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GROUNDWATER ION COMPOSITIONS IN BANGLADESH: A GEOSPATIAL APPROACH

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ABSTRACT

Untreated groundwater is the most common source of potable water for a great portion of the population of Bangladesh. Groundwater in Bangladesh exists at shallow depths which makes it easily available for extraction. A great portion of the rural and urban water supply system rely on groundwater. It also has a major contribution on irrigation. However, groundwater is not safe for use due to the presence of elevated concentrations of arsenic and other heavy metal ions such as iron, manganese, chromium, cadmium, etc. Such contaminations often have adverse health effects on people of all age. This study aims to analyze the relationship between the concentrations of arsenic, manganese and iron in groundwater and their spatial variation with topographic features such as the surface slope, elevation and land cover. Existing data on groundwater ion concentrations in the alluvial aquifers of Bangladesh was collected. The collected data was then analyzed with the help of GIS and remote sensing. ArcGIS 10.8 was used to conduct ordinary Krigging Interpolation to create spatially interpolated surfaces of different ions. The analysis reveals that high arsenic concentrations (>50 µg/L) are found in low-lying areas with low slopes. The distribution of manganese in groundwater is not the same as that of arsenic. Areas with high arsenic concentrations are found to consist of lower concentration of manganese and vice versa. The distribution of these ions according to landuse pattern have also been studied, from where it can be concluded that agricultural zones of Bangladesh are more contaminated with higeher percentage of arsenic, iron and manganese. As heavy metal ions are non-biodegradable, their toxicity gets accumulated far away from the sources of pollution. Global studies have shown that continuous exposure to heavy metals cause diseases and even intellectual impairment in children. This study will help to identify areas of unacceptable levels of arsenic, iron and manganese in accordance to the Environment Conservation Rules (ECR, 97) and develop water treatment facilities accordingly. The application of geospatial techniques to correlate relations between groundwater ion content and landuse may be used to monitor possible changes due in groundwater in response to major landuse changes.

Keywords: *Arsenic, Manganese, Iron, spatial, Interpolation*

1. INTRODUCTION

Over the last few decades, residents of Bangladesh have been using millions of hand-operated tube wells (estimated 10–12 millions) (Shamsudduha et al., 2009) to extract groundwater for drinking, farming, cleaning and other purposes. Many of these contain dangerously high levels of heavy metal ions such as Arsenic (As), Iron (Fe) and Manganese (Mn). These heavy metals, present in trace amounts have adverse health effects on people of all age. Approximately 80% of diseases in underdeveloped nations are caused by contaminated water, with a death toll of up to 10 million each year. (Tearfund & W., 2002) Heavy metal exposure can induce a variety of illnesses, including kidney damage, cancer, effects on the mind and behaviour, and, in extreme circumstances, death. So, the identification of water sources containing such harmful ions is crucial.

Amongst the wide variety of ions that exist in groundwater, the most common one that causes detrimental health effects in Bangladesh is arsenic. Groundwater is contaminated by arsenic (As) in 61 districts of Bangladesh (Hossain et al., 2013). It has been estimated that more than 20 million people drink water with arsenic levels that exceed the national guideline(WARPO, 2001).
Besides arsenic, iron and manganese contamination is also a serious issue in Bangladesh. Iron is the second most prevalent metal in the earth's crust, accounting for around 5% of all metals. Elemental Fe is uncommon in nature because the Fe ions Fe+2 and Fe+3 easily mix with oxygen and sulphur-containing molecules to create oxides, hydroxides, carbonates, and sulphides (Hossain et al., 2013). In 2001, about half of the wells tested by the British Geological Survey (BGS) and the Department of Public Health Engineering (DPHE) surpassed the Bangladesh drinking water standard for iron (1 mg/l) and approximately three-quarters surpassed the acceptable limit for Mn (0.1 mg/l). (Hasan & Ashraf Ali, 2010).

According to the overall manganese distribution from the BGS and DPHE (2001) investigation, large concentrations of manganese are found in most districts of the country. Manganese and iron distributions do not often correspond with arsenic distributions, implying that groundwater with acceptable arsenic concentrations may not have enough manganese/iron concentrations. (2009) (Shamsudduha et al)

The presenice of different ions and their composition in groundwater seem to vary from one geographical location to another. In addition to factors such as geology, mineral composition of an aquifer, rock-water interactions, groundwater composition is strongly linked with the landscape and land use above it. Chronic groundwater quality issues are caused by inappropriate land use, particularly bad land management and through hazardous sources of chemicals. Natural and manmade factors may both pollute groundwater. Residential, municipal, commercial, industrial, and agricultural activity can have an impact on groundwater quality (Khan et al., 2011). Groundwater contamination degrades drinking water quality, disrupts water delivery, and poses possible health problems.

The primary objective of this study is to analyse the spatial variation of groundwater ions (Arsenic, Manganese and Iron) with topographic features such as the surface slope, elevation and land cover with the help of geospatial tools in GIS and remote sensing, based on the database developed by the BGS and DPHE (2001). In addition, broader areas of unacceptable levels of arsenic, manganese and iron have been identified in accordance to the Bangladesh standards.

