WATER RESOURCES MANAGEMENT IN THE REMEDIATION OF GROUNDWATER ARSENIC CONTAMINATION IN BANGLADESH

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ABSTRACT

Severe arsenic contamination of groundwater in Bangladesh has disrupted the idea of using shallow tube-wells for safe drinking water throughout the country. Millions of tube-wells that had been sunk in various parts of the country are now dispensing arsenic contaminated drinking water. As a result, thousands of people are suffering from arsenic related diseases. The severity of arsenic contamination necessitates restricted use of groundwater and a move to alternative water sources such as ponds, lakes, canals, rivers and rain. Assured, affordable and sustainable safe water sources are vital for all communities to combat an arsenic disaster. Competent water resources management could play a key role to solve the arsenic contamination problem in Bangladesh ensuring the supply of safe drinking water. A community based management group is needed to operate and maintain the water sources efficiently in rural Bangladesh. This study recommends a simple community based water resources management model. The proposed model presents novel concepts and includes new parameters to find a sustainable option of safe drinking water through the active participation of local people. Above all, the present study indicates that intelligent and accountable water resources management will not be established without the conscientious participation of local communities.

Keywords: Arsenic, Groundwater, Local community, Management model, Water resources management.

1. INTRODUCTION

Bangladesh is a country of floodplains and is located on the delta of one of the world's major rivers, The Ganges River. The country is rich in water resources and has a number of rivers, canals, lakes, and huge water-bearing aquifers. Every year the country is also blessed with ample rain. Yet, the people of this country are deprived of the desired benefits from the water resources mainly due to the lack of management policy and technical drawbacks. An adept management scheme is essential to get the maximum benefits from the existing water resources without causing other problems. Unfortunately, until now Bangladesh has not achieved a satisfactory level of skill in water resources management.

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Only after the emergence of Bangladesh as a country, water resources management became recognized as essential to ensure the supply of safe drinking water throughout the country. Massive programs for sinking shallow tube-wells were introduced by the Department of Public Health Engineering (DPHE) in cooperation with United Nations Children's Fund (UNICEF) in 1973 (Begum and Karim 2000). Since that time the DPHE became the prominent leader for water supply in rural areas, and a decentralized institutional network up to the Upazila (division of district) level was established. Due to the high level of advocacy for good quality water, the private agencies and non-governmental organizations (NGOs) were encouraged to install more shallow tube-wells in rural Bangladesh. The lack of proper planning of tube-well installation resulted in excessive withdrawal of groundwater for the last 40 years (Miah 1998). Multifaceted stresses resulting from the lack of efficient water resources management have created the potential for conflicts between different segments of rural society. The failure of government to ensure the participation of rural people in planning and implementation of water resources management policy has exacerbated the tensions over arsenic contamination in groundwater.

Arsenic contamination in Bangladesh has slowly approached a disaster during the last decade due to the overexploitation of groundwater and inefficient water resources management. Rapid population growth and the lack of overall coordination have increased the demand for water and created the conflicts. The widening gap between demand and supply of water is bringing severe socio-economic and environmental problems in Bangladesh. Hence, the continued exploitation of water resources is inevitable, and therefore, water resources management seems to be a challenging task in Bangladesh. The organizations concerned with water resources management have failed to attain the required level of efficiency. Their failure in water resources management has played a major role in creating arsenic contamination in Bangladesh.

In order to mitigate the arsenic disaster, it is essential to treat the arsenic contaminated water and water sources or to avoid the arsenic contaminated water. Removal of arsenic from water is possible by ultraviolet radiation, oxidation, chemical precipitation and filtration (Safiuddin and Karim 2001). Arsenic contaminated soils and shallow groundwater aquifers could also be cleaned by flushing out arsenic contaminants. The avoidance of arsenic is also likely by the use of surface water, rainwater, and alternative groundwater sources. In this context, a comprehensive water distribution system must be implemented and a national water resources management policy should be established in order to limit the indiscriminate extraction of water. An efficient monitoring system should also be established to ensure the supply of potable water throughout the country, and to prevent further arsenic contamination in drinking water. For overall improvement of the present arsenic disaster in Bangladesh, it is highly recommended that every donor project of arsenic mitigation be legally required to ensure the community participation in water resources management. In any water supply and arsenic mitigation project, water resources management with the involvement of local community would play an important role in the remediation of groundwater arsenic contamination. Therefore, this study has reinforced the issue of community based water resources management in the present scenario of arsenic contamination in Bangladesh. This paper reveals the severity of arsenic contamination; highlights the alternative options for safe water; discusses the necessity of a sustainable national water resources management policy for the country; recommends community participation in water resources management and finally introduces a simple management model for combating arsenic contamination of groundwater in Bangladesh.

