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Original Article

A Protective Paddy Farming Assortment to Diminute Arsenic Contamination

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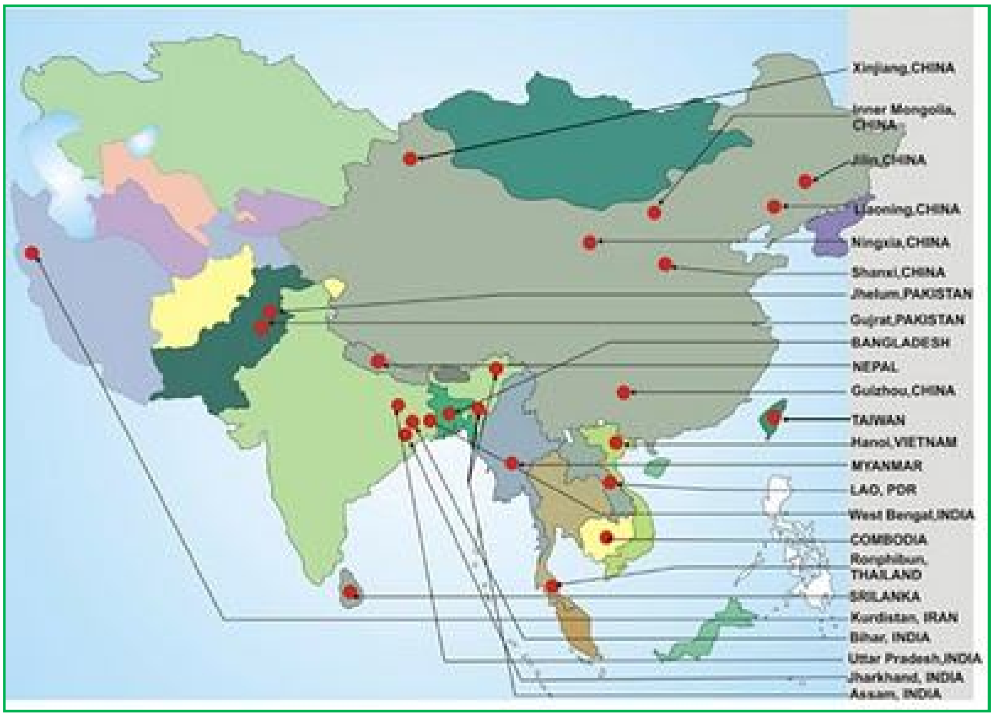
ABSTRACT
About 140 million people, especially in developing countries, are being continuously poisoned by arsenic in their drinking water. Arsenic is very poisonous metalloid that is often used in pesticides, herbicides and insecticides. The arsenic in the groundwater is of natural origin and being released from the sediment into the groundwater due to the anoxic condition of the subsurface. But not only water is poisoned by arsenic because even rice that is grown on these areas has health risk and this is very big problem for more than 70 countries, especially in South and East Asia. Rice is usually grown in puddle fields, often flooded with water from the same arsenic contaminated wells and in many Asian countries rice is the essential food. Massive epidemic of arsenic poisoning has already taken place in Bangladesh and its neighbouring countries. Studies have shown rice as a major exposure route for As in humans. A new study has revealed why rice is particularly efficient in accumulating As from soil and how to prevent such accumulations. In this context, excessive use of groundwater particularly in paddy cultivation is a major cause of concern. Therefore, modern paddy cultivation techniques which require less water to produce more rice grain need to be popularize to mitigate arsenic contamination.
***Keywords**: Irrigation water; Arsenopyrites; Redox potential; SRI; Chemical fertilizers; Aquaporin channels; Aerobic rice; Arsenites; Arsenates; LSi1; LSi2*

