

## Introduction

- Groundwater is the main source of drinking water supply for over one hundred million inhabitants in Bangladesh. The withdrawal of groundwater has been increasing over the past three decades. About 95% of the groundwater abstracted is used for irrigation and only 3% is used for drinking purposes (APSU, 2005).
- In the southern part, groundwater salinization limits the supply of fresh water to the expanding population, irrigation system and industrial production. The young (Holocene) alluvial deposits are mostly affected with high arsenic water. The arsenic contamination (having highest concentration of 401 µg/L) crisis in the shallow aquifers has engendered a wide variety of responses to the challenge of safe drinking water supply.
- Deeper aquifers generally have low arsenic concentrations and they represent a potential source of safe drinking water. The deep aquifers are subjected to intensive pumping causing large drawdown of piezometric head. It sometimes causes the dewatering of confined aquifer and reduces the production section of wells, consequently leading to a decrease in productivity.
- A systematic environmental isotope ( $\delta^{18}\text{O}$ ,  $\delta\text{D}$ ,  $\delta^{13}\text{C}$ ,  $^3\text{H}$  and  $^{14}\text{C}$ ) including geochemical study was carried out by Bangladesh Atomic Energy Commission (BAEC) to understand the groundwater flow system, sources of aquifer recharge and salinization, and possible hydraulic interconnection between aquifers and river waters. BAEC has been actively involved in technical cooperation (TC) and regional cooperative agreement (RCA) programs of IAEA on isotope hydrology for the last couple of years to promote the use of isotope techniques in understanding the groundwater system in Bangladesh.

## Study Area, Sample Location and Hydrogeology

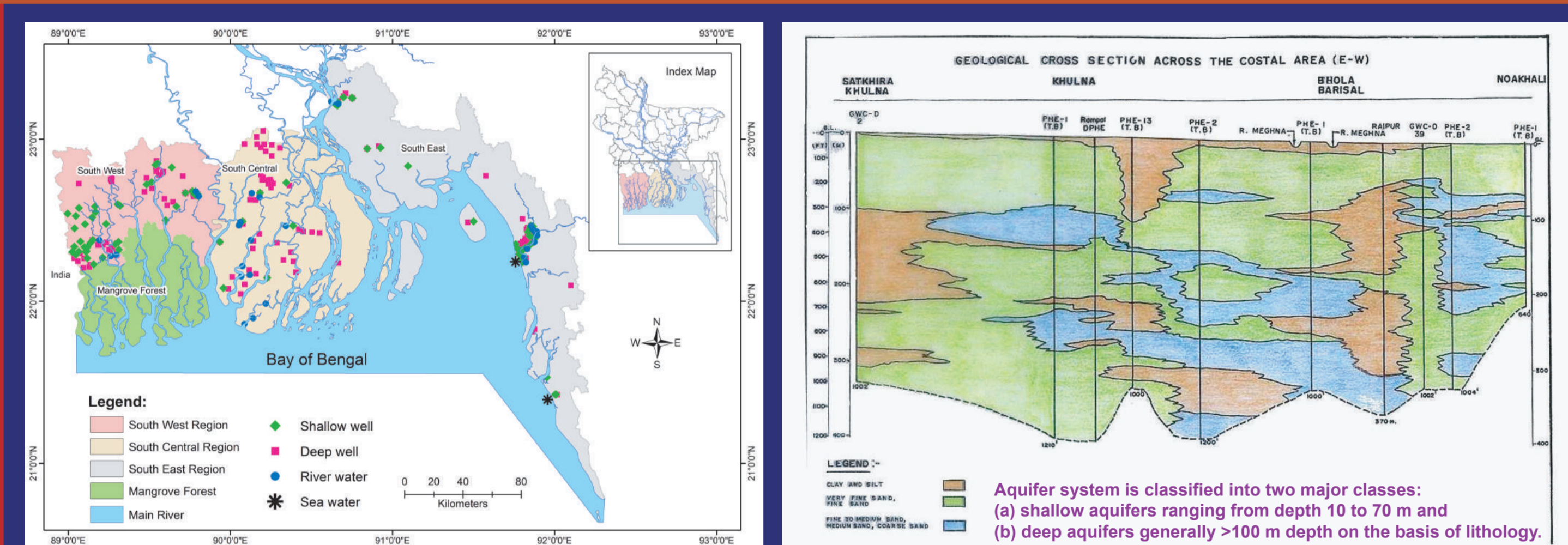


Figure 1: Location of groundwater and surface water sampling points in the study area

