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Assessment of Population Exposed to Groundwater Arsenic in As-affected Areas of Cambodia

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: High As levels in Cambodia's groundwater were first reported in a small scale, but country-wide survey in 2001 and since then a number of studies have been undertaken to identify the spatial extent of the problem, release mechanisms and intake pathways. An exposure risk study was first published in 2008 but was done only for Kandal Province.
Aims: This study aims to i) characterize the current water use pattern of people living in at risk areas; and ii) quantify the size of the population exposed to harmful levels of arsenic through the consumption of groundwater in the highly arsenic affected areas of Cambodia.
Methodology: This study consisted of questionnaire development, site selection and questionnaire application for 998 residents in 50 villages of Kandal, Kampong Cham, and Prey Veng provinces.
Results: The questionnaires revealed that rain water is the main source of water during the rainy season while tube well and surface water are relatively important sources of water for both the rainy and dry seasons. The proportion of population exposed to As levels over 50 ppb is 6.3% in the surveyed villages. We conclude that surface water is still an important source for rural Cambodians,

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thus household water treatment and storage (HWTS) programs should be further implemented to avoid the substitution health effect from As instead of microbial contamination. Regular monitoring programs should be considered since tube well water is still being used in those areas.

Keywords: Groundwater; exposure; pathways; health risk; HWTS; arsenic; Cambodia.

1. INTRODUCTION

Groundwater has been considered as a partial water source solution for rural Cambodians and also potentially more reliable and convenient than rainwater and surface water [1]. This consideration led to the increasing importance of groundwater as a source for domestic use and around 40,000 bores/tube wells have been constructed by Royal Government of Cambodia (RGC), international agencies and NGOs, plus other tube wells installed by household owners. However, the majority of tube wells were constructed without properly testing water quality. High arsenic levels in groundwater was first reported in a small scale, but country-wide survey in 2001 [2] and since then a number of studies have been conducted to identify the spatial extent of the problem, release mechanisms, and intake pathways [3,4,5,6,7,8, 9,10,11].

Since As was first identified in the groundwater of some areas of Cambodia, studies have been conducted to assess the size of the exposed population in affected areas. The first was reported in 2008 and was only for Kandal province [12]. This study utilized water supply information from the 1998 National Census and estimated that approximately 100,000 people were exposed in Kandal province. Once a national well database was established (www.cambodiawellmap.com) and data from the 2008 National Population Census was released another study was completed and revealed that there were approximately 140,000 exposed people, in 278 communes, who use tube well water with arsenic ≥50 ppb as their primary water source in the dry season. Almost one-third of the exposed population consumed tube well water with arsenic ≥250 ppb. About 95% of these people live in 3 provinces: Kandal, Prey Veng, and Kampong Cham [13].

These estimates were based on several assumptions and there are potential sources of error that will affect their accuracy. For example, households surveyed by the census were only able to answer one primary drinking water supply option. It is common for people to use secondary and even tertiary water supply options in Cambodia, and if these happened to include tube wells, they would not have been counted in the census and therefore not included in the estimate of arsenic exposure. This may have resulted in under reporting of exposures. Additionally, the estimates utilized the total percentage of unsafe well tests in a commune and multiplied it by the total number of households drinking from tube wells. However, in areas where well testing and education have occurred, it is possible that the dynamics of groundwater consumption has shifted away from drinking tested unsafe wells while many households will have continued to drink tested safe wells. This may cause the estimates to over report exposures.

Despite the potential sources of error, historical estimates are considered to be reasonable estimates of exposure for Cambodia. However, the situation of arsenic mitigation has changed since 2008. Many water supply options have been setup in affected communities and various education and well testing programs have been conducted. The next census will not occur until 2018 and data are needed before this to assess the progress achieved so far. The findings from this study can also be a supporting tool for policy and decision makers to allocate appropriate human and financial resources to the problem. Finally, it has been difficult for policy makers to monitor progress and achievements towards the goal of reducing exposure because high quality baseline data do not exist. Thus, more reliable data on the arsenic exposed population should be an input for future arsenic mitigation action in Cambodia. The objectives of the study therefore are twofold: i) characterize the current status of water use patterns of people living in at risk areas; and ii) quantify the proportion of population exposed to arsenic through the consumption of groundwater in the highly arsenic affected areas of Cambodia.

2. RESEARCH METHODOLOGY

2.1 Sites Selection and Data Collection

Three provinces were selected for study, namely Kandal, Kampong Cham and Prey Veng because they represent up to 95% of the total affected population (50%, 28.1%, and 16.4% respectively) according to [13]. Based on the national arsenic database and arsenic survey data, 412 villages where at least 10% of the well tests revealed unsafe levels of arsenic (red painted well indicated the arsenic concentration more than 50 ppb) and the total number of well tests is at least 10 were identified. From this list of arsenic affected villages, 50 were randomly selected. At each of the 50 selected villages, satellite imagery was reviewed and the area of population / habitation was chosen using Google Earth. Within this selected area, 5 GPS points were geographically randomly selected in ArcGIS10. Therefore a total of 250 randomized GPS coordinates were generated in 50 randomly selected villages from among all the villages where at least 10% of the well tests are unsafe. These GPS points are then representative of the entire arsenic affected area. At each GPS coordinate, field teams administered a questionnaire at the four nearest households to the north, south, east, and west. Therefore, the survey covered 50 villages with the total number of respondents being 998 for the three at risk provinces. Proportionately, there were 180 respondents at Prey Veng, 438 at Kandal, and 380 at Kampong Cham. Table 1 indicates the number of districts, communes and villages for this study and Fig. 1 presents the map of study areas.

2.2 Water Quality Testing

In addition to the interview session, if water from tube wells is consumed in the dry or wet seasons, the tube well was tested using a Merck Arsenic Test Kit (Colorimetric with test strips) and the result recorded. The detection range for this kit was 5-500 ppb.

