An environmental tragedy is developing in West Bengal, India where a large population is drinking arsenic-contaminated water, and an alarming number of toxicity cases associated with ingestion of arsenic-contaminated drinking water have been reported. The source of the contamination is geological; arsenic in groundwater has been found above 50 µg/l (the current drinking water standard in much of the world) in seven of the 16 districts of West Bengal. The seven affected districts of West Bengal have a population of over 34 million, and an area of 37 493 km2. Investigators in West Bengal suspect that at least 800 000 people have been consuming arsenic-contaminated water. New regions of contamination are being discovered, with a potentially exposed population of over 1 million.

The duration of arsenic exposure in India is uncertain, but it is thought that the problem began in the late 1960s when digging of tubewells commenced as part of a state-wide irrigation plan. Because groundwater was cleaner than water from tanks, ponds and the polluted Ganges River, many inhabitants

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**ArSENIC LEVELS IN DRINKING WATER AND THE PREVALENCE OF SKIN LESIONS IN WEST BENGAL, INDIA**

Debendra N Guha Mazumder, Reina Haque, Nilima Ghosh, Binay K De, Amal Santra, Dipankar Chakraborty and Allan H Smith

**Background** A cross-sectional survey was conducted between April 1995 and March 1996 to investigate arsenic-associated skin lesions of keratosis and hyperpigmentation in West Bengal, India, and to determine their relationship to arsenic water levels.

**Methods** In all, 7683 participants were examined and interviewed, and the arsenic levels in their drinking water measured.

**Results** Although water concentrations ranged up to 3400 µg/l of arsenic, over 80% of participants were consuming water containing <500 µg/l. The age-adjusted prevalence of keratosis was strongly related to water arsenic levels, rising from zero in the lowest exposure level (<50 µg/l) to 8.3 per 100 for females drinking water containing >800 µg/l, and increasing from 0.2 per 100 in the lowest exposure category to 10.7 per 100 for males in the highest exposure level (≥800 µg/l). However, 12 cases with keratosis (2 females and 10 males) were drinking water containing <100 µg/l of arsenic. Findings were similar for hyperpigmentation, with strong dose-response relationships. Among those with hyperpigmentation, 29 cases were exposed to drinking water containing <100 µg/l. Calculation by dose per body weight showed that men had roughly two to three times the prevalence of both keratosis and hyperpigmentation compared to women apparently ingesting the same dose of arsenic from drinking water. Subjects who were below 80% of the standard body weight for their age and sex had a 1.6 fold increase in the prevalence of keratoses, suggesting that malnutrition may play a small role in increasing susceptibility.

**Conclusion** The surprising finding of cases who had arsenic-associated skin lesions with apparently low exposure to arsenic in drinking water needs to be confirmed in studies with more detailed exposure assessment. Further research is also needed concerning susceptibility factors which might be present in the exposed population.

**Keywords** Arsenic, keratosis, hyperpigmentation, India, cross-sectional study, drinking water

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switched to using tubewell water. The contamination of ground- 
water with arsenic was first detected in 1978, and the first 
arSENic poisoning cases were reported in the early 1980s.5–7 
Most of the affected villages are located along the western side 
of the Ganges River. A survey conducted by Das et al.8 which 
was limited to regions with levels >50 µg/l, indicated that the 
arSENic concentration was generally between 50 to 500 µg/l in 
the drinking water supplies. However, concentrations have 
reached nearly 3000 µg/l in some villages.

Although limited epidemiological data exist, the reported 
clinical manifestations resulting from ingestion of arsenic-
contaminated drinking water include weakness, conjunctival 
congestion, hyperpigmentation, keratosis, hepatomegaly, portal 
hypertension, respiratory system effects, polyneuropathy, solid 
oedema of limbs, and malignant neoplasms.7,9 Skin abnor-
malities such as pigmentation change and keratosis have long 
been known to be hallmark signs of chronic arsenic exposure. 
Pigmentation changes and keratotic lesions were the most 
common health effect found in populations exposed to 
arSENic-contaminated drinking water in Taiwan,10,11 Chile,12 
and Argentina.13,14 Hyperpigmentation and keratoses caused 
by arsenic are quite distinctive. The hyperpigmentation is marked 
by raindrop-shaped discolored spots, diffuse dark brown spots, 
or diffuse darkening of the skin on the limbs and trunk.7 Simple 
kERatosis usually appears as bilateral thickening of the palms 
and soles, while in nodular keratosis, small protrusions appear 
on the palms and soles, with or without nodules on the dorsum 
of the hands, feet, or the legs. Skin lesions pose an impor-
tant public health problem in India because advanced forms of 
kERatosis are painful, and the consequent disfigurement can 
lead to social isolation in the villages.3 In contrast to cancers 
which take decades to develop, these skin lesions are generally 
observed 5–10 years after exposure commences.

