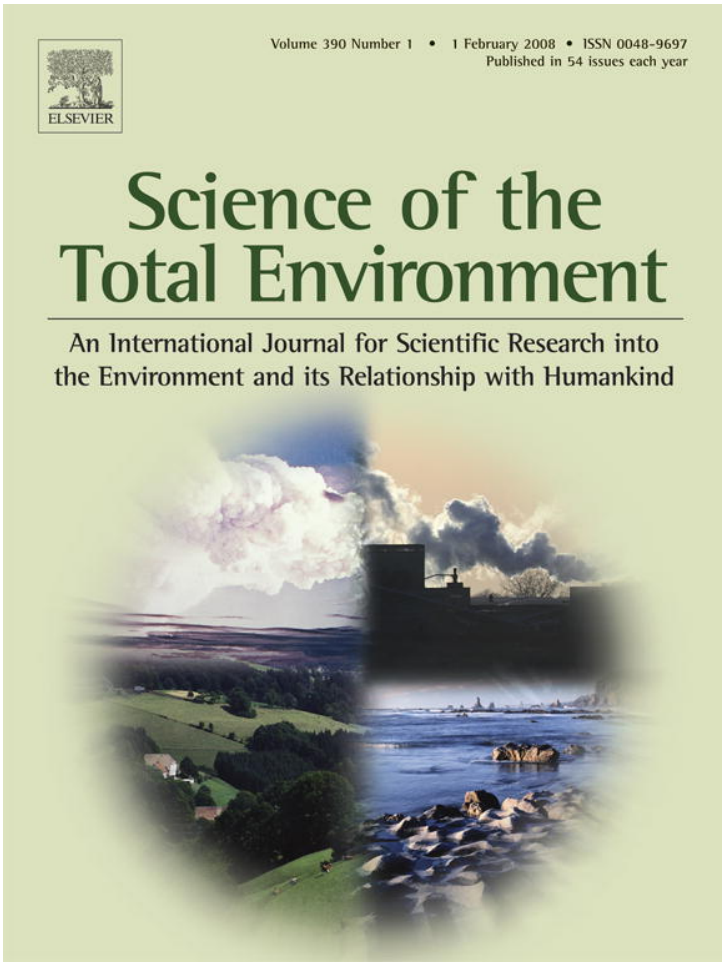

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Prevalence of skin lesions and exposure to arsenic in drinking water in Iran

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ABSTRACT

Prevalence of skin lesions was investigated among 752 participants in eight villages in Kurdistan province in Iran with emphasis on total lifetime intake of arsenic from drinking water (TLIA). The participants were selected from eight villages with different exposure levels using a cluster-sampling technique. TLIA was calculated for each individual taking into account the type of water supply and their mean annual arsenic concentration. The study showed that 49 persons (6.5%) were suffering from hyperkeratosis and 20 persons (2.7%) from hyperpigmentation. The correlation between hyperkeratosis and hyperpigmentation was significant ($R=0.325$, $p<0.01$). Using the logistic regression model it was found that the relationship between TLIA and hyperkeratosis (OR=1.14, 95% CI=1.039–1.249), and hyperpigmentation (OR=1.254, 95% CI=1.112–1.416) was also significant. In conclusion, TLIA can be applied as a reliable indicator for the assessment of exposure.