2. METHODOLOGY

2.1 Description of Study Area

Bangladesh covers an area of 147,570 square kilometer, extending from 20'34N to 26'38N latitude and from 88'01E to 92'41E longitude. It is situated at the confluence of three major rivers: the Ganges, the Brahmaputra, and the Meghna, with roughly half of its land being below the 10m contour line. The country covers a large portion of the Bengal Basin, which has historically served as a significant depocenter for sedimentary flow from the Himalayas and Indo-Burman Ranges, which are drained by the mighty river system of Bangladesh.

Bangladesh is vastly a land of alluvium plain, formed through the deposition of quaternary sediments by the Ganges, Brahmaputra and Meghna rivers. Hillocks and hills are restricted to a short strip along the southern edge of the Shillong Plateau, the eastern and southern areas of Sylhet district, and the Chittagong Hill Tracts in the southeast of the country, which border the Indian states of Tripura, Mizoram as well as Myanmar.

2.2 Dataset of Groundwater Ions

In this study, geochemical data from Bangladesh's National Hydrochemical Survey (NHS) (BGS and DPHE 2001) were utilised. The survey analyzed a total of 3,534 tubewells of different depths throughout Bangladesh, excluding the Chittagong Hill Tracts and tested samples for the presence of 20 different ions including arsenic, iron and manganese. On an average, there were 58 samples from each district and 8 samples from each upazila (sub-district). This database provided the location coordinates (geographic latitude and longitude) for all sampling locations recorded by a hand-held Global Positioning System (GPS) during the survey. This dataset was chosen due to its trustworthiness in collecting the data, processing, and analysis, as well as its country-wide coverage.

2.3 Land-use Mapping

This study used ESRI's 10 meter 2020 Landcover product which was classified from Sentinel- 2 imagery. The National Geographic Society generated a vast training dataset of billions of human-labeled image pixels, which was used by Impact Observatory's deep learning AI land classification model. The global product was created by using this model on the Microsoft Planetary Computer to analyze approximately 400,000 Earth observations from the Sentinel-2 2020 scene collection. A 10 class classification scheme is adopted. Bangladesh level data was subset from the global dataset and downloaded.

2.4 Geospatial Analysis

The ion concentration data obtained from Bangladesh's National Hydrochemical Survey (NHS) was sorted and the selected ion's concentration and associated locational attributes were obtained. The geospatial analysis involved spatial interpolation and raster surface generation. This followed by spatial distribution mapping and correlation. The ion concentration data was used to create surface maps by interpolating from the 3534 data points using Ordinary Kriging Interpolation method with a linear model. After extensive relevant literature review, ordinary Kriging technique was selected because of the wide acceptability as well as the suitability with the number of points available. In short, Krigging Method for spatial interpolation involves creation of an interpolation raster using computation from 12 neighboring points. The resultant raster was bounded by the international boundaries of Bangladesh. This continuous surface allowed better deduction about the overall spatial distribution of the concentration of ions in the groundwater.

The topographic feature of the surface landscape was obtained using a digital elevation model. Cloud computing platform Google Earth Engine was used to obtain the SRTM Digital Elevation Model (DEM) for Bangladesh. The DEM was used to obtain the slope raster using the Slope tool from the Hydrology toolset in ArcGIS 10.8.

All the raster layers including raster and vector layers were brought to the same map projection system in order to facilitate spatial overlay. This allowed visual interpretations and correlations to be made between one layer and another.

3. RESULTS

3.1 Spatial Distribution of Ions

The problem of Arsenic in groundwater seems to be a serious issue in many parts of the Southern and Eastern region of Bangladesh, with the highest concentration in Chandpur district (>250 µg/L) as shown in Fig. 1(a). The depth of this tube well containing the highest concentration of arsenic is 20 m. According to The Environment Conservation Rules 1997, the limit for arsenic in potable water is 50 µg/L. Hence, it can be concluded that 25 percent of the surveyed tube wells have groundwater arsenic that goes beyond the standard guidelines as represented in the pie chart in Fig. 2(a).

The spatial distribution of Iron in Fig. 1(b) shows a dispersed pattern, with the greatest concentration at the Sylhet region (>11 mg/L) where the depth of tube well is 58 m. On average, high concentration of iron is found in most areas, with 51 percent of the surveyed tube wells consisting of groundwater iron in excess of the Bangladesh standard of 0.3-1.0 mg/L as shown in Fig. 2(b).

Manganese concentrations (>0.7 mg/L) are high in the country's central, northern, and western areas as seen in Fig. 1(c). This is quite beyond the standard of 0.1 mg/L and it is observed that 74 percent of the surveyed tube wells have groundwater manganese that goes beyond the standard guidelines, shown in Fig. 2(c).

3.2 Surface Elevation and Ion concentration

The variation in surface topography and groundwater arsenic, iron and manganese levels have been studied using DEM, as shown in Fig. 3 and the following interpretations can be made.
Tube wells containing higher concentration of arsenic (>50 µg/L) are mostly located in the low elevation areas, mainly in the Southern parts of Bangladesh as shown in Fig. 3(a). At this location, the surface elevation is less than 20m.