2. SEVERITY OF ARSENIC CONTAMINATION IN BANGLADESH

The arsenic contamination of Bangladesh's groundwater with its genesis and toxic effects on humans has already been reported (Dhar et al. 1997, DCH 1997, Karim et al. 1997, Nickson et al. 1998, Ahmed 2000, Karim 2000). Recent studies in Bangladesh indicate that the groundwater is severely contaminated with arsenic above the maximum permissible limit of 0.05 mg/l for drinking water. Altogether 400 measurements were conducted in Bangladesh in 1996 (Smith et al. 2000). Arsenic concentrations in about half of the measurements were above the maximum permissible limit. In 1998, British Geological Survey (BGS) collected 2,022 tube-well water samples from 41 arsenic affected districts (Smith et al. 2000). Laboratory tests revealed that 35% of these water samples had arsenic concentrations above 0.05 mg/l. Moreover, School of Environmental Studies (SOES), Jadavpur

Table 1: Current Statistics of Arsenic Calamity in Bangladesh (Begum and Karim 2000, World Bank 2000, Safiuddin and Karim 2001, Meng et al. 2001)

Total number of districts in Bangladesh	64
Total area of Bangladesh	147,570 km^2
Total population of Bangladesh	129 million
WHO arsenic drinking water standard	0.01 mg/l
Bangladesh arsenic drinking water standard	0.05 mg/l
Total number of shallow tube-wells in Bangladesh	5 million
Total number of affected shallow tube-wells	3 million
Number of districts surveyed for arsenic contamination	64
Number of districts having arsenic above 0.05 mg/l in groundwater	59
Area of affected 59 districts	126,134 km^2
Population at risk	70 million
Population potentially exposed	24 million
Number of patients suffering from arsenicosis	10,554
Number of patients died of arsenicosis	10

University, India and Dhaka Community Hospital (DCH), Bangladesh had jointly analyzed 22,003 tube-well water samples collected from 64 districts of Bangladesh between August 1995 and February 2000 (SOES and DCH 2000). Five years of sampling indicated that arsenic concentration in groundwater was above 0.01 mg/l in 54 districts and above 0.05 mg/l in 47 districts. Furthermore, a recent study of World Bank reports, "With more than an estimated 20 million of its 126 million people assumed to be drinking contaminated water and another 70 million potentially at risk, Bangladesh is facing what has been described as perhaps the largest mass poisoning in history. High concentrations of naturally occurring arsenic have already been found in water from thousands of tube-wells, the main source of potable water, in 59 out of Bangladesh's 64 districts" (World Bank 2000). The contemporary statistics given in Table 1 reveal the severity of arsenic contamination in Bangladesh. In fact, arsenic contamination has become a serious problem in 16 districts of the country affecting 15 million people (Safiuddin and Karim 2001). The groundwater of Kushtia, Meherpur, Chuadanga, Jhenidah, Nawabganj, Naogaon, Khulna, and Rajshahi has been badly contaminated by arsenic. Since 95% of the population of Bangladesh is drinking groundwater, arsenic contamination has evolved into a serious health hazard. Arsenic is accumulating in humans through the intake of arsenic contaminated drinking water. As the people are also getting arsenic from the food chain, the problem is growing more severe. SOES and DCH performed a field survey for arsenic patients in 32 districts of Bangladesh (SOES and DCH 2000). The researchers analyzed a total of 5440 hair, 5321 nail, 1125 urine, and 820 skin scale samples collected from 210 arsenic affected villages. The results analysis given in Table 2 show that over 80% hair samples were found to contain arsenic above the level indicating toxicity. Arsenic concentrations were also above the normal ranges in more than 90% nail and 95% urine samples. The normal concentration of arsenic in hair is 0.08-0.25 mg/kg. Levels above 1 mg/kg indicate toxic exposure (Arnold et al. 1990). The normal arsenic content in nails is 0.43-1.08 mg/kg (Dhar et al. 1997) and the normal amount of arsenic in urine ranges from 0.005 to 0.040 mg/day (Farmer and Johnson 1990). Obviously, the arsenic contents in hair, nails, urine and skin scales of the affected people in Bangladesh are very high. This indicates that arsenic is being ingested in humans at a rate faster than it can be excreted. Therefore, many people in Bangladesh are suffering from arsenic driven

Table 2: Arsenic Contents in Hairs, Nails, Skin Scales and Urines of the Patients in the Affected Regions of Bangladesh (SOES and DCH 2000)

Field survey from August 1995 to February 2000 (239 days)	
Total number of analyzed hair samples	4386
Percentage of samples having arsenic above toxic level[1]	83.15%
Total number of analyzed nail samples	4321
Percentage of samples containing arsenic above normal level[2]	93.77%
Total number of analyzed urine samples	1084
Percentage of samples having arsenic above normal level[3]	95.11%
Total number of analyzed skin scale samples	705
Percentage of samples containing arsenic above 1 mg/kg	97.44%
Field survey from April 1999 to February 2000 (27 days)	
Total number of analyzed hair samples	1054
Percentage of hair samples having arsenic above toxic level	89.35%
Total number of analyzed nail samples	1000
Percentage of nail samples containing arsenic above normal level	94%
Total number of analyzed urine samples	41
Percentage of urine samples having arsenic above normal level	97.50%
Total number of analyzed skin scale samples	115
Percentage of samples containing arsenic above 1 mg/kg	100%

diseases. Patients with arsenical skin-lesions have been identified in 30 districts. Melanosis and keratosis are the most common manifestations among the arsenic affected people, although patients of leuco-melanosis and hyperkeratosis have also been found. A few cases of skin cancer, gangrene and Bowen's disease have also been identified. In brief, the majority of the people in Bangladesh are

