The University of Manchester
MANCHESTER 1824

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Modelling arsenic hazard in groundwater in Cambodia

Luis Rodriguez-Lado,

Aimee Hegan & David Polya

The University of Manchester
MANCHESTER 1824

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Background (I)

- Arsenic contaminated shallow groundwaters are extensively utilized for drinking, irrigation and cooking in many parts of the world represents a major environmental hazard.
- High arsenic concentrations have also been noted in Cambodian groundwaters
  - Polya et al (2003,2005a); Stanger (2006) Feldmann et al. (2007); Buschmann et al. (2007); Berg et al. (2007); Rowland et al. (2008); Benner et al. (2008), Kocar et al. (2008); Polizzotto et al. (2008)
- Hazardous exposure noted
  - Reiji et al. (2003), Polya et al. (2005b), Gault et al. (2008)
- Detrimental health outcomes
  - Sampson et al. (2008)
- Presented here is an objective model for the distribution of As in Cambodian groundwaters

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Background (II)

- Detailed map of distibution of As in groundwaters required for robust risk assessment
- Existing maps are useful but have several short-comings:
  - Not objective (Fredericks, 2004; Stanger , 2005; Berg et al., 2007)
  - Coarse scale (Polya et al. 2005a; Winkel et al, 2008)
- Presented here is an objective model for the distribution of As in Cambodian groundwaters

The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

- Health Impacts of Arsenic
- Arsenic in Cambodia
  - Early Models of Distribution
  - Geostatistical Modelling
- Implications

The University of Manchester
MANCHESTER 1824

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Health Impacts of Chronic Arsenic Exposure

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Some arsenicosis patients from arsenic affected districts of Bangladesh


Pigmentation


Keratosis on Palm & Sole

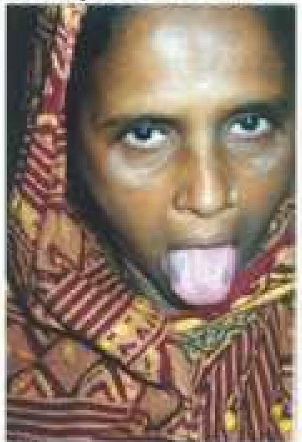

Ulcer on leg


Multiple Bowen's


Squamous cell carcinoma


Amputation due to Gangrene


Gangrene on leg


Mucus membrane melanosis

SOES Group Publication: Science Publishers, Inc. Book. 2003(11), 291-329

Reproduced with kind permission of Dipankar Chakraborti, SOES, Jadavpur University

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Pregnancy Outcome

Pregnant women were drinking Arsenic contaminated water in Eruine village, Laksham P.S., Comilla district, Bangladesh (As. conc. 600 – 1100 µg / L in Drinking Water.

Pregnancy Outcome per 1000 live birth (N = 26)

Pre-term birth	140
Low birth wt.	250
Spontaneous abortion	200
Still birth	125
Neo-natal death	125

MANCHESTER 1824

The University of Manchester

EU ASIA-LINK CALIBRE

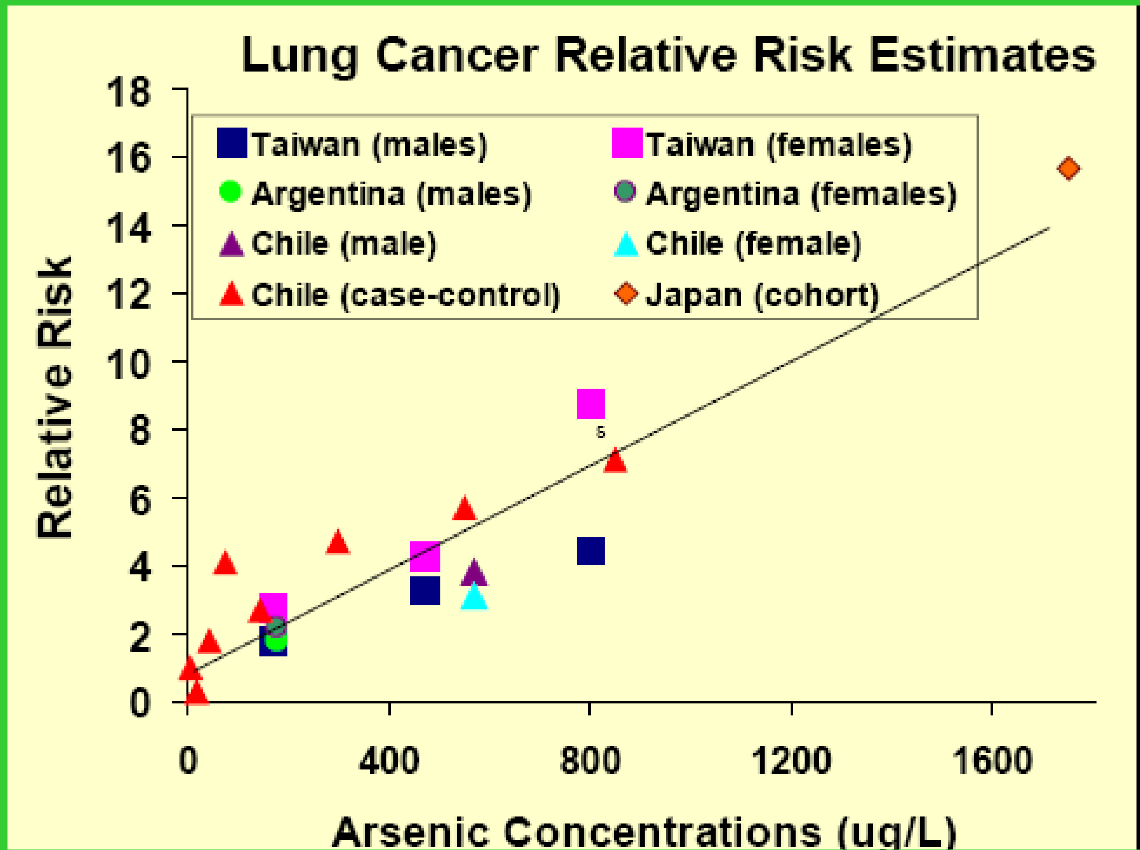
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Excess Lung Cancer Risks



From Allan Smith (2007) Royal Geographical Society Annual Meeting, London, August 2007, http://www.geog.cam.ac.uk/research/projects/arsenic/symposium/S1.4_A_Smith_et_al.pdf

The University of Manchester
MANCHESTER 1824

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Cancer risks from chronic exposure to As in drinking water

- 10 ppb = 1 in 500 die
- 50 ppb = 1 in 100 die [married to smoker]
- 500 ppb = 1 in 10 die [active smoker]
- 5000 ppb = all die

From Allan Smith (2007) Royal Geographical Society Annual Meeting, London, August 2007,

http://www.geog.cam.ac.uk/research/projects/arsenic/symposium/S1.4_A_Smith_et_al.pdf

EU ASIA-LINK CALIBRE

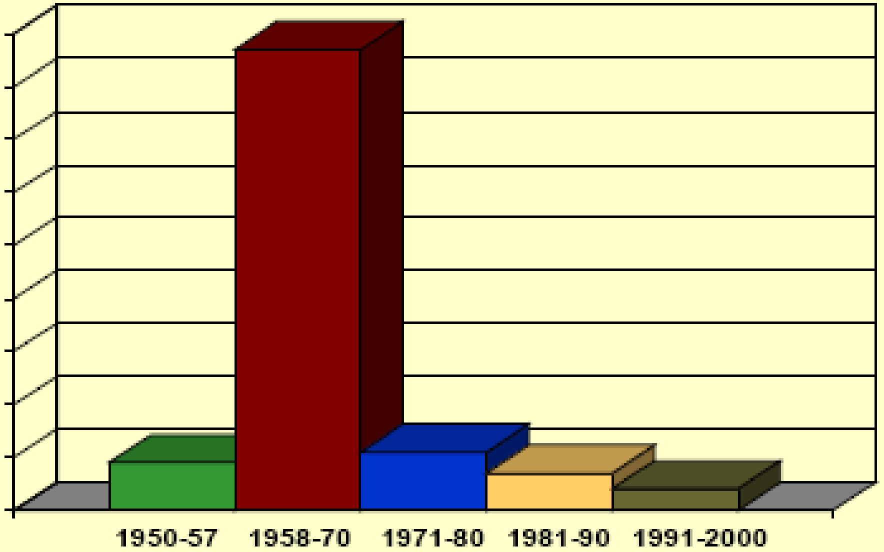
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Arsenic concentrations in Antofagasta and Mejillones water by year. Arsenic contaminated water sources were used from 1958, and an arsenic removal plant was installed in 1971.



From Allan Smith (2007) Royal Geographical Society Annual Meeting, London, August 2007,

http://www.geog.cam.ac.uk/research/projects/arsenic/symposium/S1.4_A_Smith_et_al.pdf

MANCHESTER 1824

The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

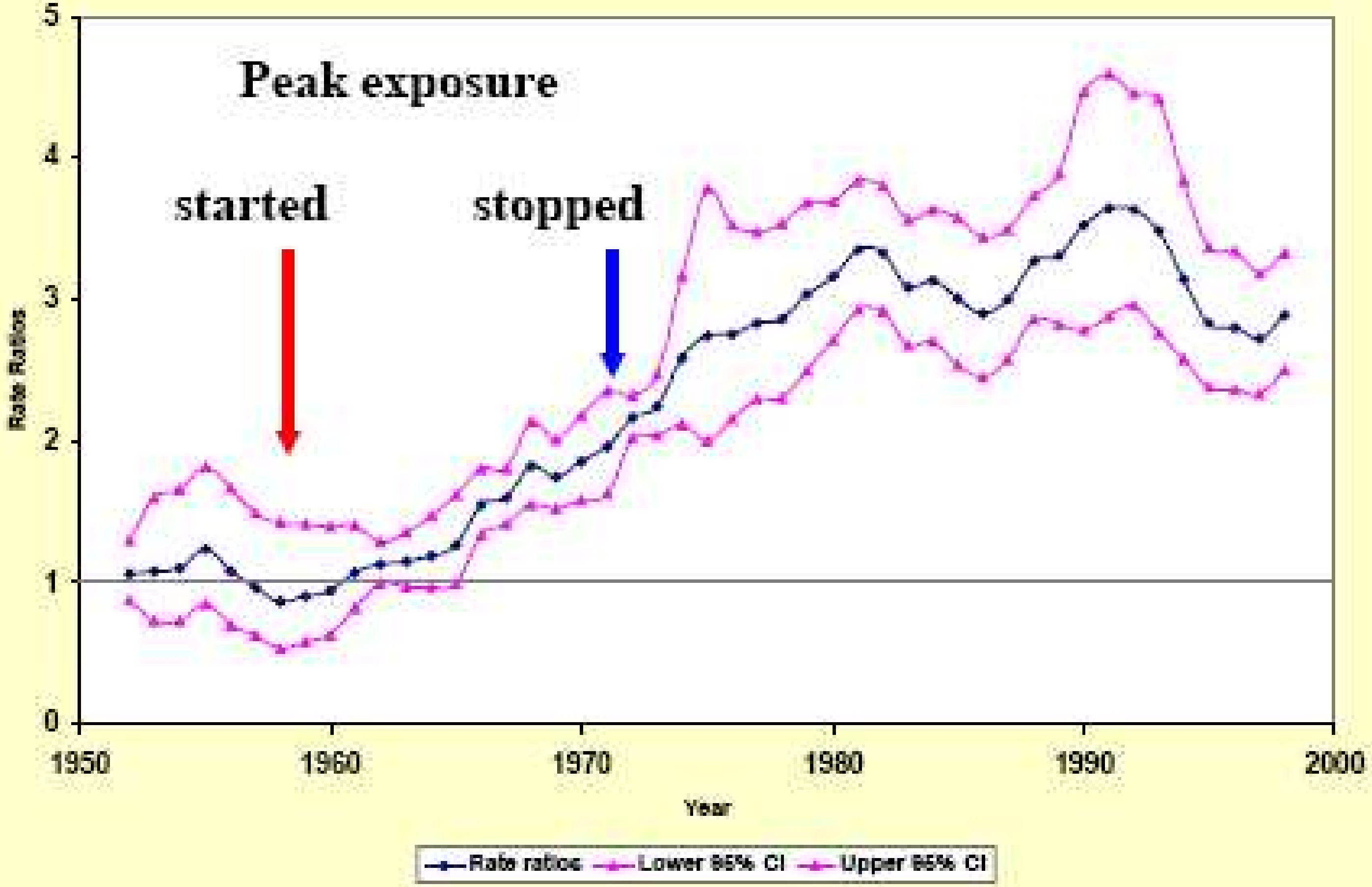
RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Mortality from lung cancer among men, Region II Chile

Marshall et al, J. Natl Cancer Inst, 2007



From Allan Smith (2007) Royal Geographical Society Annual Meeting, London, August 2007,

http://www.geog.cam.ac.uk/research/projects/arsenic/symposium/S1.4_A_Smith_et_al.pdf

The University of Manchester

MANCHE 18

EU ASIA-LI
CALIBRI

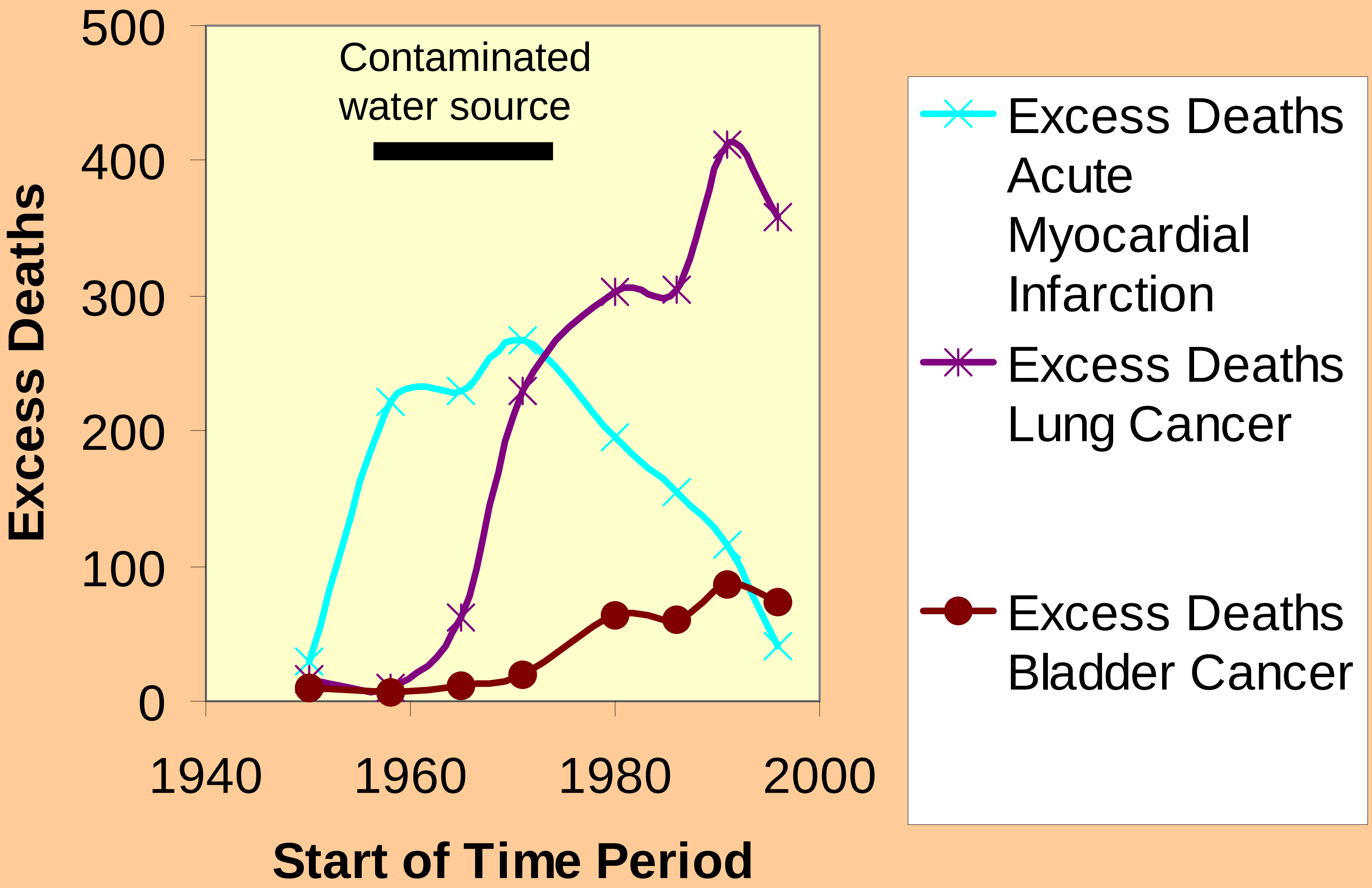
NUOL
(Lao PDR

RUPP
(Cambodi

UJF, Greno
(France)