Tube wells containing high concentration of iron (>1 mg/L) are distributed through the country, both in high and low elevation areas as shown in Fig 3(b). Majority of such tube wells are concentrated at places where elevation is less than 20 m. Also, considerable quantity of tube wells with high iron content exists at areas where elevation is between 20-50 m, especially in the North. Data for even higher elevations is not available.

Manganese containing tube wells are also existing in almost every region of the country, with maximum of them concentrated in the Western part of the country as shown in Fig. 3(c).

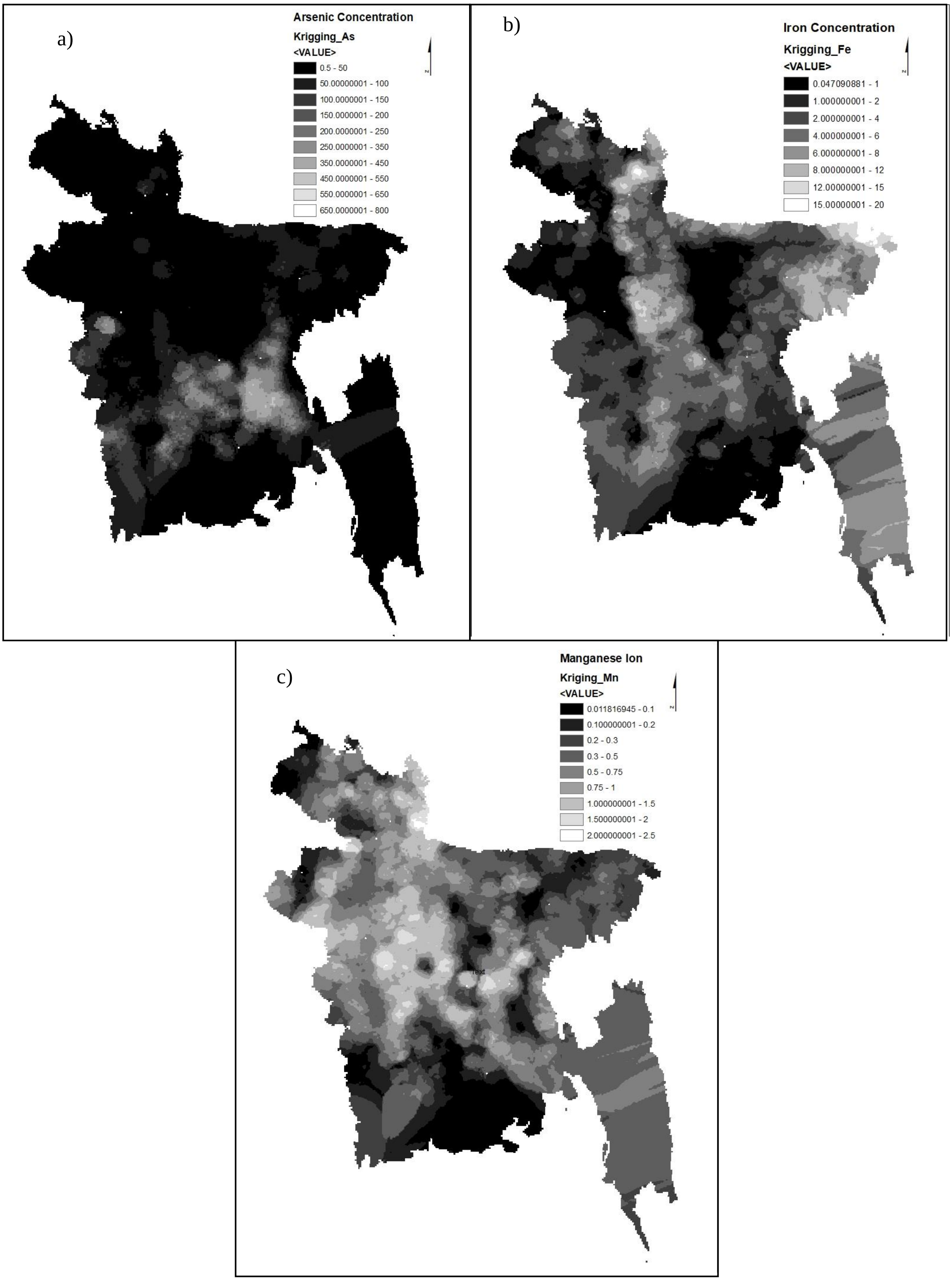

Fig.1: Maps showing the spatial distribution of a) Arsenic Concentration (µg/L), b) Iron Concentration (mg/L) and c) Manganese Concentration (mg/L) in Groundwater made through Kriging Interpolation Method in ArcMap 10.8

