ARTICLE IN PRESS

Applied Geochemistry xxx (2008) xxx–xxx

Contents lists available at ScienceDirect

Applied Geochemistry

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

# Arsenicosis in Cambodia: Case studies and policy response

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ARTICLE INFO

Available online xxxx

ABSTRACT

Naturally occurring As found in groundwaters has been identified to be a problem in at least 10 provinces of Cambodia with Kandal being one of the most heavily impacted. Estimates, using groundwater quality and population data for Kandal Province of Cambodia, suggest that over 100,000 people are at high risk of chronic As exposure. Levels in some areas approach 3500 μg/L, against the Cambodian Standard of 50 μg/L. Considerable work remains to adequately characterize the extent of As hazard and its possible health effects in Cambodia and the region. It is likely that additional populations will develop health problems attributed to As, of particular concern is arsenicosis. The symptoms of arsenicosis have been generally assumed to develop after 8–10 years of consumption of water with elevated As levels, however, new cases discovered in Cambodia have been identified with exposure times as short as 3 years. The rapid onset of arsenicosis may be attributed to contributing risk factors related to socioeconomic status, including malnutrition. It is thus imperative to develop strategies to rapidly identify possible regions of enrichment, to minimize exposure to As-rich waters, and to educate affected populations. To date the response to the As hazard has been led by the Ministry of Rural Development in cooperation with international organizations and NGOs, to identify at risk areas, and educate communities of the risk of As-rich water. However better coordination between government bodies, NGOs and donor agencies active in the field of water supply and treatment is essential to minimize future As exposure.



## 1. Introduction

Arsenic hazard of groundwater is well documented in Bangladesh (DPHE, 1999; BGS, 1999; Watanabe et al., 2001; Harvey et al., 2004), West Bengal (India) (Mazumder, 2003; Rahman et al., 2003) and Vietnam (Berg et al., 2001). These and other areas exhibiting high groundwater As share some common geological characteristics including rapid, recent deposition of organic matter-rich sediments, the ultimate source of which is the Himalayan mountain range (Smedley and Kinniburgh, 2002; Polya et al., 2005; Charlet and Polya, 2006). Generally these areas are located in extensive delta regions such as those of Bengal and the Red River. In these regions, many people have developed arsenicosis and cancers, and large populations are at risk of developing a variety of health problems (Berg et al., 2007).

In Cambodia, large numbers of household and community tube wells have been shown to have elevated levels of As predominantly associated with low lying areas along the Mekong River and Tonle Bassac. Distribution of As in shallow Cambodian groundwaters has been documented in a number of published (Polya et al., 2003, 2005; Berg et al., 2007; Buschmann et al., 2007; Kocar et al., 2008; Rodriguez-Lado et al., 2008; Quicksall et al., 2008) and unpublished (JICA, 1999, 2001; Milton, 2003; Fredericks, 2004) studies.

Numerous studies have examined the chemical, biological and physical processes that contribute to spatial distribution and heterogeneity of As in groundwaters in Cambodia (Polya et al., 2003, 2005; Rowland et al., 2007;

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doi:10.1016/j.apgeochem.2008.06.022

Pederick et al., 2007; Lear et al., 2007; Berg et al., 2007; Buschmann et al., 2007; Kocar et al., 2008).

This paper presents both the history of response to the risk of As exposure in Cambodia since its discovery in groundwater, and previously unpublished case studies of the three communities identified to have villagers suffering from arsenicosis.

## 2. Cambodian response

In Cambodia, elevated levels of As were first discovered in 1999 during a national drinking water quality assessment program conducted by the Ministry of Rural Development with the support of the World Health Organization. The study looked at 100 wells in 13 provinces and identified elevated levels of As in 3 wells located in Kandal province (Feldman and Rosenboom, 2001).

In response to this discovery, As field test kits were deployed across a number of provinces to assess the extent of the As hazard in groundwater access points. This initial survey, which included several thousand wells, identified several As-impacted regions within Cambodia (Fig. 1).

The Royal Government of Cambodia formed the Arsenic Inter-Ministerial Subcommittee in 2001 to form government policy. One of the first actions of the Subcommittee, in 2003, was to adopt an interim Cambodian standard for As concentration in drinking water of 50 μg/L. This interim standard was based on previous WHO guidelines, which have been provisionally revised to 10 μg/L in recognition of health effects associated with chronic low-level As exposure (WHO, 2006). By adopting the higher standard, it was believed that As risk management would be more focused on those areas at greatest risk of adverse health impacts.

