Table 2. Pearson's correlation between heavy metals in water samples

	Ni	Cu	Zn	Cd	Cr	Mn
Ni	1					
Cu	0.677	1				
Zn	0.885	0.726	1			
Cd	0.920	0.706	0.991	1		
Cr	0.901	0.456	0.844	0.898	1	
Mn	0.941	0.679	0.984	0.997	0.917	1

Correlation is significant at $P < 0.05$, $P < 0.01$.

Table 3. Concentration of heavy metals in *Anabas testudineus* collected near (within 20 m) the dump site and control site (mg/kg)

Anabus testudineus	Cd	Zn	Cu	Ni	Mn
Muscle (exp)	0.011 ± 0.001	2.441 ± 0.16	0.241 ± 1.04	BDL	1.120 ± 0.06
Muscle (control)	BDL	0.762 ± 0.32	0.019 ± 0.01	BDL	0.221 ± 0.19
Skin (exp)	0.043 ± 0.02	1.410 ± 1.02	0.160 ± 0.09	BDL	0.528 ± 0.22
Skin (control)	BDL	0.814 ± 0.414	0.011 ± 0.06	BDL	0.101 ± 0.07
FAO (2003)	0.05	40	10	10	50

Values represent mean of three replicates.

found to be within the MPL of FAO[9]. The concentrations of Mn (skin tissue), Cu (skin and muscle tissue) and Cd (skin and muscle tissue) was found to be higher than those in fish tissues from the control site. There are reports of accumulation of heavy metals in fishes inhabiting contaminated water[10]. As indicated by the results obtained in the present study, Zn and Mn also showed higher concentration in *A. testudineus* tissue, similar to the trend in surface water. Zinc toxicity is rare, but the concentration in water up to 40 mg/kg may induce toxicity, characterized by symptoms of irritability, muscular stiffness and pain, loss of appetite and nausea[11]. The heavy metal concentration in fish tissues was found to be higher compared to that in the habitat as recorded in other similar studies[12,13]. Heavy metals might accumulate up to toxic concentrations and cause ecological and health hazards. The present study indicates that *A. testudineus* collected near the dump site has accumulated heavy metals from the habitat. Bioaccumulation of heavy metals may lead to biomagnification through the food chain.

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Uranium anomalies in groundwater of Sangrur district of Punjab (India) for cancer risk assessment

THE permissible limit of uranium in drinking water is 30 $\mu g\ l^{-1}$ as recommended by the World Health Organization (WHO)[1]. The accumulation of uranium inside the human body targets the kidneys and lungs[2–4] due to chemical and radioactive effects. Drinking water is the major source of uranium to the human body and contributes about 85% of ingested uranium[5], food contributes the remaining 15%. An equivalent of 0.1 mg/kg of body weight of soluble natural uranium exposure results in some short-lived chemical damage to kidneys[6]. Uranium is a radioactive heavy metal; it

Table 1. Uranium content in groundwater of Sangrur district and corresponding risk factors

Location	Water source	TDS (ppm)	Uranium concentration (ppb)	Uranium concentration (Bq l^{-1})	Excess cancer risk 10^{-4}	LADD (μg kg^{-1} day^{-1})	Hazard quotient
Ghrachon	Motor pump (MP)	419	56.28	1.42	1.59	3.26	0.72
Nagra	MP	636	119.95	3.03	3.40	6.94	1.53
Nagri	MP	347	59.04	1.49	1.67	3.42	0.75
Maur 1	MP	592	43.46	1.10	1.23	2.51	0.56
Maur 2	MP	623	38.52	0.97	1.09	2.23	0.49
Fatehgarh	MP	435	66.98	1.69	1.90	3.88	0.86
Alipur	MP	285	33.53	0.85	0.95	1.94	0.43
Jhall	Hand pump (HP)	292	07.89	0.20	0.22	0.46	0.10
Chhokran 1	MP	309	60.97	1.54	1.73	3.53	0.78
Chhokran 2	MP	320	20.11	0.51	0.57	1.16	0.26
Chhokran 3	MP	200	44.44	1.12	1.26	2.57	0.57
Lassoi 1	HP	395	22.15	0.56	0.63	1.28	0.28
Lassoi 2	HP	290	66.94	1.69	1.90	3.87	0.85
Jorepul	HP	129	02.47	0.06	0.07	0.14	0.03

decays into many other radioactive metals or gases which can further become a health hazard[7]. Though uranium is a weak radioactive metal, if the uranium content of drinking water is high it may be hazardous to human health. The assessment of health hazards risk is important due to the high content of uranium in water and the extent to which it is ingested into the human body. Uranium estimation in water systems of the Punjab state and its neighboring areas was reported by some workers[8–14].

Sangrur district falls in the southern part of the Punjab state and is bounded by lat. 29°44′45″N and long. 75°14′45″E. Samples were collected at different locations in Sangrur, Bhawanigarh and Malerkotla blocks of the district. Before collecting the samples, the hand-pump or the motor pump was run for a few minutes and the samples were then collected in pre-processed bottles after rinsing twice with the water to be collected. Samples were filtered with 0.45 μ filter paper. The samples were analysed for U content within a week using calibrated LED flourimeter (Quantalase Enterprises, Indore)[15].

