4th International Forum on Sustainable Future in Asia
4th NIES International Forum, 23-24 January 2019, Hanoi, Vietnam

Environmental Arsenic Exposure and Human Health in the Mekong River Basin of Cambodia

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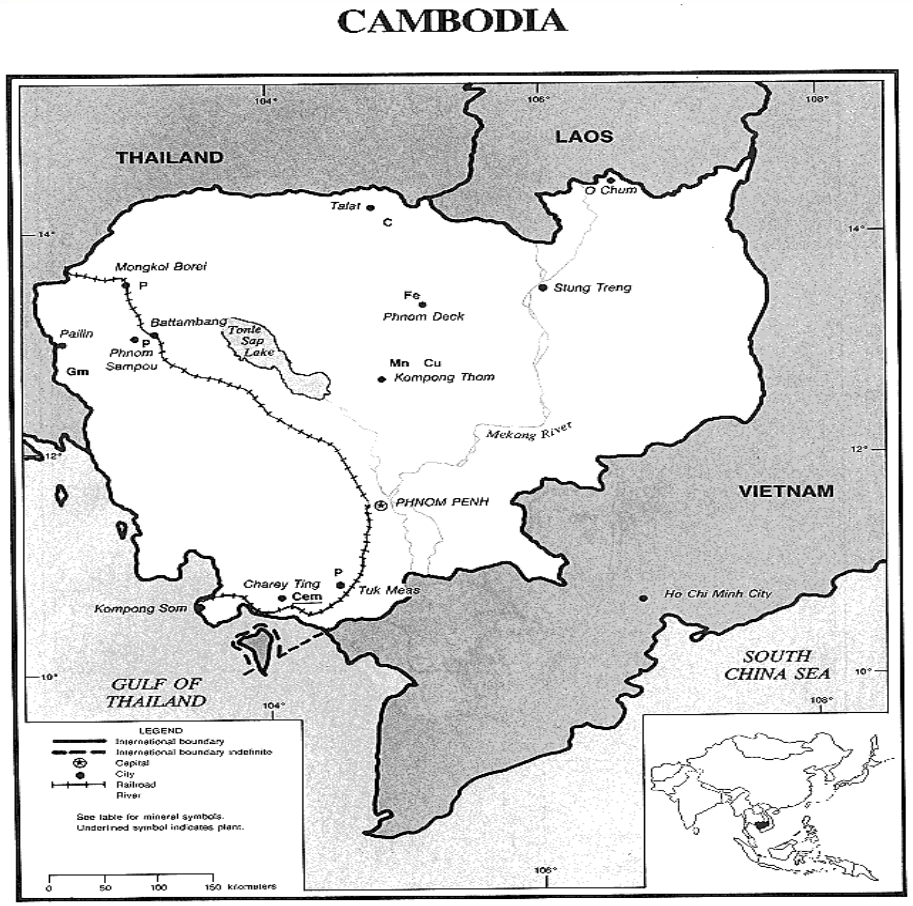
24 January 2019

Content

1) Groundwater drinking pathway
2) Daily food consumption (foodstuffs)
3) Groundwater and rice

Introduction



- Land area: 181,035 km^2
- Total population (2015): 15,578,000
- GDP per Capita: 1,218$ (2015)
- Boundary:
  - Thailand and Lao PDR on the West and the North
  - Viet Nam on the East and the Southeast.
  - The Gulf of Thailand on the Southeast

- 80% of Cambodian populations live in rural areas (NISC, 2012)
- 28.5% of populations are living under the national poverty line in 2010 (WFP, 2012)

Introduction

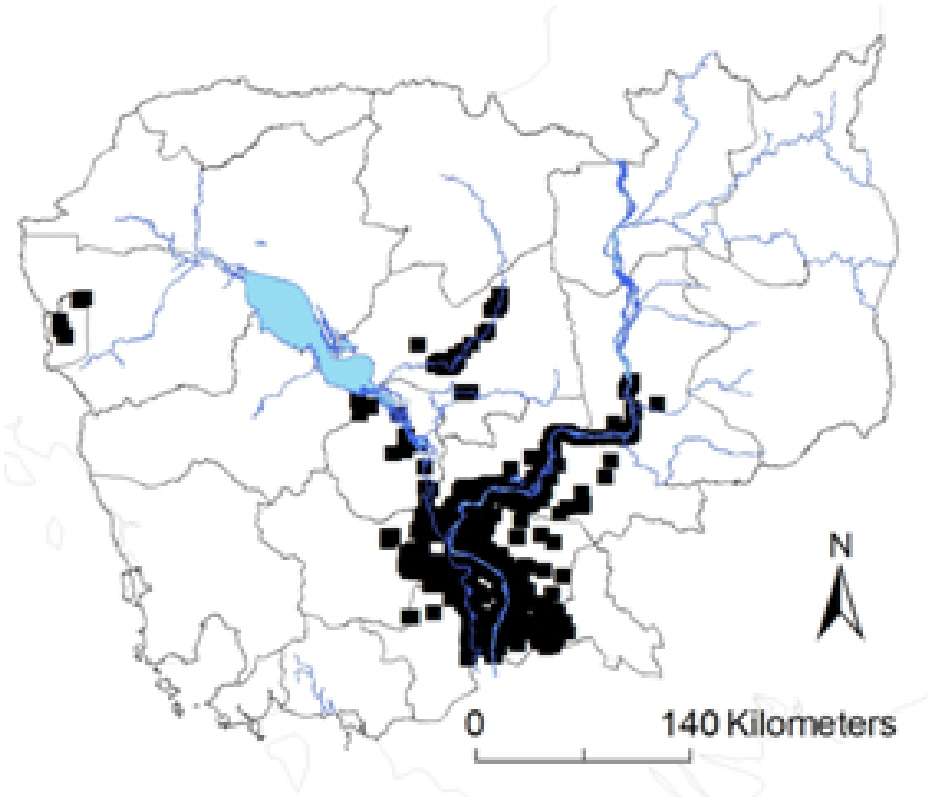
1) Abundance and Hazard of arsenic

- Oxidation state: -3, 0, +3 and +5 (WHO, 2004)
- Well-known mineral: Realga (As_4S_4), orpiment (As_2S_3), arsenolite (As_2O_3), loelingite ($FeAs_2$) and arsenopyrite (FeAsS)
- Abundant in shale, coal and ore deposits
- Contamination: Natural processes and anthropogenic activities

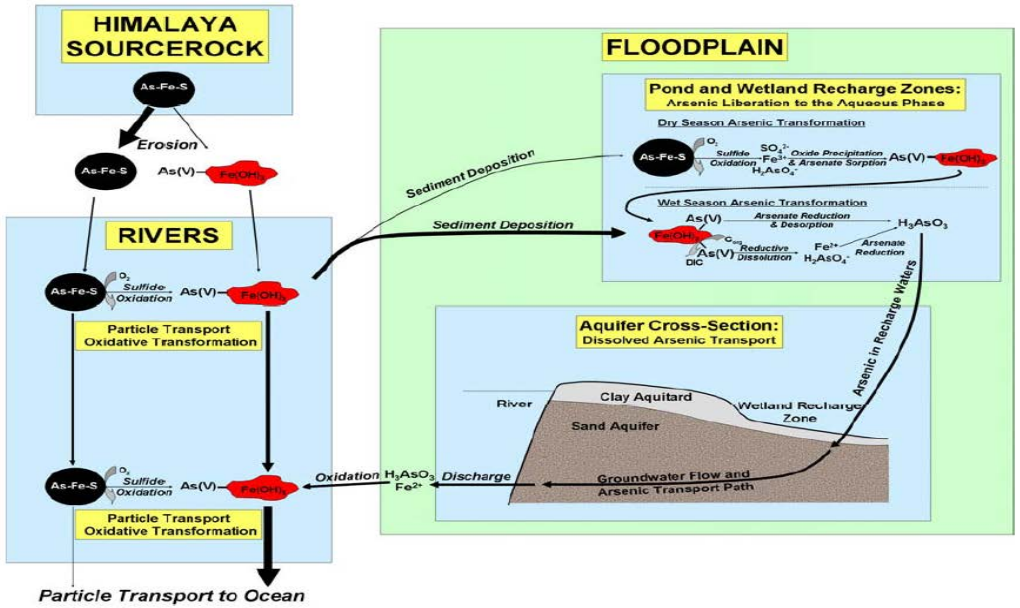
Acute toxicity: Gastrointestinal discomfort, abdominal pain, vomiting, diarrhea, bloody urine, shock, Coma and death (70-180 mg, 1-3 $mgAskg^{-1}$)

Chronic exposure: Dermatological manifestation (pigmentation, melanosis and hyperkeratosis), skin cancer, lung cancer and cancer of urinary bladder.

