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Research paper

Groundwater recharge influencing the arsenic enrichment in the aquifer of west Bengal

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Abstract

Arsenic contamination, a very serious issue, has a detrimental effect on the living being. Arsenic contamination is found in the Gangetic plains, with West Bengal as the most affected state. In the present study, an attempt has been made to use weighted overlay analysis for arsenic hazard zonation based on the factors that influence the groundwater in a terrain. Weighted overlay analysis was done for mapping the arsenic contamination zone by assigning weightage and rating to geomorphology, land use/land cover, soil type, cropping intensity, slope and drainage density in North 24 Parganas. The whole region has been formed by the sedimentation from the river, and soil at the surface contains higher concentration of arsenic. Arsenic may get released from the sediment by various mechanism and transport downward along with the infiltration of rainwater. Thus, arsenic contamination in groundwater is influenced by the arsenic rich sediments, slope, and drainage pattern of the area. The arsenic concentration in collected groundwater samples shows the same result as obtained from the weighted overlay analysis except in the area with deeper water level. Thus, weighted overlay analysis along with water level data can be an effective method for determining the risk of arsenic in an area.

Keywords: *Arsenic; Groundwater; Rainfall; Water level; Weightage.*

1. Introduction

The Bengal basin, formed by the sedimentation of the river Ganges, Brahmaputra, and Meghna along with their tributaries form the world's largest fluvio-deltaic basin (Alam et al. 2003), and is regarded as most acutely arsenic affected geological region in the world (Mukherjee et al. 2008). These rivers flood large parts of their alluvial plain during monsoon (Ravenscroft et al. 2005), and the sediment load carried by them is reported to be the greatest load of any river systems (Milliman & Meade 1983). Thus, the Bengal basin receives a huge amount of land-derived and weathered sediments through Himalayan Rivers (Tareq et al. 2003). During the Holocene time, the southern belt of the Himalayas was subjected to high erosion and intense rainfall (Williams & Clarke 1984). It may have led to the transportation of arsenic bearing products with the accumulation of bulk sediments in the Gangetic plains. Major sink of arsenic in the aquatic environment is the iron-rich sediments (Peterson & Carpenter 1986), and in soil, it is largely controlled by Fe, Mn and organic matter redox reactions (Brannon & Patrick 1987). The primary source of arsenic in the sediments, the process of its release into groundwater is still not clear and different hypothesis have been proposed by different researchers. High levels of arsenic in groundwater is attributed to oxidative dissolution of arsenic-rich pyrite or arsenopyrite (Mandal et al. 1998; Chowdhury et al. 1999), reductive dissolution of arsenic-rich iron oxyhydroxides (Acharyya et al. 1999; Nickson et al. 2000), and water-rock reaction with arsenic bearing minerals (Smedley et al. 1996; Nimick 1998).
Arsenic contamination in groundwater is a very serious concern as its chronic exposure may lead to skin cancer (Bunnell et al. 2007), cardiovascular and peripheral vascular diseases (Xia et al. 2009). Arsenic also inhibits plant growth, its reproductive capacity with losses in fertility, yield and fruit production (Finnegan & Chen 2012). Extensive work has been carried out in the Bengal basin related to arsenic varying from the level of contamination in groundwater to factors controlling its release. Various researches have correlated the arsenic contamination to the geological setting of the area (Acharyya et al. 2000), and geomorphology (Acharyya & Shah 2007; Biswas 2010). However, some recent works show the modelling of arsenic contamination taking into account the contributing factors. Mukhopadhyay et al. (2006) used GIS and fractal approach to delineate arsenic contaminated zones in the Bengal Delta of India. Ckakraborty et al. (2007) used DRASTIC and GIS to assess the vulnerability of the aquifer to arsenic pollution in Malda district of West Bengal.
The distribution of arsenic is controlled by basin geology, geomorphology, scale of heterogeneity, depositional facies, hydrogeology, hydrogeochemistry and land use of the area (Bhattacharya et al. 1997; Smedley & Kinniburgh 2002). The chemical characteristic of groundwater in an aquifer is affected by the precipitation and infiltration of water through soil zone. The quality of groundwater is also influenced by the chemical composition of soils, as during rainy season contaminants can move into the aquifer along with the percolation of rainwater. In the present work, an attempt has been made to utilise the weighted overlay analysis tool of Arc GIS to prepare the map of arsenic risk zonation of an area. This tool has been used in various studies like landslide hazard zonation, groundwater potential zonation etc., thus an effort has been made to utilise this tool in mapping the arsenic hazard based on the factors those have influence on the groundwater of an area. In the study, secondary data of the area like geomorphology, land use/land cover, soil type, cropping intensity, slope and drainage density pattern have been used in the weightage overlay.

2. Study area

West Bengal, part of the Bengal basin in India, is severely affected from arsenic contamination in groundwater and it has been reported from about 400 km stretch from Maldah district in the North to South 24 Parganas district in the south (PHED 1993; CGWB 1999). North 24 Parganas, the south eastern part of the West Bengal, lies in the Bhagirathi-Hooghly river sub-basin covering 4093 sq km. Due to increasing use of shallow big diameter tubewells for irrigation, there is much fluctuation in the water table with the sharp decline in the water level. North 24 Parganas, the most populous district in West Bengal was selected for the study purpose. It is the deltaic district of the West Bengal, and contains moribund delta in the north, active delta in the south and matured delta in the middle (CDAP). It is one of the arsenic affected regions in West Bengal, and the dependence of population for freshwater is totally on the groundwater. Groundwater is present mainly in the intermediate and lower aquifers, located at shallower depth in North 24 Parganas (Chakraborti et al. 1996). The area has hot and humid climate receiving adequate rainfall from the North-East and South-West monsoon. North 24 Parganas is drained by the Bhagirathi River in the west, river Ichamati in the east and rivers Kalindi and Raimangal in the south eastern part. Since the population density is very high, extent of urbanization is increasing with the decrease in the area under cultivation. XRD analysis of light grey micaceous fine to medium sand of sub-surface sediments of 24 Parganas district showed the mineral assemblage of kyanite–garnet–staurolite–biotite–tourmaline–chlorite–hornblende–epidote, and reddish-brown sand have staurolite–garnet–sillimanite–opaque–tourmaline–kyanite–biotite–chloride–epidote (PHED 1993).According to the Geological and mineral map of West Bengal (provided by Survey of India), the geological unit in the district is Panskura/Daintikri Formation of Holocene period.

