Participatory Governance and Inter-sector Coordination for Sustainable Solutions of Arsenic Contamination of Ground Water in India: An Explorative Study

Atanu Sarkar*

ABSTRACT

Around nine million people living in India are at risk by consuming arsenic contaminated water. While several technological solutions failed to address the problem, magnitude of suffering of the people has increased over the period. The study aims to find out the solutions, which are effective, feasible, locally acceptable, and ecologically appropriate. Data were collected through in-depth study, focus group and informal discussion from the households of arsenic affected villages and by review of literature, policy documents, interaction with concerned authorities and technical experts. The study shows that the current policies need collective thinking, community participation and bottom-up action to deliver effective sustainable solution. Modern output driven agricultural policy has led to destruction of traditional mode irrigation and water conservation and over exploitation of groundwater, which triggered arsenic contamination and hence human exposure. The study shows that for sustainable solution, inter-sector approach including the management of agriculture, water, health, ecology to be effectively implemented and integrated. Gradual reduction of groundwater dependence, along with effective management of surface water as an alternative, would be the major step to bring down further contamination and exposure. Introduction of new variety of seeds, which require less water, can reduce dependence on ground water. More emphasis is also needed to improve the support system in terms of quality and accessibility of health care and rehabilitation services of the chronically debilitating sufferers, to reduce further disease burden and economic loss. Arsenic filters could provide temporary respite, but not recommended for long-term solution, due to ecological impact of highly toxic sludge to be generated from the filters. Rainwater harvesting can be a viable alternative solution as arsenic affected areas belong to moderate to high rainfall zone.

Key words: Arsenic, irrigation, sustainable development, community mobilization, disparity

INTRODUCTION

In 1983, the first person with manifestation of chronic exposure of arsenic due to consumption of arsenic contaminated ground water was diagnosed in the state of West Bengal (India). People were exposed to arsenic from domestic hand pumps and groundwater irrigation wells, extracting water from underground aquifers. Latest figure shows that, in India; nine districts in West Bengal, two districts each in Assam and Bihar and one district each in Uttar Pradesh and Jharkhand are affected by arsenic. (Chakraborti 2006) Based on WHO's safety guideline (i.e. 0.01 milligram per liter), it has been estimated that around nine million people living in West Bengal are at risk by consuming arsenic contaminated water and around 15 per cent of the arsenic exposed population showed related skin diseases. (Chakraborti 1994, 1996, 1997, 2006, Rahman 2001)

Arsenic contamination of groundwater in this region has been accepted to be of geological origin, though the exact mechanisms still remain poorly understood. Arsenic originated naturally in the earth's crust in the Himalayan region and for the past many centuries, the river of Ganga and other rivers have been depositing arsenic-laden sediments across the river basin. Common explanation is that due to human intervention in the form of groundwater over exploitation, arsenic from aquifer, which remained dormant for millions of years, has

* Department of Policy Studies, TERI University, India Habitat Centre, Lodhi Road, New Delhi, India. Email: atanus@teri.res.in, contactatanu@yahoo.co.on

started leaching into the irrigation and drinking water sources through complex geochemical reaction. (Chakraborti 1994, Nickson 2000, Ravenscroft 2001, Mukherjee 2006) Over exploitation of ground water was caused by a number of factors, which have been an integral part of the changing agricultural practices of this region, for instance; incremented cropping frequency, increase in land use and changing cropping pattern, which required more water for irrigation. The traditional pattern of irrigation (surface water from rivers, old canals, and tanks) could not meet the high demand and also lacked state patronage, which resulted in loss of their potentiality due to gradual silting. Hence, there has been a growing dependence on the ground water for irrigation. (Rawal 1998) Phosphate fertilizer is thought to leach arsenic in aquifers by geochemical reaction (Acharyya 2000). Since early seventies, for drinking purpose hand pumps have been being promoted to prevent water borne infectious diseases due to drinking of contaminated surface water. (Chakraborti 1994) The effort indeed reduced the mortality due to water borne diseases, particularly among the children. (Unicef 1998) But this major public health policy has also resulted in arsenic exposure to the people using contaminated hand pumps. Currently more than 50 per cent of hand pumps and irrigation wells in the affected areas are arsenic contaminated. (Chakraborti 2006)

Darkening of skin on the chest, back, or limbs and thickening of palm and sole and corn like swelling are the early common symptom. Severe form of symptoms leads to cracks, fissures and bleeding, which result in difficulty in bending of palms while holding objects, and restriction of walking due to pain. Weakness and numbness of limbs, tingling sensation due to arsenic related neurological manifestations have been found among several affected people. Respiratory manifestations including breathing problems and occlusion of blood vessels causing gangrene of limbs are also found among a number of cases. (Guha Mazumdar 2000, Sarkar 2004, Rahman 2005a) It crosses placenta and may lead to premature labor, spontaneous abortion, and congenital malformation of the offspring. (WHO 2005, Guha Mazumdar 1988) Arsenic also causes cancer after its prolonged exposure. (Rahman 2005b) From available data on humans, it has been calculated that lifelong ingestion of 0.001 milligram per kilogram of body weight per day is associated with a risk of skin cancer of about 0.1per cent (1/1000). (Smith 1992, Bates 1992) WHO has predicted that in most of the southern part of Bangladesh (bordering West Bengal and also severely affected by arsenic), almost 1 in every 10 adult deaths will be a result of cancer triggered by arsenic poisoning in the next decade. (Smith 2004) Similar kind of trend could be predicted as well for West Bengal and other affected states in India, as the states have similar nature and extent of problem. Several studies suggest a strong association between nutritional status and dietary intake and clinical manifestations of chronic arsenicosis. People with low dietary intake of protein and micronutrients (calcium, selenium, vitamins A, C & E) are more prone to arsenic-related diseases. (Vahter 1998, Mitra 2004) Despite making several efforts to solve the arsenic problem, the suffering of the people remains unchanged; rather there is evidence of spreading of contaminated aquifers in newer areas.

OBJECTIVES & METHODS

The main objectives of the study were to critically analyze the present developmental practices and its possible implication in arsenic contamination of groundwater along with its ecological impact, health outcomes, social dimensions and consequences of the problem. The study has also explored the merits and demerits of existing mitigation strategies and sought sustainable solutions, which are effective, feasible, locally acceptable, participatory in nature, and ecologically appropriate. Although the study has addressed India, major focus has been given to West Bengal as the arsenic problem is more serious and all kinds of intervention program and research have been done only in this state. There is comparatively very little information of arsenic from Uttar Pradesh, Bihar, Jharkhand and Assam, as the problems are of recent phenomena, yet the developmental paradigm in agriculture, water and sanitation and

health is very much similar to West Bengal. Majority of data were collected during the field visits in the arsenic affected villages and rest were obtained by review of research papers, government documents and discussion with concerned higher authorities and technical experts. The field based data were collected in two phases – first was the part of social epidemiological study of chronic arsenicosis, which was carried out in late nineties in one of the worst affected districts (Murshidabad) of West Bengal, second phase (in 2005) as a follow-up study in the same field areas to find out the changes happened in human suffering, their coping mechanism, policy and other arsenic affected district (North 24 parganas) for wider view.