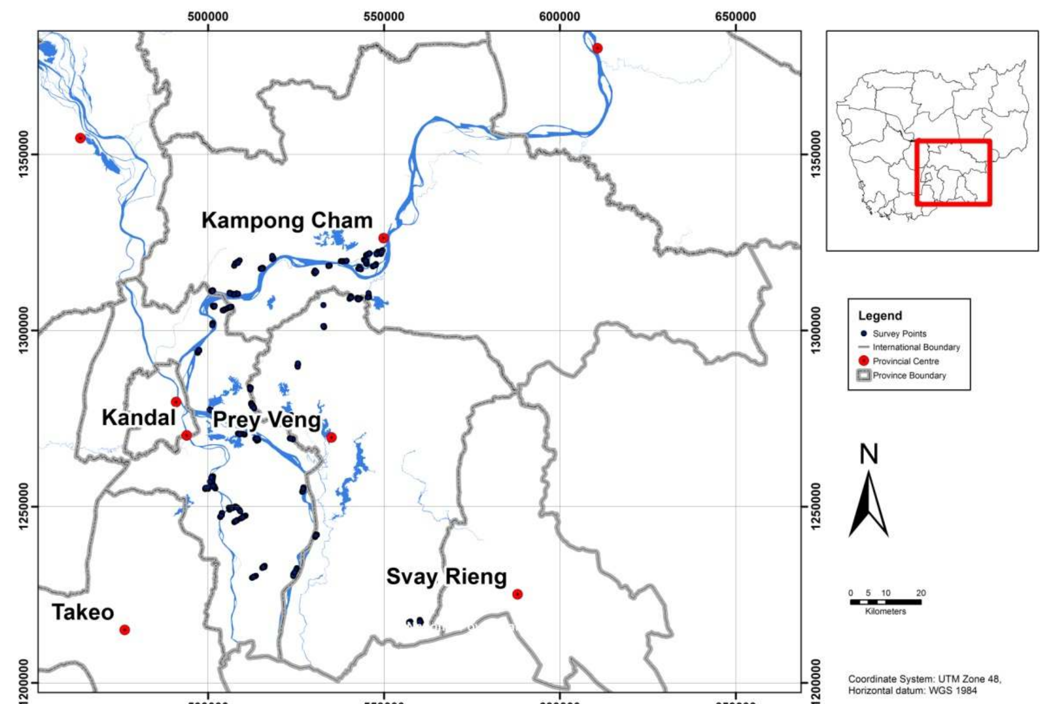

Fig. 1. Map of study areas

Table 1. Distribution of sample over the study area

Province	District	Commune	Village	Respondent
Prey Veng	5	9	9	180
Kandal	7	17	22	438
Kampong Cham	4	13	19	380
Total	16	39	50	998

2.3 Data Analysis

The survey data were jointly collected by Resource Development International (RDI) staff and Royal University of Phnom Penh (RUPP) students under the supervision of a United Nations Children's Fund (UNICEF) and RUPP team. Data entry and analysis were carried out by the RUPP team with SPSS version 18.0.

3. RESULTS AND DISCUSSION

3.1 Water Use Pattern

To get baseline data on water use pattern, four questions were included in this study. The water use patterns here try to understand the main source of water usage for drinking, cooking and other domestic purposes (washing, bathing and cleaning, livestock and gardening) during both the rainy and dry seasons. A question about water treatment methodology also was included to assess household practices in daily handling of drinking water.

3.1.1 Major source of drinking water

It is important to note here that only 12.5% of total respondents use water for drinking and cooking separately. Interestingly, it appears rainwater is the main source for drinking water in the arsenic affected areas for both seasons, followed by bought water, tube well water, and surface water respectively. However, it also is noted that there is a slightly increased use of rainwater and decreased use of tube wells and bought water in wet season. One of the reasons is that rainwater is more available in the rainy period and people may try to collect and store rainwater for the dry season due to the shortage of water in the dry period. Bought water in this study included both surface water and water from tube wells. Fig. 2 illustrates water source for drinking by seasons at the selected study areas.

However, when considering the availability of those water sources and preference, tube wells become the first priority source of water for drinking in the dry season with 26.33 % of total respondents, followed by bought water and surface water source with 25.33% and 14.51% respectively. We included the idea of "preference" here to get a deeper understanding of villager's thinking and behavior with respect to water use. They may not necessarily use this water, but we wanted to know their source preference. Tube wells as a preferred source decreased to only 16.98% in the wet season while rainwater users' preference was sharply increased from 10.21% to 50.85% comparing the dry to wet season. Thus, there is a significant proportion of the population using tube wells for drinking purposes in all seasons while rainwater becomes the major water source during the rainy season. Figs. 3 and 4 indicate the priority (preference) ranking for the selected water source of the local people in the at risk areas of arsenic.