Figure 2: E-W lithological cross section across the coastal areas of Bangladesh

### Identifying safe drinking water in the coastal area



## Results and Discussion (Hydro-Chemistry)

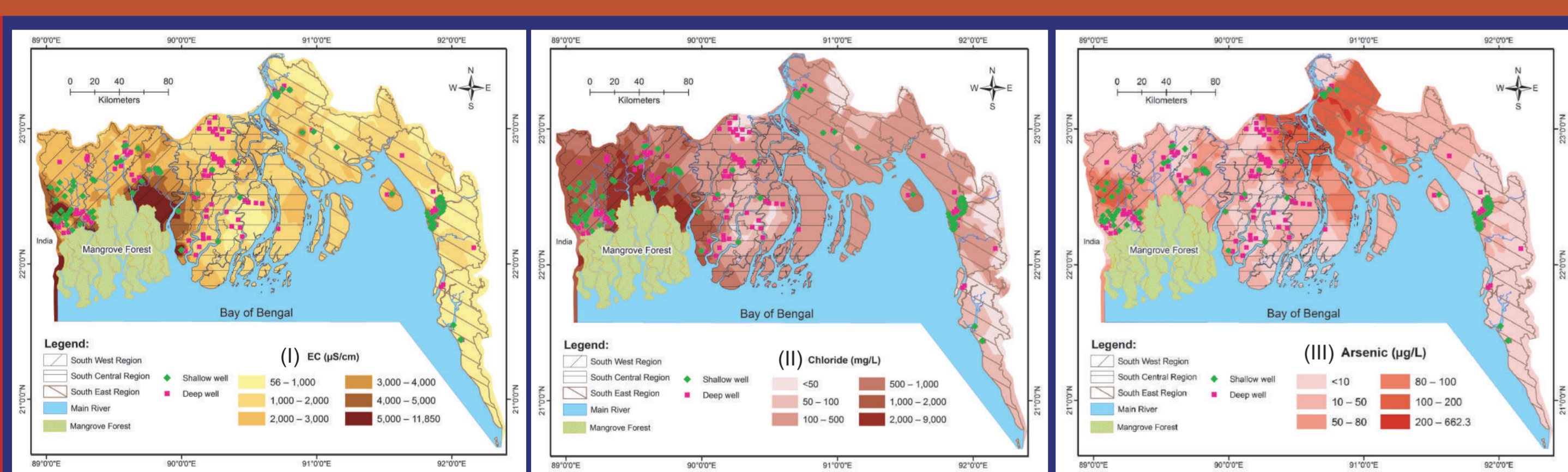


Figure 3: Spatial distribution of (I) electrical conductivity (EC), (II) Chloride concentration and (III) Arsenic concentration in the coastal area of Bangladesh.

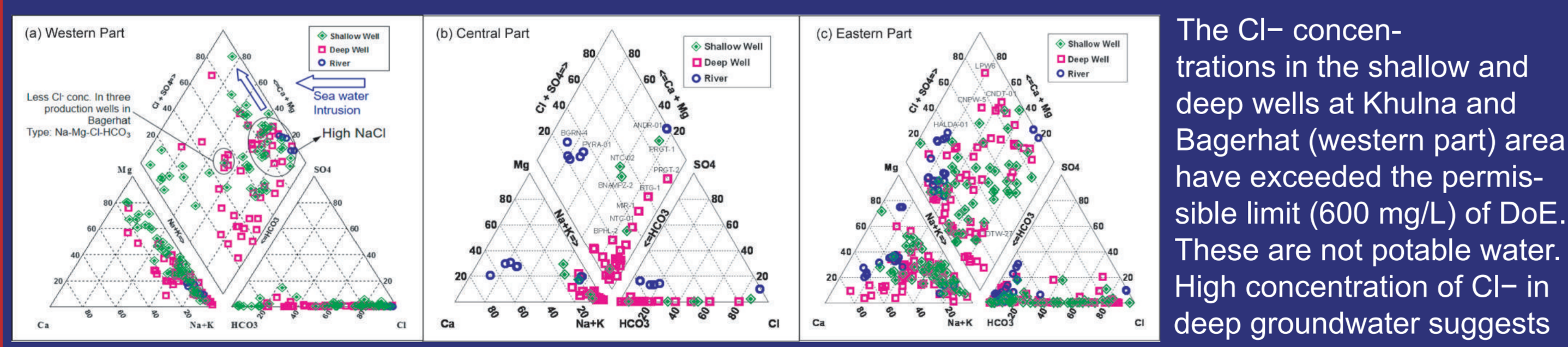


Figure 4: Piper Trilinear diagram showing the spatial evolution of the water chemistry in the shallow and deep aquifers of coastal area