University
Manchest
(United
Kingdom

Excess Deaths Attributable to Arsenic in Region II, Chile (Males only) (after Smith et al., 2007)



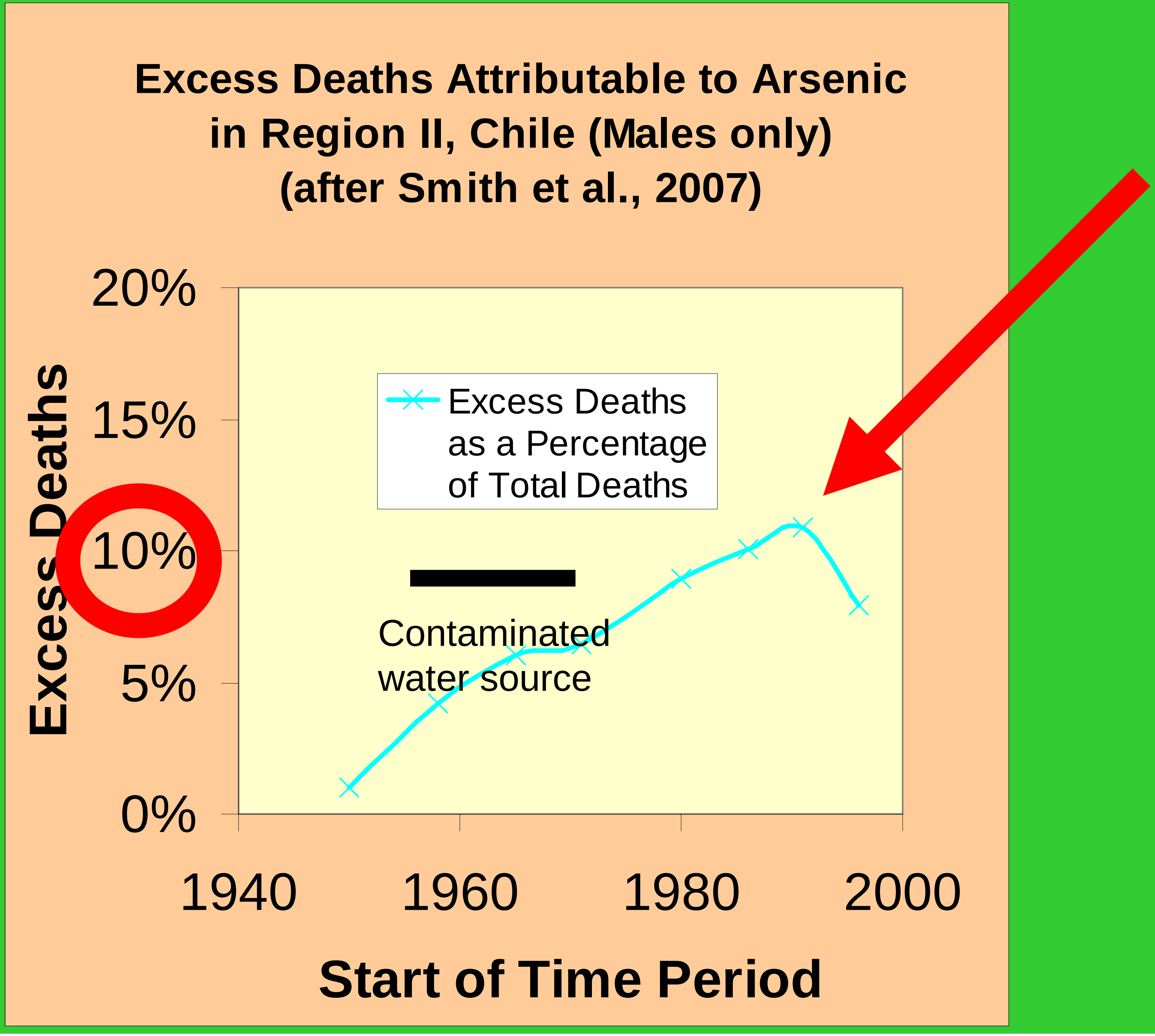
EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

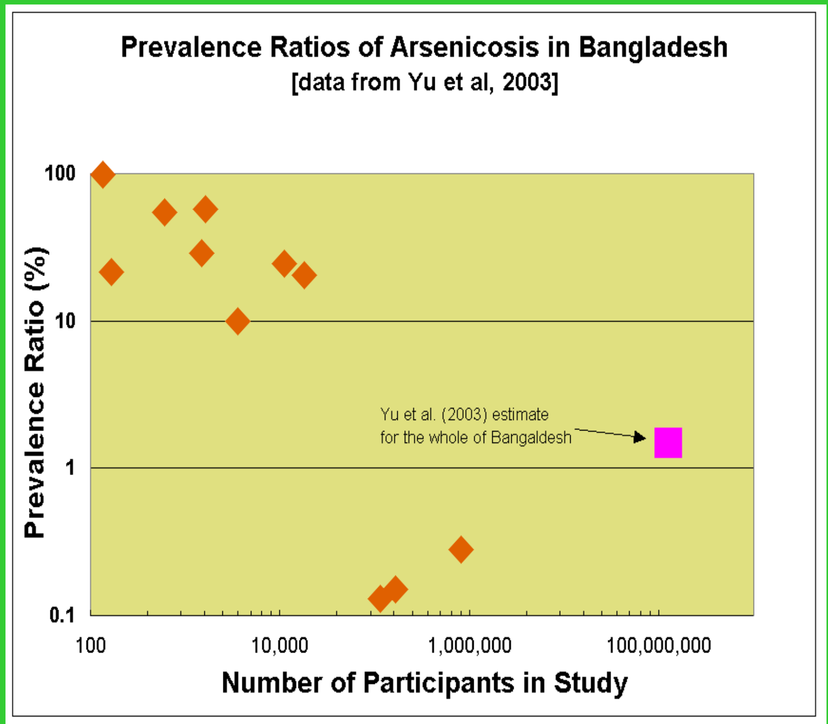


MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE
NUOL (Lao PDR)
RUPP (Cambodia)
UJF, Grenoble (France)
University of Manchester (United Kingdom)

Arsenicosis in Bangladesh

- Small scale studies
  - prevalence 10 – 99 %
  - bias to high impact areas
- Large scale studies
  - prevalence 0.1 to 0.3 %
  - bias due to under-reporting & difficulties in diagnosis
- Yu et al (2003) model
  - prevalence 1.5 % nationwide



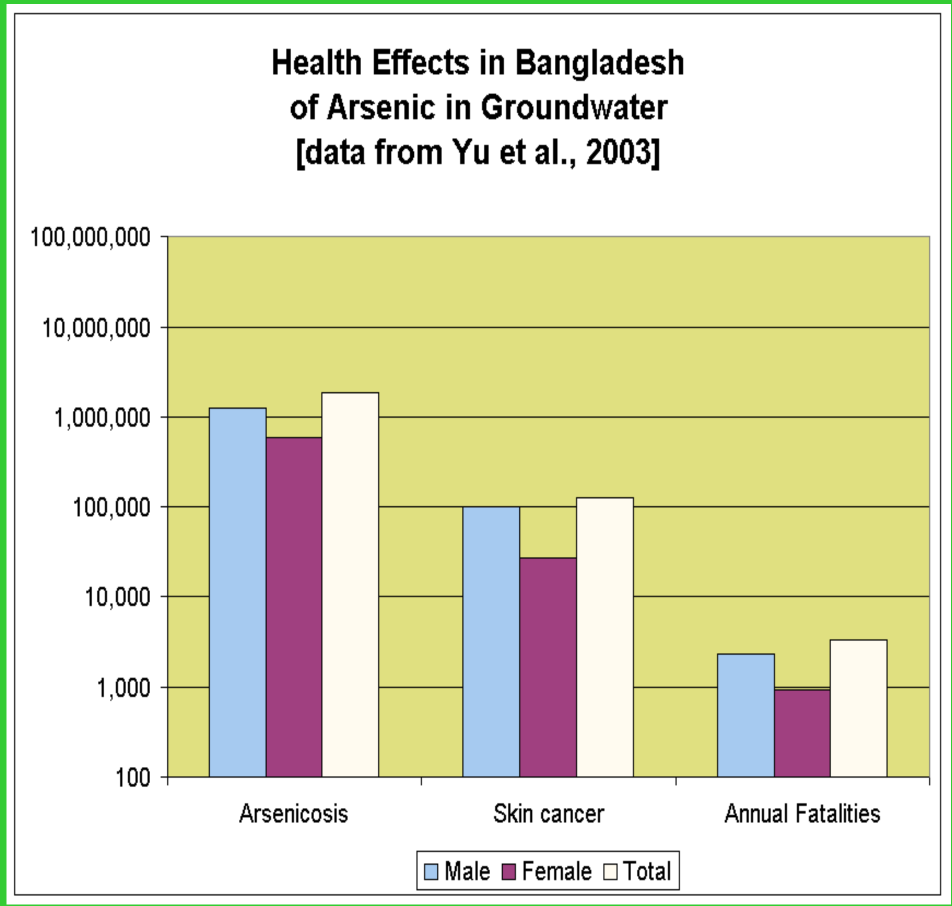
MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE
NUOL (Lao PDR)
RUPP (Cambodia)
UJF, Grenoble (France)
University of Manchester (United Kingdom)

Health Effects in Bangladesh of Arsenic in Groundwater

- ~ 2,000,000 people to develop arsenicosis
- ~ 3,000 fatalities/year from internal cancers

Source: Yu et al. (2003) based upon present groundwater concentrations and a non-intervention policy



The University of Manchester

MANCHESTER 1824

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Arsenic Distribution in Cambodian Wellwaters

The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Why Cambodia ?

- Increasing groundwater usage since 1990s
- Might Cambodia be an analogue for Bengal at an earlier stage of groundwater resource development ?

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

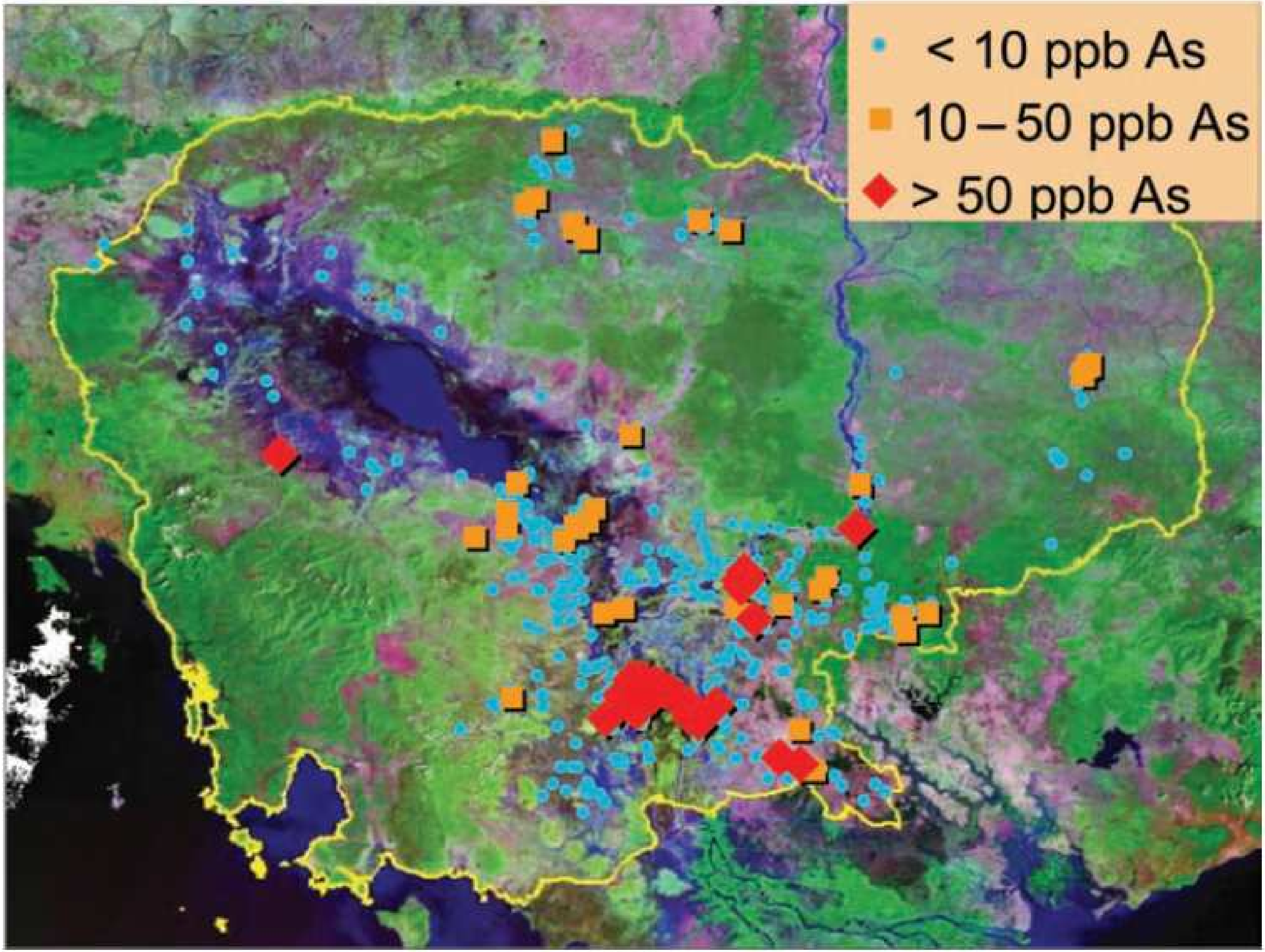
University of Manchester (United Kingdom)

