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Drinking Water Problems and Possible Alternatives in Coastal Region of Bangladesh: A Case Study

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Abstract

Safe drinking water for the coastal areas of Bangladesh has become a big challenge. Arsenic adulteration and salinity intrusion in surface water body has accelerated the scarcity of water in the coastal region. As situation ameliorating and also investment for water-borne diseases is decreasing, it becomes the major threat for a third-world country like Bangladesh. There are lots of alternatives for water supply but there are also a huge number of constraints. Most of the traditional dug wells (DW), ring wells (RW) and alternative pond sand filters (PSF) are now inoperative due to shortage of fresh surface water body and also adequate maintenance. Except a few, most of the shallow tube wells (STW) and deep tube wells (DTW) in coastal areas face arsenic (As) contamination. There could be a blended solution for these problems based on existing situation, constraint, hydrogeology and individual's economy. Different kinds of filters, reverse osmosis (RO), solar desalination plants (low-cost and small scale) and fuel-powered desalination plants (high-cost and large scale), etc., would be a good solution for mitigation of these problems. Solar PSF and rain water harvesting (RWH) might be an effective solution for some areas, respectively where fresh water and rainfall is abundant.

Keywords: *Arsenic contamination, salinity intrusion, climate change, pond sand filter, rain water harvesting, desalination, natural disaster*

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INTRODUCTION

Bangladesh is a deltaic country with a total area of 147,570 km^2 and a population of over 156 million. It is often called the "land of rivers" where almost 800 rivers (including their tributaries) form a large network of hydro-system that has a length of 24,140 km. The 710 km long coastal belt extended over 76 Thanas is identified as acute problem area where complex hydrogeological conditions and adverse water quality make water supply difficult as compared to rest of the country (Figure 1). There are 57 trans-boundary rivers in the entire coastal belt which are crisscrossed by many rivers and their tributaries under active tidal influence. The south-west coastal regions have been experiencing acute shortage of safe drinking water due to increase in salinity intrusion in surface and ground water and presence of arsenic (As) contamination in ground water over the past few years and these are worsened by sea water level rise and natural disasters. The presence of As in groundwater in Bangladesh has thus destroyed this decade-long success of provision of safe water, and the access to safe drinking water has now declined to almost 80% [1]. Arsenic (As) contamination in tube well (TW) water, which serves as the primary source of drinking water in Bangladesh, has now been recognized as a serious public health problem [2, 3].. It has been estimated that about 29 million people in Bangladesh are exposed to drinking water with arsenic exceeding Bangladesh standards of 50 μg/L and 49 million people exceeding provisional WHO guideline value of 10 μg/L [4].

Water scarcity problem has been intensified by the new dimension of problem which is salinity intrusion in the coastal region. The fresh water aquifers at reasonable depths are also not available. Such is the case in Satkhir, a district where the absence of saline-free safe drinking water is a mirage for people. Not only the tube well density is rather poor (about 50%

with respect to the country average), most of the tube wells draw saline water, since ground water aquifers (even confined aquifers) have been found to be saline affected [5]. Moreover, many tube wells are sunk 300 ft below ground and a significant proportion of such tube wells draw water in highly reducing conditions. This phenomenon is abominated by recent natural calamities in lower-lying coastal districts along the Bay of Bengal. Cyclone Sidr in November 2007 and Cyclone Aila in May 2009 when the storm surge of 3 m (10 ft) impacted western regions of Bangladesh, provide recent examples of devastating storm-surge in Bangladesh [5]. According to newspaper reports, the fresh water crisis had intensified after cyclone Aila hit in 2009 when the polders in the coast were damaged and the region was submerged by saline water. District-wise Aila damage assessment of water infrastructure conducted by DPHE suggested that among the affected districts, the district of Khulna and Satkhira were the worst affected areas in terms of WatSan facilities where 278 PSFs were damaged. High tidal surges, during the disaster, contaminated all fresh water sources with polluted saline water. The situation was acute in Gabura union of Shyamnagar, Satkhira district, where most of the drinking water sources were damaged. Many people were forced to drink such polluted water since they did not have any other option and consequently suffered from water-borne diseases such as allergy, skin diseases, cholera and diarrhea.