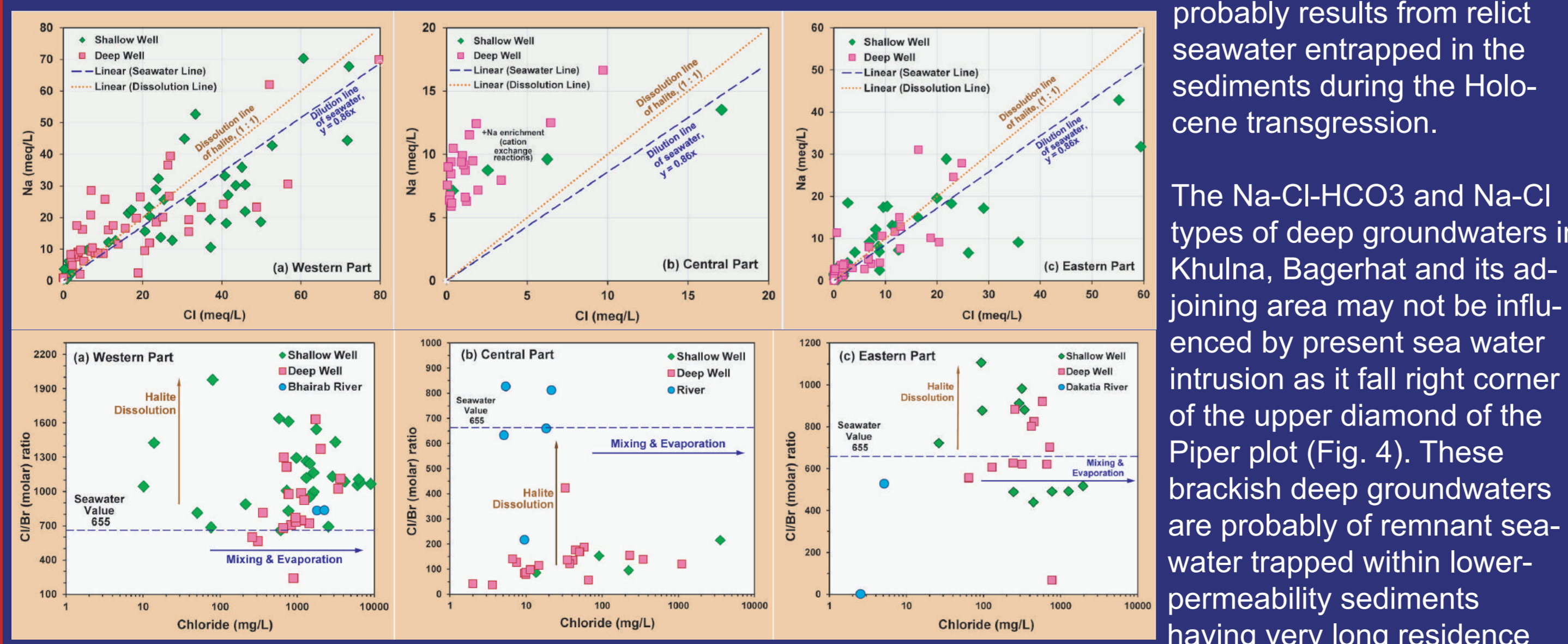


Figure 5: Geochemical characterization - Origin of groundwater salinity

The Cl<sup>-</sup> concentrations in the shallow and deep wells at Khulna and Bagerhat (western part) area have exceeded the permissible limit (600 mg/L) of DoE. These are not potable water. High concentration of Cl<sup>-</sup> in deep groundwater suggests they are brackish water. These brackish waters are probably results from relict seawater entrapped in the sediments during the Holocene transgression.

The Na-Cl-HCO<sub>3</sub> and Na-Cl types of deep groundwaters in Khulna, Bagerhat and its adjoining area may not be influenced by present sea water intrusion as it fall right corner of the upper diamond of the Piper plot (Fig. 4). These brackish deep groundwaters are probably of remnant seawater trapped within lower-permeability sediments having very long residence time (~20,000 years BP).