In 2002, several non-government organizations (NGOs) were commissioned to develop Information, Education and Communication (IEC) materials for community education about the risks of consuming As-rich groundwater. An educational program for school children was developed and implemented in a few schools in high risk areas. High quality educational videos intended to educate communities about the risks of As exposure have been produced, but have not yet been aired on television due to the concerns that such information might drive people to start using other sources that are prone to pathogenic contamination without appropriate point-of-use treatment. Wells shown to have As levels greater than the Cambodian Standard were painted red, in line with similar practices in Bangladesh. Red painted wells indicate to community members that the water from the well is not safe for drinking. This educational effort was partly successful in that communities often followed recommendations regarding water quality and ceased drinking from As-rich wells. The positive impact of this initiative however has been significantly reduced by the continued installation, in high risk areas, of a large number of new tube wells, which have not been tested for As.

In an initial health assessment funded by the WHO and UNICEF in 2002, the first suspected cases of arsenicosis were identified in Cambodia. An intensive follow up survey of As hazard and community health study in 2003 was conducted by Milton in association with the Ministry of Health, and Resource Development International Cambo-

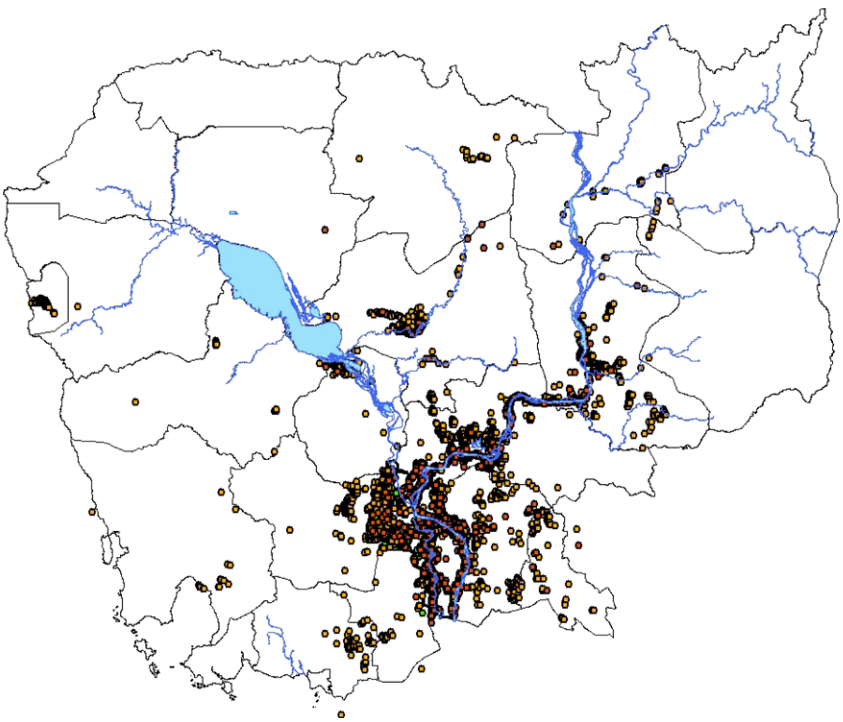

**Fig. 1.** Arsenic testing map of Cambodia.

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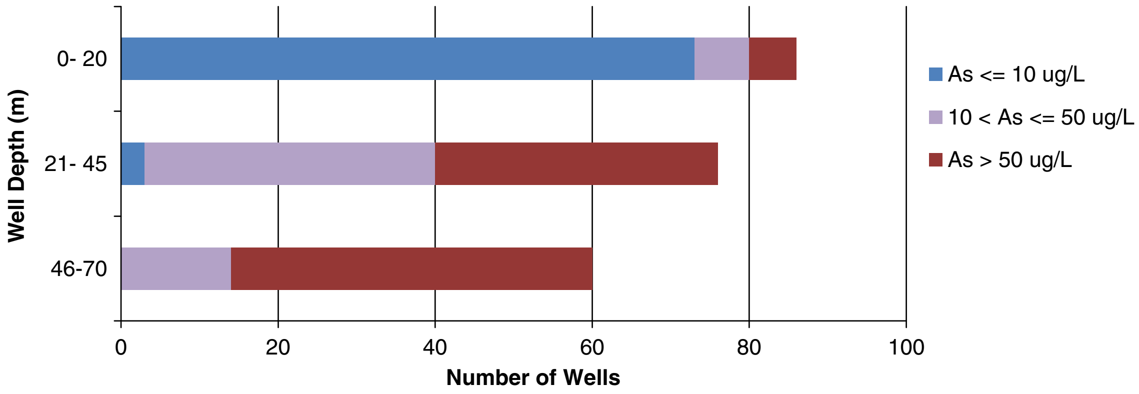