Salinity intrusion is accelerated by the increase in sea water level as a result of climate change. SAARC Meteorological Research Council (SMRC) found that the trend of sea level rise in Hiron point, Char Ganga and Cox's Bazar, three tidal stations of Bangladesh, is 4.0 mm/year, 6.0 mm/year and 7.8 mm/year respectively based on 22-year historical data [6]. There are lots of alternative options for drinking water but not all of them are effective. Most of the ring-wells (RW) and ponds in the coastal region were almost occupied by saline water during the Sidr and Aila. TWs are found useless for saline intrusion. So, it can be said that the two historical and low-cost water supply solutions for the poor coastal inhabitants are significantly demolished. Options remaining for them are pond sand filter (PSF) (manual and solar), rain water harvesting, desalination plant (solar, electric power based) and some case shallow and deep TWs.

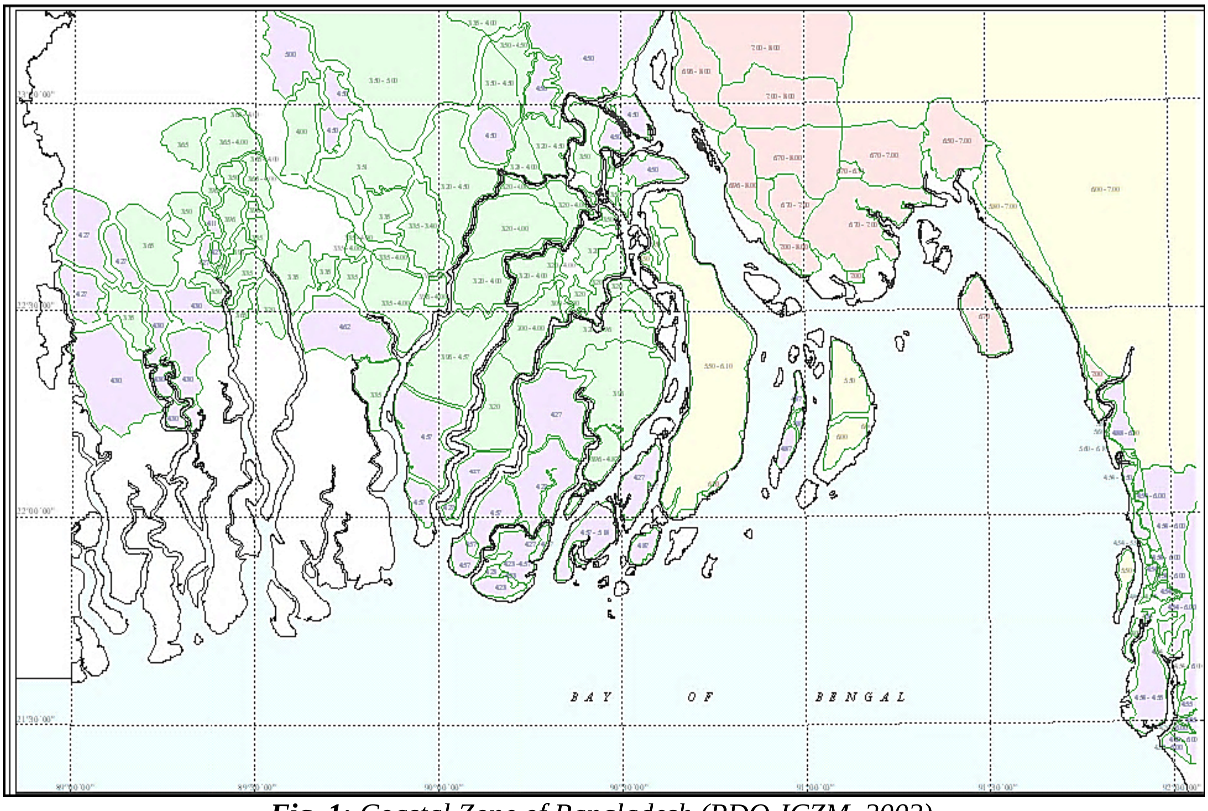

Fig. 1: *Coastal Zone of Bangladesh (PDO-ICZM, 2002).*

The objectives of this paper are to identify, compare and suggest the water supply options for coastal people.

Hydrogeological Condition

The hydrogeological conditions of the coastal area within short distances vary considerably. Alluvial and deltaic sediments of the Ganges, Brahmaputra and Meghna rivers build the Bengal Basin, the eastern part of which is Bangladesh [7]. The aquifer sands are fine-to-medium grained with typical hydraulic conductivities of 10–50 m/d which contain water that is less reducing, low in Fe and As, and is generally less mineralized (Ravenscroft, 2003). Aquitards are more prominent southwards and normally contain brackish groundwater. The brackish water is connate, and is locally leaked into underlying sands [8]. As the aquifers become more strongly confined, the waters tend to become more reducing and higher in Fe [9]. Ground water flows from north to south in the main aquifer having localized outflow into rivers and ponds in dry season and inflow into the aquifer from surface water sources in the rainy season (Figure 2).