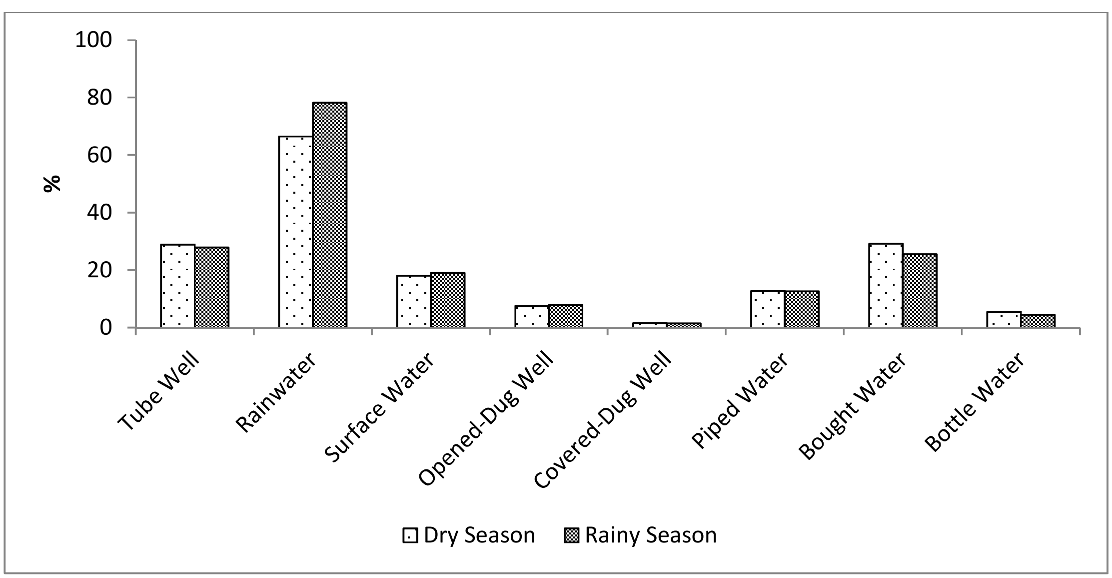

Fig. 2. Water source for drinking by seasons

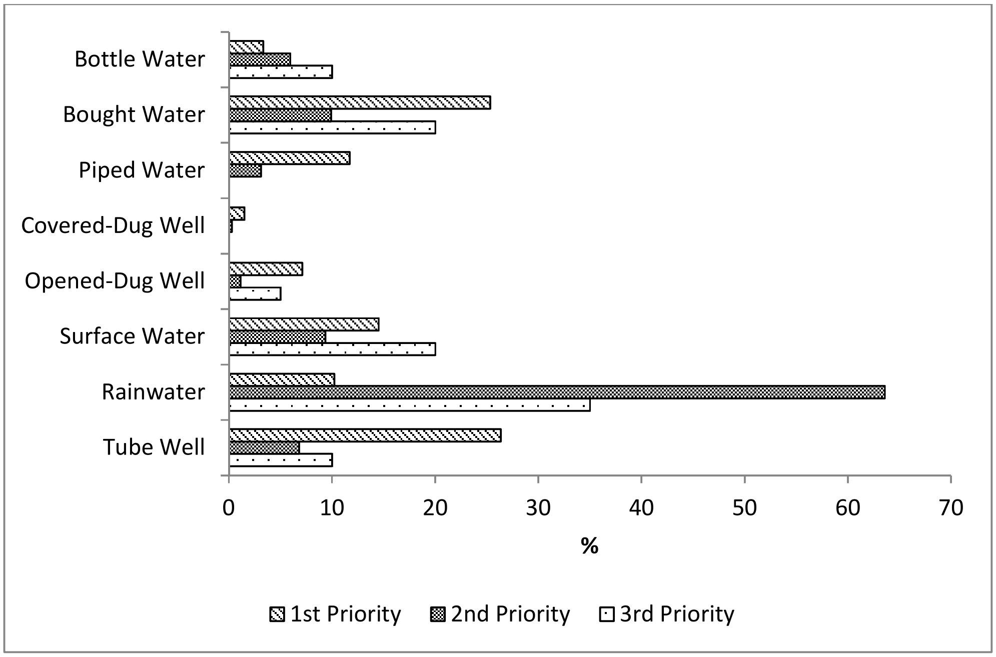

Fig. 3. Priority ranking for drinking water in dry season

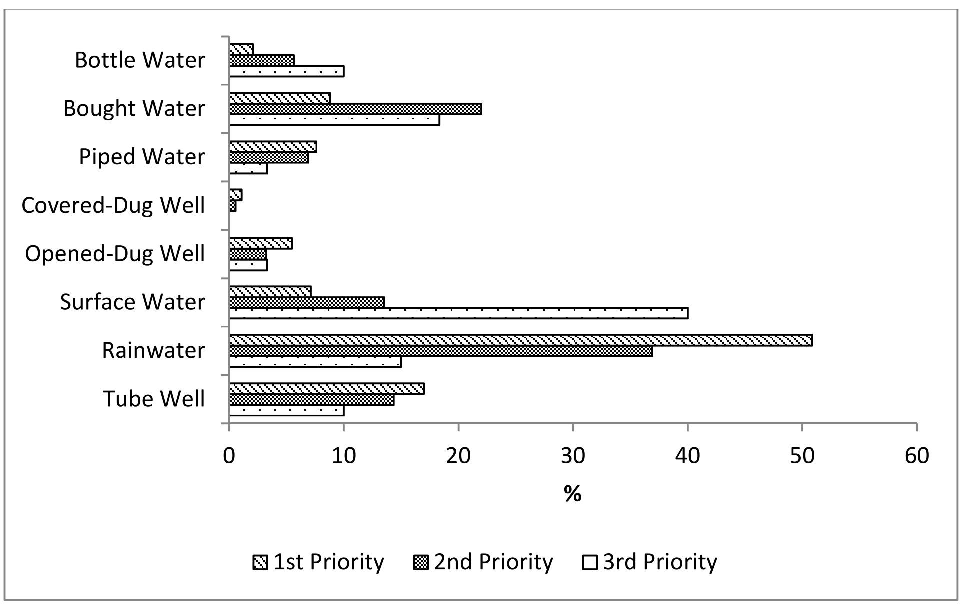

Fig. 4. Priority ranking for drinking water in wet season

Rainwater was identified as the main drinking water source both in this study and a Knowledge, Attitude and Practices (KAP) study reported by the Ministry of Rural Development [14] in 2009. However, an increase in rainwater consumption appears to have occurred in the wet season between the time of the two studies (57.08% from [14] and 78.02% for the current study). A sharp increase of rainwater use in the dry season from 4.12% [14] to 66.5% in this study, also was observed. This might reflect the effort of national and local government as well as local NGOs in community education on the use of rainwater. The use of surface water decreased from 33.2% and 42% to 19.1% and 18.2% in the wet and dry seasons respectively, as reported by the two studies. Tube well water users slightly increased from 17.02% and 22.20% [14] to 27.9% and 29% in wet and dry seasons, as reported in this study.

3.1.2 Major source of cooking water

Statistically, a similar source pattern was found in terms of water for cooking on a daily basis. Tube wells were an important water source for cooking for the full year (>30% response) while rainwater was still the main source for cooking for local people in the arsenic prone areas of Cambodia for the wet season. In the dry season the use of rainwater dramatically dropped to 28.8% and the use of bought water slightly increased from 25.9% to 30% from the dry to rainy season. Surface water remained steady for both seasons at less than 20%. Fig. 5 depicts water source for cooking by seasons at the selected study areas.