A water sample of quantity 6 ml was used to find its uranium content. The sample was taken in a clean and dry quartz cuvette made up of ultrapure fused silica. The instrument was calibrated with standard uranium solution of known activity. The water sample of quantity 6 ml was mixed with 10% of the buffer solution made from sodium pyrophosphate and orthophosphoric acid of pH 7. Buffer solution is used for the same fluorescence yield as for uranium complexes present in the water.

The concentration of the uranium in the water sample is calculated as follows:

Calibration factor CF = (Concentration of uranium in standard solution)/(Fluorescence of standard – fluorescence of water).

Concentration of uranium in water sample = CF × (fluorescence from water sample – fluorescence from distilled water).

These calculations were done by the instrument itself. The instrument averages the fluorescence for 256 pulses and displays the average value of U concentration in the sample.

The ingestion of uranium through drinking water results in both radiological risk (carcinogenic) and chemical risk (non-carcinogenic). The methodology used to assess radiological and chemical risks due to uranium concentration in the water samples is described elsewhere[16].

The Malwa belt of Punjab state, including Sangrur district, is known for high U content in groundwater and soil and prone to high cancer risk. Uranium content and TDS (total dissolved salts) values are listed in Table 1. Uranium content varies from 2.47 ppb (hand pump on Canal bank) to 119.95 ppb (motor-driven pump in Nagra village) in Sangrur district. Surprisingly, the TDS values measured in groundwater showed some correlation with U content in water (Figure 1). The sample with highest U content of 119.95 ppb corresponds to the highest value of 636 ppm of TDS; and one with lowest content of U corresponds to the lowest TDS value of 129 ppm. The average value of U content for Sangrur district is 45.91 ppb which is within the safe limit of 60 ppb of uranium in groundwater fixed by the Atomic Energy Regulatory Board (AERB)[17] in India. However, other agencies fix it at much lower limits of 30 ppb (EPA, USA)[18]; 30 ppb (WHO)[1]; 9 ppb (UNSCEAR)[19] and 1.9 ppb (ICRP)[20]. If the uranium content of water data (Table 1) is compared with the safe limit of 60 ppb in the guideline of AERB, there are four samples with marginally high U content and only one sample showing anomalous value of 119.95 ppb.

The excess cancer risk assessment for uranium content of groundwater samples of Sangrur district is estimated using the standard formulation[16,18]. The radiological risk was calculated due to ingestion of natural uranium in drinking water, assuming a consumption rate of 4.05 l/day and lifetime expectancy of 63.7 years for both males and females[21]. The excess cancer risk was observed to be in the range of 0.07×10^{-4}–3.40×10^{-4}. The value of excess cancer risk in the surveyed samples is lower in nine, equal in one and higher in four samples than the maximum acceptable level of 1.67×10^{-4} according to AERB (India) guidelines. If we assume lifetime water consumption rate of 4.05 l/day with the present uranium content of water, the mean value of excess cancer risk in the surveyed district comes out to be slightly higher than 1 per 10,000 people.

Uranium is a radioactive heavy metal. Hence it has health impacts due to both its radioactive and chemical nature. If we consider chemical toxicity of uranium, the kidneys are the most important target organ. In general, the chemical toxicity

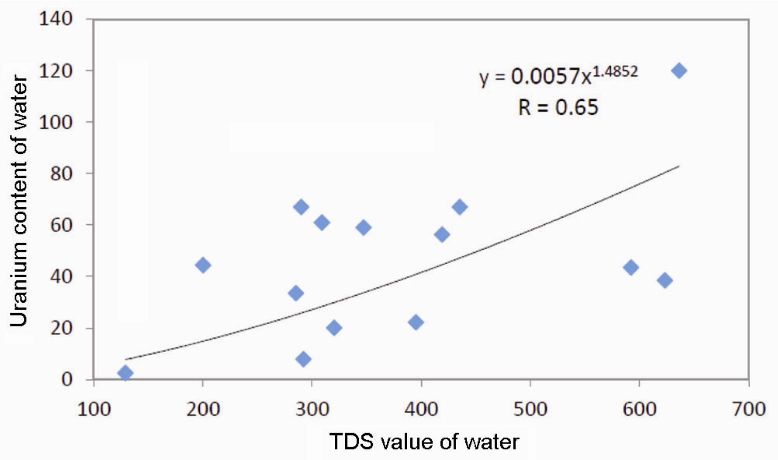

Figure 1. A plot of uranium content versus TDS of water samples.

of uranium dominates over its radiological toxicity on the kidney, at lower exposure levels[22]. The chemical toxicity has been estimated from the value of lifetime average daily dose (LADD) and hazard quotient[23]. Hazard quotient was estimated by comparing the calculated LADD values with the reference dose level of 4.53 μg kg^{-1} day^{-1}. The reference level was calculated for maximum contamination level of uranium in water of 60 μg/l. The variations in values of LADD and Hazard quotient were observed from 0.14 to 6.94 μg/kg/day and from 0.03 to 1.53 respectively.

We may conclude as follows: (i) the concentration of uranium in groundwater samples of Sangrur district is within the safe limit of 60 ppb recommended by AERB, India, except for some anomalies; (ii) uranium content in groundwater of Sangrur district is higher than Mohali and Fatehgarh districts[23], but lower than Bathinda district of Punjab[24]; (iii) U content in groundwater shows somewhat poor correlation with TDS values (Figure 1); (iv) it will be of interest to study why the U content shows some gradient when we move from north to south of Punjab; this may be attributed to geological, morphological and hydrogeological features of the landscape.

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