1. Introduction

Arsenic is widely found in the earth's crust and is the 20th most abundant natural element (Duker et al., 2005). The major cause of human arsenic toxicity is contamination of drinking water from natural geological sources (Ratnaike, 2003). Chronic arsenic poisoning has been reported to be manifest among individuals living in areas where high arsenic concentrations in the drinking water is endemic (Berg et al., 2001; Hopenhayn-Rich et al., 2000; Pi et al., 2000; Smith et al., 2000a). Skin lesions including pigmentation changes, mainly on the trunk and extremities, and keratosis of the palm of the hands and soles of the feet (palmar and plantar hyperkeratosis) are the result of chronic ingestion of inorganic arsenic and provide the hallmark signs of this condition (Duker et al., 2005; Kitchin, 2001; Mazumder et al., 1998; Milton and Rahman, 1999; Tondel et al., 1999). They are the most common and distinctive health effects found in populations exposed to arsenic-contaminated drinking water in Taiwan, Chile and Argentina (Mazumder et al., 1998). Change in pigmentation (i.e. melanosis) and keratosis of the hands and feet usually appear after 5–15 years of exposure (Tseng, 1977) and more recently have been seen to occur within a period of about 5 years (Kitchin, 2001). It appears that skin cancer lesions related to arsenic exposure act as early warning signals of the subsequent development of cancers of the internal organs many years later (Bates et al., 1992; Cowlishaw et al., 1979; Roat et al., 1982; Tello, 1988; Tsuda et al., 1995; Upshaw et al., 1979). With newly affected sites discovered during the last decade, a significant change has been observed in the global scenario of arsenic contamination, especially in Asian countries (Mukherjee et al., 2006). In Iran, the first case of chronic

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arsenic poisoning was recognized in Kurdistan province in 1986. This particular case was of a woman with intense skin lesions who lived in a village in Bijar County and had lost her legs as a result of gangrene due to the consumption of water containing high levels of arsenic. Some limited monitoring of drinking water resources had shown a high concentration of arsenic >1 mg/L in some villages in this county (Mosaferi et al., 2003). Unfortunately exposure of people to arsenic through contaminated drinking water in some villages of this county continued up to 2000 when a stationary safe water supply program was initiated. Other areas in Iran where there is arsenic contamination continue to be discovered. The present epidemiological study is the first study of arsenic exposure, in which we studied the prevalence of skin lesions (keratosis and pigmentation) among the population resident in villages where there had been a contaminated water supply, 5 years after corrective measures had been taken. The research objectives were as follows:

- Determination of the extent of skin lesion (i.e. keratosis, pigmentation) prevalence in the exposed and unexposed populations
- Determination of the correlation between skin lesions and TLIA in Bijar villages which represent a new area in the world where exposure to arsenic contamination has been recognized.

2. Materials and methods

2.1. *Study area and sampling methods*

Kurdistan province is located in the West of Iran, bordering Iraq between 34° 44′ to 36° 30′ North, and, 45° 31′ to 48° 16′ East (Fig. 1). This province is one of the most mountainous provinces of Iran and has a generally cold climate. Kurdistan province represents about 1.7% of the area of the entire country and has more than 1,450,000 inhabitants. In the Northeast of the province, there are some villages in Bijar County (a 580-km^2 area with an average altitude of about 1750 m above sea level) where drinking water has been contaminated with naturally-occurring arsenic. In addition to Bijar, the region of Ghorveh has also faced a similar problem. The present study was carried out in the Bijar region. Our definition of exposure is: "consumption of drinking water with an arsenic concentration above 0.05 mg/L (Maximum Contaminant Level (MCL) of the National Iranian Drinking Water Standard). As it was thought that cumulative exposure may have some health impacts, total lifetime intake of arsenic (TLIA) from drinking water was calculated for each individual taking into account the type of water supply and its mean annual arsenic concentration using the following formula:

$$\mathrm{TLIA} = \sum d_i \times \mathrm{AIA}_i$$

$$\mathrm{AIA}_i = C_i \times 1g/1000\,\mathrm{mg} \times \mathrm{LPCD} \times 365\,\mathrm{days/year}$$

Where:

TLIA is the total lifetime intake of arsenic from drinking water (g),
d_i is the duration of the ith water source used by each individual (year),
AIA_i is the annual intake of arsenic through consumed water in the form of water or tea (g/year),
C_i is the mean annual concentration of arsenic in the drinking water (mg/L)

Fig. 1 – Location of studied area on map of Iran.

LPCD (liter per capita per day) is the volume of drinking water used by each individual in the form of water or tea (L/day).