**Fig. 2.** Distribution of low (<10 μg/L As), medium (10–50 μg/L As) and high (>50 μg/L As) arsenic wells from four communes in the Kean Svay District, Kandal Province.

dia (RDIC) and funded by UNICEF and WHO (Milton, 2003). A total of 494 wells were analyzed within the Kean Svay district of Kandal Province, 29% demonstrated As concentrations greater than 500 μg/L. More than 7800 villagers were assessed for visible manifestations of arsenicosis. No cases of arsenicosis were confirmed, though this initial study was limited to 12 villages and did not include biological sample analyses to conclusively document As exposure.

The initial studies examining the distribution of As in groundwaters have been extended by numerous organizations. A national database of As field test kit results was established in 2004 by the Ministry of Rural Development. This database chronicled As enrichment in Kandal and other parts of Cambodia. Unfortunately, the database was plagued by a wide variety of implementation issues and is not currently being maintained.

In Cambodia, large scale domestic water sources are seldom available. Thus, most water treatment efforts are inherently small-scale. Household-level As removal technologies such as active water filtration, Fe flocculation and sedimentation implemented in other countries have been laboratory tested in Cambodia with mixed results (Khan et al., 2000; Meng et al., 2001; Luzi et al., 2004; Uy, 2006; Chiew et al., 2008) Concerns on operation and maintenance of household level systems are yet to be resolved. No systematic and comprehensive field implementation of remediation technologies in Cambodia has yet taken place due to questions about their efficacy and maintenance requirements. As a result, management and mitigation of As laden drinking water in Cambodia has been focused around accessing alternative water sources.

Various groups have examined the spatial distribution of As in groundwater. The results of these studies led RDIC to begin installing shallow hand dug wells equipped with rope pumps in 2003. Currently over 300 shallow hand dug wells have been installed in Kandal Province to a depth of less than 15 m. These wells demonstrated significantly lower levels of As than the deeper adjacent tube wells (Fig. 2). Further efforts to monitor and distribute data about As occurrence have been undertaken by RDIC through its GIS-based Drinking Water Quality Index (DWQI) analysis tool. Spatial information and reports on water quality – including As levels – are published on the internet and distributed to local and central government to empower informed decision making regarding source options (RDIC, 2007). These data indicate that As enrichment is widespread throughout Kandal province, with localized regions showing extreme As hazard. Areas of highest risk are most prevalent in low lying areas and levees adjacent to the modern Mekong and Tonle Bassac rivers (Fredericks, 2004; Polya et al., 2005; Buschmann et al., 2007). Low As areas are also common in some areas of Kandal province and elsewhere within Cambodia. The basis for differences in As levels is not yet well established (Polya et al., 2005; Rodriguez-Lado et al., 2008).

Studies documenting As exposure, as evidenced by above baseline concentrations of As in human hair, nails and urine, have subsequently been published by Kubota et al. (2006) and Gault et al. (2008) in relation to Kampong Cham and Kandal provinces, respectively.

In August 2006, the first Cambodian cases of arsenicosis were discovered in Preak Russey, Kandal Province, 2 km west of the Tonle Bassac. The patients were discovered during a routine Knowledge, Attitudes and Practices (KAP) survey undertaken by the Provincial Department of Rural Development. (Samnang, 2006).

## 3. Methods

To date, cases of arsenicosis have been confirmed in 3 areas in Cambodia – Preak Russey, Lvea Em and Preak Chrey (Fig. 3). The occurrences, assessment and relevant features of these three areas are outlined below.

### 3.1. Geostatistical analysis and mapping

Geostatistical analyst functions in ESRI's ArcGIS were utilized to generate a parameter concentration gradient map. Kriging methods were employed to interpolate concentrations between data points. A prediction standard error map was also generated to indicate the degree of confidence in interpolated concentrations. Adequate pre-