[1] Toxic level of arsenic in hairs: 1 mg/kg
[2] Normal level of arsenic in nails: 0.43 – 1.08 mg/kg
[3] Normal level of arsenic in urines: 0.005 – 0.04 mg/day

grappling with an arsenic driven health crisis. Indeed, the magnitude of the arsenic problem in Bangladesh surpasses the aggregate problem of all the twenty countries of the world where groundwater arsenic contamination had been reported. This is the worst case of arsenic contamination the world has ever experienced.

3. ALTERNATIVE OPTIONS FOR SAFE WATER

The situation of groundwater arsenic contamination in Bangladesh is so serious that immediate steps should be taken to find the suitable alternative water sources or to purify the water collected from contaminated sources and deliver potable water to all seriously affected areas for drinking and cooking purposes. The organization of alternative sources of water should be given high priority. If no efficient arsenic removal measure is quickly forthcoming, the only solution is to seek alternative sources of safe water. In the present situation of arsenic contamination, surface water sources such as the ponds and rivers must be the first option for safe water and, therefore, the old habit of drinking surface water should be reconsidered. Furthermore, rainwater can be collected directly and used for household consumption. Thus, rainwater harvesting should be the second option. The third option for safe water could be alternative groundwater sources in conjunction with the treated arsenic contaminated water. Deep tube-wells, infiltration galleries, infiltration wells, and sanitary dug-wells can be used as alternative sources of arsenic free groundwater. Simultaneously, shallow tube-wells with permissible arsenic (< 0.05 mg/l) in extracted water should continue to be used with regular monitoring and testing of water to ensure the acceptability.

3.1 Surface Water

Bangladesh possesses a number of rivers, canals and natural depressions (haors, baors and beels). The total length of the rivers is about 22,050 kilometers. They carry about 7080 million cumec of water during the rainy season. This huge amount of surface water can meet all the requirements if it is utilized properly. Surface water sources are relatively free from arsenic but extremely polluted by bacteria and perilous pathogens. Therefore, surface water must need effective treatment if it is intended to be used as drinking water. The establishment of treatment plants in rural areas is not feasible since surface water delivery is expensive and its implementation is also time consuming. Still, surface water could be a major alternative option to satisfy safe water requirements. In the current scenario of arsenic disaster in Bangladesh, treated surface water could be used for drinking, cooking, and for other household purposes. However, a low-cost simple technology is necessary for the local communities to purify the surface water.

Surface water can be purified passing through a special filter bed of sand or other locally available equivalent materials. This type of filter is commonly known as pond sand filter (PSF) and is already popular in Bangladesh. At present, about 375 units are in operation in the coastal region of Bangladesh serving more than 200 people per unit (Begum and Karim 2000). PSF can effectively remove turbidity and bacterial contamination, and, therefore, could be recommended for small rural communities in the arsenic affected areas of Bangladesh. The construction cost of a PSF unit is not out of the reach of local communities. The monthly maintenance cost is also negligible. Monthly maintenance includes washing of the sand bed with plain water and preferably drying in sunlight. Continuous care is required to maintain the quality of water. Thus, the awareness and participation of local people is essential for the smooth running of community based water supply system established with a PSF unit.

Polluted surface water can also be purified by disinfection. Simple boiling, ultraviolet radiation such as sunlight (solar radiation), and chemicals such as chlorine and ozone could be used in disinfection. In the poor villages of Bangladesh, solar water disinfection could be easy and cost-effective. Solar water disinfection is a simple and low-cost water treatment method to improve the microbiological quality of drinking water (Wegelin and Sommer 1998). This method will be sustainable if surface water is pretreated through sedimentation, flocculation or filtration. Individual families and small communities would be able to use this technology without any need for significant financial investment or the support of an external agency. Therefore, solar water disinfection might be a feasible solution to the problem of arsenic contamination for low-income communities.

3.2 Rainwater

Rainwater in rural areas of Bangladesh is fairly clean and considered water of 'gold standard'. Dhaka Water Supply and Sewerage Authority (WASA) has shown that rainwater is free from bacteria and other pollutants (Begum and Karim 2000). Therefore, rainwater harvesting can be practiced as a second preference in the community based water supply system to combat the arsenic disaster in Bangladesh. The average annual rainfall in Bangladesh is about 2200 mm (Begum and Karim 2000). Seventy-five percent of it occurs between May and September. Potable drinking water from rainwater harvesting could be supplied effectively to the people in arsenic contaminated areas. In a water supply system totally based on rainwater harvesting, the excessive rainwater collected in wet season could also be stored for consumption during the dry season. For this, sustainable collection, storage and distribution methods need to be developed based on the existing practices in India, Maldives, Thailand and some of the Caribbean countries. In addition, proper education and training should also be provided with state of the art options for storage and distribution of rainwater in order to avoid microbiological contamination.