3. Materials and methods

High levels of arsenic are found in the areas of low groundwater level, gentle slope and low surface elevation. These factors are interrelated and are controlled by the abstraction of groundwater (for irrigation and urban-water supplies), rainfall/precipitation, geology, and geomorphology. The methodology followed for the analysis and preparation of thematic maps has been shown in the flow chart (Fig. 1). In the present work, factors like geomorphology, landuse/landcover, soil type, cropping intensity, slope and drainage density were included.

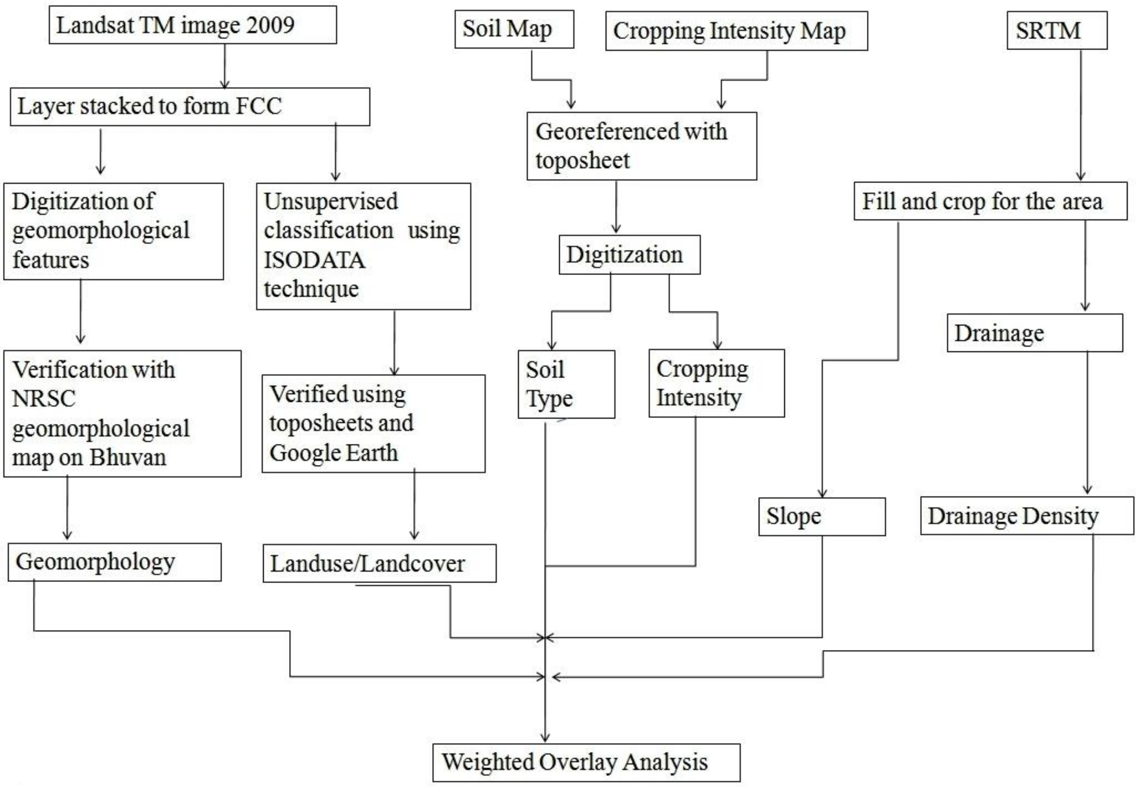

Fig. 1: Flow Chart of the Methodology Adopted in the Study.

Data used: Landsat TM image (2009), DEM image (SRTM)
Ancillary Data: Soil map, Crop Intensity map, Toposheets (1:50,000 scale, provided by Survey of India), Rainfall data, Water Level data
Software: Erdas Imagine, Arc GIS
Landsat image (Path-row 148-44; 45) for the year 2009 was downloaded from the USGS site. The downloaded images were cloud-free and the bands were in the Geo-TIFF format. All the bands in the TIFF formats were layer stacked to form a false colour composite (FCC) image of the area; the thermal band was excluded. The FCC image was used for the preparation of Geomorphology map and Land use /Land cover map. Geomorphology map was prepared by digitizing the geomorphological features on FCC and verifying it with the georeferenced toposheets, Google Earth, and NRSC geomorphology map on Bhuvan. Land use/ Land cover map was prepared by the Iterative Self-Organizing Data Analysis Technique (ISODATA) of unsupervised classification. Unsupervised classification does not require foreknowledge of the classes and works on clustering algorithms to classify an image (Richards 1993). The image was initially classified into 40 different classes and was then merged into six through recoding the attributes of classified images by verifying it using toposheets and Google Earth.
SRTM DEM data have been used by Shamsudduha et al. (2009) for studying the spatial relationship of groundwater arsenic distribution with topography and water table fluctuation. SRTM image can be useful in the assessment of terrain on a large scale and provide an efficient method for assessment of site favouring the accumulation of sediments based on the slope of the terrain. SRTM DEM image was downloaded from the USGS site. The DEM image was filled to avoid imperfections, and the slope map was derived using Surface Analysis and drainage map was derived

using Hydrology in Spatial Analyst Tool in Arc GIS. Drainage derived from DEM was used to derive drainage density of the area. Crop Intensity and Soil map was downloaded from https/north 24 parganas.gov.in/n24/page.php (assessed on 07/11/14). The maps were georeferenced using georeferenced toposheets and then were digitized to form the vector layer. The Weighted Analysis was performed using an Overlay tool by converting all the vector layers to raster layer. Each thematic layer and their features were given weightage and ranking respectively to produce a contamination map.

