Spatial Variability of Arsenic in the Environment and in Rice– implications and uses of information at different scales

D. N. R. Paul[a], M. S. Kabir[a] and S. Sinh[a], M. A. M. Miah[a], G. M. Panaulla[b], R. H. Loeppert[c], J. M. Duxbury[d], C. A. Meizner[b] and S. DeGloria[d]

[a] Bangladesh Rice Research Institute, [b] CIMMYT, Bangladesh, [c] Texas A & M University, [d] Cornell University

Introduction

Soils are prone to contamination from atmospheric and hydrological sources (Navas and Machin, 2002) and contamination of this natural resource is posing serious environmental concerns. Spatial variability of soil input data can strongly influence the reliability of results of logical, empirical and physical models of soil (Burrough, 1993, Wilding et al, 1994). Information on the soil macro and micronutrient levels and trace elements could be of great interest for agricultural use (Wilcke et al., 1998). Studies to establish the environmental levels of various heavy metals are of increasingly interest in order to delineate areas of potential toxicity. Around the world, several studies have evaluated the heavy metal concentrations in soils (Kabata-Pendias and Pendias, 1984; Brummner et al., 1986; Wopereis et al., 1988; Vaselli et al., 1997). However, in Bangladesh, such studies are non-existent to date and therefore, very little are known about the distribution of such elements in general and arsenic (As) in particular. With the growing concern of As in ground water used for drinking and irrigation in Bangladesh, an adequate understanding of its spatial variability in soils and plants becomes essential. Spatial database on soil and ground water arsenic would be a basis for a wide variety of economic and environmental applications and to assess the relationship between geochemistry and health.

Scale is one of many factors influencing soil variability. The spatial characteristics of the sampling units – their size, shape, spacing (lag distance) and extent – are the important scale concepts (Dungan, 2002). Scale is defined as the resolution within the range of a measured quantity (Schneider, 1994). The characteristics of a variable's distribution depend on the area or volume i.e., on the scale over which it is measured or calculated. Inference about mean and variance, strength and nature of spatial autocorrelation, spatial anisotropy, patch and gap sizes, as well as multivariate relationship are all dependent on the scale of measurement i.e., on size and shape of the sampling units, lags and extent of sampling (Dungan et al, 2002). Quantification of soil spatial variability at multiple scales is important in ecological modeling, environmental prediction, precision agriculture and natural resources management (Hangsheng, et al, 2004). Knowledge of soil As at multiple scales and its impact on rice plants will enhance the use of soil information for designing appropriate management techniques for rice production. This study, aims at assessing spatial dependence and mapping spatial distribution of As concentration in soil, ground water and rice grains and exploring implication of spatial distribution maps at multiple scales of sampling.

Methodology

The scales in this study were the combination of extent and lag of the sampling units. Three different scales were used for soil sampling. (1) National scale: sampling points were located in three randomly selected unions of every alternate *Thana* at lag distance of approximately 20-40 Km, (2) *Thana* scale: sampling points were selected at random but approximately at the lag distance of 1-2 km and (3) Command area scale: the sampling points were approximately at 20x20m grids within the command area of a shallow tube well (STW). South-west and south central hydrological zones together was used as the national scale. In each case, soil samples (top soils: 0-15cm depth) and plant samples (for measuring As concentration in rice grain) were collected within the command area of the selected shallow tube well (STW) used for irrigation using standard soil sampling procedure. Flow-injection hydride generation flame-atomic-absorption spectroscopy was used to determine As concentration in irrigation water, soil and in rice grain.

Semivariance was calculated to determine the spatial dependency of As in ground water, soil and rice grain. Maximum lag distance and lag interval for the semivariance were determined iteratively to best fit the model having highest R^2, lowest residual sum of squares (RSS). Spatial distribution maps of As concentration within the sampling extent were created using block kriging at command area and IDW at *thana* and national scales.

Results and Discussion

The descriptive statistics presented in Table 1 showed that As concentration in any measure (mean, maximum, quartile, etc) was the highest for ground water and lowest for rice grain. Average soil As was about 14 times higher than water As and 55-70 times higher than As concentration in rice grains. Scale of sampling affected almost all measures of As. The measures were, in general, higher for command area scale followed by *thana* scale. In contrast, variability of As concentration as measured by CV, was the lowest for command area scale and highest for national scale (Table 1). The very high value of CV indicated spatial variability of As level for all of ground water, soil and rice grain irrespective of scale of sampling. The magnitude of variability appeared to be similar for soil and rice grain but was comparatively smaller than that of water. Moreover, the estimates of As concentration was more precise in smaller extent than in larger extent. Results gave clear indication that sampling in smaller extent provides better understanding on the levels of As contamination in ground water, soil and rice grain,

Table 1. Some descriptive statistics of arsenic concentration in ground water, soil and rice grain under different scales of measurement.