For example in the case of an individual who has lived for 20 years in a village that has a spring with a mean annual arsenic concentration of 0.1 mg/L as the only source of drinking water, the TLIA is calculated as follows:

$$\text{AIA} = 0.1\,(\text{mg/L}) \times 1/1000 \times 2 \times 365 = 0.073\,\text{g/year} \Rightarrow \text{TLIA} = 20 \times 0.073 \Rightarrow \text{TLIA} = 1.46\,\text{g}$$

During the interview, residence time in the village was established for each participant and if a participant had spent any time in another place with a known concentration of arsenic in the drinking water, the AIA was calculated separately for each place and the results were then added together. In the case of individuals who had used multiple sources of drinking water, the distribution of the intake levels was determined using information obtained from each individual regarding the water sources they had used (which, how much and how long). Taking into account the type of water supply and its mean annual concentration of arsenic, the intake from each source and the TLIA were then calculated.

Fortunately during the study none of the springs had dried up and in only one case (Gheshlaghloo village) had the water source been changed, leaving the old spring available but not in use, when we measured its arsenic concentration. We established historical levels of exposure by comparing current arsenic levels of water sources with some available measurements from the past. Our comparison showed that current levels of arsenic in water sources were similar to those of previous years. We thus concluded that current levels of exposure could be extrapolated to previous exposure in the region under study.

According to our definition, inclusion criteria were residence in the study region for at least 10 years and age≥10 years. The sample size was 752 individuals divided almost equally into males (44%) and females (56%). This sample was collected randomly from eight villages classified into different levels of exposure (without exposure; arsenic concentration: <0.05 mg/L, low-exposure level; arsenic concentration: 0.05–0.15 mg/L, medium-exposure level; arsenic concentration: 0.15–0.3 mg/L, high exposure level; and arsenic concentration: ≥0.3 mg/L). In those villages where the total eligible population exceeded the designated sample size, a cluster-sampling method was used for the selection of individuals. Each cluster consisted of five consecutive neighboring inhabitants. The initial starting point was determined randomly and the others were defined on a systematic basis.

2.2. *Interview and physical examination*

All interviews and physical examinations were carried out at the participants' homes during the fall of 2003. Fortunately all of the residents in the villages agreed to cooperate with the research team and there were no refusals. The following data were gathered for each person: general information including full name, age, sex, weight, height, details of length of residence in the village, smoking history; and health-related information including the presence of hyperkeratosis and hyperpigmentation. In order to provide a more accurate diagnosis for the skin lesions, the physicians on the research team referred to the guidelines published by the United Nations (Mazumder, 2000) and pictures available on web sources before the start of the study. During the physical examination and after measurement of height and weight, each participant was interviewed by a physician for the presence of skin lesions, discomfort and other diseases if any, followed by auscultation and observation of the degree of skin hyperpigmentation, hyperkeratosis and the severity of each lesion covering the body surface. In some cases a second physician also examined the subject in order to confirm the observations recorded during the first skin examination. Biomarker samples including at least 1 g of scalp hair from distal parts in female participants were collected and analyzed using the Neutron Activation Analysis method following vigorous irradiation (the results of this analysis are presented in Mosaferi et al. (2005)).

2.3. *Water sampling and arsenic measurement*

In order to determine villages with polluted water supplies, field monitoring and analysis of drinking water sources (spring, well, or tap) in about 44 villages in a area which was well-known to has polluted drinking water was carried out in

Table 1 – Analysis of drinking water sources of villages studied

	pH	EC (μs/cm)	TDS (mg/L)	Hardness (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	Total cations (meq/L)	Total anions (meq/L)	Arsenic concentration, annual mean (SD) (mg/l)
Gheshlaghloo	7.9	232	190	151	122	3.7	3.57	0.01 (0.006) [a]
Golghabagh	7.3	452	310	194	138	4.17	4.05	0
Najaf Abad	6.9	627	330	213	190	4.11	4.44	0
Ebrahim Abad	7.5	760	550	286	336	7.8	7.47	0.135 (0.033)
Gheshlagh Noruz	7.5	1343	800	394	258	10.38	9.75	0.105 (0.030)
Babanazar	7.3	665	465	155	152	4.35	4.25	0.202 (0.025)
Bashooki	7.3	736	535	231	154	5.7	5.86	0.192 (0.017)
Gavandak	7.4	1046	820	298	260	8.5	8.4	0.460 (0.02)
Total mean (SD)	7.37 (0.27)	743 (319)	510 (221)	236 (77)	190 (53)	6.09 (2.5)	5.97 (2.3)	0.138 (0.154)