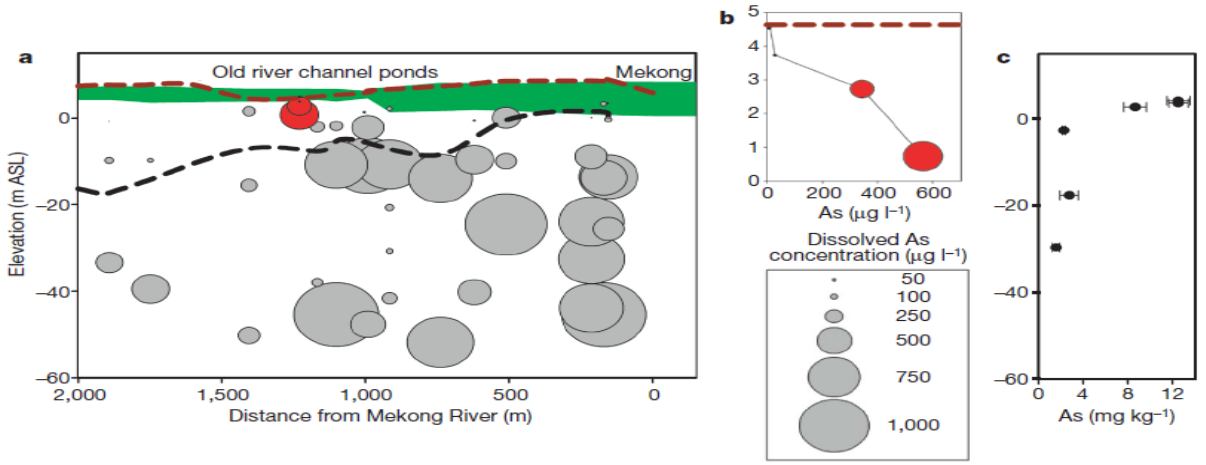
- 40% of the total populations **CANNOT** access to improved drinking water sources (UNICEF, 2012)
- Groundwater is the main source for drinking although many people live alongside surface waters



Groundwater arsenic-affected area (RDI, 2012)



(Polizzotto et al., 2007)



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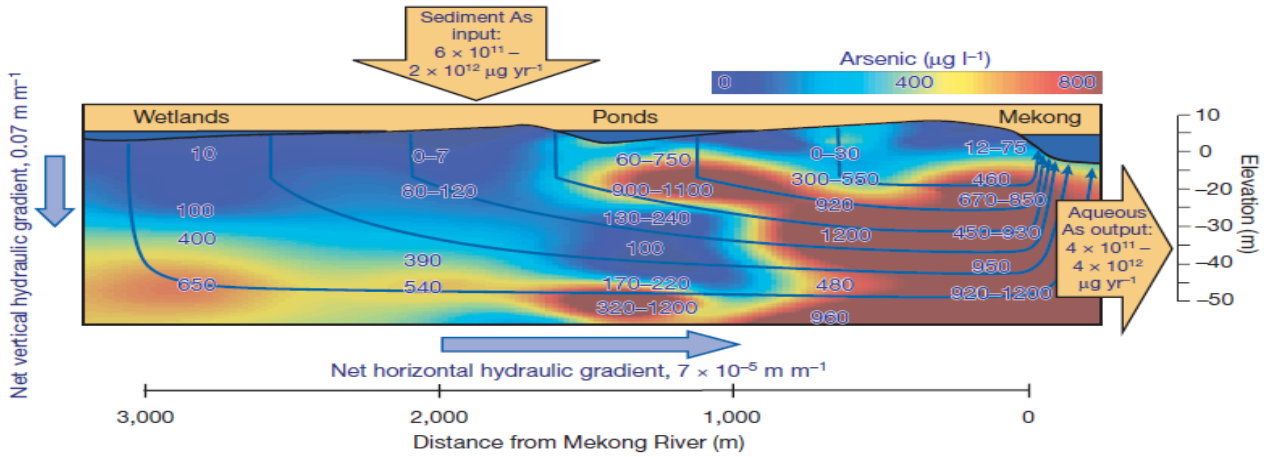


Source of arsenic release to ground water in Asia

General objectives

This study aims to provide a comprehensive investigation and the magnitude of arsenic exposure pathways in the Mekong River basin of Cambodia.

1) Assess health risk of arsenic from groundwater drinking pathway
2) Assess health risk of arsenic intake from local food consumption

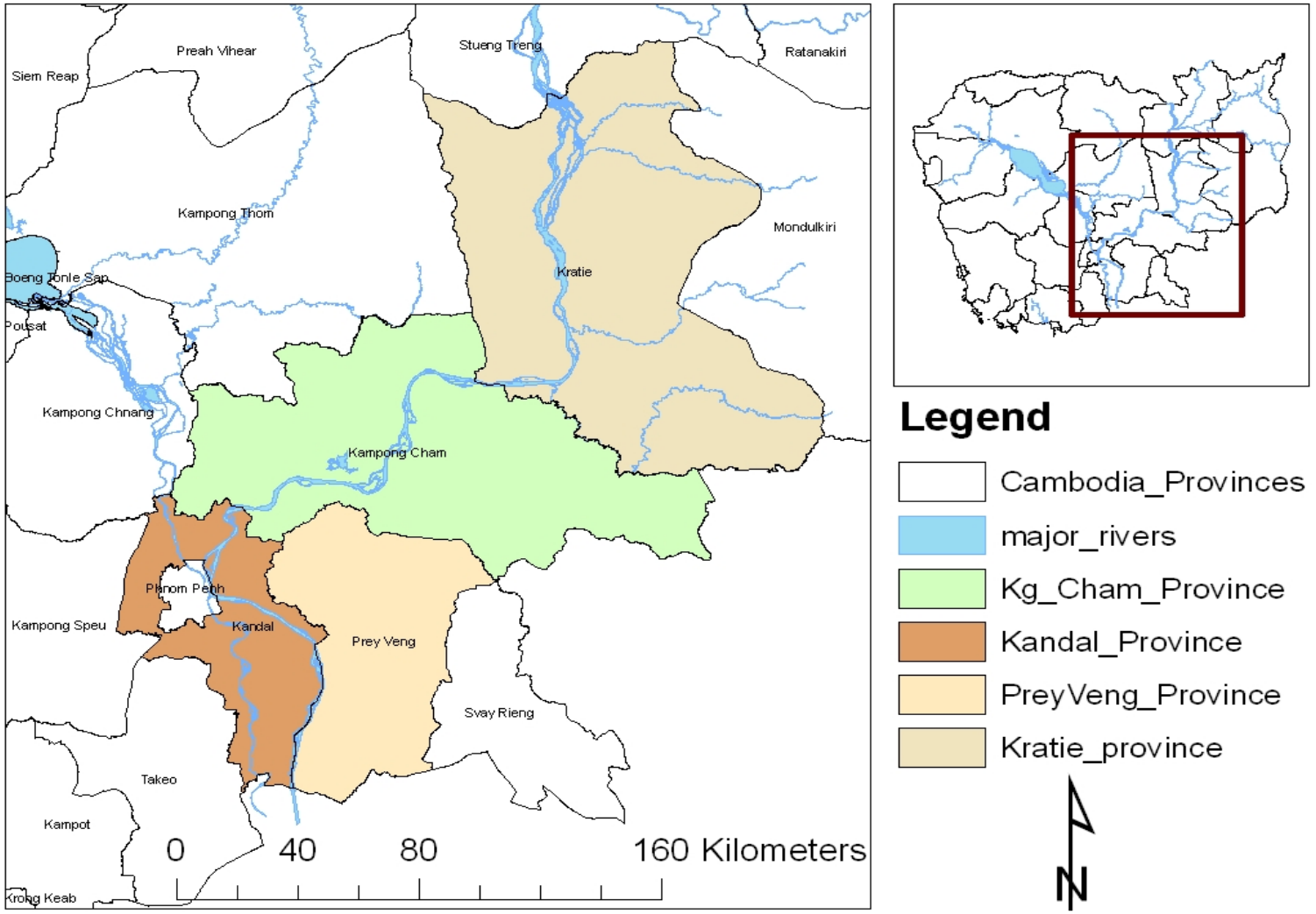


Figure 1 Map of sampling sites


a

HEALTH RISK ASSESSMENT MODEL

$$ADD = \frac{As_w \times IR \times EF \times ED}{AT \times BW} \quad (1)$$

ADD: Average daily dose from ingestion (mg kg^{-1} d^{-1})
As_w: Arsenic concentration in water (mg L^{-1})
IR: Water ingestion rate (L d^{-1})
EF: Exposure Frequency (d yr^{-1})
ED: Exposure Duration (yr)
AT: Average time/Life expectancy (d)
BW: Body weight (kg)

$$HQ = \frac{ADD}{RfD} \quad (2)$$

HQ: Hazard Quotient (Risk is considered occurring if HQ > 1.00)
RfD: Oral reference dose of total inorganic As (RfD = 3×10^{-4} mg kg^{-1} d^{-1})

$$R = 1 - \exp(-SF \times ADD) \quad (3)$$

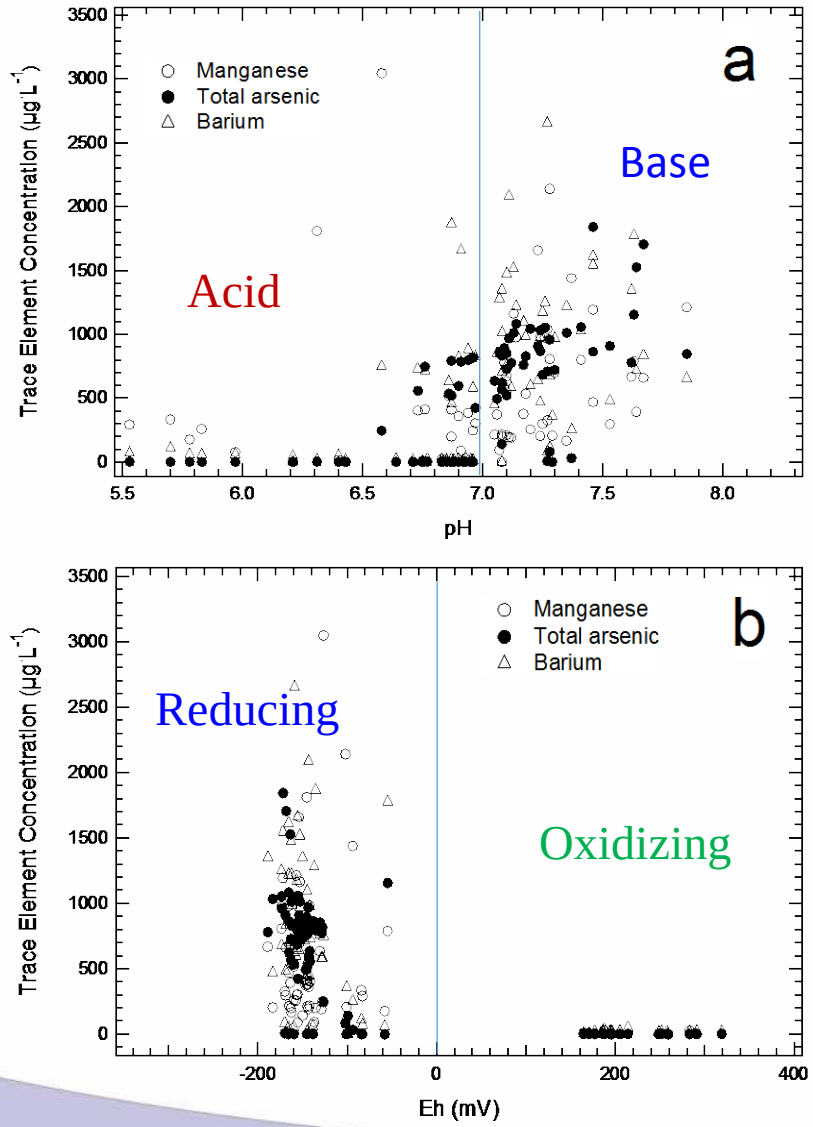
Where SF = 1.5 (mg kg^{-1} d^{-1})$^{-1}$ is a slope factor of As for carcinogen
USEPA (Integrated Risk Information System (IRIS): arsenic, inorganic, CASRN 7440-38-2, 1998)

Table 4 – Summary of body weight (BW), ingestion rate (IR) and exposure duration (ED) of respondents in each of the study areas.