Considering the preference ranking of water, rainwater identified as the primary source of water for cooking sharply increased from 7.53% (dry season) to 46.3% during the wet season. Figs. 6 and 7 provide the comparison on preference of water source for cooking in both seasons.

Unfortunately, the use of water for both cooking and drinking was correlated with only availability and not with As level. This result is consistent with the KAP survey in 2009 [14] which clearly mentioned that the availability of water is the driver for the selection of water usage in the daily living of local people.

3.1.3 Major source for other domestic usages of water

Excluding seasonal variation, six water sources are used by local people in arsenic affected areas for domestic purposes. Water use for irrigation is not included in this study as part of the domestic consumption. More than half of the population used rainwater for washing, bathing and cleaning while less than half of the respondents used tube well for the same purpose (Fig. 8). Some 33% used surface water for similar activities. The remaining small portion used dug wells, piped water and bought water for domestic purposes.

Livestock is another water consumption activity. Three sources of water are used by respondents for livestock/animal feeding as the main source for water supply, namely tube well, rainwater and surface water with almost similar proportions of 47.6%, 46.2% and 40.4%, respectively. About 25% of respondents still use dug well, piped water and bought water for livestock activities (Fig. 8).

Similarly, tube wells, rainwater and surface water were the main water sources for gardening (51.1%, 41.2% and 33.2% respectively). Around 25% of the respondents used other water sources for the same activity.