[a] The most recent arsenic concentration.

the summer of 2003 by means of on-site analysis using the Ez arsenic test kit. This kit is manufactured by the Hatch Company and has been widely used for monitoring arsenic levels in wells in Bangladesh (van Geen et al., 2005). According to the manufacturer, this kit is able to measure the total concentration of arsenic within two different ranges using different sample volumes. With a sample volume of 50 ml, the detection range is 0.01 to 0.5 mg/L and with a sample volume of 9.6 ml, the detection range is 0.035 to 4 mg/L. Sulfamic acid and zinc are used as reactants in addition to a paper strip containing $HgBr_2$. One of the advantages of this kit is that it uses lead acetate 10% which eliminates any interference caused by the production of H_2S. The reaction is complete after 20 min and the color change of the paper strip is compared with the indicator color to determine the arsenic concentration. Before starting field monitoring, the reliability of this kit was tested to ensure its appropriateness (the results of this study are presented in Mesdaghinia et al. (2005)). The results showed that this kit could reliably determine the presence of arsenic in water at concentrations above 0.01 mg/L. After field monitoring and determination of the arsenic concentration of the water supplies had been carried out, the five villages of Ebrahim Abad, Babanazar, Bashooki, Gavandak and Gheshlagh Noruz were selected as the exposed area and the three villages of Najaf Abad, Golghabagh and Gheshlaghloo were selected to represent the unexposed area. To establish the drinking water concentrations of arsenic at the selected villages, sampling of each water source to determine a mean annual concentration of arsenic was continued until the summer of 2004. For this purpose, we analyzed water sources that had been used for drinking both in the past and present. These water sources were then monitored for 1 year and a single sample was collected and analyzed each season (four samples during one year). Finally, we established the mean annual arsenic concentration of each water source by calculation of the mean concentration. During the sampling period, water samples were collected in acid-washed PET bottles which for the analysis of arsenic, were acidified with HCl to pH<2 in order to prevent losses due to adsorption during analysis using the Silver Diethyldithiocarbamate (SDDC) method (Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998). Although the acid used depends upon the subsequent analytical procedure, hydrochloric acid is the choice for sample preservation prior to analysis using the HGAAS, HGAFS, and SDDC methods. The SDDC colorimetric method is fairly reliable and for waters containing in excess of about 0.01 mg/L represents a cheap and fairly rapid method (Rasmussen et al., 2003). During the analysis, the precision and accuracy of the SDDC method was studied using both synthetic and actual water samples according to Standard Methods. For the analysis of heavy metals using atomic absorption spectrometry another sample of water from each village was acidified with nitric acid. In addition one sample from each water source was refrigerated at 4 °C and analyzed for common parameters, e.g. cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), anions (HCO_3^-, SO_4^{2-}, Cl^-), total dissolved solids (TDS), Electric Conductivity (EC), hardness, alkalinity and pH. Information regarding the type of water source, consumption history and changes over time was collected using a structured questionnaire.

Table 2 – Prevalence of skin lesions among people with different intakes of arsenic via drinking water