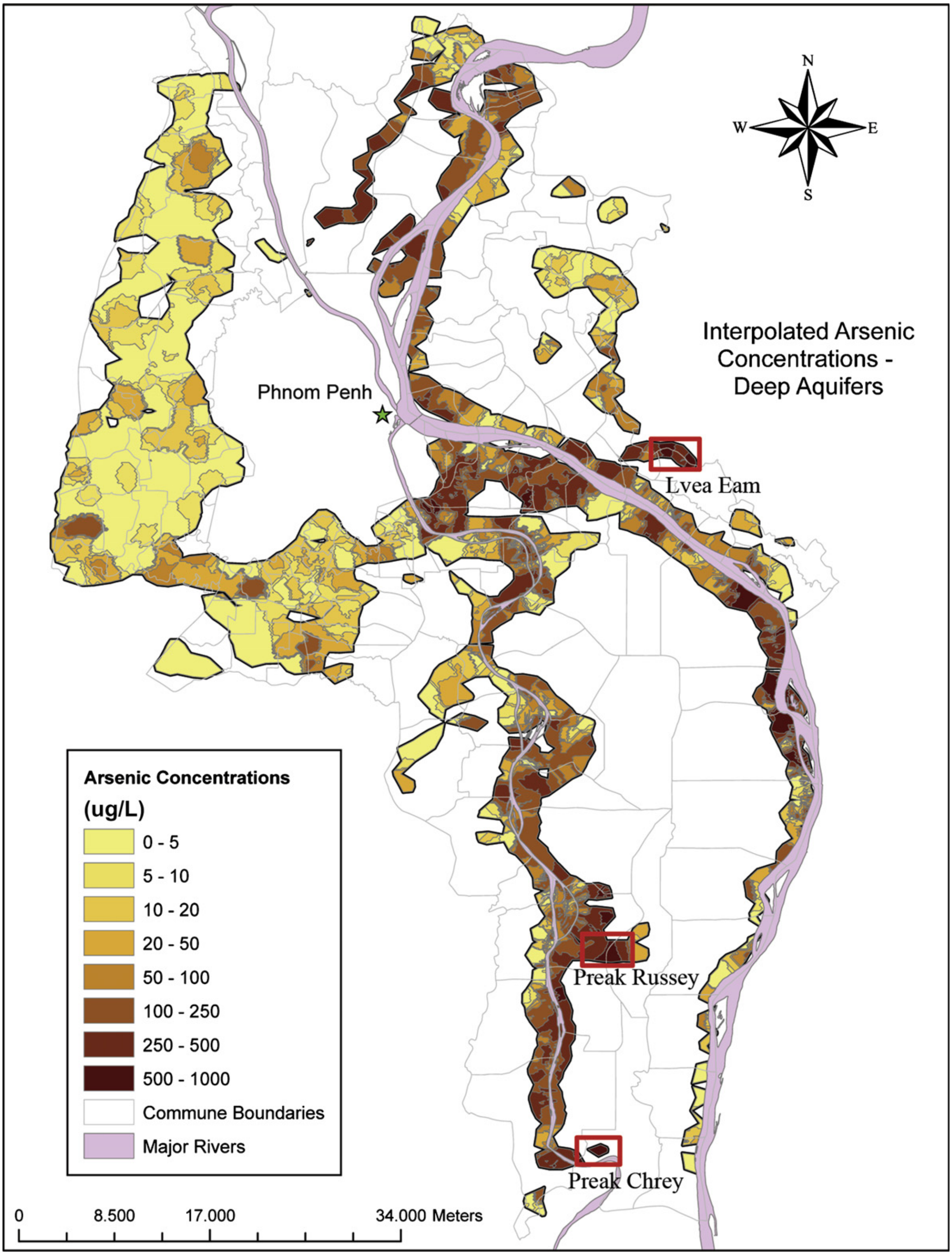


**Fig. 3.** Arsenic concentration gradient map of Kandal Province.

diction error was determined by comparing error gradients and distances from sample points. A standard error mask was generated for the As database. The mask was used to define a region where predictions exhibit a high degree of confidence. The population potentially affected by elevated concentrations of As was estimated. Population data for the 147 communes in Kandal province were made available from the 2004 census (NIS, 2004), however, populations are generally concentrated along roadways and calculated population densities would be inaccurate. In order to accurately predict impacted populations, inhabited regions were defined using village locations, roadways, and comparisons to satellite and topographic maps. A population buffer of 200 m was applied to village locations and 100 m to roadways. Interpolated concentration gradients were manipulated to display a region exceeding the Cambodian standard for As in drinking water of 50 μg/L. This region was then clipped by prediction standard error masks and the inhabited area to determine the inhabited area subject to groundwater concentrations above guideline values. Population densities for each commune were recalculated by applying the total population for each commune to the defined inhabited area. For each commune, the populated area impacted by groundwater concentrations above the Cambodian standard was multiplied by the revised population density to estimate the potentially impacted population. A tube well usage rate was determined from the 2004 census (NIS, 2004) and was used to predict the actual impacted populations.