## Results and Discussion (Environmental Stable & Radioactive Isotopes)

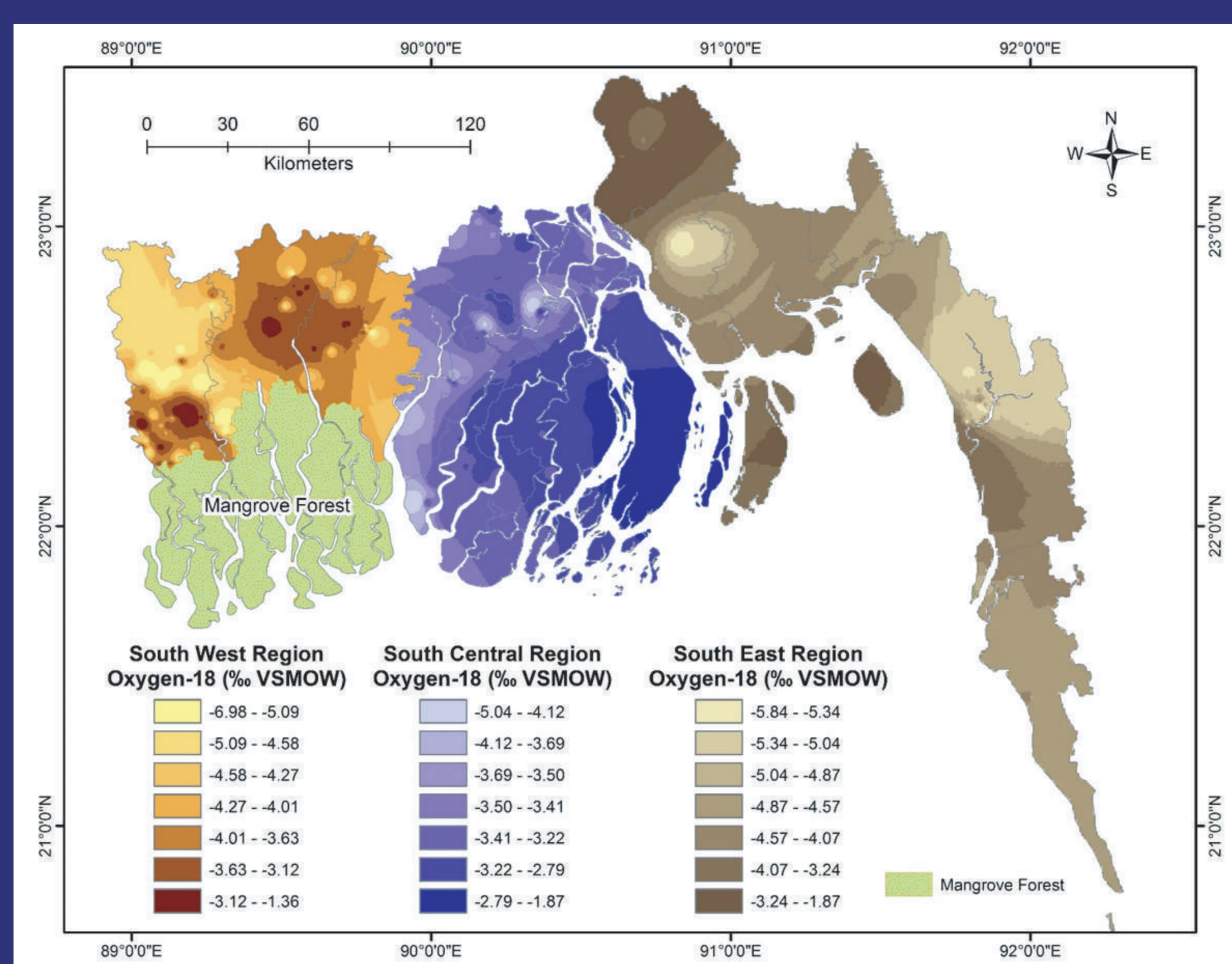


Figure 6: Spatial distribution of Oxygen-18 of groundwater samples are depicted individually in three regions; (a) western, (b) central and (c) eastern.

