氏　　　　名	ほせいん　けい　えむ　でろわー HOSSAIN K. M. DELOWAR
学位の種類	博士（農学）
学位記番号	甲第３９０号
学位授与年月日	平成１７年　９月２２日
学位授与の要件	学位規則第４条第１項該当
学位論文題目	Arsenic contamination in water, soil and plants in Bangladesh and its remedial measures （バングラディシュにおける水、土、植物体中の砒素汚染とその除去方法）
学位論文審査委員	（主査）　吉　田　勲
	（副査）　藤山英保　猪迫耕二 武田育郎　西山壯一

学位論文の内容の要旨

In Bangladesh, underground water is the major source of irrigation and drinking water due to the limitation of surface water. Now-a-days, arsenic contamination has emerged as one of the major concerns of public health of the country. Arsenic has contaminated the groundwater in about 85% of the total area of Bangladesh. In order to know the current scenario of arsenic contamination, we overviewed the various findings related to this issue. Recent reports of the British Geological Survey show that the groundwater in all 61 surveyed districts out of 64 is now contaminated with arsenic. On the other hand, a survey report of School of Environmental Studies, Jadavpur University, and Dhaka Community Hospital shows 47 districts are contaminated. The population exposed to the arsenic poisoning through drinking water is more than 25 million. In regard to arsenic pollution, Bangladesh is the most vulnerable country in the world. Unfortunately, until now, the cause of groundwater arsenic contamination has not been detected. Initially, several anthropogenic sources of arsenic were presented. Gradually, all were rejected based on the field observations. Finally, it was recognized that the source of arsenic is in the geological deposits.

The two prevailing hypotheses, pyrite oxidation and oxy-hydroxide reduction, describe the cause of contamination. However, neither has been studied thoroughly with accurate field data. Therefore, the verdict is still out whether to support one hypothesis over the other. Thousands of people are suffering from arsenic diseases ranging from melanosis to skin cancer and gangrene, and many have even died. Unfortunately, there is no specific treatment for chronic arsenicosis, other than ceasing further intake of arsenic contaminated water. To overcome this predicament, awareness of the problem and the creation of watershed management are necessary.

With a view to determine the amount of arsenic present in soil, water and plant samples we conducted several experiments in affected areas. We also attempted to correlate the arsenic contamination with food chain. The arsenic levels in soil varied substantially in different locations and also in rice growing seasons. The accumulation of arsenic was higher in irrigated Boro (December-June) season than rainfed Aman (July-November) season. The level of arsenic ranged from 7.37-10.97 mg kg^{-1} in study areas. The highest concentration was found in Monirampur upazilla in Jessore district in Boro season followed by central Chapainawabgonj in Chapainawabgonj district in the same season. The successive irrigations with arsenic contaminated water increased the level of arsenic accumulation of soil in Boro season. The arsenic concentration in water also varied greatly in different locations of Bangladesh. Out of 8 locations, the tubewell water of 6 locations was found to be higher than the safe limit (0.05 mg L^{-1}). The tubewell water from two locations of Chapainawabgonj was highly contaminated having concentrations of 0.48 mg L^{-1} and 0.46 mg L^{-1}, respectively. The accumulation of arsenic in rice grain was lower than the rice straw in all cases. The contaminated rice straw might increase the arsenic in cattle raised in areas where straw is used as feed. The leaf vegetables- amaranth had higher arsenic accumulation than the fruit vegetables; tomato, brinjal. Therefore, the use of leaf vegetables in arsenic contaminated areas would greatly increase health concern.