RESULTS

Modern Agricultural Practices

Cropping: Despite sufficient rainfall and existence of water bodies, groundwater has remained as the major source of irrigation. Paddy cultivation was given a top priority by agriculture department and farmers as well, as majority of the population of West Bengal prefers rice as a staple food. High profit margin in paddy cultivation initially encouraged the farmers to go for its mass cultivation. (Rawal 1998) But paddy cultivation needs huge amount of water in irrigation as compared to other crops. Hence, cropping pattern also contributed significantly on increased water consumption, particularly in dry season. For example, 'Boro' rice (rice cultivated in the dry season of late winter) relies upon naturally stored water (either lake, pond, under ground aquifer) or river. As it is cultivated in January; when the major surface water sources (ponds, small streams and rivers) get dried up or shrink to insignificant quantity, groundwater becomes the only option. From 1980 to 2001, 'Boro' production in West Bengal increased from 0.86 million tons to 4.54 million tons (5.27 times). Total area cultivated for rice production increased from four million hectares in 1st five year plan (1950) period to 6.1 million hectares in 2000. (GoWB 2003)

Irrigation: There was growing demand of water in irrigation, which has been largely fulfilled by ground water extraction. In fact, irrigation department gave major thrust on ground water irrigation by means of capital investment, rural credit, and influence of local agricultural development units. In early seventies, availability of diesel and electricity with relatively cheaper price, easy credit promoting through local government and bank, and assurance of higher profit margins encouraged the people to invest money in buying pumps for groundwater irrigation. Also many farmers, who could not afford pumps, have purchased water from the pump owners and eventually groundwater became popular commodity in rural areas. (Rawal 2001a) Interaction with several farmers has revealed that irrigation pumps gave them a feeling of self reliance as there was no need to depend upon rain or river based canal irrigation or sharing of existing water resources with neighbors. Between 1970 and 1990, groundwater irrigation in West Bengal had increased by 575 per cent to meet the growing demand of agriculture. (Rawal 1998) From 1975-76 to 1992 the area irrigated with groundwater increased from 0.14 to 0.77 million hectare (i.e. from 13.6 to 35.4 per cent of net irrigated area). In 1995-96, 1.74 million hectare land was irrigated by groundwater. There are total 1.5 million hand pumps and irrigation pumps in West Bengal. (GOI 1998, GoWB 2003, SWID 2005) Seventy five per cent of irrigations in nine arsenic affected districts were met by ground water. From 1975-76 to 1995-96 the density of groundwater irrigation wells (per 100 square kilometer) increased from 298 to 952. Other forms of irrigation (canal, well, tank and other sources) could not show such impressive growth due to lack of state support. (Rawal 2001b) In Uttar Pradesh the growth of private groundwater wells (both electric and diesel) for irrigation started from 3 thousand in 1951 to 0.6 million in 1977 and to 8.2 million in 1998-99. (Pant 2004)

Groundwater abuse and lack of coordination: While, modern agricultural practice led to dependence on ground water, its wastage further stressed on the natural resource. Considering groundwater as a free commodity and abundance in quantity, negligence and lack of awareness from community and local governance, often led to over exploitation of ground water. Due to absence of vigilance and flouting of government norm, there has been indiscriminate sinking of irrigation wells and extraction of groundwater more than requirement. (GoWB 1993, GoWB 2005) Many irrigation wells are very close to each other and their simultaneous operation often leads to fall of water table in aquifers. In Uttar Pradesh the free boring scheme in 1984-85 resulted in over exploitation of groundwater. From 1884-85 to 2001-02 the total number of free borings stood at 2.5 million. (Pant 2005) 'Jute' the major cash crop in West Bengal also requires huge amount of water during the process of extraction of its fiber. Often the farmers draw ground water to fill up dry pond for processing of jute fiber. In fresh water fish cultivation, often the dried small ponds are filled up with groundwater. Paradoxically, large old lakes and water bodies are drained out to use the land for crop cultivation. It indicates the lack of macro level planning and poor understanding of sustainable development. At higher policy level water issues are managed by a number of ministries and there is a lack of coordination among them. Villagers also expressed their lack of awareness and utter helplessness restraining them from using groundwater as erratic rainfall, poor water carrying capacity of the existing water bodies due to silting and complex socio-political transformation affecting earlier practice of amicable sharing of natural resources including the surface water. Groundwater trading by irrigation pump owners has become integral part of current rural economy. (Rawal 2001b)

Fertilizer: Introduction of modern agriculture practice encouraged and promoted the farmers to use chemical fertilizer. Three major types of fertilizers are used, nitrogen, phosphate and potassium and among them phosphate fertilizer is known to be one of the reasons of arsenic leaching of ground water. (Acharyya 2000) From 1992 to 2001, the use of phosphate fertilizer in West Bengal has increased from 0.2 to 0.32 million metric tons. (GoWB 2003)

Agricultural economy of the region: The economy of the region is primarily based on agriculture and agriculture related industries. Majority of the farmers belong to low socio economic status and more than 50 per cent of farmers in West Bengal posses less than 1 acre of land, which is not even sufficient to sustain subsistence level of living. (GoWB 2003) Land reform in West Bengal brought down the rich and poor gap to some extent in rural area and improved the access to resources due to proactive role of the institutions. (Bardhan 2004, Chatterjee 1998) Condition of landless laborers and marginal farmers in Bihar, Uttar Pradesh are grim due to lack of social security and inequality. (Sitaraman 1996, Suryanarayana 1996, Sundaram 2003) Poverty is found to be an important determinant of exposure to arsenic, its consequences, access to service and social security and nutritional status.

Drinking water – present practice

Ninety five per cent populations living in rural West Bengal are dependent on groundwater reserves for drinking water. (Chakraborti 2000) Drinking water and food cooked with contaminated water became major source of arsenic. Wide spread availability of hand pumps at individual household level often changed the practice of storing of water. Earlier most of the people did not have hand pumps and stored water after collecting it from public source. Study shows that the settling of water leads to chemical reaction of arsenic with atmospheric air and resulted in its precipitation and separated by supernatant but relatively arsenic free water. Nowadays, many households own hand pumps and drink water directly from them with out allowing it to settle and thus getting more exposed to arsenic. (Sharma 2006) The farmers while working in agriculture fields drink water directly from irrigation bore wells, which are also often arsenic contaminated. (Sarkar 2004)

Disparity

Food and nutrition security: Clinical manifestations of arsenic are influenced by micronutrients and proteins, which are available in animal protein, pulse, green vegetables and fruits, but they are not reachable to poor people. (Vahter 1998) Pulse production in West Bengal declined from 0.24 million tons in 1980 to 0.17 million tons in 2003. (GoWB 2003) But, due to low production, price of pulse has become higher and hence not affordable to poor. It is ironical that pulse is popularly known as 'poor man's meat' as it contains high protein and cheaper than animal protein. Vegetable production increased from 4.7 million tons in 1980-81 to 7.5 million tons in 2000-01. But, due to improved transport facility, locally produced green vegetables and fruits are transported and sold to nearby cities and other states and eventually they remained non-available in the market or not affordable to the poor. Even the farmers, who produce the green vegetables and fruits, could not afford to consume their product, in order to get cash to buy other household products. In West Bengal 1.7 per cent children younger than 11 years of age exhibits arsenical skin lesions, mostly from poor socio-economic and with low nutritional status. (Mitra 2004, Chakraborti 1994)

Socio economic status and severity of manifestation: Poor people are more sufferer as they are exposed to contaminated water with high arsenic level and have little or no choice to go for alternative solution and indeed poverty is associated with lack of food and nutrition security. A population based study conducted in Murshidabad district found that 73 per cent irrigation wells and 62 per cent hand pumps used for domestic use were arsenic contaminated. (Sarkar 2004) Poor agricultural laborers, who spend almost half a day in farm lands, drink arsenic contaminated water from irrigation wells. Therefore, poor farmers are doubly exposed both at home and workplace. Rich households have better access to information on alternative solution and have more financial capacity to spend for alternative arsenic free water; for instance sinking new dug well, which can provide arsenic free water or buying arsenic filter for domestic use.[a] Also they visit less frequently in the field except during supervision of agriculture activities. Rich also has more local political influence to divert government funds and schemes for personal gain, for instance installation of arsenic removal filter nearby own house for easy access.