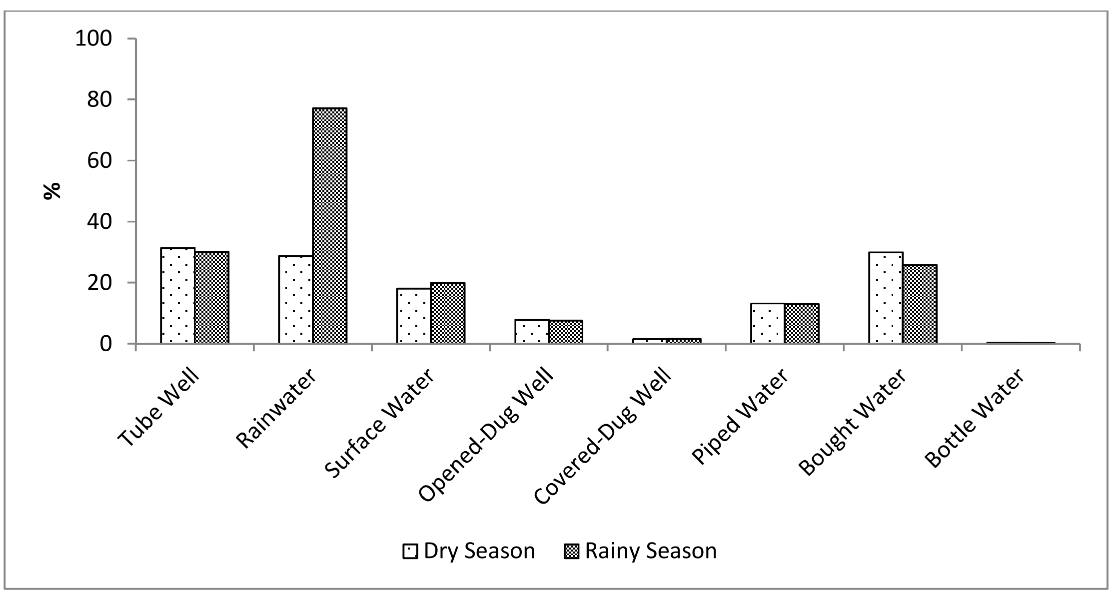

Fig. 5. Water source for cooking

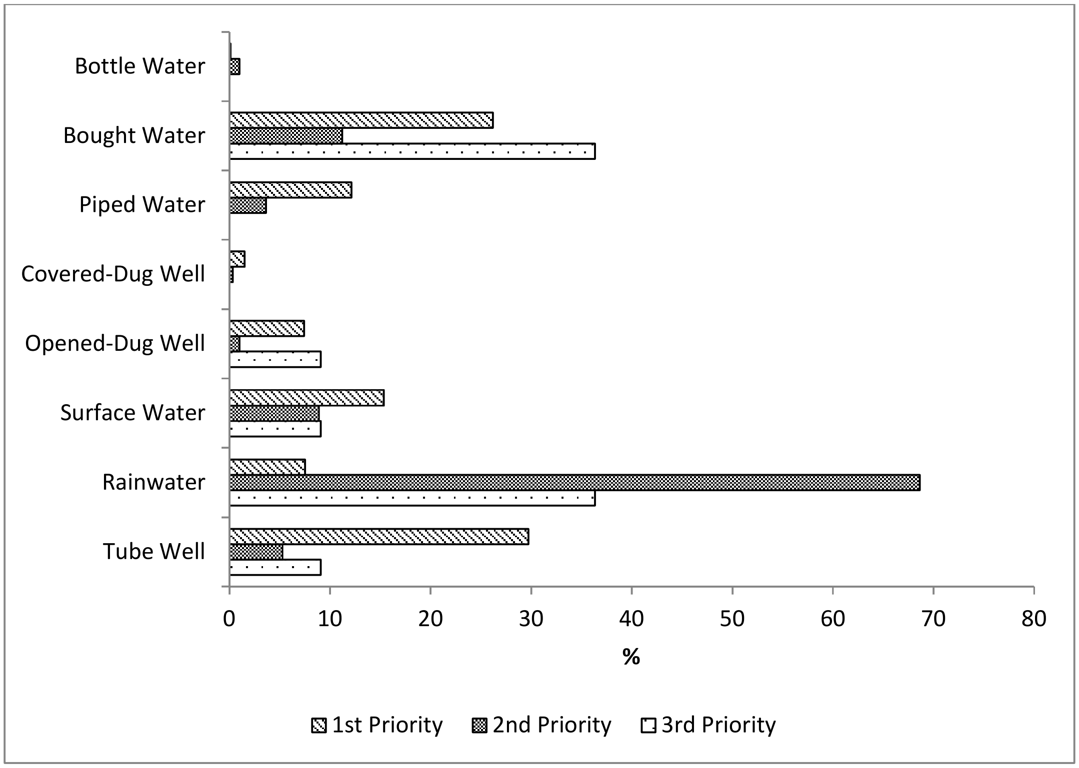

Fig. 6. Priority ranking for cooking water in dry season

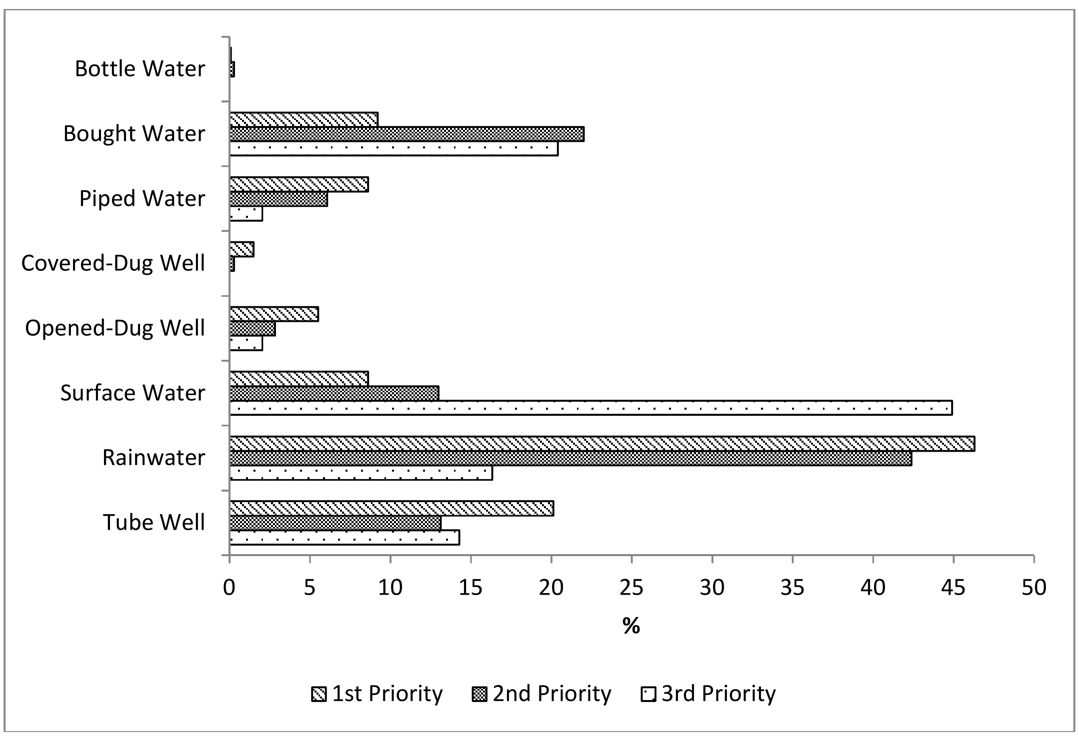

Fig. 7. Priority ranking for drinking water in wet season

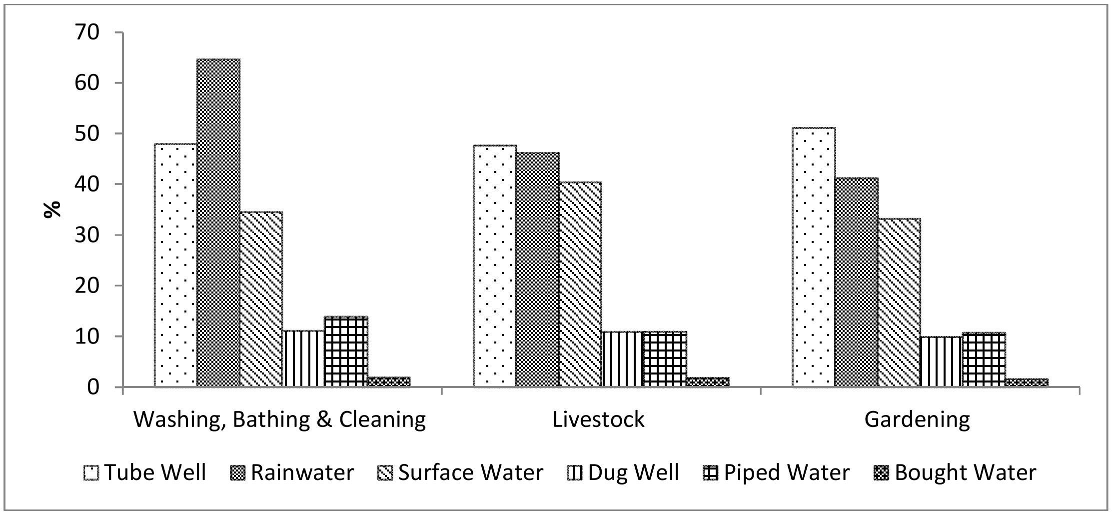

Fig. 8. Water source of domestic use

3.1.4 Method for drinking water treatment

The survey data showed that 82.1% of respondents treated their drinking water, with the habit for drinking untreated water being the main reason for not treating their drinking water. Notably, the majority of people that treat their drinking water do so regardless of the source of water they are using (more than 60% for all sources). This statistic clearly indicates that people tend to treat their drinking water due to habit rather than for safety reasons. Fig. 9 shows the frequency of drinking water treatment by source.

More than 80% of respondents reported that they boil water before drinking regardless of water source, while some 10% of local people use a filter as the means for treating their water. There are many kinds of filters available in Cambodia and the study did not classify the kind of filter being used by local communities. This finding was similar to a study by RDI [13] that around 60% of people treat their water before drinking or cooking and most of them (80-90%) rely on boiling as means for water treatment. Less than 1% of respondents expressed that they use chemical (Alum) for treating their drinking water. A summary of means for treating drinking water is presented in Fig. 10.