To ensure food security, the Bangladesh government has supported the cultivation of a number of high yielding rice varieties, which require a large volume of irrigation water. The use of groundwater for irrigation has increased abruptly over the last couple of decades. About 80% of pumped groundwater is utilized in the agricultural sector, but the groundwater in many areas of Bangladesh is severely contaminated with arsenic. So, there is a possibility of arsenic accumulation in rice and rice plants from arsenic-contaminated irrigation water. This study aims at assessing the extent of accumulation of arsenic in rice plants and its effects on growth and yield of rice. Arsenic concentrations in paddy soils (irrigated with 0, 2.5, 5, 10, 15, and 20 mg L^{-1} of arsenic water) were 0-0.2, 0-0.95 and 0-0.27 mg kg^{-1} at tillering, heading and ripening stages. Rice grains accumulated arsenic from soil/water and arsenic accumulation varied greatly in the two rice varieties studied. Arsenic concentrations in rice grains were 0-0.07 and 0-0.14 mg kg^{-1} dry weight in rice varieties

BRRIdhan-28 and Iratom-24, respectively. The growth and yield of rice plants were reduced significantly with increased doses of arsenic but the grain weight was not affected. Among the different yield components, the number of tillers per pot, number of effective tillers per pot and grain yield per pot reduced greatly with the higher dose (20mg L^{-1}) of arsenic applied. Yield reduction of more than 60% and 40% for Iratom-24 and BRRIdhan-28, was found with 20 mg L^{-1} of arsenic as compared to control. The reduction in straw yield was also significantly higher for both of rice varieties with the 20 mg L^{-1} arsenic application.

We performed a comparative study of three available groundwater arsenic removal methods used in Bangladesh for recommending a suitable method(s) at household level. Among the three methods studied, the Three-Pitcher system removed arsenic up to 98% whereas AAN-Filter and NIFSF methods removed arsenic up to 95%. The arsenic removal efficiency and water flow rate decreased significantly after three-month continuous operation in Three-Pitcher and AAN Filter methods and two-month continuous operation for NIFSF method. Calcium concentration was decreased to half by Three-Pitcher and AAN Filter methods but increased substantially in the NIFSF method. Calcium released from bleaching powder used in NIFSF method might cause this increased amount of calcium in filtered water. Anion concentrations in the filtered water changed in both directions. A significant increased in chloride was found in NIFSF water probably due to the chlorination of bleaching powder. Total dissolved solid (TDS) decreased 50-65% in filtered water using these methods. Considering all of the parameters, Three-Pitcher method was the best, but the others were effective, too. The choice of methods largely depends on the socio-economic conditions of the rural people. Before recommending any method for large-scale use in arsenic removal, further study needs to be done.

We concluded that there was significant and profound level of arsenic contamination in the topsoil, water and plant samples collected from different locations in Bangladesh. Majority of the plants exhibited arsenic levels above safe limit. The arsenic problem in Bangladesh is increasing very rapidly. Therefore, there is an urgent need for extensive and detailed study of heavy metal pollution across Bangladesh. Moreover, cheap and economically viable preventive measure should be identified to control this menace for the poor susceptible people of Bangladesh.

論文審査の結果の要旨

バングラデシュの利用可能な地表水量には限界がある．地下水は灌概水や飲料水の主要源であ

る．しかし，バングラデシュの約85%の地下水がヒ素に汚染されており，近年，環境圏のヒ素汚染による国民の健康問題が深刻さを増している．
そこで本論文では，ヒ素汚染の現状を調査すると共に，土壌，地下水および作物体中に含まれるヒ素量を測定し，食物連鎖におけるヒ素収支などを明らかにしている．

まず最初に，本論文は，ヒ素汚染の現状を認識するために様々な知見を概説した．近年のイギリスの地質調査グループの報告では，調査対象とした64地区のうち61地区でヒ素汚染が確認されている．また，Jadavpur大学とDhaka公立病院の調査では，47地区でのヒ素汚染が確認された．その結果,2500万人以上の人が，飲料水を介してヒ素中毒による黒色素沈着症や皮膚癌に患っており，かつ，多くの人々が亡くなっている．ヒ素を含んだ水の摂取をやめる他に慢性ヒ素症の特効薬はない．この状況を打開する為には，これらに関して問題意識を持ち，集水域を管理することが必要である．

