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Hydrogeological aspects of arsenic contamination of Maner Block, Patna, Bihar, India

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ABSTRACT

The study area is a part of the Mid Ganga Basin that lies in Patna district, Bihar state. It is made up of thick (>300 m) pile of sediments comprising layered sequences of sand, silt and clay deposits. Within the layered sequences, medium to coarse sand beds are embedded which form aquifers. The annual normal rainfall of the area is 1200 mm, 86% of which takes place during monsoon period spanning between June and September. High Arsenic concentrations (> 50 ppb) have been reported from the several blocks of the Patna districts including Maner. The present work deals with the study of hydrogeological aspects arsenic contamination of the Maner Block of the Patna district. The present study is an attempt to decipher relationship between arsenic occurrences and its relation with other major elements present in the area. Relation between different elements is understood by preparing graphs. It is seen that Fe, HCO_3 and Arsenic (As) generally indicates the increase of concentrations towards Ganga River. Higher concentrations of arsenic (> 50 ppb) were encountered mainly in the newer alluvium (T0), whereas the Older Alluvium appears to be arsenic free.

Introduction

Features of Mid Ganga have been studied earlier by Saha et al, 2006, 2009, 2010, Sinha and Sarkar, 2009, B.A. Shah, 2007, Sahu et al., 2010. In groundwater resource management, in Bihar, a significant role is played by chemical quality of groundwater for drinking as well as for irrigation (Saha 1999). Recently, in Mid-Ganga Basin, Arsenic contamination (>50 ppb) was reported (Chakraborty et al. 2003).

The present work is limited to the study of geomorphology and Arsenic contamination of Maner, Patna district. It lies on the southern river bank of Ganga River, and occupies a part of Ganga-Son interfluve region of the Mid-Ganga Plain (Fig. 1).

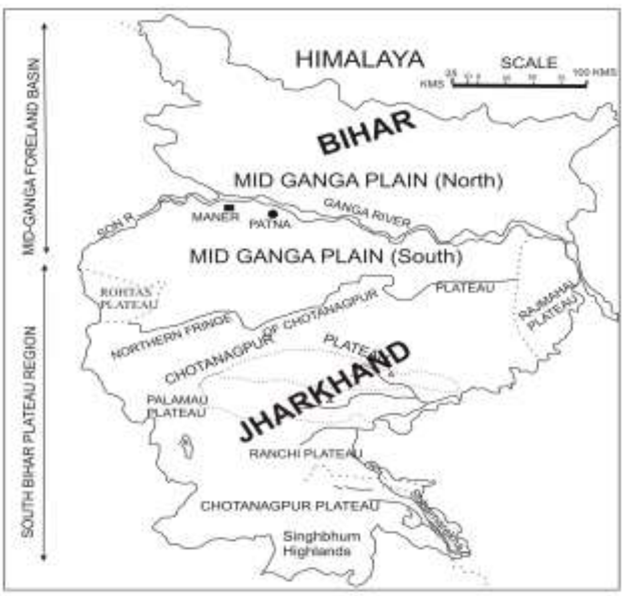

Fig. 1 Regional physiographical map of the area [modified after Saha and Dhar 2011]

The work involves field surveys to study the geological and geomorphic setup and collection of ground water samples, for ascertaining their chemical characteristics. Some elements such as Ca, Mg, Na, K, HCO_3, Cl, SO_4, NO_3, Fe and Arsenic (As) have been analyzed and studied during the current studies. It helps in detecting the areas of contamination and their relation between them. The landforms, like cut-off lakes and meander scars in the area indicate northward shifting of the Ganga and westward migration of the Son. Annual normal rainfall of the area is about 1200 mm, 86 per cent of which are received during the monsoon months spanning between June and September. A detail map of the study area is given in Fig. 2.