Arsenic Distribution in Cambodia

- >> 40,000 wells installed
- > 5,000 wells tested
- > 1,000 wells test-data compiled here
  - Based upon analyses by or verified by University of Manchester

- Risk map generated on the basis of these
  - cf. Cambodian (50 ppb) and WHO (10 ppb) "MCL"s
  - Not robust in identifying all "at-risk" areas
  - Considerable heterogeneity even at local scale

The University of Manchester



EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

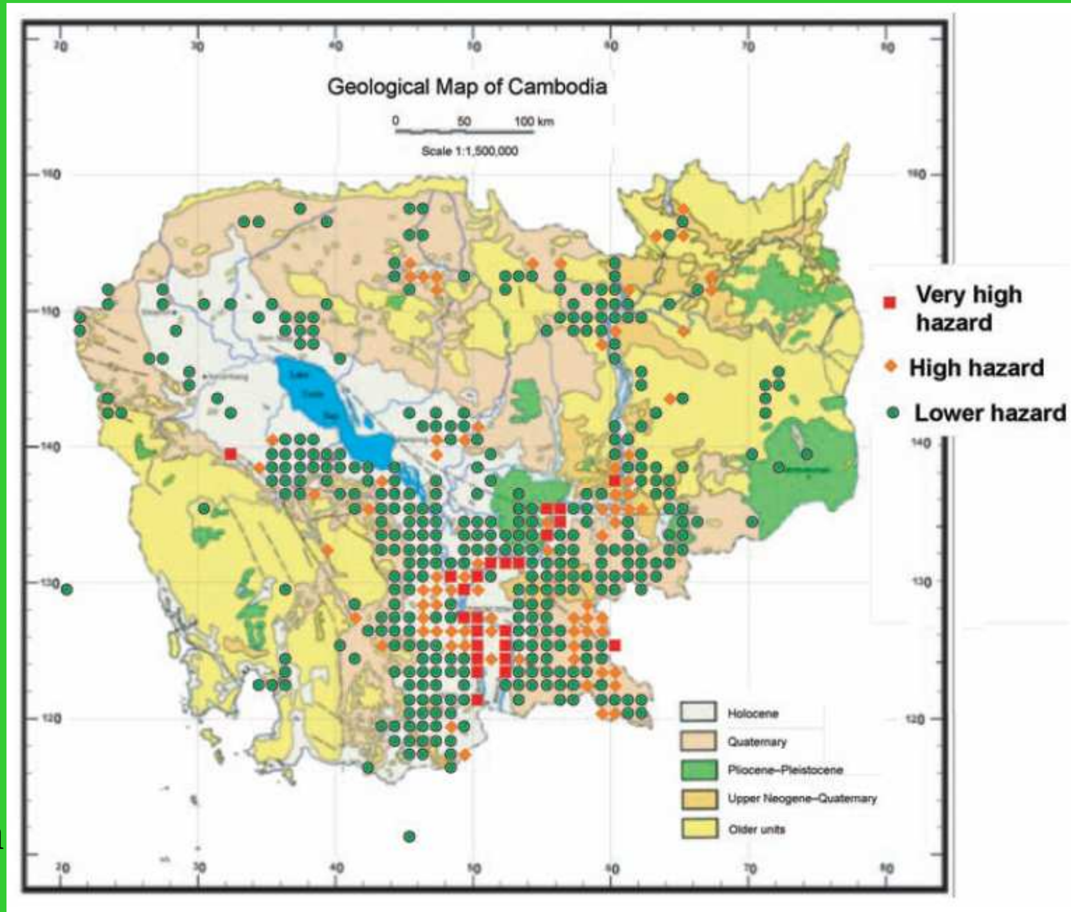
UJF, Grenoble (France)

University of Manchester (United Kingdom)

Arsenic Hazard Maps - Cambodia

From: Polya et al. (2005) *Mineralogical Magazine*, 69 (5), 807-823.

Environmental Mineralogy, Geochemistry and Health Thematic Issue, October 2005 (Eds. Eva Valsami-Jones, Dave Polya and Karen Hudson-Edwards)



The University of Manchester

MANCHESTER 1824

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Indicators of High Arsenic Wellwaters in Cambodia

- Holocene sedimentary aquifers
- Depths > 15 m
- Proximity to major river channels, especially Mekong and Bassac Rivers
- Downstream of Kampong Cham and especially Phnom Penh

BUT

- Criteria <u>not</u> wholly inclusive or exclusive

The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

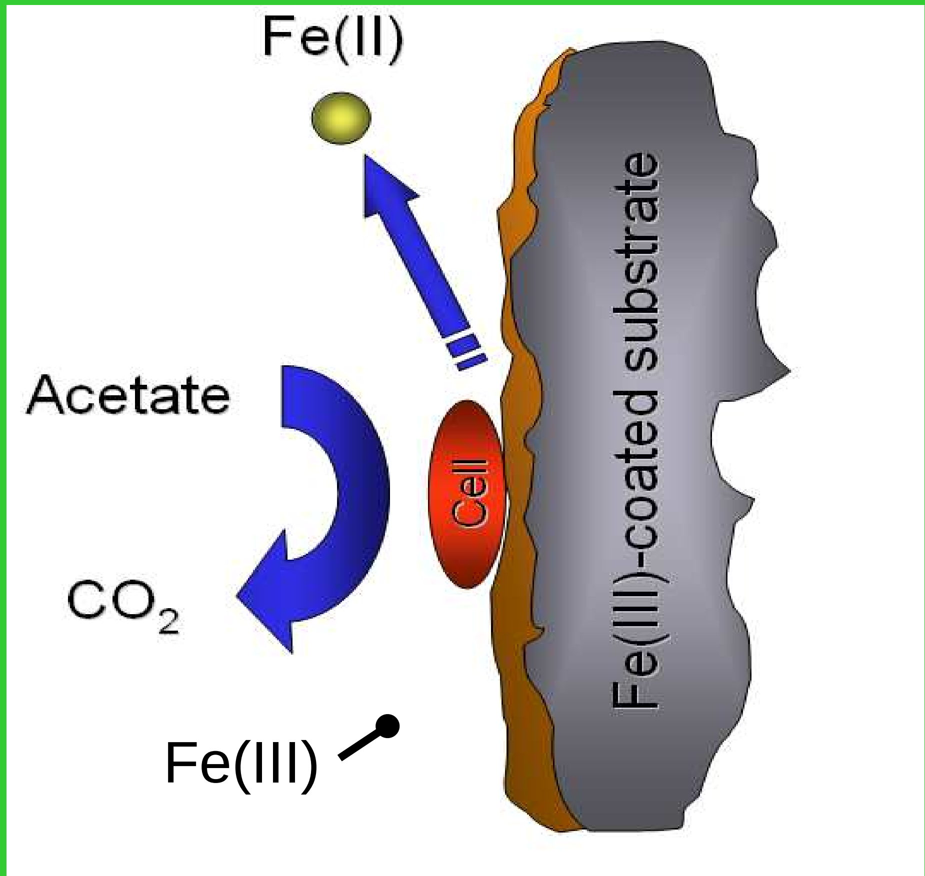
RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Models of Arsenic Release

Dissimilatory Fe(III) reduction



The University of Manchester

MANCHESTER 1824

EU ASIA-LINK CALIBRE

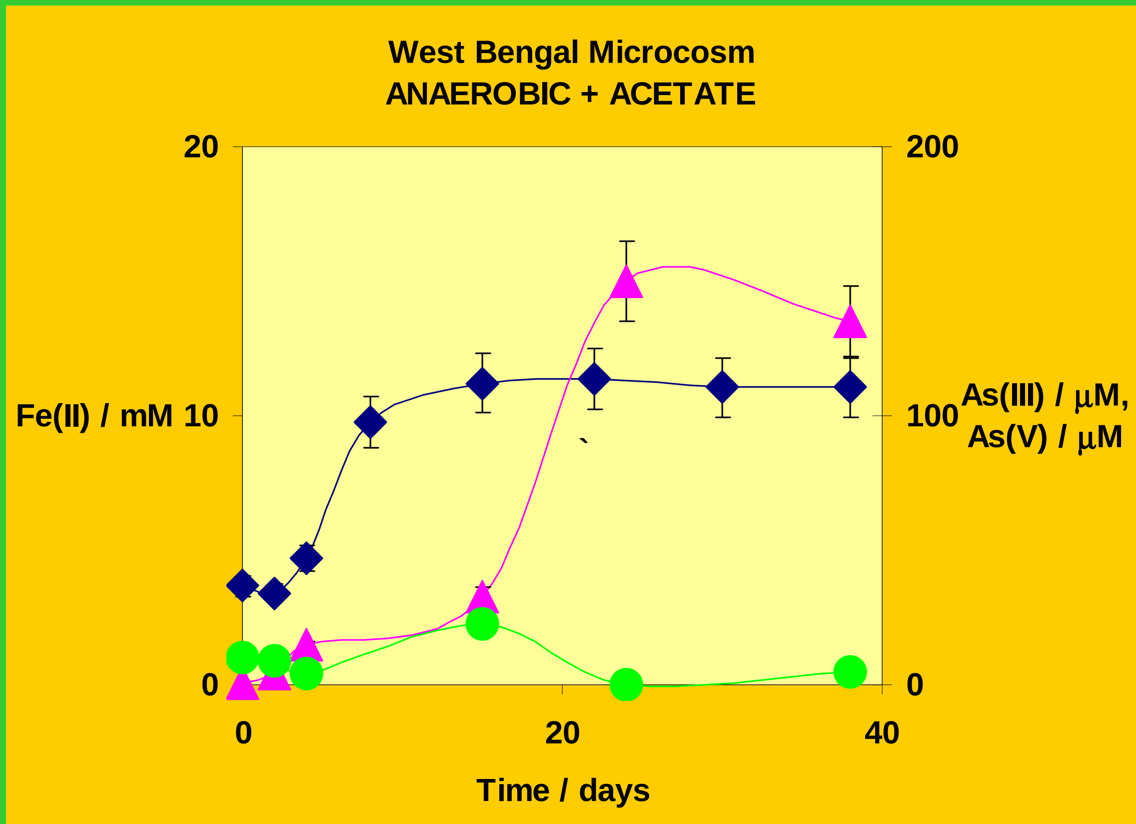
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Anaerobic metal-reducing microbes mediate arsenic release



Islam, Gault, Boothman, Polya, Charnock, Chatterjee & Lloyd (2004)

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Comparison of Cambodian & Bengali As-rich Groundwaters

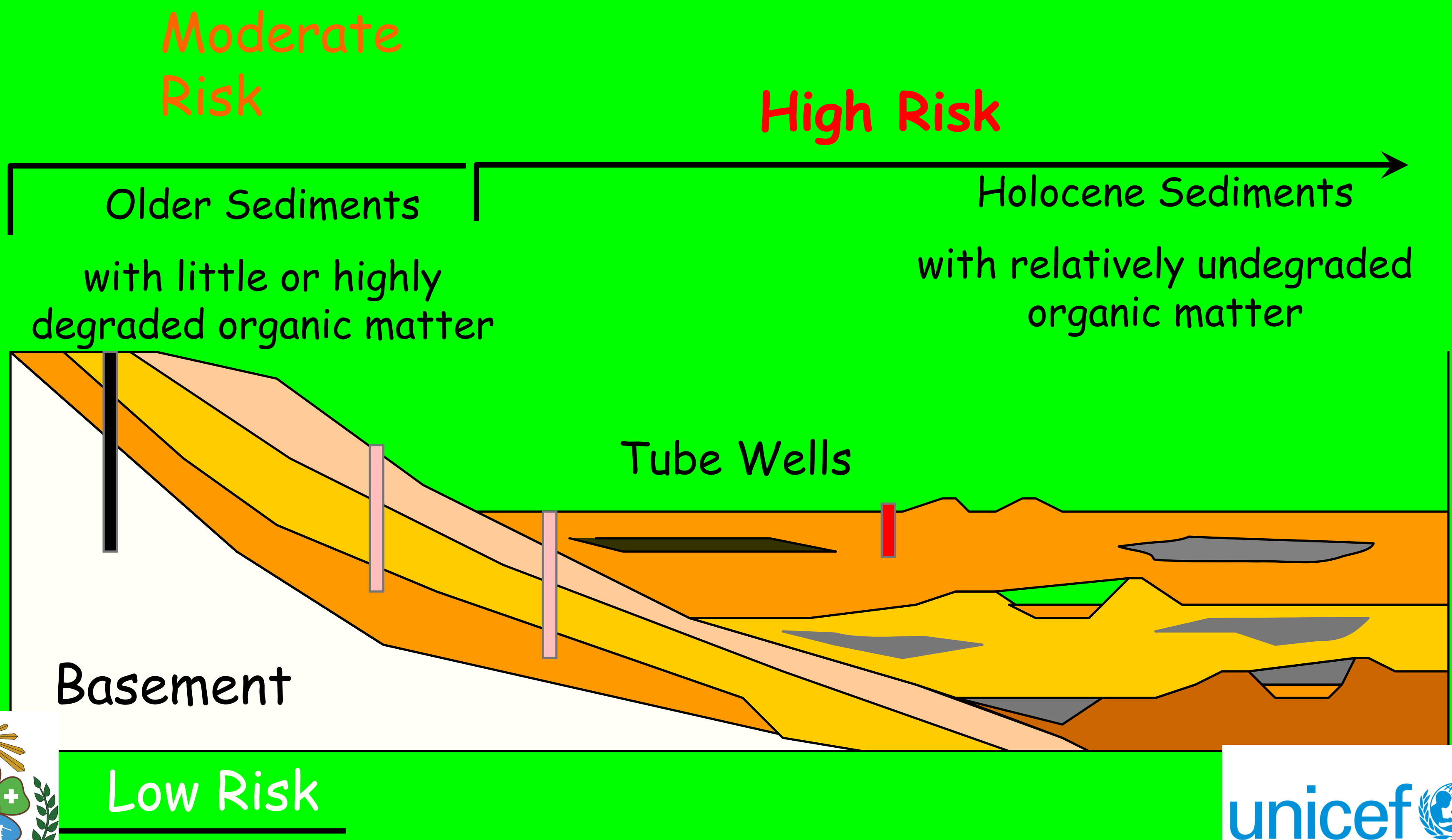
- Cambodia
  - circum-neutral
  - low Eh
  - high Fe & Mn
  - low SO_4, NO_3, Cl^- & F^-
  - high alkalinity

Polya (2002); Polya et al. (2003); & this study

- Bengal Basin
  - circum-neutral
  - low Eh
  - high Fe & Mn
  - low SO_4, NO_3, Cl^- & F^-
  - high alkalinity

Smedley & Kinniburgh (2002) and references therein

Risk of High Arsenic in Wells in Relation to Sediment Age
(after Fredericks, pers. comm. with permission)



The University of Manchester
MANCHESTER 1824

EU ASIA-LINK CALIBRE

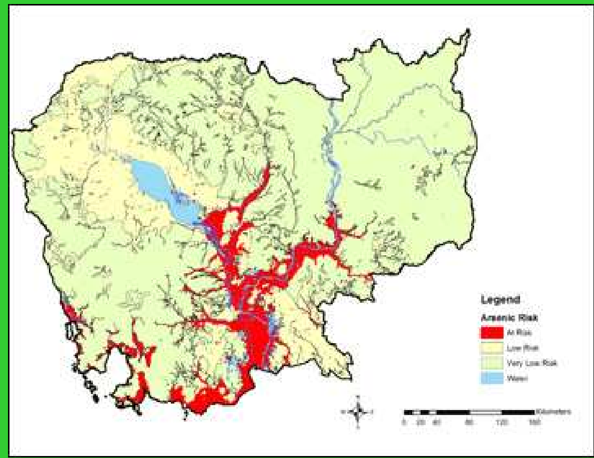
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Other Maps



Fredericks (2004)

Stanger (2005)

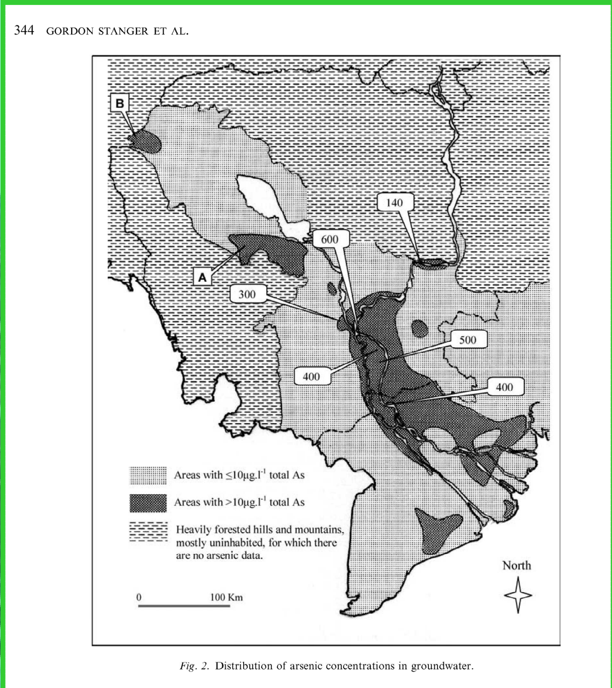

344 GORDON STANGER ET AL.

Fig. 2. Distribution of arsenic concentrations in groundwater.