Vast storage of rainwater is required to supply water throughout the year. It is possible by providing several rainwater harvesters (RWHs) in series or constructing large underground storage tanks, which would hold enough water to cover the whole year. Although rainfall storage would be too costly for rural households, it would not be too expensive to prohibit the technology if it were planned as an integral water supply system for a community. Rainwater can also be stored in sanitary ponds. A community drinking water supply scheme based on rainwater in sanitary ponds with provision for withdrawal of water through hand pumps and treatment through PSF-like filters is a good option. This method would also be cost-effective and feasible in rural areas. Therefore, the development of a rainwater harvesting plant should be given high priority to mitigate the arsenic disaster in Bangladesh.

3.3 Groundwater

Seventy-nine percent of rural people in Bangladesh drink groundwater extracted by shallow tube-wells (Begum and Karim 2000). It is not easy for them to switch quickly to the use of surface water and/or rainwater. Hence, the usage of groundwater from shallow tube-wells with permissible arsenic concentration should be continued until getting the appropriate alternative water sources with desired level of acceptability. At the same time, arsenic free alternative groundwater sources must be sought.

3.3.1 Groundwater from Shallow Tube-wells

Shallow tube-wells appeared to be the best option for a water supply free of pathogens. The occurrence of chronic arsenic poisoning has greatly diminished the success of shallow tube-wells. There are approximately 5 million shallow tube-wells in Bangladesh. Arsenic contamination of groundwater has polluted about 3 million of these tube-wells (Meng et al. 2001). Therefore, polluted tube-well water must be purified when the other alternative options of potable drinking water are not feasible. There are a variety of technologies for the treatment of arsenic contaminated water (Jekel 1994). Filtration and direct co-precipitation filtration (DCF) are mostly being used in affected areas of Bangladesh. A cost-effective filter candle called Safi filter has been developed locally. A Safi filter can provide approximately 40 liters of treated water per day. This amount of drinking water is more than sufficient for a family of six.

A household bucket filter has also been devised based on the principles of co-precipitation and filtration (Meng et al. 2001). The technique needs an iron coagulant that is mixed with water for a few minutes. The iron coagulant dissolves in water and binds with the arsenic molecules resulting in iron-arsenic flocs. The water is then poured into the bucket filter and passed through the highly absorptive sand bed packed at the bottom of the filter. Finally, clean water is collected through a tube connected to the bottom of the bucket filter. The precipitated arsenic sludge remains in the sand filter. This method of arsenic removal is very simple, cost-effective and user-friendly. It would supply about 50 liters of water per day.

Another arsenic removal technique that has become popular in Bangladesh is the three-pitcher method. This technique is based on a method of filtration that has been used in Bangladesh for many years and utilizes three 18-liter pitchers (kolshis) made of unglazed clay (Khan et al. 2000). The first pitcher contains iron chips and coarse sand while the second pitcher includes wood charcoal and fine sand. The water poured into the top pitcher gets filtered while passing through the first two pitchers. The filtered water is then collected in the third pitcher. This filter is inexpensive and very simple to construct. The villagers will be able to obtain the materials locally and construct such a device for themselves.

3.3.2 Groundwater from Other Sources

Deep aquifers (depth > 100 m) have been found to be relatively free from arsenic contamination (Karim and Begum 1999). Hence, deep tube-wells can be sunk when all other options are not economically viable. At the same time, it should be kept in mind that the excessive use of deep aquifers would subsequently result in a similar disaster after 10-15 years. The deep aquifers are also susceptible to contamination if arsenic contaminated water percolates from the upper shallow aquifers. However, the recharge of deep aquifers by gravity percolation through coarse media and replenishment by horizontal movement of water could keep them free of arsenic even after prolonged water extraction.

Arsenic free groundwater could also be collected from infiltration galleries, infiltration wells, and sanitary dug-wells. An infiltration gallery is a nearly horizontal tunnel constructed through a shallow aquifer. The gallery obtains its water from the aquifer by various porous drainpipes. Conversely, infiltration wells are constructed in series and connected to a larger collecting well known as Jack well. Compared to the infiltration galleries and infiltration wells, sanitary dug-wells are particularly cost-effective and suitable in the poor villages of Bangladesh. Dug-wells were the traditional sources of drinking water before the emergence of tube-wells. At the early stage, these wells were basically a vertical hole in the ground with a depth of 4.5 to 6 meters. With the improvement of local technology, people started using earthen, cement concrete (CC) or reinforced cement concrete (RCC) rings to raise the serviceability of dug-wells. Lately, it has been observed that the dug-well water, though coming from almost the same layer as the shallow tube-wells, does not contain arsenic above the maximum permissible limit. This observation indicates that the release of arsenic is linked with the groundwater movement based on the withdrawal patterns. The occurrence of arsenic is controlled by the vertical component of groundwater flow. It is also related to the physical, chemical, and biological environment of groundwater in and around the water sources (Matsumoto and Hosoda 2000). Nearly horizontal movement of groundwater results in reduced arsenic concentration in dug-well water. Consequently, the researchers urge that the dug-wells could help the arsenic affected people. The local villagers already know the technology. It is only necessary to protect the water from contamination during the process of water collection and to improve the water quality. The traditional dug-wells could be upgraded into sanitary dug-wells by including a hand pump and a filter unit. The water from a dug-well can be pumped into the filter unit, which would remove turbidity and microbes. One sanitary dug-well is capable of supplying almost 1000 liters of water per day. Thus, the sanitary dug-well might be an affordable and sustainable option for the poor people of Bangladesh.