### 3.2. Physical examination

All patients were assessed for visible manifestations by trained physicians from the Ministry of Health using the WHO protocol which is outlined in the WHO SEARO Technical Publication No. 31, 2005. Some patients displayed what appeared to be physical manifestations of arsenicosis while others had none. Biological samples were collected during the field visit.

### 3.3. Sample collection

A total of 76 hair samples were collected from three communities in Kandal Province of Cambodia. Thirty six samples were collected from the village of Preak Russey; this area had previously been identified as having arsenicosis patients. Twenty eight samples were collected from Lvea Eam and 12 samples from Preak Chrey; both areas had suspected cases of arsenicosis. Villagers were selected based upon two simple criteria – their willingness to allow samples to be taken and their claim to have used wells containing unsafe levels of As, as had determined initially by field test kits.

### 3.4. Total arsenic analysis

Hair samples were first washed with baby shampoo. The samples were rinsed thoroughly with deionized water. Samples were then placed inside an ultrasonic bath in a cleaning solution (1:3:1 ethanol, water, acetone) for 2 h. Samples were rinsed with deionized water and dried followed by a standard two acid ($HNO_3$, $H_2SO_4$, 5:1) tissue digestion procedure. An aliquot of the resulting solution was tested by graphite furnace atomic absorption (Varian AA 600, atomic absorption spectrometer) using standard techniques. Ten duplicate samples were also sent out to a third party lab for independent verification.

## 4. Results

### 4.1. Geostatistical analysis

An impacted population analysis was performed by developing an As concentration gradient map (Fig. 3) as well as an inhabited regions map (Fig. 4) which was linked to population data from the 2004 census. Results of this analysis suggest a population of at least 380,000 live in the high risk zones of Kandal Province. Applying the well usage rates reported for these areas in the 2004 census (27%) suggest that 102,600 are being exposed to groundwaters exceeding the 50 μg/L standard (NIS, 2004).

### 4.2. Geology

All three case study areas, where arsenicosis is documented appear from satellite data and on the ground inspection to occur on natural levees assumed to be formed by lateral movement of river channels. Old river banks are known to play a major role in the release of arsenic into groundwater (Buschmann et al., 2007; Papacostas et al., accepted for publication; Quicksall et al., 2008; Kocar et al., 2008). These riverbanks contain abundant organic matter, which helps to stimulate Fe reducing conditions and the subsequent release of As into groundwater (Nickson et al., 2000; McArthur et al., 2004; Fredericks, 2004; Islam et al., 2004; Polya et al., 2005; Rowland et al., 2007). Each of the three areas experience annual flooding. Annual flooding may influence regional hydrology and help to deliver As from throughout the sediment column into aquifers that are tapped by tube wells (Kocar et al., 2008). It should be noted that Preak Russey is different from the other locations in that it is not located directly on a river.

### 4.3. Laboratory results: hair analysis

A total of 76 hair samples were analyzed for total As concentration from the three communities identified to have residents suffering from what appeared to be arsenicosis (Table 1). Half of those selected for testing displayed classical visible manifestations of arsenicosis the other half did not.

## 5. Arsenicosis cases

### 5.1. Preak russey

In response to the discovery of an individual displaying symptoms of arsenicosis, a combined Ministry of Rural Development and RDIC team undertook extensive community surveys in the identified target area to verify and further understand the extent of the problem. The survey teams identified 263 suspected arsenicosis cases all of which displayed visible manifestations including varicose hyperkeratosis (Fig. 5), this represented 13% of the total population (Samnang, 2006). The arsenicosis symptoms could be directly attributed to As exposure. All water access points within the community were tested and all tube