次に，筆者は，蛍光X線分析器を用いて，バングラデシュの汚染地域における土壌，地下水および各種作物体中に含まれるヒ素量を測定し，食物連鎖におけるヒ素汚染の相互関係を明らかにせんとした．土壌中のヒ素量は，調査地域やイネの成長期によって明らかに異なっていた．ヒ素集積量は，雨期(7-11月)よりも灌概期(12-6月)に多く，7.37〜10.97mgkg^{-1}であった．ヒ素は，灌概期のChapainawabgonj地区Chapainawabgonj中央において最も集積しており，次いで，同時期のJessore地区Monirampurupazillaにおいて集積していた．
また，地下水中のヒ素濃度も地域によって大きく異なっていた．8地点中6地点の井戸水は安全基準値(0.05mgL^{-1})より高く，中でも，Chapainawabgonjの2地点の井戸水のヒ素濃度は0.46，0.48mgL^{-1}と高く，ヒ素汚染は深刻である．
米粒中のヒ素量は稲ワラ中のヒ素量よりも少なかった．家畜飼料としてワラが使用されている地域では，ヒ素に汚染された稲ワラが増加していた．
葉菜のアマランスは，果実のトマトやナスよりも多量のヒ素が集積していた．そのことからヒ素の汚染地域では，葉菜の摂取による健康問題が非常に増加している．

バングラデシュ政府は食物の自給率確保のために，多量の灌漉水が必要な高生産性のコメ品種を推奨している．地下水の灌概利用がここ数十年で急激に増加し，約80%の揚水地下水が農業利用されている．しかし，バングラデシュの多くの地域では地下水が多量のヒ素によって汚染されており，灌概利用することによって，コメや稲にヒ素が蓄積されている危険性がある．そこで，ヒ素濃度の異なる灌漑水(0，2.5，5，10，15および20mgL^{-1})を用いて2種類の稲を栽培し，灌漑水が，土壌や稲の生長および収量に及ぼす影響を調査した．その結果，水田土壌中のヒ素濃度は，分けつ期，出穂期および登熟期でそれぞれ0〜0.2，0〜0.95および0〜0.27mgkg^{-1}であった．米粒は土壌や水を通してヒ素を蓄積しており，BRRIdban-28とIratom-24の米粒中のヒ素濃度は乾物重当りそれぞれ0〜0.07と0〜0.14mgkg^{-1}で，品種によってヒ素蓄積量が大きく異なって

いた．また，ヒ素投与量の増加とともにイネの生長と収量は明らかに減少したが，粒重は変化がなかった．ヒ素施与量によってポットあたりの出穂数，有効出穂数および収量が異なり，多量のヒ素投与(20mgL^{-1})によってそれぞれ大きく減少した．品種に関係なく，20mgL^{-1}ヒ素施与区では稲ワラの収量が大きく減少し，Iratom-24 および BRRIdhan-28 の稲ワラの収量は，対照区と比較してそれぞれ 60%および 40%の減少が認められた．

本研究ではさらに，バングラデシュの家庭レベルにおいて適した地下水中のヒ素除去法として 3 方法を取り挙げ，比較検討した．AAN-Filter 法と NIFSF 法では 95%までヒ素を除去したのに対して，三段土壌層法では 98%までヒ素を除去した．全ての要因を考慮すると，三段土壌層法が最良な方法であることがわかった．

本論文の特徴は，バングラデシュの重要課題の一つであるヒ素汚染を食物や飲料水の観点から検討し、その結果，環境圏は明らかにヒ素に汚染されており，かつ，多くの植物体は，安全基準より高いヒ素量を含んでいること,かつ，ヒ素濃度の異なる灌漑水を使用した稲作栽培などを行い，水，土，植物体間のヒ素収支を行明らかにした点にある。以上のことから，本論文は学位論文として十分な価値を有すると判定する．