Rainfall data for 5 years used in the study was available on the site of Indian Meteorological Department. Water Level data were downloaded from the Ground Water Information System (gis2.nic.in/cgwb), the points were marked on the Google Earth, and then interpolation map of water level data was created for the year 2005, 2006, and 2007. Though the water level data is available on the site from 2005 to 2013, but only three years have been selected for presentation of the map because of the availability of data for maximum number of measuring stations. Some soil and water samples were collected from the North 24 Parganas as a part of the study. Arsenic in soil samples was analysed using XRF (X-Ray Fluorescence) and in water samples using Hydride Generator in Atomic Absorption Spectrophotometer. As the numbers of samples were limited and the area of sampling was restricted to only the middle portion of the district, arsenic contamination in soil and groundwater was interpolated for the portion of the district.

4. Result and discussion

4.1. Geomorphology

Changes in the course of the rivers have a major impact on the morphology of their floodplains (Mirza et al. 2001). Organic matter content, composition and mineralogy of the sediment are influenced by the fluvial geomorphological processes, which may control the distribution of the arsenic (Polya et al. 2005; Buschmann et al. 2007). The area can be broadly divided into northern upper part of fluvial origin with many geomorphic features, and the lower, i.e, southern part of the district of coastal origin with some anthropogenic features. Fig.2 shows the geomorphology map of the area having paleochannel, older flood plain, meander scar, oxbow lake, cutoff meander, and abandoned channels as the major geomorphic features in the older flood plain of the district. The older deltaic plain is present in the southern part of the district, and due to very fine soil in the area it is used as water deposits. Varied hydrodynamic conditions of the river like sediment load, stream movement, and stream current are responsible for the formation of oxbow lakes, abandoned channels and meander scars (Bhowmick et al. 2013). Oxbow lakes are crescent shape water bodies, whereas meander scar has same shape without water. Abandoned channel and cutoff meander are formed when the river channel change their courses. These abandoned channels, oxbow lakes, swamps get filled with water seasonally or perennially and are also the site for the accumulation of biomass and organic matter (Acharyya & Shah 2007).

4.2. Landuse/ Landcover

Land use and Land cover classification are one of the most important and widely used applications in remote sensing. Land cover refers to the natural vegetation, water bodies and all the naturally occurring features on the Earth; while land use refers to the modification of the natural environment by human activities. The Land use/Land cover classification of the area was done for the month of February, 2009. The area was classified into water deposits, river, vegetation, settlement, barren and cultivated agricultural fields, the features which can be interpreted and analysed on the basis of visual interpretation of the image. The major part of the district is the agricultural field, of which cultivated area is more than the barren one. In the study, term barren agricultural field is given to those lands which are agricultural, but not cultivated at the time of acquisition. About 33.71 % of the area comes under the cultivated agricultural field and 13% under the barren field. 13.20 % of the area comes under the settlement (mostly in the western part of the district). In the southern part, the area is used as water deposits, as it has water supply from the rivers. Fig. 3 shows the land use/ land cover classification of the area.

4.3. Soil type

Soil map was prepared by digitizing the map available on the site after georeferencing it with toposheet. The district has four types of soil- fine, fine loamy, fine- coarse loamy and fine-fine loamy (Fig. 4). Permeability and hydraulic conductivity in the aquifer is largely controlled by the heterogeneity in the sediment size (Hoque et al. 2008; Aziz et al. 2008). Fine soil is present in the southern part of the district, and the area is used as the water deposits because fine soil provides more holding capacity because of less permeability of soil. Fine-fine Loamy is also present in the southern part between fine soil and the rivers. Fine-coarse loamy soil is present along the river in the older flood plain of the district. In the district, fine loamy and fine-coarse loamy soil provides the best texture to soil, as loamy soil is considered to be the best soil for the agriculture.

4.4. Cropping intensity

The Cropping intensity map was prepared by digitizing the map available on the site by its geometric correction. Cropping pattern is also important factor because it tells about how many times the land is being utilised for the agriculture. As the cultivation depends on the irrigation from the groundwater supply due to the scanty surface water source and erratic rainfall, map of cropping intensity is beneficial in this study as it shows where the chances of abstraction of groundwater is more.

The map has been classified into 3 classes- above 200%, 150-200%, and 100-150% (Fig. 5). Cropping intensity exceeds 100% in the areas where more than 1 cycle is permitted. With the development of irrigation facilities, multiple cropping has improved, thus increasing the cropping intensity.

4.5. Slope

Slope (0-90°) was derived from the DEM using spatial analysis tool in GIS. The generated slope map (Fig. 6) shows that terrain is almost flat, but for the convenience of the overlay, slope map was divided into nine classes from lower to higher slope gradient. Topographically flat areas contain high concentration of arsenic, which indicate that arsenic get mobilized down slope (Safiullah et al. 2001; DPHE report 2000). Low slope area will retain water for the longer duration and will allow greater infiltration of recharge water, while areas with steep slope show smaller amount of infiltration due to more run-off. High levels of arsenic have been reported in areas having low surface elevation and gentle slopes in the Bengal basin (Shamsudduha et al. 2009), Pannonian Basin of Hungary (Varsanyi & Kovacs 2006), and the Bassac and Mekong River banks and alluvium deposits in Cambodia (Buschmann et al. 2007).