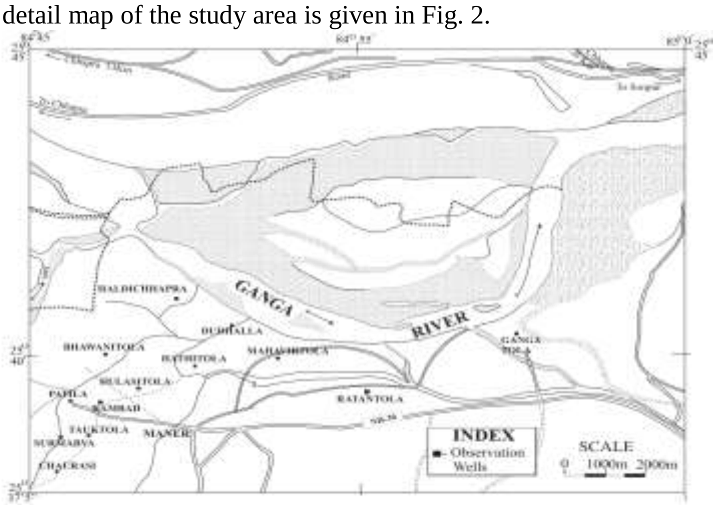

Fig. 2 Maner Block, Study Area

Geology of Maner Block

Regional geology

The state shares the eastward extension of many primary geological elements of the northern part of the Indian subcontinent which are the belt of Himalayan foothills in the northern fringes of the west champaran, the northernmost district

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of the state, the vast Ganga plains, the Vindhyan (Kaimur) plateau extending into the Rohtas region, the coal bearing Gondwana basin forms the part of Central India, Damodar valley Rajmahal belt, Satpura range extending into a large part of Chotanagpur plateau (CNP). To the south CNP is bounded by the Mahanadi Gondwana basin that starts initially as a broad belt and then extends as a linear belt, south-eastwards from Central India. The basin separates CNP rather sharply from the Eastern Ghats on the south but some signatures are still present on the northern fringes of the Mahnadi basin and are even widespread in the northern half of the CNP. Bihar is fringed by the Himalayas in the north and Bengal basin in the east, and somewhat more distant Indo-Burmese arc. These are continuing to evolve since Jurassic and their evolution has had a dominant dynamic impact on the north eastern part of the shield. Nearly two-thirds of Bihar is under cover of the Ganga basin, which is part of "largest terrestrial foreland basin on the earth's surface" (Burbank et al.1996).

The basin and the Siwalik formations extending into its north-western part are products of the Himalayan orogeny. The Ganga sediment however covers the basement rocks and hence direct field evidences are rare in the northern part of the state which is the Gangetic delta.

Local geology

The geological area forms a part of the Son Ganga interfluve plain in Patna district, Bihar lying at the south of the river Ganga (Fig. 3). The sediment contribution in this belt is both from the southern peninsular high and northern extra peninsular high. Peninsular sediments visually appear to be dominant over the extra peninsular sediments.

Ganga river system has brought sediments from extra peninsular mountains area whereas Son-Kao-Karbonasa-Durgavati-Punpur-Phalgu-Dhadra flowing through Vindhyan and Chottanagpur gneissic complex brought sediments material from peninsular high to build vast gently undulating alluvial tract to the south of Ganga The sediments are mainly consolidated to semi consolidated sand, silt and clay of different colour. The huge sediment pile may be resting over northerly sloping Precambrian basement. Physiographicaly the area is a part of the Indo-Gangetic plain between the southern and northern peninsular blocks. The area is represented by gently undulating alluvial fill deposit of Son Ganga river system.

Groundwater properties

The area is underlain by Middle to Late Quaternary sediments, viz., alluvium, clay, silt, sand, gravel, and pebbles with concretions of calcareous materials. The aquifers are made up of fine to medium-grained sand. Occasionally coarse-grained sediments or layers of gravel are also found at places. Groundwater potential of the aquifers varies from good to very good category. The depth of the wells ranges from 10.50m to 37m. . The pre-monsoon depth of water table was reported to be around 2-5 m bgl and in post monsoon water table height increases by about 1-2m.

The transmissivity of the aquifer varies from 3786-19540 m^2/day. The yield, of deep tube wells, tapping these deeper aquifers, ranges from 260m^3/hr to 1500m^3/hr with a drawdown of 6 m. The depth of piezometric surface in the area varies from 6.25m to 16.30m bgl (Ground Water Information Booklet, Patna District 2007).