INTRODUCTION
Rice being an irreplaceable source of major food supply to people of Asia as a whole and Indian subcontinent to be precise, is predominantly cultivated through wetland production system (75 % of total production turns up from 79 million hectare wetland cultivation). About 92% of the world rice is produced and consumed in Asia which shares more than 50% of the total irrigation water employed for rice production. Irrigated rice has very low water-use-efficiency and consumes 3,000-5,000 litres of water to produce 1 kg of rice. The available amount of water for irrigation is, however, increasingly getting scare worldwide. In many Asian countries, per capita water availability is expected to decline by 15-54% by 2025 as compared to 1990 [1]. The traditional rice production system not only leads wastage of water but also causes degradation of soil-plant environment and reduces water-use efficiency. Along with higher water requirement, the traditional system of transplanted rice production leads to over-exploitation of groundwater. Another problem involves over-exploitation of groundwater which causes serious problems. This practice causes pollution when aquifers are recharged with irrigation water contaminated with chemicals [2].

ARSENIC CONTAMINATION IN GROUNDWATER-SOIL SYSTEM
The origin of arsenic contaminated groundwater in West Bengal (India), and Bangladesh is geological, from sediments derived from the upland Himalayan catchments [3]. The arsenic-affected aquifer sediments were deposited from the Ganges River during Holocene [4]. Over 200 arsenic containing minerals have been identified with~ 60% being arsenates, 20% sulphides and sulpho salts and the remaining 20% including arsenides, arsenates, oxides and elemental As. The

