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Arsenic in rice: state of knowledge and perceptions in Cambodia

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1. Introduction

As a strategy to reduce risk associated with seasonal drought and enhance cropping intensity, farmers in the Lower Mekong and Bassac River basins of Cambodia have resorted to exploiting groundwater resources through shallow tube wells. This approach offers distinct advantages over poorly designed surface-based irrigation systems that were constructed during the Pol Pot era in Cambodia in the 1970s. While farmers' access to groundwater resources allows for individual approaches to on-farm water management and greater flexibility, it does hold potential risks in the Lower Mekong basin due to the presence of naturally occurring pockets of arsenic-bearing ground water which can have extremely elevated levels of up to and over 500 micrograms (µg) per litre, which pose a threat to human health (Fredericks and Arsenic Secretariat 2004).

The Cambodian government has been promoting the intensification of rice farming through an additional crop in the dry season, and Cambodian rice farmers are increasingly accessing groundwater to fully irrigate paddy. Under these flooded anoxic conditions, underground arsenic deposits in the form of arsenite (As^{III}) become increasing available and are readily taken up by rice plants, thereby entering the food chain. This has health implications for households regularly consuming contaminated rice over extended periods.

The potential impact of arsenic entering the human food chain through the consumption of rice grain in Cambodia has only recently been considered

While the impacts of arsenic on human health, including cancer and skin lesions, became evident in the early 2000s as Cambodians turned to groundwater as a source of cleaner drinking water (Fredericks and Arsenic Secretariat 2004), the potential impact of arsenic entering the human food chain through the consumption of rice grain in Cambodia has only recently been considered (Phan et al. 2013; Gilbert et al. 2015).

This study assesses the current state of knowledge and perceptions of arsenic contamination in rice among different stakeholders in Cambodia and identifies major knowledge gaps and possible policy responses to the issue.

The paper explores two research questions:

1. How do different stakeholders understand and perceive the issue of arsenic in rice, in terms of public health, potential mitigation measures, and policy?
2. What are the major knowledge gaps regarding rice in arsenic that would affect policy-making?

The next section details the methodology. Section 3 outlines the state of academic knowledge on arsenic in rice. Section 4 reviews stakeholder perceptions of arsenic in Cambodia based on key informant interviews and a roundtable on public health and mitigation measures to arsenic contamination in rice. The paper concludes with a discussion.

2. Methodology

We conducted a literature review to assess the state of academic knowledge on arsenic in Cambodian rice farming. In November 2016, in partnership with the Cambodia Development Resource Institute (CDRI), we interviewed representatives from 18 stakeholder organisations representing academia, agriculture, local communities, local and international non-governmental organisations (NGOs), government line agencies, and the private sector to understand their knowledge and perspectives on the issue.

Finally, on 24 February 2017 we held an Inception Roundtable on Arsenic Uptake in Rice in Cambodia with 47 participants from the government, universities, research organisations, and local and international NGOs.[1] The purpose was to share research findings from experts, discuss measures to address the issue, and identify key knowledge gaps. The roundtable was co-hosted by the General Directorate of Agriculture (GDA) of the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Cambodia, CDRI, and SEI. The comments made by stakeholders in this report have been anonymised.

1 See Annex 1 for a complete list of organisations participating in the roundtable.

3. State of academic knowledge

The key findings that emerged from the literature review are presented below.

3.1 Arsenic, drinking water and public health

Arsenic is one of the heavy metals that can be persistent in the environment and cause widespread health risks from excessive and chronic exposure. Drinking water and food are the main exposure routes; drinking water is the dominant source of intake if the concentration of arsenic is at least 10 µg per litre. In the Asia-Pacific region, arsenic is present in elevated concentrations in some natural waters, especially groundwaters with sulphitic minerals and volcanic secondary rock deposits. In Bangladesh and West Bengal major public health crises have resulted from elevated arsenic concentrations in groundwater (WHO 2011b). Consuming drinking water with elevated arsenic levels not only causes arsenicosis,[2] it has also been found to cause a range of cancers including skin, bladder and lung cancers (WHO 2011a).

Naturally occurring arsenic contamination of groundwater is now known to occur in many regions in the Asia-Pacific. Shallow groundwaters (i.e. 15–100m) in the unconsolidated floodplain sediments of large river basins, such as those of the Mekong River, Red River, Ganges River and Brahmaputra River, are particularly at risk. Arsenic concentrations in these areas range from 0 µg/l to over 500 µg/l (Fredericks and Arsenic Secretariat 2004). However, even at the highest concentrations, detrimental health impacts of consuming arsenic-contaminated groundwater are usually only observed after the water has been regularly consumed for at least 10 years. No groundwaters have concentrations high enough to cause acute and immediate health impacts (Fredericks and Arsenic Secretariat 2004).

Although the health hazards of elevated levels of arsenic in groundwater have been known for over a century, the issue was only recognised in Southeast Asia (mainly in Cambodia and Viet Nam) over the past twenty years (Polya et al. 2008). In Cambodia, arsenic concentrations are highest within the Mekong River floodplain, particularly in Kandal and Kampong Cham provinces, though high concentrations can also be found in Kratie, Kampong Thom, Prey Veng and Preah Vihear (Polya et al. 2010).