To determine the prevalence of the various health effects 
associated with arsenic, a cross-sectional study was conducted 
in one of the most affected districts of West Bengal, the South 
24 Parganas between April 1995 through March 1996. The 
South 24 Parganas was a suitable location for this survey 
because of the heterogeneity in exposure, which enabled the 
investigators to collect exposure-response data. The drinking 
water arsenic levels in this district ranged from non-detectable 
to 3400 µg/l. The most prevalent health effects found in the 
study population were keratosis and hyperpigmentation, and 
are the focus of this paper.

Methods

Study area and population

Two particular areas within this district were targeted for the 
survey. The first area was selected because high levels of arsenic 
were detected in some, but not all, of the shallow tubewells as 
determined in a prior study.1,7 The second area included the 
remaining part of the district where people used shallow tubewell 
water for drinking purposes. Our survey was the first of its 
kind in this area; thus, no reports of elevated arsenic levels were 
available before the survey. The two areas combined contain a 
total population of 150 457. A total of 7818 individuals 
participated in the drinking water study. Water-arsenic levels 
were obtained for 7683 of the participants (4093 females and 
3590 males), who constitute the study subjects for this paper.

The high exposure region included 25 villages. Convenience 
sampling was used for this study which involved remote rural 
areas. The study team went to the centre of each village and 
selected the most convenient hamlet (group of houses) to 
commence sampling. Each member of the household present at 
the time of the interview was invited to participate. An inter-
view was administered and a brief medical examination was 
conducted. Sampling continued house-to-house in a village 
until 50 to 150 participants were recruited.

The low exposure region included 32 villages within 16 
administrative blocks. Sampling in this region was restricted to 
villages with more than 100 houses. One or more villages were 
selected at random from each of the 16 blocks depending on the 
population size. Only one village was selected for sampling from 
a small block, but two or three villages were selected if the block 
was larger. Again, the study team went to the centre of each 
village and selected the most convenient hamlet to commence 
sampling; but, this time residents of every fourth house were 
invited to participate.

Interview and medical examination

Each participant was questioned briefly about his or her sources 
of drinking water, current diet and water intake, medical symp-
toms, height and weight and other variables. A general medical 
examination was given, including a careful inspection for arsenic 
skin lesions.

The criteria for classifying keratoses and hyperpigmentation 
as arsenic-caused were as follows. Keratoses had to involve 
diffuse bilateral thickening of palms and/or soles with or with-
out nodules of various shapes and sizes. Hyperpigmentation was 
identified if there were areas of mottled dark brown pigmen-
tation bilaterally distributed on the trunk. Hyperpigmentation was 
frequently present also on the limbs, and sometimes alongside 
spots of depigmentation, but these characteristics were not 
regarded as essential for the diagnosis. All patients were exam-
ine in the field by one of two physicians who have had about 
10 years experience each in diagnosing arsenic-caused skin 
lesions in West Bengal, including examining patients regularly 
in the Arsenic Clinic in the hospital linked with the Post-
graduate Medical Institute in Calcutta.

The field work was designed to minimize subjectivity in 
examining for skin lesions. Field workers inevitably knew if a 
village they were working in was located in the high exposure 
area or the low exposure area, but they did not know the 
tubewell arsenic concentrations at the time of the survey. Each 
participant was first interviewed by a trained field worker con-
cerning their drinking water consumption and tubewell used, 
and then examined by one of the two physicians. Water sam-
pleS were obtained from the tubewell on the same day as the 
interview and medical examinations, but results of analyses for 
arSENic were not known until months later. Thus, the physical 
examinations for skin lesions were conducted blind as to water 
arSENic concentrations which varied widely, with contaminated 
wells scattered irregularly throughout the study region.

Water sampling and arsenic measurement

Water samples were collected from private and public tubewells 
used for drinking and cooking purposes by each recruited house-
hold. Arsenic levels were measured by flow-injection hydride 
generation atomic absorption spectrophotometry. Daily dose per
body weight was computed by multiplying the water-arsenic concentration by estimated daily water intake, and then dividing by body weight.