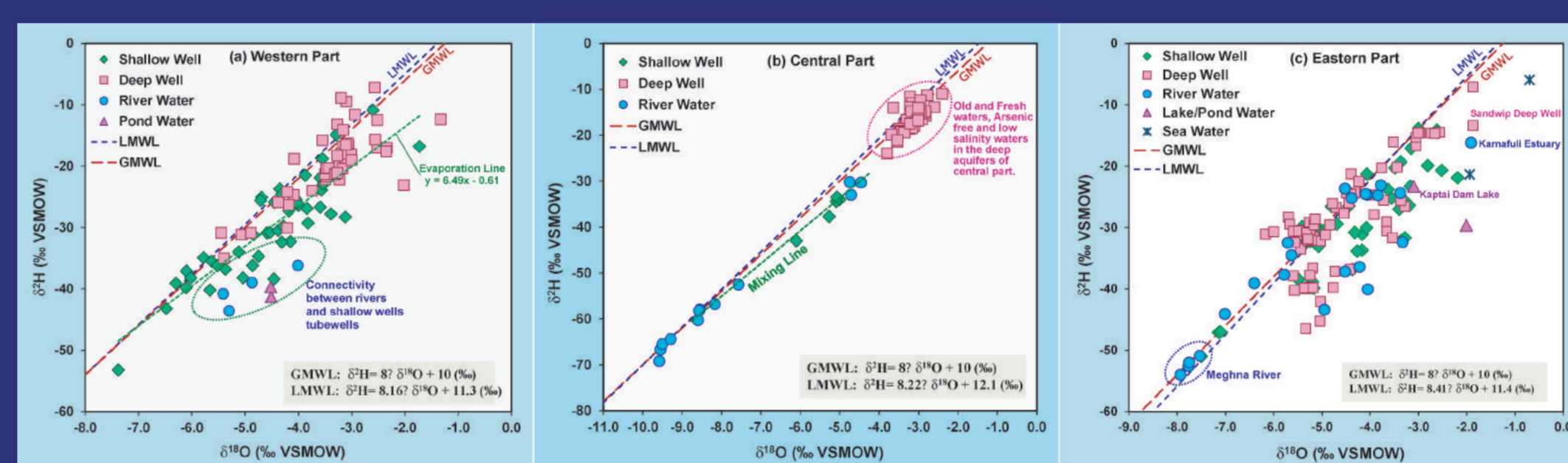


Figure 7: Stable oxygen and hydrogen compositions of shallow & deep groundwater and river water

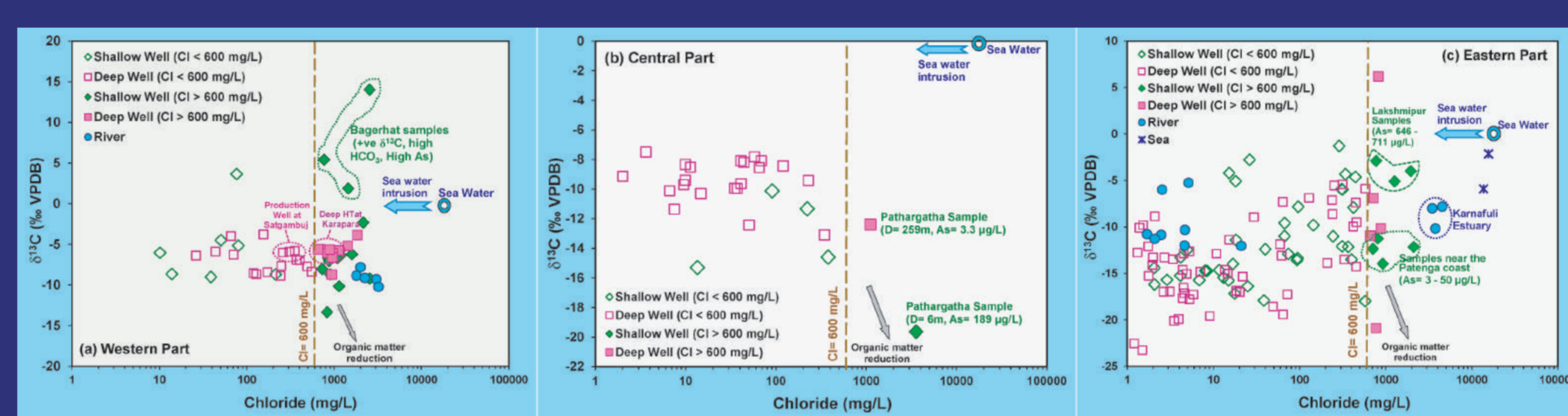


Figure 8: Isotopic properties of  $\delta^{13}\text{C}$  versus chloride for groundwaters with low and high salinity