Precipitation from south-west monsoon is the main source of the recharge to the ground water system. The pre-monsoon depth of water table was reported to be around 2-5 m bgl and in post monsoon water table level rises by about 1-2m in the Block. The ground water flow direction of the area is towards north–northeast thus describing the perennial effluent nature of River Ganga (Fig. 3).

Fig. 3 Map showing water level contour, Maner Block, Patna

Geomorphology

On either side of the Ganga River of Bihar is covered by Middle Ganga Plains. The Ghaghra, the Gandak and the Kosi, are the several major tributaries of the Ganga whose drainage cuts through its northern banks and merge with it, whereas the Son joins from the south.

Northern part of the middle Ganga plains can be divided geomorphologically into a series of megafans, e.g. Gandak (Mohindra et al. 1992) and Kosi (Gohain and Parkash 1990), and interfan areas that themselves contain dynamic rivers and was described as 'cone' and 'intercone' by Geddes (1960).

Geomorphologically, the Ganga foredeep is subdivided into two broad units: Peidmont Plain and the Central Alluvial Plain (Saha and Dhar 2011). The Central Alluvial Plain extends from the Peidmont Plain to the exposed basement rocks of Peninsular India. Bulk of sediments accumulated in the Indo-Ganga foredeep basin was from the Himalayan hill range where Peninsular India has minor inputs (Shah 2008).

Earlier, it was thought that the migration of the Ganga River towards the north of the basin was due to large sediment input of Son megafan from the peninsular region (Swamee et al. 2003). However, later it was suggested that the possible cause for northward migration of River Ganga was due to the tilting of the basin. (Saha et al. 2009)

Patna district is a part of the Indo-Gangetic alluvium, one of the three main physiographic divisions of India, which separates Extra-Peninsular region in the north from the peninsular region in the south. Since the Middle Pleistocene times the tectonic foredeep basin has been getting filled up by alluvial sediments and level plains are formed. The block generally has flat relief and is situated on the flood plains of the Ganga.

River terraces are parts of flood plains which are produced by surges of erosion and have become elevated above the bank full level of active channel as a result of wide spread channel incision. The episodes of degradation and aggradations can result in formation of series of terraces of different heights and valley fills, having a complicated internal structure.

Cotton (1940) divided the river terraces into two types: i) Cyclic or paired terraces and, ii) Non-cyclic terraces or non-paired terraces (Thornbury 1969). This is shown in Fig. 4. Cyclic or paired terraces are two similar terraces having same elevation on each side of the river. This is formed when down cutting is greater than lateral erosion and is common in straight channel river. Non-cyclic or non-paired terraces correspond to similar terraces with different elevations between them on each side of the river, this results when lateral erosion is dominant than down cutting. This type of terraces is common in meandering river.

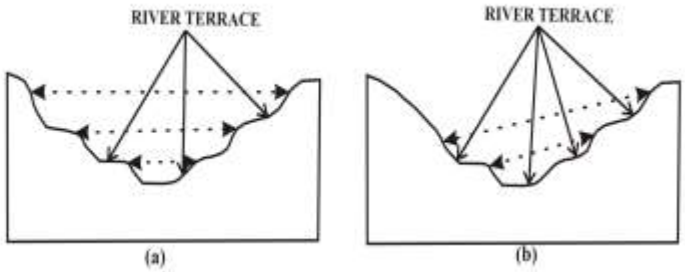

Fig. 4 Diagram showing difference between (a) Paired or Cyclic terrace (b) Nonpaired or Non-cyclic terrace

During Late-Pleistocene and early Holocene many small drainages, dense channel networks, lakes and swamps were developed on the Central Alluvial Plain resulting lower base level, which was followed by sea level rise in early Holocene (Singh 2001). The major parts of the Ganga Plain consist of interfluve upland terrace surface of Pleistocene Older Alluvium (T2-Surface) (Kumar et al. 1996), which is covered, at some places, by shallow Holocene sediments and is generally arsenic free. The Holocene Newer Channel Alluvium (T0) is characterized by organic rich argillaceous sediments deposited in low-lying fluvial and fluvio-lacustrine setting and are highly arsenic contaminated. The River Valley Terrace Alluvium (T1-Surface) occurs above the active flood plain deposits and is generally arsenic free (Fig. 5). The Litho-geomorphic sequence of the area is shown in Table 1.