Village	Sex		Total	Age (year)			Length of residence in village (years)			Height (cm)			Weight (kg)			History of smoking (years)			TLIA (g)		Pigmentation	Keratosis
	Female	Male		Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Mean (SD)	Max	No (%)	No (%)
Gheshlaghloo	53	48	101	10	82	30 (16)	1	65	23 (13)	131	179	158 (10)	24	93	58 (14)	0	40	6.1 (10.5)	2.52 (1.37)	7.64	9 (8.9)	29 (28.7)
Golghabagh	27	31	58	10	70	28 (14)	3	70	25 (15)	126	176	155 (12)	26	87	56 (14)	0	70	4.3 (13)	0 (0)	0	0 (0)	0 (0)
Najaf Abad	65	50	115	10	74	32 (16)	2	74	28 (17)	132	187	159 (9)	29	122	63 (15)	0	40	1.1 (5.3)	0 (0)	0	0 (0)	3 (2.6)
Ebrahim Abad	24	18	42	11	65	28 (14)	2	65	19 (12)	121	180	156 (12)	24	81	56 (14)	0	20	1.2 (3.9)	1.73 (1.34)	12.97	3 (7.1)	8 (19)
Gheshlagh Noruz	53	33	86	11	72	27 (17)	2	72	26 (17)	123	180	148 (10)	22	88	50 (15)	0	20	0.7 (3.3)	0.35 (0.25)	0.62	0 (0)	1 (1.1)
Babanazar	69	51	120	10	80	30 (18)	2	80	25 (16)	129	183	157 (11)	25	94	53 (14)	0	60	2.5 (8.5)	1.83 (0.81)	6.74	0 (0)	1 (0.8)
Bashooki	49	49	98	11	70	29 (16)	1	60	23 (13)	98	185	157 (10)	28	105	57 (15)	0	25	3.8 (7)	3.63 (6.23)	13.36	4 (4.1)	5 (5.1)
Gavandak	80	52	132	10	93	31 (20)	2	93	27 (20)	126	188	157 (14)	21	140	55 (19)	0	80	7.3 (14.5)	5.25 (2.69)	12.97	4 (3)	2 (1.5)
Total	420 (55.9%)	332 (44.1%)	752																		20 (2.7)[a]	49 (6.5)[b]

[a] Female 11 (2.6), Male 9 (2.7), Pearson Chi-Square = 0.006, $df = 1$, P value = 0.938.

[b] Female 26 (6.2), Male 23 (6.9), Pearson Chi-Square = 0.165, $df = 1$, P value = 0.685.

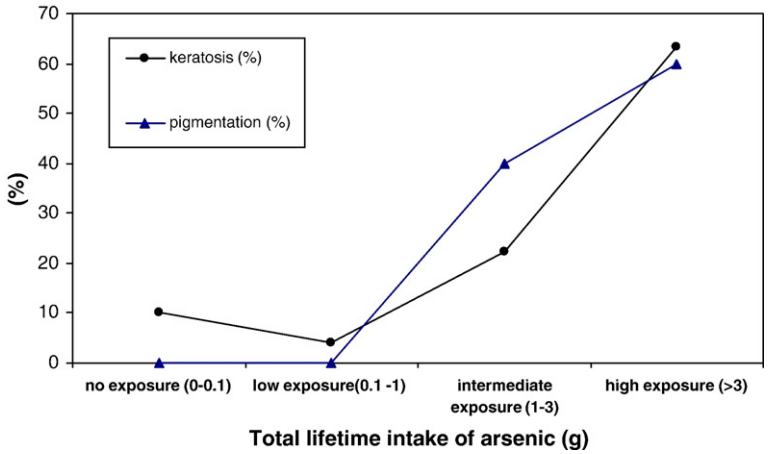

Fig. 2 – Observed frequency of hyperkeratosis and hyperpigmentation versus total lifetime intake of arsenic.

2.4. *Statistical analysis*

Descriptive statistics, the Chi-square test and the logistic regression model were used for comparison of the frequency of skin lesions between the different groups with regard to exposure to arsenic and TLIA. To increase the robustness of the study with regard to establishing a correlation between exposure to arsenic and skin lesions, and taking into account the national MCL for arsenic in drinking water, the authors decided to categorize the TLIAs by number of individuals in a group. To this end, results from the same number of individuals in each group of participants from the different study areas were used for statistical tests. So we defined a TLIA of 0–0.1 g as no exposure, 0.1–1 g as low-exposure, 1–3 g as intermediate exposure and a TLIA>3 g as high exposure.

In the statistical analysis we have assumed that the correlation between the TLIA and skin lesions is linear and have applied this assumption in the final logistic model. The OR was calculated for an intake of 1 g of arsenic and on this basis the groups were compared with one another. However, in order to obtain a better sense of the data in the primary analysis (univariate), categorical analysis was also carried out.