Berg et al. (2007)

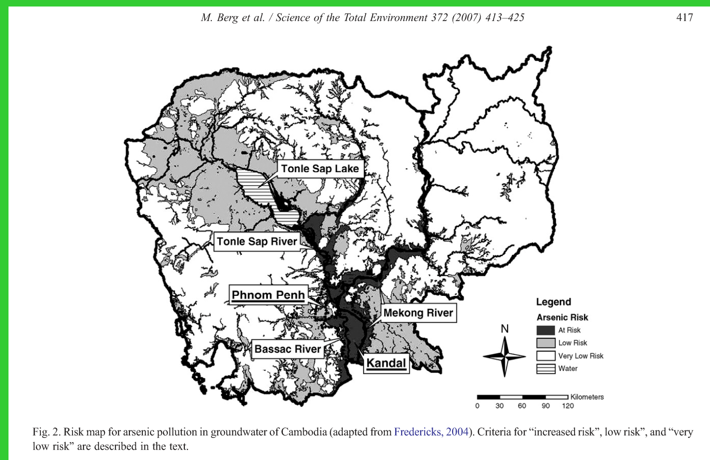

M. Berg et al. / Science of the Total Environment 372 (2007) 413–425 417

Fig. 2. Risk map for arsenic pollution in groundwater of Cambodia (adapted from Fredericks, 2004). Criteria for "increased risk", low risk", and "very low risk" are described in the text.

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Why geostatistics?

- Objective estimate:
  - of the As concentrations
  - of the associated uncertainty
- Auxilliary predictors with high sampling density data As can be used
- Automation
  - e.g through R scripts

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Geostatistical Modelling of Arsenic-in-groundwater

- Selection of auxilliary variables
  - Proxies for expert-determined relevant factors
  - High spatial resolution
    - Satellite derived / DEM / Slope / NDVI
  - PCA to obtain independent components
- Multiple linear regression
- Kriging of spatially distributed residuals
- Validation against validation dataset

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Arsenic Database

- 9661 groundwater samples (compiled by Polya et al., 2005 and includes data from AISC)
- 7 different surveys over period 2000-2004
- Heterogeneous data quality
  - Duplicates, blank data and negative values

- Cleaned database
- Subset : 1490 samples
- Depths between 16-100 m
- As up to 830 ppb (mean = 87 ppb)

Subset groundwater database

EU ASIA-LINK CALIBRE

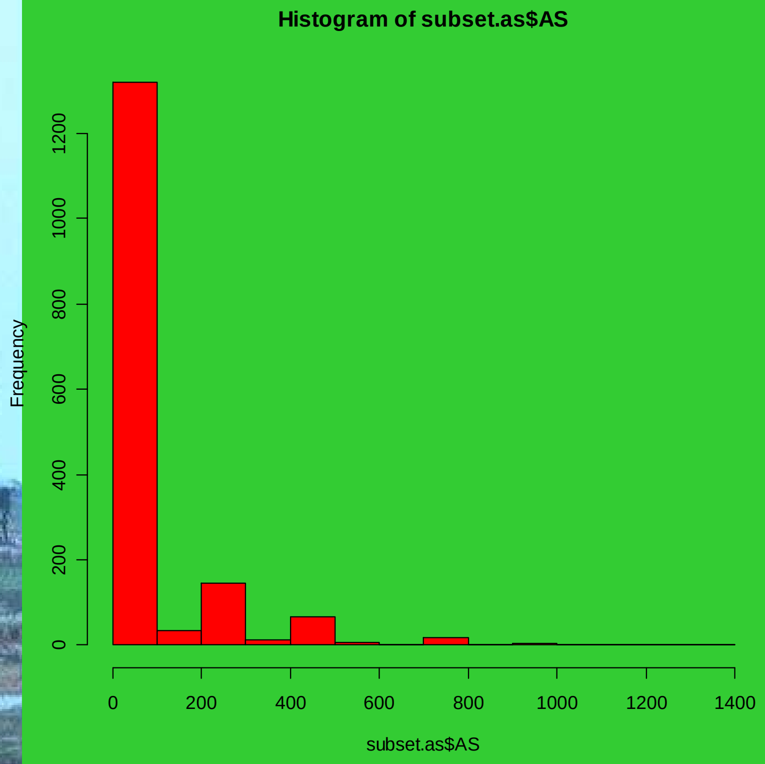
NUOL (Lao PDR)

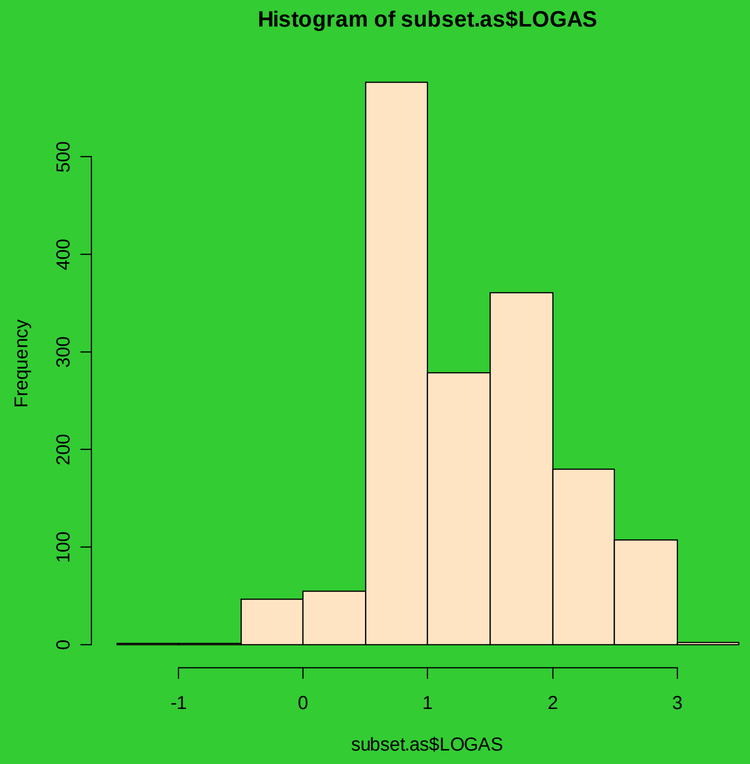
RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

All statistical analyses performed on logarithm transformed As data.





MANCHESTER 1824

The University of Manchester

Groundwater database

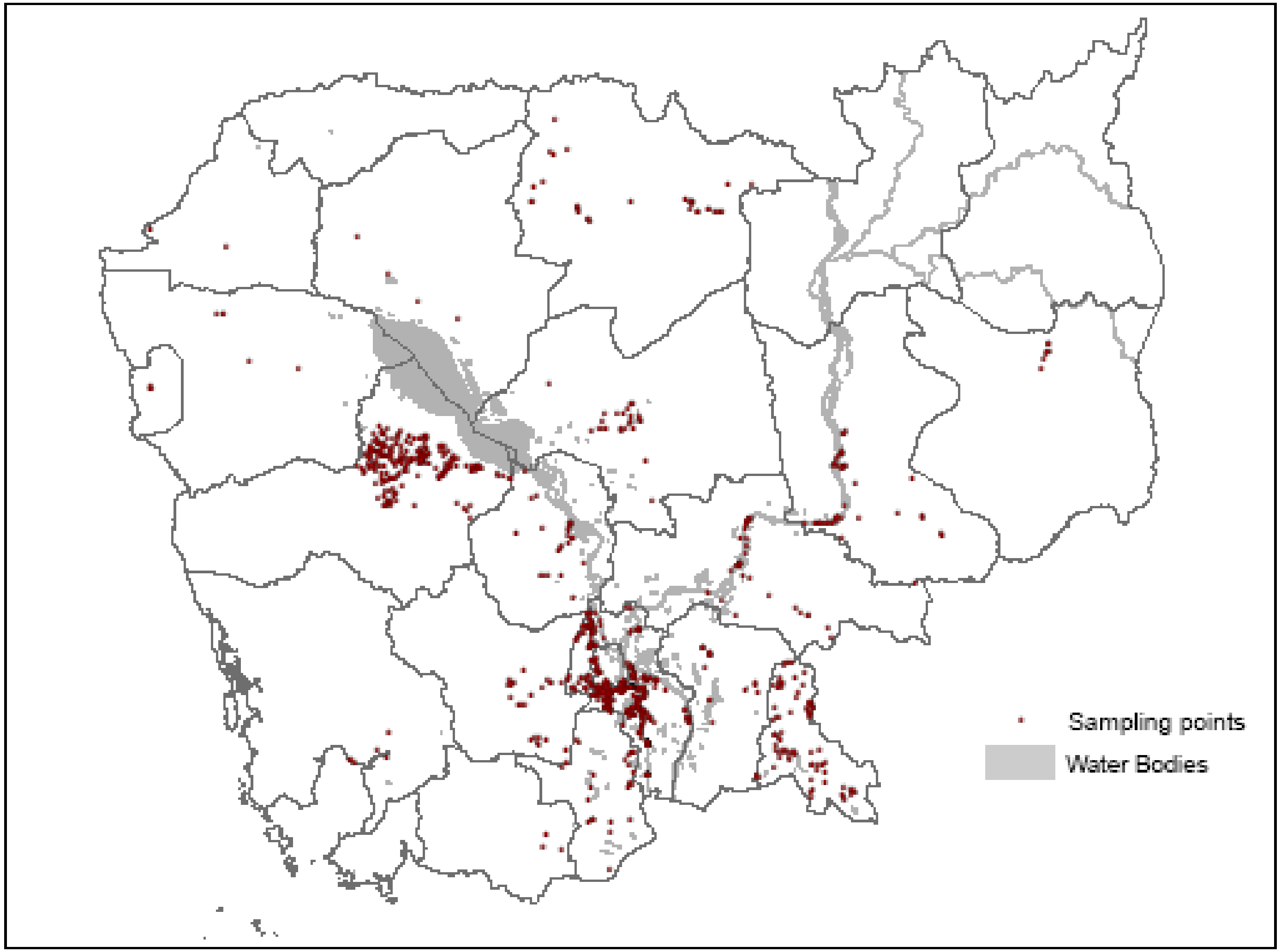
EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)



The University of Manchester

MANCHESTER 1824

Model and Validation datasets

1. Random selection
2. Equality of the distribution functions

EU ASIA-LINK CALIBRE

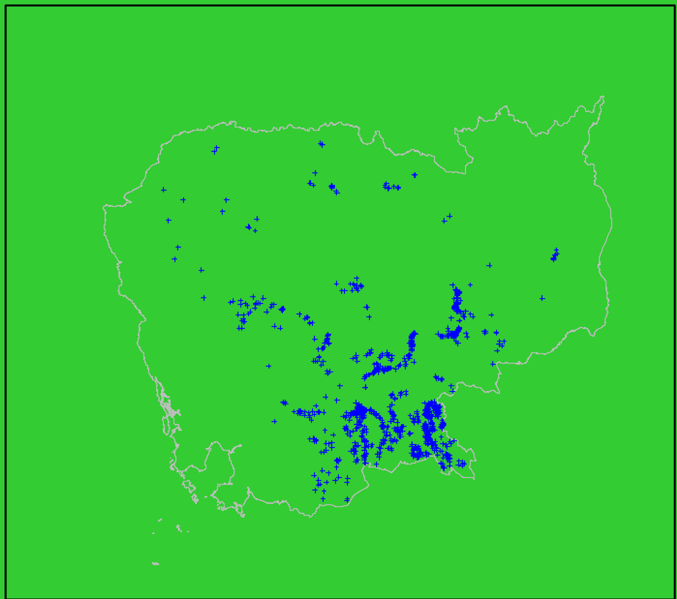
NUOL (Lao PDR)

RUPP (Cambodia)

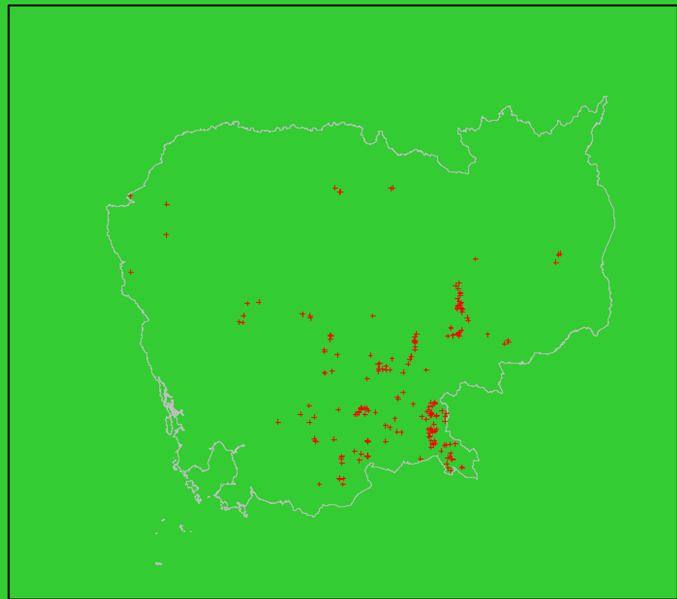
UJF, Grenoble (France)