most common of the As containing mineral is arsenopyrites (FeAsS), others being Orpiment (As_2S_3), Realgar (AsS) and Energite (Cu_3AsS_4), Onishi [5].



This picture shows countries in Asia affected with groundwater arsenic contamination and is clearly visible that arsenic contamination is becoming problem in many of Asian countries. Five major incidents caused by groundwater arsenic contamination were in Bangladesh, West Bengal-India, Inner Mongolia, Xin-Xiang Provinces in China and Taiwan.

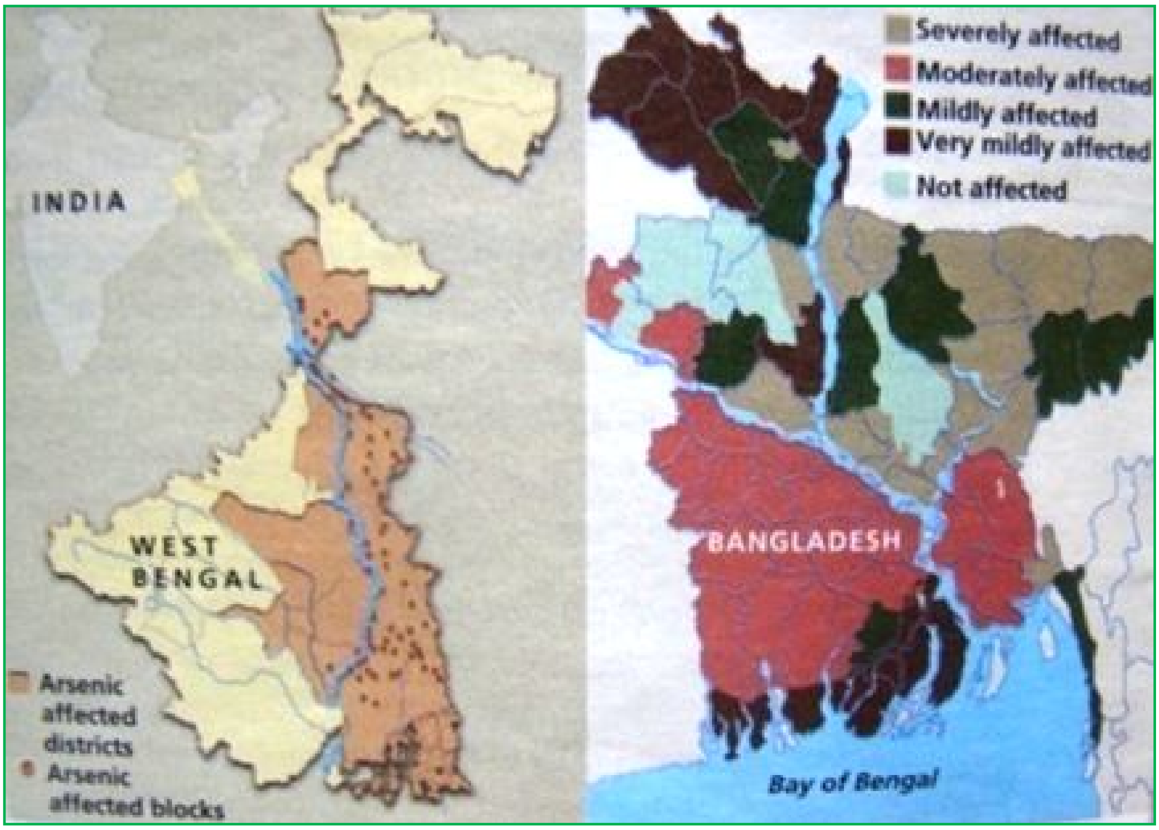
The scale of the problem is grave and unprecedented covering a geographical area of 38,861 square kilometre, while exposing 50.4 million people in Bengal deltaic basin to risk. The widespread arsenic contamination in groundwater in different parts of West Bengal, distributed over 111 blocks (3417 village), located primarily in twelve districts in West Bengal even to the tune of 2500 $jagL^{-1}$ (Tube well test data, JPOA with UNICEF, (http//www.soeiu.org;www.unicef.com). The source of such contamination being of geogenic origin summer paddy (*boro*) cultivation using large amount of groundwater, is believed to play an important role. One of the major sources of origin of arsenic in groundwater in India is the over-exploitation of groundwater for agricultural irrigation, particularly in rice cultivation. The continuous use of irrigation water carrying high concentration of arsenic may lead to its accumulation beyond the critical limits and affect the quality of crops [6].