Statistics	Ground water		Soil			Grain		
	Thana	National	Command area	Thana	National	Command area	Thana	National
	As level (ppm)							
Minimum	0.07	0.00	12.28	4.3	4.48	0.11	0.09	0.04
Maximum	4.41	2.91	25.19	51.79	39	0.59	1.01	0.67
Mean	1.35	0.83	20.16	18.13	13.22	0.29	0.32	0.24
1st quartile	0.70	0.15	18.49	12.11	8.78	0.21	0.23	0.15
2nd quartile	1.21	0.65	20.33	17.65	11.29	0.26	0.3	0.2
3rd quartile	1.79	1.36	21.83	23.54	15.3	0.35	0.38	0.31
CV(%)	64.47	90.34	13.21	43.17	52.21	36.35	44.43	56.17
Sample size	105	98	63	104	98	59	103	88

Note: There was no ground water As data

The frequency distribution of As concentration (not shown) was positively skewed and deviated from normal distribution either in terms of skewness or kurtosis or both in all cases at national and *thana* scale. Lognormal transformation of soil and grain and square root transformation of ground water made the distribution of As concentration approximately normal. At command area scale, the distribution of As concentration (in soil and rice grain) was fairly normal. Semivariance was, therefore, computed on the transformed data at national and *thana* scale and on original data at command area scale. For ground water As, the best fitted semivariogram model was exponential and that for soil and grain As was spherical. The goodness of fit was quite low (R^2 value ranged from 46% to 56%) for national scale, which could be attributed to large lag distance of sampling points not enough to capture spatial dependence. Nevertheless, the results exhibited spatial dependence at all scales. The variance due to spatial structure was higher than the random error implying that the spatial structure accounted for the major portion of sampling variance. The effective range i.e., the spatial range of dependence was quite large, even larger than the sampling extent at national and *thana* scale posing a question on the use of kriging for interpolating As concentration at un-sampled area that uses the estimated semivariogram in the process of interpolation. Uneven spatial distribution and large lag distance of sampling points could be two possible reasons for such a large effective range.

As expected, kriging resulted imprecise interpolation of As concentration for un-sampled area at national and *thana* scale but did well at command area scale. The Inverse Distance Weight (IDW) method was found relatively more precise than kriging and, hence, was used for interpolation and mapping As concentration in soil, water and grain at national and *thana* scale. At national scale, Figure 1(a) exhibited spatial distribution of soil As with large area under same concentration level not reflecting the real situation as indicated by the As surface at *thana* scale. On the other hand, the spatial distribution at *thana* scale appeared to be convincing since the spatial distribution at command area scale closely represented the As situation at *thana* scale. In case of ground water and rice grain, the spatial distribution of As at *thana* scale seemed to be consistent with the information provided at national scale (Fig. 1(b) and (Fig. 1(c)). Result seems to indicate that spatial distribution of ground water and grain As is less sensitive to the lag distance and spatial distribution of sampling points than soil As. Nevertheless, as the results suggest, the spatial distribution of As at national scale, if generated using proper sampling plan, will provide a generalized pattern of As concentration across the horizon. The information will be useful at the policy level for identification of areas where more intensive investigation on As contamination needs to be undertaken and prioritizing national program for management or mitigation of As problems both for crop production and health issues. At *thana* scale, on the other hand, the As surface will give more clear picture of As status within the *thana* that can provide useful information for local level planning to design appropriate management technique, research strategy or action plan to combat As problem. The spatial distribution of As in command area is expected to provide with more or less the actual As status at the field level leading to farmers' management option for crop production to avoid toxic effect of As in rice grain.

Conclusions

All measures of As are in general, higher and more precise at command area scale followed by *thana* scale. There exists spatial dependence of As concentration in soil, ground water and rice grain and the parameters of such dependency can be estimated more precisely at the sampling scale where the sampling points are more uniformly distributed across the extent of sampling with smaller lag distance. The spatial distribution of As concentration in soil and ground water to be useful at national scale, the distribution of sampling points should be uniform as possible with smaller the lag distance between sampling points. Sampling from 1 km grids (preferred) or randomly selected irrigated and non-irrigated fields from each union may be a possible sampling strategy. With proper sampling, the spatial distribution of As concentration at national scale would be very useful at the policy level for identification of areas where more intensive investigation on As contamination needs to be undertaken and prioritizing national program for management or mitigation of As problems. At *thana* scale, the information would help local level planning to design appropriate management technique, research strategy or action plan and develop extension mechanism for management /mitigation of As problem. At command area scale, the knowledge of spatial distribution will lead farmers' management option for safe crop production.