University of Manchester (United Kingdom)

Model dataset (1237 samples)



Validation dataset (253 samples)



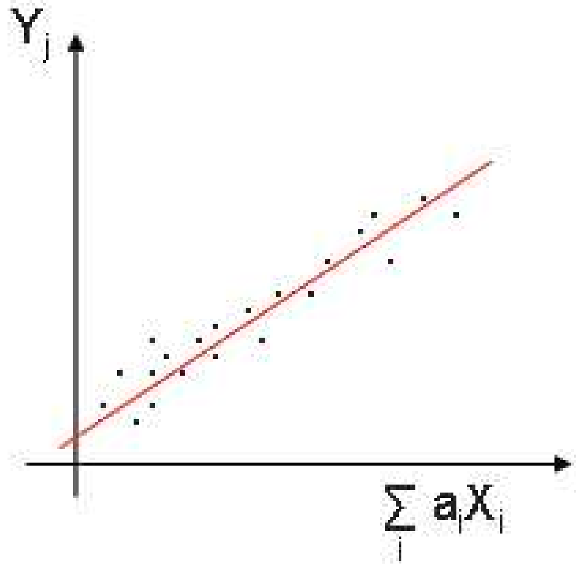
Regression-kriging

❶ Multiple Linear Regression

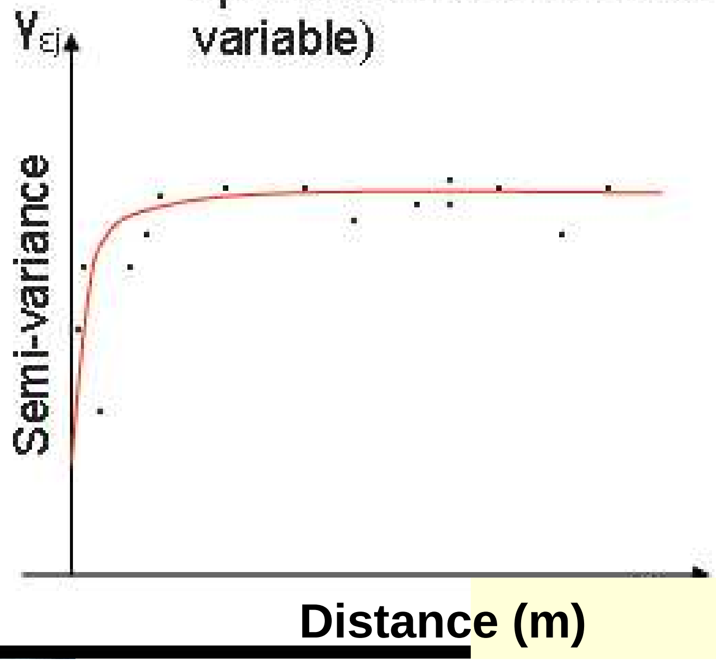
Spatially continuous — Punctual

$$Y_j = \underbrace{a_1 X_1 + a_2 X_2 + \ldots + a_n X_n}_{\text{Spatially continuous}} + \underbrace{\varepsilon_j}_{\text{Punctual}}$$

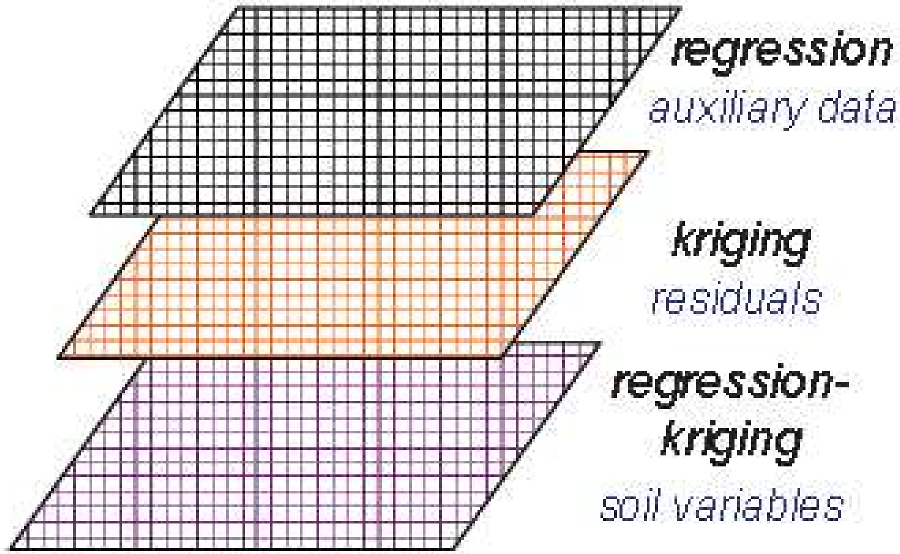
Soil variable *j* — Auxiliary data *i* — residuals *j*



❷ Kriging (interpolation process according to spatial autocorrelations of the variable)



❸ Summation of the two maps



EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Auxiliary variables

- Collection of auxiliary variables
  - Topographic variables- Digital Elevation Model (DEM)
    - Slope
    - Topographic Wetness Index
    - Convergence Index
    - Flow length
  - Remote sensing images (2 years)
    - Normalized Difference Vegetation Index (NDVI)
    - Principal components
  - Geology

- These auxiliary variables were transformed to 16 principal components to avoid multicollinearity.

EU ASIA-LINK CALIBRE

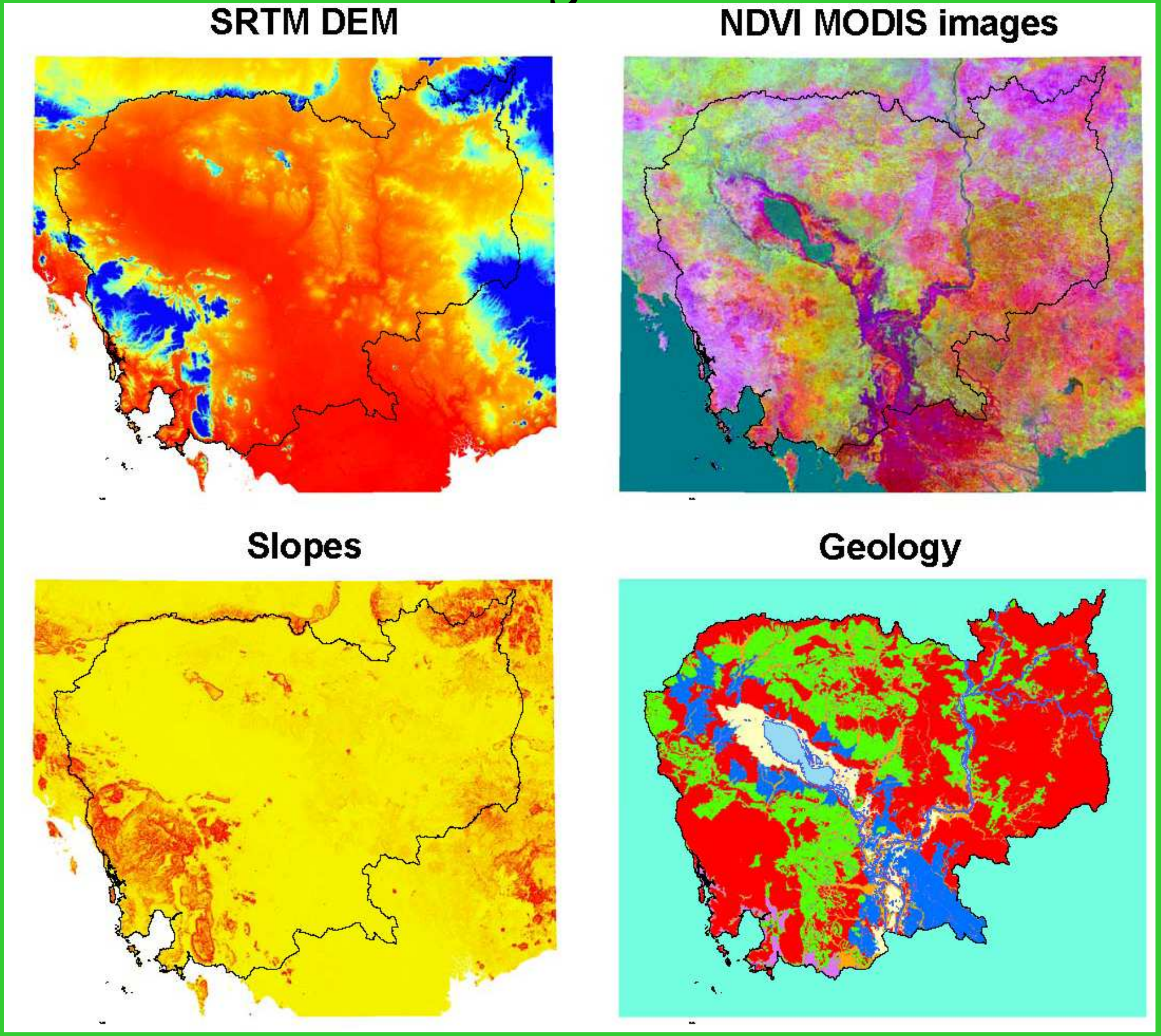
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Auxiliary variables



MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

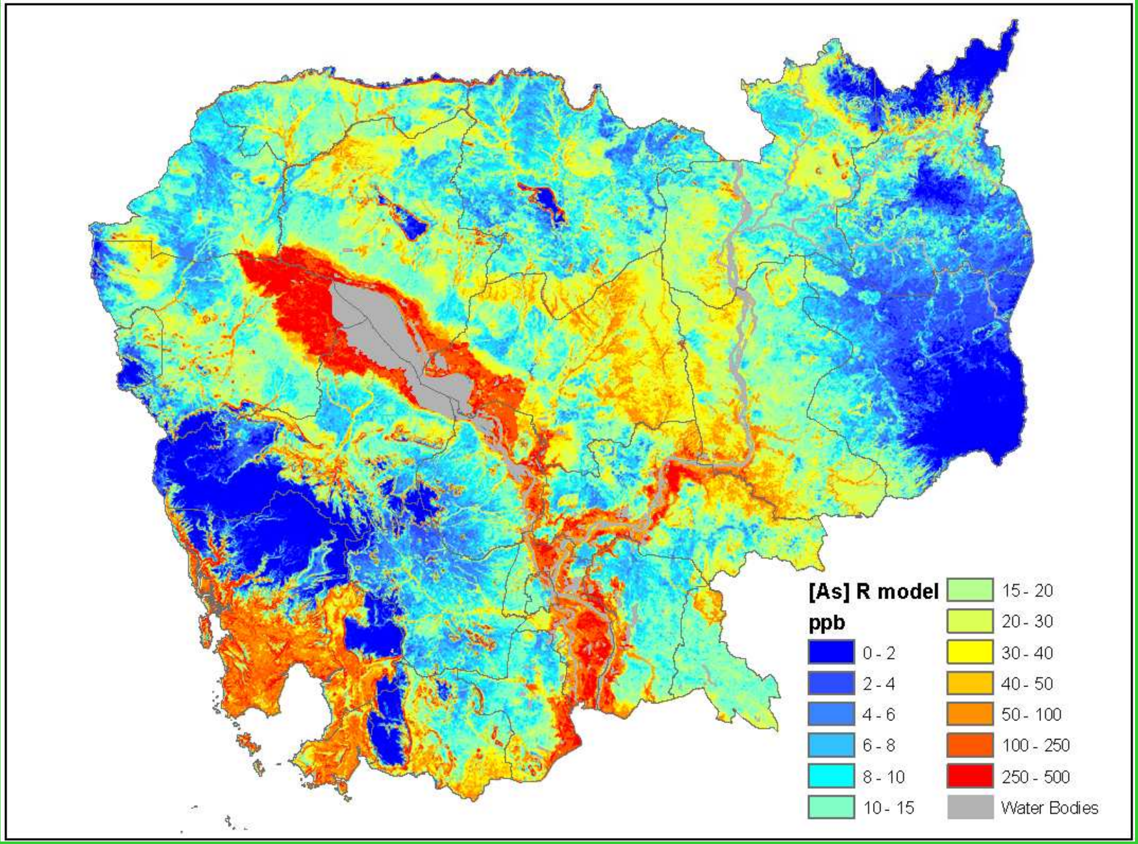
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Results: Regression model



MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

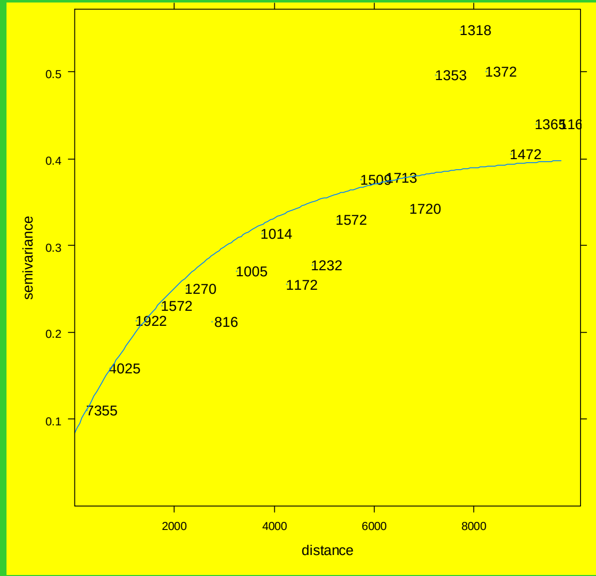
NUOL (Lao PDR)

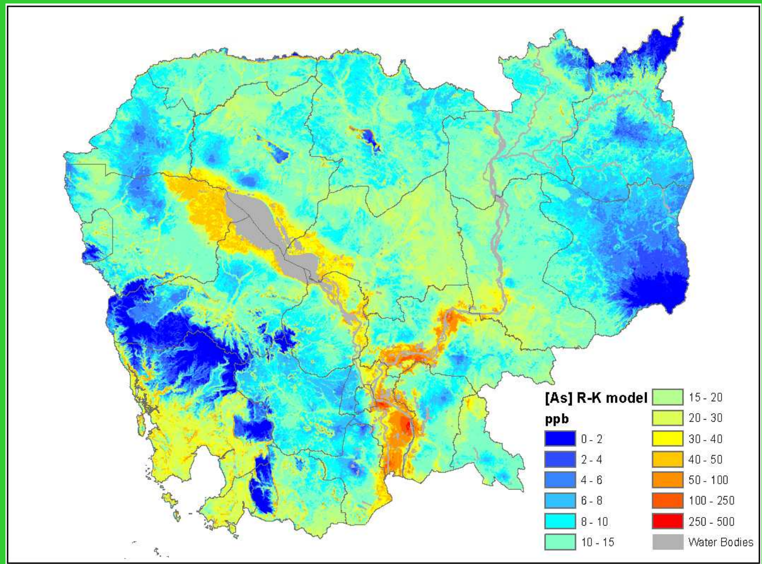
RUPP (Cambodia)