Arsenic in groundwater is generally present in a dissolved state namely, arsenates or arsenates or both, besides the organic forms. The toxicity of arsenic compounds in groundwater depends largely on its oxidation state, and hence on redox potential status and pH. The arsenates are much more soluble, mobile and toxic than arsenates in aquatic soil environments. Reduction of arsenate to arsenates is facilitated by low reduction potential which is encountered under anoxic soil conditions, with arsenite being more soluble and mobile than arsenate [7]. Rice plant is susceptible to arsenic toxicity since it is grown under submerged conditions [8,9]. Hence, it is necessary to develop alternative rice farming systems that require less water and reduce excessive use of groundwater. To save irrigation water, an alternate farming strategy, *viz.* System of Rice Intensification (SRI) has been developed and it is

reported that system has high water productivity with some amount of saving (~20%) without any compromise on productivity.

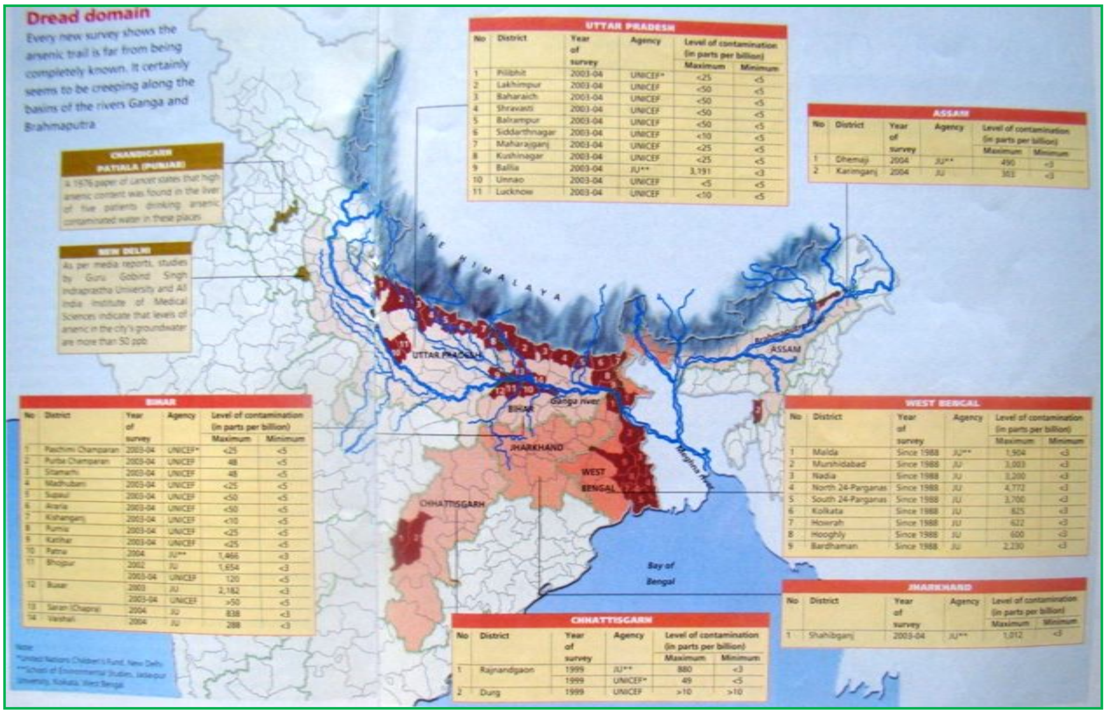
What this will mean for future rice production is that it will depend heavily on the development of water-efficient measures producing more rice per unit of water input. The trend now is to develop management policies for the efficient operation of irrigation systems, technologies that reduce water consumption, changes in rice plant itself and the ways in which it is grown; so as to use water more efficiently and to provide economic incentives to farmers to reduce water losses. Therefore, considerable research efforts are now being focussed to develop 'SRI' and 'Aerobic rice' farming system. Therefore, both the modern rice farming practices described below could be the answer towards over-exploitation of arsenic contaminated groundwater and there by diminuting the problems of arsenic loading of rice crops (as high as 10 mg/kg). The methods, merits and prospects of both the rice production systems are narrated briefly in the following section.

STUDY TRACKS HOW TOXIC ELEMENT ENTERS RICE THROUGH SOIL



The arsenic affinity: Studies have shown rice as a major exposure route for As in humans. A new study has revealed why rice is particularly efficient in accumulating As from soil and how to prevent such accumulations.

[**AS FOUND IN RICE PRODUCTS TOO:** Studies have revealed high As levels in rice and rice products such as rice bran and rice crackers. A study published in April 2008 in the Proceedings of National Academy of Sciences (PNAS) reported high levels of As in baby rice sold in super markets in the UK. The samples of products tested came from Japan and the UK. 35 per cent of baby rice samples tested had an average As level of 0.11-0.25mg / kg. However, this is not the first time that the dangers of As in rice have been highlighted. Based on analysis of samples collected through a survey of household in Nadia district of West Bengal, researchers from University Manchester, UK, have linked As to prevalence of cancer in the region (Journal of Applied Geochemistry). **]**