**Statistical analysis**

Participants were stratified by age, and the prevalence of keratosis and hyperpigmentation were calculated for each sex separately. To allow comparison without distortion by age, the prevalences were directly standardized to the age distribution of all participants of the same sex in the study population. Skin effects were examined by water arsenic levels which were categorized as follows: <50, 50–99, 100–149, 150–199, 200–349, 350–499, 500–799, and >800 µg/l. Tests for trends in proportions were based on the \( \chi^2 \) distribution using the midpoints of each grouping of arsenic-water levels. Since age adjustments had little impact on non-adjusted prevalence estimates, the tests for trends were conducted on the unadjusted data. In view of a clear one-directional *a priori* hypotheses, one-tailed \( P \)-values are presented.

The prevalence of skin lesions was also examined by tertiles of daily arsenic dose per body weight (µg/kg/day). Using all subjects, the cut points for the tertiles were: 3.2 and 14.9. The highest dose per body weight found was 73.9 µg/kg/day. Tests for trend in proportions were conducted using the mid-points of each dose tertile (1.6, 9.1, and 44.4 µg/kg/day).

To obtain an approximate indication of nutritional status, we examined individual body weight in relation to standard weight values. Each subject’s weight was compared to a table of average values for Indian males and females based on height, age and sex. These standards were compiled from an extensive database of weights, heights and ages of Indian females and males obtained from a life insurance company, and are widely used by insurance companies in India. The cutoff for categorizing subjects into those who might be of poor nutritional status and those with adequate nutrition was 80% of the standard weight; i.e. those with weights 20% or more below the standard for their age, sex, and height were considered likely to have poor nutrition, while those above this cutoff were considered likely to have adequate nutrition. Because of small numbers in the age-specific categories with low body weight, indirect age standardization was conducted. Using those who had adequate nutritional status as a reference group, standardized morbidity ratios (observed cases with skin lesions divided by expected cases) were calculated for each tertile of dose per body weight. Statistical tests of significance were based on the Poisson distribution and 95% confidence intervals (CI) were calculated using exact methods.

**Results**

**Tubewell water concentration**

The age, sex and water-arsenic level distribution of the study population is presented in Table 1. The tubewell arsenic concentrations ranged from non-detectable to 3400 µg/l. Altogether, measurements were made on 644 tubewells used by the study participants; 282 of these tubewells had arsenic concentrations >50 µg/l. Keratosis prevalence was examined by arsenic-water levels. Of the 4093 female participants, 48 had keratotic skin lesions (Table 2). A clear relationship was apparent between water levels of arsenic and the prevalence of keratosis. The test for trend yielded a \( P \)-value <0.001. Similar findings were found for males (Table 2) and for hyperpigmentation in both males and females (Table 3 and Figure 1).

**Dose per body weight**

The prevalence of skin lesions was also examined by daily dose per body weight (µg/kg/day). The age-adjusted prevalence of keratosis in females rose from 0.8 per 100 in the lowest tertile...
Table 2  Keratosis prevalence per 100 by age groups and arsenic exposure level (µg/l) among females with number of cases in parentheses

<table>
<thead>
<tr>
<th>Age group</th>
<th>Arsenic level (µg/l)</th>
<th>&lt;50</th>
<th>50–99</th>
<th>100–149</th>
<th>150–199</th>
<th>200–349</th>
<th>350–499</th>
<th>500–799</th>
<th>≥800</th>
<th>Total</th>
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<tbody>
<tr>
<td><strong>Females</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>≤9</td>
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<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>2.0 (1)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>0.2 (1)</td>
<td></td>
<td></td>
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<tr>
<td>10–19</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>1.9 (1)</td>
<td>2.6 (3)</td>
<td>0.0 (0)</td>
<td>3.1 (2)</td>
<td>11.5 (3)</td>
<td>1.0 (9)</td>
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<tr>
<td>20–29</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>1.0 (1)</td>
<td>1.4 (1)</td>
<td>1.5 (2)</td>
<td>3.2 (2)</td>
<td>0.0 (0)</td>
<td>4.2 (1)</td>
<td>0.6 (7)</td>
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<tr>
<td>30–39</td>
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<td>2.5 (2)</td>
<td>0.0 (0)</td>
<td>2.2 (1)</td>
<td>2.5 (2)</td>
<td>2.5 (1)</td>
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<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>5.6 (2)</td>
<td>9.5 (2)</td>
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<td>10.0 (1)</td>
<td>2.3 (8)</td>
<td></td>
</tr>
<tr>
<td>50–59</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>4.4 (1)</td>
<td>11.1 (2)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>10.0 (3)</td>
<td>27.3 (3)</td>
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</tr>
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<td>≥60</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>11.1 (1)</td>
<td>5.9 (1)</td>
<td>3.7 (1)</td>
<td>5.0 (1)</td>
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<tr>
<td>All ages</td>
<td>0.0 (0)</td>
<td>0.5 (2)</td>
<td>1.0 (3)</td>
<td>2.3 (6)</td>
<td>2.0 (10)</td>
<td>2.6 (7)</td>
<td>3.0 (10)</td>
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<tr>
<td>Age-adjusted</td>
<td>0.0</td>
<td>0.4</td>
<td>1.2</td>
<td>2.3</td>
<td>2.0</td>
<td>2.7</td>
<td>3.1</td>
<td>8.3</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