		Kandal				Kratie				Kampong Cham			
		BW	Age	IR	ED	BW	Age	IR	ED	BW	Age	IR	ED
Male children	N	32				8				23			
	Mean	20.1	8.5	1.1	5.8	22.0	8.3	1.1	6.0	19.0	7.4	1.1	4.0
	Median	20.0	8.0	1.0	6.0	18.5	7.0	1.0	5.0	18.0	7.0	1.0	3.0
	S.D (σ)	4.8	2.3	0.3	2.4	6.3	2.4	0.2	2.6	4.9	2.5	0.3	2.3
	Min	12.0	5.0	0.5	2.0	16.0	6.0	1.0	4.0	11.0	3.0	1.0	1.0
	Max	28.0	12.0	2.0	12.0	34.0	12.0	1.5	11.0	30.0	12.0	2.0	10.0
Male adults	N	96				25				47			
	Mean	51.1	37.4	1.9	8.5	57.4	44.0	1.8	10.1	52.2	34.7	2.3	5.2
	Median	52.0	33.0	2.0	8.0	56.0	47.0	2.0	11.0	52.0	31.0	2.0	5.0
	S.D (σ)	9.3	18.6	0.6	4.3	11.0	21.5	0.4	2.5	12.6	18.7	0.7	2.9
	Min	28.0	14.0	1.0	2.0	31.0	13.0	1.0	5.0	25.0	13.0	1.5	1.0
	Max	79.0	76.0	4.0	19.0	80.0	83.0	2.5	13.0	80.0	76.0	4.0	12.0
Female children	N	30				6				19			
	Mean	20.1	9.1	1.0	5.1	21.7	9.3	1.0	7.0	18.4	6.8	0.9	3.9
	Median	20.0	10.0	1.0	4.5	23.0	9.5	1.0	7.5	15.0	6.0	1.0	4.0
	S.D (σ)	5.5	2.5	0.3	2.9	4.5	2.2	0.0	1.8	7.3	2.9	0.3	2.2
	Min	7.0	3.0	0.5	1.0	14.0	6.0	1.0	4.0	12.0	2.0	0.5	1.0
	Max	32.0	12.0	2.0	10.0	26.0	12.0	1.0	9.0	42.0	12.0	1.5	10.0
Female adults	N	139				50				95			
	Mean	47.4	37.7	1.6	8.5	48.5	43.4	1.4	11.0	52.1	39.0	2.0	5.2
	Median	47.0	37.0	1.5	8.0	48.0	43.5	1.5	12.0	50.0	34.0	2.0	5.0
	S.D (σ)	8.2	16.8	0.5	4.4	6.9	19.7	0.3	1.8	9.0	18.2	0.6	3.2
	Min	29.0	13.0	1.0	1.0	35.0	14.0	1.0	5.0	35.0	14.0	1.0	1.0
	Max	89.0	84.0	3.5	19.0	65.0	80.0	2.0	13.0	78.0	85.0	4.0	12.0

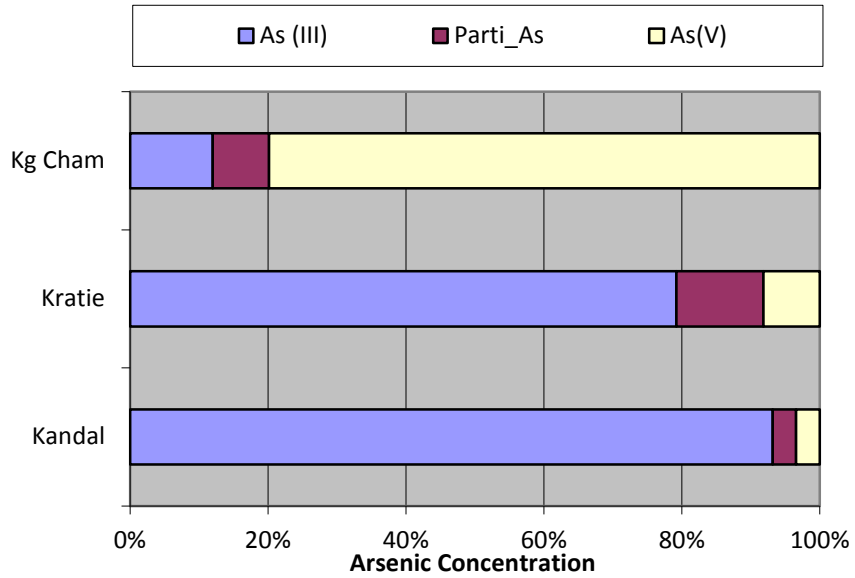
Body Weight (BW) is in Kg, Age in year(s), Ingestion rate (IR) in L d^{-1} and Exposure Duration (ED) in year(s).

Groundwater chemistry



Arsenic is released from solid phase to pore water through desorption process enhanced by alkaline condition

Arsenic is released to groundwater in reducing conditions



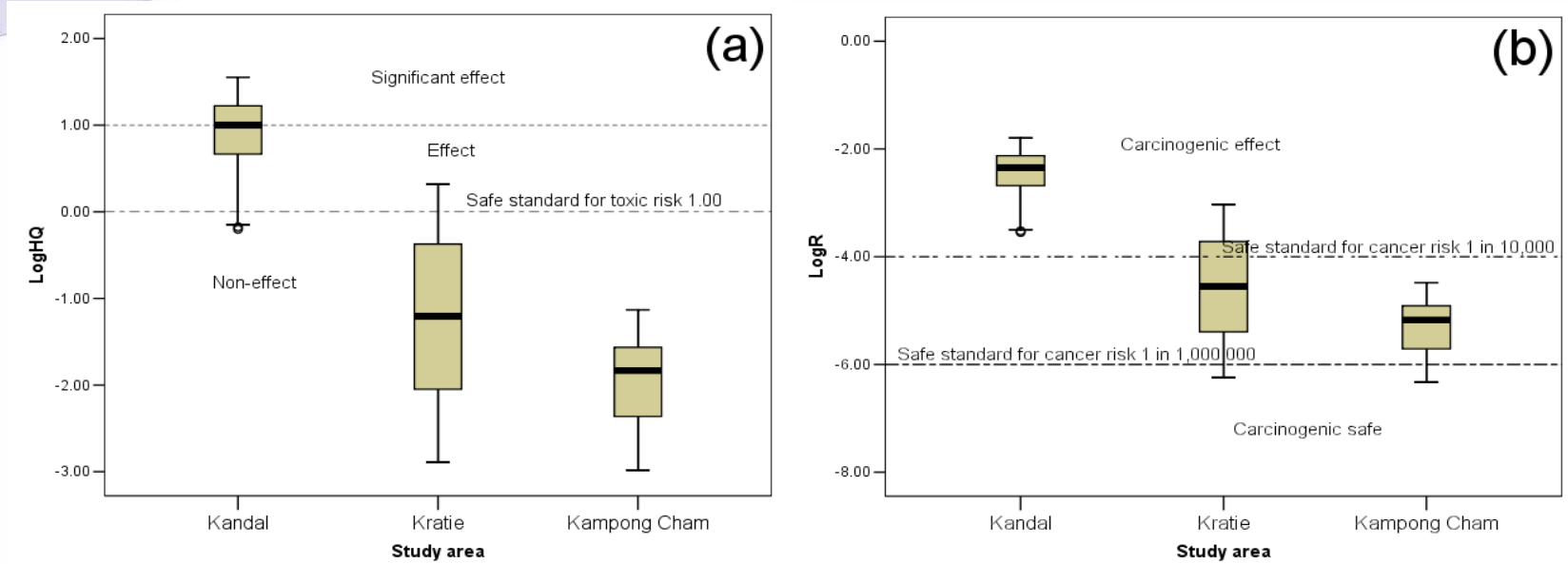
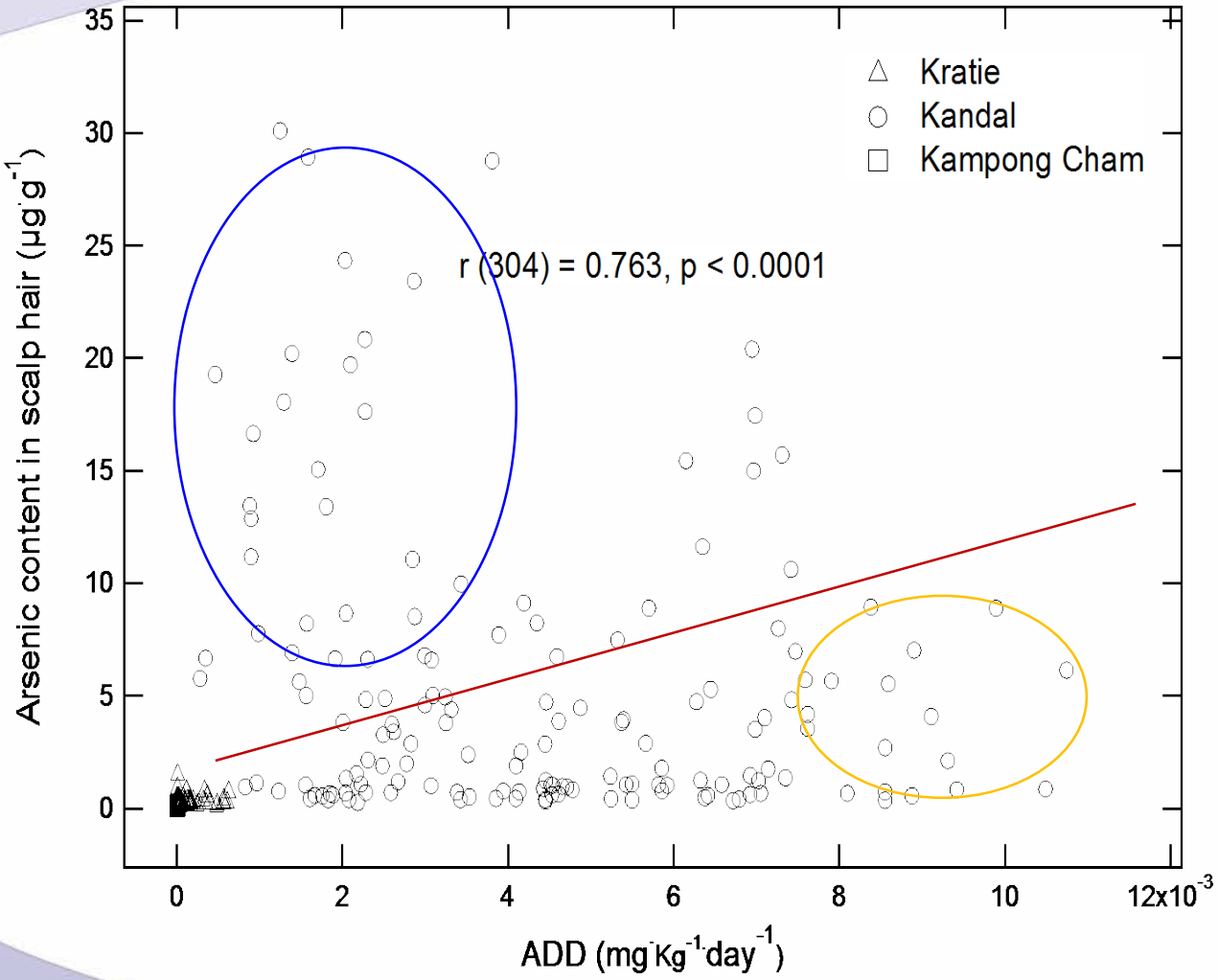