Figure 1 shows that tube wells in many communities in these low-lying areas along the Mekong and Tonle Bassac rivers have been found to have high levels of arsenic (Sampson et al. 2008; Fredericks and Arsenic Secretariat 2004). For instance, water from all 46 tube wells tested by Phan et al. (2010) in Kandal province contained arsenic concentrations higher than 50 µg/l.[3]

Sampson et al. (2008) estimated that over 100 000 people in Cambodia are at high risk of being chronically exposed to groundwater with arsenic levels exceeding 50 µg/l. In some shallow wells, arsenic concentrations have been as high as 3500 µg/l (Sampson et al. 2008). Although arsenicosis symptoms are widely thought to take up to 10 years of exposure to appear, Sampson et al. (2008) observed these symptoms in Cambodians who were exposed to arsenic-rich well water after only three years (Polya et al. 2008).

3.2 Arsenic exposure through rice consumption

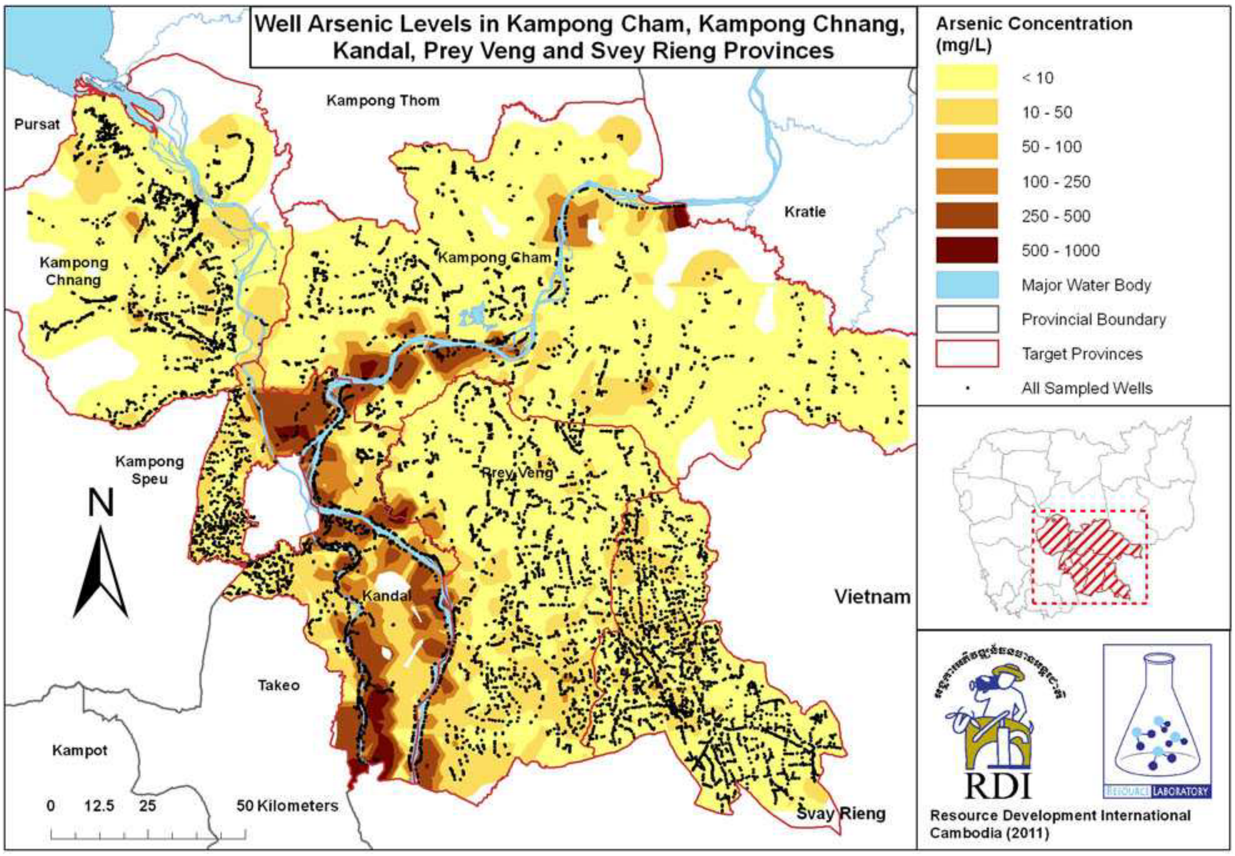
Rice consumption has been found to be a major exposure pathway for arsenic ingestion in areas where arsenic-rich groundwater, such as West Bengal and Bangladesh (Hossain 2006; Mazumder and Dasgupta 2011), have been used in irrigation of the crop. Indeed, rice intake is the most important exposure pathway for communities that do not drink groundwater or where drinking water arsenic concentrations are less than 50 µg/l (Banerjee et al. 2013). This is due to a combination of factors:

- the irrigation of rice with groundwater, particularly in the dry season, and the accumulation of arsenic in the topsoil from irrigation
- the anaerobic conditions of flooded paddy fields in which arsenic exists as As(III), which is soluble in water and readily available for plant uptake

2 Arsenicosis is an effect of arsenic poisoning resulting from exposure to arsenic over a long period of time. Its health effects include skin problems (such as colour changes to the skin, and hard patches on the palms and soles of the feet) and cancers of the skin, bladder, kidneys and lungs.