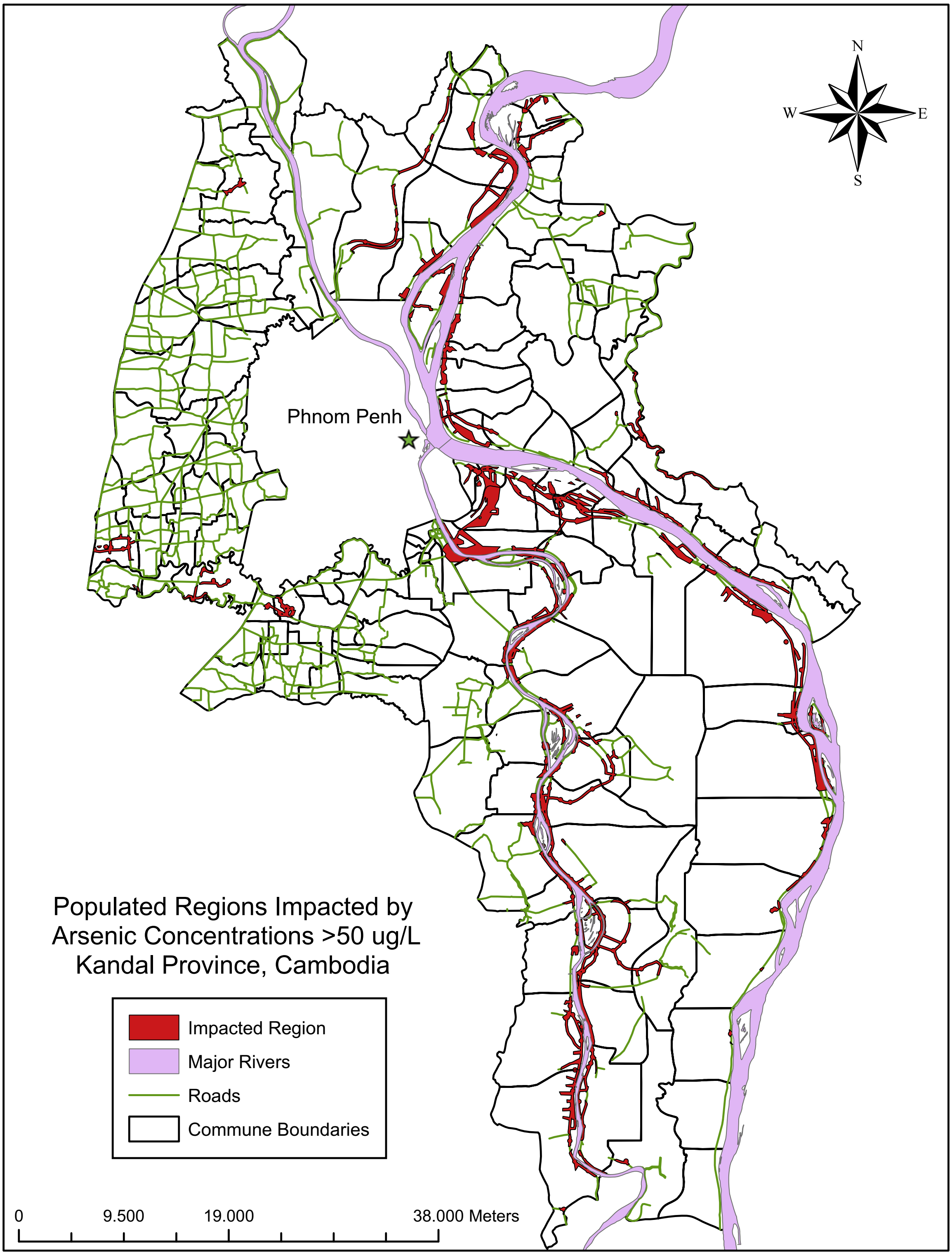


**Fig. 4.** Inhabited regions map of Kandal Province.

wells were found to have levels of As between 1000 and 3500 μg/L. Such high As levels have well documented effects on health (Saha et al., 1999; Rahman et al., 2003).

Dr. D.N. Guha Mazumder, an expert in arsenicosis, was engaged to examine the suspected cases, along with laboratory analysis of individual's hair and nail samples, per-

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**Table 1**
Arsenic concentration in hair samples from arsenicosis patients from Preak Russey, Lvea Em and Preak Chrey, Cambodia

| Location | Number of individual | Range (mg/kg) | Geometric mean (mg/kg) |
|---|---|---|---|
| Preak Russey | 36 | 2.1–13.94 | 5.64 |
| Lvea Em | 28 | 0.05–6.48 | 1.01 |
| Preak Chrey | 12 | 0.13–9.21 | 1.73 |

**Fig. 5.** Hand and feet of villagers suffering from Hyperkerotosis as a results of arsenic ingestion.

formed by several different laboratories, which confirmed the diagnosis. Arsenic concentrations in these biological samples were highly elevated relative to normal levels, further establishing that biological As exposure as the major cause of these symptoms (Samnang, 2006).

During the surveys it was noted that the majority of families displaying visible manifestations were significantly poorer than their neighbors. The relative economic status of villages was determined by the building materials used in the construction of their dwellings. Those suffering from visible manifestations reported significantly lower levels of protein, fruits and vegetables in their regular diet than those who did not display symptoms.