Table 2.8 Percentage of residents exposed to toxic and carcinogenic effects in each of the study areas (%)

Study area	HQ > 1.00	Cancer Risk Probability (R)			
		> 1 in 10^2	> 1 in 10^3	> 1 in 10^4	> 1 in 10^6
Kandal (n = 297)	98.65	13.80	92.59	100.00	100.00
Kratie (n = 89)	13.48	0.00	0.00	33.71	97.75
Kampong Cham (n = 184)	0.00	0.00	0.00	0.00	93.48

HQ: Hazard Quotient; R: Carcinogenic risk probability
1 in 10,000 is the highest safe standard for carcinogenic risk
1 in 1,000,000 is the safe standard for carcinogenic risk



1) Residents in the Kandal province study area might be exposed to more toxic and carcinogenic risks than those of the Kratie and Kampong Cham province study areas.

2) Positive significant correlations between arsenic content in hair (As_h), arsenic levels in groundwater (As_w), and individual average daily doses (ADD) of arsenic was found

2) Study areas & fieldwork (Foodstuffs)

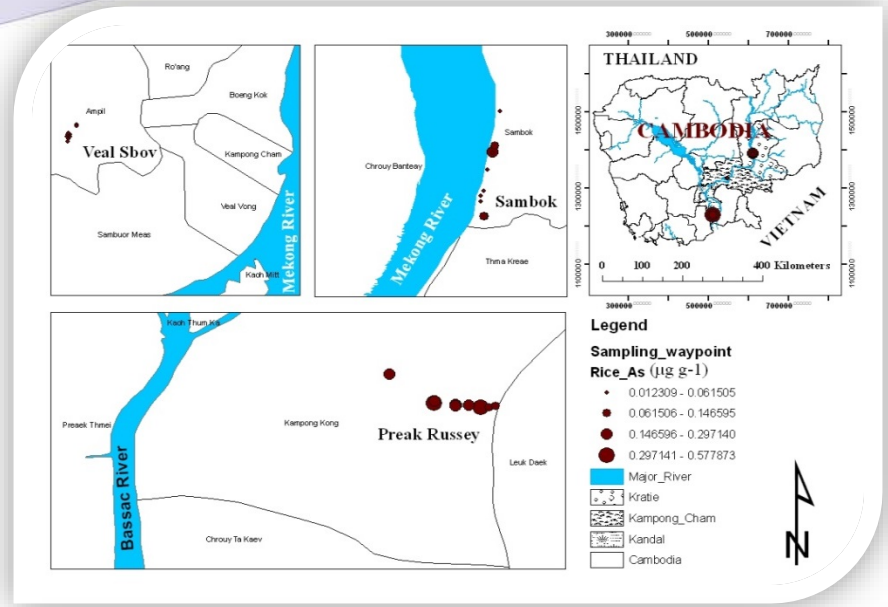
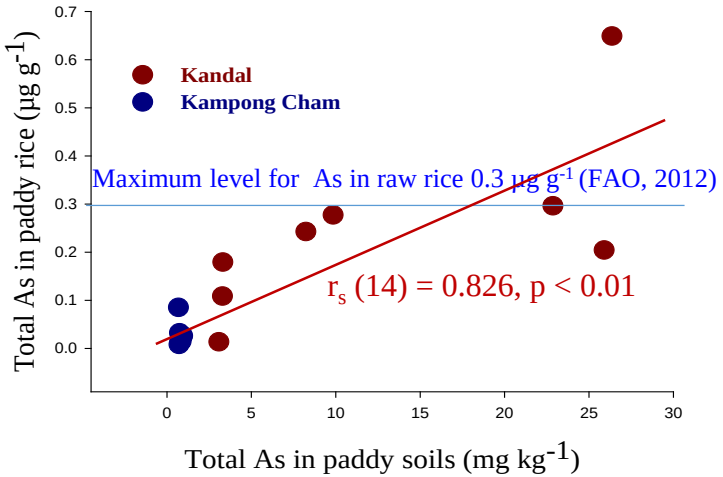


Table 3.1 Number of foodstuff samples

Sample	Kandal	Kratie	Kampong Cham	total
Uncooked rice	10	10	10	30
Cooked rice	10	10	10	30
Vegetable	15	9	15	39
Fish	10	10	10	30
Total	45	39	45	129

All foodstuffs were washed with deionized water and dried at 50 ^{o}C over night before digestion

Correlation of arsenic in paddy soil and rice

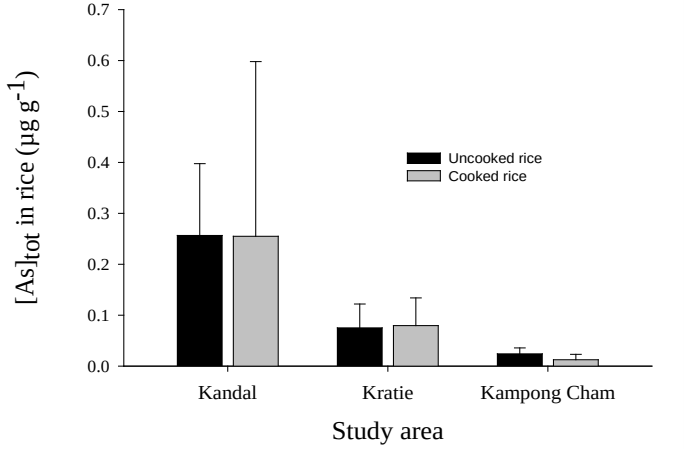


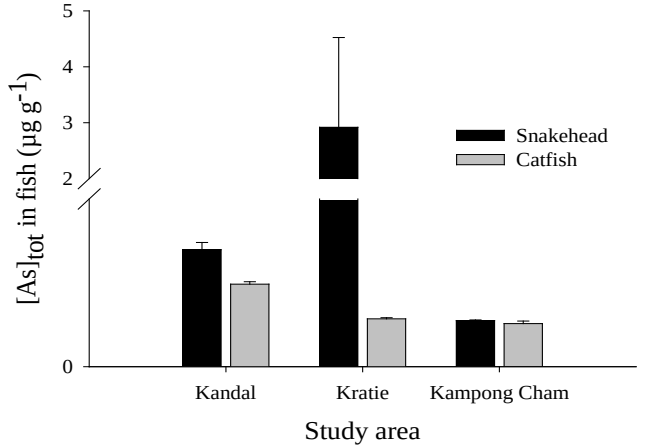
There is a significant positive correlation between arsenic in paddy soil and paddy rice

Table 3.2 A comparison of the total arsenic concentrations in paddy soil (mg kg^{-1}) and paddy rice (μg g^{-1}) in Kandal (n = 8) and Kampong Cham (n = 8)

Variables	Mean ± SD	Median	Range	*t*	*df*	*p*
Paddy soil				3.271	7.001	0.014
Kandal	12.858 ± 10.430	9.040	3.070 - 26.360			
Kampong Cham	0.794 ± 0.088	0.780	0.680 - 0.930			
Paddy rice				3.261	7.229	0.013
Kandal	0.247 ± 0.187	0.224	0.014 - 0.649			
Kampong Cham	0.029 ± 0.024	0.025	0.008 - 0.085			

The *t* and *df* were adjusted because variances were not equal, SD: Standard deviation