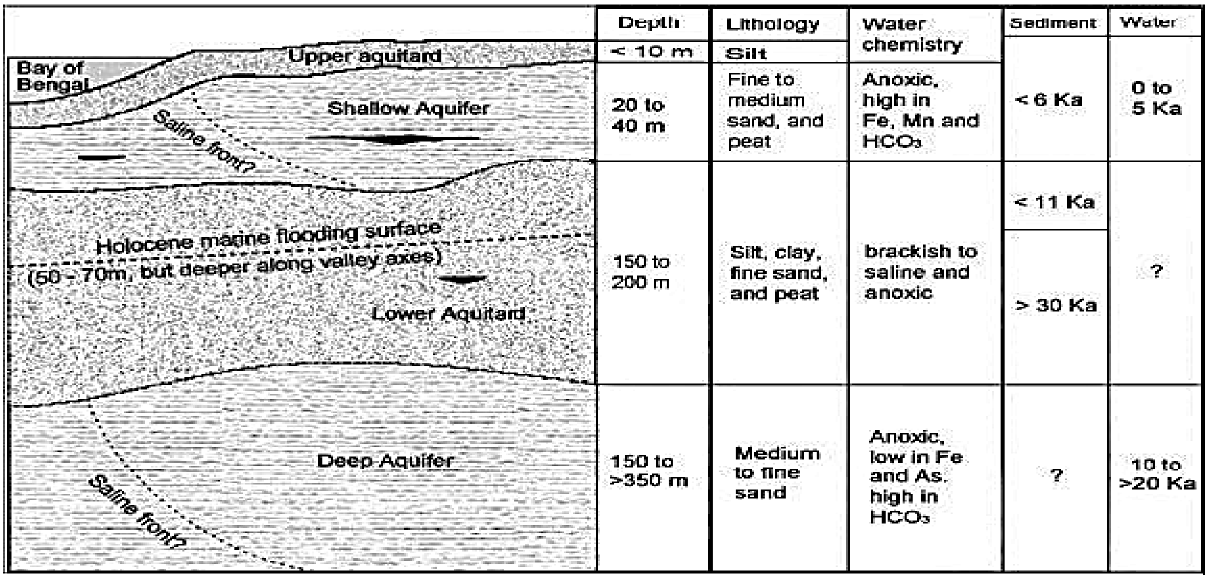

Fig. 2: *Schematic of Aquifer Stratigraphy in the Coastal Zone of Bangladesh.*

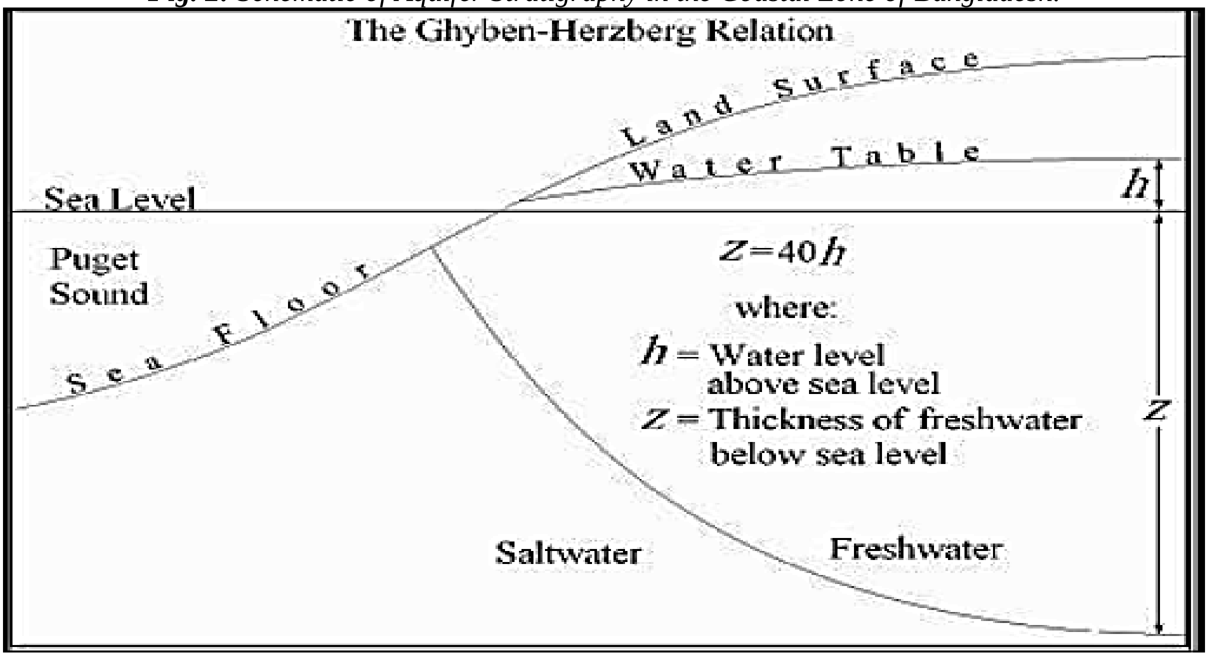

Fig. 3: *The Ghyben-Herzberg Relation.*

The ground water gradient in the coastal area is about 1:20,000. Transmission of the main aquifer in the coastal area ranges from 250 m^2/day to 10,000 m^2/day with an average value of 1000 m^2/day. The storage capacity of the aquifer generally increases with depth with the increase in the size of aquifer consisting materials. The entire area is underlain by thick water-bearing formations of varying depths and the regional hydrogeology is very complex. Shamsuddin [10] observed that the salinity distributions in Khulna, Barisal and Patuakhali regions were not in agreement with the Ghyben-Herzberg theory.

Brackish ground water is available within 0 to 2.5 m below the ground surface in the coastal area. Low saline ground water is available in deep aquifers at a depth greater than 200 m in some regions [11]. It is believed that a continuous flow of fresh water in these deep aquifers from north to south has pushed saline water towards the sea. Beneath the old ponds and the rivers, the pockets of fresh water are also available around low saline surface water sources usually. For years, the lens of fresh water has been formed due to outflow of fresh water or accumulated rain water from the surface water source into the aquifer. It has been found that the thickness of the lens of fresh water beneath the pond is directly related to the age of the pond. The low saline water in and around most of 81,000 ponds in the coastal area is considered as a potential source for low-cost water supply in the coastal area [11].

PRESENT WATER QUALITY AND WATER SUPPLY CONDITION

In coastal region, water quality is quite different than the rest part of the country but water availability was not as severe as it is now. There are some reasons responsible for this huge shortage of drinking water, namely, arsenic, climate change and natural disaster.

Water Quality

Water quality is the main constraint in the coastal area affecting water supply system. During dry season, salt water intrusion in the surface and ground water is the major problem. The people's indiscriminate use and unhygienic sanitary practices have polluted the available low saline surface water sources and made them unsafe for domestic uses. The application of organic and inorganic fertilizers in ponds for fish cultivation has aggravated the deterioration of water quality. There are fecal coliforms (FC) in surface water bodies (i.e., rivers, unprotected ponds, etc.) counts between 500 and 3000 per 100 mL [11]. From bacteriological point of view, ground water is a more