#### 5.1.1. Response

A number of measures were undertaken within the community to curtail exposure to As-rich drinking water. Community education in the target areas was undertaken including use of mobile karaoke units to ensure high levels of awareness of the risks of As exposure in the community. Shallow wells equipped with rope pumps were installed to provide an alternative water source. Twelve shallow hand dug wells were installed and were tested for As. Ten were found to have As levels below the Cambodian Standard. These wells were monitored monthly for one year to ensure As levels remained within safe limits. These new wells provide sources of drinking water to village residents. The remaining wells whilst having levels significantly below that of the adjacent tube wells did not meet the Cambodian Standard. These higher-As wells were never opened for operation and were subsequently sealed. Rainwater harvesting systems were also installed in local schools. Point-of-use ceramic water filters were distributed to allow community members to treat surface and shallow well water for drinking. These mitigation efforts have been extended to many other villages affected by elevated As levels to help curb the onset of widespread arsenicosis.

### 5.2. Lvea em

In 2005, an RDIC education program visited an area along the Kandal/Prey Veng border on the Tonle Touch River to educate the community of the risks of drinking the groundwater, and painted the wells red. This education effort helped to curtail use of high As drinking water, but arsenicosis cases were not detected. It was noted that the wells in these communities were installed in 2002, two years after the discovery of the As hazard in groundwater, with this area being identified as high risk.

In 2007, over 40 suspected cases of arsenicosis were identified from a survey of approximately 400 people. A number of these arsenicosis cases have now been confirmed through visual inspection and tissue analysis. Samples from tube wells in the areas were analyzed for As and showed levels greater than 1000 μg/L. A number of confirmed arsenicosis cases reported consuming groundwater for as short a time as 3 years (Kol, 2007). The reported time frame was supported by the installation date of tube wells; prior to their introduction the community relied upon surface waters for drinking water. Advanced symptoms of arsenicosis were observed in younger patients including one who was 12 years old with extreme visible manifestations. This young patient claimed to have stopped drinking groundwater for 2 years and had not experienced any noticeable reduction in symptoms. Tissue samples were analyzed for As levels and were extremely elevated. The persistence of their symptoms and existence of elevated As levels in tissue indicates that numerous factors may influence the effectiveness of treatment and remediation.

During the surveys it was noted that the majority of families displaying visible manifestations were significantly poorer than their neighbors. The relative economic status of villages was determined by the building materials used in the construction of their dwellings. Those suffering from visible manifestations reported significantly lower levels of protein, fruits and vegetables in their regular diet than those who did not display symptoms.

#### 5.2.1. Response

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Rainwater harvesting systems were installed at local schools. Point-of-use ceramic water filters were distributed at the local schools and are being made available for purchase by villagers. Villagers were taught to begin using river water as their source for drinking, but only with appropriate treatment for pathogens.

### 5.3. Preak chrey

The most recent discovery of arsenicosis patients was in the village of Preak Chrey. Preak Chrey is located on the banks of the Tonle Bassac River on the border of Kandal Province and Vietnam. During a routine investigation of water quality a RDIC survey team located a villager who displayed visible manifestations of arsenicosis. In response to this discovery the village of Preak Chrey was surveyed by the Ministry of Health and RDIC team with the support of the World Health Organization. During this survey conducted in 2007 several patients were identified who met all the visual criteria for arsenicosis. Tissue samples were collected and were subsequently analyzed for total As. Groundwater was also collected and analyzed for As and showed levels greater than 1000 μg/L. Results showed villagers who claimed to drink water from contaminated wells all had elevated levels of As in their tissue confirming arsenicosis as the most likely cause of the physical symptoms (Kol, 2007).

#### 5.3.1. Response

At the time of writing, there has not been any significant response to the situation in Preak Chrey other than some simple education conducted during the brief investigation.

## 6. Discussion

The documented cases of arsenicosis occur in three communities. The occurrences in each location were discovered by accident and not as part of a specific program to locate arsenicosis patients. All three communities have extensive groundwater arsenic hazards; however, numerous other communities exposed to similar or higher As levels have not developed symptoms of arsenicosis. There are several possible explanations for this outcome.