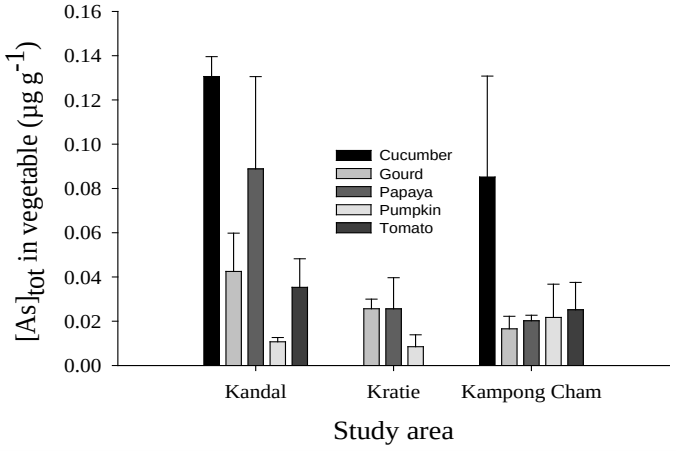


Table 3.4 One-Way Analysis of Variance comparing regional groups on the total arsenic concentrations in uncooked rice, cooked rice, fish and vegetable

Sources	df	SS	MS	F	*p*
Uncooked rice					
Between Groups	2	0.298	0.149	19.907	0.000
Within Groups	27	0.202	0.007		
Total	29	0.501			
Cooked rice					
Between Groups	2	0.314	0.157	3.889	0.033
Within Groups	27	1.089	0.040		
Total	29	1.403			
Fish					
Between Groups	2	12.607	6.303	5.604	0.009
Within Groups	27	30.372	1.125		
Total	29	42.978			
Vegetable					
Between Groups	2	0.011	0.006	4.173	0.023
Within Groups	36	0.048	0.001		
Total	38	0.059			

***df*: degree of freedom; SS: sum of squares; MS: mean square**

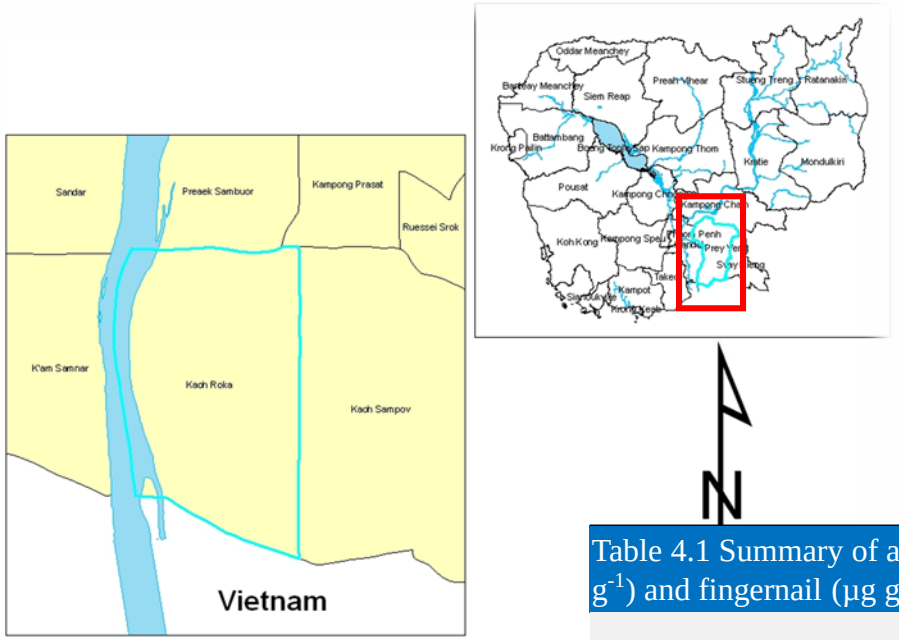
Table 3.5 Summary of $[As]_{tot}$ (μg g^{-1}), $[As]_i$ (μg g^{-1}), daily intake (μg d^{-1}) and daily dose (μg kg^{-1} d^{-1})of inorganic arsenic concentration in each of the study areas

	Kandal			Kratie			Kampong Cham		
Foodstuffs	Mean ± SD	Median	Range	Mean ± SD	Median	Range	Mean ± SD	Median	Range
Rice									
$[As]_{tot}$	0.255 ± 0.343	0.135	0.010 - 1.189	0.079 ± 0.057	0.073	0.005 - 0.190	0.012 ± 0.011	0.007	0.004 - 0.031
$[As]_i$	0.204 ± 0.274	0.108	0.008 - 0.951	0.064 ± 0.046	0.059	0.004 - 0.152	0.010 ± 0.009	0.005	0.003 - 0.025
Daily intake	91.784 ± 123.436	48.510	3.546 - 428.108	28.590 ± 20.691	26.398	1.917 - 68.360	4.484 ± 3.840	2.413	1.478 - 11.124
Daily dose	1.765 ± 2.374	0.933	0.068 - 8.233	0.550 ± 0.398	0.508	0.037 - 1.315	0.086 ± 0.074	0.046	0.028 - 0.214
Fish									
$[As]_{tot}$	0.178 ± 0.034	0.174	0.144 - 0.222	1.502 ± 1.837	0.091	0.084 - 3.993	0.080 ± 0.004	0.081	0.071 - 0.083
$[As]_i$	0.018 ± 0.003	0.017	0.014 - 0.022	0.150 ± 0.184	0.009	0.008 - 0.399	0.008 ± 0.000	0.008	0.007 - 0.008
Daily intake	0.765 ± 0.144	0.746	0.618 - 0.951	6.435 ± 7.872	0.390	0.358 - 17.115	0.341 ± 0.018	0.347	0.305 - 0.358
Daily dose	0.015 ± 0.003	0.014	0.012 - 0.018	0.124 ± 0.151	0.008	0.007 - 0.329	0.007 ± 0.000	0.007	0.006 - 0.007
Vegetable									
$[As]_{tot}$	0.062 ± 0.048	0.043	0.010 - 0.141	0.020 ± 0.012	0.019	0.004 - 0.042	0.034 ± 0.033	0.021	0.009 - 0.137
$[As]_i$	0.043 ± 0.033	0.030	0.007 - 0.098	0.014 ± 0.008	0.013	0.003 - 0.029	0.024 ± 0.023	0.015	0.006 - 0.096
Daily intake	3.080 ± 2.391	2.151	0.480 - 7.030	0.995 ± 0.580	0.960	0.190 - 2.085	1.688 ± 1.638	1.071	0.450 - 6.865
Daily dose	0.059 ± 0.046	0.041	0.009 - 0.135	0.019 ± 0.011	0.018	0.004 - 0.040	0.032 ± 0.031	0.021	0.009 - 0.132
All (Foods)									
Daily intake	95.629 ± 125.971	51.407	4.644 - 436.089	36.021 ± 29.143	27.748	2.465 - 87.560	6.513 ± 5.496	3.831	2.233 - 18.347
Daily dose	1.839 ± 2.423	0.989	0.089 - 8.386	0.693 ± 0.560	0.534	0.047 - 1.684	0.125 ± 0.106	0.074	0.043 - 0.353

Inorganic arsenic was assumed to be 10% in fish, 80% in rice and 70% in vegetable. The daily consumption rates of fish, rice and fruit vegetable were 42.86 g d^{-1}, 450 g d^{-1} and 71.43 g d^{-1} respectively. The average body weight of Cambodia residents was 52 kg.

$BMDL_{0.5}$ = 3.0 μg kg^{-1} d^{-1}

3) Study area (Groundwater & rice)



Map of the sampling site

Table 4.1 Summary of arsenic concentrations in groundwater (µg L^{-1}), rice (µg g^{-1}) and fingernail (µg g^{-1}).

	Arsenic concentration		
Statistics	Groundwater	Rice	Fingernail
N	11	11	23
Mean	118.312	0.201	0.830
Median	31.180	0.209	0.707
SD	138.527	0.050	0.631
Min	0.972	0.091	0.099
Max	351.500	0.285	2.382

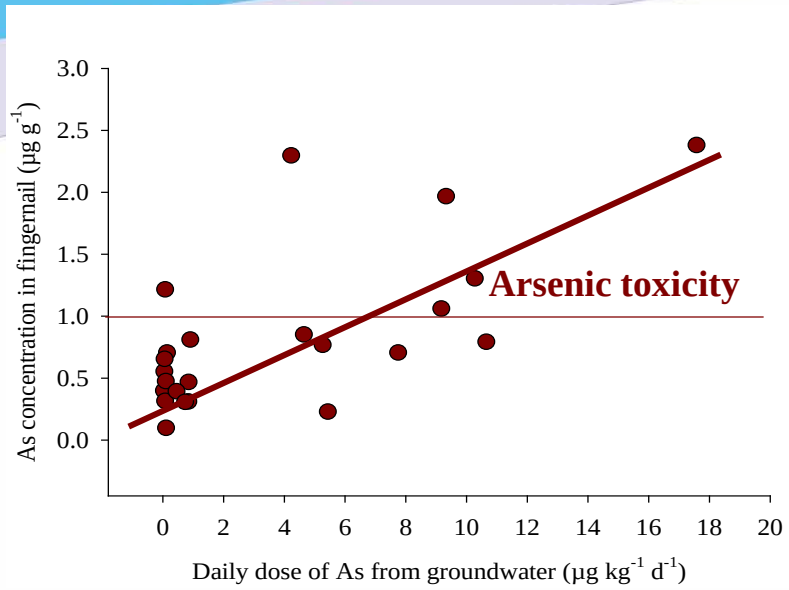
SD, standard deviation; Min, minimum; Max, maximum