dependable source in Bangladesh. But in the coastal area, the presence of chlorides, and dissolved iron in excess of acceptable limits is the main water supply problem. Ahmed [12] and Choudhury [13] assessed people's general opinion about the quality of water they drink. The people in the problem area use tube well water having 5 mg/L of iron and 1000 mg/L of chlorides without much hesitation but water of such quality is not acceptable in other regions of the country. Since these water quality parameters normally do not involve health risk, people's acceptance receives priority in water supply in the coastal area. Taking this into considerations, DOE (1991) recommended the maxim limits of 1000 mg/L for chlorides and 5 mg/L for iron in case of hand pump tube well in the absence of a better alternative source in problem and coastal areas of Bangladesh.

Water Accessibility Methods and Their Limitations

Two types of tube wells, shallow from 20 to 75 m and deep tube wells from 75 to 350 m operated manually for ground water extraction in the coastal area, are used [11]. The Department of Public Health Engineering (DPHE) has divided the coastal regions into three types of area based on the availability of fresh groundwater. In the coastal area 146,538 shallow tube wells and 40,827 deep tube wells were sunk up to June 1993 and the population coverage achieved was 216 persons per TW against the national coverage of 79 persons per TW in the shallow water table areas [14]. There are areas where tube wells are not successful to produce low saline water. Problem intensity computed based on 1991 census report indicates that the problem is very acute near the coast. The source problem intensity in most of the coastal areas is more than 50% [15]. As a result, in spite of sinking a large number of hand pump tube wells, the water supply situation in many areas remains unsatisfactory. Moreover, failure of existing

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tube wells to yield water of satisfactory quality is quite frequent. The percentage TW producing water with chlorides and dissolved iron in excess of permissible limit computed from BUET-BIDS study [16]. A small percentage of total population is covered by piped water supply in the coastal area only available in major urban centers. Many PSFs are found inactive as a result of fresh water (PW) access due to recent surge and also lack of proper maintenance by owner. At present, coastal populations are mainly dependent on natural sources such as rain water and pond water for drinking purposes. There are few tube wells in the pockets of deep aquifers which in most cases are hard to reach. Finding no alternative, many also use bacteriologically unsafe surface water.