Health services: General health service is poor in quality due to lack of infrastructure, manpower and motivation. Most of the curative management of patients suffering from arsenic related manifestations is essentially available in cities not easily accessible to poor rural population. In the present situation, only rich and middle class people could afford to go for treatment. Efficacy of the current treatment protocol is still debatable and there is need for further research. Moreover, several patients complained of recurrence of symptoms after completion of treatment due to re-exposure of arsenic contaminated water after coming back from hospitals. Field visit has revealed increased in number of arsenicosis cases and deaths as well, but majority of them have not been reported in health register in local government hospital due to poor surveillance system. (Sarkar 2006a, 2006b)

Consequences of chronic arsenicosis

Disability affecting the productivity, household economy and overall quality of life: The present study shows that due to symptoms of chronic arsenicosis the economic productivity has been significantly affected and in turn deteriorated over all quality of life. (Sarkar 2004, 2005b) The social consequences in terms of regular interaction, marriage mostly affect the people with severe manifestation and as poor people are more sufferers, they bear the brunt of the chronic arsenicosis. Gender wise, male are more suffers as they are more exposed, but women face more social wrath and exclusion in their daily interaction and marriage. (Hassan

2005, Rahman 2005c, Chowdhury 2001, WHO 2000) The accessibility to treatment or treatment seeking also has gender dimension. Women mostly seek treatment from local doctors who could not offer rational treatment and any respite.

Ecological impact

Arsenic in soil: Arsenic has entered from groundwater to topsoil in irrigated lands and eventually into the food chain. This aspect of arsenic toxicity has been ignored till now and needs to be explored further. A study in West Bengal shows that the mean arsenic concentrations is in higher side in agricultural land soils irrigated with arsenic contaminated water, compared to the fallow land soils. It was found that the mean arsenic deposition per land by single hand pump per year was 2.31 kilogram. It showed that from the existing 3200 irrigation pumps in Deganga Block of the affected North 24-Parganas is causing deposition of 6.4 tons of arsenic in the agricultural fields per year. There is every possibility that in due course of time the arsenic from aquifers may contaminate the surface water of ponds, lakes, which are arsenic free. (Roychowdhury 2002)

Arsenic in crops, and other food products: Analysis of arsenic intake through food and water showed that 20-40 per cent of arsenic comes from rice, vegetables. (Chowdhury 2001) Rice from contaminated regions contained dangerous levels of arsenic, as compared to crops grown elsewhere. Arsenic was found in both cooked and raw vegetables above allowable level. Vegetables that grow underground (tuber, potato etc) contain greater amount of arsenic in them than others do. (Meharg 2004, Meharg 2002, Das HK 2004, Zahangir 2003) Studies found that majority of arsenic absorbed by plants are deposited in roots and plants followed by economic products (crops). But the leaves can be potential source of arsenic for livestock if used as fodder. In fact, in rural Bengal where there is no enough pasture land for grazing livestock, leafy parts and stems of agricultural plants remain the major sources of fodder. (Das DK 2005) Presence of arsenic in fodder grown in the affected areas can adversely affect cattle and subsequently, human beings via the plant-animal-human pathway. (Das DK 2005, Nandi 2005) Scientists have detected arsenic in cow's milk. (Alam 2003) Roots of the plants remain in the soil and converted into natural manure and eventually the arsenic is deposited inside the roots go back to upper layer of the soil and remains as potential source of arsenic for next crops.

Wider implication: It is important to note that even people from unaffected areas get arsenic into their bodies by eating rice or vegetables, grown in arsenic affected areas. In the arsenic affected villages, urine samples of people, who were drinking arsenic safe water; were also having elevated level of arsenic than expected in normal people. Calculations show that the intake of arsenic through food items is greater than the WHO's maximum limit regarding drinking water. Its presence is restricted not only to drinking water and vegetables but it has also been found in local ice creams and soft drinks in affected areas. The food processing and other manufacturing units use arsenic contaminated ground water of daily production, which may very well contain arsenic. (Hironaka 2003) Arsenic in agricultural products has larger implication on population health and local economy. If the situation is not improved, the agriculture product of the affected areas may not be accepted in the market and will have terrible impact on local economy.

Current mitigation strategy

Current mitigation strategies are broadly divided into promotion of arsenic filter, river water scheme, deep well, dug well, rainwater harvesting and surveillance. (GoWB 2005b, Bhattacharya 2004, SOS-Arsenic 2006) River water schemes are based on filtration of water (both microbiologically and chemically) and supply through pipeline to the villages situated

nearby river. Deep bore wells are sunk after exploring deeper aquifers, which are arsenic free.[b] There is an effort to promote clean water from dug well, which is arsenic free. It has been observed that the dug well water is free from arsenic as it is located above the arsenic contaminated aquifers. There is no system of disease surveillance so far, but with the help of government and bilateral agencies, the water testing facilities are being decentralized and have become more accessible to the community.

Critical review of existing mitigation strategy

Technological failure: Major problem of community-based filters is frequent breakdown and lack of quality check. Arsenic removal plants (ARPs) installed in various water supply systems are found non-functioning. The ARPs are based on modern technology, which cannot be managed by villagers in remote areas. Any minor technical problems will amount to complete collapse of the plant. Evaluation of ARPs shows that even after treatment, arsenic concentration showing above 0.05 milligram per litre (five times more than WHO's recommended level). There is also no quality control of domestic filters. The filter materials need to be changed or cleaned on regular basis to retain its filtering capacity, but due to lack of support system and/or awareness; several households use the filters for longer period. Deep wells could not sustain the supply of arsenic free water as opined by various experts. There is possibility of leaching of arsenic from higher arsenic contaminated layer to safer layer lying below. (Hossain 2005, Das D 2006) Most pertinent issue regarding arsenic filter is managing highly toxic sludge produced after use of filters. Till now the common practice is to discard them in open areas. This toxic sludge can be hazardous to the people, animals and indeed ecology by contaminating soil and surface water. Dug well provides arsenic free water; but it has some disadvantages, such as bad odour due to chlorination and occurrence of water borne disease due to bacteriological contamination from seepage of sewage or contaminated surface water. The major technical disadvantage of rainwater harvesting is the building materials used (thatched roof) in rural Bengal, which has poor run off and cannot yield sufficient quantity of water. River water supply can cover large population, but it needs high capital investment and there is chance of leakage or wastage and bacteriological contamination during supply. (Smith M 2003)

Lack of integration: Arsenic problem is a very complex developmental issue and needs to be integrated from policy level at top to grass root level. Public health engineering department (PHE) is responsible for water testing, identification of safe water source and dissemination of information with community and other department. But due to lack of coordination and sharing of information between health department and PHE, there is failure to identify local hotspots (i.e. cluster of arsenic contaminated hand pumps) and subsequent actions (i.e. surveillance of cases and community awareness). Our field-based study revealed that several dug wells are located adjacent to swampy land with full of water hyacinths and villagers refused to visit, as they were not accessible and bad odour of water.

Poor community awareness, mobilization, and participation in complex rural society: Community participation in planning process, implementation and monitoring and evaluation was not well visible. Hence, several policies developed at central level could not garner community support and eventually failed to yield desired result. Most of the community-based filters are not working or working with out quality check. The initiative of public-private-community-partnership has failed to yield any expected results due to lack of commitment, mistrust and lack of preparation (community mobilization and integration of partner organization) before implementation.