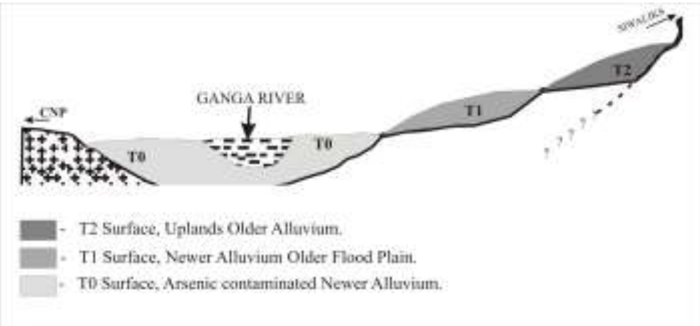

Fig. 5 Schematic diagram showing major geomorphic divisions in vertical section

Hydrogeochmical Investigations

Samples from different villages of Maner block is collected during May (pre-monsoon). During the field work in May, 45 samples were collected from hand pumps (15–35 m), to assess the variation of As and other major elements in groundwater. From some villages As contamination was reported, from their multiple samples were collected. For 10 min wells were pumped, and then samples were collected, to get fresh water from aquifer. The samples were collected in clean high-quality polythene bottles which was thoroughly rinsing three-four times with the same water and then sample was taken. The water samples were filtered on site using 0.45 mm membrane filter. Afterwards it was brought to laboratory for analyses of Ca, Mg, Na, K, HCO_3, Cl, SO_4, NO_3 and Fe following the methodology recommended by APHA (1995). Arsenic was also analyzed by using ICP.

The Older Alluvium was recognized by the presence of yellow–brown clay with profuse calcareous and ferruginous concretions (Kumar et al. 1996). Newer alluvium was characterized by organic rich argillaceous sediments brought by entrenched channels and floodplains. Saha et al (2009) graphs showing relations between the major elements and also with Arsenic was used as the guideline. An area of about 160 km^2 has been mapped in MGP along the Ganga River Maner block, Patna in Bihar (Fig. 2).

Arsenic analysis of 45 water samples, from Maner block, Patna, from tube wells was tested and was analyzed from SGS, Kolkata. Other major elements such as Ca, Mg, Na, K, HCO_3, Cl, SO_4, NO_3 and were analyzed from Department of Geology, National Institute of Technology, Durgapur by using UV spectro-photometer, titration and flame photometer.

Chemical quality of groundwater

The total dissolved solids of the block have an average of 164.61 mg/l which is below 1,000 mg/l which means that the groundwater is fresh (WHO, 1996). The average pH of the groundwater of the area is 7.63 and chemistry of anions is dominated by high concentration of HCO_3 (Fig. 6) as $CO_3$is normally present above pH 8.5. In the area, HCO_3 present has an average value of 276.7 mg/l and CO_3 is absent. In the Mid Ganga newer alluvial tracks there are many back swamps, cutoffs and oxbow lakes; consequently, the surface water remains stagnant in depressions for longer period of time which indicates shallow water table with very low fluctuation changes in pre- and post- monsoon of water table. Thus, infiltration from this stagnant surface water to the sub-surface water body takes place. Hence HCO_3 concentration of the groundwater below is increased. (Saha et al. 2009).

Groundwater of the study area also contains about 12% of calcium and also 6% magnesium (Fig. 6), which means that the groundwater is hard. The hardness of groundwater is expressed in terms of the amount of calcium carbonate, the principal constituent of limestone, or equivalent minerals that would be formed if the water were evaporated. Water is considered soft if it contains 0 to 60 mg/L of hardness, moderately hard from 61 to 120 mg/L, hard between 121 and 180 mg/L, and very hard if more than 180 mg/L. In the study area the total hardness of groundwater has an average 219 mg/L, so it is very hard groundwater.

