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Chapter 6

Pathway of Arsenic from water to food, West Bengal, India

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6.1 INTRODUCTION

Arseniasis (manifested in the form of skin lesions, vascular damage, cancers of the bladder, lung, liver and kidney, etc.) arises from the ingestion of excessive quantities of arsenic, through drinking water (as in Bangladesh, West Bengal (India), Inner Mongolia, Shaanxi, Xinjiang (China), Taiwan, western USA, Argentina, Chile, etc – vide comprehensive reviews by Aswathanarayana, 2001; Chappell *et al*, 2002), diet (Norra *et al*, 2005; Mukherjee *et al*, 2006) and inhalation of arsenic-containing aerosols (arising from the burning of high-As coal for cooking, keeping warm and drying of grains, as in Guizhou province of China ; Sun, 1999). In consonance with the theme of the volume, the chapter traces the pathway of arsenic to man through food, in relation to the content of the element in irrigation water.

The large agrarian population of West Bengal drink groundwater with arsenic content anywhere between 0.05 and 3.7 mg/L. Greater than 44% of this population suffers from arsenic related diseases like conjunctivitis, melanosis, hyperkeratosis, and hyper pigmentation. In certain areas gangrene in the limb, malignant neoplasm and even skin cancer have also been observed.. The worst affected are children below the age of 12 years. Recent work reveals that arsenic is geogenic and anthropogenic input is small (Chandrasekharam *et al*., 2001; Chandrasekharam, 2005; Stueben *et al*., 2003). Several mechanisms of arsenic release into groundwater have been documented from various parts of the world (Smedley and Kinniburgh, 2002). Examples of reducing (e.g. Bengal Basin), oxidizing (Argentina and Chile) and both reducing and oxidizing mechanisms (USA) have been well documented (Smedley and Kinniburgh, 2002). Adsorption and desorption/dissolution by iron and manganese oxides are the commonly recognized processes of arsenic release into the groundwater (Smedley and Kinniburgh, 2002; Stueben *et al*., 2003). Besides naturally occurring redox conditions, West Bengal is experiencing “irrigation controlled” redox conditions, especially in areas where rice cultivation through tube-well irrigation is practiced. Irrigation practices have contributed a large quantity of arsenic in to the shallow aquifers of West Bengal.

6.2 BIOACCUMULATION OF ARSENIC FOOD CROPS

It is well known that the soluble inorganic arsenicals are more toxic than the organic ones, and the trivalent forms (AsIII) are more toxic than the pentavalent ones (AsV).
Arsenic is a deadly poison in large doses to humans, but the arsenic poisoning in West Bengal and Bangladesh arose from slow poisoning over prolong period. Arsenic poisoning in mammals is less prevalent, as most of the mammals have a built-in mechanism to detoxify arsenic. They do so through the process of methylating inorganic arsenic to methylarsonic acid or dimethylarsonic acid. The methylated arsenites are less reactive, less toxic, and more readily excreted in urine. About 60-70 % of arsenic is thus excreted within 48 hours (Aswathanaraya, 2001). In the case of humans, this mechanism does not exist and hence arsenic gets accumulated in several parts of the body. Accumulation of arsenic in human hair (180 – 20340 µg/kg) and nails (380-44890 µg/kg; Mukherjee *et al.,* 2006) in West Bengal and Bangladesh, is indicative of chronic arsenic toxicity. Urine analysis can be made use of to monitor the *ongoing* exposure, and arsenic content of nails and hair is a good indicator of *chronic* arsenic toxicity. Recent work indicates that, besides groundwater, food is a major pathway of arsenic in to human system (Norra *et al*., 2005, Huq and Naidu, 2005).

In West Bengal, groundwater used for irrigation contains 0.05 and 3.7 mg/L of Arsenic (Stueben et al., 2003; Norra *et al*., 2005). In the light of this, detailed investigations have been carried out in Malda district in West Bengal on the distribution, speciation and mobility of arsenic in the soils of paddy and wheat fields and also on the concentration of arsenic in different parts of rice (Boro and Aman variety) and wheat plants cultivated in such soils (Norra *et al.,* 2005). The arsenic content in groundwater used for irrigation in this area varies from 519 to 782 µg/L. Boro is cultivated using groundwater from December to May while Aman is cultivated from July to December using rain water. Arsenic content in different parts of rice and wheat plants and in respective soils is given in Table 1 (Norra *et al*., 2005).