3. Results

Table 1 shows the characteristics of the drinking water consumed in the villages studied. The characteristics were different and considering hardness, the water sources were classified into hard or very hard water (total hardness>150 mg/L as $CaCO_3$). The highest levels of hardness and TDS were observed in Gheshlagh Noruz, while in Gheshlaghloo the levels were the lowest. In the case of metals except arsenic, concentrations of heavy metals were lower than the WHO guideline levels. The most recent level of arsenic was highest in Gavandak. Concentrations of arsenic in the drinking water were relatively stable throughout the year in all the villages, however, there appeared to be a slight increase in levels during the winter months when the ground was covered with snow which facilitated the percolation of water into the soil. However in Gheshlagh Noruz this trend was reversed. There were significant correlations between arsenic levels and EC, TDS, hardness, alkalinity, chloride, sulphate, bicarbonate, calcium and sodium of analyzed waters ($p<0.001$). The highest correlation was observed between arsenic and TDS ($R=0.764$).

The basic characteristics of the study subjects, TLIA and frequency of skin lesions in the villages are presented in Table 2. The average age, length of residence, height, weight and smoking history of the subjects were respectively, 30.3 years (SD=17.1), 25.2 years (SD=16.5), 156.6 cm (SD=12), 56.4 kg (SD=16) and 2.73 years (SD=8.6). Although the minimum length of residence in the villages studied was <10 years, all the study subjects were chosen from those individuals who had been resident in the study area for at least 10 years and therefore cumulative doses of arsenic were calculated for all participants. There was no significant difference between mean age and duration of residence in the villages ($p>0.05$). However in the case of mean height, weight and smoking history, differences were significant ($p<0.001$). This study showed that 49 (6.5%) and 20 individuals (2.7%) suffered from hyperkeratosis (female 26 (6.2%), male 23 (6.9%), Pearson Chi-Square=0.165, $df=1$, P value=0.685) and hyperpigmentation (female 11 (2.6%), male 9 (2.7%), Pearson Chi-Square=0.006, $df=1$, P value=0.938), respectively. There was no significant difference between males and females and prevalence of skin lesions by sex and BMI and the odds ratios comparing different levels of exposure were not significant. Cases of palmar, plantar or both types of keratosis were observed with a frequency of 0.7, 0.9 and 4.9%,

Table 3 – Logistic regression analysis between hyperkeratosis, hyperpigmentation, intake of arsenic and age

	Variable	OR [a] (e^{β})	95% C.I. for e^{β}
Hyperkeratosis	TLIA (g)	1.14	1.039–1.249
	Age (year)	1.024	1.009–1.04
Hyperpigmentation	TLIA (g)	1.254	1.112–1.416
	Age (year)	1.029	1.006–1.052

For hyperkeratosis adjusted for age, EC, TDS, hardness, alkalinity, Cl^-, HCO_3^-, Na^+, $Al^{3+}$and Fe^{3+}.
[a] For hyperpigmentation adjusted for age and EC.

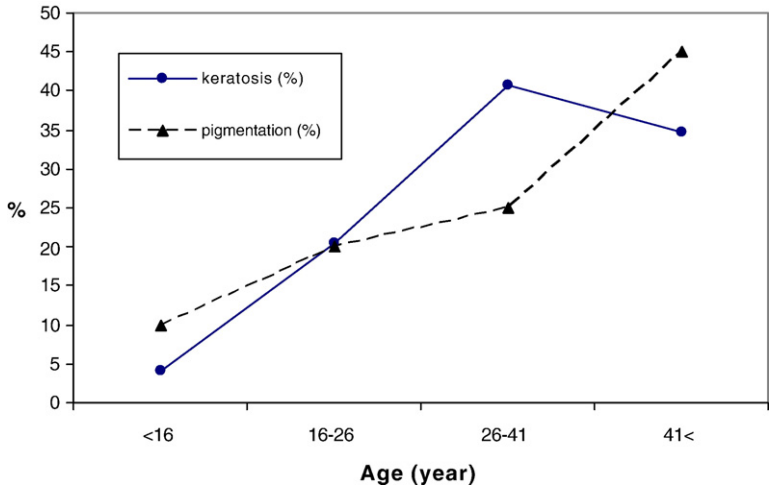

Fig. 3 – Observed frequency of hyperkeratosis and hyperpigmentation versus age.