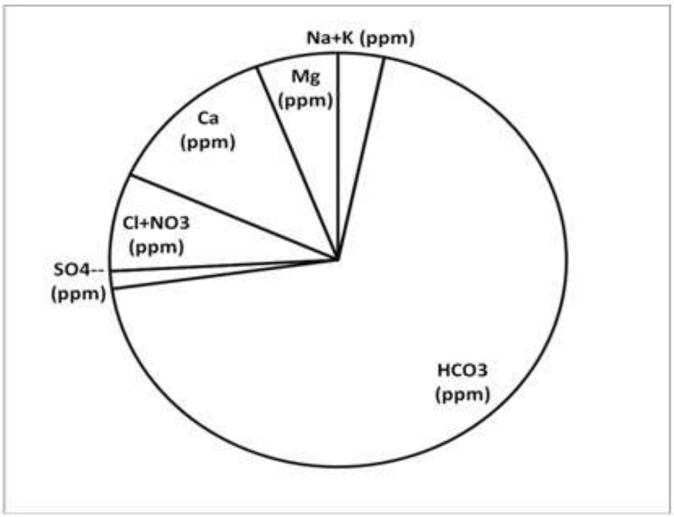

Fig. 6 Pie diagram of chemical quality of groundwater, Maner Block, Patna district

Results and Discussion

Here an attempt has been made to decipher the various mechanism and geochemical processes for As-contaminated groundwater in Maner block. Increase of concentrations of different species in groundwater is expected due to the evaporation process and effect the shallow water table (Saha et al. 2009). Dominance of evaporation process indicates constant Na/Cl ratio, assuming no precipitation of mineral species (Jankowski and Acwarth 1997). When halite dissolution takes place for Na, molar ratio of Na/Cl should be 1 approximately. Na released from silicate weathering can be interpreted when value is >1 (Mey beck 1987). Maximum samples lie below the equiline in the Na versus Cl plot (Fig. 7), indicates the excess Na from silicate weathering in the area. (Stallard and Edmond 1983).

The samples having Ca/Mg ratio <1 are characterized by Na^- and HCO_3^- dominated groundwater (Saha et al. 2009). The Ca/Mg ratio ranges between 0.39 and 3.36. If the ratio is equal to 1, dissolution of dolomite should occur whereas higher ratio indicates the source from calcite (Maya and Loucks 1995). This indicates the removal of Ca from groundwater by formation of caliche nodules (Saha et al. 2009). Kumar et al. (2006) suggested that the ratio between 1 and 2 indicates calcite dissolution. In Maner block, about 69% of the samples have Ca/Mg ratio greater than 1 (Fig. 8), which in turn indicates detrital calcite dissolution is responsible for Ca in groundwater.