Causes of Water Scarcity

Following are the main causes for massive problems of drinking water scarcity in the coastal region.

Arsenic Contamination

Due to extensive use of groundwater from the shallow aquifers of the Bengal Delta Plain (BDP) in Bangladesh and the ease of TW installation at affordable costs, the number of domestic water supply wells increased many folds over the last three decades and 90% of these are privately owned [16]. The number of TWs present today is estimated between 8–10 million whereas it was only about 50,000 during the British colonial rule [17]. Most of the hand pumped TWs are installed at depths varying between 20 and 30 m [18].

Arsenic is a naturally occurring poisonous, colorless, tasteless and odorless element and is widely distributed in the crystal rocks [19]. It occurs in the naturally occurring alluvial sediments as a component of different minerals. Generally, TWs installed at shallower depths (15–50 m) are found to be highly contaminated [20–22]. Although, several hypotheses have been suggested for the mechanisms to cause the substantial input of As in the groundwater of Bangladesh (Figure 3) [23–25].

Arsenic contamination in groundwater and its toxic effect on human health is a major public health problem in Bangladesh [23, 26]. Thus, arsenic contamination has reduced the estimated national population coverage with safe water supply from 97 to 74% [26]. According to survey data from 2000 to 2010, an estimated 35 to 77 million people in the country have been chronically exposed to arsenic in their drinking water in what has been described as the largest mass poisoning in history [27, 28]. Supply of safe drinking water remains the most crucial issue in the whole as mitigation program.

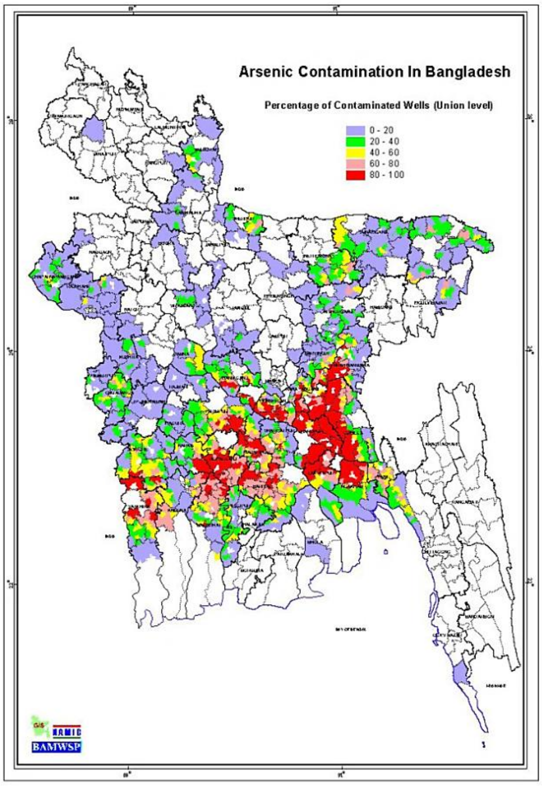

Fig. 4: *Arsenic Contamination in Bangladesh (Main Report 2004).*

Salinity Intrusion and Climate Change Saltwater intrusion is defined as the movement of saline water into a freshwater aquifer or surface reservoir, and if the source of this saline water is sea water, then this process is known as seawater intrusion. Generally, aquifers in hydraulic connection with saline or sea water may contain saltwater in adjacent portions while other portions of the aquifer contain fresh water. Freshwater is slightly less dense (lighter) than saltwater, and it tends to float on top of the saltwater when both fluids are present in an aquifer.