Table 1. Arsenic content in the soils of rice and wheat and in different parts of rice and wheat plants.

	As (mg/kg) in rice plant	As (mg/kg) in wheat plant
Soil	7 to 10	10 to 17
Root	169-178	0.3-0.7
Stem	6 to 7	0.4-0.7
Husk	1	
Grain	0.3	0.7

Similarly, arsenic content in vegetables grown using groundwater with high arsenic content in West Bengal and Bangladesh have been reported by several workers (Roychowdhury *et al*., 2003, Huq and Naidu, 2005). Arsenic content in vegetables and cereals grown using groundwater with 85 to 108 μg/L of arsenic content in several districts in West Bengal varies from 20-21 μg/kg, and 130-179 μg/kg, respectively (Mukherjee *et al*., 2006). This concentration is 300% greater compared to the mean concentration generally reported in vegetables and cereals elsewhere in the world (Dabeka *et al*., 1993). Due to repeated irrigation with such groundwater, soils, supporting the vegetables and cereals, also registered high arsenic content (10.7 mg/kg; (Roychowdhury *et al*., 2002). It has also been reported that the arsenic uptake by plants is influenced by the amount of arsenic absorbed by soils and the plant species (Huq and Naidu, 2005). For example, "*arum*" a leafy vegetable, is widely consumed by the locals as a source of vitamins, "A" and "C", and iron. Uptake of arsenic by this plant varies with in the region. In certain areas "*arum*" has recorded arsenic content as high as 138 mg/kg while in certain other areas the concentration is as low as 0.21 mg/kg (Huq and Naidu, 2005). Thus people consuming 100gm of "*arum"* that contains 0.22 mg/kg of arsenic will reach the maximum daily allowable limit of arsenic by eating this leafy vegetable alone. According to provisional tolerable intake value of arsenic set by WHO (1993), an adult male can consume 9-11 μg/kg body weight/day while an adult female can consume 11 -13 μg/kg body weight/day of arsenic. Children, below 10 years, can consume 12 -15 μg/kg body weight /day of arsenic. Thus consuming even small quantity of arum with 138 mg/kg of arsenic will far exceed the limit set by WHO. This gives an idea of the amount of arsenic ingested by people daily through vegetables alone. Even food cooked with arsenic contaminated groundwater showed high values (0.12 – 1.45 mg/kg; Huq and Naidu, 2005) and fell well above the limit prescribed by WHO. Thus it is clear that bioaccumulation of arsenic (in food crops) is strongly influenced by the irrigated water, soil type, its chemical and physical characteristics, micro-organisms (Mukherjee *et al.,* 2006). Accumulation of arsenic by food crops is a consequence of the irrigation practices adopted by the local population for long periods.

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6.3 IRRIGATION PRACTICES IN WEST BENGAL

Increasing demand for food changed the entire system of agriculture in rural West Bengal. Nearly 72% of West Bengal population (88 million as on 2001) live in rural areas and are agrarian by profession. More than 90 % of the land in West Bengal is under irrigation and paddy is widely cultivated. Since groundwater is easily accessible, agrarian community as well as the government agencies practiced tube well irrigation since 1959, by extracting large quantities of groundwater from shallow as well as deep aquifers. Arsenic content in both deep and shallow aquifers varies from 0.05 to 560 μg/L (Stueben *et al*., 2003; Norra *et al*., 2005; Mukherjee *et al*., 2006). These aquifers are located within the 3.5 km thick sedimentary sequences of different geological ages (Fig 1; Chandrasekharam, 2006). Though, on a local scale, three prominent aquifers are identifiable (Stueben *et al*., 2003) due to the presence of clay horizons between the aquifers, on a regional scale this distinction is not applicable due to swelling and pinching of clay layers.

This practice of tube well irrigation started in 1959 and in 1976, 20,000 tube wells were drilled providing water for cultivation through out the year. In 2001 this number has gone