SUSTAINABLE MITIGATION STRATEGY

The main objective of the sustainable strategy should be to reduce dependence on arsenic contaminated ground water, both in irrigation and domestic use, to improve the support system in terms of health care and rehabilitation of the chronically debilitating sufferers. (Sarkar 1999, 2000a, Chowdhury 2000) Even if exploitation of groundwater is required, it should not exceed the rate of normal recharging of aquifer in order to keep groundwater balance. The major target will be to transform 'population at risk' to 'population out of risk'. There can be two prong strategy – macro level (from national perspective to district level) and micro level (from district level to community level). Also the strategies should have two major time dimensions – looking for immediate solution and long term plan. Indeed it is very challenging task to undo the damage made over several decades, but there is also a need to overhaul the present development strategy for better future of the next generation. No policy should be universally implemented in whole affected areas and it should be from case to case basis depending upon local geographic and social condition. Any intervention program should be integrated and participatory in nature. Initiative to use local technology, which is low cost and based on locally available materials, can add to sustainability of the strategy. All efforts to mitigate arsenic should include alternative institutions, panchayat, self help provider, local clubs etc. All the strategy should be integrated in nature in order to synergize each effort. (Sarkar 2002) Also the strategy to be complied with UN Millennium Development Goals (MDGs), where integration of the principles of sustainable development into policies and programs, reversal of loss of environmental resources and sustainable access to safe drinking water are taken as major goals. (Sarkar 2006c)

Participatory Governance and Inter-sector Coordination

In West Bengal, a very unique and large-scale experiment in economic and political decentralization, which was introduced in the late seventies has been projected as exemplary success. The provision and maintenance of all local public goods and implementation of most local public projects were handed over to formally elected village councils or '*panchayat*'[c]. Earlier, these functions were discharged by bureaucrats working under state and central governments and this system received widespread criticism as inefficient, corrupt and inequitable. Panchayat played a key role in agricultural development in West Bengal starting from land reform, agricultural policy including cropping policy, irrigation and other components (fertilizer, crop price etc). Current central government policy is also favoring the devolution of power and decision making through panchayat, for instance National Rural Health Mission (NRHM), a new initiative to rejuvenate the ailing rural health care is to be carried out with direct participation of panchayat. (GOI 2005) Now panchayat is a local nodal body to carry out all major activities such as agriculture, public distribution system of food, health, rural employment, infrastructure development (housing, road), natural resource and watershed management, water supply, sanitation etc. (GOI 2007) Although in rural development of West Bengal, panchayat played a major role, in arsenic mitigation strategy their role is surprisingly minimum. But, author argues, the proposed sustainable strategy (given below) can be implemented if panchayat becomes a major stakeholder of the planning process. It can ensure equity in sharing arsenic free water, resource distribution, gender equity in access to health care and rehabilitation, food and nutrition security, mobilization and active participation of community as well as community based organizations. In current situation, panchayat is not well equipped to address the arsenic issue from development perspective (except health issue which is more apparent and visible) and so all short term measures are being accepted without verification of their long-term implications. Therefore there is a need of building capacity at panchayat level, enabling them to understand arsenic contamination of groundwater from sustainable development, ecological, rights perspective along with the health dimension, which is the only major concern at village level. The causal analysis of

arsenic contamination of groundwater shows there is a need to integrate multiple disciplines such as health care, agriculture development, natural resource management, technological innovations and social sciences.

Strategies

To provide arsenic free domestic water: Strategy to be developed to promote household filter, community based filter, slow sand filter, dug well, rain water harvesting, river water and deep well water after filtration. Although the existing mitigation program has incorporated most of the above strategies, stress should be given on to identify the best practice/s based on the local geographical and socioeconomic context and community choice. Arsenic filter can be a temporary but effective choice till the development of long term alternative strategy of supplying water from arsenic free sources, for instance river and rain water. Selection of filters is to be based on cost, efficiency and convenience to maintain in rural setup. (Smith M 2000a, 2000b) State has to develop best practice of highly toxic sludge management in the local context.

As most of the arsenic-affected regions receive abundant rainfall, rainwater harvesting could be a feasible proposition in these areas. West Bengal has around 1410-2134 mm of annual rainfall. (ICRISAT 2006, CSE 2000) This immense quantity of surface water flows through the major rivers and overflows their banks. The extra water can be effectively used in cooking, drinking, kitchen garden, and cattle feeding. Collecting rainwater directly from the hard rooftops (tiles or concrete) or channeling the rain into shallow water bodies or even dug wells for household use is viable alternative. Recharging groundwater aquifers is cost effective, but increases the groundwater table significantly and also it would contribute to reduce arsenic concentration by dilution effect. Field experience and literature survey show the significant improvement of disease manifestation after shifting from arsenic contaminated water to arsenic free water for daily consumption. But it is essential to combine all these strategies with good sanitation practices. (Athavale 2003, Pecey 1989, Verma 2003) The dug well located with in the vicinity of recharge area can provide water through out the year. Experience of various grass root agencies working in rainwater harvesting for direct use from storage and recharging groundwater aquifers are very encouraging. (GOI 1981, GOI 1991) Promotion of arsenic free water for livestock feeding is to be done in order to prevent contamination animal products. Awareness generation among the villagers is imperative to promote arsenic free water for livestock. Prevention of wastage is the key to sustain the supply of arsenic free water. The technologies currently being adapted would need significant capital investment and wastage of water will lead to over-stressing of the machineries and groundwater reserve and eventually might lead to break down of the system.

To increase acceptability and demand for alternative water source in community: It is an important aspect to sustain the supply of arsenic free water. For last two to three decades people are being habituated of using of hand pumps after rejecting the traditional dug wells, river and pond waters and developed a sense of independence in use of natural resource (water). Therefore, a special attention is to be needed to convince the villagers to accept the traditional sources and sense of sharing of natural resources. First step can be making them understand the scientific notion behind the promotion of traditional sources to prevent arsenic exposure. Awareness generation on health benefit of alternative water source & to remove wrong perception is necessary to increase the acceptability of the alternative sources. Selection of water distribution points is very important to increase its acceptability and use and its ongoing maintenance across the rural society. Innovation of new technology to improve the bacteriological quality of dug well with out objectionable chlorine odor will increase compliance of dug wells. (Smith M 2003)

To provide arsenic free water in irrigation: Promotion of arsenic free water in irrigation is important to save agriculture product from arsenic contamination. Entire Bengal, particularly the arsenic affected areas are the land of rivers with numerous streams, ponds and lakes, which can be the potential source of arsenic free water in irrigation. In West Bengal, there are 0.28 million hectare of water bodies, 0.04 million hectares of lakes, oxbow lakes[d], 4000 hectares of sewage/dirty water bodies/lakes and 2526 km streams or water channels and thousands of ponds, small lakes (beel)[e], which can be potential source of water for irrigation. (GoWB 2003) Himalayan foothills areas in Nepal have abundant rainfall, which mostly flows down towards India (UP, Bihar and West Bengal) in the form of small streams and rivers. (Singh 2003a, Singh 2003b) But the major challenging task is to improve their water carrying capacity as due to gradual silting on account of poor maintenance resulted in rising level of river, pond and lake beds. Moreover due to lack of regulation and public awareness several embankment sites of centuries old lakes are occupied by local community and started using the beds for cultivation and destroyed the whole ecosystem. Now most of these lakes become dry during the winter season due to silting and deliberate drainage of water for cultivation in the pond beds. But according to experts even if the existing water bodies and wetlands are saved, the current arsenic problem can be significantly managed. It's the dynamics of local economy which determine the fate of the water bodies and hence to save the existing water bodies more pragmatic strategies to be adopted to make more economically attractive. Only enactment and public awareness would not be sufficient. The existing dug well, canals, ponds, wet lands and lakes can be rejuvenated by de-silting and removal of water hyacinth and other weeds and increasing water carrying capacity. Raising bank of the water bodies with excavated silt, followed by tree plantation will increase strength of the embankment and further increase water carrying capacity. Check dams across the small streams and river will ensure water supply during the lean period in winter and summer. On the other hand, natural recharge of water from check dam and water bodies will increase the ground water table and restore the local ecology. Multiple small check dams are more effective than single big dam. In fact, there is strong scientific evidence to show that village scale rain water harvesting will yield much more water than big or medium dams making the latter an extremely cost ineffective and unscientific way of providing key water needs especially in dry areas. (Evenari 1971, Agarwal 2000) These ponds can be converted to potential reservoirs for fish cultivation through planned excavation and utilization. Fish culture will not only improve the rural economy also make the water bodies as sustainable supply of surface water in irrigation. (Agarwal 2000, SDNBD 2006) In fact, declining profit margin in agriculture owing to its rising cost might encourage the farmers to shift to fish culture.