To explain why rice has an affinity of As compare to other cereal crops, the researchers examined the role of to protein transporters- Lsi 1 and Lsi 2. Known to transport silica (in the form of silicic acid) into plants, these transporters belong to a family of proteins that form pores in a biological membrane. In accordance with the study, Lsi 1 adds entry of As from the soil to the roots while Lsi 2 facilitates its entry from the roots to shoot and grain. Both the proteins (Lsi 1 and Lsi 2) mediate transportation of silicic acid from the shoots via the roots while in the absence of silicic acid there was preference for As, explained the research published online Proceedings of National Academy of Sciences (July 14, 2008). For the study, the researchers compared As accumulation between wild variety of rice and their mutant varieties where genes responsible for Lsi 1 and Lsi 2 protein transporters were knocked out. In the mutant variety where only Lsi 1 was removed, As in the shoots and the roots was 71 per cent and 53 per cent lower than wild variety. When Lsi 2 was knocked out, As in the shoots was 75 per cent lower relative to the wild variety of rice. When researchers grew mutant and wild varieties in the field, mutant variety had 13- 19 per cent lower concentrations of As than wild variety. According to the lead author of the study, Jian Feng Ma, Research Institute for Bio-resources , Okaya University (Japan) mutation in Lsi 2 has greater impact on As accumulate on in shoots and grain in field-grown rice than Lsi 1 as the former is responsible for taking As to grains and shoots. Ensure silica availability: when silicic acid was added to the medium, As concentration in the wild-type shoots decreased significantly. "Since silicic acid and As are carried by the same transporters, both of them compete for uptake. When the soil is rich in silica, the uptake of As is reduced," Ma reported. Arsenic -poisoning affects millions worldwide and is very common in Bangladesh and West Bengal in India. In both regions, rice is the major part of the diet. Professor S C Santra (Department of Environmental Science, Kalyani University , Kolkata) states, As transport in rice roots shares the same pathway as silicic acid. This explains why rice is efficient in As accumulation. There are other crops that can accumulate As. But the rate of absorption varies from plant to plant. Even with the race, different varieties have different accumulation rate. For As- reduction, Ma suggests: water-logged conditions allow certain microbes to work on arsenite to release As which is taken by rice. These microbes work in anaerobic conditions. So growing rice aerobically in raised beds, reduce its mobilization. This process can decrease As transfer from soil to grain. The other approach could be to create transgenic- rice to avoid absorption. The Chinese Academy of Eco- Environmental Science have shown that when rice grows in flooded fields, iron deposits are trapped in their roots, which protects rice plants from As contamination. It was also shown that more iron deposits form when phosphorous levels in soil are low. This implies that if a low- phosphorous chemical fertilizer is used, arsenic may be blocked from moving to rice seeds. The issue of As- contamination assumes more alarming proportions given a study conducted by researchers at the University of Aberdeen, UK which showed that Indian rice contains high levels of arsenites (iii) and arsenates (v).

ARSENIC DIMINUTION THROUGH SRI TECHNIQUE OF PADDY FARMING

'*Rice plant can grow in water but it is not necessary that paddy field be inundated with water*' – this is the philosophy behind the development of SRI technology [10]. SRI is a farming practice for biologically enriched environment for growth. Yields are increased by 50-100% or more, with a reduction in plant populations (by 80-90%), less water (by 25-50%), without using new 'improved' varieties (all varieties respond to the method) or using chemical fertilizers (just adding compost to the soil), with usually lowered costs of production, and thus considerably increased net economic returns per hectare. Because of some special anatomical features, rice can grow well even in standing water; but it does not require standing water as a rule. The practice of growing rice in inundated condition is mainly to control weed growth. But such conditions result in lack of aeration and consequent stunted root growth. That is why the fields are not flooded under SRI technology. Irrigation water is provided so as to wet the soil. The field should be irrigated again when the soil develops hairline cracks. Depending upon the soil and the environment conditions, the frequency of irrigation should be decided. As the soil is not flooded, the roots of the paddy plant grow healthy, deeply in all directions. As the field is intermittently irrigated and dried, the microorganisms survive well which make nutrients available to the plant.