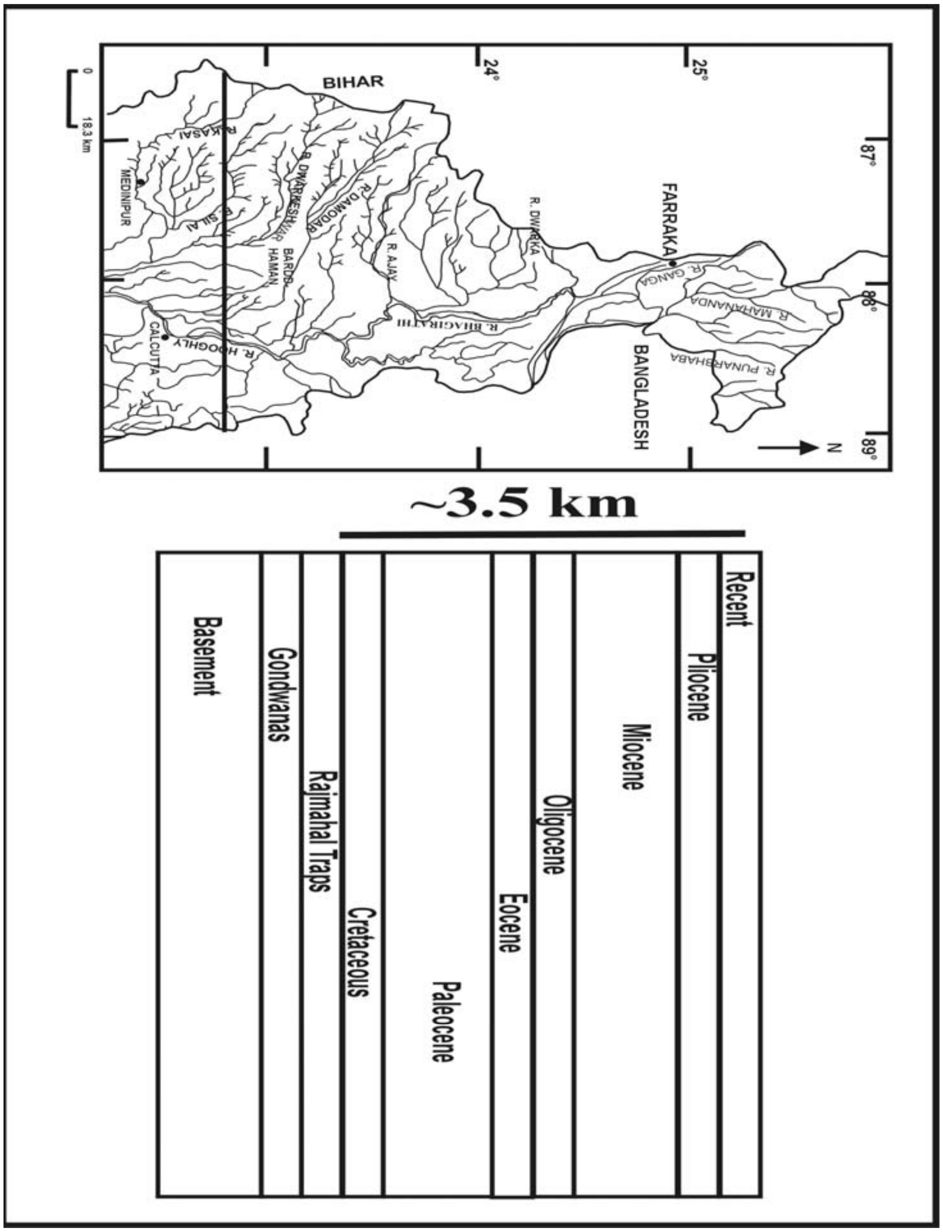

Figure 6.1. Map of West Bengal showing the drainage pattern and the sedimentary sequence across (indicated by thick line) the southern part of the basin.

up to 5,50,000 bringing over 47,650 km^2 of land under rice cultivation. Farmers are able to cultivate their land through out the year and a system of multiple cropping method emerged as a lucrative farming practice. Thus the same soil is ploughed several times to accommodate different food crops (Chandrasekharam, 2005). This system of irrigated farming supported ancillary industries like animal husbandry, fertilizer and other agro-based industries and created huge employment for the rural population. Thus millions of people were benefited by this method of farming. What was not realized by the agrarian population is the dark cloud lurking behind the 'feel good" life pattern. Tube well irrigation has completely eclipsed the lift irrigation system that was practiced since 1976 in West Bengal. For example in the year 1976, 20,000 shallow and deep tube wells were drilled as against 700 lift irrigation units from rivers. Subsequently after a period of ten years, the number of lift irrigation units fell to about 69 while tube well irrigation units went up by an addition of 5634 tube wells. Considering the surface drainage system of West Bengal (Fig.1), the local government should have encouraged lift irrigation and canal irrigation schemes instead of supporting tube well irrigation (Chandrasekharam, 2005). Investigation on rice plants from an area cultivated using surface water has shown that the arsenic content in the roots is about 20 mg/kg compared to those cultivated using tube wells reported in Table 1.