respectively. The severity of keratosis was mild (4.1%), moderate (2.1%) and severe (0.3%). Hyperpigmentation was observed on the limbs, trunk or both with a frequency of 1, 0.4 and 1.3%, respectively. The severity of hyperpigmentation was mild (2%), moderate (0.4%) and severe (0.3%). In some cases, both types of lesion, keratosis and hyperpigmentation, had persisted for up to 30 years. Skin lesions were most frequently observed in Gheshlaghloo village. In this village exposure to a very high level of arsenic (>1.5 mg/L) had occurred continuously for 3 years in the past (16 years previously). Frequency of hyperpigmentation based on the amount of arsenic ingested during a lifetime is shown in Fig. 2. As can be seen, there were no cases of hyperpigmentation in the non-exposed group (TLIA<0.1 g) or the low-exposure group (TLIA=0.1–1 g), while in the other groups with medium exposure (TLIA=1–3 g) and high exposure (TLIA>3 g), the prevalence of hyperpigmentation was 3.5 and 6%, respectively ($p<0.001$).

The frequency of hyperkeratosis in both the low-exposure and non-exposed groups was negligible. On the other hand, hyperkeratosis in the medium-exposure (TLIA=1–3 g) and high exposure (TLIA>3 g) groups showed a prevalence of 4.9 and 15.4%, respectively ($p<0.001$).

The correlation between hyperkeratosis and hyperpigmentation was significant ($R=0.325$, $p<0.01$). There was also a significant correlation between the TLIAs from drinking water and the occurrence of hyperkeratosis (OR=1.14, 95% CI=1.039–1.249), or hyperpigmentation (OR=1.254, 95% CI=1.112–1.416) using the logistic regression model (Table 3).

As shown in Fig. 3, the prevalence of skin lesions was not limited to a particular age group but the frequency of skin lesions increased with age. The highest prevalence of keratosis was seen in the age group from 26 to 41 years, while the same figure for pigmentation was observed in the age group≥41 years.

4. Discussion

According to the literature, the prevalence of skin lesions among individuals exposed to arsenic in the drinking water is a well-known outcome of chronic arsenic poisoning. The present research aimed to investigate the prevalence of skin lesions (hyperkeratosis and hyperpigmentation) among the residents of eight polluted and non-polluted villages and the correlation with TLIA. According to our findings, 5 years after exposure to arsenic in drinking water had ceased the skin lesions on the palm of the hands and soles of the feet of exposed individuals had not healed naturally and had persisted. This fact suggests that the treatment and recovery of individuals affected by arsenic poisoning is a long-term process.

In the water samples analyzed the arsenic content was almost proportional to the concentration of dissolved solids due to further possible dissolution from the earth's crust. The fluctuation of arsenic levels during the different seasons may be due to the varying degree of infiltration and also to the increasing levels of the water table in shallow aquifers as a result of melting snow. When the arsenic-bearing layer is near to the earth's surface, any water percolation will wash increasing concentrations of arsenic into the shallow groundwater. However, when the arsenic-bearing layers are located at a deeper level in the earth's crust, the effect of increased water percolation is a dilution of the arsenic concentration in the aquifer. In the other hand percolated water dose not passes directly through arsenic-bearing layer.

An interesting finding of our research is the role that the TLIA plays in assessing the relationship between arsenic and skin lesions using a comparison of arsenic concentrations measured over the duration of the study. For instance in Gheshlaghloo, despite the mean annual concentration of arsenic in drinking water being near to the guideline level set by the WHO and less than the Iranian national MCL (0.05 mg/L), the prevalence of keratosis and hyperpigmentation was still highest in this village. The reason for this becomes apparent when the TLIAs of this village are compared to those of other villages (e.g. Golghabagh and Najaf Abad). So it can be concluded that when the sources of drinking water have been changed over time, the present level of arsenic in drinking water may not be a reliable indicator of exposure, especially in cross-sectional studies. For a more accurate estimation of exposure, it is necessary to investigate the