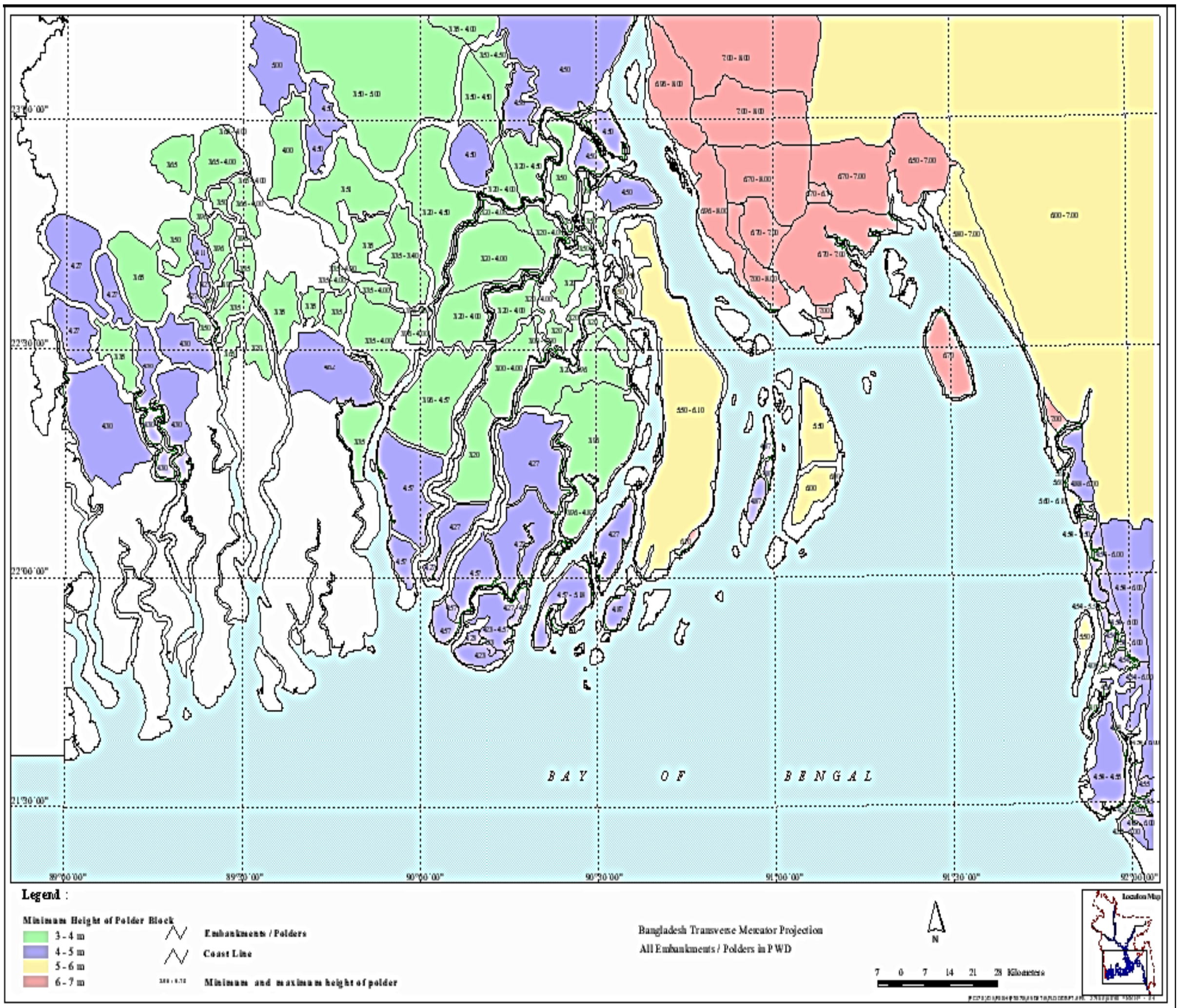

***Fig.5:** Coastal Sea Level Rise.*

***Table 1:** Climate Change Scenarios for Bangladesh.*

Year	**Temperature change (°C) mean**		**Precipitation change (%) mean**		**Sea level rise (cm)**		
	Monsoon season	Dry season	Monsoon season	Dry season	3rd IPCC (upper range)	SMRC	NAPA scenario
2030	0.8	1.1	+6.0	-2.0	14	18	14
2050	1.1	1.6	+8.0	-5.0	32	20	32
2100	1.9	2.7	+12.0	-10.0	88	60	88

The relationship based on the density difference between saltwater and freshwater is used to estimate the depth of saltwater based on the thickness of the freshwater zone above sea level. The relationship is known as the Ghyben-Herzberg relation. A study by Ahmed and Alam [3] mentioned one meter change of sea level by the middle of 21st century; it combines a 90 cm rise in sea level and about 10 cm local rise due to subsidence. A pilot study of Department of Environment mentioned [29] a potential future sea level rise for Bangladesh is 30–50 cm by 2050. An increasing tendency in sea level rise from west to east along the coast has also been found. Sea level rise yields the significant salinity intrusion. National Adaptation Programme for Action [30] team on the basis of 3rd IPCC report and prediction of SAARC Meteorological Research Centre has established the likely climate change and sea level rise scenarios for Bangladesh. Table 1 illustrates those scenarios. In this study, the authors focus on the analysis based on 14, 32 and 88 cm sea level rise.