To sustain surface water in irrigation: Provision of arsenic free surface water would not be viable to the villagers, unless appropriate agricultural strategy is taken to reduce dependence on water in irrigation. Promotion of certain types of crops which require less water but can ensure adequate or more profit can be a meaningful solution. In rural Bengal, most of the water bodies are owned by more than one families and complex economic relation pertaining to land ownership might create complicated inter household trouble if the same water bodies are used in fish culture and irrigation particularly in a lean period or in extraordinary drought and then jeopardize the whole effort of sustainable development. Therefore, reduction of dependence of water in irrigation can be only viable option to prevent any future disputes. Interaction with several farmers and agriculture officials reveal that due to rising cost of diesel and electricity, several farmers have been compelled to go for alternative crops, which require less water (for example mustard, corn, wheat, flower and vegetable etc). As rice is the traditional and popular staple food, new variety of paddy crops, which require less water, can be a better option in order to meet and sustain the market demand. But before introduction; proper feasibility study, its ecological impacts and cost and marketing can be appraised. Financial security (including credit facility and crop insurance to promote new crop facility) and capacity building of farmers are needed to change the paradigm of current agriculture.

(GoWB 2003) Government of West Bengal already enacted a law to protect precious groundwater, which can be extended to surface water management also in future.[f] Drip irrigation can be another option to reduce wastage of groundwater. But before investment in drip irrigation proper cost benefit analysis has to be done. (Dhawan 2000)

To prevent further arsenic leaching in aquifer and to remove arsenic from soil: All efforts of water management will be sustainable and further strengthened if the efforts are made to stop further leaching of arsenic into aquifers. Based on literature review and interaction with experts, it was revealed that promotion of organic farming in order to reduce use of phosphate fertilizer can be one option. (Acharyya 2000) On the other hand green manure is believed to be responsible for arsenic up take from soil and reduce arsenic up take by crop plants. (Das DK 2005) Some agricultural scientists tried to reduce arsenic content from soil through changing cropping sequence with out increasing arsenic in the economic parts of the agricultural product. But this approach is still in experimental stage as its economic sustainability has not been evaluated so far. There is also microbiological technique applied to remove arsenic from soil and aquifer, for instance use of common green algae. This is also in experimental stage and detail ecological impact to be assessed before commercial production and application of this novel technique and disposal of algae and sludge. (Kauser 2006)

To provide medical and nutrition care and rehabilitation: Although there is no definitive medical treatment available except 'keratolytic' agents to soften the corn like patches of palms and soles and chelating agents to remove arsenic deposited in body. To reach the population of inaccessible location, decentralization of the health service is required. Scientific and realistic definition of chronic arsenicosis is very important in order to assess the distribution of true cases and would contribute in future epidemiological studies. Further research is required to develop rational, feasible and effective medical management. Alternative and indigenous system (for instance ayurvedic, homeopathic etc) could be tried, as several publications claimed to have encouraging result and need further exploration for scientific evidence. Capacity building and training of medical doctors and health workers from primary health care centres located in rural areas, other rural hospitals and private dispensaries to be conducted in order to improve the surveillance, which will in turn increase the clinical case detection. This approach will also help earlier detection of the pre-cancerous and cancerous lesion and will increase the survival rate. Public awareness regarding clinical symptoms and subsequent action will also contribute in community-based surveillance in both affected and unaffected areas and help to get right picture of distribution of cases. Nutrition and food security would prevent the early manifestations and avert disease progression of chronic arsenicosis as good protein and micronutrients are believed to play protective role by rapid detoxification of arsenic. But poor people could not afford to get supplemented by therapeutic means. Fresh, traditional and locally available fruits (berry etc) and green vegetables can be cheap, effective and sustainable options. Due to deforestation and cutting of fruit orchards, the once abundantly available traditional fruits have become rare. But further plantation of these fruit trees and community mobilization can revive the old culture and benefit the people. Chronic arsenicosis caused a number of physical disabilities and economic hardship due to declining output. Alternative economic activities or jobs can be proposed, which can provide sustainable inflow of income to the poor households with minimum physical work and mainstream the people with disabilities. There is legal provision of disability rehabilitation due to arsenic poisoning as India is signatory to equality of people with disabilities in the Asian and Pacific (ESCAP) and bound to provide adequate attention to the poor sufferers. But due to ignorance to the legal framework of protection of disabilities due to chronic arsenicosis, the people are deprived of their rights.[g] In India, the persons with disabilities act have provision for at least 3% reservation of vacancies in jobs in government establishment and seats in admissions in educational institutions. The act also provides for 3% reservation for persons with disabilities in various poverty alleviation schemes and it can be

applicable to arsenic affected people. In order to improve the prompt identification of newer affected areas and trend of spreading contamination, decentralization of testing facilities is essential. Reliable field-testing kits can be promoted at panchayat level for rapid identification of water quality and also supply of spectro-photometry at block level for verification of arsenic level if found positive with field testing kits.

Communication: Good and effective communication is essential for successful implementation of the decades old environmental health problem as it brings the community, policy makers, and service providers closer. Proper communication with the community is needed in order to increase their acceptability, ownership and sustainability by identifying the best practice in the local context. Communication also play important role in motivation and behavioral centric approach among the villagers and other stakeholders and so spreading positive message and sharing success story can be incorporated. In health education, emphasis should be given to social problem.

Operational research: Operational research is an important aspect of improvisation of ongoing programs in order to make them more effective. Regular study of *knowledge, attitude and practice* of all approaches – domestic water supply, surface water management, sludge management, new cropping practice, groundwater recharge, organic farming, medical service and rehabilitation, community involvement in developmental activities. Till now there is no clear policy on sludge management and therefore dumping of generated sludge from filter in open or improperly closed pit (closed top but open bottom) is still the usual practice. Even the sealed concrete chambers can not be considered safe forever due to fear of leaking due to faulty construction or overflow due to poor management and also the possibility of accidental exposure. Therefore there is a need of development of ecologically sound strategy to manage the sludge in order to minimize the environmental damage. According to some experts, the sludge developed by filters can be drained in latrine. Due to bacterial action in latrine the arsenic might be transformed into relatively harmless gaseous compound and further diluted after getting mixed with atmospheric air. (World Bank 2000) But still it is a debatable issue and needs more study. There are some innovative methods applied at local level, for example in north 24 pargana district of West Bengal, cement is mixed with arsenic sludge and developing concrete latrine pit and distributed among the villagers, which is as a part of national policy of total sanitation drive in rural India. This effort gives temporary respite in managing arsenic contamination through filters and subsequent sludge management. But according to the concerned staff, soon the demand of toilet will reach at saturation level and they have already decided to use arsenic sludge in making concrete roof top and promoting them in low cost housing. Indeed, the concealing or confining arsenic in concrete is not method of choice for prolong duration. If the concrete base damages and dumped in the field or backyard afterwards, there is also possibility of arsenic leaching in to the environment. There is also microbiological technique applied in pilot basis to reduce toxic effect of arsenic by converting trivalent to pentavalent arsenic, which is less toxic. (Kauser 2006) But the use of new microorganism needs to be carried out with a lot of precaution in order to preserve the micro ecosystem. Surveillance of arsenic in food chain and water can be an important component of operational research to measure the efficacy of existing strategy of supply of arsenic free water in domestic and irrigation use and assessment of ecological damage. There is no global standard for arsenic level in food and affecting the assessment of exposure risk. There should be proper guideline on assessment of environment exposure, health and ecology based risk assessment and followed by risk management. Research on arsenic mobility in aquifer and intensive geo-hydrological mapping by using GIS is essential for understanding of extent and proper distribution of arsenic in the affected area.