4.6. Drainage density

The drainage was derived from the SRTM DEM using Flow Accumulation and Flow Direction tool of the GIS. The drainage map was used to create the drainage density map, and was reclassified into 9 classes. Drainage density is the total length of all the streams in a drainage basin divided by the total area of the basin. Fig. 7 shows the drainage density map of the area from lower to higher density. Drainage of an area is dependent on the slope, the more is the slope the more is the run-off and higher drainage. It is also affected by the permeability of soil and underlying rock type as impermeable surface and exposed rock lead to more runoff and less infiltration.

4.7. Weighted overlay analysis

The weightage and rating system based on the relative importance of the contributing factors was carried out to prepare the zonation map. The vector layers were converted to raster format; slope and drainage density raster layers were reclassified into raster having the same attributes. All the raster layers were added into the overlay tool in order of importance and % influence was assigned to them. Each class within a thematic layer was assigned rating from 0 to 9. The weight and rating assigned to each layer and their classes are presented in Table 1. As the arsenic contamination in an area depends on many factors like weathering, ion exchange, pH; the secondary data used in the study which influence the groundwater quality and quantity in an area were assigned equal weightage. The ranking to each feature class was assigned on the basis of their effect in arsenic contamination as well as their role in infiltration of subsurface water during rainwater percolation. Surficial geology is mapped as a single uniform unit in the district, and thus was not included in the analysis.

Mukhopadhyay et al. (2006) reported that arsenic contamination has a close spatial association with geomorphic features like the paleochannel, abandoned channels and cutoff meander channels. A study conducted by Acharyya & Shah (2007) also shows that the arsenic affected areas are located close to the abandoned or channel meanders. The geomorphic features were assigned rating on the basis of Hydraulic conductivity which influences the transmissivity that can be instrumental in the mobilization of arsenic into groundwater. Thus the geomorphic features formed due to the change in the hydrodynamic condition of the river were assigned higher ratings in comparison to river and water deposits. In land use/land cover higher rating was assigned to cultivated agricultural field and barren agricultural field, as in these areas extraction of groundwater would be high to fulfil the irrigation demand. Loamy soil has the maximum infiltration capacity while fine soil or compact clay is nearly impermeable and allows very small amounts of infiltration. Neidhardt et al. (2013) reported that groundwater extraction promotes changes in the distribution of dissolved arsenic within the aquifer. Thus, the area under cropping intensity >200 % was given higher rating as it will require more irrigation facilities thus leading to the heavy abstraction of groundwater. Arsenic may get released through weathering and transport downward through recharging water (Polizzotto et al. 2005). Accumulation of finer sediments enriched with arsenic adsorbing minerals is higher in the areas with low surface elevation with sluggish groundwater movement (Shamsudduha et al. 2006; Mukherjee et al. 2007). The slope map of the study area shows that maximum slope observed in the area was 3°. The area is a flat and low lying plain, thus area under least slope was given maximum rating of 7. Low slope was given a high rating because it will allow maximum time of penetration for rainwater or flood water. The slope is directly proportional to drainage density also. High slope will cause more-runoff, thus higher drainage density. Drainage density was classified into 9 classes and area under the least drainage density which will allow the water to stay for longer period of time was given maximum rating of 9. The area which has more drainage density and will allow more run-off was given the rating 1.

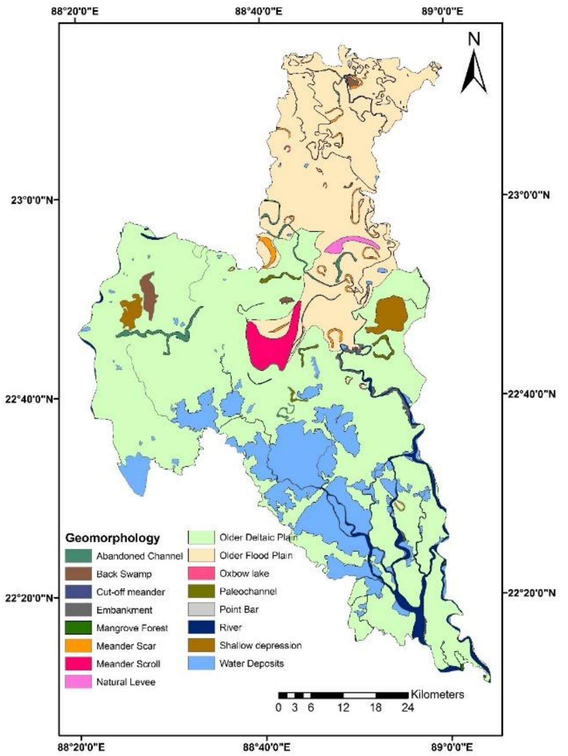

Fig. 2: Geomorphology Map of the District.