Similar findings also were reported in terms of drinking water treatment and its frequency by the KAP study [14]. Both studies reported that more than 60% of respondents always treat their drinking water before consumption and boiling represents the biggest portion of the population who treat their water.

3.2 Current Arsenic Exposure Population

3.2.1 Characteristics of respondents using tube well

Around 31.6% of total respondents (n=998) claimed that they are still using tube well water for drinking/cooking. By province, the response was 27.3%, 47.3%, and 25.4% for Kandal, Prey Veng, and Kampong Cham, respectively.

Out of the 31.6% of total respondents (which is equal to 315 respondents), who claimed that they are still using tube well water, 16.8% (53 out of 315) had an ID-POOR card (Identification of Poor Households). ID-POOR refers to the determination of poor households, their level of poverty, and area poverty rates. Such determinations are done based on the procedure and criteria stated in the sub-decree for ID-POOR of the Royal Government of Cambodia [15] (Table 2). To explore further about the relationship between respondents holding ID-POOR Cards and respondents still using tube well water for drinking/cooking, a Pearson Chi-square test was employed. The result showed that there is a relationship between respondents holding ID-POOR Cards and using tube well water for drinking/cooking at a 5% significance level (Pearson Chi-Square=17.3, df=2, asymptotic significance of 2-sided=0). This means that the respondents who are holding an ID-POOR card tend to use tube well water for cooking/drinking and respondents who are currently not holding an ID-POOR card tend not to use tube well water for cooking and drinking.

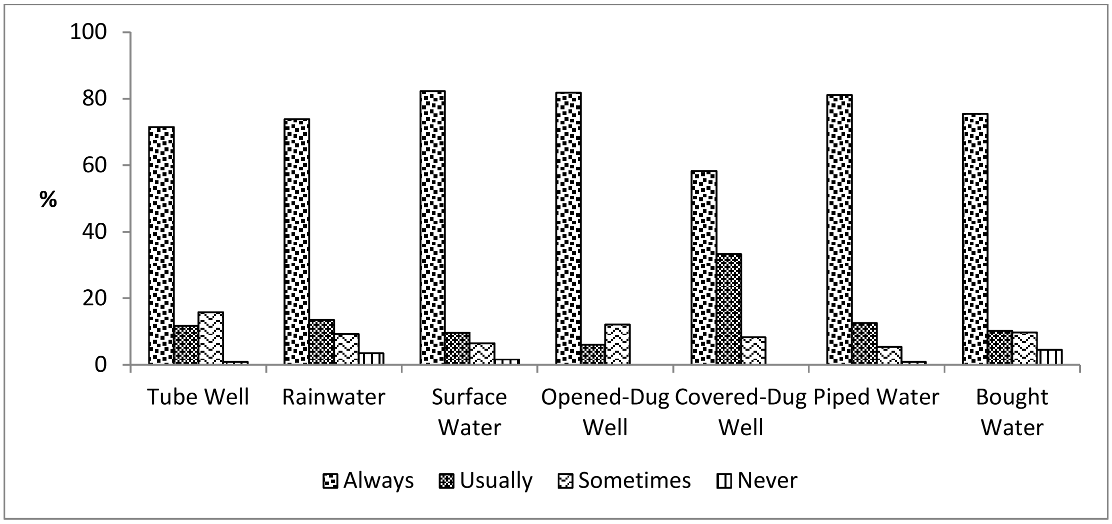

Fig. 9. Frequency of treating drinking water by sources

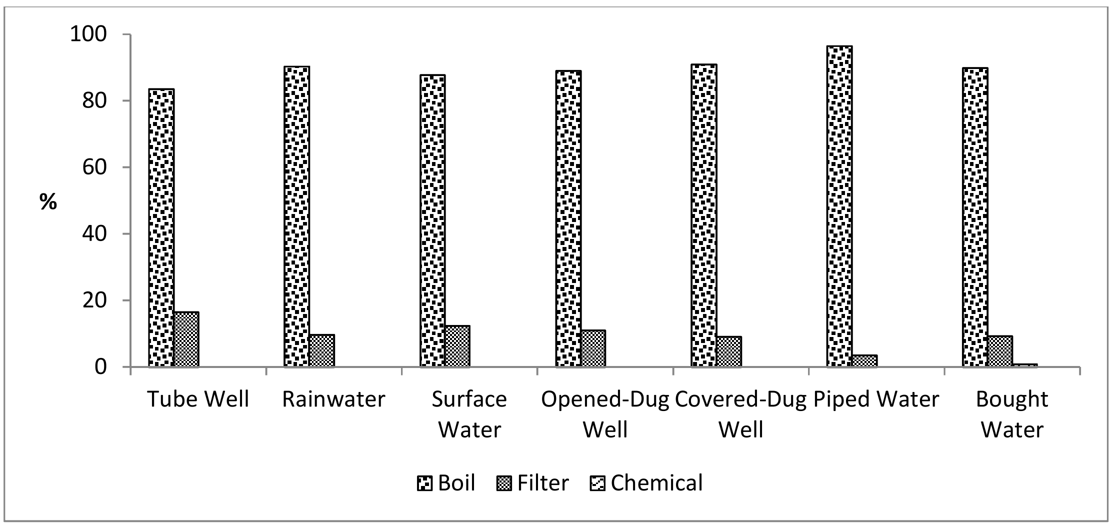

Fig. 10. Types of treating drinking water by sources

Table 2. Crosstab of people who still are using tube well water for drinking/cooking and families holding ID-poor card (n=998)

ID poor	Using tube well water for drinking/cooking now					
	Still using		Stop using		Total	
	Frequency	%	Frequency	%	Frequency	%
Have	53	5.3	70	7	123	12.3
Do not have	240	24.1	515	51.6	755	75.7
Not available here	22	2.2	98	9.8	120	12
Total	315	31.6	683	6.84	998	100

Among the respondents who have an ID-POOR card and still are using tube well water, most of them (64.1%, n=53) are living in Prey Veng Province. Kandal Province was second with 22.6% (n=53).