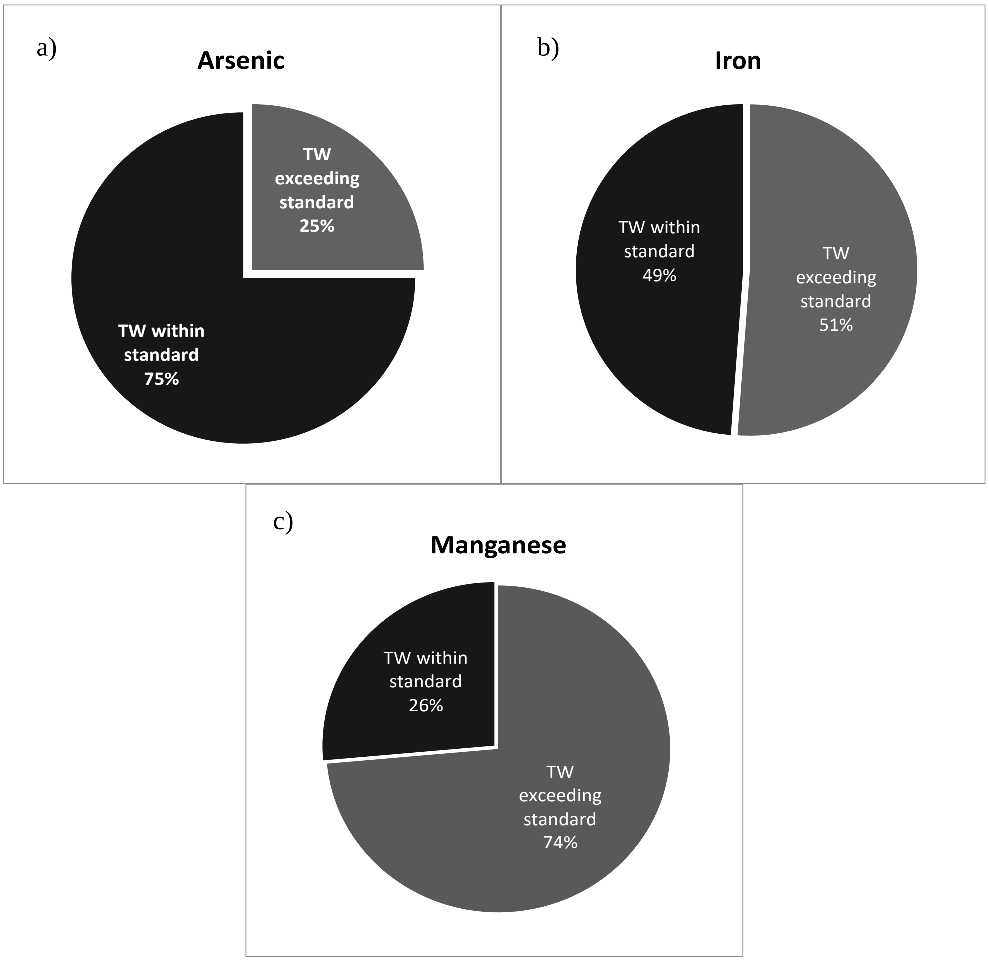

Fig.2: Percentage of tube wells exceeding their corresponding standards (ECR 1997) of Ion concentration