Higher socio-economic status is associated with better nutrition, which is thought to play a key role in reducing physical susceptibility to As and delay the onset of arsenicosis. Nutrition has numerous direct effects on As toxicity. For example, As efflux from the body requires As reduction, and is most efficient when ascorbic acid and other vitamins are available (WHO, 2003; Hadi and Parveen, 2003; Argos et al., 2007). It was clearly noted in the interviews that families displaying visible manifestations were significantly poorer than neighbors who displayed no symptoms. They also reported eating less meat, eggs, fruits and vegetables. The three identified communities reported most caloric intake to be from rice. Most of the inhabitants of these areas are farmers and one would think they consume their own fruits and vegetables, but many reported in their interviews that they refuse to eat their own produce other than rice because of the application of high concentrations of pesticides.

Each of the three areas has limited access by land transport. This inaccessibility limits commerce, education, nutrition and health care opportunities, all associated with lower socio economic status. Accessible areas were also the first to receive education concerning the risks of As-laden groundwater. Better education and access to information in these regions may have played a role in more rapid decision making by community members to select alternate water resources. It is also noted that As-rich water is generally aesthetically poor, primarily due to the prevalence of Fe. This leads those with the financial ability to seek alternate water sources such as piped water, bottled water, filtered surface water, and rainwater harvesting systems – fortuitously reducing As exposure. Rainwater is considered by most Cambodians to be the preferred water source in rural areas.

It was noted that families who were wealthier were more likely to own traditional rainwater jars and with increased wealth there was an increase in the number of jars. Families that owned several water jars generally did not display visible manifestations of arsenicosis. None of the families in the impacted communities had a sufficient amount of rain water storage to make it through the dry season, but it was at least enough to significantly reduce consumption of well water for a good portion of the year. The village of Trabeak Pok which adjoins Preak Russey appears significantly wealthier based upon the quality of their housing: this community has a private piped water system and no villagers were found who were suffering from visible manifestations of arsenicosis.

## 7. Conclusions

Arsenicosis will most likely continue to be a problem unless major changes in practices are made throughout the areas most impacted by As. Failure to communicate between international and governmental agencies and NGOs has led to the continued installation of tube wells in areas known to be of high risk of As enrichment. The communication between agencies and other vested parties needs to be more effective to maximize their success in dealing with this emerging crisis. The use of web based data is a move in the right direction, but more needs to done to ensure information is more accessible. The regular turnover of staff at various agencies and NGOs require there to be regular reminders to these groups about the issue of As. Organizations operating within Cambodia need to be accountable for activities that increase the risk of As exposure to communities. The Ministry of Rural Development, a Cambodian governmental agency, has informed organizations that all wells should be tested for As before being commissioned. However, this policy is seldom, if ever enforced and many organizations continue to install wells without proper testing. A new policy also needs to be implemented on private well drillers that require them to properly test all newly installed wells, and inform home owners and local government leaders about the results.

A more aggressive educational program needs to be undertaken in the As –impacted regions of Cambodia as

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many As-related health problems may exist or develop that do not express themselves with distinctive symptoms as does arsenicosis. The continued development and distribution of information tools, and monitoring of community health, and wells is essential for reducing further exposure of community members to As and incidences of arsenicosis. A new program to locate communities who are suffering from arsenicosis needs to be undertaken immediately. Recently, an initial decision not to air the educational karaoke videos about As risks was overturned. The videos will now be aired on national television and feature a phone hotline service, with the intention of allowing rapid identification and location of new arsenicosis cases.

More needs to be done to ensure that communities of lower socioeconomic status have access to improved water sources and improving nutrition in these areas as a measure to combat the effects of As exposure. A survey of Preak Russey, conducted in early 2008, concluded that villagers already suffering from arsenicosis continue to consume water from wells with high levels of As. Those interviewed responded that it was too difficult to carry water from other sources and they did not have the energy or financial resources to change the situation. Fortunately, for Preak Russey, a piped water system is due to be on line by June of 2008. Under this new system the poorest villagers will be given 1 $m^3$ of water per month free of charge, usages above the 1 $m^3$ will be charged at a standard rate. While funding is not available to respond to all communities with a piped water system every effort should be made to ensure all communities do have access to safe water.

In summary, management of high As groundwaters in Cambodia is possible through: a full identification of at risk areas; comprehensive educational programs; and the enforcement of policies by the Royal Government of Cambodia with appropriate financial and technical support of key donors and organizations to facilitate educational programs and the development of alternative water supplies.

## Acknowledgements

We would like to acknowledge David Polya and Michael Berg for their amazing efforts in organizing the symposium at the University of Manchester. We would also like to thank the Ministry of Rural Development of the Royal Government of Cambodia for their continued partnership especially Dr. Moa Saray and Dr. Chea Samnang. The views expressed in this paper do not necessarily represent the views of any of these organizations or those with which the authors are affiliated.

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