6.4 TUBE WELL IRRIGATION AND IMPACT ON ARSENIC CONTENT

In large parts of West Bengal both deep and shallow aquifers contain arsenic beyond the limit (>10 µg/L) prescribed for drinking water standards by WHO (Chandrasekharam *et al*., 2001; Stueben *et al*., 2003; Smedley and Kinniburgh, 2002). Because of heavy rainfall and frequent floods, arsenic content in the shallow aquifers tends to be low due to high base flow. It would be interesting to know the arsenic content in the shallow aquifers prior to 1959, the year which triggered tube well irrigation practice. How ever this data is not available for comparison.

West Bengal experiences floods every year due to south-west and north-east monsoons thus extending the rain fall from June to December. About 43% of the total area of 89,000 km^2 gets flooded during monsoon causing considerable loss of life, property and physical damage to more than 30% of population (total population as on 2001 is 88 million). Further, rice cultivation requires 5-10 cm standing water in the field and thus cultivable and non cultivable lands are under reducing environment through out the year.

According to Masscheleyn *et al.* (1991), at higher soil redox levels (~ 500 mV) arsenic solubility is low while at low redox levels (-200mV) the soluble arsenic content increases thirteen- fold as compared to 500 mV. Maximum conversion of As (V) to As (III) takes place under redox potential of + 100 mV and below. Around + 150 mV, iron and manganese also get mobilized into the aqueous phase releasing arsenic into the solution. This process has been recognized in the field conditions also in several areas in West Bengal, where dissolution of both iron and manganese oxides are responsible for increasing the arsenic levels in groundwater (Stueben *et al.,* 2003, Norra *et al*., 2005). Onken and Hossner (1996) reported a most interesting experimental finding, which is very relevant to the conditions prevailing in West Bengal. According to this experiment, soil solution under flooding conditions recorded maximum concentration of arsenic compared to the soils under non-flooding conditions. Release of soluble arsenic under flooding conditions takes place within few hours of flooding. The work reported by Masscheleyn *et al.* (1991) and Onken and Hossner (1996) suggest a strong concordance between experimental work and flooding of rice fields in West Bengal.

Indian farmers plough the roots of the rice plants back into the soil after harvesting. This practice is prevalent in the Indian agrarian community for centuries. Due to change in redox conditions during the subsequent crops, the arsenic in rice roots gets mobilized and infiltrates in to the shallow aquifers. Thus arsenic from groundwater, after entering the food chain, gets concentrated in the roots and enters the shallow aquifer thus establishing an *"arsenic flow cycle"* in the rice fields. If this practice continues, the probability of contaminating the entire shallow (and deeper aquifers) aquifers is very high in the very near future and entire West Bengal population may not get safe drinking water from the shallow as well as deep aquifers.

6.5 ARSENIC REMOVAL TECHNIQUES FOR DOMESTIC WATER

Over the past two decades, research laboratories across the world developed arsenic removal techniques to provide safe drinking water to the rural population. Oxidation, coagulation and ion exchange process are some of the methods commonly recommended to remove arsenic from drinking water (Driehaus, 2005). In oxidation technique, As(III) is oxidized to As (V) by using oxidants like potassium permanganate and Fenton's reagent. Arsenic precipitate is removed by filtration. Alumina and Fe^{2+} salts are used to remove arsenic through coagulation process. This is most frequently applied for arsenic removal at pH below 7.5. In the case of ion exchange method, a resin with chelating groups saturated with ferric ions is applied for removal of As (V) and As (III). Both redox forms effectively removed in optimum pH level (pH 3-6 for As (V) and pH 8-9 for As (III). Though such methods are very effective in obtaining arsenic free drinking water, they are not widely practiced due to several socio-economic impediments. Rooftop rainwater harvesting for drinking water is a sensible way to get over the problem.

6.6 ARSENIC REMOVAL TECHNIQUES FOR IRRIGATION WATER

Rott and Friedle (1999) proposed a novel technique for the subterranean removal of arsenic from groundwater *in situ*. Oxygen-enriched water is injected under pressure into the aquifer. The introduced oxygen activates the autotrophic micro-organisms, oxidizes As (III) to As (V), and facilitates the precipitation of arsenic and its absorption on iron hydroxide and manganese oxide. Field experiments validate the technical viability of the method, but the socio-economic viability of this technique is yet to be established.