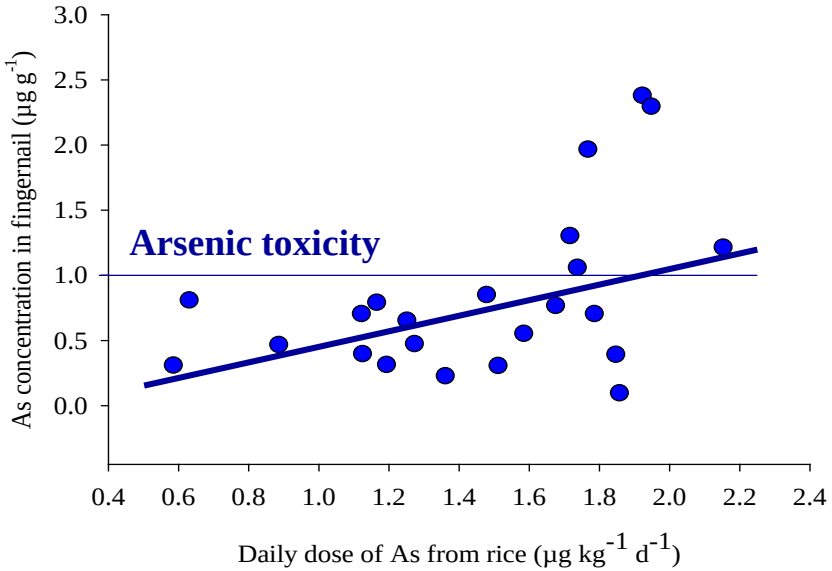
Table 4.2 Summary of inorganic arsenic concentration, daily intake and daily dose of inorganic arsenic from groundwater and rice

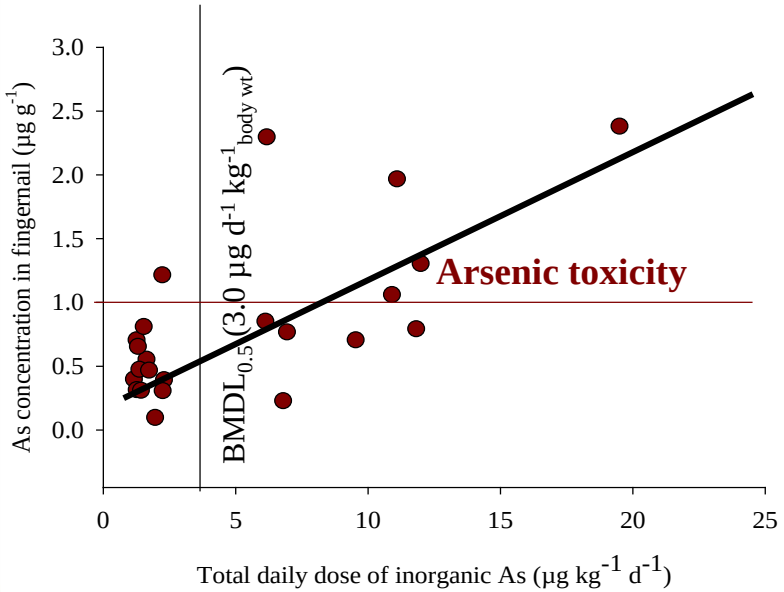
	Groundwater			Rice		
	Mean ± SD	Median	Range	Mean ± SD	Median	Range
Inorg-As concentration	118.312 ± 138. 527	31.18	0.972 - 351.500	0.167 ± 0.040	0.171	0.073 - 0.228
Daily intake (μg d^{-1})	196.455 ± 243.140	46.77	0.97 - 703.00	68.955 ± 20.886	75.359	27.977 - 102.454
Daily dose (μg kg^{-1} d^{-1})	3.855 ± 4.846	0.843	0.035 - 17.575	1.459 ± 0.421	1.511	0.585 - 2.152

SD, standard deviation

$BMDL_{0.5}$ = 3.0 μg kg^{-1} d^{-1}







As concentration in fingernail is positive significant associated to daily dose of As from groundwater (Spearman's rho, $p < 0.05$)

As concentration in fingernail is positively associated to daily dose of As from rice, but not statistically significant.

There is positive significant correlation between the As concentration in fingernail and daily dose of total inorganic As (Spearman's rho, $p < 0.05$)

Table 4.3 Inter-correlation between As concentrations in groundwater, rice, fingernail, daily dose of As from groundwater, rice and daily dose of total As

Variables	Rice	Fingernail	Groundwater intake	Rice intake	Total intake
Groundwater	0.563**	0.455*	0.971**	0.164	0.847**
Rice	--	0.355	0.563**	0.646**	0.749**
Fingernail	--	--	0.542**	0.406	0.555**
Groundwater intake	--	--	--	0.238	0.893**
Rice intake	--	--	--	--	0.576**

***p < 0.05; **p < 0.01**

1) The daily dose of inorganic As of Prey Veng residents was greater than the lower limits on the benchmark dose for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$ equals to 3.0 μg d^{-1} $kg^{-1}_{body\ wt.}$).

2) Positive significant correlations between groundwater As concentration, daily dose of As from groundwater and daily dose of total inorganic As with As concentration in fingernail were found.

Arsenicosis patients in Kandal province, Cambodia

Conclusions

1) Residents in the highly contaminated study area of Kandal are exposed to more toxic and carcinogenic risks than those in the Kratie and Kampong Cham provinces.

2) The results indicate that arsenic accumulation in Cambodian residents' bodies is mainly through groundwater drinking pathway

3) The daily dose of inorganic arsenic of the residents in Kandal province is higher than the lower limits on the benchmark dose for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$ equals to 3.0 μg kg^{-1} d^{-1})

4) Arsenic in rice is an additional source which is attributed to high arsenic accumulation in the residents' bodies in the Mekong River basin of Cambodia

Publications

Environ Geochem Health
DOI 10.1007/s10653-015-9759-z

ORIGINAL PAPER

Current status of arsenic exposure and social implication in the Mekong River basin of Cambodia

Kongkea Phan · Kyoung-Woong Kim · Laingshun Huoy · Samrach Phan · Soknim Se · Anthony Guy Capon · Jamal Hisham Hashim

Front. Med. 2011, 5(4): 420–433
DOI 10.1007/s11684-011-0158-2

REVIEW

Arsenic geochemistry of groundwater in Southeast Asia

Kyoung-Woong Kim (✉)[1], Penradee Chanpiwat[1], Hoang Thi Hanh[1], Kongkea Phan[1], Suthipong Sthiannopkao[2]

WATER RESEARCH 44 (2010) 5777–5788

Available at www.sciencedirect.com

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

Health risk assessment of inorganic arsenic intake of Cambodia residents through groundwater drinking pathway

Kongkea Phan[a,f], Suthipong Sthiannopkao[b,*], Kyoung-Woong Kim[a,*], Ming Hung Wong[c], Vibol Sao[d], Jamal Hisham Hashim[e], Mohamed Salleh Mohamed Yasin[e], Syed Mohamed Aljunid[e]

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Journal of Hazardous Materials

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

Arsenic contamination in the food chain and its risk assessment of populations residing in the Mekong River basin of Cambodia

Kongkea Phan[a,e], Suthipong Sthiannopkao[b,*], Savoeun Heng[c], Samrach Phan[c], Laingshun Huoy[c], Ming Hung Wong[d], Kyoung-Woong Kim[a,**]

International Journal of Hygiene and Environmental Health 215 (2011) 51–58

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.de/ijheh

Surveillance on chronic arsenic exposure in the Mekong River basin of Cambodia using different biomarkers

Kongkea Phan[a,c], Suthipong Sthiannopkao[b,*], Kyoung-Woong Kim[a,**]

Environmental Pollution 185 (2014) 84–89

Contents lists available at ScienceDirect

Environmental Pollution

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

Assessing arsenic intake from groundwater and rice by residents in Prey Veng province, Cambodia

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Environmental Pollution 182 (2013) 111–119

Contents lists available at SciVerse ScienceDirect

Environmental Pollution

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

Assessing mixed trace elements in groundwater and their health risk of residents living in the Mekong River basin of Cambodia

Kongkea Phan[a,f], Samrach Phan[b], Laingshun Huoy[b], Bunseang Suy[b], Ming Hung Wong[c], Jamal Hisham Hashim[d], Mohamed Salleh Mohamed Yasin[d], Syed Mohamed Aljunid[d], Suthipong Sthiannopkao[e,*], Kyoung-Woong Kim[a,*]

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Environmental Research 135 (2014) 37–41

Contents lists available at ScienceDirect

Environmental Research

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

Environmental arsenic epidemiology in the Mekong river basin of Cambodia

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WATER RESOURCES RESEARCH, VOL. 45, W00D32, doi:10.1029/2008WR006984, 2009

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Time-lapse geophysical imaging of soil moisture dynamics in tropical deltaic soils: An aid to interpreting hydrological and geochemical processes

D. A. Robinson,[1,2] I. Lebron,[1,2] B. Kocar,[3] K. Phan,[4] M. Sampson,[4] N. Crook,[1] and S. Fendorf[3]

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Applied Geochemistry

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

Integrated biogeochemical and hydrologic processes driving arsenic release from shallow sediments to groundwaters of the Mekong delta

Benjamin D. Kocar[a], Matthew L. Polizzotto[a], Shawn G. Benner[b], Samantha C. Ying[a], Mengieng Ung[c], Kagna Ouch[c], Sopheap Samreth[c], Bunseang Suy[c], Kongkea Phan[c], Michael Sampson[c], Scott Fendorf[a,*]

Contents lists available at ScienceDirect

Applied Geochemistry

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

Groundwater flow in an arsenic-contaminated aquifer, Mekong Delta, Cambodia

Shawn G. Benner[a,*], Matthew L. Polizzotto[b], Benjamin D. Kocar[b], Somenath Ganguly[a], Kongkea Phan[c], Kagna Ouch[c], Michael Sampson[c], Scott Fendorf[b]