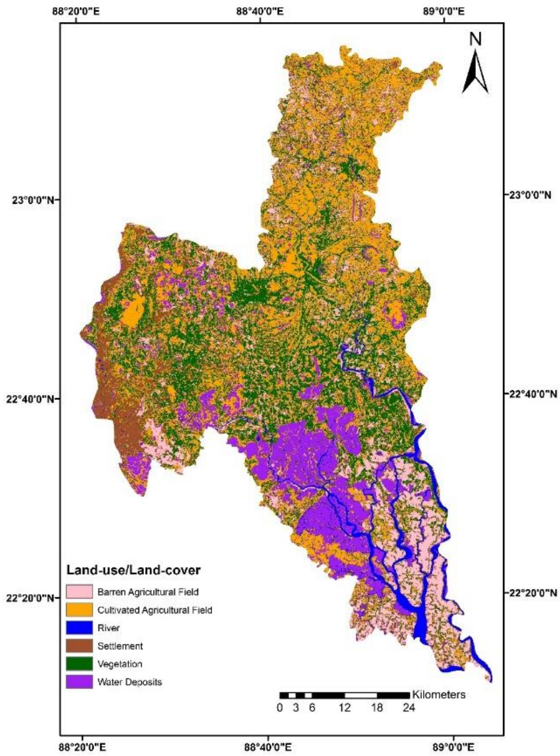

Fig. 3: Land Use/Land Cover Map of the District.

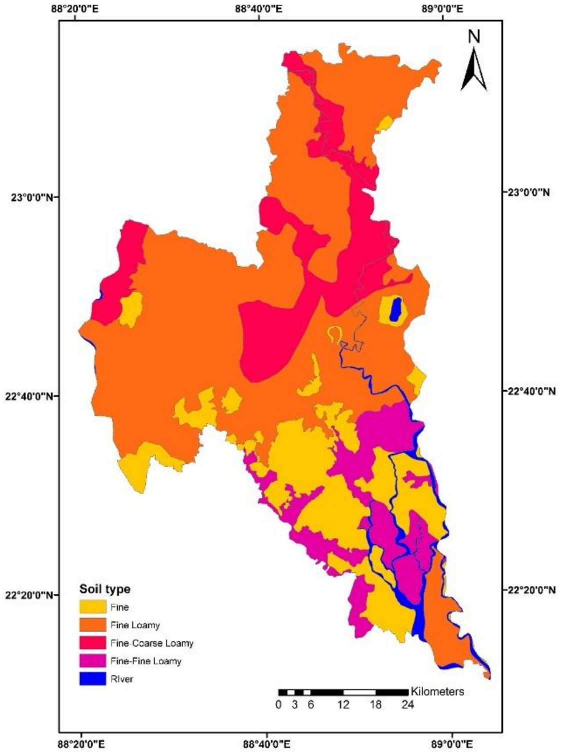

Fig. 4: Soil Map of the District.

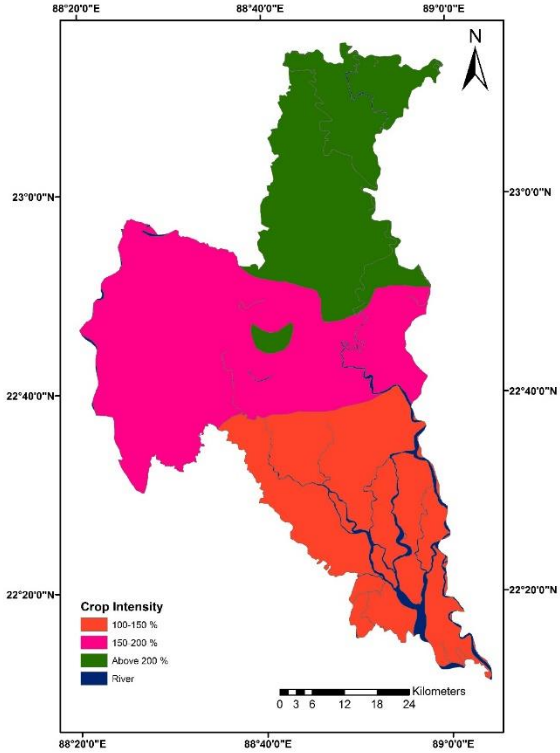

Fig. 5: Cropping Intensity Pattern in the District.

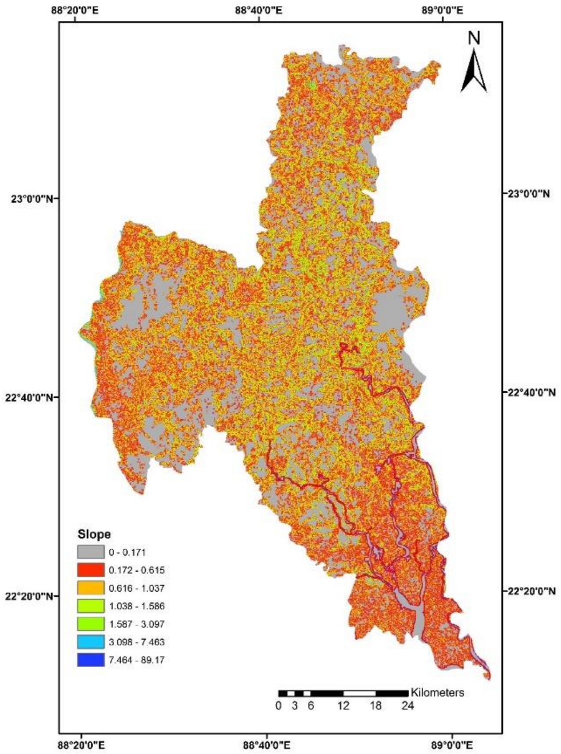

Fig. 6: Slope of the Area.