4. NEED OF SUSTAINABLE WATER RESOURCES MANAGEMENT

There are significant water resources in Bangladesh. Major sources of water include rains, rivers, canals, natural depressions and groundwater. However, the availability of water in Bangladesh is not consistent throughout the year; it varies with the seasons. For instance, the availability of surface water in 1990 ranged from 3,710 million cubic meters during the dry season to 111,250 million cubic meters during the wet season (BBS 1995). Every year there is a large gap between demand and supply during the dry season. Thus, the water supply becomes critical in the dry season. The efficient utilization of surface water, groundwater and rainwater could avoid this critical condition. For this, it is essential to develop a sustainable water resources management device, which will encompass both quantity and quality aspects of water and safeguard the water resources from any kind of contamination. The overall management approach will take account of the following aspects:

1. Review of ecological data concerning arsenic contamination of groundwater in different regions of the country.
2. Identification of arsenic mitigation options and assessment of their feasibility, reliability and community acceptance.
3. Development of community based management groups in Gram Parishad (Village Administration).
4. Assurance of female participation in the local communities.
5. Campaign of arsenic health education and sanitation awareness in the local community.

6. Encouragement in the usage of alternative sources of water like rivers, canals, ponds, dug-wells, and rain.
7. Development of short and long-term community based investment programs with cost-sharing principles to operate and maintain the water supply system competently.
8. Cost estimation of sustainable community based water supply infrastructures and promotion of institutional arrangements to operate the systems efficiently.
9. Review of water resources management systems reformed in Gram Parishad and establishment of the linkage with governmental, non-governmental and private agencies for the overall coordination and surveillance.

5. WATER RESOURCES MANAGEMENT POLICY

A sustainable water resources management policy requires using water cost-effectively in all sectors and maintaining the overall harmony in the environment. If the socio-economic and environmental issues are not considered in a holistic manner, the gain in one sector from a project implementation may very well be offset by the losses accrued in other sectors. Particularly, if effective public participation does not materialize and transparency and accountability in water management are not established, the society would remain deprived of the immense benefits of water resources. Therefore, government, NGOs, private agencies and local communities should be integrated into the management process by the regulatory framework and administrative rules.

5.1 Organizations for Water Resources Management

Institutional structure at national and local levels is necessary for the formulation and implementation of the policies for improved water resources management and public investment. At present, there are three major participants in water resources development and management programs: governmental organizations, NGOs, and private agencies. A new dimension must be included in water resources development and management programs by community involvement. In order to implement a sound water resources management policy, the level of inter-connectivity amongst different organizations shown in Fig. 1 should be established.

5.2 Role of Government in Water Resources Management

Under ideal conditions, the government should presume the responsibility for the overall management of water resources for the benefit of society, undertake major development programs and provide public services. The government must have the overall authority through the statutory departments like DPHE to control the NGOs, private agencies and the community based Gram Parishad by adept regulatory framework and strict administrative rules.

5.3 Role of NGOs in Water Resources Management

There are a number of NGOs acting in different parts of Bangladesh. Most of the NGOs have received the acceptance of local communities. These organizations could have important roles to play in the development of private water markets. NGOs could assist in the formation of user groups, facilitate information exchange and even provide capital assistance to small entrepreneurs. NGOs could also contribute significantly to the social and environmental activities including educating the public, monitoring environmental hazards and mobilizing the people to undertake protective measures for water resources. In the present situation of arsenic contamination in Bangladesh, NGOs can work actively with other organizations to purify the contaminated water, to encourage the people to use alternative sources of safe water and to campaign the health and sanitation awareness for the benefits of local communities. Therefore, the management policy measures for water resources should be defined in such a way so as to facilitate the role of NGOs.