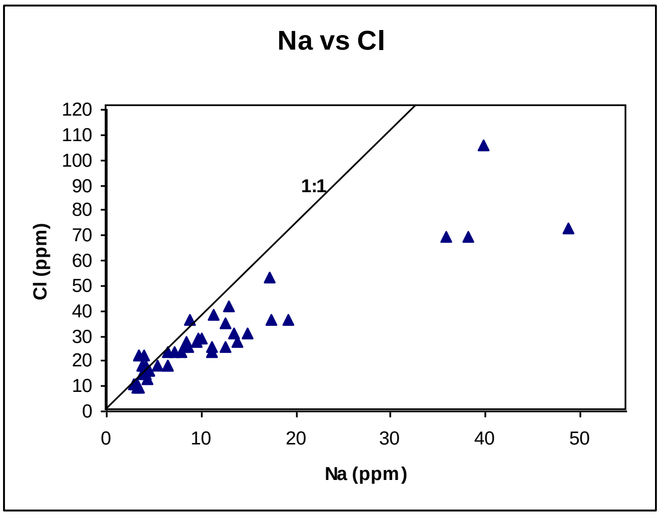

Fig. 7 Relation between Cl and Na, Maner Block, Patna

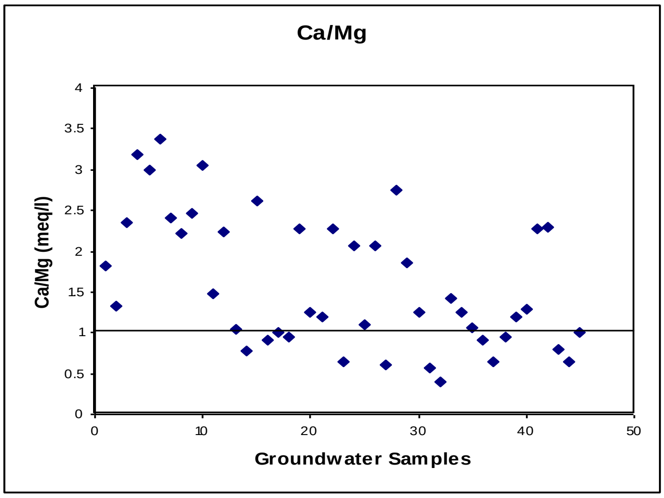

Fig. 8 Plot of Ca/Mg ratio, Maner Block, Patna

Holland (1978) suggested weathering reaction of calcite ($CaCO_3$) and dolomite (Ca, Mg $(CO_3)_2$) reaction as:

$$CaCO_3 + H_2CO_3 = Ca^{2}+ + 2HCO^{-3}$$

$$Ca,Mg(CO_3)^2 + 2HCO_3 = Ca^{2+} + Mg^{2+} + 4HCO^{-3}$$

Sediment accumulation in the southern part of Ganga Plain is not only contributed by River Ganga, Son also plays an important role (Fig. 2). 120 km south of River Ganga Vindhyan Supergroup is present and is the major area for supply of sediments, which is brought by Son to the region. Source of detrital calcite and dolomite is the Semri Group's limestone and dolomite beds (Dasgupta 1997). Positive correlation between HCO_3 and Mg (r^2 = 0.740) and between HCO_3 and Ca (r^2 = 0.114) in newer alluvium (Table 2) reveal dissolution of detrital calcite and dolomite.

More than 78% of the samples from Maner block, Patna exhibit HCO_3 exceeding (Ca +Mg) (Fig. 9), indicating dissolution of calcite and dolomite (Tyagi et al. 2008). In the plot of (Ca + Mg) versus Cl (Fig. 10), maximum number of samples of Maner block are falling below the equiline which indicates (Ca + Mg) is dominant over salinity. The mean value of (Ca+Mg)/HCO_3 are 0.96 indicating that the source of the alkaline earths in groundwater from dissolution of carbonates (Sami 1992).

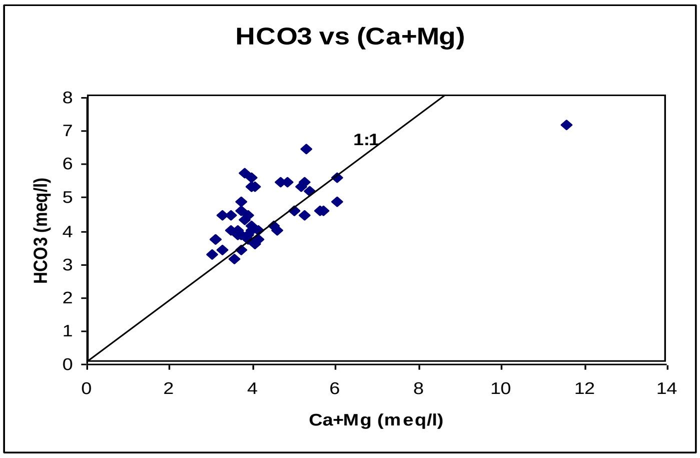

Fig. 9 Relation between HCO_3 and (Ca+Mg), Maner Block, Patna

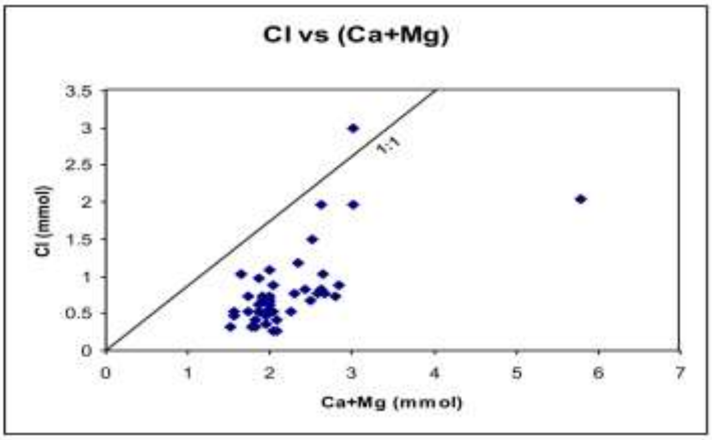

Fig. 10 Relation between Cl and (Ca+Mg), Maner Block, Patna

As and Fe having positive correlation (r^2 = 0.378) which indicates their movement by same geochemical process in groundwater. The better correlation in samples of Maner block is understood in As versus Fe scatter plot and indicates higher As load (Fig. 11).