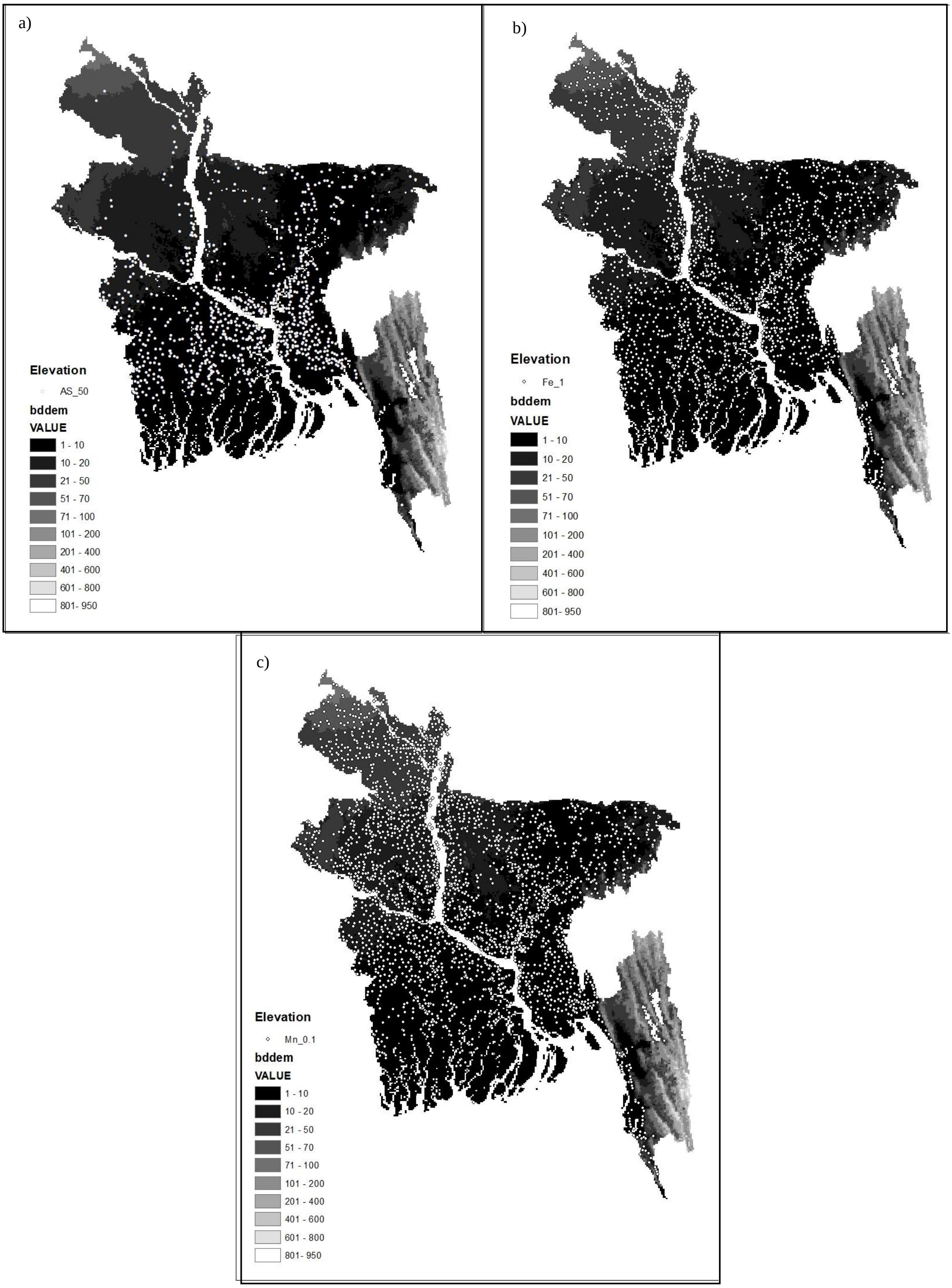

Fig.3 Digital Elevation Model (DEM) of Bangladesh, showing the distribution of tube wells containing a) Arsenic concentration > 50 µg/L, b) Iron concentration > 1 mg/L and c) Manganese concentration > 0.1 mg/L. Elevation in metres.