3.2.2 Tube well water quality

As was tested for the tube wells of 285 of the 315 respondents that reported they still used tube wells. The result shows that the percentage of respondents exposed to arsenic levels below the Cambodian standard of 50 ppb was about 77.9% of the total respondents still using tube well water for drinking/cooking (n=285). The percentage of respondents exposed to arsenic levels higher than the standard was approximately 22.1% (63 out of 285) (Figs. 11, 12 and 13).

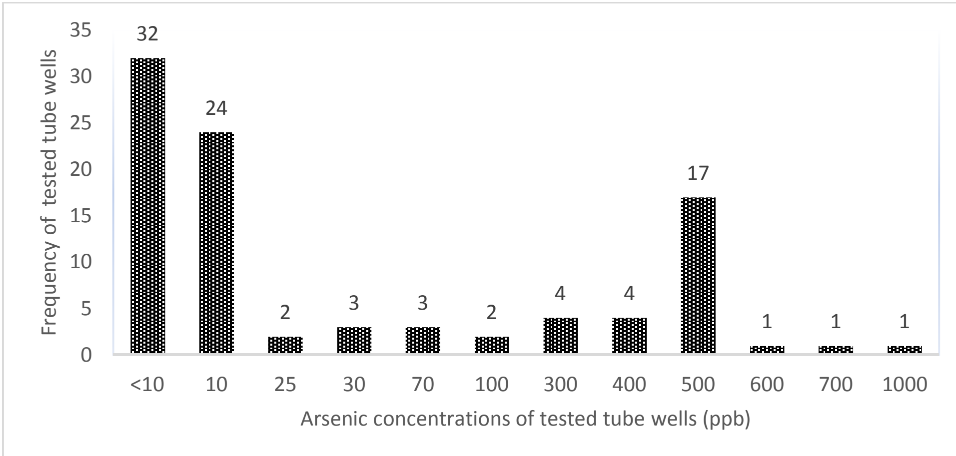

Fig. 11. Frequency of tested tube wells and As concentrations in Kandal

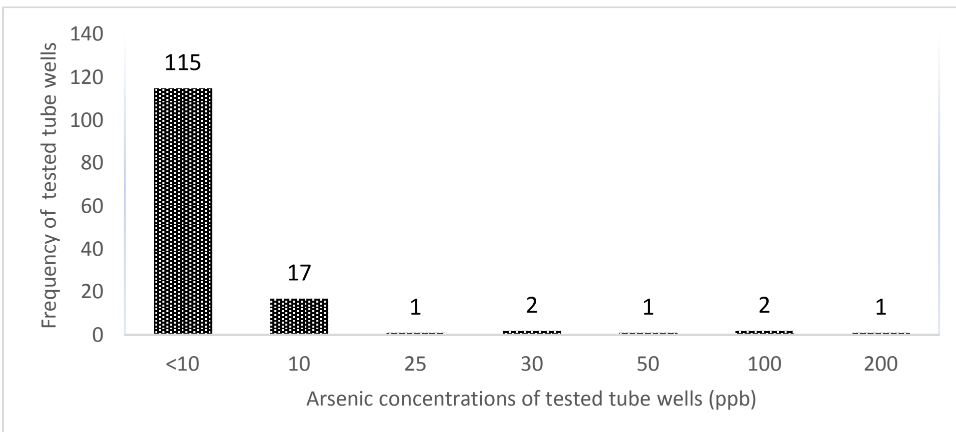

Fig. 12. Frequency of tested tube wells and As concentrations in Prey Veng

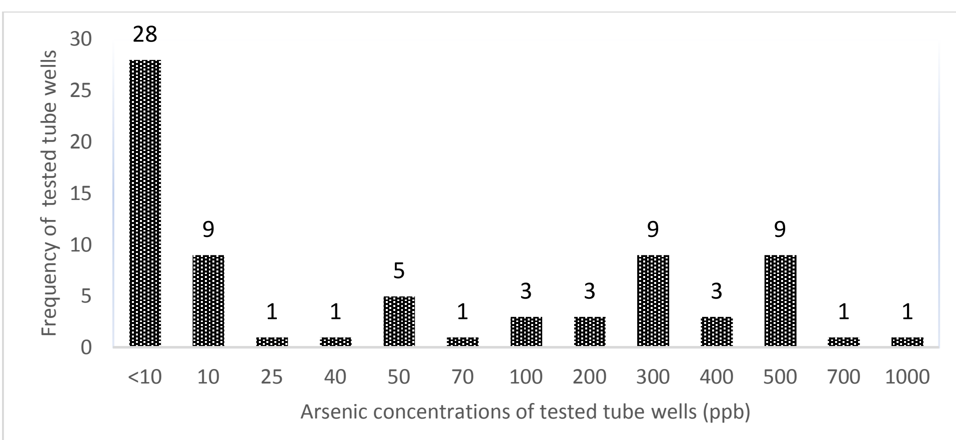

Fig. 13. Frequency of tested tube wells and As concentrations in Kampong Cham

Specifically, among of the respondents exposed to arsenic levels exceeding the standard (n=63), about 49.2% were from Kandal Province, 46% from Kampong Cham Province, and 4.8% from Prey Veng Province (Table 3).

3.2.3 Frequency of arsenic exposure via drinking and cooking

The result of the survey shows that among total respondents (n=998) from the randomly selected arsenic affected villages[1] of Kandal, Kampong Cham, and Prey Veng Province, the percentages of respondents whose exposure to arsenic levels was in the 10-50 ppb range and over 50 ppb was approximately 6.6% (66 out of 998 respondents) and 6.3% (63 out of 998 respondents) respectively. Out of the 6.3% of the respondents exposed to arsenic levels higher than 50 ppb, the provincial distribution was 3.1%, 2.9% and 0.3% for Kandal, Kampong Cham, and Prey Veng (n=998) respectively. Further detail about the percentages of respondents exposed to different arsenic levels within each province can be seen in Table 3.