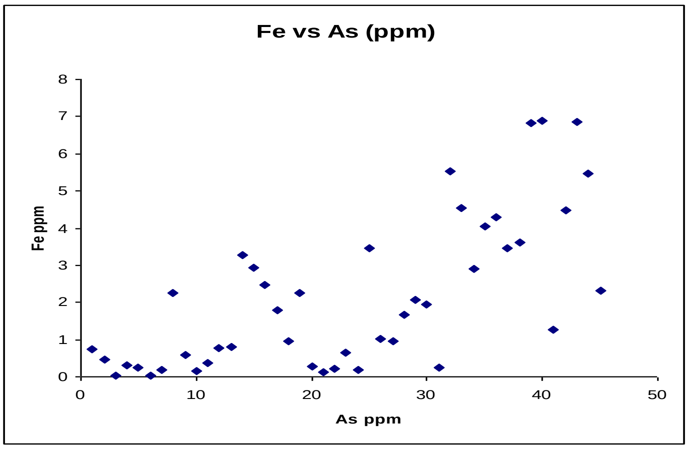

Fig. 11 Relation between Arsenic and Iron, Maner Block, Patna

Many areas of Maner block remains waterlogged for a longer period of time and hence become site for biomass accumulation Fig. 12 (A, B). This area lies in the flood plain of the Ganga and sedimentation takes place by rapid aggradations and fluvial swamps formation (Singh 2001). During rainfall, infiltration of water takes place and organic carbon, contributed by the biomass, is carried vertically with these water bodies to the groundwater (Saha et al. 2009). When organic matter is added to the shallow aquifer become highly influenced to As, which presumably stimulates microbial respiration and subsequent reductive dissolution of iron oxyhydroxides (FeOOH) (Saha et al. 2009). As sorbed in oxyhydroxides and Fe^{2+} is released by this process (Nickson et al. 2000), which results in their positive correlation in groundwater. HCO_3 ion is also generated from this process (Saha et al. 2009) and thus positive correlation (r^2 = 0.409) is also seen between As and HCO_3 in Maner block of Patna, Bihar (Fig. 13).

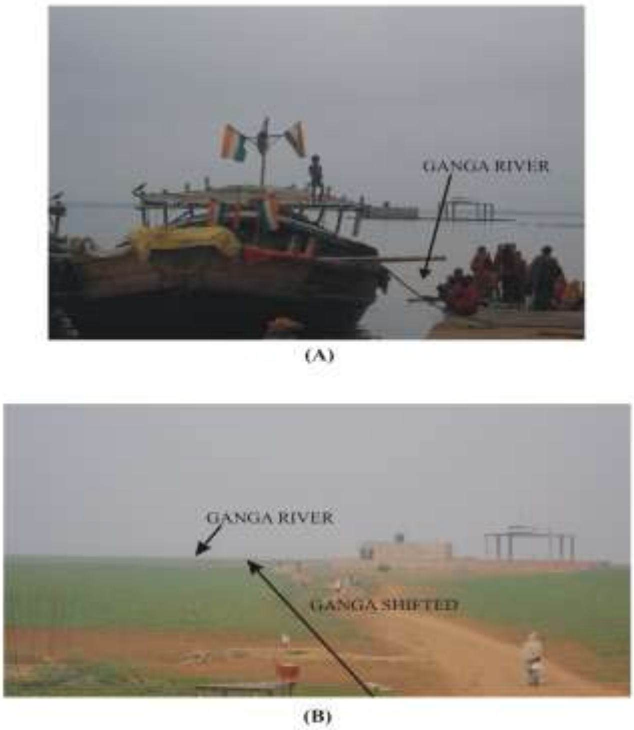

Fig. 12 (A) - Picture taken in September, 2011 at Haldichapra, Maner Block, Patna
(B) - Picture taken in December, 2011 at Haldichapra, Maner Block, Patna