Analysis for linear trend in proportions using unadjusted data: *P*, 0.0001 for each sex.

Table 3  Hyperpigmentation prevalence per 100 by age groups and arsenic exposure level (µg/l) among females with number of cases in parentheses

<table>
<thead>
<tr>
<th>Age group</th>
<th>Arsenic level (µg/l)</th>
<th>&lt;50</th>
<th>50–99</th>
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<th>200–349</th>
<th>350–499</th>
<th>500–799</th>
<th>≥800</th>
<th>Total</th>
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<tbody>
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<td><strong>Females</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤9</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>1.9 (1)</td>
<td>0.0 (0)</td>
<td>2.4 (2)</td>
<td>12.0 (6)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>1.7 (9)</td>
<td></td>
</tr>
<tr>
<td>10–19</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>1.7 (1)</td>
<td>5.6 (3)</td>
<td>7.7 (9)</td>
<td>1.8 (1)</td>
<td>3.1 (2)</td>
<td>11.5 (3)</td>
<td>2.2 (19)</td>
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<tr>
<td>20–29</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>1.0 (1)</td>
<td>4.0 (3)</td>
<td>4.4 (6)</td>
<td>11.1 (7)</td>
<td>6.0 (5)</td>
<td>8.3 (2)</td>
<td>2.1 (24)</td>
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<tr>
<td>30–39</td>
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<td>1.3 (1)</td>
<td>12.5 (6)</td>
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<td>8.9 (7)</td>
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<tr>
<td>40–49</td>
<td>0.0 (0)</td>
<td>4.7 (2)</td>
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<td>5.7 (3)</td>
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<tr>
<td>50–59</td>
<td>0.8 (1)</td>
<td>6.9 (2)</td>
<td>5.9 (1)</td>
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<td>8.6 (3)</td>
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<td>5.0 (1)</td>
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<td>3.7 (1)</td>
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<tr>
<td>All ages</td>
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<td>1.5 (4)</td>
<td>4.7 (11)</td>
<td>5.0 (22)</td>
<td>8.9 (22)</td>
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<tr>
<td>Age-adjusted</td>
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<td>9.0</td>
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</table>

Analysis for linear trend in proportions using unadjusted data: *P* < 0.0001 for both sexes.
(<3.2 µg/kg/day) to 3.5 per 100 in the highest tertile (>14.9 µg/kg/day) (Table 4). Using the unadjusted data, the one-tailed P-value test for trend for females was 0.03. A steeper pattern was apparent with males (P < 0.001, Table 4). In the lowest tertile, the age-adjusted prevalence of keratosis was 0.8 per 100 among males; in the highest tertile, the prevalence reached 11.0 per 100. The findings for hyperpigmentation paralleled those for keratosis (Table 4), with males again showing higher prevalence based on estimation of dose per body weight.

**Findings among those with low body weights**

Of the 2320 females with known body weights, 690 (30%) were below the standard weight by >20%. Of the 2123 males with known values, 808 (38%) were below the standard weight by >20%.

Compared to those with adequate nutrition, subjects >20% below the standard weight had a higher age-adjusted prevalence of keratosis (Table 5). The overall SMR for keratosis was 2.1 for females (95% CI: 0.8–4.6, P = 0.07) indicating that the age-adjusted keratosis prevalence among females with potentially poor nutrition was approximately twice that of females considered to have adequate nutrition. The overall SMR for males was 1.5 (95% CI: 0.9–2.4, P = 0.08). The combined SMR for both sexes was 1.6 (95% CI: 1.0–2.4, P = 0.02).

Weaker associations were found for hyperpigmentation. The overall SMR for females was 1.8 (95% CI: 0.8–3.5, P = 0.09) (Table 5). Thus, women with poor nutritional status had an age-adjusted hyperpigmentation prevalence nearly twice that of females considered to have adequate nutrition. This increase was less apparent in males, where the increase in the age-adjusted prevalence was only 10% greater among those with poor nutrition (SMR = 1.1, 95% CI: 0.7–1.7, P = 0.39). Combining men and women, the overall SMR was 1.2 (95% CI: 0.8–1.8, P = 0.17).