3.2.4 Estimated population exposed to arsenic

Based on the above calculated rate (6.3%) of population exposed to an arsenic level that exceeded the Cambodian standard of 50 ppb and the total population of 412 arsenic affected

Table 3. Percentages of respondents exposed to different arsenic levels of tube well water by province

Province[2]	**Statistics**	**Arsenic conc. (ppb)**			**Total**
		<5	**10-50**	**Over 50**	
Kandal	Count number of respondents	13.0	29.0	31.0	73.0
	% within tested tube well (n=73)	17.8	39.7	42.5	100.0
	% within respondents in the province (n=438)	*3.0*	*6.6*	*7.1*	*16.7*
	% within total of respondents using tested tube well (n=285)	4.6	10.2	10.9	25.6
	% within total respondents in the three province(n=998)	**1.3**	**2.9**	**3.1**	**7.3**
Prey Veng	Count number of respondent	115.0	21.0	3.0	139.0
	% within tested tube well (n=139)	82.7	15.1	2.2	100.0
	% within respondents in the province (n=180)	*63.9*	*11.7*	*1.7*	*77.2*
	% within total of respondents using tested tube well (n=285)	4.0	0.7	0.1	4.9
	% within total respondents in the three province(n=998)	**11.5**	**2.1**	**0.3**	**13.9**
Kampong Cham	Count of respondents	28.0	16.0	29.0	73.0
	% within arsenic concentration (n=73)	38.4	21.9	39.7	100.0
	% within total respondents in the province (n=380)	*7.4*	*4.2*	*7.6*	*19.2*
	% within total respondents using tested tube well (n=285)	9.8	5.6	10.2	25.6
	% within total respondents in the three province(n=998)	**2.8**	**1.6**	**2.9**	**7.3**
Total	Count number of respondents	156.0	66.0	63.0	285.0
	% within tested tube well	54.7	23.2	22.1	100.0
	% within total of respondents using tested tube well (n=285)	54.7	23.2	22.1	100.0
	% within total respondents in the three province (n=998)	**15.6**	**6.6**	**6.3**	**28.6**

[1]Arsenic affected villages refers to villages in Kandal, Kampong Cham and Prey Veng Province where there are at 10% of tested tube wells in the villages have arsenic level higher than 50 ppb.
[2] The provinces here refer to selected arsenic affected villages of each province (Kandal, Prey Veng and Kampong Cham) only, not the entire province.

Table 4. Estimated population who expose to arsenic level over 50 ppb of 412 arsenic affected villages by province in 2011

Province	Numbers of villages	Population 2011			Estimated exposure population to arsenic > 50 ppb (rate=6.3%)		
		Male	Female	Total	Male	Female	Total
Kandal	195	181,265	189,379	370,644	11,420	11,931	23,351
Kampong Cham	132	61,462	66,262	127,724	3,872	4,174	8,046
Prey Veng	85	48,333	50,437	98,770	3,045	3,178	6,223
Total	412	291,060	306,078	597,138	18,337	19,283	37,620

villages in Kandal, Prey Veng and Kampong Cham Province in 2011 retrieved from the Cambodian Commune Database, it can be estimated that in the three provinces there were approximately 37,620 people exposed to arsenic levels of over 50 ppb. It also can be noted that among the three provinces having a population exposed to arsenic levels greater than 50 ppb, Kandal had the highest figure of about 23,351 people; meanwhile, Prey Veng had the lowest figure of 6,223 people. Further detail about the estimated population exposure in 2011 can be found in Table 4.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The following conclusions can be drawn:

- Water use pattern: There is no one best water source for all seasons. Rainwater is a major source of water for both cooking and drinking only in the rainy season. However, tube well water is somehow important in both seasons followed by surface water. While comparing the availability and quantity, tube well water and bought water share more than 50% as the first priority water source for local people in the dry season and likewise rainwater become the first priority water source for drinking in the rainy season. Boiling of water is the most common method for local communities to treat their drinking water (80%).
- Frequency of arsenic exposure and estimated arsenic exposure population: The population exposure frequency to arsenic over 50 ppb for the affected villages in the three provinces is approximately 6.3%. Notably, in the case of calculating the exposure rates by provinces, the rates of Kandal, Kampong Cham and Prey Veng are 7.1%, 7.6% and 1.7% respectively. The estimated population exposed to arsenic over 50 ppb for the 412 arsenic affected villages in the three provinces in 2011 is approximately 37,620 people, with the percentages of exposed population in Kandal and Kampong Cham contributing about 62.1 % (23,351 people) and 21.4% (8,046 people) to the total number of exposure cases.

4.2 Recommendations

- Surface water is still an important water source for communities as almost 20% of them use it for both seasons. This may lead to the risk of microbial contaminant if proper treatment and storage are not in place. Even though most of those surveyed boil water (80%), nearly all people stored water at home where it can be susceptible to microbial contamination through improper handling. Promoting surface water as an alternative water source is possible but a comprehensive Household Water Treatment and Storage (HWTS) program should be included to avoid substitution health effects from arsenic to microbial related illness.
- There are still a significant number of tube well water dependents (almost 30%) for both seasons. An effort in promoting awareness raising and education programs still is needed to help the poor and tube well water dependents in the arsenic impacted areas to have a better understanding about arsenic and its health effects. In addition, a regular well monitoring program should be established to assess risk change over time.
- This study found that there is still significant number of people using tube wells for drinking, and likely are at risk of

developing arsenicosis, thus arsenic mitigation and the provision of safe water supply programs should be in place to ensure that they are safe from using tube wells with contaminated water, as well as to accelerate the progress towards achieving the Government of Cambodia's Vision for Rural Water Supply, Sanitation and Hygiene Sector that everyone in rural communities has sustained access to safe water supply and sanitation services, and lives in a hygienic environment by 2015.

DISCLAIMER

SEAGA (Southeast Asian Geographers Association) International Conference 2014, Siem Reap, Cambodia (at Royal University of Phnom Penh), 25 - 28 November 2014.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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