitigation interventions that show promising results. It is highly likely that farmers in Bengal delta will continue to use groundwater for irrigation in the foreseeable future because there are no other alternate sources of irrigation. Therefore, understanding and adopting these mitigation measures is necessary to minimize the negative impacts of irrigating with As contaminated water.

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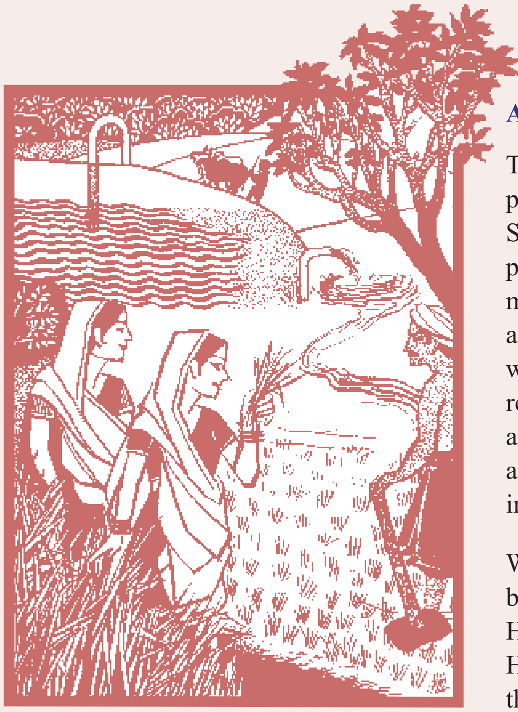

About the IWMI-Tata Program and Water Policy Highlights

The IWMI-Tata Water Policy Program (ITP) was launched in 2000 as a co-equal partnership between the International Water Management Institute (IWMI), Colombo and Sir Ratan Tata Trust (SRTT), Mumbai. The program presents new perspectives and practical solutions derived from the wealth of research done in India on water resource management. Its objective is to help policy makers at the central, state and local levels address their water challenges – in areas such as sustainable groundwater management, water scarcity, and rural poverty – by translating research findings into practical policy recommendations. Through this program, IWMI collaborates with a range of partners across India to identify, analyze and document relevant water-management approaches and current practices. These practices are assessed and synthesized for maximum policy impact in the series on Water Policy Highlights and IWMI-Tata Comments.

Water Policy Highlights are pre-publication discussion papers developed primarily as the basis for discussion during ITP's Annual Partners' Meet. The research underlying these Highlights was funded with support from IWMI, Colombo and SRTT, Mumbai. However, the Highlights are not externally peer-reviewed and the views expressed are of the author/s alone and not of ITP or either of its funding partners.

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