Strategy to be adopted at macro level

Prioritization of strategy: Due to resource problem and enormity of other public health issues, there is a need to prioritize the program. Ideally, it is essential to incorporate all strategies to get benefits of sustainable development. But to begin with, major priority should be to provide arsenic free water to the people and in irrigation to stop human exposure to arsenic through food chain. There is also need of international cooperation and exchange of information among the affected countries. (Sarkar 2000b)

CONCLUSIONS

Sustainable water management will not only save millions of people from arsenic menace but improve the rural economy and ecology and preserve rural society. In depth analysis of the problem shows how the present developmental paradigm destroyed the traditional but sustainable agriculture practice and pushed the lives of millions of people at risk. The piece meal approach in mitigation program could not yield any tangible benefit. On the other hand, few experiences in India show how sustainable mitigation program can bring down the disease burden in the affected areas. Arsenic problem is an environmental health emergency and a result of unsustainable agriculture policy, inequity and top down approach in framing mitigation strategy. Hence, there is an urgent need to tackle the problem by means of community participation, strengthening local governance, advocating interdisciplinary strategies. We have to understand that in rural India; even a highly successful technology may not succeed unless there is an honest political commitment, appropriate in rural circumstances and is well accepted by the rural mass. Solutions are lying in the affected areas, but right vision is needed to identify and appropriate them. Imbibing the concept of surface water management is indeed challenging as the use of this natural water has almost been forgotten. (Hanchett 2002) Community awareness and its mobilization in planning and implementation are necessary to undo the environmental damage made over past decades. In other words, the mitigation program is not just the sole responsibility of bureaucrats and technocrats; rather they are the facilitators to ensure the application of knowledge on the right path.

Notes

[a] Usually arsenic is found at the level of 40 feet (or beyond) below the surface, on the other hand dug well reaches maximum up to 15-20 feet below surface where water is relatively arsenic free. But the water of dug well gets easily contaminated by microorganisms causing water borne diseases, due to seepage from nearby latrines and open defecation site.

[b] Arsenic is found in some specific aquifers and the depths vary from place to place. But it has been found that deeper to certain arsenic layers, water is arsenic free and effort has been made to identify the deeper arsenic free layer in order to supply potable water to the community. But sinking of deep well is expensive and maintenance cost is more and not feasible in long run. So, local authorities also tried to extract water from relatively less arsenic contaminated layers and supplying water after treatment.

[c] The *panchayat* system as a form of local self-government has been embodied as an 'aspiration' in the 1950 Constitution and in practice it was devolved to the states for implementation. But no action was taken on this matter by any state till the late seventies and early eighties when opposition parties were elected to power in some states, notably West Bengal and Karnataka. The experience of West Bengal under the panchayat system stands in sharp contrast with the other states in India and together with land reform it has been credited for playing an important role in the impressive economic turnaround of the state since the mid 1980s. Encouraged by success of West Bengal, the 73rd Constitutional Amendment Act was enacted in 1993 to bring grassroots democratic processes in significant manner in whole country. The direct participation, initiative, and involvement of the people in a new model of self-governance were thought to be essential to achieve growth and development. (Ghatak 2002)

[d] Oxbow lake (locally known as 'Baor') is the unique features in Bengal delta (Bangladesh and West Bengal). It is a dead arm of a river in the Bengal delta as in the case of the Ganges. They range in size from half a square kilometer to 10-15 sq km. Baors generally have water throughout the year. The most common view regarding its origin is that when a river changes its course some of its sections at the supply source get silted-up, cuts off the arms and develops as oxbow lake. Baors receive water only when the parent river is in high flood. Usually during the wet season a baor receives local rainwater. At times, the accumulated water may spill over from the adjacent floodplain and may cause local flooding. Baors are considered to be very important wetlands of Bengal delta and support a wide range of aquatic lives and maintain a unique ecosystem.

[e] 'Beel' a large surface water body that accumulates surface runoff water in the depressions, which are essentially topographic blows produced by erosions giving a marshy character. Runoff is the term applied to the water that flows away from a catchment after falling on its surface in the form of rain. 'Beels' can be formed due to many causes. In some cases a string of them is found along a line of drainage, suggesting that they are the remains of some big river, which centuries age deserted it channel in favor of a new one somewhere else. In other cases, they are probably due to the actions of the river, which be centuries of silt deposits have raised their beds and marginal banks so high that they flow above the level of the surrounding area. These are seen all over Bengal delta. Many of the beels dry up in the winter but during the rains expand into broad and shallow sheets of water, which may be described as fresh water lagoons. A few larger ones are fed by floodwater during the wet season from the parent river channel. Most of these large 'beels' have shrunk quite considerably in recent decades.

[f] State government already made clear cut guidelines on installation of new hand pumps and clearance will be on the basis of certain norms such as location and distance from existing hand pumps etc. In 2005 there is government of West Bengal notification after approval of West Bengal legislature. It was named as 'the West Bengal ground water resources (management, control and regulation) act 2005'. The assent of the governor was first published in 31 August 2005. The minimum distance between two submersible pumps should be 200 meters. The distance between two high density pumps should be 1 kilo meter. The distance between high density pump and low density pump should be 600 meters. (GoWB 2005a)

[g] India is a signatory to the proclamation of full participation and equality of people with disabilities in the Asian and Pacific (ESCAP) held in Beijing 1992. India is also a signatory on UN declaration of human rights 1948, which talked about right live, right to livelihood. The persons with disabilities act 1995 encompasses almost every key issues right from prevention, early detection of disabilities, mainstream education in an appropriate environment, non-discrimination, barrier freer environment, employment, sustainable income generation, manpower development, affirmation action, social security. It has put in place the mechanism for evolution of comprehensive policies on disability both at the centre, state, their execution, monitoring and quasi-judicial redress of grievances of persons with disabilities. A combination of actions by the government, the civil society and the NGOs will help in achieving the desired outcomes. The actions are needed in the areas of early detection of disabilities and intervention (medical rehabilitation), accessibility of built environment, information and communication, positive shift in the mindset of people including persons with disabilities about their strength (social rehabilitation), inclusive education (educational rehabilitation). It is expected that when these four have been addressed the negative effect of a disability on a person in minimized and s/he can realize her/his maximum potential. These areas can be facilitated by favorable legislation. Majority of the persons with disability are amongst the poorest of the poor and poorer people are more prone to disabilities.

Reference

1. Acharyya, S.K. et al (2000), Arsenic toxicity of groundwater in parts of the Bengal basin in India and Bangladesh: the role of Quaternary stratigraphy and Holocene sea-level fluctuation, Environmental Geology, Vol. 39, No 10, pp 1127-1137.
2. Agarwal, A. et al (2000), Introduction, *Making Water Everybody's Business,* Centre for Science and Environment, New Delhi.