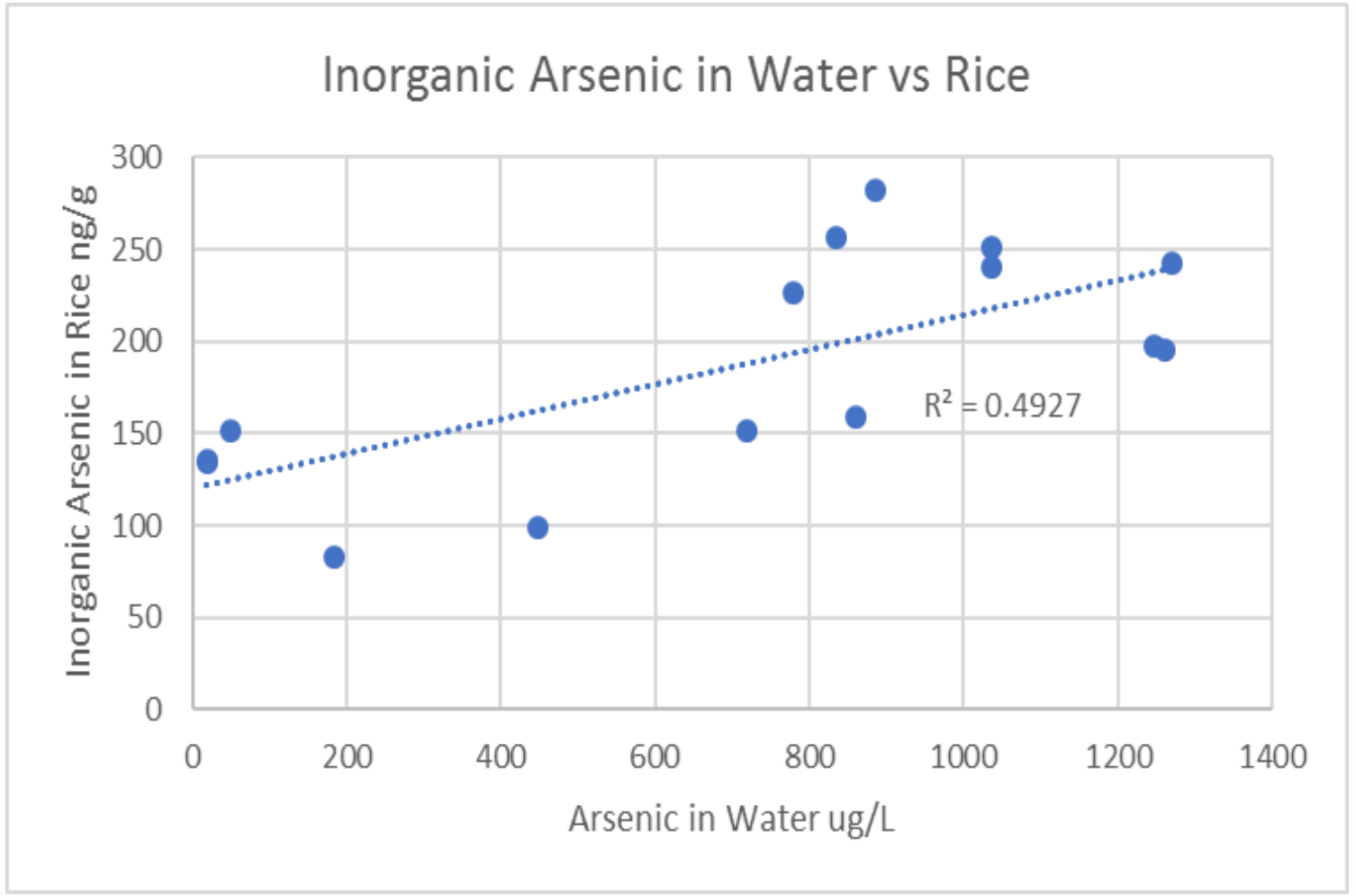
[a] Department of Geosciences, Boise State University, Boise, ID 83705, USA
[b] School of Earth Sciences, Stanford University, Stanford, CA 94305, USA

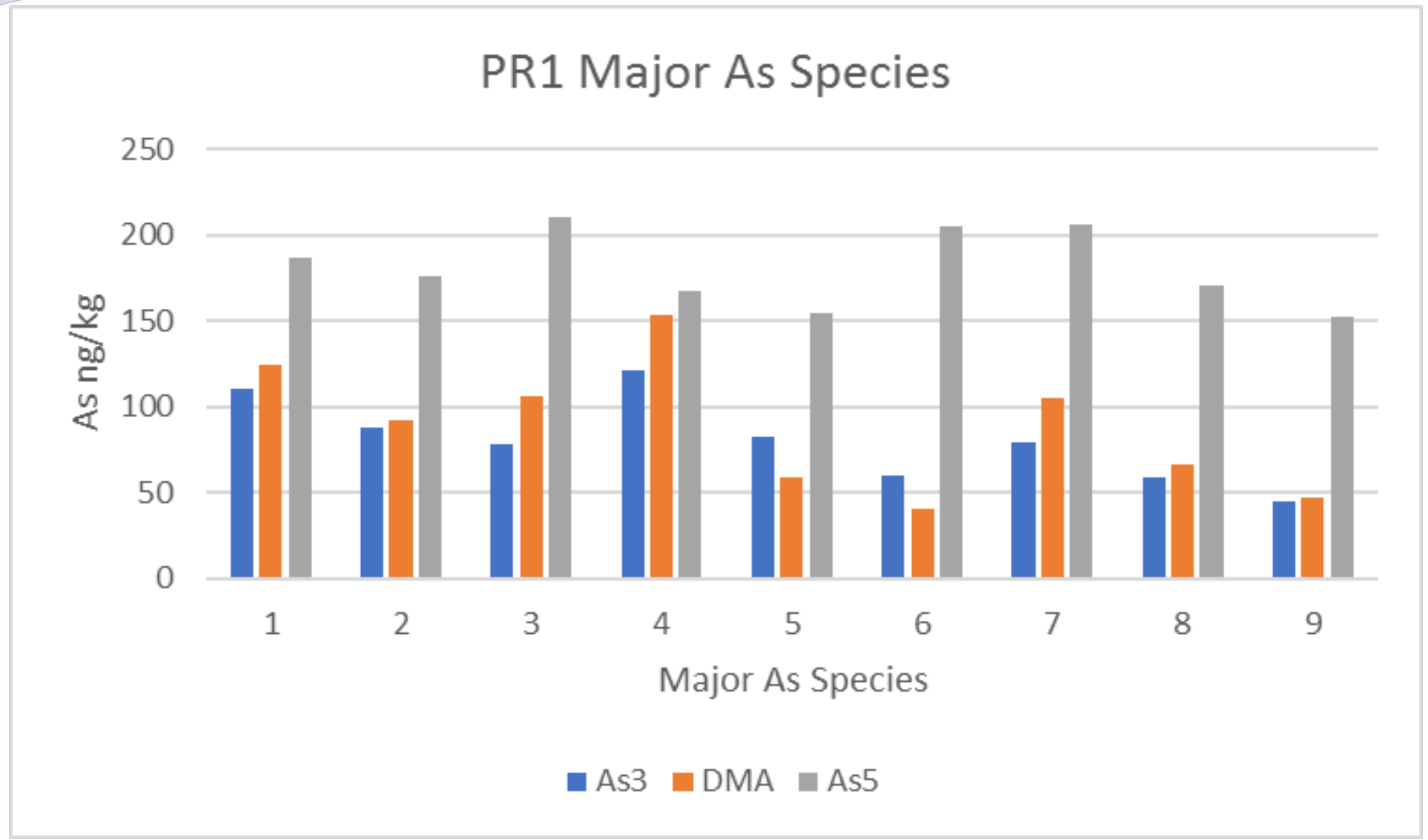
Science of the Total Environment

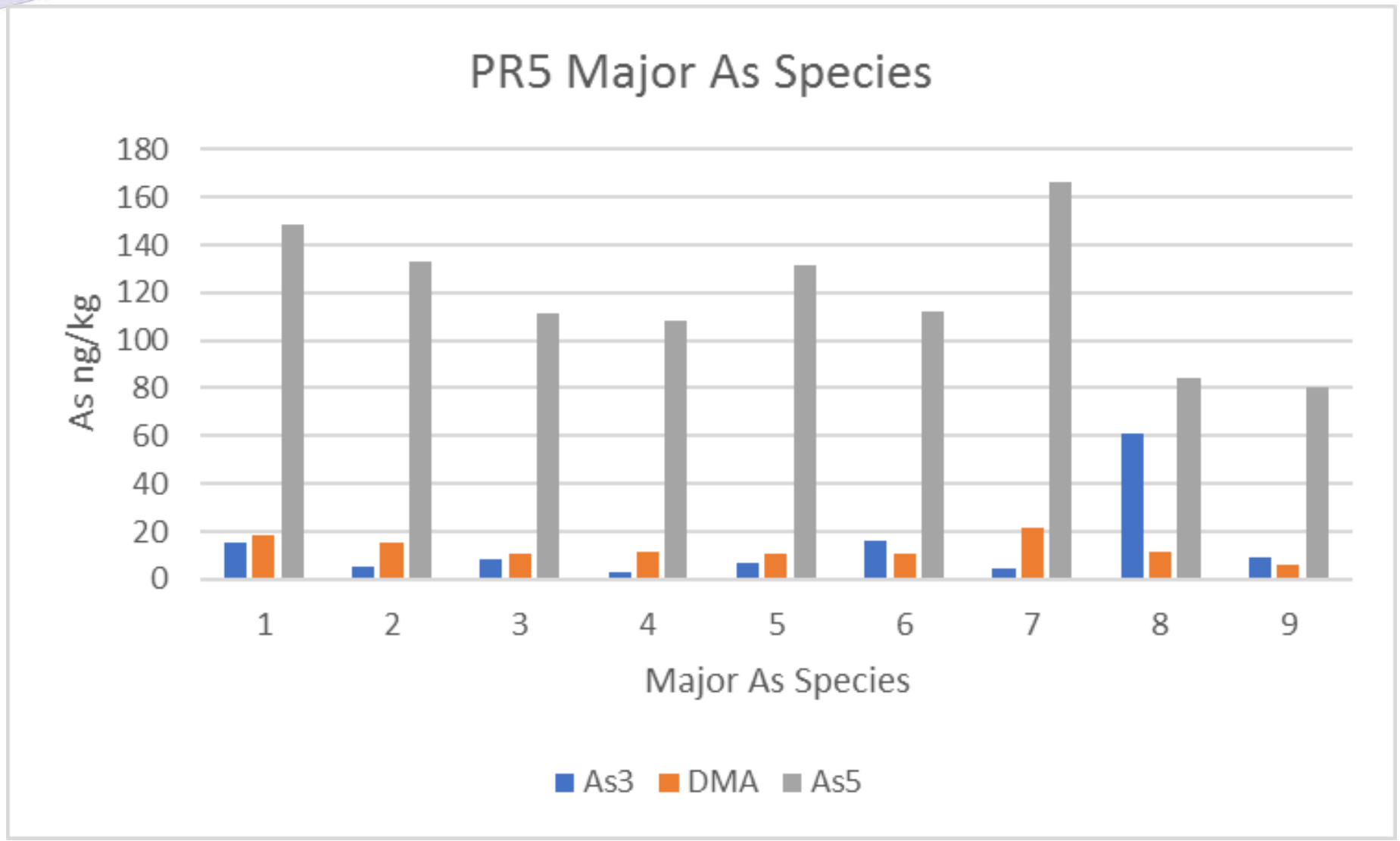
air arsenic levels and prevalence of arsenicosis in three Cambodian provinces