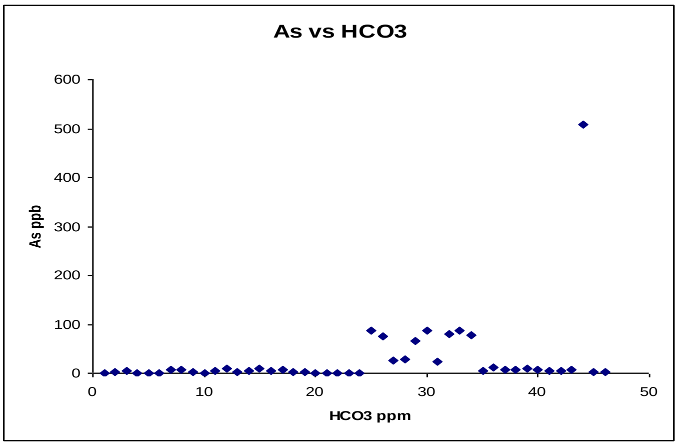

Fig. 13 Relation between As and HCO_3

Conclusion:

Geomorphologically, we can say that the Ganga River in this area has formed Non-cyclic or non-paired terraces, because on the southern side of Ganga River we get only T0, whereas on northern part we get T0, T1 and T2. The arsenic concentration is high wherever newer alluvium is present i.e. T0. The level of contamination in the study area is quite high but patchy in distribution and occurrence. Most of the aquifers that are contaminated lie in the Holocene newer alluvial tracts.

Groundwater in the area has TDS <1,000 ppm and thus it is fresh (WHO 1996). Maner block, lying in the flood plain of newer alluvial deposits, is situated near to the bank of the Ganga River and the groundwater is highly affected arsenic contamination (>50 ppb). Vindhyan Supergroup lies to the South-West of the area, is source for the dissolution of detrital calcite and dolomite and release of As and Fe^{2+} in ground water in the area is related to this process. The area lies in the flood prone area of River Ganga and thus water remains logged for a longer period of time which stimulates biomass accumulation and becomes the source of organic carbon which infiltrates latter to the groundwater. This organic carbon initiates reduction of iron oxy-hydroxides releasing As and Fe^{2+} is in ground water, which results in positive correlation between Fe and As. Other geochemical processes such as seepage from domestic sewage and dissolution of silicate minerals are present in the area.

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Table 1 Litho-geomorphic sequence of the area

Geomorphic Designation	*Surface*	*Lithology*	*Age*
Channel Alluvium	*T0*	*Fine sand & silt, grayish white, un-oxidized, un-consolidated*	*Holocene*
~~*Unconformity*~~~~~~~~~~~~~~~~~			
Terrace Alluvium	*T1*	*Grayish silt, silty clay, occasional sand bed, unconsolidated, unoxidized*	*Holocene*
~~*Unconformity*~~~~~~~~~~~~~~~~~			
Older Alluvium	*T2*	*Yellowish brown to deep brown clay, hard, Compact, oxidized, impregnated with caliche, Nodule mostly occurring as beds*	*Meso to Neoproterozoic*

Table 2 Correlation matrix of the major elements of the samples

	Ph	Ca	Mg	HCO_3	SO_4^{--}	NO_3	Na	K	Cl	Fe	As
Ph	1										
Ca	-.064	1									
Mg	-.419	.128	1								
HCO_3	-.399	.114	.740	1							
SO_4^{--}	-.450	.448	.789	.490	1						
NO_3	-.495	.424	.781	.584	.911	1					
Na	-.455	.354	.865	.615	.958	.919	1				
K	-.403	.394	.747	.473	.873	.875	.892	1			
Cl	-.455	.350	.873	.630	.939	.913	.986	.909	1		
Fe	-.284	-.442	.133	.379	-.221	-.083	-.066	-.099	-.013	1	
As	-.385	-.039	.244	.409	.013	.235	.091	.127	.155	.378	1