Perhaps the best way to solve this problem of arsenic is to use surface water resources, especially in regions like West Bengal that has excellent drainage net-work (Fig. 1).

6.7 REMEDIAL SOLUTION

The government of West Bengal realized the effect of irrigation on the quality of groundwater and is advocating rainwater harvesting to improve the quality and quantity of groundwater in the state. The Central Groundwater Board (CGWB) has been entrusted with this task for three districts. From the drainage net work (Fig. 1), it is apparent that the entire Bengal Basin has sufficient surface water to recharge the aquifers. How far

CGWB will succeed in reducing the incidence of arsenic in groundwater through rainwater harvesting is matter to be examined over a period time. Perhaps adopting alternate methods of irrigation may be a viable solution to control arsenic levels in the shallow aquifers as well as in the food crops.

According to Indian Council of Agricultural Research (ICAR, 1992), West Bengal can be divided in to six major agro-ecological sub-regions. The four most important sub-regions are: 1. Hot dry sub-humid; 2. Hot moist sub-humid (Bengal Basin); 3. Hot per-humid; 4. Hot moist sub-humid (Gangetic delta).

The hot moist sub-humid regions (e.g. Baharampur in Murshidabad district) have different type of soil and experiences flooding while hot dry sub-humid regions (e.g. Ahmadpur in Birbhum district) are free from flooding with soil type different from the former region (Chandrasekharam, 2005). The most interesting fact is that in the hot moist sub-humid regions agriculture is based on irrigation and crops are grown through-out the year while in the hot dry sub-humid regions rain/canal-fed cultivation is adopted. In both these regions rice is cultivated extensively. As described above, arsenic accumulation in rice roots in canal/rain cultivated areas is far less compared to the areas where tube wells are used for irrigation. The arsenic content in the rivers draining the Bengal Basin is less than 1.9 μg/L .

Thus in general, groundwater from deep and shallow aquifers is extensively used in central and eastern regions while surface water irrigation is common along the western region. Though the mitigation of the reducing conditions due to floods is not possible, recycling of arsenic-containing groundwater for irrigation can be avoided. Since rice is cultivated through rain/canal irrigation in large part of West Bengal, attempts should be made to promote similar irrigation culture in the moist sub-humid regions of West Bengal as well. Considering the drainage system in the Bengal Basin (Fig. 1), this is possible by creating a net work of surface irrigation canal system through out the Bengal basin. This will provide arsenic- free water to the rice crop and prevents accumulation of arsenic in root zone of the plants. Both groundwater in the shallow aquifers and the soil solutions can thus be made free from arsenic. The local government should take initiative to educate the farmers of the advantages of such system for the benefit of the large population. In the long run this will provide safe drinking water as well arsenic free food to the population of West Bengal.

REFERENCES:

Aswathanarayana, U. (2001) *Water Resources Management and the Environment*, Lisse (The Netherlands), A.A. Balkema, p. 314-328

Chappel, W.R., Abernaty, C.O., Calderon, R.L. and Thomas, D.J. 2002. (Eds). Proceedings, 5th Conference on arsenic exposure and health effects, July 14-18, 2002, San Diego, California, Elsevier Pub. 400 p.

Chandrasekharam, D., Julie Karmakar., Berner, Z. and Stueben, D. (2001) Arsenic contamination in groundwater, Murshidabad district, West Bengal. *Proceed. Water-Rock Interaction 1.* (ed) A.Cidu, 1051-1058 A.A.Balkema, The Netherlands.

Chandrashekharam, D. (2005) Arsenic pollution in groundwater of West Bengal, India: where we stand. *In "Natural arsenic in groundwater: occurrence, remediation and management"* (eds) J Bundschuh, P Bhattacharya and D Chandrashekharam), AA Balkema, Taylor & Francis Group, London: 25–29.

Chandrasekharam, D. (2006) Geogenic arsenic pollution of groundwater: West Bengal. *In " Groundwater Flow and Mass Transport Modeling"* (ed) T. Vinoda Rao, Allied Pub. Pvt.Ltd., New Delhi, 2006, 132-144.

Dabeka RW, Mckenzie AD, Lacroix GMA, Cleroux C, Bowe S, Graham RA, Conacher HBS and Verdier P. (1993). Survey of arsenic in total diet food composites and estimation of the dietary intake of arsenic by Canadian adults and children. *J. AOAC Int.* 76: 14–25.