3. Alam, M. G. et al (2003), Arsenic and Heavy Metal Contamination of Vegetables Grown in Samta village, Bangladesh. *Science of Total Environment*, Vol. 308, No. 1-3, pp 83-96.
4. Athavale, R. N. (2003) Water Harvesting and Sustainable Supply in India, *Centre for Environment Education,* Ahmedabad (India).
5. Bardhan, P. et al (2004), Poverty alleviation efforts of panchayats in West Bengal, *Economic and Political Weekly,* February 28, 2004, pp 965 – 974.
6. Bates, M. N. et al (1992), Arsenic Ingestion and Internal Cancers: A Review, *American Journal of Epidemiology*, Vol. 3, pp 462-476.
7. Bhattacharya, D. et al (2004), Arsenic-polluted groundwater in West Bengal: a cost-effective remedy, *Current Science,* Vol. 86, No. 9, 10 May, pp 1206-1209.
8. Chatterjee, B. (1998), Poverty in West Bengal – what have we learnt? *Economic and Political Weekly,* November 21, 1998, pp 3003 - 3014.
9. Chakraborti, D. et al (1994), Arsenic Contamination in Ground Water in Six Districts of West Bengal, India: the Biggest Arsenic Calamity in the World, *Analyst,* Vol. 119, pp 168-170.
10. Chakraborti, D. et al (1996), Arsenic in Ground Water in Seven Districts of West Bengal, India – The Biggest Arsenic Calamity in the World. *Current Science*, Vol. 70, No. 11, pp 976-986.
11. Chakraborti, D. et al (1997), Ground Water Arsenic Calamity in Bangladesh, *Current Science*, Vol. 73, No. 1, pp 48-59.
12. Chakraborti, D. et al (2000), Groundwater Arsenic Contamination in Bangladesh and West Bengal, India**,** *Environmental Health Perspectives*, Vol. 108, No. 5, pp. 393-397.
13. Chakraborti, D. et al (2004), Groundwater arsenic contamination and its health effects in the Ganga-Meghna-Brahmaputra plain, *Journal of Environmental Monitoring,* Vol. 6, pp 74N-83N.
14. Chakraborti D. et al (2006), Groundwater arsenic contamination in the Ganga-Padma-Brahmaputra plain of India and Bangladesh, (*plenary lecture*) *Second international conference on groundwater for sustainable development – problem, perspectives and challenges, 1 – 4 February 2006, New Delhi,* India, in book of abstracts, p 169.
15. Chakraborti, D. (2006), 'Groundwater Arsenic Contamination in Ganga-Meghna-Brahmaputra (GMB) Plain', *http://www.soesju.org/arsenic/arsenicContents.htm?f=ganga.htm*, as viewed on October 2006.
16. Chowdhury, U.K. et al (2000), Groundwater arsenic contamination in Bangladesh and West Bengal, India, *Environmental Health Perspectives,* Vol. 108, No. 5, pp 393-397.
17. Chowdhury, U.K. et al (2001), Groundwater arsenic contamination and human suffering in West Bengal, India and Bangladesh, *Environmental Science,* Vol. 8, No 5, pp 393-415.
18. CSE (2000), *A Water Harvesting Manual*, Centre for Science and Environment, New Delhi, p 6.
19. Das, H.K. (2004), Arsenic Concentrations in Rice, Vegetables and Fish in Bangladesh: A Preliminary Study, *Environment International*, Vol. 30, No, 3, pp 383-387.
20. Das, D. (2006), A Simple Household Devise to Remove Arsenic from Groundwater and Two Years Performance Report of Arsenic removal Plant for Treating Groundwater with Community participation, www.unu.edu/env/arsenic/Das as viewed on 17th Sep, 2006.
21. Das, D.K. et al (2005), Interaction of arsenic with zinc and organics in a rice (*oryza sativa* L.)–cultivated field in India, *The Scientific World Journal* (2005) 5, 646–651.
22. Dhawan, B.D. (2000), Drip irrigation – evaluating return, *Economic and Political Weekly,* Oct 14, pp 3775-3780.
23. Evenari, M. (1971), The Negev: The Challenge of a Desert, *Oxford University Press,* UK.
24. Ghatak, M. et al (2002), Recent Reforms in the Panchayat System in West Bengal - Toward Greater Participatory Governance?, *Economic and Political Weekly*, Jan 5, pp 45 – 58.
25. GOI (1981), Annual Report, Indian Meteorological Department, New Delhi.
26. GOI (1991), Census of India, New Delhi.
27. GOI (1998), Water and Related Statistics, Central Water Commission, New Delhi, pp 14, 108-109.
28. GOI (2005), National Rural Health Mission (2005-2012): Mission Document, Ministry of Health and Family Welfare, Nirman Bhawan, New Delhi.
29. GOI (2007), Ministry of Rural Development, http://rural.nic.in/ as viewed on 30th Mar 2007.
30. GoWB (1993), 'Circular', Agriculture (minor irrigation) department, State water investigation department, Kolkata.
31. GoWB (2003), 'West Bengal -Rural Development Special Issue', Department of Information and Culture, Government of West Bengal, Basumati Corporation, Kolkata, West Bengal. *(in Bangla)*

32. GoWB (2005a), 'West Bengal Act XVIII of 2005, the West Bengal ground water resources (management, control and regulation) act 2005,' The Kolkata Gazette, Kolkata.
33. GoWB (2005b), Master plan for arsenic contamination in West Bengal, Public Health Engineering Department (PHED), West Bengal, Kolkata (unpublished document).
34. Guha Mazumdar, D.N. et al (1988) Chronic Arsenic Toxicity from Drinking Tube Well Water in Rural West Bengal, *Bulletin of WHO*, Vol. 66, pp 499-506.
35. Guha Mazumdar, D.N. et al (2000), Arsenic in drinking water and the prevalence of respiratory effects in West Bengal, India, *International Journal of Epidemiology,* Vol. 29, pp 1047-1052.
36. Hanchett, S. et al (2002), Increasing Awareness of Arsenic in Bangladesh: Lesions from a Public Education Programme, *Health policy and Planning,* Vol. 17,No. 4, pp 393-401.
37. Hassan, M.M. et al (2005), Social implications of arsenic poisoning in Bangladesh, *Social Science and Medicine*, Vol. 61, pp 2201-2211.
38. Hironaka, H. et al (2003), Arsenic Concentration of Rice in Bangladesh. In: Fate of Arsenic in the Environment, *Proceedings of the BUET-UNU International Symposium*, Dhaka, February 5-6.
39. Hossain, M.A. et al (2005), Ineffectiveness and poor reliability of arsenic removal plants in West Bengal, India, *Environmental Science and Technology,* Vol 39, No. 11, pp 4300-4306.
40. ICRISAT (2006), Annual Rainfall, http://www.icrisat.org/text/research/nrmp/dfid/Text/ as viewed on 25th March 2006.
41. Kauser, J. et al (2006), Microbial Removal of Arsenic, *Water, Air and Soil Pollution: Focus*, Vol. 6, No.1-2, February 2006, pp. 71-82.
42. Meharg, A. (2002), Arsenic uptake and metabolism in arsenic resistant and nonresistant plant species, *New Phytologist,* Vol. 154, pp 29-43.
43. Meharg, A. (2004), Arsenic in Rice – Understanding New disaster for South East Asia, *Trends in Plant Science,* Vol. 20, No. 20, pp 1-3.
44. Mitra, S. R. et al (2004), Nutritional Factors and Susceptibility to Arsenic-Caused Skin Lesions in West Bengal, India, *Environmental Health Perspectives,* Vol. 112, No. 10, pp 1104-1109.
45. Mukherjee, A.B. et al (2006), Groundwater arsenic contamination in India: extent and severity, in (Eds) Ravi Naidu et al, *Managing Arsenic in the Environment: from soil to human health*, CSIRO, Australia, pp 553-593.
46. Nandi, D et al, (2005), Arsenic residues in hair samples from cattle in some arsenic affected areas in West Bengal, India, *Bulletin of Environmental Contamination and Toxicology,* Vol. 75, pp 251-256.
47. Nickson, R.T. et al (2000), Mechanism of Arsenic Release to Groundwater, Bangladesh and West Bengal, *Applied Geochemistry,* Vol. 15, , pp 403-13.
48. Pant, N. (2004), Trends in groundwater irrigation in eastern and western UP, *Economic and Political Weekly,* July 31, 2004, pp 3463-3468.
49. Pant, N. (2005), Control of and access to groundwater in UP, *Economic and Political Weekly,* June 25, 2005, pp 2672-2680.
50. Pecey, A et al (1989), *Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural Areas*, Intermediate Technology Publications, London.
51. Rahman, M.M. et al (2001), Chronic Arsenic Toxicity in Bangladesh and West Bengal, India – A Review and Commentary, *Clinical Toxicology,* Vol. 39, No. 7, pp 683-700.
52. Rahman, M.M. et al (2005a), Arsenic contamination of Groundwater and Its Health Impact on Residents in a Village in West Bengal, India, *Bulletin of WHO*, Vol. 83, No. 1, pp 49-57.
53. Rahman, M.M. et al (2005b), The magnitude of arsenic contamination in groundwater and its health effects to the inhabitants of the Jalangi – one of the 85 arsenic affected blocks in west Bengal, India, *Science of the Total Environment*, Vol. 338, pp 189-200.
54. Rahman, M.M. et al (2005c), Status of groundwater arsenic contamination and human suffering in a gram panchayat (cluster of villages) in Murshidabad, one of the nine arsenic affected districts in West Bengal, India, *Journal of water and Health,* Vol.3, No 3, pp 283-296.
55. Ravenscroft, P. et al (2001), Geochemical and Palaeohydrological Controls on Pollution of Groundwater by Arsenic. *Arsenic Exposure and Health Effects IV,* W.R. Chappel, C.O., Elsevier Science Ltd, Oxford.pp 53-77.
56. Rawal, V. et al (1998), Changing Trajectories: Agricultural Growth in West Bengal 1950-1996, *Economic and Political weekly,* Vol. 33, pp 2595-2602.
57. Rawal, V. (2001a), Irrigation Statistics in West Bengal-1, *Economic and Political Weekly,* July 7, pp 2537-2544.