3 The Cambodian national standard for arsenic in drinking water is a limit of 50 µg/l. The WHO standard is 10 µg/l.

Figure 1. Arsenic levels and distribution in selected Cambodian provinces. Source: (RDI 2012)



- the high efficiency with which rice takes up arsenic compared to other cereal crops, and
- the consumption of rice as a staple in communities in these areas.

In addition, the concentration of arsenic in rice depends on factors such as the variety of rice and the processing method. Cooking rice with arsenic-rich water also increases arsenic intake (Mondal and Polya 2008; Dittmar et al. 2010; Su et al. 2010; Sharma et al. 2014). In West Bengal, Banerjee et al. (2013) found that people consuming rice with levels of arsenic over 200 µg/kg experienced more genotoxic effects even without drinking arsenic-tainted groundwater.

Studies in Cambodia have indicated that arsenic intake through rice consumption is an additional exposure pathway to drinking water. Phan et al. (2013) found that the intake of inorganic arsenic through food in Kandal province was higher than the minimum daily dose required for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$) (Phan et al., 2013).[4]

Most of that inorganic arsenic intake was from rice. In Prey Veng province, the same increased risk of lung cancer was found for the dose of inorganic arsenic intake from groundwater and rice consumption combined. Wang et al. (2013) found that rice was the second largest contributor to daily arsenic intake in Kandal and Kampong Cham, after fish. As a result, the daily arsenic intake through foodstuffs in Kandal exceeded the $BMDL_{0.5}$. A study by O'Neill et al. (2013) in Prey Veng indicated that residents who used groundwater from an arsenic-contaminated tube well to cook rice consumed around eight times more arsenic than the World Health Organization (WHO) safe limit.

Gilbert et al. (2015) conducted a market survey of rice in Cambodia (from seven different provinces), Thailand and Viet Nam sold in Kandal province. The study found that the mean arsenic concentration

4 $BMDL_{0.5}$ is the benchmark dose lower-confidence limit for inorganic arsenic for a 0.5% increased incidence of lung cancer in humans.

in rice grown in Cambodia was higher than that in rice from Thailand and Viet Nam, with the highest concentration in white sticky rice from Cambodia. However, the calculated daily dose of inorganic arsenic from consuming Cambodian rice was lower than the $BMDL_{0.5}$. Gilbert et al. (2015) also examined arsenic intake in Preak Russey village in Kandal province, which was where the first cases of visible arsenicosis were documented. Although the community had switched to drinking water with an arsenic content of less than 50 µg/l, the daily dose of inorganic arsenic from consuming both water and locally grown rice still exceeded the $BMDL_{0.5}$ in 12 out of 15 individuals.

3.3 Mitigation measures

Researchers have proposed several agronomic measures to mitigate arsenic uptake in rice, that include: irrigating with surface water rather than groundwater; cultivating rice in aerobic conditions for at least part of the cropping season (such as through alternate wetting and drying); using cultivars with lower arsenic accumulation rates; reducing rice straw and organic matter inputs into soils; and making silicate based soil amendments to soils requiring silicon (Wichelns 2016).

3.4 Rice export policies

Rice is widely cultivated in Cambodia and serves as a major source of nutrition and employment. Paddy rice production systems occupy approximately 75% of the arable land in the country (World Bank 2016). An estimated three million people are employed in the rice value chain, accounting for nearly 20% of employment for the country's working age population (IFC 2015). Rice constitutes a 33% share of food spending for the average household and 46% of food spending for poor households (World Bank 2016).

The crop contributes significantly to agricultural GDP and poverty alleviation – two of Cambodia's key policy development initiatives (Johnston, Try, et al. 2013). To achieve these objectives, the government has focused on rice intensification through dry season irrigation as well as securing wet season rice. One notable policy to promote rice as an export commodity was the 2010 rice export policy, which aimed to reach a goal of exporting one million tons of rice by 2015. The policy planned to reach this target by increasing rice milling capacity, increasing food quality standards to promote export, and modernising farming techniques. The policy also included specific measures to support farmers such as improving land titling, which had the aim of helping farmers gain greater access to credit (FAO 2014). Supplemental policy measures to improve irrigation for rice, such as the National Strategy for Agriculture, were also part of the package.

Exports failed to reach the targeted one million tons by 2015, falling short by 0.5 million tons (Thath 2016). However, rice production, domestic consumption and export in Cambodia has steadily increased since 2008 (see Table 1). Furthermore, between the periods 2002 and 2011, the cultivated area of rice increased from 2.14 million hectares to 2.97 million hectares (see Table 2).