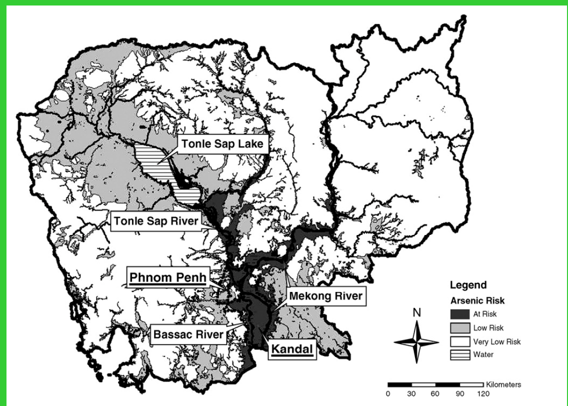
UJF, Grenoble (France)

University of Manchester (United Kingdom)

Results: RK- model







The higher As concentrations are located in the vicinity of the Mekong river system.
Positive correlation of Flow Length Index, organic-rich sediments, alluvial deposits and the Normalized Vegetation Index with increased probability of high As concentration

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

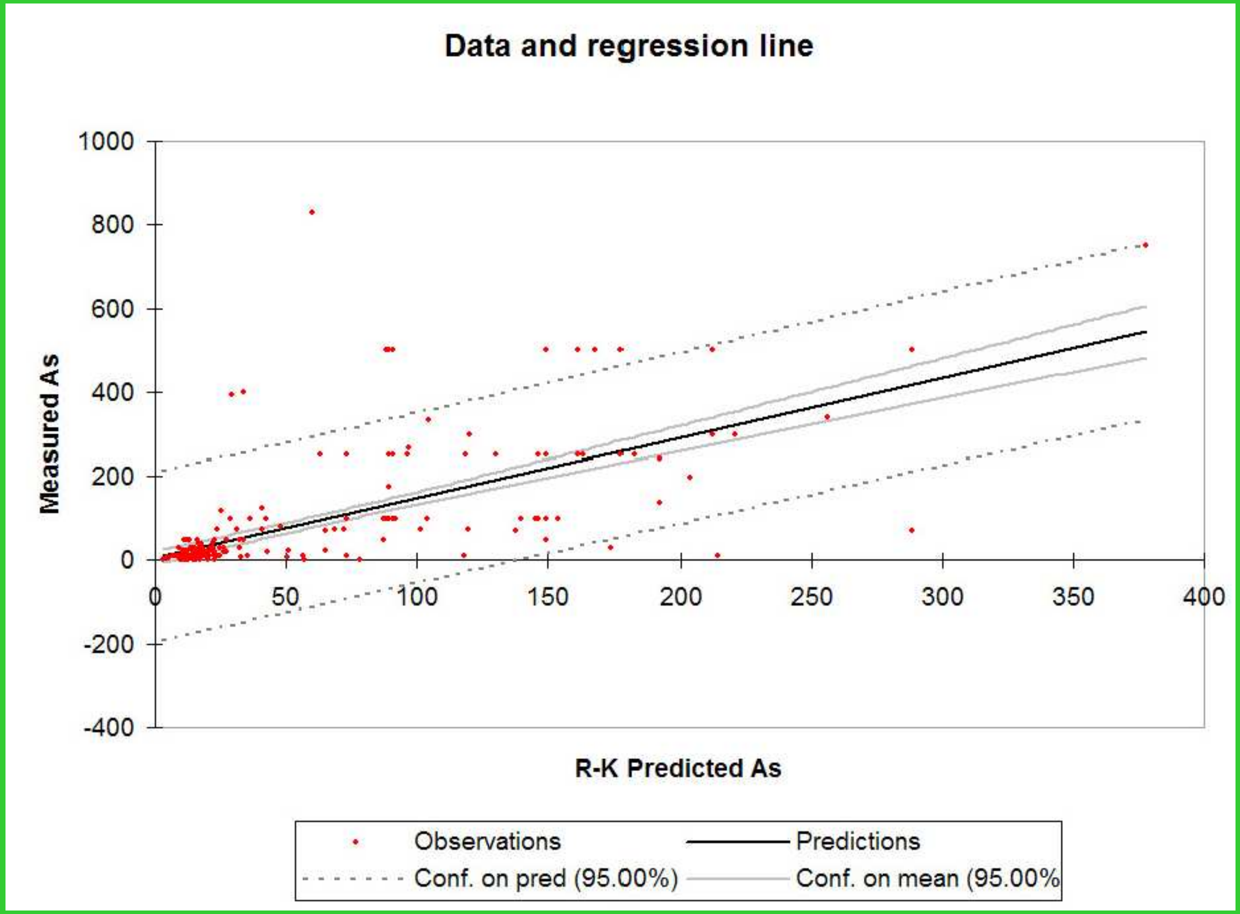
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Validation of RK Model



The University of Manchester
MANCHESTER 1824

EU ASIA-LINK CALIBRE

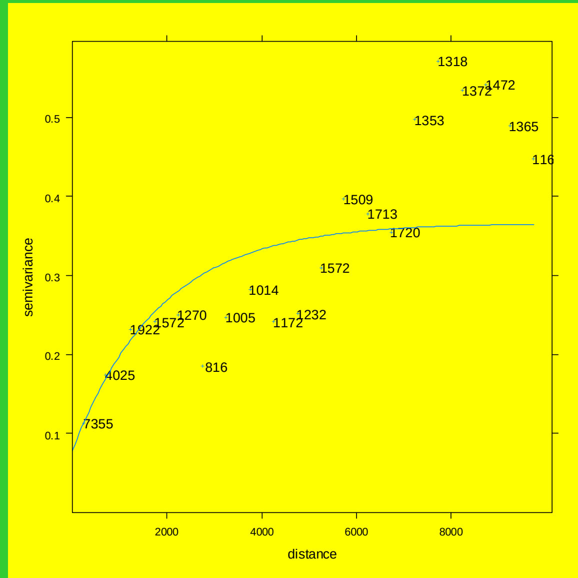
NUOL (Lao PDR)

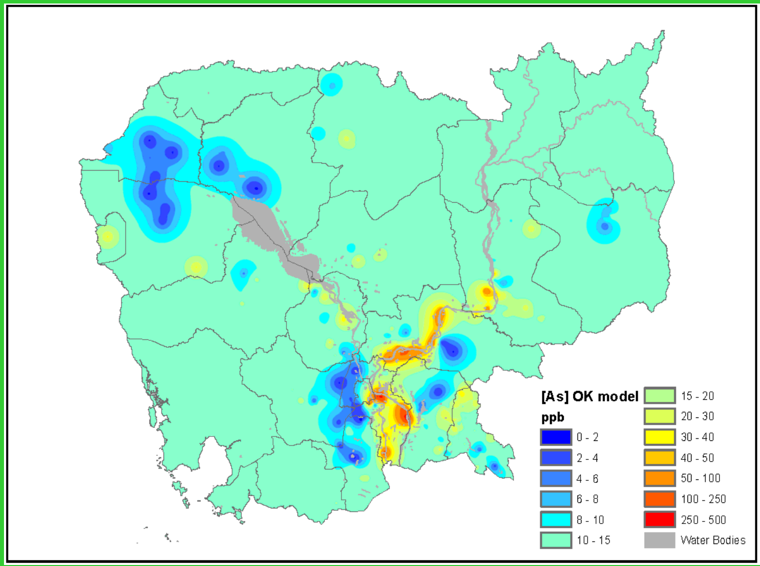
RUPP (Cambodia)

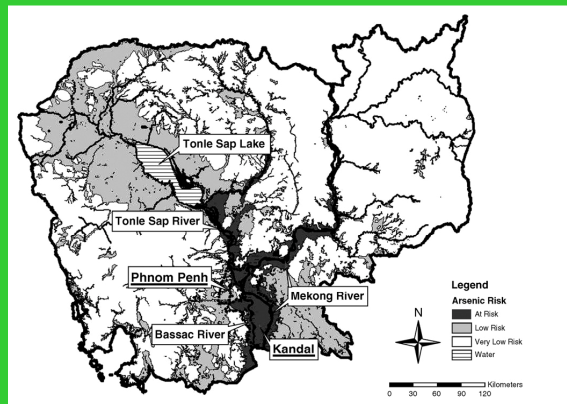
UJF, Grenoble (France)

University of Manchester (United Kingdom)

Results: OK- model







The higher As concentrations are located in the vicinity of the Mekong river system.
Positive correlation of Flow Length Index, organic-rich sediments, alluvial deposits and the Normalized Vegetation Index with increased probability of high As concentration

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

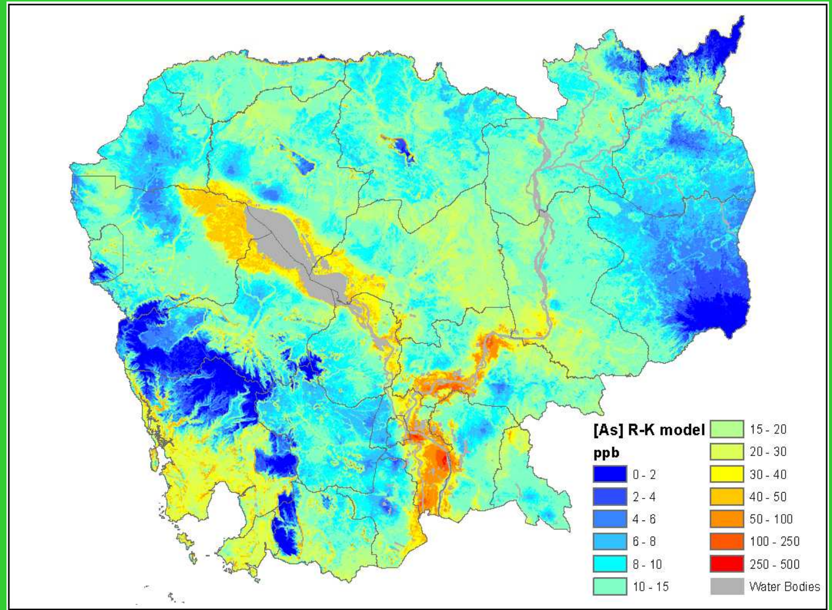
NUOL (Lao PDR)

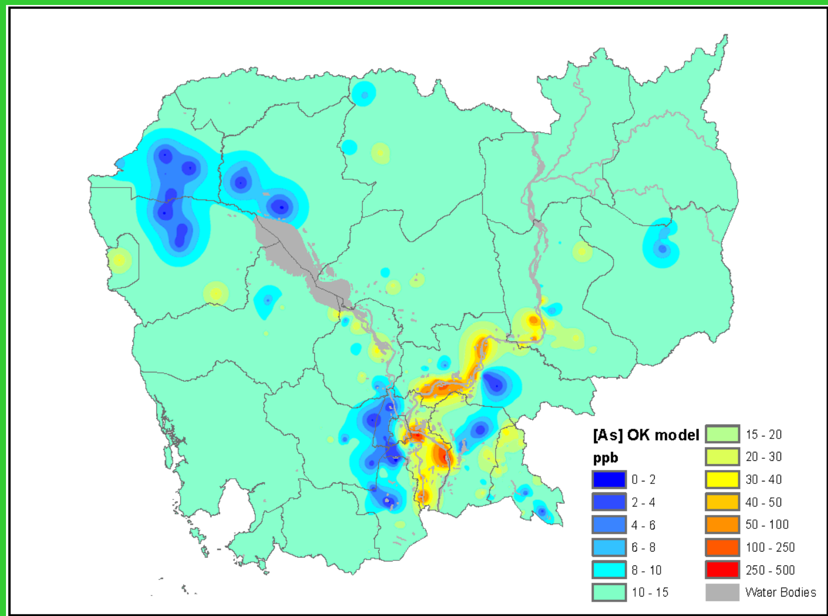
RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

RK
(Regression Kriging)
vs
OK
(Ordinary Kriging)





EU ASIA-LINK CALIBRE

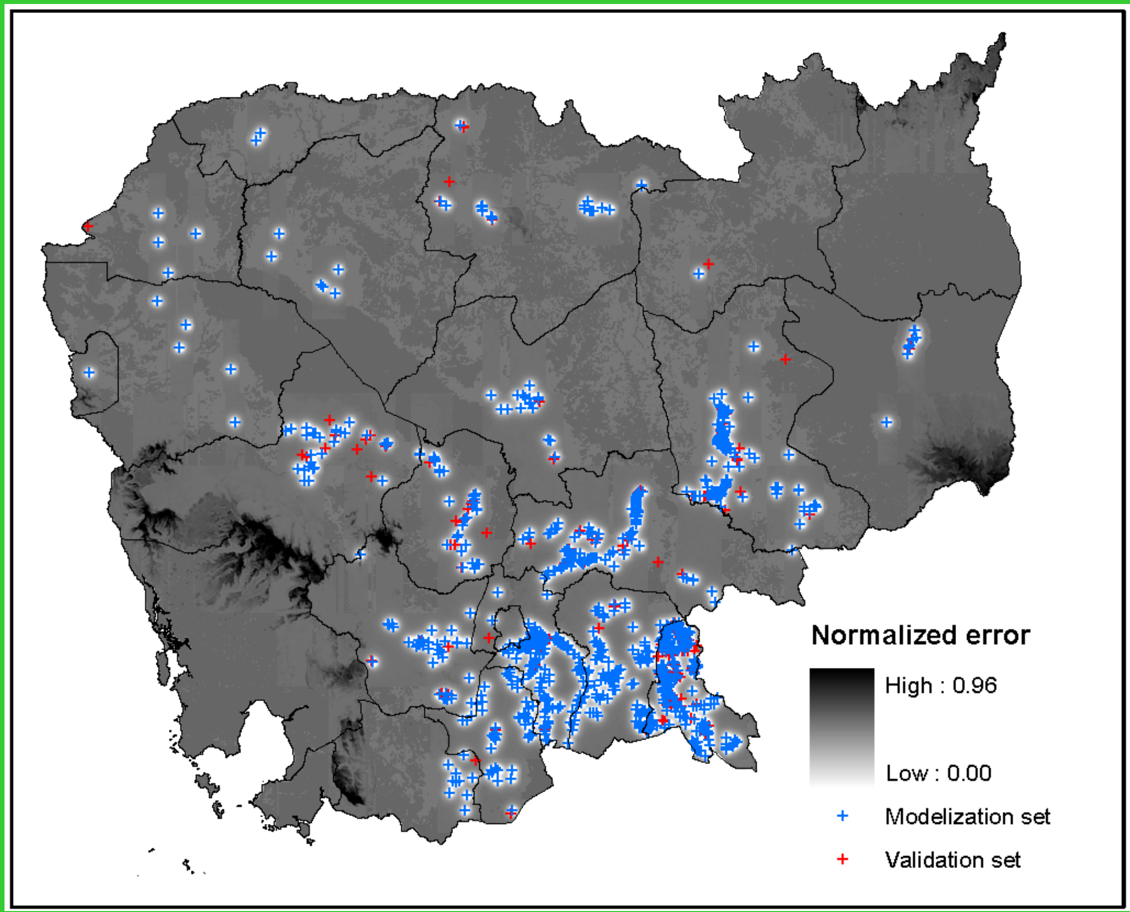
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Uncertainty Map for RK



The University of Manchester

MANCHESTER 1824

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Conclusions (I)

- Spatial distribution of As in Cambodian groundwaters is closely connected with relief.
- Comparison of OK and RK
  - statistically similar but RK more realistic
- Communication of uncertainty
  - Uncertainty map
  - Multiple equally-likely renditions
- More samples are required to increase the accuracy of this model
  - especially in the poorly sampled areas
  - especially in parameter space (e.g. high altitude)