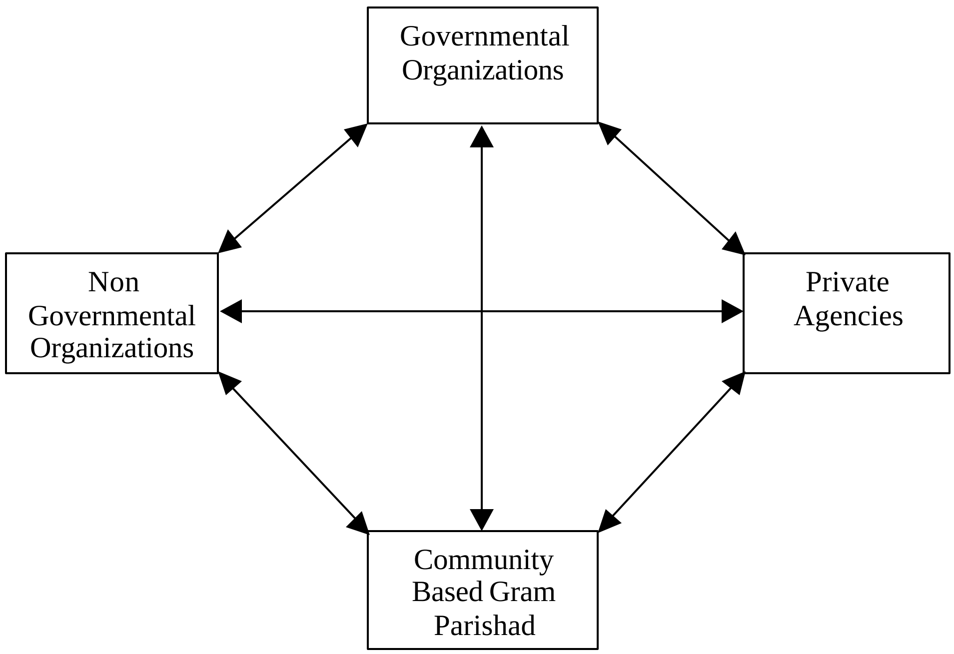

Fig. 1: Different Organizations for Water Resources Management

5.4 Role of Private Agencies in Water Resources Management

Private agencies can increase the management efficiency of water resources through investment, consultation and technical support. It is the appropriate role of the government to control the overall exploitation and management of water resources. Concurrently, the private agencies would invest in developing the commercial aspects of water system production, treatment and delivery. There are a number of private agencies currently running in Bangladesh. These agencies are capable of providing consultation, design and construction, operation and maintenance, and other services in water sectors. In past, operational services in agriculture were given to the private agencies (Faruqee and Choudhry 1996). This step was wise and became successful. The similar step might be adopted to decentralize the water services in order to achieve the desired level of efficiency in water resources management.

5.5 Role of Local Community in Water Resources Management

The involvement of local communities is very important for the coordinated development and utilization of water resources throughout the country. Many water development projects have failed due to the lack of understanding of local indigenous production systems and failure to take into account social and cultural relationships. The participation of local communities and the associated consultation process should be the key features in water resources management. With a lack of public participation in water resources management, alarming situations like arsenic contamination of groundwater may arise due to the inefficiency in control and allocation of water. Therefore, emphasis should be given to the involvement of local people at the feasibility stage of water resources planning process. If the local communities are not involved at the planning stage of different water projects and their roles in operation and management are not defined, pragmatic cost recovery policies will not be successful, and eventually the project will not run smoothly.

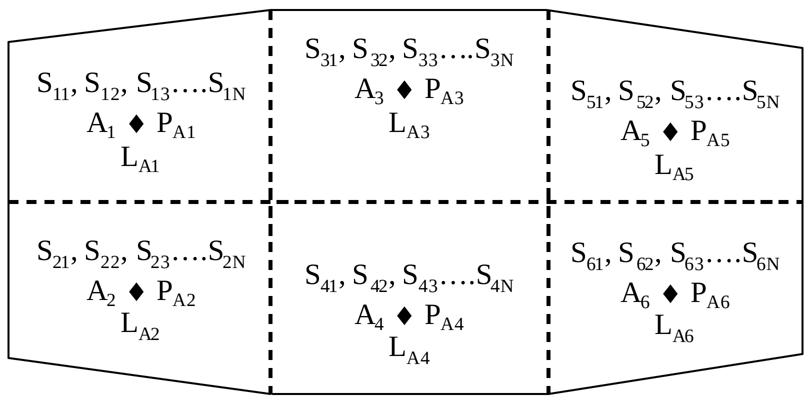

Fig. 2: Smaller Community Based Division of a Village

5.6 Regulatory Framework and Administrative Rules

Effective regulatory measures must be established among the organizations for competent water resources management. Regulatory systems are needed to monitor and enforce laws, agreements, rules and standards. The principal areas covered by regulations are water rights and allocation, standards of service, water quality and environmental protection, watershed management, soil and water conservation, prices charged by regulated utilities, ease of entry to water service industries, etc. Clear administrative rules should also be established to determine the priority of use, allocation mechanism, duration and the quantity and quality of water supply. These rules are required to protect both governmental and private sector investments and to assure fair water allocation in the market.

6. COMMUNITY BASED WATER RESOURCES MANAGEMENT

Arsenic contamination of groundwater requires a new dimension in water resources management. The Gram Parishad, acting through community based management groups, should take the leading role in planning, implementation and operation of water supply systems. The following procedure can be adopted to develop a sustainable community based water supply system:

Villages are the smallest administrative unit in Bangladesh. Each village can be divided into several smaller communities (SCs) with a population of 250 to 500 for each SC area. Fig. 2 shows such a conceptual division. A management group will be formed for the residents of each SC area. This group will be responsible to maintain, operate and supply safe water for the residents. In each SC area, the management group will undertake a water resources inventory to identify the surface water sources and to estimate their storage with the variation of seasons, to estimate the amount of rainwater throughout the year, and to define alternative groundwater sources for arsenic free water. A management group will also instruct the local people with different issues of water resources management. Gram Parishad in consultation with other liable management organizations would direct and guide the activities of all community based management groups.