Table 1. Rice commodity balance between 2008 and 2013. Source: World Bank (2015)

Category	2008	2009	2010	2011	2012	2013
	thousands of tons					
Total rice production, paddy	7175	7586	8250	8779	9291	9389
Total rice production, milled equivalent	4305	4552	4950	5267	5575	5633
Domestic utilisation	2862	2937	3039	3126	3212	3256
Total rice surplus	1443	1614	1911	2142	2368	2378
Total formal export of milled rice	1.5	12.61	105.26	201.89	205.71	378.85
Estimated informal paddy export in milled equivalent	100	200	350	1472	1600	1536

Table 2. Diversification in cultivated area of Cambodian crops, 2002–2011. Source: (World Bank 2015)

Indicator	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Cultivated crop area (thousands ha)	2473	2718	2823	2939	3111	3199	3321	3519	3730	3990
Cultivated area under paddy (thousands ha)	2137	2314	2374	2444	2541	2586	2616	2719	2796	2969
Share of paddy in total cultivated area (%)	86	85	84	83	82	81	79	77	75	74

Recent figures from the Cambodian Rice Federation show that exports of milled rice reached 500 000 tons in 2016 and the government had discussed a renewed export goal of 1.5 million tons annually. The majority of rice exports (62%) are bound for the European market (IFC 2015). Additionally, Cambodian rice has increasingly been recognised for its quality and has won awards from 2012–2014 at the World Rice Conference with its fragrant rice variety Phka Rumduol or Phka Malis (Cambodia jasmine rice) (IFC 2015; Vannak 2017).

Despite the government's ambitious policies to increase rice export, there are cultural, economic and technical barriers to reaching the annual export target of 1.5 million tons. One of the major barriers is that farmers are diversifying the crops they grow. In a World Bank survey of farmers in Cambodia, 66% of farmers were diversifying their cropping systems and moving towards production of more highly demanded and profitable crops such as vegetables, maize and cassava. Farmers generate gross margins of up to US$ 505/ha for cassava, US$ 303/ha for maize, and US$ 1393/ha for vegetable production compared to US$ 295/ha for dry season rice and US$ 245/ha for wet season rice. Furthermore, the share of rice within the cultivated area as a ratio declined from 86% in 2002 to 74% in 2011 (see Table 2) as the cultivation areas of other crops, such as maize and especially cassava, increased drastically as farmers found these crops more profitable (World Bank 2015). Yet despite favourable market conditions and an increase in cultivation area for other crops, the study also found that farmers continued to grow rice, mainly for cultural reasons (World Bank 2015).

A further challenge to increasing rice production is the limited availability of irrigation systems for dry season cropping. As of 2015, 62% of Cambodia's rice was produced in the wet season with a mere 12% being produced in the dry season, clearly indicating the limited functional installed irrigation capacity in the country (World Bank 2015).

Farmers are willing to take on additional financial and other risks to increase the area of rice cultivated in the dry season, because returns on investment are higher for the dry season than for the wet. For instance, farmers are increasingly using pump irrigation, particularly for the cultivation of rice and vegetable crops over other types of crops (see Figure 2). In fact, rice producers spend up to 20% of their total variable costs on irrigation through small pump sets. Additionally, the area of dry season cropping increased from 13% in 2008 to 17% in 2013 (World Bank 2015). Further, while the returns on investment are higher for the dry season than in the wet season, the risk of pest damage is also higher, as are costs of inputs required in terms of suitable varieties, fertiliser, and pesticides. Opportunities for dry season production are therefore available only to farmers with the capacity to invest and take investment risks (Johnston, Try, et al. 2013).

3.5 Groundwater and irrigation

Use of groundwater for small-scale irrigation is growing in Cambodia. Farmers in the Mekong lowlands have been able to install shallow tube wells to pump water from shallow alluvial aquifers for dry season cultivation. In Cambodia, groundwater irrigation is known to occur in Siem Reap, Battambang and Kampong Chhnang provinces in the Tonle Sap region, Kampong Cham in the Phnom Penh region, and Prey Veng, Svay Rieng, Takéo, and Kandal in the south. From 1996 to 2005, the number of tube wells for irrigation in Prey Veng expanded more than 15-fold to 25 000 tube wells. In one commune, over 90% of farmers had installed tube wells (Johnston, Roberts, et al. 2013).

Small-scale pump irrigation allows farmers to access water without the large investments required for surface-based irrigation infrastructure. It also provides farmers with direct, timely and reliable control over water use. Groundwater is used to partially irrigate an early or late wet season rice crop that is grown in addition to the traditional wet season crop, or to supplement irrigation of the wet season crop and late-season recession rice. Groundwater access has therefore contributed significantly to the increase in double cropping (Johnston, Roberts, et al. 2013).

Critical to enhancing the use of groundwater in Cambodia is the question of its sustainability as a resource, which is not well understood. Different sources have reported widely disparate aquifer recharge rates, making it difficult to determine sustainable withdrawal rates. In some areas, over-abstraction of groundwater has resulted in water depletion, water quality deterioration, and high energy costs for pumping. Informal small-scale pump irrigation might therefore not be a viable source of water in the long-term (Johnston, Roberts, et al. 2013).