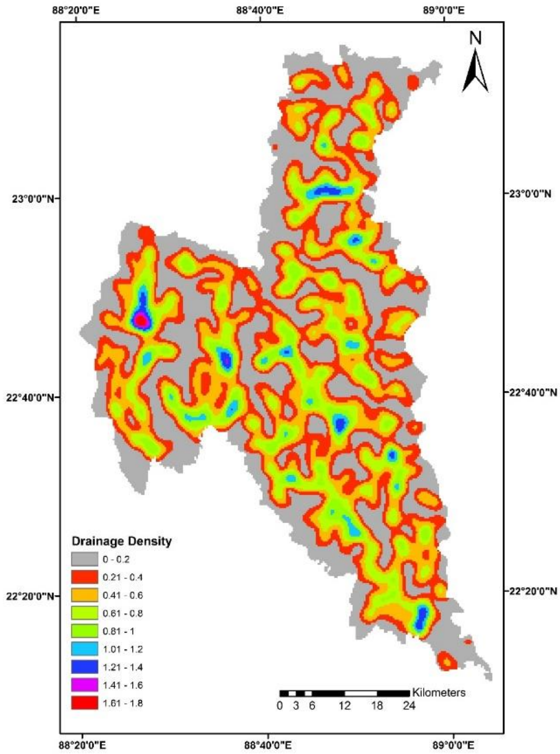

Fig. 7: Drainage Density Pattern in the Area.

Table 1: Weightage and Rating Assigned to Themes

Theme	Weightage	Classes	Rating
Geomorphology	17	River	1
		Water Deposits	2
		Oxbow Lake	6
		Cut-off meander	7
		Meander Scar	7
		Abandoned Channel	6
		Back Swamp	6
		Embankment	3
		Paleochannel	9
		Meander Scroll	8
		Natural Levee	5
		Point Bar	4
		Shallow Depression	6
		Older Flood Plain	5
		Mangrove Forest	1
		Older Deltaic Plain	4
Land Use/ Land Cover	17	Water Deposits	2
		Cultivated Agricultural Field	8
		River	1
		Vegetation	2
		Settlement	3
		Barren Agricultural Field	6
Soil Type	17	Fine	3
		River	1
		Fine-Coarse Loamy	6
		Fine-Fine Loamy	5
		Fine Loamy	8
Crop Intensity	17	River	1
		Above 200 %	6
		150-200 %	5
		100-150 %	4
Slope	17	0-0.171	7
		0.172-0.615	6
		0.616-1.037	5
		1.038-1.586	4
		1.587-3.097	3
		3.098-7.463	2
		> 7.464	1
Drainage Density	16	0-0.2	9
		0.21-0.4	8
		0.41-0.6	7
		0.61-0.8	6
		0.81-1	5
		1.01-1.2	4
		1.21-1.4	3
		1.41-1.6	2
		1.61-1.8	1

The result of weighted overlay (Fig.8) is the potential zone for contamination of arsenic. The result of this analysis was classified into 5 classes for the convenience and was zonated into possibility from very low to very high (Fig.8). Most part of the district comes under the risk from medium to very high. As, in this study all the layers were given equal importance, the result can vary if weightage given to each layers are different. The result of this study shows that low slope and less drainage density of an area will favour the percolation of arsenic from the accumulated sediments enriched with arsenic adsorbing minerals.

4.8. Arsenic in soil and groundwater

22 soil samples and 27 groundwater samples were collected from part of North 24 Parganas. XRF analysis of these soil samples shows that the upper sediment also contains arsenic in concentrations ranging from 0.013 to 10 ppm. Most part of this area was having the arsenic in the range from 2 to 6 ppm (Fig. 9a). Groundwater samples analysis shows that the arsenic concentration in groundwater varies from 0.775 ppb to 69.35 ppb in groundwater (Fig. 9b). Arsenic in the soil samples may be either due to its deposition with the sediments from the river or it may have accumulated due to irrigation from the arsenic contaminated groundwater. In this study, it is assumed that arsenic in the sediments is due to its deposition during the sedimentation along with the eroded sediments carried by the river from the Himalayas and the foothills. High concentration of bicarbonate and iron with low concentration of sulphate in the groundwater of the region (Singh et al. 2014) suggests that the oxidation of organic matter (Lovley 1987) hydrolysis of feldspar and weathering of mica (Breit 2001) are the dominant processes in the evolution of groundwater chemistry. It also reflects that in the Holocene sediments groundwater gradient is low as their deposition has not undergone the flushing as reported in Pleistocene and older sediments (Ravenscroft et al., 2005).

Arsenic may get released from soil through various processes like the reductive dissolution of Fe (III) oxyhydroxides (Nickson et al. 1998), weathering and ion exchange process (Singh et al. 2014). Released arsenic may percolate into groundwater along with infiltration of rainwater or floodwater. The extraction of groundwater is maximum from November to March (non- rainy seasons) for irrigation. The district receives rainfall from April to October with the maximum in the July and August (Fig.10). Thus, chances of arsenic concentration are maximum in the area where slope and drainage favour the maximum infiltration and sediments especially in geomorphic features have high arsenic level. Beside this, depth to water table is also an important factor which controls the ability of pollutant to reach the aquifer. The shallow aquifers are more prone to contamination than deeper aquifer, and the shallow aquifers are mostly unconfined or semi-confined and get recharged from the top. High abstraction of groundwater could lead to downward infiltration of arsenic rich water from the surface during the recharge of water table in the monsoon season. The interpolation map of the arsenic in groundwater validates the result obtained from the weighted overlay analysis. Higher concentration of arsenic is found in the area of high and very high contamination zone of overlay analysis. Both results differ only in the western part of the district, and this difference may be due to water level at greater depth in this region (Fig.11). Fig. 11 shows the interpolation map of water level data available for 38 points in the district from 2005 to 2007. Thus, the result obtained from weighted overlay analysis along with the water level data can be used for the assessment of arsenic contamination chances in the Gangetic plains or in the fluvial plains.