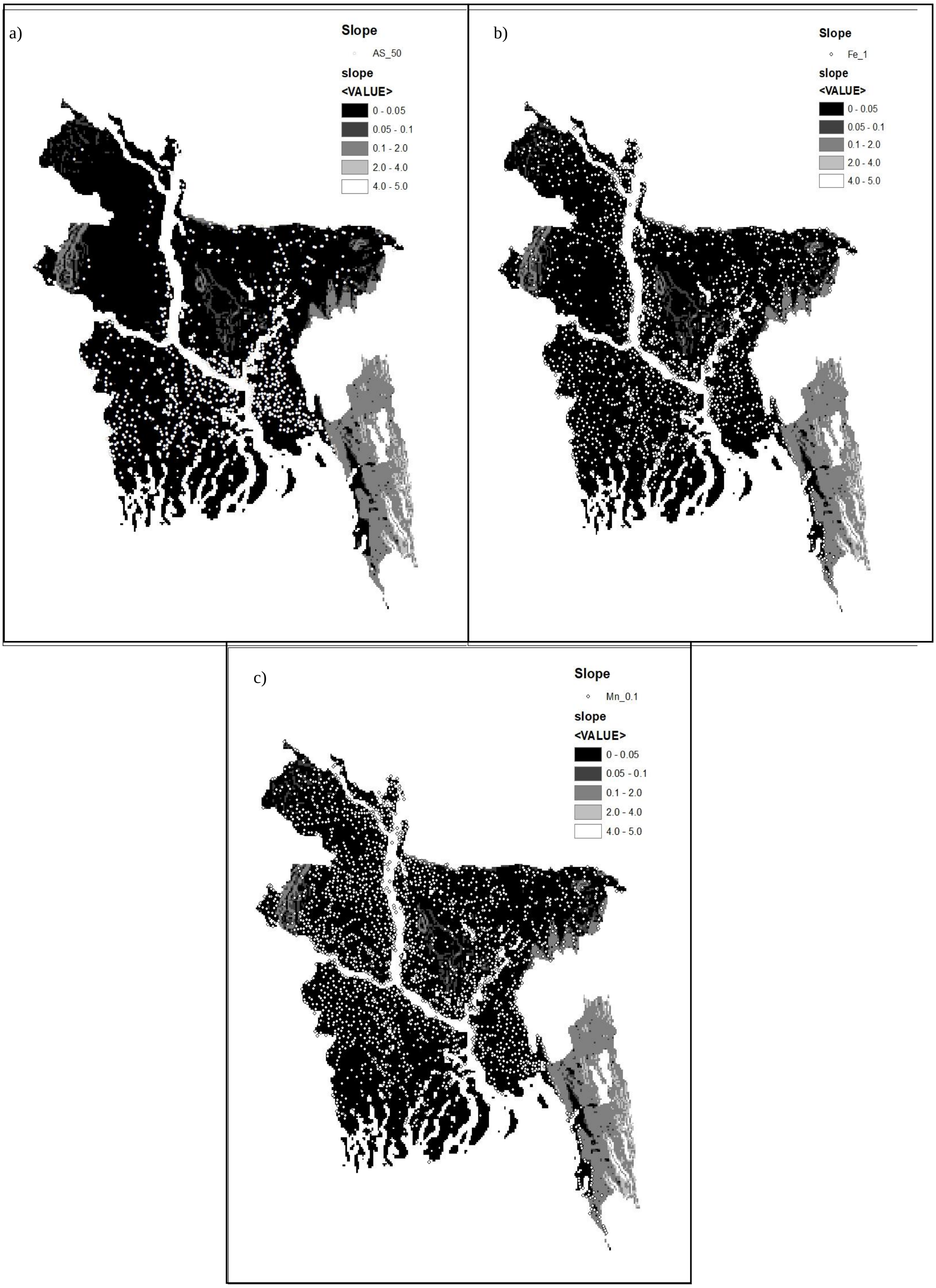

Fig.4: The topographic slope of Bangladesh (derived using DEM) showing the distribution of tube wells containing a) Arsenic concentration > 50 µg/L, b) Iron concentration > 1 mg/L and c) Manganese concentration > 0.1 mg/L.

3.3 Slope and Ion concentration

The topographic slope of Bangladesh lies within 4 degrees, for more than 90% area of the country as seen in the topographic slope map of Fig. 4. The Chittagong hill tracts and the Sylhet district in the eastern region of the country have a bit elevated topography with higher slopes (10-80 degrees).
The majority of arsenic contaminated tube wells are found in low-slope sections of the country. However, tube wells with low arsenic concentrations are also found in low slope regions, whereas high arsenic tube wells are not seen in higher slope locations.

Higher concentration of Iron and Manganese ions are observed to be found in the low slope regions. However, the high slope areas are not totally free from these ions. Through visual inspection, it can be observed that the high slope areas along the Chittagong hill tracts and parts of Sylhet region contain an approximate manganese concentration of 0.4-0.5 mg/L.

3.4 Well Depth and Ion concentration

Arsenic, iron and manganese ion concentration was found to be lower in the deeper tube wells (>150m), compared to the shallower ones as shown in Fig. 5. However, it must be noted that only about 9 percent of the surveyed tube wells were deeper than 150 meters. So, this conclusion might not be an accurate representation of the overall situation.