The question arises why groundwater use and development for agriculture is relatively limited in Cambodia compared to, for example, in South Asia where groundwater irrigation has expanded continuously, bringing negative impacts on groundwater resources. There are a variety of possible reasons for this, including the costs associated with pumping, particularly in areas where viable aquifers are deep; limited knowledge of the spatial and temporal distribution of the resource; the poor quality of much of the floodplain soils in Cambodia that are largely degraded and low in nutrients, which discourages the drilling of tubewells; and the fact that government agencies such as the Ministry of Water Resources and Meteorology (MOWRAM) have not encouraged the use of groundwater resources because of concerns over long-term sustainability. However, there is general consensus that groundwater irrigation has not grown substantially because the resource is not viable and if it were, it would have already been exploited (Johnston et al., 2014).

4. Stakeholders' perceptions about arsenic in rice in Cambodia

4.1 Arsenic in rice and public health

This section discusses stakeholder perceptions from key informant interviews and roundtable on the issue of arsenic in Cambodian rice. From both activities, it is apparent the public health concerns about exposure to arsenic through drinking water are well known and have been addressed by international and local NGOs (i.e UNICEF, WHO and Resource Development International), academics, and government departments (the Ministry of Rural Development and Ministry of Health) in Cambodia. However, both the interviews and roundtable revealed that an awareness of, and attention to, rice as an exposure pathway is much more limited.

Regarding testing rice for heavy metal contamination, many key informants were unclear of what studies have been conducted and their results. Reportedly, authorities have either tested, or are aware of testing of, rice samples from different areas in the country. One informant reported arsenic to have been detected in Pkar Rumduol rice grown in sandy soils outside of the Mekong basin, but the concentrations are unknown. An informant referenced studies which were conducted on arsenic in groundwater, paddy rice and cooked rice in Kratie, Kampong Cham, and Kandal, which found that Kandal rice had higher arsenic residues than rice from the other two provinces, but the concentrations were lower than the WHO threshold. This informant was likely referring to the study by Phan et al. (2013) which found that the upper range of daily arsenic intake from food consumption (mainly rice) alone in Kandal was higher than $BMDL_{0.5}$. Another key informant noted that only rice destined for export is tested for arsenic content, and that inspection companies had not found any elevated levels of arsenic in Cambodian rice as of late 2016. It was noted that that the European Union and United States do not permit any amount of arsenic in imported rice.

There is an important knowledge gap in terms of traceability: there is little or no record of the supply chains of rice sold in markets, either to its sources or to consumers in and outside Cambodia. This lack of traceability is key to understanding the risk of arsenic exposure through rice consumption. It was noted during the interviews that that much of the rice grown for domestic consumption has its origins around the Mekong River in Cambodia and is sold in Phnom Penh and in nearby towns, which are areas where rice consumption would be the main arsenic exposure pathway, rather than drinking water. During the roundtable, there were many comments that rice grown in Kandal is for domestic consumption, but that rice from Kratie and Kampong Cham is also exported to Viet Nam. While rice imports from Viet Nam, for example from An Giang province, are occurring, it would be important to assess samples as An Giang province is known to have high arsenic levels in groundwater.

The issue of arsenic contamination is highly sensitive, given Cambodia's emphasis on the importance of rice exports to its GDP. The economic implications of concerns appeared to be of greater concern to stakeholders at the roundtable than public health concerns.

4.2 The agronomy of arsenic uptake in rice and mitigation measures

The majority of informants and roundtable participants were aware that farmers in Cambodia use groundwater to irrigate rice crops during the dry season, when surface water is insufficient. However, there is a lack of clarity on which provinces predominantly use groundwater for irrigation. Informants reported that the government is promoting the cultivation of short- and medium-term varieties in place of long-season varieties, so that farmers can grow three crops of rice per year with the use of groundwater, and that Kampong Chhnang, Prey Veng and Takéo are the provinces that cultivate three rice crops per year and therefore use groundwater irrigation. Participants of the roundtable also included provinces such as Kandal and Svay Rieng among provinces that use groundwater for rice irrigation. There was little agreement at the roundtable on the extent to which arsenic-rich groundwater is used to irrigate rice. Hence, this is an area that requires further research. Participants also pointed to preliminary research into groundwater irrigation hotspots and arsenic that has been carried out in Kandal and Koh Thom provinces by various universities and international organisations.

One informant stated that irrigation with groundwater started around ten years ago in some areas, especially in Kandal province, and that the rate of use has increased rapidly in recent years. Indeed, this perception is supported by studies like Johnston et al. (2013), which have observed flagged increased rates of groundwater use in certain areas. Yet, despite this, the Cambodian government is also reported to have been concerned about groundwater depletion and discouraged groundwater extraction. Additional factors including financial and biophysical conditions inhibit groundwater access (see section 3.5). These factors all influence the use of groundwater for irrigation by Cambodian farmers and arsenic uptake in rice.

One measure mentioned by roundtable participants to mitigate arsenic uptake in rice is the development of surface water irrigation. An example given was the surface water irrigation schemes of the Cambodia Agricultural Value Chain Program (CAVAC) in Kandal, Takéo, Prey Veng, and Tboung Khmum provinces, which are used for second and third rice crops.[5] In some cases, these investments replace groundwater irrigation as they bring significant cost savings.

