ABSTRACT

Groundwater is a hidden and common pool resource. It is commonly believed that groundwater is omnipresent, and can be drawn on demand in any quantity wherever and whenever required. This conception has given rise to indiscriminate boom of groundwater withdrawal structures of various types namely, hand-pumps, bore-wells, tube-wells, etc. to meet ever increasing demands in individual household, community and social sector for different uses. Those, over the years, have triggered a number of invading issues such as; depletion of groundwater level and deteriorating groundwater quality. As a consequence of which have emerged a threat to scarcity of groundwater, failure of wells, severe health hazards, etc. Deterioration of groundwater quality is increasingly being recognized as the cause of water scarcity in many areas.

Groundwater, when it is in aquifer, possesses some fascinating features, such as; usually it travels very slowly and hence has long residence time. The space-time availability of groundwater is characterized by the porosity and permeability of the geological formations of the aquifer. The geological nature of the soil also determines the chemical composition of the groundwater. There is a misconception that the composition of groundwater does not change naturally. However, a common cause of change in water quality is interaction between aquifer material and the water flowing through them. Factors that control the dissolved minerals in groundwater include (i) the types of minerals that make up the aquifer, (ii) the length of time that the water is in contact with the minerals, and (iii) the chemical state of the groundwater. Different rocks have different minerals and groundwater in contact with those materials will have different compositions. The longer the contact time with minerals, the grater the extent of its reaction with those minerals and the higher will be the content of dissolved minerals. The chemical state of groundwater is generally defined in terms of three parameters: the temperature, pH, and oxidation-reduction potential. These factors are often influenced by chemical reactions between the groundwater and aquifer materials and in turn control the chemical composition of groundwater. If the aquifer material processed the toxic elements from weathered rocks, the changes in the chemical state of groundwater, which may be due to different water levels and annual recharge events, may trigger activation or dissolution of toxic elements in the groundwater.

Occurrence of Arsenic in groundwater, in excess to the permissible limit of 50 μg/L in the Ganges-Brahmaputra fluvial plains in India covering seven states namely, West-Bengal, Jharkhand, Bihar, Uttar Pradesh in flood plain of Ganga River; Assam and Manipur in flood plain of Brahamaputra and Imphal rivers and Rajnandgaon village in Chhattisgarh state, is one such large scale groundwater quality disaster, described internationally as the World biggest natural groundwater calamity to the mankind after Bangladesh. These fluvial plains represent Holocene aquifers of recent alluvial sediments and have the routes originated from the Himalayan region. Since the groundwater arsenic contamination first surfaced in 1983 from

nearly 33 villages in 4 districts in West Bengal, up till 2008; 9 districts covering 3417 villages in 111 blocks in West Bengal, 15 districts covering 57 blocks in Bihar, 3 districts covering 69 villages in 7 blocks in Uttar Pradesh, 1 district covering 68 villages in 3 blocks in Jharkhand, 3 districts covering 9 blocks in Assam, 4 districts in Manipur, and 1 district covering 4 villages in 1 block in Chhattisgarh have been detected for groundwater arsenic contamination. The area and population of these states are 529674 km^2 & approx. 360 million respectively, in which 88688 km^2 and approximately 50 million people have been projected vulnerable to groundwater arsenic contamination. People in these affected states are chronically exposed to arsenic drinking arsenic contaminated hand tube-wells water. With every new survey, new arsenic affected villages and people suffering from arsenic related diseases are being reported and the problem resolving issues are getting complicated by a number of unknown factors. Further to those, Arsenic groundwater contamination has far-reaching consequences including its ingestion through food chain, which are in the form of social disorders, health hazards and socioeconomic dissolution besides its sprawling with movement, and exploitation of groundwater. Whether the knowledgebase, understandings and technological options available are adequate to resolve the issues or, there are further needs of more investigations and studies to strengthen understanding of geochemical processes to mitigate and remediate arsenic from groundwater, are some of the concerns to be addressed for attaining sustainability in supply of arsenic safe groundwater to the affected areas.

Although the exact sources and mobilization processes of such large scale occurrence of arsenic in groundwater are yet to be established the cause is understood to be of geogenic origin released from soil under conditions conducive to dissolution of arsenic from solid phase on soil grains to liquid phase in water and percolation of fertilizer residues may have played a modifying role in its further exaggeration. There are numbers of hypotheses about the source of arsenic and probable reasons of its occurrence in groundwater. Among the hypotheses of sources, which have been described, Arsenic is transported : (i) by the River Ganges and its tributaries from the Gondwana coal seams in the Rajmahal trap area located at the west of the basin; (ii) by the north Bengal tributaries of the River Bhagirathi and the River Padma from near the Gorubathan base-metal deposits in the eastern Himalayas; and (iii) with the fluvial sediments from the Himalayas and chemical processes of arsenic in groundwater, the most accepted one is recognized as transport of arsenic from the Himalayas with the fluvial sediments. Regarding chemical processes of occurrence of arsenic in groundwater, out of two hypotheses, one describing oxidation of **As**-bearing pyrite minerals and the other one recognizing due to dissolution of **As**-rich iron oxyhydroxides (FeOOH), the later case is hypothesized as the most accepted one. Whether the reasons of dissolution of arsenic from soil to aqueous phases are excessive exploitation of groundwater is yet to be established.