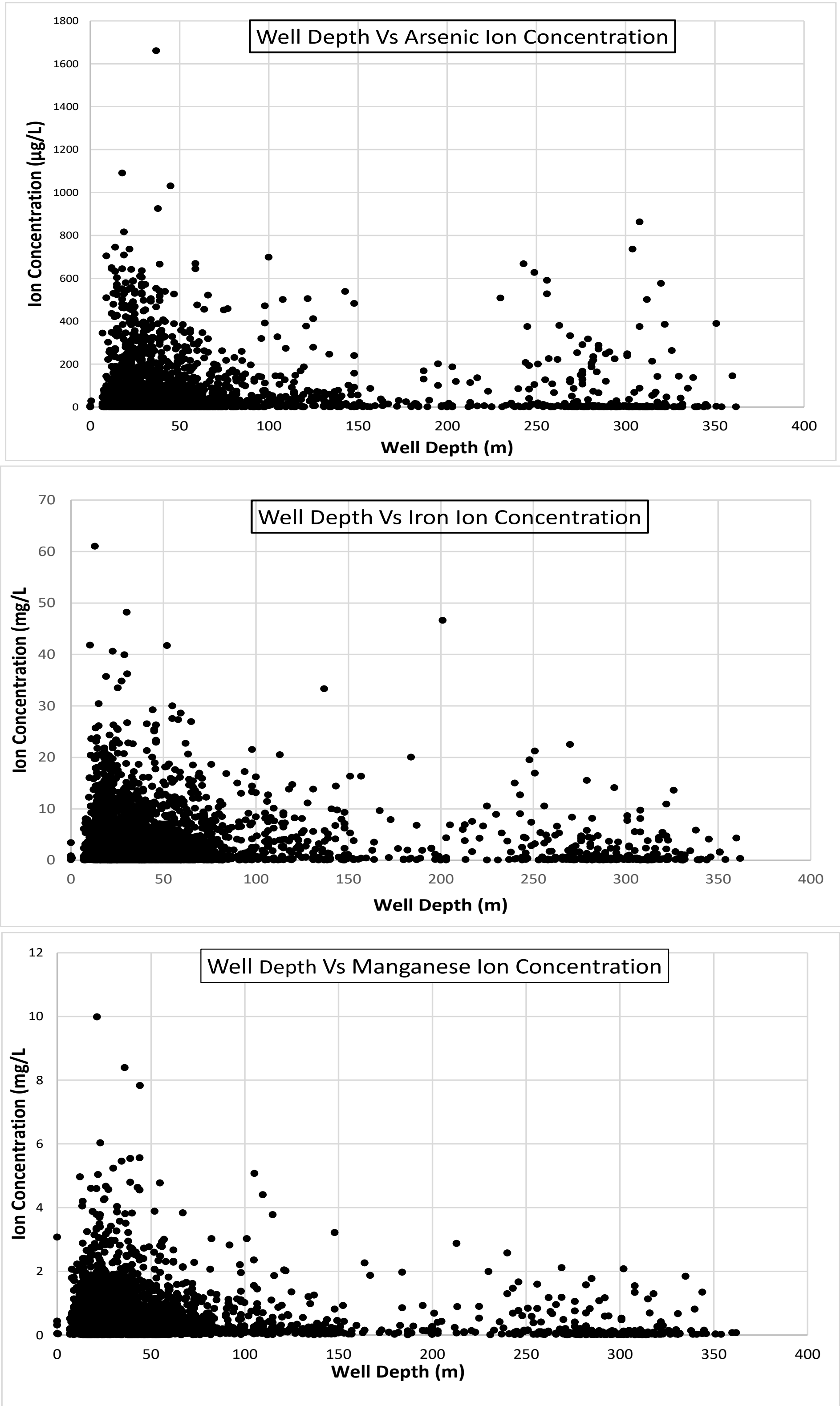

Fig. 5: Relation of Ion Concentration with Well Depth

3.5 Land-use and Ion Distribution

The land-use pattern of Bangladesh mainly comprises of agricultural land and densely vegetated areas, as portrayed by the land-use map in Fig 6. The relation between land-use pattern and the distribution of arsenic, iron and manganese have been obtained through visual inspection.
The arsenic contaminated tube wells were found to exist in the agricultural areas of the country, mainly at the Southern and North-Eastern parts. The densely vegetated regions of the South also had high levels of Arsenic.

Irons ions are also found at great concentration in the agricultural zones, especially at the Northern and central parts of the country. High concentration of iron was also observed at the vegetated areas of the South and built-up areas of the South-Eastern region.
The prevalence of Manganese ions were observed more at the built-up zones of the North and central parts of the country. Tube wells contaminated with high levels of manganese also existed in the agricultural zones of the North and Western parts.

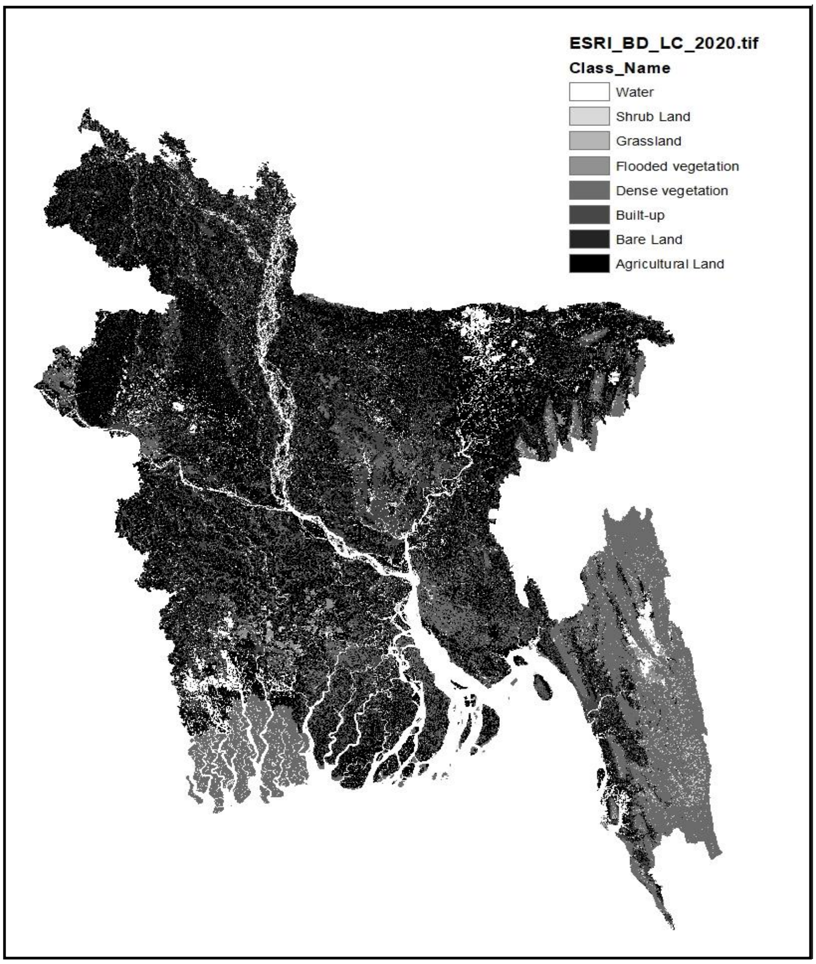

Fig.6: Land-use Map showing the major land-use pattern of Bangladesh

3.6 Interrelation between Arsenic, Iron and Manganese

Manganese distributions throughout the country do not typically match to arsenic distributions, which imply that groundwater with acceptable arsenic concentrations, may not have appropriate manganese concentrations. However, the areas affected with high concentration of arsenic are found to suffer from high iron content. This might be due to the presence of iron-reducing and oxidizing micro-organisms as claimed in a few studies.(Hassan et al., 2016) In addition to the activity of specific microorganisms directly involved in the biogeochemical cycling of arsenic, arsenate-reducing bacteria also releases arsenite [As(III)] and arsenate-oxidizing bacteria produces arsenate [As(V)], which might be the reason for the observed interrelation between arsenic and iron. (Hassan et al., 2016)