At the roundtable, mitigation measures suggested for farms included switching from rice to other crops during the dry season and growing rice varieties that take up less arsenic, because there are some varieties that have a greater propensity to take up arsenic and to accumulate it in grain.[6] One participant raised the example of farmers in Kandal province who, during the dry season, cultivate lotus in floodplain lakes instead of rice. However, there were also concerns about market barriers to changing farming practices: farmers fear not being able to access markets for alternative crops, whereas there are guaranteed buyers for rice.

Participants also identified four key knowledge gaps that need to be addressed in order to develop effective mitigation strategies. First, there is a need to better understand agronomic aspects of arsenic uptake in rice through groundwater irrigation, including risk assessments on the extent of uptake, and to identify rice varieties that take up less arsenic as well as the stages during rice growth at which arsenic is taken up. The second suggestion was the need for better market traceability of rice with arsenic. Third, there is a need for mitigation measures at the farm level, and for farm trials and demonstrations to illustrate the feasibility of changing water management and cropping practices. Finally, participants highlighted the need to understand the short- and long-term health impacts of consuming rice with arsenic.

5 The CAVAC schemes are funded by the Australian government.

6 The suggestion for alternative rice varieties with less propensity to uptake rice has been well studied. See e.g. Norton, G.J., Islam, M.R., Deacon, C.M., Zhao, F.-J., Stroud, J.L., McGrath, S.P., Islam, S., Jahiruddin, M., Feldmann, J., Price, A.H., Meharg, A.A. (2009). Identification of low inorganic and total grain arsenic rice cultivars from Bangladesh. Environmental Science and Technology. 43. 6070–6075. https://doi.org/10.1021/es901121j

5. Discussion

Arsenic entering the human food chain through rice consumption is directly linked to the development of groundwater irrigation in areas known to have high arsenic levels in groundwater. There are clear knowledge gaps that need to be addressed in terms of the exact extent of this development and the traceability of rice grown using arsenic-rich groundwater in Cambodia. However, it is known that the use of shallow groundwater for agriculture has increased in Cambodia, particularly in the southern provinces (Johnston, Roberts, et al. 2013), although this development has been relatively limited compared with other parts of Asia (Johnston et al. 2014). Government policies and measures to intensify commercial rice production, such as dry season irrigation and multiple croppings, have encouraged increases in dry season rice cultivation in terms of acreage and production levels, which has also increased the use of pump irrigation.

However, despite increasing emphasis on rice export and production, there seems to be no clear government plan for improved water management for cultivating rice. While programmes like CAVAC are developing and rehabilitating surface-based irrigation schemes for farmers, for the most part they are taking irrigation matters into their own hands and increasingly installing small-scale and often unsustainable pumps for groundwater irrigation for expansion of dry season cultivation. The continued expansion of dry season cultivation through groundwater irrigation, if it continues, has the potential to increase arsenic uptake in rice cultivation. This could lead to long-term health issues, as well as impacts on export markets, and therefore needs to be addressed through both agriculture and public health policies. There is therefore a clear window of opportunity for the government to guide the development of groundwater irrigation to prevent arsenic in rice from becoming a more serious public health issue as it has in parts of South Asia such as in Bangladesh and West Bengal.

As small-scale groundwater irrigation increases, it is important to consider whether it is the most effective and sustainable agricultural water management strategy for meeting the government's policy objectives. There are economic challenges to expanding dry season rice production, including the high levels of investment required, risks borne by farmers, and the attractiveness of cultivating other, more high-value, crops. There are also problems in regulating informal use of small-scale groundwater irrigation in order to prevent aquifer depletion, especially with the significant water requirement of fully irrigated rice. Dry season irrigation of rice crops might therefore not be economically and environmentally viable, as its limited growth so far suggests.

However, development of groundwater irrigation could still play a role in Cambodia's agricultural water management strategy in a way that reduces arsenic uptake in crops in arsenic-rich areas, if certain measures are put in place. Firstly, groundwater can supplement surface water during wet season rice cultivation as insurance against drought (Johnston et al. 2014). Secondly, cultivating rice in more aerobic conditions can to a certain extent reduce arsenic uptake from groundwater. Thirdly, groundwater can be used to irrigate crops with a lower requirement for water and lower arsenic uptake efficiency, and non-food crops. These would ideally be crops with higher economic value than rice, to increase returns given the high irrigation costs.

Overall, the issue of arsenic in rice in Cambodia is not yet well understood, and greater investment in research is needed.

In particular, there is a need for more data on:

- the current levels of arsenic in Cambodian rice and its potential threat to food safety
- the increase in groundwater use for dry season rice production, and
- the traceability of rice with high arsenic levels from farm to market and consumers.

Participants in the roundtable agreed that the Government of Cambodia should play a key role in research, public awareness, and mitigation on these issues, suggesting better public-private engagement to support its efforts.

One recommendation from our study is for the government to adjust its rice export policy by, for example, developing surface water irrigation and shifting to crops with higher economic value, which could help to reduce reliance on potentially arsenic-contaminated groundwater as the main source of irrigation water for dry season rice cultivation. This adjustment would address economic, sustainability and health concerns over using groundwater for irrigation.