58. Rawal, V. (2001b), Expansion of Irrigation in West Bengal: Mid-1970s to Mid-1990s, *Economic and Political Weekly,* October 20, pp 4017-4024.
59. Roychowdhury, T. et al (2002), Arsenic and Other Heavy Metals in Soils from An Arsenic-Affected Area of West Bengal, India, *Chemosphere,* Vol. 49, No. 6, pp 605-618.
60. Sarkar, A. (1999), Arsenic poisoning in ground water of West Bengal: Cause, effect and comprehensive strategy for sustainable development. In: *1st biennial conference of Indian Society for Ecological Economics (INSEE),* 20-22 December 1999, ISEC, Bangalore, India.
61. Sarkar, A. (2000a), Arsenic poisoning in ground water of West Bengal: An example of negative impact of green revolution on human health. In: *44th National Conference jointly organized by Indian Public Health Association (IPHA), Indian Association of Epidemiologists (IAE) & Indian Society of Malaria & Other Communicable Diseases (ISMOCD),* 10-12 March 2000, Agra, India.
62. Sarkar, A. (2000b), Arsenic poisoning in Gangetic delta: cause, effect and urgent need of close cooperation between India & Bangladesh to fight against it. In: *Proc. South Asian Conference on Legacy of Mahbub-Ul Haq - Human Development.* May, 2000, New Delhi, India.
63. Sarkar, A. (2002), Unsustainable agricultural policy and arsenic contamination of ground water in Bengal basin: A social epidemiological study. In: *Proc. South East Asia Congress of Epidemiology (Regional meeting of International Epidemiological Association) "From Preventing Disease to Promoting Health & Quality of Life".* 24-27 February, 2002, Jhansi, India. Book of Abstract 72.
64. Sarkar, A. (2004), Social epidemiology of arsenic poisoning of Murshidabad district in West Bengal, (*PhD Thesis submitted and defended*) Centre of Social Medicine and Community Health, School of Social Sciences, Jawaharlal Nehru University, New Delhi, India.
65. Sarkar, A. et al (2005), Social dimensions of chronic arsenicosis in West Bengal (India). In: *Proc.17th annual conference of International Society of Environmental Epidemiology (ISEE) "Sustaining World Health through Environmental Epidemiology: Setting a New Global Research Agenda".* 13-16, September, 2005, Johannesburg, South Africa. Abstract in *Epidemiology* (2005) 16 (5): S68.
66. Sarkar, A. (2006a), Role of social factors as determinants for chronic arsenicosis in India. In: Ramanathan A.L., Bhattacharya P., Chandrasekharam D., Keshari A.K., Thangarajan M., & Bundschuh J. (Eds) *Proc. International Groundwater Conference (IGC 2006) "Groundwater for Sustainable Development – Problems, Perspectives and Challenges".* 1-4 February, 2006, Jawaharlal Nehru University, New Delhi, India. Book of Abstract 225-226.
67. Sarkar, A. et al (2006b), Role of inequality and inequity in chronic arsenicosis and its consequences. In: *Proc. International conference on environmental epidemiology and exposure "Science, Population Diversity, Caution and Precaution".* 2 – 6, September, 2006, Paris, France. Book of Abstract 333.
68. Sarkar, A. et al (2006c), Towards finding a sustainable solution for arsenic contamination of ground water: A SWOT analysis. In: *Proc. International conference on environmental epidemiology and exposure "Science, Population Diversity, Caution and Precaution".* 2 – 6, September, 2006, Paris, France. Book of Abstract 340.
69. Sharma, A.K. et al (2006), Exploiting natural iron precipitation against arsenicosis, *Second international conference on groundwater for sustainable development – problem, perspectives and challenges, 1 – 4 February 2006, New Delhi,* India, in book of abstracts, p 224.
70. Smith, A.H. et al (1992), Review of Cancer Risks from Arsenic in Drinking Water. *Environmental Health Perspectives,* Vol. 97, pp 259-267.
71. Smith, A.H. et al (2004), Arsenic drinking water regulations in developing countries with extensive exposure, *Toxicology,* Vol. 198, pp 39-44.
72. Smith, M.M. et al (2003), A dugwell program to provide arsenic-safe water in West Bengal, India: preliminary results, *Journal of Environmental Science and health,* Vol. A38, No. 1, pp 289-299.
73. Smith, M.M. (2000a), An assessment of alternative methods of providing arsenic free water in villages of north 24 Parganas, West Bengal, India, http://projectwellusa.org/publications/art1_alternativemethods.htm as viewed on September 2005.
74. Smith, M.M. (2000b), The best adaptable method to provide arsenic-free water to the arsenic affected villages of N 24 Parganas, http://projectwellusa.org/publications/art1_alternativemethods.htm as viewed on September 2005.
75. Singh, H.P. et al (2003a), Rainwater Management in Semi-arid Regions, *Proceedings of National Symposium on Rainwater Management for Water Security*, Jabalpur (India), January 6-7 pp 28-34.

76. Singh, H.P. et al (2003b), Rainwater Conservation and Management Technologies in Rainfed Agriculture Focussing Indigenous Knowledge, *Proceedings of National Symposium on Rainwater Management for Water Security*, Jabalpur (India), January 6-7.
77. Sitaramam, V. et al (1996), Minimum needs of poor and priorities attached to them, *Economic and Political Weekly,* September, 1996, pp 2499-2505.
78. SOS-Arsenic (2006), Groundwater - Hydrogeology of Bangladesh, http://www.sos-arsenic.net/english/groundwater/#4 as viewed on 25th March 2006.
79. Sundaram, K et al (2003), Poverty in India in the 1990s – an analysis of changes in 15 major states, *Economic and Political Weekly,* April 5, 2003, pp 1385-1393.
80. Suryanarayana, M.H. (1996), Poverty estimates and indicators – importance of data base, *Economic and Political Weekly,* September, 1996, pp 2487-2497.
81. SWID (2005), State Water Investigation Directorate, http://www.wbwidd.org/english/swid/activities2.htm as viewed on 25th march 2005.
82. Unicef (1998), State of the children's report, Unicef, New York.
83. Vahter, M. (1998), Exposure to Arsenic During Early Human Development, *Proceedings of the International Conference on Arsenic Pollution of Groundwater in Bangladesh: Causes, Effects and Remedies,* Dhaka, February 8-12.
84. Verma, H. N. (2003), Rainwater Characteristics and Management Problems in Humid and Per Humid Regions, *Proceedings of National Symposium on Rainwater Management for Water Security*, Jabalpur (India), January 6-7, pp 8-16.
85. WHO (2000), Towards an assessment of the socioeconomic impact of arsenic poisoning in Bangladesh, Department of Health in Sustainable Development, water, Sanitation and Health, World Health Organization, Geneva.
86. WHO, (2005), A Field Guide for Detection, Management and Surveillance of Arsenicosis, *SEARO-WHO,* New Delhi.
87. World Bank (2000), Arsenic mitigation in West Bengal and Bangladesh – case study, Water and sanitation Program, The World Bank, New Delhi, India.
88. Zahangir, A.M. (2003), Accumulation of Arsenic in Rice Plants from Arsenic Contaminated Irrigation Water and Effect on Nutrient Content, In: Fate of Arsenic in the Environment, *Proceedings of the BUET-UNU International Symposium*, Dhaka, February 5-6.