Over the last 25 years, since the groundwater arsenic contamination first surfaced in the year 1983, a number of restorative and substituting measures coupled with action plans focusing mainly towards detailed investigations to understand the physiochemical process and mechanism, alternate arrangement to supply arsenic free water to the affected populace have been initiated mainly in West Bengal. Efforts have also been made in the development of devices for arsenic removal and their implementation at the field. While in other States, they are meager. Despite number of corrective and precautionary measures, the spread over of arsenic contamination in groundwater continues to grow and more new areas have been added to the list of contaminated area. The problem resolving issues, thus, seem to be partial and inadequate, that need to be strengthened by strategic scientific backing.

Numerous investigations have come out with number of findings, and alternatives propositions, varying from identification of shortfalls to success stories. Undoubtedly, each research study has its own merits and added new information; however, a need arises to translate all those research outcomes to problem resolving issues through framework of activities. The present state of affairs of the arsenic menace in India demands a systematic translation of success stories of one place/region to another, and overcoming the shortfalls by conceiving R & D studies in areas wherever they are deemed fit. Advancement in understanding of geochemical and mobilization processes, devising satisfactory arsenic removal filters, identification of shortfalls in operation and maintenance of arsenic removal techniques, delineation of risk free deeper aquifers for groundwater tapping as an alternate source of groundwater, developing surface water based water supply schemes in many arsenic affected areas, success stories of community participation in running arsenic removal plants, etc. are some of the important achievements, which could help deriving a comprehensive framework of activities leading to mitigation and remediation of the issues emerging out of arsenic menace.

Towards the supply of arsenic safe water by treatment of contaminated groundwater using arsenic removal filters and devices, a variety of treatment technologies, mainly based on oxidation, co-precipitation, adsorption, ion-exchange and membrane process, have been developed and extended to the field. However, the efficiency and applicability/appropriateness of the technologies have proved more conflicting than successful mainly because of disadvantages associated with them with regard to management of large amounts of toxic sludge produce from the devices and O & M difficulties. There is, therefore, a need for further refinement in those treatment devices besides their sustainability in terms of economic viability and social acceptability. To provide arsenic safe groundwater from alternate long distance sources piped water supply scheme, based on surface sources in feasible locations has been put in place and successfully operating in West Bengal. Tapping of deeper aquifers underneath the contaminated zones in many locations is proving feasible alternative. Numerous studies highlight different concepts with regard to mobilization processes and suggested for deriving alternative sources for supply of water to the affected areas, those include; watershed management, artificial groundwater recharge, tapping of deeper aquifers, etc. However, the concerns are: (i) whether available knowledge, understanding and technologies are adequate to achieve sustainable solution of the arsenic remedy for different hydro geological setups? (ii) As to how to proceed for envisaging alternate feasible solutions?

(iii) Whether ex-situ removal techniques are feasible solution, and how it can be made more cost effective, eco-friendly and socially acceptable? (iv) What are the feasible solutions for in-situ remedy of arsenic from contaminated aquifers? etc. After all, arsenic safe groundwater is to be made available to meet demands for both domestic and agricultural requirement in arsenic affected and arsenic vulnerable areas.

It is in these contexts; the Vision document entitled **"Mitigation and Remedy of Groundwater Arsenic Menace in India"** is envisaged. The document is designed to focus mainly on: (i) up to date status of arsenic menace in India, (ii) state-of-the-art of scientific knowledgebase, understanding and technologies available from both national & international perspectives, (iii) technologies in place, (v) preventive and corrective measures taken so far and results thereof, (v) shortcomings, and possibility of employing success stories of one place to another region, (iv) further work to be undertaken, (vi) roadmap to achieve the targeted milestones, (vii) framework of activities to be taken up, etc. For figuring these concerns and issues, a total of ten different Chapters linking one to another are deliberated. Of which, first six chapters illustrate the knowledgebase, understanding, status , technologies available followed by a critical appraisal, while the other four chapters elaborate on further work required for achieving sustainable solution for arsenic menace, roadmap to achieve those along with an envisaged 'Plan of Actions' and financial requirement to achieve those targeted tasks. These chapters have been contributed by a number of resource persons from all over the Country.

The chapters are organized as follows: Chapter-1 discusses general aspects of Arsenic Source, occurrence and geochemistry; Chaper-2 brings out status of Arsenic menace in India with a critical appraisal; Chapter-3 explains the Sources and causes of groundwater Arsenic contamination in Ganga-Brahmaputra Plains along with results of different studies carried out by researchers; Chapter-4 highlights the mitigation and remediation measures initiated by different states and results achieved; Chapter-5 includes Technological options and Arsenic removal technologies available and practiced in the field and their performances and shortfalls; while Chapter-6 encompasses a critical appraisal of activities carried out so far and results achieved thereof with a suggested view of future risk, scope to remediate, technological competence, etc. Chapter 7 brings out the gap and identifies the areas on which further concentrated efforts would be required; Chapter-8 provides a roadmap of tasks to be initiated with a framework of activities including phasing their scope under the Government of India ongoing schemes; Chapter-9 details out the financial requirement and operation aspects of the activities emphasized in the document including proposition of Central-State sharing of finances; while Chater-10 figures out as to how the Mission can be managed to attain the targeted goals with an estimate of a time frame.

A framework of activities with an estimated financial target of **Rs.200 crores** for a period of five years has been envisaged to resolve arsenic menace exposed in seven States in India. It is believed, earnestly, that likely results from these elaborated scientific tasks will help building the strategy to mitigate and remove groundwater arsenic menace in India.