**Discussion**

This is the first population study assessing water levels of arsenic and skin lesions in India in a structured population survey. Clear exposure-response relationships were found between water-arsenic levels and the prevalence of skin effects. The steepest exposure-response relationships were found for males (Figure 1, Tables 2 and 3). This finding is not explained by the fact that males have a greater water consumption because this pattern was also apparent when the prevalence of skin lesions was analysed by tertiles of daily dose per body weight, using identical groupings for each sex (Table 4).

The most striking finding was identifying cases with skin lesions who apparently had low levels of arsenic in their drinking water. It is possible that these individuals were exposed to high levels of arsenic from drinking water sources other than the one measured in the survey; e.g. from their worksite or past residences. We are currently planning a further investigation focusing on participants in this study with low levels of arsenic in their drinking water.

Previous studies conducted in West Bengal have reported numerous cases of skin lesions. Chakraborty and Saha conducted a cross-sectional study of five affected regions in West Bengal.
Bengal. Their study revealed that high amounts of arsenic in the tubewell water were associated with keratoses and hyperpigmentation, the most common health effects in their study population. Of 784 exposed individuals, 197 (25%) were found to have keratosis or hyperpigmentation. The mean drinking-water arsenic concentration among those with skin lesions was 640 µg/l (range 200–2000 µg/l). Among those without any skin lesions, the mean arsenic concentration was 210 µg/l (range 0–740 µg/l).

Studies conducted in other countries have also investigated the prevalence of hyperpigmentation and keratosis in regions with elevated arsenic levels in drinking water; however, the studies either lacked individual exposure data or had small numbers. For instance, arsenic levels in Taiwan were reported by village.10,11,18 Mean arsenic levels were reported for an entire affected village in Mexico19 and China,20 and by towns in Chile.12 Thus, a major strength of this study is that it is the first large population-based study with individual exposure data, which can provide critical information with which to characterize the exposure-response relationship.

The overall SMR for keratosis suggested that those with poor nutritional status had an age-adjusted prevalence that was 1.6 times higher than those with better nutritional status. The prevalence of hyperpigmentation was also higher among those with poor nutritional status, with an age-adjusted prevalence of 2.9 times higher than those with better nutritional status. The prevalence of both keratosis and hyperpigmentation increased with increasing age groups, and the prevalence was higher among females than males. The prevalence of keratosis and hyperpigmentation was also higher among those with exposure to high levels of arsenic, with standardized morbidity ratios (SMR) ranging from 1.5 to 2.2 for keratosis and from 1.6 to 1.8 for hyperpigmentation.
times greater than those considered to be adequately nourished (SMR = 1.6, 95% CI: 1.0–2.4, P = 0.02). The overall SMR for hyperpigmentation for both sexes combined was 1.2 (95% CI: 0.8–1.8, P = 0.17). These small differences do not suggest that malnutrition is the reason for the high prevalence of skin lesions in West Bengal. Nevertheless, it is still possible that some dietary factors affect the susceptibility of the whole population, malnourished or not.

Limitations of this cross-sectional study involve the methods that were used for the sampling strategy and estimation of the doses. Because the survey involved remote rural areas, a perfectly random sample could not be obtained. However, no reason exists to believe that the convenience sampling strategy used would have resulted in a non-representative study population. The dose calculations relied upon estimates of daily water consumption. Although this measure is prone to error because of inaccurate recall of water intake, the main determinant of the exposure is the arsenic concentration in water. Therefore, it is unlikely that gross discrepancies in reported water consumption exist which could have led to a major misclassification of dose. Nevertheless, more detailed exposure assessment and measurement of all past and present water arsenic levels may show that those thought to be consuming low arsenic water may actually have been more heavily exposed from other sources.

In conclusion, this study demonstrates clear exposure-response relationships between the prevalence of skin lesions and both arsenic water levels and dose per body weight, with males showing greater prevalence of both keratosis and hyperpigmentation. Based on limited exposure assessment, some cases appear to be occurring at surprisingly low levels of exposure. There is evidence that the risks were somewhat greater for those who might be malnourished. Further studies are needed to confirm the apparent low exposure effects, to determine why males have more skin effects than females at the same doses per body weight, and to identify susceptibility factors which may be present in this population.

Acknowledgements

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