Natural Calamities and Other Factors

Natural disasters (i.e., cyclone, surge, etc.) frequently cause the traditional ponds or surface water bodies to inundate with sea water and turn these out unsuitable for any form of human use. The people in Satkhir received the highest amount of sufferings from drinking water shortage soon after Aila attack. Aila devastated all the drinking water sources (ponds and tube wells). The Daily Sun reported that after the devastating cyclone, Aila that hit the coastal belt in May 2009, most of the people especially poor people in the areas still do not have access to sufficient quantity of drinking water as the cyclone damaged most of the sources of water. In the Aila-hit areas, tube well is not successful due to the presence of high salinity in the shallow and deep aquifer level. Ponds with pond sand filter, reserving rainwater in households and community level are now the only major sources of safe drinking water. Approximately 34% of households (108,415 people) still do not have access to sufficient quantity of safe drinking water after two years of the cyclone, as reported by Oxfam's Bangladesh office.

Safe drinking water scarcity is induced through intrusion of saline water inland, water logging and lack of fresh water aquifers except from the impacts of natural disasters and climate change. Intrusion of saline water inland with less flow of water from upstream occurs specially during the dry season. This means that a significant portion of the south-western coast is under stress in identifying suitable sources for drinking and irrigation water. Water from the river, in most of the time throughout the year, is highly turbid and saline. The low saline pond water is used for many domestic purposes but is completely unsuitable for drinking.

ALTERNATIVE WATER SUPPLY OPTIONS

Alternative water supply options are working well in some areas but not functioning properly in some other areas. The major objectives of this study to identify reasons of non-functioning and in order to develop a comparative information and better understanding of the options, assessment of alternative water supply options in both technical and social aspects are essential.

Pond Sand Filter

Filtration is the process whereby water is purified by passing it through a porous material or media. In slow sand filtration a bed of fine sand is used through which the water slowly percolates. The suspended matter present in the untreated water is largely retained in the upper 0.5–2 cm of the filter bed. This allows the filter to be cleaned by scraping away the top layer of sand.

The filter cleaning operation need not take more than one day, but one to two more days are required after cleaning for the filter bed again to become fully effective [31]. In the coastal belt of Bangladesh, where much of the groundwater is saline, the local people are dependent on surface water from dug ponds. However, water from these ponds is not potable without adequate treatment.

DPHE with funding from UNICEF has installed slow sand filtration units into which pond water is fed using a tube well. These units are called pond sand filters (PSFs). The use of PSF technology to filter surface water is also considered appropriate for areas where groundwater is contaminated with arsenic. One pond sand filter can supply the daily requirement of water for drinking and cooking for 40–60 families [31].

This is an alternative and popular option of potable water supply through treatment of surface water in coastal belt and arsenic-prone areas for providing domestic water supply. Intervention of PSF by UNICEF and the DPHE was carried out along the coastal belt; however, lack of maintenance caused them to be abandoned. It has been reported that many of the PSFs constructed in the past in other arsenic-affected areas where BRAC is providing As mitigation options, are now abundant as the owners of the ponds restarted commercial fishing activities [32].

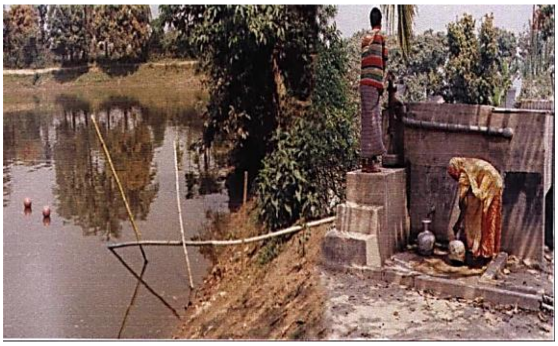

Fig. 6: *Pond Sand Filter Components.*

PSF needs careful maintenance to keep it operative. Continuous water supply is required to work that effectively. But humans do not always care about it. This situation can be ameliorated by using solar pump which is sensitive with the presence of water in the tank of PSF. PSF is a low-cost technology with very high efficiency in turbidity and bacteria removal (Figure 6). Although PSF has very high bacteria removal efficiency, it may not remove 100% of the pathogens from heavily contaminated surface water. In such cases, the treated water may require chlorination to meet drinking water standards. In addition, salinity and iron content of the pond water should not exceed 600 and 5 ppm, respectively, at any time of the year. PSFs, in most cases, are not disaster resilient.