4. DISCUSSION

Arsenic pollution of groundwater is incredibly challenging in Bangladesh, where tube well water collected from shallow aquifers is the primary supply of drinking and cooking water for the majority of the country's population. Aside from residential usage, large amounts of groundwater are utilized for irrigation during the dry season, mostly for the growth of dry-season rice (boro) and wheat.(Ashraf Ali, 2006)

Arsenic pollution in groundwater follows a unique geographical pattern, with the greatest contamination in the south and southeast region (excluding Chittagong and the Chittagong Hill Tracts) and the least in the northwest and raised portions of the north-central region. In this study, high levels of arsenic (> 50 µg/L) were generally observed in the Southern region of Bangladesh, where the surface elevation is below 20 m, the slopes are gentle and the tube wells are shallow. From the analysis of the national hydrochemical survey data, it can be concluded that 25 percent of the surveyed tube wells have arsenic exceeding the ECR standard for drinking water.

The widespread occurrence of manganese in groundwater has introduced a new dimension to Bangladesh's already challenging safe water supply scenario. It has been observed that in many regions, groundwater with acceptable arsenic concentrations does not contain appropriate manganese concentrations. If unsafe manganese concentrations in wells are taken into account, the population exposed to unsafe water would grow substantially more than that projected for arsenic alone.
From this study, it can be concluded that high manganese concentrations are mostly found in the central, northern and western regions of Bangladesh, where surface elevations and slope are on the lower side. However, the Eastern parts of the country (Chittagong and Sylhet regions) contain relatively less manganese. It has also been seen that the majority of the highly concentrated tube wells have a depth of less than 150 m.

The presence of iron in groundwater is a common scenario in most parts of Bangladesh. Higher concentration of iron is mostly observed along the central strip and in the Eastern (Sylhet and Chittagong region) parts of the country. It can also be concluded that the areas affected from high arsenic concentrations also suffer from high iron content.

The health effects of arsenic contaminated water are well known around the world. Long-term exposure to high levels of arsenic can cause cancer and skin lesion (Smith et al., 2000). Long-term intake of inorganic arsenic may cause developmental consequences, diabetes, lung illness, and cardiovascular diseases (World Health Organization). Shallow aquifers polluted with high levels of arsenic are the principal supply of irrigation water in many sections of the nation, and it is estimated that over 900 tonnes of arsenic is cycled each year with irrigation water (Ashraf Ali, 2006). Thus, arsenic build up in rice field soil and its entry into the food chain via rice plant absorption are major concerns. The concentration of arsenic in rice field soils was found to be substantially greater in arsenic-affected locations where irrigation water included higher arsenic levels than in unaffected areas (Ashraf Ali, 2006).

So far, the manganese issue has received very little attention in the water supply industry. The effects of Manganese pollution on human health are relatively less well-known. Manganese in water has been linked to causing reduction of neurobehavioral function in children, even at low levels. Higher levels of manganese exposure are linked to worse memory, attention, and motor function performance in children (Rahman et al., 2021). Given the extensive prevalence of manganese in groundwater of Bangladesh, it is critical to improve manganese awareness among the public.

Iron is one of the most abundant trace elements found in the earth's crust, and it is most commonly found in the form of oxides. The majority of iron contamination is caused by the discharge of waste water (Hossain et al., 2013). The presence of iron does not generally pose any health risk; however overdosing might be potentially hazardous. Over exposure to iron contaminated water causes cancer, diabetes, liver and heart diseases (Sarkar et al., 2019). Presence of iron imparts a metallic taste to drinking water and also causes aesthetic disruption. It also enhances the growth of certain bacteria which might impose health concerns (Moore, 1999).

5. CONCLUSION

The objective of this study was to investigate the spatial distribution of arsenic, iron and manganese in groundwater, and relate it with different topographic features such as surface elevation, slope, well depth and land use. The results of this study require to be validated by extensive field work. More detailed survey need to be carried out to identify areas of excessive heavy metal ions in groundwater which have harmful health implication. Also, extensive study of groundwater chemistry and its relation with topographic features needs to be done to analyze the reasons behind the observed trends, which is beyond the scope of this study.

In this study, it has been found that 25% of the tube wells surveyed contained arsenic in concentrations greater than the ECR 1997 standard of 50 µg/L. Most of these tube wells are located at the Southern regions of the country, where the surface elevation is less than 20 m and topographic slope is generally less.

About 51% of the surveyed tube wells contained iron in concentrations greater than the ECR 1997 standard of 1mg/L. The distribution of iron contaminated tube wells is rather common, majority of which are concentrated in the Southern region, where surface elevation and slope is less. However, the other parts of the country are not free from high iron content.
With 74% of the surveyed tube wells containing concentrations exceeding the ECR 1997 standard of 0.1mg/L, the distribution of manganese throughout the country is alarming. Such tube wells are mainly located in the northern, western and central parts of Bangladesh.
It has also been found that the shallow tube wells whose depth is less than 150m contain higher concentration of arsenic, iron and manganese. Also, these contaminated tube wells were mainly found in the agricultural zones of the country.

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