history of water sources with regard to arsenic concentration over the whole period of exposure. Another interesting fact is the role of the exposure period in the prevalence of skin lesions. The case of Gheshlaghloo showed that ingestion of a high concentration of arsenic for a short period results in a greater increase in the prevalence of skin lesions compared to ingestion of a lower concentration of arsenic for a longer period of time with similar cumulative dose. However, it may not be feasible to extrapolate the above observation to mortality due to cancer caused by arsenic in drinking water as the intake of arsenic for a longer period and its cumulative effect may be more important. For instance, evidence from limited information gathered during the study in Bashooki where the highest TLIAs were found and also anecdotal evidence, support the hypothesis that exposure to arsenic in the drinking water for long periods increases mortality from cancer. In this village, the rate of mortality due to internal cancer, e.g. bladder, was high compared to that in other villages e.g. Gheshlaghloo. A similar situation was observed at Ebrahim Abad but not in Gavandak however. This may be due to the better economic conditions and diet of Gavandak residents compared to the other villages. For the observed prevalence of skin lesions in the present study the overall prevalence of skin lesions compared to similar studies was low, 6.5 and 2.7% for keratosis and pigmentation, respectively. In the study of Tseng et al. (1968), the overall prevalence of keratosis and pigmentation was 7.1 and 18.3%, respectively. In the West Bengal study prevalence of keratosis was strongly related to water arsenic levels, 8.3% among females in areas where the drinking water contained >0.8 mg/L, and 10.7% among males at the highest exposure level (Mazumder et al., 1998). In another study in Bangladesh, out of 1481 exposed subjects, 29% had at least one sign of skin lesion with a higher prevalence in men compared to women. Arsenic levels in drinking water ranged from non-detectable to 2.04 mg/L (Rahman and Axelson, 2001). In the study of Smith et al. (2000b) in Chiu Chiu in Chile where the inorganic arsenic level of water was reported to be between 0.75 and 0.8 mg/L, 36% of the population sampled suffered from pigmentation changes. In a more recent study in 53 widely-dispersed villages in Bangladesh, 16740 women aged 18 years or over more examined for skin lesions. Overall, the observed prevalence was 176 cases (1.3%) among the 13705 women examined, varying from 0% in 26 villages to 23% in one village; lesions were observed more frequently on the hands than on feet. The estimate doubled with concentrations of arsenic from 0.011 to ≤0.05 mg/L and increased more than 20 times at arsenic concentrations of >0.05 mg/L (McDonald et al., 2006). The differences between our findings and those of similar studies can be attributed to different levels of exposure to arsenic, immigration of individuals from villages with polluted water supplies to safe areas, mortality from cancers related to arsenic during the last 5 years, and relative remediation of moderate skin lesions. If the present study had been carried out during the exposure period, the results might have been different from those presented here. However, considering villages individually, in some villages (i.e. Gheshlaghloo and Ebrahim Abad) the prevalence of skin lesions was comparable to that reported in the above-mentioned studies.

The prevalence of skin lesions varied among villages and families. This might also be due to genetic and nutritional differences in the study area. This possibility has been reported in previous studies (Abernathy and Morgan, 2001; Smith and Smith, 2004). In conclusion, our study found a clear exposure–response relationship between the prevalence of skin lesions and TLIA as a reliable indicator of exposure. In similar epidemiological studies where the sources of drinking water have been changed, TLIA may prove to be a better indicator of arsenic exposure than the current level of arsenic in drinking water.

In polluted areas of Kurdistan province, other outcomes of arsenic in drinking water (e.g. internal cancers) should be studied in addition to the prevalence of skin lesions. For countries similar to Iran, regular monitoring and surveillance of arsenic levels in drinking water sources particularly in high risk areas with natural arsenic contamination, is essential for the maintenance of public health considering the effect that exposure to arsenic in drinking water has on human health. Also a Geographic Information System (GIS) map of arsenic contamination needs to be established and implemented by government health departments to provide a better understanding of the situation so that preventive strategies for arsenic-related disorders can be established.

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