Growing rice in an aerobic environment where As is added adsorbed on oxidized Fe surfaces and is largely unavailable to rice. Arsenic may also be present as arsenate where uptake is suppressed by phosphate [11]. Rather than arsenite found in flooded soils which is readily affected by phosphate. The SRI of Cornell University utilizes an alternating wet-dry water management for much of the season. Under SRI technology, instead of letting in the water until it reaches the end of the field, it may be stopped (depending upon the local conditions) after ¾ of the field is irrigated. The water automatically spreads to the entire fields. In this way a considerable amount of irrigation water can be saved. Therefore, SRI technology may play a pivotal role in reducing excessive use of ground water for irrigation *boro* paddy. Production of rice on the raised beds also reduced the arsenic content of rice plants, consistent with lower As availability. As soil arsenic is increased, the concentration of arsenic in rice straw increased linearly in both the bed and conventional treatments, but was 3-6 fold lower in rice grown on beds [12].

ARSENIC DIMINUTION THROUGH AEROBIC RICE FARMING

Rice farmed in traditional lowlands with continuous submergence conditions is the single biggest user of groundwater. Since water scarcity is increasing, it is imperative to develop alternative rice farming technologies that requires less water. Aerobic rice farming is now getting considered with the aim of increasing water and nitrogen use efficiencies. Compared to continuous flooding, aerobic management lowers arsenic assimilation by the plant, thus reducing grain arsenic content [13]. However, this practice opens new issues related to the adaptive capability of traditional farmers (from West Bengal) to the increased soil oxygen availability and, therefore, to their future quantitative and qualitative performances with respect to grain yield and quality.

The varieties / cultivars developed for lowland conditions, when grown under aerobic conditions (soil moisture below saturation) show drastic reduction in grain yields. This necessitates development of new rice farmers that can respond to limited amount of water and produce high yields under aerobic conditions. Hence a new system of rice production called *'Aerobic rice'* has been developed recently. It has been defined as farming of high-yielding rice varieties in direct-sown, non-puddled, aerobic soils (umplanned condition) under irrigation (2Singh and Chinnusamy, 2006). Water requirement for lowland rice varies from 1,500 to 3,000mm. Aerobic rice production system eliminates continuous seepage and percolation loses, greatly reduces evaporation as no standing water is present, and thus helps in enhancing water productivity. A comparison of water requirement of transplanted paddy and aerobic rice system clearly shows that aerobic system can save about 45% water (Table 1).

Table 1:Seasonal Water Requirement (mm) of Puddle Lowland Transplanted Rice as Compared with Aerobic Rice in Tropical Climate

Purpose	Lowland \Flooded Rice	Aerobic Rice
Land Preparation	150-300	100
Evaporation	200	100
Transpiration	400	400
Seepage and Percolation	500-1500**	335
Total Seasonal Water Requirement	1,650-3,000	935

** = Soil with a Seepage loss of 5-15mm/day

CONCLUSION

Production of rice on raised beds is a viable strategy to minimize the effects of soil contamination with As on *boro* season rice productivity, and to reduce the As content of both grain and straw. Previous experience has shown that irrigation water inputs are reduced by 25-40% with raised bed culture, saving both water and reducing As loading to soil. The more aerobic conditions of the raised bed reduced As content of straw to one-sixth of that found with the conventional paddy at soil As levels <25mg kg^{-1} and to one-third when soil As was >25mg kg^{-1}, thereby substantially reducing As exposure of animals consuming rice straw. The As content of brown rice from raised beds was halved from 0.5 to 0.25 mg kg^{-1} at soil As levels <25 mg kg^{-1}, but was similar to that in conventional paddy at higher soil As levels [12]. Human intake of As from daily consumption of 400g rice containing 0.5 mg As kg^{-1} is equal to that from 4L of water containing 0.05 mg kg^{-1}, indicating that intake of As from rice needs to be considered when setting drinking water standards. Raised bed culture can reduce human health risk associated with As intake from rice exposure route. Taking due cognizance of the above facts, it can be concluded that both SRI and aerobic rice system are promising technologies of rice farming, which save about 40-50% water with a marginal reduction in grain yield of about 10-20% as compared with lowland submerged farming methodology. Thus ‘SRI Technology of Paddy Farming’ and ‘Aerobic Rice System’ could be water-use efficiency and diminuting AS loading of rice crop.

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