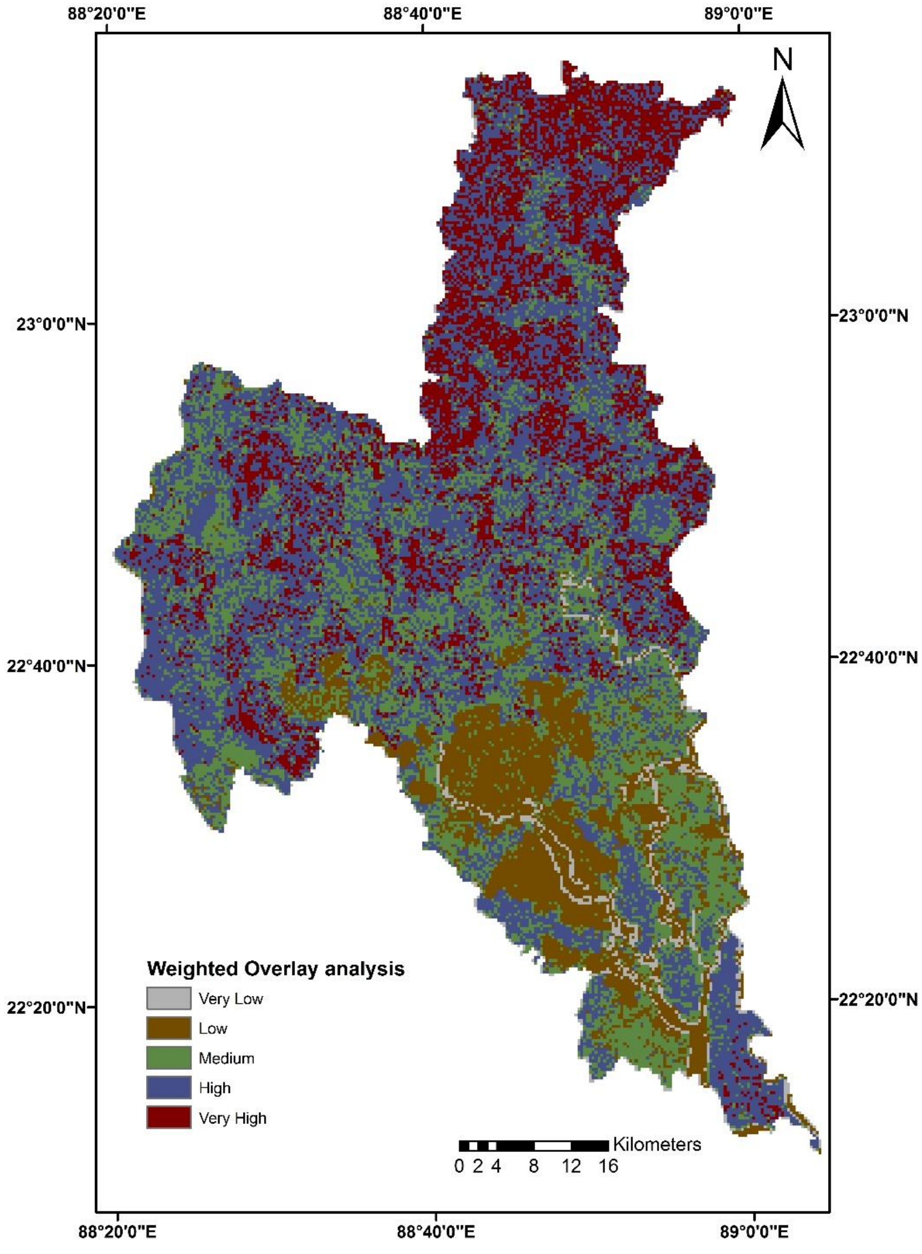

Fig. 8: Arsenic Hazard Zonation of the North 24 Parganas District.