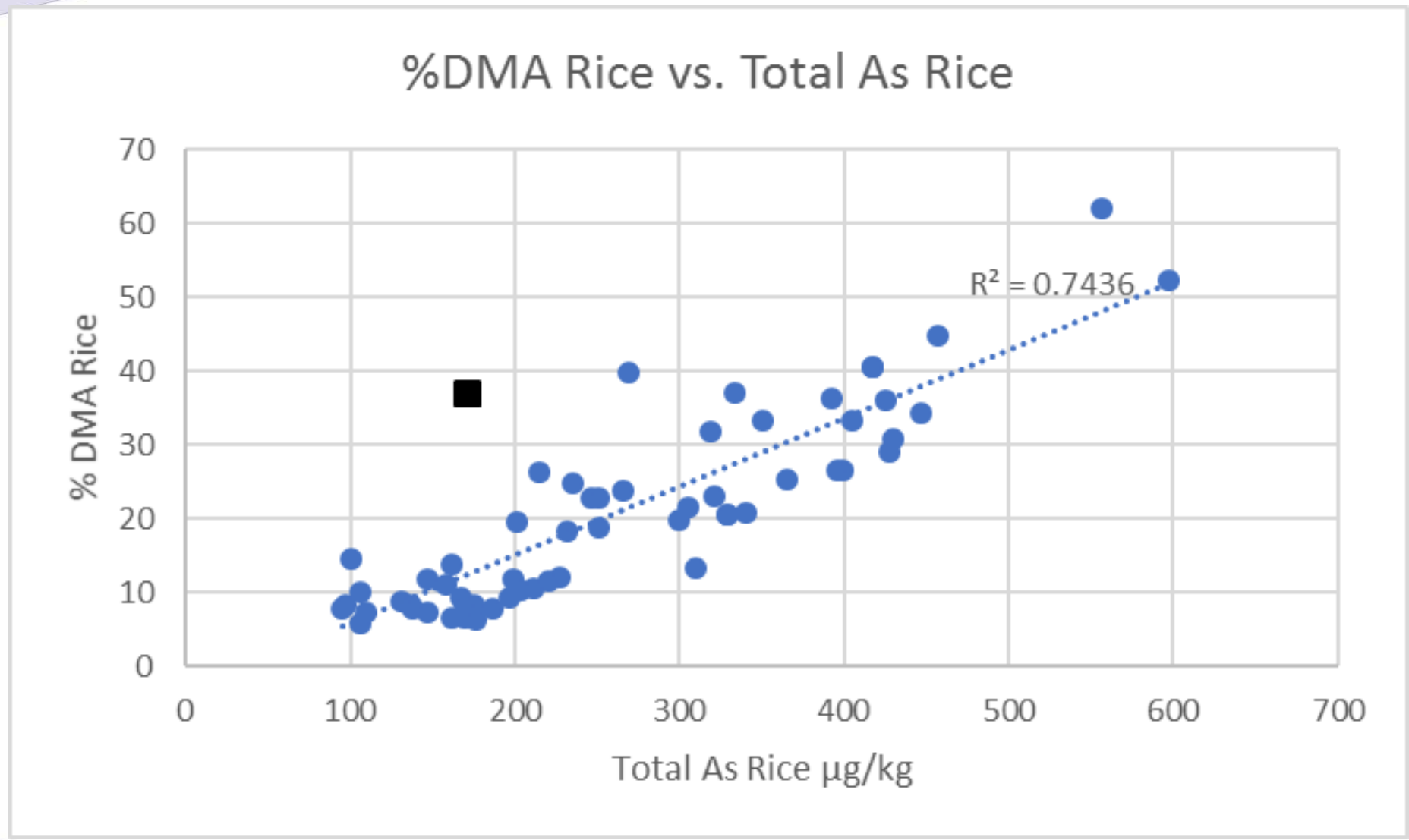
mal Hisham Hashim[a,b,*], Rozhan Syarif Mohamed Radzi[b,c], Syed Mohamed Aljunid[a,b], rizal Muhammad Nur[a], Aniza Ismail[b], David Baguma[a], Suthipong Sthiannopkao[d,e], Kongkea Phan[e],

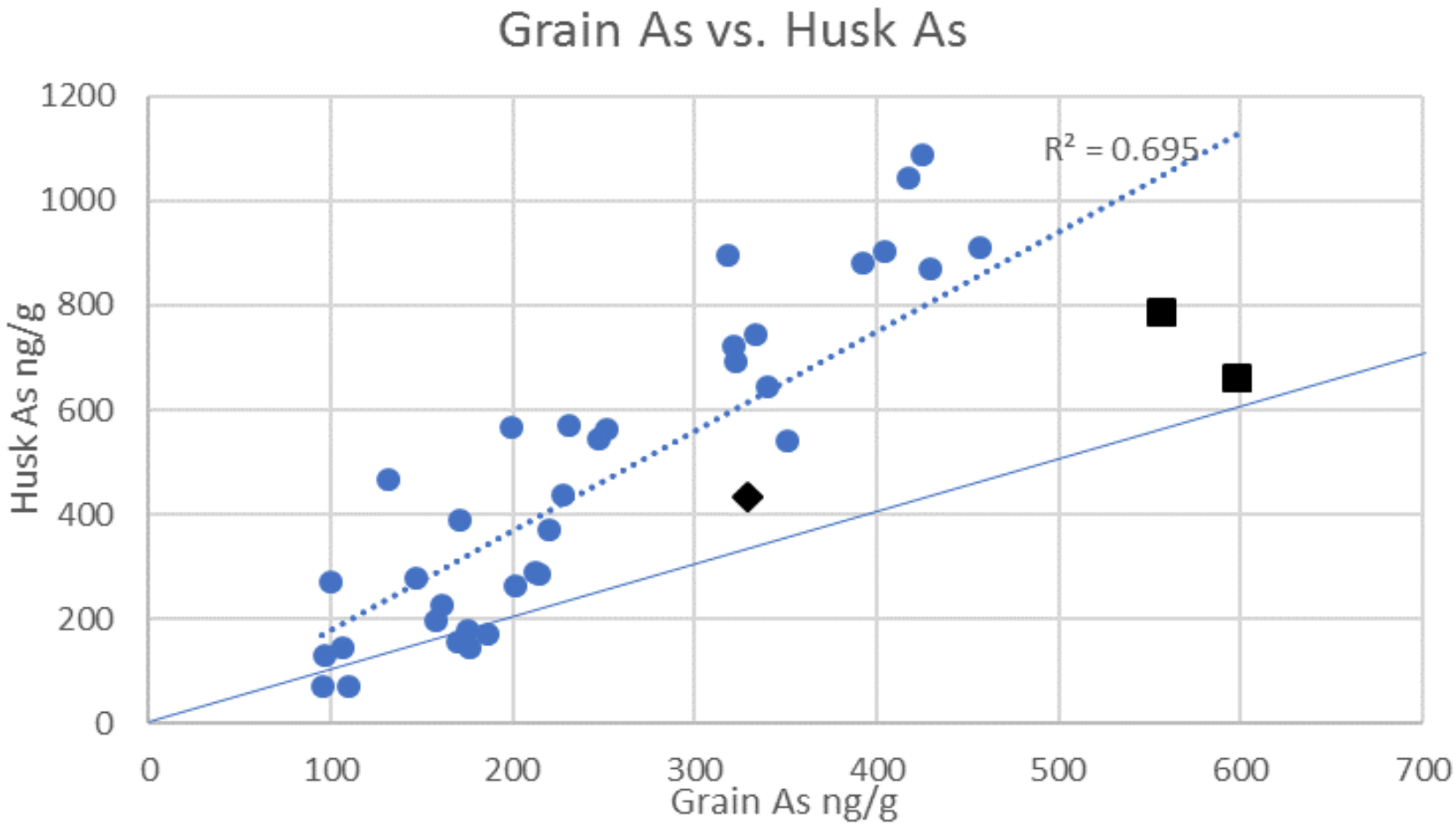
Ongoing work




PR1 Major As Species
250
200
150
100
50
0
As ng/kg
1
2
3
4
5
6
7
8
9
Major As Species
As3
DMA
As5


PR5 Major As Species
As ng/kg
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
Major As Species
As3
DMA
As5


%DMA Rice vs. Total As Rice
% DMA Rice
Total As Rice µg/kg
R² = 0.7436
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700


Grain As vs. Husk As
Husk As ng/g
Grain As ng/g
R² = 0.695
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700

Acknowledgement

Gwangju Institute of Science and Technology

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CCS CAMBODIAN CHEMICAL SOCIETY

Thank you for your attention!

Q & A ???

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