7. MANAGEMENT MODEL

A simple logical management model is proposed in the following sections based on the availability of safe water from groundwater and other sustainable alternative sources. Water demands for irrigation and livestock are included in this model. This is because arsenic free water should be used for irrigation and livestock since arsenic is also accumulating in humans from the food chain. Conversely, this model excludes the water uses in industrial sectors and non-consumptive purposes as they are not of prime importance in the community based water supply systems. However, the ultimate objective of this model is to select the cost-effective and compatible option of arsenic free water for drinking, cooking, and other household purposes.

7.1 Water Resources Inventories

There might be several water resources in each SC area of the village. These sources could include rivers, canals, ponds, rainwater or safe tube-wells and other groundwater sources. Based on the availability of water from each category, easy to access sources should be identified. During the selection of water sources, priority must be given to choose at least one source from each category. However, an easy to access pond and an easy to use safe shallow or deep tube-well could be chosen to ensure the regular supply of drinking water in each SC area. Rainwater could also be harvested at the household level. In using the groundwater sources, a policy could be developed on restrictions of groundwater extraction. One tube-well (shallow or deep) can be chosen at the central location of SC area so that everyone has easy access to the tube-well. This particular tube-well will only be used to supply drinking water. For technical and economic feasibility and smooth management, a price can be fixed for every liter of tube-well water. This cost will develop a psychological base among the users to avoid wasting water and to encourage direct consumption. This plan will also secure responsible local communities with a commitment to establish and preserve their own water supply system.

7.2 Estimation of Water Demand

The people of villages mostly use water for drinking, cooking, washing, bathing, livestock, and irrigation. In Bangladesh, water is dominantly consumed in irrigation. The projected irrigation water demand for the next 20 years is about 14,290 million cubic meters to irrigate 6.90 million hectares out of 7.56 million hectares of irrigable land (Chowdhury 1998). Both surface water and groundwater are used in irrigation. Water for drinking and cooking purposes is mainly supplied from groundwater sources. Besides, both groundwater and surface water are used in villages for washing, bathing and livestock.

The dry season in Bangladesh, which occurs normally during November to April, is characterized by a drastic reduction in the river flow and a fall in the groundwater level when the demand for irrigation water is necessarily high. Consequently, both domestic water supply and irrigation are subjected to stress due to the uncoordinated withdrawal of surface and groundwater. Therefore, the conjunctive use of surface and groundwater is essential for optimum utilization of water resources. Adept measures must be directed to utilize the major surface water resources. Given that water resources are finite, strategies must be developed to influence the water demand and to increase the efficiency of water use rather than to provide more water for the communities.

For the proposed model, let us assume that the areas and populations in various SCs of a particular village are A_1, A_2, A_3,……, A_N and P_{A1}, P_{A2}, P_{A3},….., P_{AN}, respectively, and each SC area has the specific water resources such as S_{11}, S_{12}, S_{13},……., S_{1N} for area A_1. Also, L_{A1}, L_{A2}, L_{A3},..……, L_{AN} are the numerals of livestock for different SC areas. Considering H_1, H_2, H_3,……., H_N as per day per person water demands of different age groups for various purposes (drinking, cooking, bathing, etc.), and U_1, U_2, U_3,………, U_N as per day per livestock water demands of different types for various purposes in SC areas, total water demand for an SC area A_1 can be estimated as follows:

For humans:
$D_{HA1} = H_1P_1 + H_2P_2 + H_3P_3 + \ldots\ldots\ldots + H_NP_N$
Where,
D_{HA1} = Total water demand for humans in SC area A_1
P_1, P_2, P_3,..…….., P_N are the number of persons for different age groups in SC area A_1
P_{A1} = Total population in SC area $A_1 = P_1 + P_2 + P_3 + \ldots\ldots\ldots + P_N$

For livestock:
$D_{LA1} = U_1L_1 + U_2L_2 + U_3L_3 + \ldots\ldots\ldots\ldots + U_NL_N$
Where,
D_{LA1} = Total water demand for livestock in SC area A_1
L_1, L_2, L_3,……….., L_N are the number of livestock from each type in SC area A_1
L_{A1} = Total livestock in SC area $A_1 = L_1 + L_2 + L_3 + \ldots\ldots\ldots + L_N$

Now, if D_{IA1} is the water demand for irrigation in SC area A_1, the total water demand (TWD) for this area can be estimated as follows:
$TWD = D_{HA1} + D_{LA1} + D_{IA1}$

7.3 Selection of Alternative Water Sources

Based on the availability and accessibility of water sources, a logical model as portrayed in Fig. 3, would be formed to define the alternative water sources with a view to fulfill the TWD of an SC area. The following decisions can be taken to select the efficient alternative water sources depending on the reliability, safety, and cost-effectiveness:

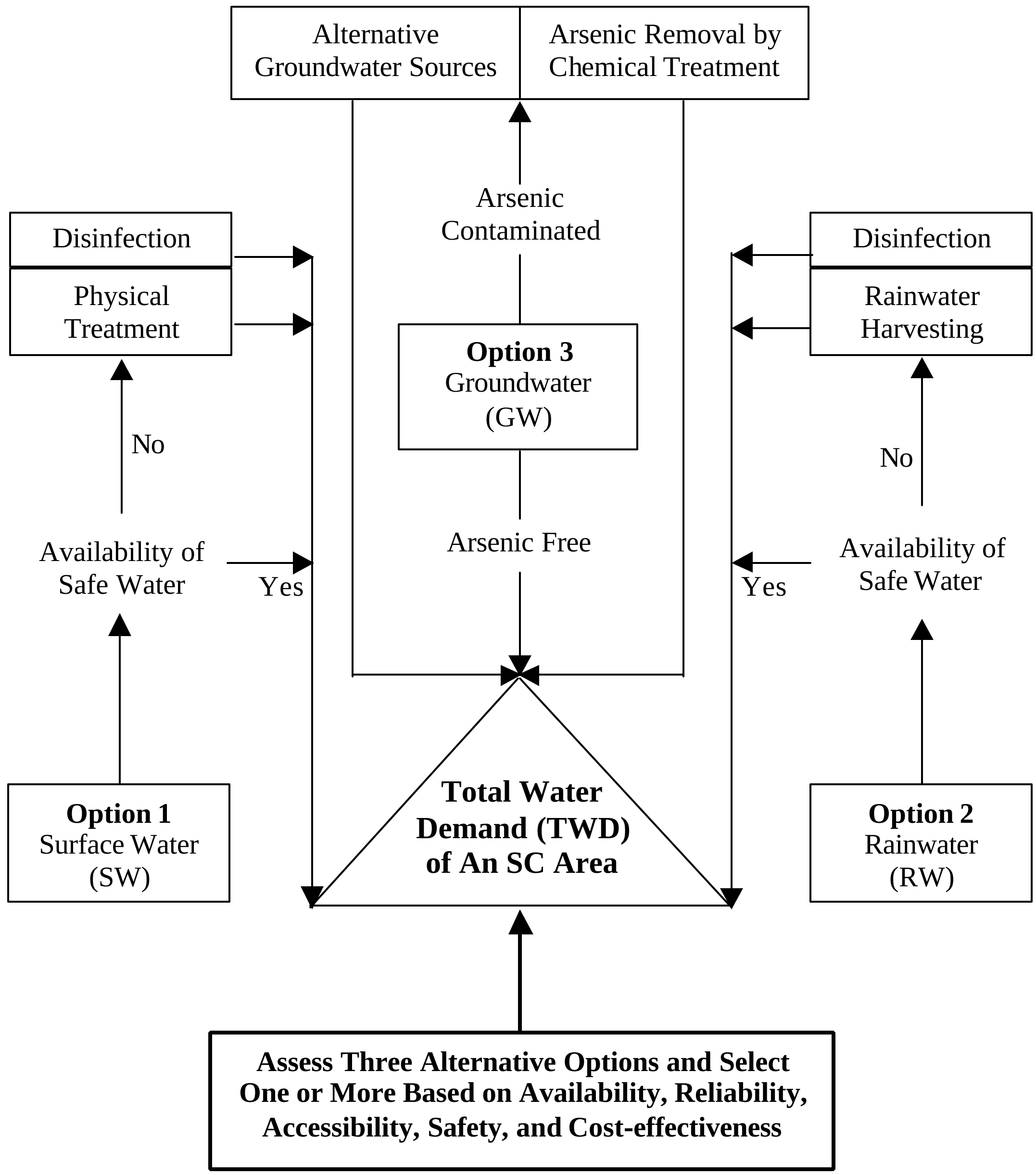

Fig. 3: Flowchart of the Logical Management Model

1. Surface water sources must be selected if the storage of surface water (SW) is sufficient to satisfy the TWD of an SC area. Otherwise, SW combined with rainwater (RW) and/or groundwater (GW) could be chosen.
2. Where SW is not available or accessible, RW and/or GW should be used to fulfill the TWD of an SC area.

3. Where both SW and RW are not available, GW from existing and/or alternative sources must be used to satisfy the TWD of an SC area.

8. CONCLUSIONS

Optimum efficiency in water resources management is required to remedy the environmental arsenic disaster in Bangladesh. The proposed management model would facilitate resolution of the crisis of safe drinking water. The following conclusions can be drawn from the present study:

1. Alternative sources of safe water must be established rather than treatment of arsenic contaminated groundwater.
2. Sustainable water supply systems based on surface water and/or rainwater must be developed in those affected areas where groundwater is severely contaminated by arsenic.
3. Arsenic free shallow tube-wells should continue to be used, and concurrently, other groundwater sources need to be established for safe water.
4. Removal of arsenic from contaminated groundwater should also be executed at household and/or community levels.
5. Competent water resources management, whether it emphasizes surface water, rainwater or groundwater, must involve the participation of local communities.

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