Finally, despite these government policies and Cambodia's heavy reliance on rice for food security and economic development, market trends may overtake government interventions, as trends show that farmers are already choosing to grow more profitable and low-risk (i.e. financial, agricultural and climate risks) crops over rice.

References

Banerjee, M., Banerjee, N., Bhattacharjee, P., Mondal, D., Lythgoe, P. R., Martínez, M., Pan, J., Polya, D. A. and Giri, A. K. (2013). High arsenic in rice is associated with elevated genotoxic effects in humans. *Scientific Reports*, 3. 2195. DOI:10.1038/srep02195.

Dittmar, J., Voegelin, A., Maurer, F., Roberts, L. C., Hug, S. J., Saha, G. C., Ali, M. A., Badruzzaman, A. B. M. and Kretzschmar, R. (2010). Arsenic in Soil and Irrigation Water Affects Arsenic Uptake by Rice: Complementary Insights from Field and Pot Studies. *Environmental Science & Technology*, 44(23). 8842–48. DOI:10.1021/es101962d.

FAO (2014). *Country Fact Sheet on Food and Agriculture Policy Trends*. FAO, Rome. http://www.fao.org/3/a-i3761e.pdf.

Fredericks, D. and Arsenic Secretariat (2004). *Situation Analysis: Arsenic Contamination of Groundwater in Cambodia*. UNICEF and Ministry of Rural Development, Phnom Penh, Cambodia. A report prepared for the Arsenic Inter-Ministerial Sub-Committee.

Gilbert, P. J., Polya, D. A. and Cooke, D. A. (2015). Arsenic hazard in Cambodian rice from a market-based survey with a case study of Preak Russey village, Kandal Province. *Environmental Geochemistry and Health*, 37(4). 757–66. DOI:10.1007/s10653-015-9696-x.

Hossain, M. F. (2006). Arsenic contamination in Bangladesh—an overview. *Agriculture, Ecosystems & Environment*, 113(1–4). 1–16.

IFC (2015). *Cambodia Rice Export Potential and Strategies*. CAMBODIA AGRIBUSINESS SERIES - no. 4. IFC, Phnom Penh. https://www.ifc.org/wps/wcm/connect/ed10f08049a04cfd8bbcabe54d141794/Cambodia+Market+Survey-Final-2015.pdf?MOD=AJPERES.

Johnston, R., de Silva, S. and Try, T. (2014). Investing in water management to improve productivity of rice-based farming systems in Cambodia. *Proceedings of a dialogue held in Phnom Penh, Cambodia, 7-9 May 2014.*, L. Robins (ed.). Vol. ACIAR Proceedings 142158. Proceedings of the A policy dialogue on rice futures: rice-based farming systems research in the Mekong region, Canberra, Australia. Australian Centre for International Agricultural Research. http://aciar.gov.au/files/pr142-web.pdf.

Johnston, R., Roberts, M., Try, T. and de Silva, S. (2013). *Groundwater for Irrigation in Cambodia.* International Water Management Institute, Colombo, Sri Lanka. http://www.iwmi.cgiar.org/Publications/issue_briefs/cambodia/issue_brief_03-groundwater_for_irrigation_in_cambodia.pdf. IWMI-ACIAR Investing in Water Management to Improve Productivity of Rice-Based Farming Systems in Cambodia Project. Issue brief #3, June 2013.

Johnston, R., Try, T. and de Silva, S. (2013) Agricultural Water Management Planning in Cambodia. 1. IMWI, Colombo. http://www.iwmi.cgiar.org/Publications/issue_briefs/

Mazumder, D. G. and Dasgupta, U. B. (2011). Chronic arsenic toxicity: studies in West Bengal, India. *The Kaohsiung journal of medical sciences*, 27(9). 360–370.

Mondal, D. and Polya, D. A. (2008). Rice is a major exposure route for arsenic in Chakdaha block, Nadia district, West Bengal, India: A probabilistic risk assessment. *Applied Geochemistry*, 23(11). 2987–98. DOI:10.1016/j.apgeochem.2008.06.025.

O'Neill, A., Phillips, D. h., Kok, S., Chea, E., Seng, B. and Sen Gupta, B. (2013). Arsenic in groundwater and its influence on exposure risks through traditionally cooked rice in Prey Vêng Province, Cambodia. *Journal of Hazardous Materials*, 262. 1072–79. DOI:10.1016/j.jhazmat.2013.03.063.

Phan, K., Sthiannopkao, S., Heng, S., Phan, S., Huoy, L., Wong, M. H. and Kim, K.-W. (2013). Arsenic contamination in the food chain and its risk assessment of populations residing in the Mekong River basin of Cambodia. *Journal of Hazardous Materials*, 262. 1064–71. DOI:10.1016/j.jhazmat.2012.07.005.

Phan, K., Sthiannopkao, S., Kim, K.-W., Wong, M. H., Sao, V., Hashim, J. H., Mohamed Yasin, M. S. and Aljunid, S. M. (2010). Health risk assessment of inorganic arsenic intake of Cambodia residents through groundwater drinking pathway. *Water Research*, 44(19). 5777–88. DOI:10.1016/j.watres.2010.06.021.