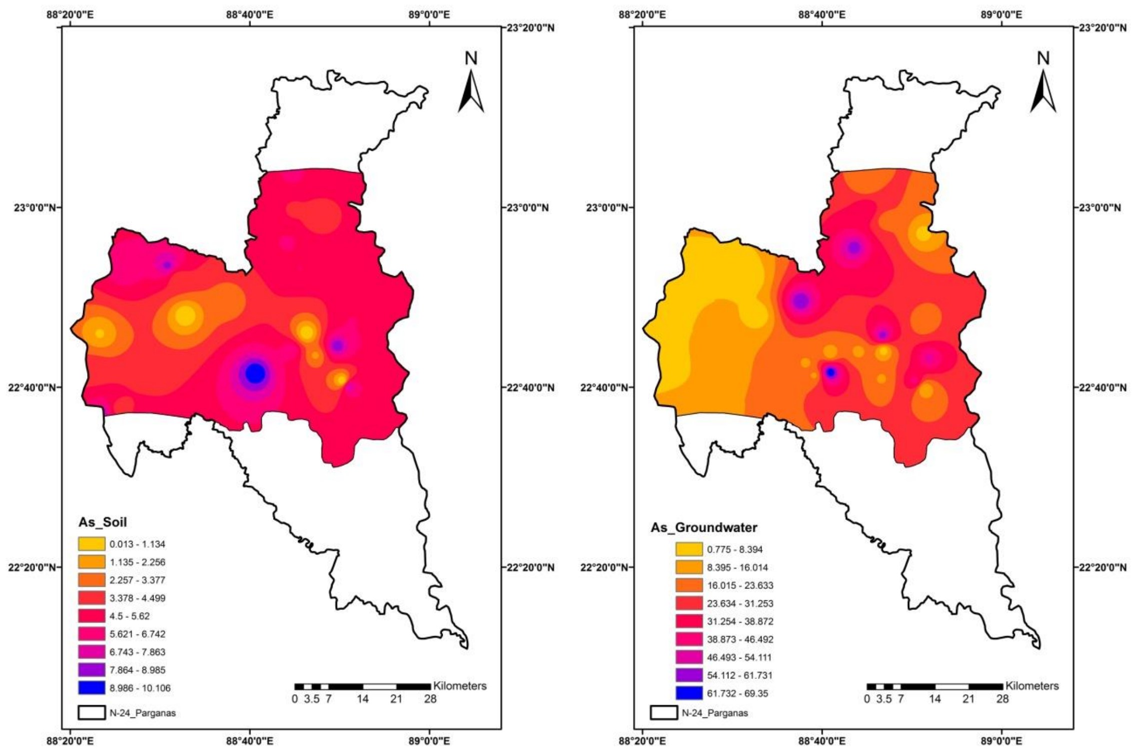

Fig. 9: Arsenic Concentration in (A) Soil Samples (B) Groundwater Samples.

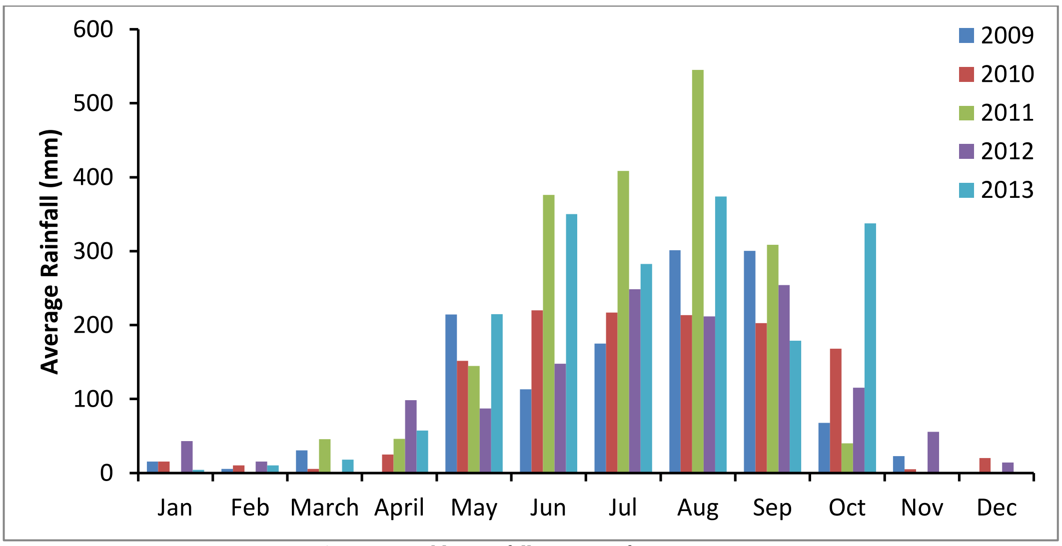

Fig. 10: Monthly Rainfall Variation for 2009-2013.

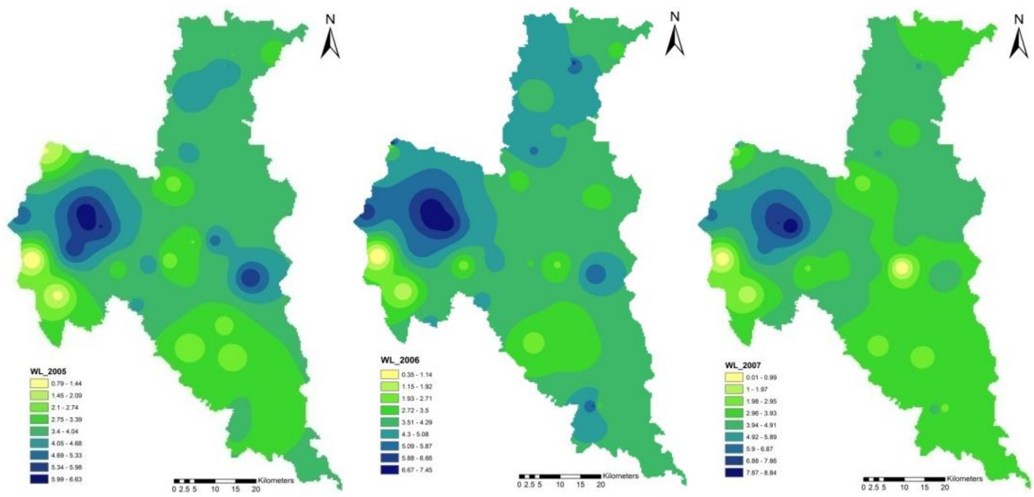

Fig. 11: Interpolation Map of Water Level Data of the District (2005-2007).

5. Conclusion

The present study was conducted to explore the possibility of using weightage overlay analysis tool for arsenic hazard zonation. All the factors that have an influence on the quality and quantity of groundwater may be incorporated in the overlay analysis. In the study, geomorphology, land use/land cover, soil type, cropping intensity, slope, and drainage density was used for the arsenic hazard zonation of the area. Changes in geomorphology, slope, drainage pattern, land use of the area take place over a very long period of time. Water level data was not included in the overlay because there is fluctuation in water level data of the district for every year. The generated map was validated with the available data for arsenic concentration in groundwater for a part of the district. The result generated from weighted overlay and interpolation of arsenic in groundwater shows the positive correlation except in the western part of the district, where the groundwater is present at greater depth. The limitation of this study was that it was not possible for the author to sample for the whole district. The validation of the result obtained from the weighted overlay analysis would be more if the concentration of arsenic for whole district is available. This study can be useful in those areas, where there is a probability of arsenic contamination.

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