Rain Water Harvesting

The most common low-tech and low-cost technique used by communities is rainwater harvesting (RWH). Rainwater harvesting is the process of collecting, diverting and storing rainwater from an area (usually roofs or another surface catchment area) for direct or future use. In some areas of Bangladesh, the potential for rainwater harvesting is good; however, the amount of rainfall varies across the country. Rashid [33] shows that mean annual precipitation ranges from 1,400 mm (55 in) along the country's east-central border to more than 5000 mm (200 in) in the far north-east. The wet months are mid-June to late September and the dry period is from January to April. About 80% of the annual precipitation occurs in the monsoon period. Rainfall patterns were confirmed with local communities to ascertain the feasibility of RWH, and alternatives and parallel use of other options were considered before constructing RWH jars. The capacity of a jar is about 32,000 L and the cost is about Tk. 8000 [31]. It was observed that the cost was too prohibitive for it to spread locally. Also, in every case, the RWH was used by more than one family so the water lasted for a limited period (maximum one month when the rainy season stops, i.e., not long enough to cover the full dry period).

Fig. 7: *Rain Water Harvesting System.*

RWH reduces the demand on mains water supplies and also reduces the amount of urban storm runoff due to its buffering effect on storm events, which in turn reduces the amount of pollutants being washed into surface waters that are used to recharge shallow ground waters (Figure 7). It requires capital investments for relatively large storage tanks in situations where there is a poor rainfall distribution and poorer families will not have the financial resources to invest in this technology.

Desalination

Desalination is the specialized treatment method used to remove dissolved minerals and mineral salts (demineralization) from the feed-water (fresh water, brackish water, saline water, but mainly from sea water) and thus to convert it to fresh water mainly for domestic, irrigation or industrial use. Solar powered desalination plants, reverse osmosis (RO) and nanotechnology high tech and high cost drinking water solutions were also looked at. Solar powered desalination plants and reverse osmosis (RO) machines are both options to reduce the salinity of water. One of the local NGOs installed four RO machines along the coastal region, which treat saline water and produce pure drinking water. Members expressed some reservations about this, due to the high set-up and maintenance costs associated with this technology. In an effort to make, it more cost effective and efficient, the literature highlighted the use of nanotechnology - car bon nanotubes (CNT). CNT is a filtering agent that RO desalination machines can use, which can significantly reduce the cost of RO plants.

In drought prone regions, desalination is a reliable source of water, which is not affected by variations in rainfall. Provision of adequate and reliable water supply in urban areas encourages general economic development. On the other hand, it requires intensive use of energy. A desalination plant involves high capital costs and recurrent costs, because of its reliance on high energy requirements and if its location is far from urban areas a distribution network needs to be installed to transfer desalinated water to the mains water supply.

CONCLUSIONS AND RECOMMENDATIONS

Ground water source was the most convenient source for drinking water supply in the coastal region of Bangladesh. But this scenario has changed due to introduction of As adulteration, salinity intrusion which is empowered by natural disaster and sea level rive due to climate change. Most of the surface water body (i.e., pond) has been filled up by saline water as result of Sidr and Aila. There are many areas where DW, STW and DTW extract As contaminated water. Along with recent cyclone, surge and also negligence in maintenance has led the PSD inoperative. RWH requires high initial cost and rainfall distribution is uneven.

Solar desalination is a very slow process and yields very less amount of water comparing with demand. Fuel-powered desalination plant claims a big initial investment that is quite impossible for poor coastal people. Arsenic problem could be solved for some areas by using existing techniques (i.e., Stevens Institute of Technology Filter, Tetrahedron Filter, Sono three-pitcher Filler, BUET Activated Alumina Filter and Alcan Enhanced Activated Alumina Filter, etc.). Manual and solar PSF could be the best for Bangladesh if we can assure proper maintenance and enough water supply. Solar desalination might be a good option if its efficiency can be upgraded. RWH is obviously a better temporary solution and it could be a long-term contributor in water supply if people have the financial capability for initial fixed investment on reservoir. So, above all coastal region water solution could be a blend of all options depending upon the demography and hydrogeology.

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