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Rice is a major exposure route

TABLE 4. Arsenic Speciation and Dietary Exposure of Bangladeshi Market Rice

rice variety	rice distribution	origin (district)	grain	total arsenic μg As g⁻¹	DMA^{V} μg As g⁻¹	$As^{III} + As^{V}$ μg As g⁻¹	species sum μg As g⁻¹	extraction efficiency (%)	organic arsenic (%)	inorganic arsenic (%)	contribution to MTDI (%)[a]
Chinigura	speciality	Chapai	medium	0.03 ± 0.00	0.01	0.01	0.02	97 ± 23	49 ± 19	48 ± 4	4
Bashphoo	local	Bhairab	medium	0.04 ± 0.00	<LOD	0.03	0.03	70 ± 14	1 ± 1	69 ± 13	13
Kataribogh	speciality	Dinajpur	long	0.06 ± 0.00	0.01	0.04	0.05	77 ± 4	17 ± 4	60 ± 0	17
Parija	local	Dinajpur	long	0.07 ± 0.00	0.01	0.03	0.04	53 ± 3	11 ± 3	42 ± 1	13
Bashphool	local	Dhaka	medium	0.09 ± 0.01	<LOD	0.05	0.05	59 ± 3	4 ± 4	55 ± 1	21
Nazirshai	common	Sherpur	long	0.09 ± 0.00	0.02	0.06	0.07	80 ± 8	17 ± 8	63 ± 3	25
Parija	local	Natore	long	0.10 ± 0.00	0.01	0.07	0.08	84 ± 8	15 ± 9	69 ± 0	29
Parija	local	Chapai	long	0.10 ± 0.00	0.03	0.04	0.07	70 ± 3	25 ± 1	44 ± 2	17
Nazirshail	common	Dhaka	long	0.14 ± 0.01	0.01	0.09	0.10	70 ± 7	3 ± 3	64 ± 7	38
BRRI dhan28	common	Natore	long	0.15 ± 0.00	0.01	0.10	0.10	69 ± 5	6 ± 1	63 ± 5	42
Zami	speciality	Sylhet	medium	0.17 ± 0.01	0.02	0.09	0.11	60 ± 7	10 ± 8	53 ± 1	38
Parija	local	Bogra	long	0.20 ± 0.02	0.04	0.11	0.15	75 ± 2	21 ± 2	54 ± 1	46
Parija	local	Rajshahi	long	0.21 ± 0.02	0.05	0.12	0.17	83 ± 1	24 ± 0	59 ± 1	50
Miniket	common	Kushtia	long	0.22 ± 0.01	0.04	0.19	0.23	103 ± 4	16 ± 0	86 ± 4	79
BRRI dhan29	common	Tangail	long	0.30 ± 0.01	0.03	0.21	0.24	82 ± 2	11 ± 2	71 ± 0	88

[a] Contribution of inorganic arsenic to MTDI assumes a body weight of 60 kg and a consumption rate of 0.5 kg per day.

From Williams et al. (2005) *Env. Science & Technology*

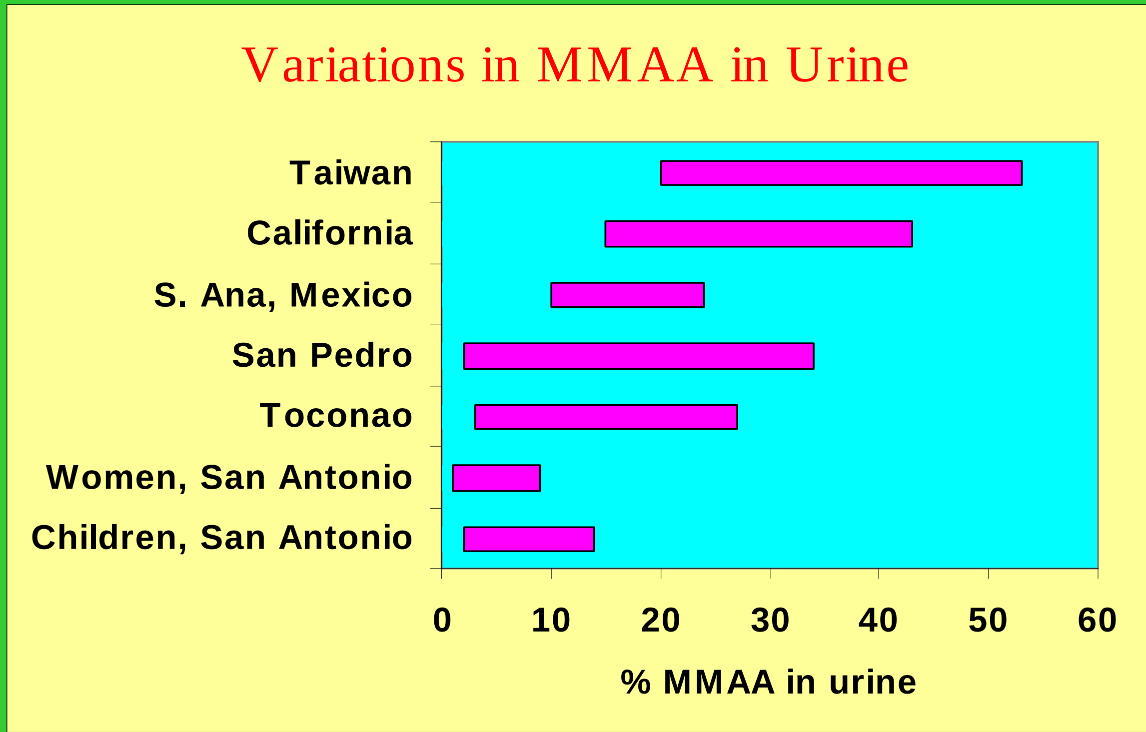
EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)



- Detoxification effectiveness indicated by urine % MMAA
- Large variations between individuals & populations
- Highest in populations with long exposure history
- Lowest in women & children [i.e. most at risk]

Source: Chen et al after various sources including Hopenhayn-Rich et al., 1993, 1996; Vahter et al., 1995; Chiou et al., 1997; Del Razo et al., 1997 Concha et al. ,1998

The University of Manchester
MANCHESTER 1824

EU ASIA-LINK CALIBRE

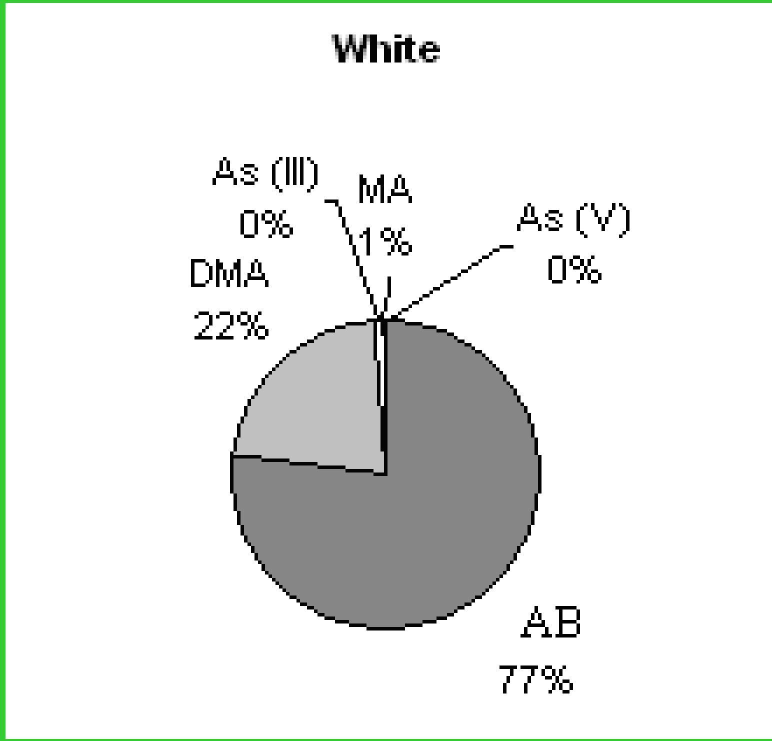
NUOL (Lao PDR)

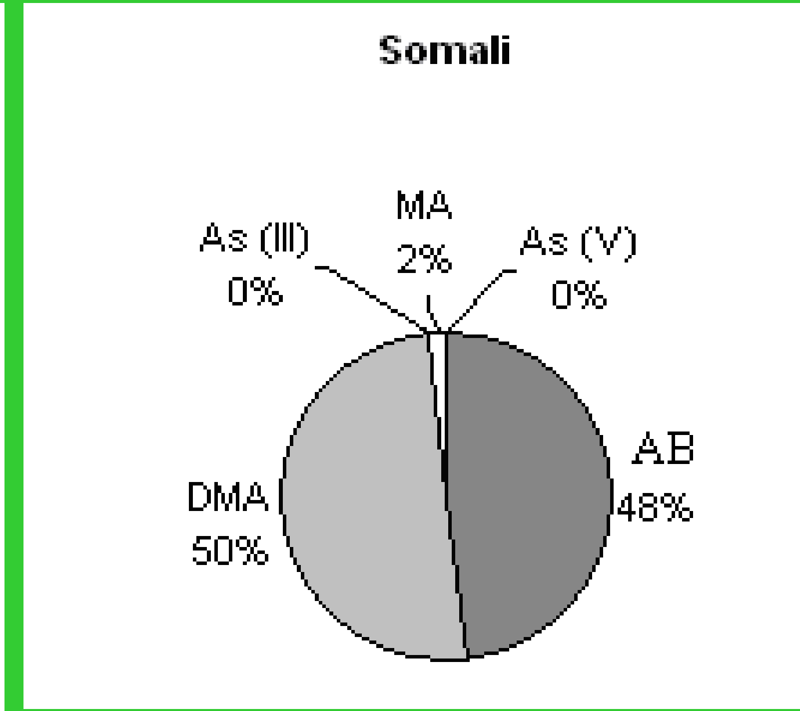
RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Dietary or Genetic Controls on Arsenic Uptake and Metabolism





From: Brima, Haris, Jenkins, Polya, Gault and Harrington **(2006)**
Applied Pharmacology & Toxicology (in press)

The University of Manchester

MANCHESTER 1824

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Risk Assessment & Remediation

- Source – Transport – Receptor Models
  - Groundwater arsenic hazard
  - Exposure Routes
    - Drinking water vs food
  - Target populations
    - Age, gender, genetic disposition

- Remediation Strategies
  - *In situ* remediation (e.g. bio-, O_2-injection)
  - *Ex situ* remediation (e.g. filters, Fe(III) pptn.)
  - Well-switching (short-term only ??)
  - Change to treated surface water supplies

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

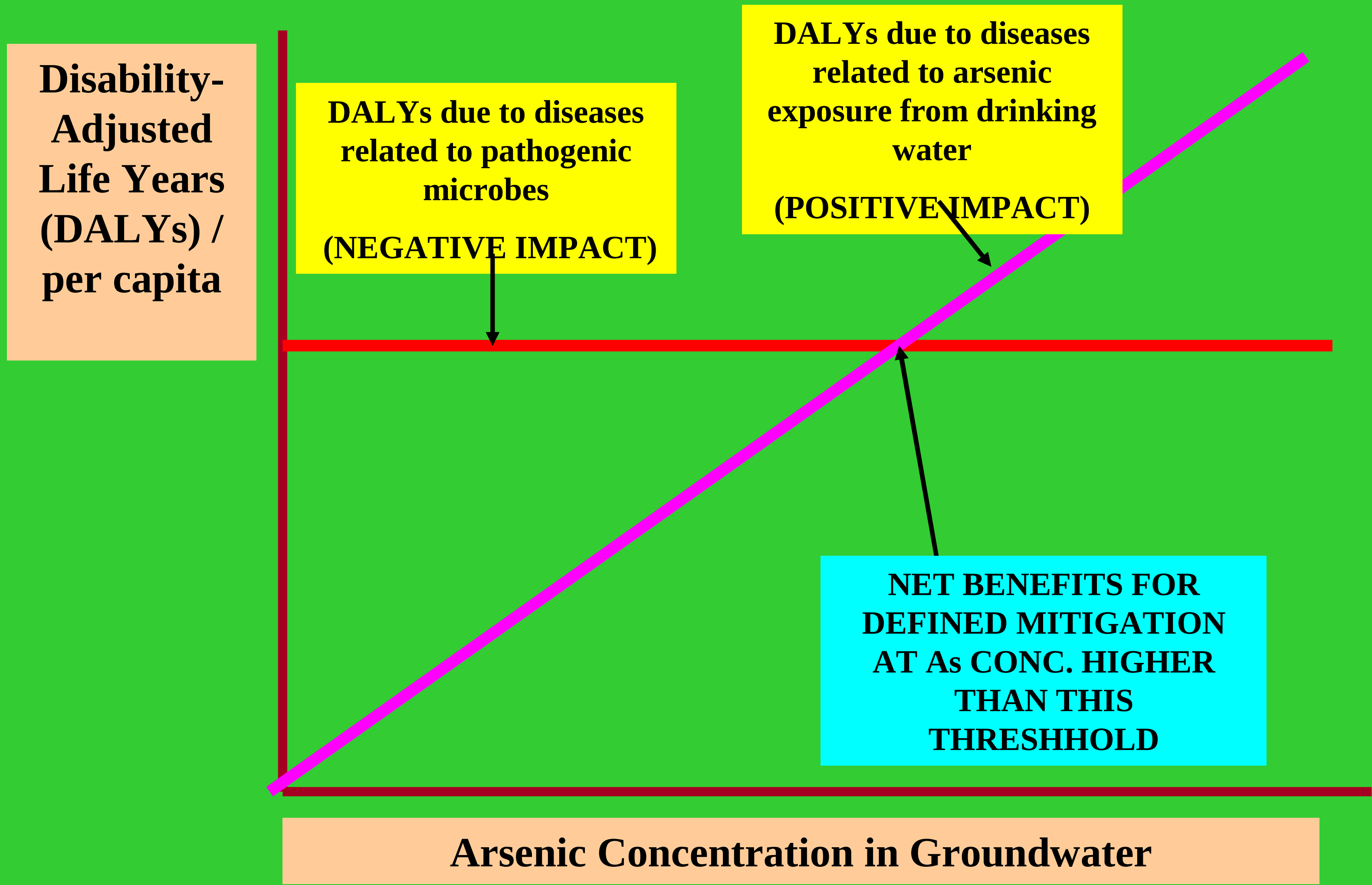
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