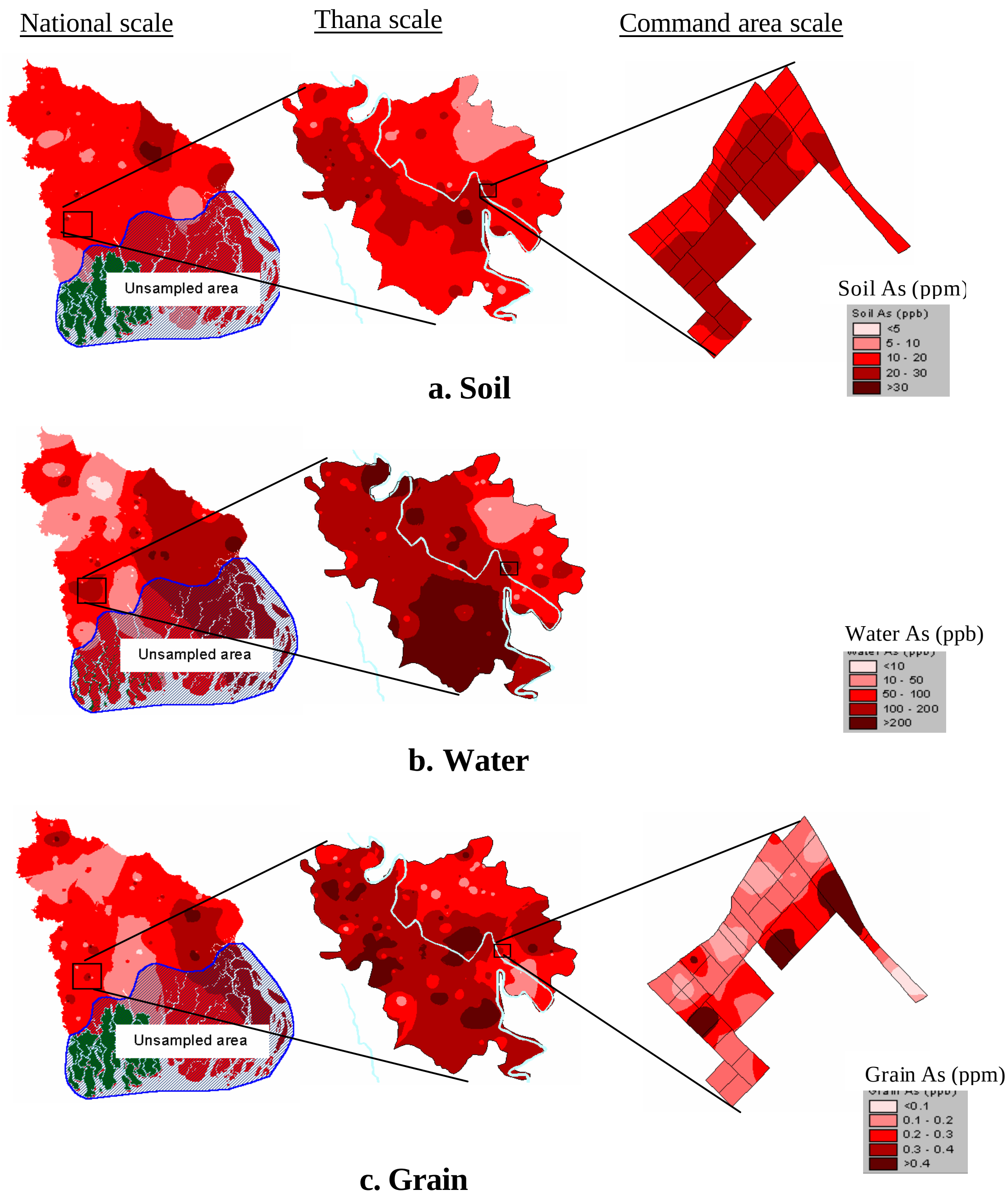

Fig. 1. The spatial distribution of arsenic concentration in soil, ground water and rice grain under different sampling scales (there was no data on ground water As)

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