Driehaus, W. (2005) Technologies for arsenic removal from potable water. *In " Natural arsenic in groundwater: Occurrence, Remediation and Management",* (Eds). J. Bundschuh, P. Battacharya and D. Chandrasekharam, Taylor and Francis Group Pub., London, 189-203.

Huq, S.M.I. and Ravi Naidu (2005) Arsenic in groundwater and contamination of the food chain: Bangladesh Scenario. *In " Natural arsenic in groundwater: Occurrence, Remediation and Management",* (Eds). J. Bundschuh, P. Battacharya and D. Chandrasekharam, Taylor and Francis Group Pub., London, 95-101.

ICAR, 1992. Indian Council of Agricultural Research, Report 48.

Masscheleyn, P., Delaune, R.D. & Patrick Jr., W.H. (1991). Effect of redox potential and pH on arsenic speciation and solubility in a contaminated soil. *Environ. Sci. Tech*., **25**: 1414-1419.

Mukherjee, A.B., Bhattacharya, P., Jacks, G. Banerjee, D.M., Ramanathan, A.L., Mahanta, C. Chandrashekharam, D. and Naidu, R. (2006) Groundwater Arsenic Contamination in India: Extent and severity. *in*: "Managing Arsenic in the Environment: From soil to human health" (Eds) R. Naidu, E. Smith, G. Owens, P. Nadebaum, and P. Bhattacharya. CSIRO Publishing, Melbourne, Australia, 664 p.

Norra, S. Aggrawala, P., Wagner, F., Berner, Z., Chandrasekharam, D.. and Stüben. D. (2005) Impact of irrigation with As rich groundwater on soil and crops: a geochemical case study in Malda District, West Bengal. *App. Geochem,* ***20**, 1890-1906.*

Onken, B.M. and Hossner, L.R. (1996). Determination of Arsenic species in soil solution under flooded conditions. *Jour. Soil Sci. Soc. Am.,* **60**: 1385-1392.

Rott, U., & Friedle, M. (1999) Subterrenean removal of arsenic from groundwater. In Chappell, W.R., Abernathy, C.O., and Calderon, R.L. (Eds.) *Arsenic Exposure and Health Effects*. Amsterdam : Elsevier, p. 389-396.

Roychowdhury T, Tokunaga H and Ando M (2003) Survey of arsenic and other heavy metals in food composites and drinking water and estimate of dietary intake by the villagers from an arsenic-affected area of West Bengal, India. *Sci. Total Environ*. **308**: 15–35.

Smedley, P.L. and Kinniburgh, D.G. (2002) A review of the source, behaviour and distribution of arsenic in natural waters. *App. Geochem*., **17**: 517-568.

Stüben, D., Berner, Z., Chandrasekharam, D. and Julie Karmaka (2003) Arsenic pollution in groundwater of West Bengal, India: Geochemical evidences for mobilization of As under reducing conditions. *App. Geochem*,**18**: 1417-1434.

WHO (1993) World Health Organization. *Guidelines for drinking water quality*, vol. 1, Recommendations, 2nd edn, WHO, Geneva.

Food and Water Security (Ed) U. Aswathanarayana, Taylor & Francis Group, London, UK 315 p

Overview

Apart from drinking water, food is now known to be a source of arseniasis in West Bengal (India). Bioaccumulation of arsenic in food crops is strongly influenced by the arsenic content of the irrigated water, and chemical, physical, and microbial characteristics of the soil. The arsenic content of vegetables and cereals grown using arsenious groundwater (85 to 108 µg/L) in West Bengal is 300% greater compared to the mean concentration generally reported in vegetables and cereals elsewhere in the world. For instance, people consuming 100gm of "*arum*", a leafy vegetable, that could contain 0.22 mg/kg of arsenic, will reach the maximum daily allowable limit of arsenic by eating this leafy vegetable alone. Even food cooked with arsenic contaminated groundwater showed high values (0.12 – 1.45 mg/kg) that fell well above the limit prescribed by WHO. Arsenic accumulation in rice roots is high where tube wells are used for irrigation. When the roots of the rice plants are ploughed back into the soil after harvesting, the arsenic in rice roots gets mobilized and infiltrates in to the shallow aquifers. Thus arsenic from groundwater, after entering the food chain, gets concentrated in the roots and enters the shallow aquifer thus establishing an "*arsenic flow cycle*" in the rice fields. This is a catastrophe waiting to happen. This can only be prevented by using canal water for irrigation, and rooftop rainwater harvesting for drinking water.