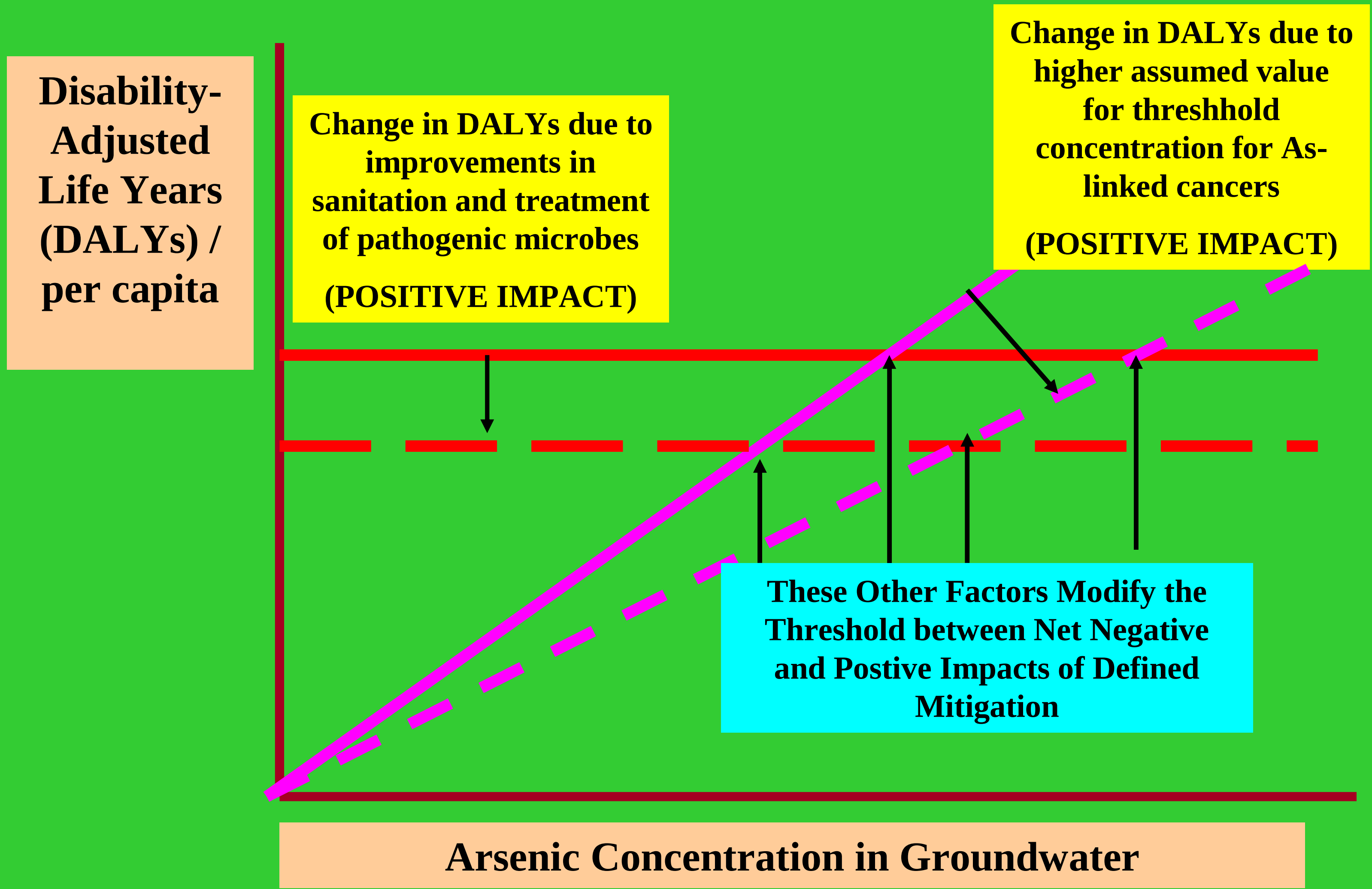
University of Manchester (United Kingdom)

Relative Impacts of Switching: Well to Surface Waters



EU ASIA-LINK CALIBRE
NUOL (Lao PDR)
RUPP (Cambodia)
UJF, Grenoble (France)
University of Manchester (United Kingdom)

Impact of Other Factors



MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

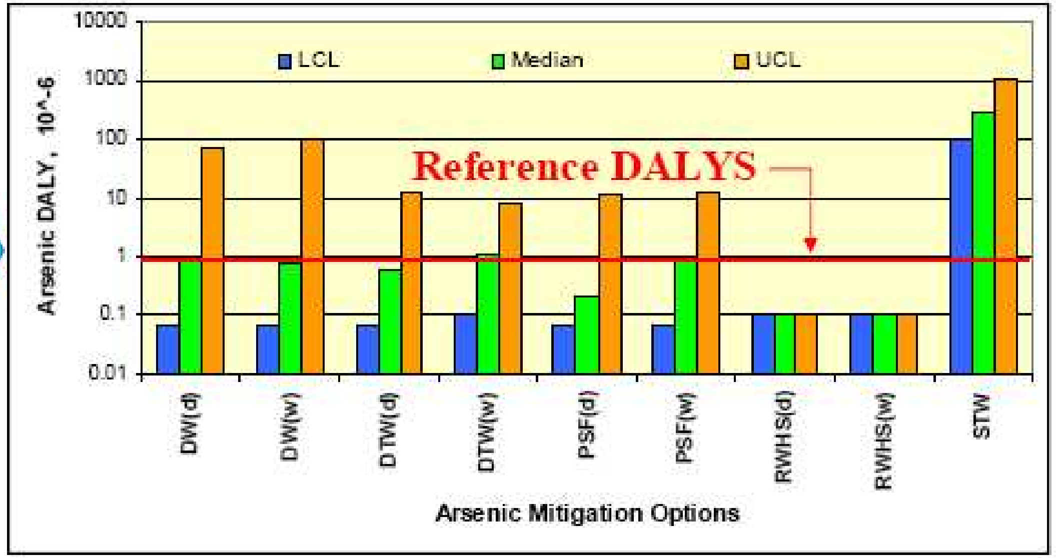
NUOL (Lao PDR)

RUPP (Cambodia)

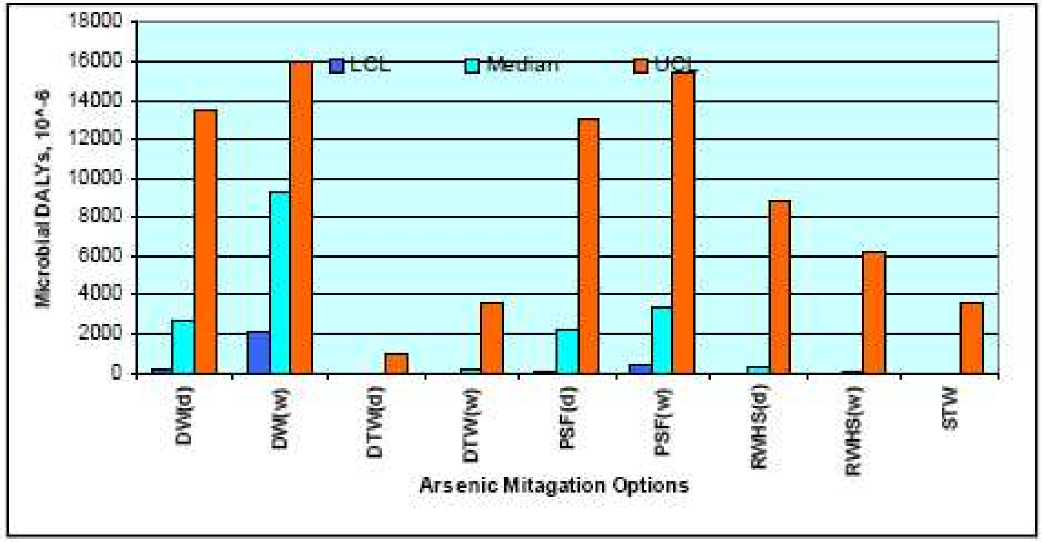
UJF, Grenoble (France)

University of Manchester (United Kingdom)

Arsenic DALYs



Microbial DALYs



From Guy Howard (2007)

The University of Manchester
MANCHESTER 1824

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Conclusions (II)

- Policy changes need to be informed by robust risk assessment
  - Objective hazard maps
  - Non-drinking water exposure routes
  - Genetic, gender & social controls
  - Future secular changes
  - Risk substitution
  - Effectiveness of remediation measures

The University of Manchester

MANCHESTER 1824

EU ASIA-LINK CALIBRE

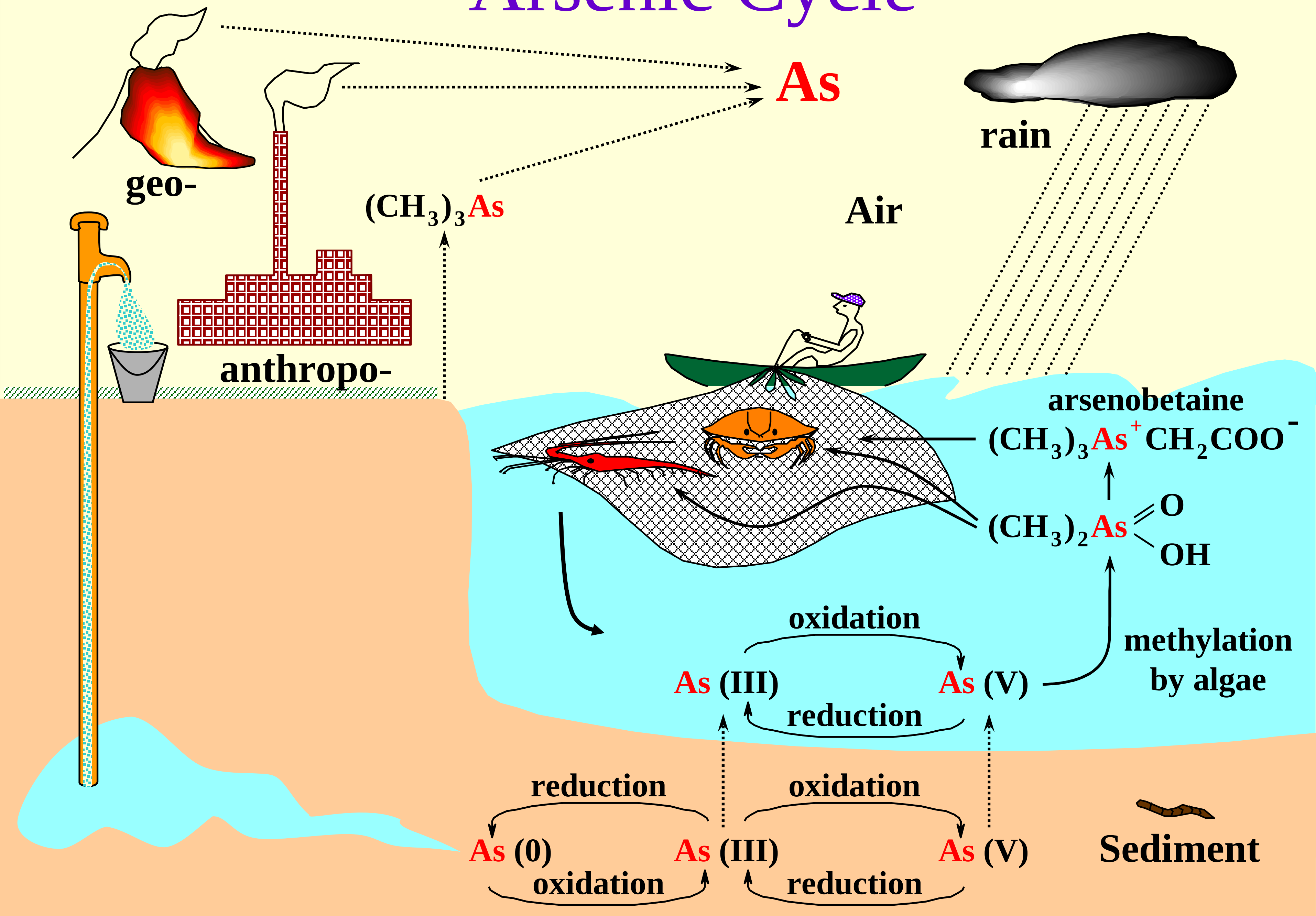
NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Arsenic Cycle



MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

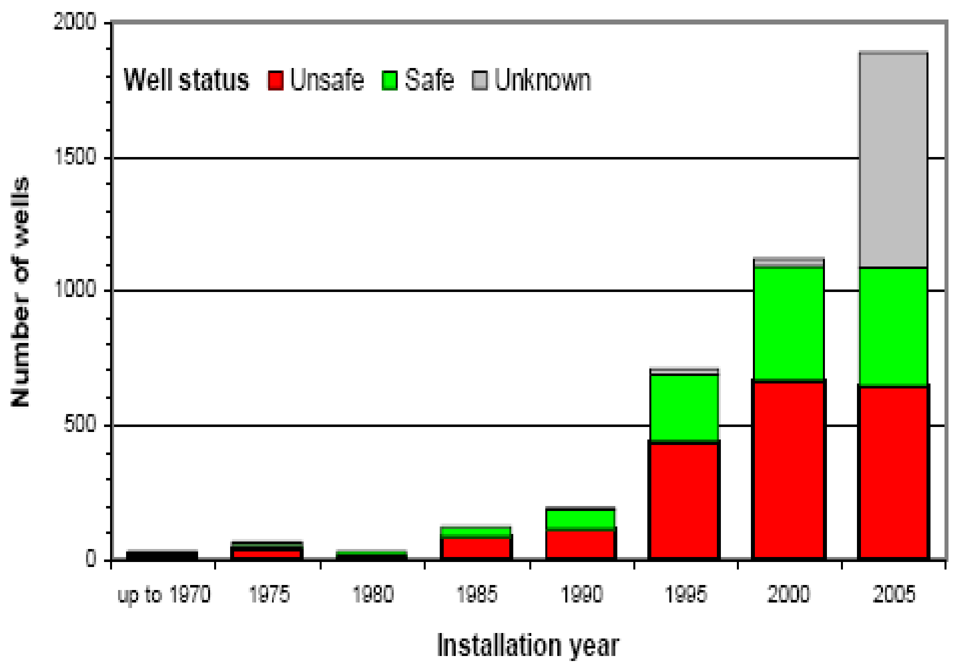
RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Policy / As / Bangladesh

- Increasing exposure to arsenic hazard in Bengal
- Policy issues remain unresolved



Status of Wells Installed 1970 – 2005, Araihazar Upazila, Bangladesh.

From M.F. Ahmed et al. (2006) *Science*, **314**, 1687. [15/12/2006]

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Implications of Models of Arsenic Release for Remediation Strategies in Cambodia

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Implications of Models (I)

- Arsenic distribution is likely to be highly variable; may be lower in deeper wells

- Well-switching to nearby wells (either deeperwith lower arsenic concentrations may be an effective short-term remediation strategy for many people

Implications of Models (II)

- Massive groundwater abstraction (especially for irrigation purposes) may result in medium to long-term secular increases in arsenic concentrations, even at depth
  - Well-switching only effective short-term
  - Long term well water quality uncertain
- Urgently require detailed geochemical data to test conflicting models of arsenic release

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE
NUOL (Lao PDR)
RUPP (Cambodia)
UJF, Grenoble (France)
University of Manchester (United Kingdom)

Consumer Preferences

- As-bearing groundwaters often high in Fe and H_2S
- Easily noticeable:
  - Red colouration on exposure to air
  - Smell
- Tend not to be used as drinking water
- Not comprehensive screening

MANCHESTER 1824
The University of Manchester

EU ASIA-LINK CALIBRE

NUOL (Lao PDR)

RUPP (Cambodia)

UJF, Grenoble (France)

University of Manchester (United Kingdom)

Well Testing

- Arsenic is not easy to detect directly
  - Tasteless
  - Colourless
  - No smell
- Well testing required