Polya, D. A., Berg, M., Gault, A. G. and Takahashi, Y. (2008). Arsenic in Groundwaters of South-East Asia: With Emphasis on Cambodia and Vietnam. *Applied Geochemistry,* 23(11). 2968–76. DOI:10.1016/j.apgeochem.2008.06.024.

Polya, D., Polizzotto, M. and Fendorf, S. (2010). Arsenic in Groundwaters of Cambodia. In *Water Resources and Development in Southeast Asia*. SE Asia Center, New York. 31–56.

RDI (2012). Summary of Groundwater Quality in Cambodia – Data, Maps, and Priority Parameters. *RDI Cambodia*, March. http://rdic.org/dwqi-groundwater-summary/.

Sampson, M. L., Bostick, B., Chiew, H., Hagan, J. M. and Shantz, A. (2008). Arsenicosis in Cambodia: Case studies and policy response. *Applied Geochemistry*, 23(11). 2977–86. DOI:10.1016/j.apgeochem.2008.06.022.

Sharma, A. K., Tjell, J. C., Sloth, J. J. and Holm, P. E. (2014). Review of arsenic contamination, exposure through water and food and low cost mitigation options for rural areas. *Applied Geochemistry*, 41. 11–33. DOI:10.1016/j.apgeochem.2013.11.012.

Su, Y.-H., McGrath, S. P. and Zhao, F.-J. (2010). Rice is more efficient in arsenite uptake and translocation than wheat and barley. *Plant & Soil,* 328(1/2). 27–34. DOI:10.1007/s11104-009-0074-2.

Thath, R. (2016). Potentials and Constraints of Cambodian Rice Export. *Munich Personal RePEc Archive*, (MPRA Paper No. 71490). 15.

Vannak, C. (2017). Cambodian rice among the world's best three. *Khmer Times*, 9 November. http://www.khmertimeskh.com/5089690/cambodian-rice-among-worlds-best-three/.

Wang, H.-S., Sthiannopkao, S., Chen, Z.-J., Man, Y.-B., Du, J., et al. (2013). Arsenic concentration in rice, fish, meat and vegetables in Cambodia: a preliminary risk assessment. *Environmental Geochemistry and Health*, 35(6). 745–55. DOI:10.1007/s10653-013-9532-0.

WHO (2011a). Arsenic in drinking-water: background document for development of WHO Guidelines for Drinking-water Quality.

WHO, ed. (2011b). *Guidelines for Drinking-Water Quality*. 4th ed. World Health Organization, Geneva.

Wichelns, D. (2016). Managing Water and Soils to Achieve Adaptation and Reduce Methane Emissions and Arsenic Contamination in Asian Rice Production. *Water*, 8(12). 141. DOI:10.3390/w8040141.

World Bank (2015). *Cambodian Agriculture in Transition: Opportunities and Risks*. Economic and Sector Work, Report No. 96308-KH. World Bank, Phnom Penh. http://documents.worldbank.org/curated/en/805091467993504209/pdf/96308-ESW-KH-White-cover-P145838-PUBLIC-Cambodian-Agriculture-in-Transition.pdf.

World Bank (2016). *Leveraging the Rice Value Chain for Poverty Reduction: In Cambodia, Lao PDR and Myanmar*. Economic and Sector Work Report. World Bank, Washfington, D.C. https://openknowledge.worldbank.org/bitstream/handle/10986/24711/Rice0sector0de0Lao0PDR00and0Myanmar.pdf?sequence=1&isAllowed=y. 105285-EAP.

Annex 1

The following stakeholder organisations were engaged.

Key informant interviews

- Local administration in Kampong Kong Commune, Kandal province
- Ministry of Agriculture, Forestry and Fisheries (Provincial Departments of Agriculture, Forestry and Fisheries; General Directorate of Agriculture; Department of Plant Protection, Sanitary and Phytosanitary; and Department of Agricultural Extension)
- Ministry of Health
- Ministry of Rural Development (Department of Rural Water Supply)
- Ministry of Environment (National Council for Sustainable Development)
- Cambodian Agricultural Research and Development Institute (CARDI)
- Cambodia Rice Federation
- Cambodia Agricultural Value Chain Program (CAVAC)
- Cambodian Center for Study and Development in Agriculture (CEDAC)
- Resource Development International Cambodia (RDIC)
- World Health Organization (WHO)
- United Nations International Children's Fund (UNICEF)
- International University
- International Rice Research Institute (IRRI)
- Institute of Technology of Cambodia
- Royal University of Phnom Penh
- Prek Leap National College of Agriculture
- Kampong Cham National School of Agriculture

Roundtable participants:

- Ministry of Agriculture, Forestry and Fisheries (Provincial Departments of Agriculture, General Directorate of Agriculture; and Department of Agricultural Extension; Department of Agriculture Land Resources Management)
- Ministry of Health
- Ministry of Rural Development (Department of Rural Water Supply)
- Cambodian Agricultural Research and Development Institute (CARDI)
- Cambodia Agricultural Value Chain Program (CAVAC)
- Resource Development International Cambodia (RDIC)
- United Nations International Children's Fund (UNICEF)
- International University
- Institute of Technology of Cambodia
- Royal University of Phnom Penh
- Lehigh University, USA

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