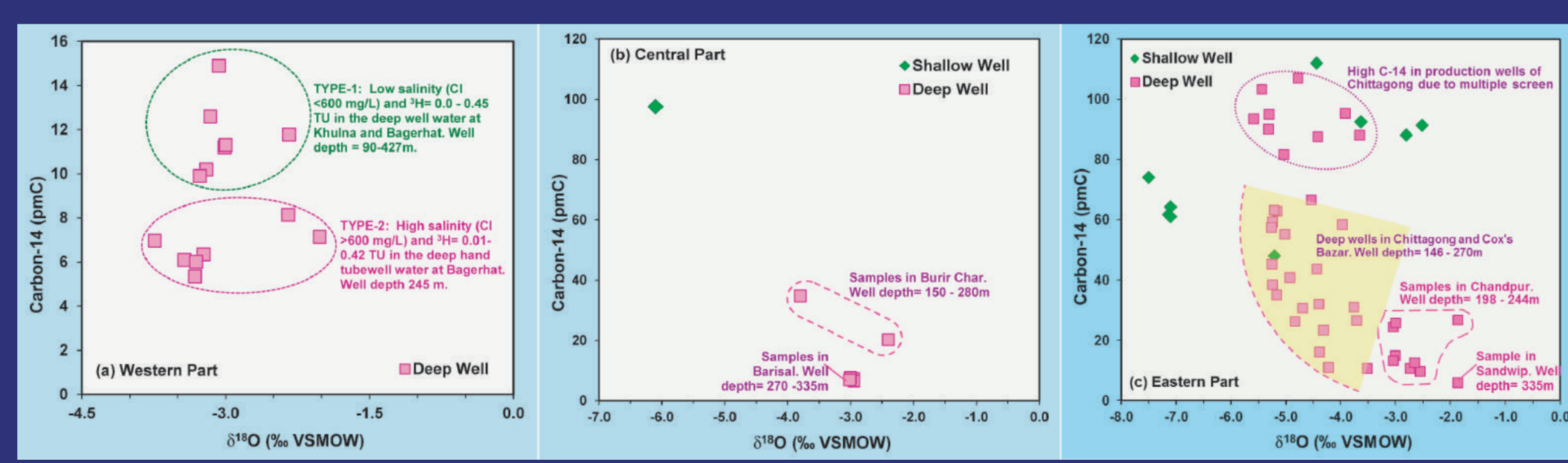


Figure 9: Oxygen-18 and carbon-14 compositions of shallow and deep groundwaters

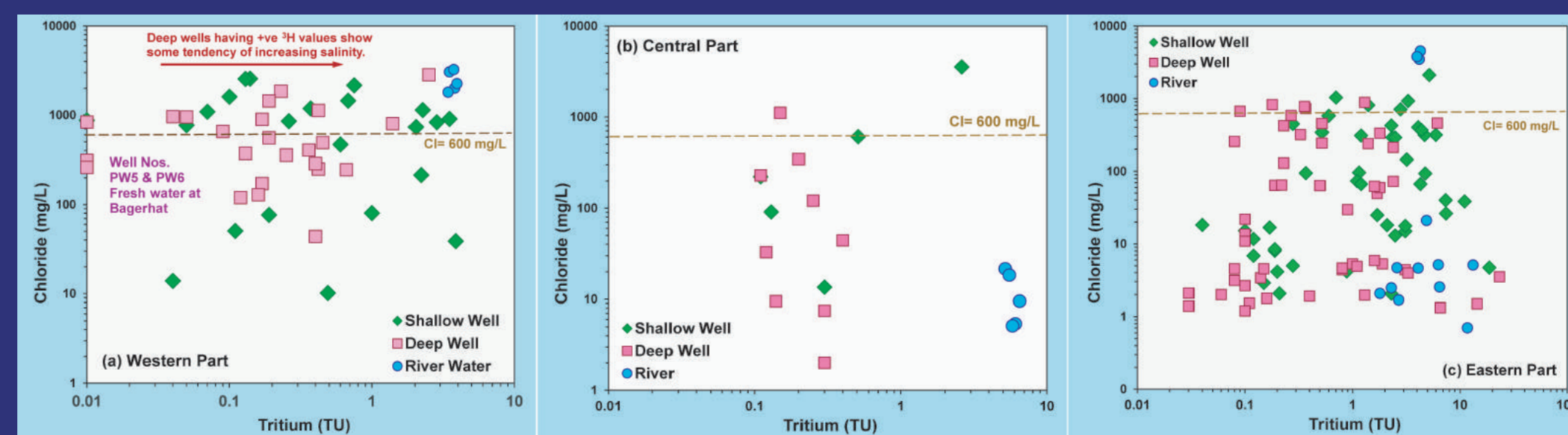


Figure 10: Relation between Tritium ( $^3\text{H}$ ) and Chloride contents in groundwater samples

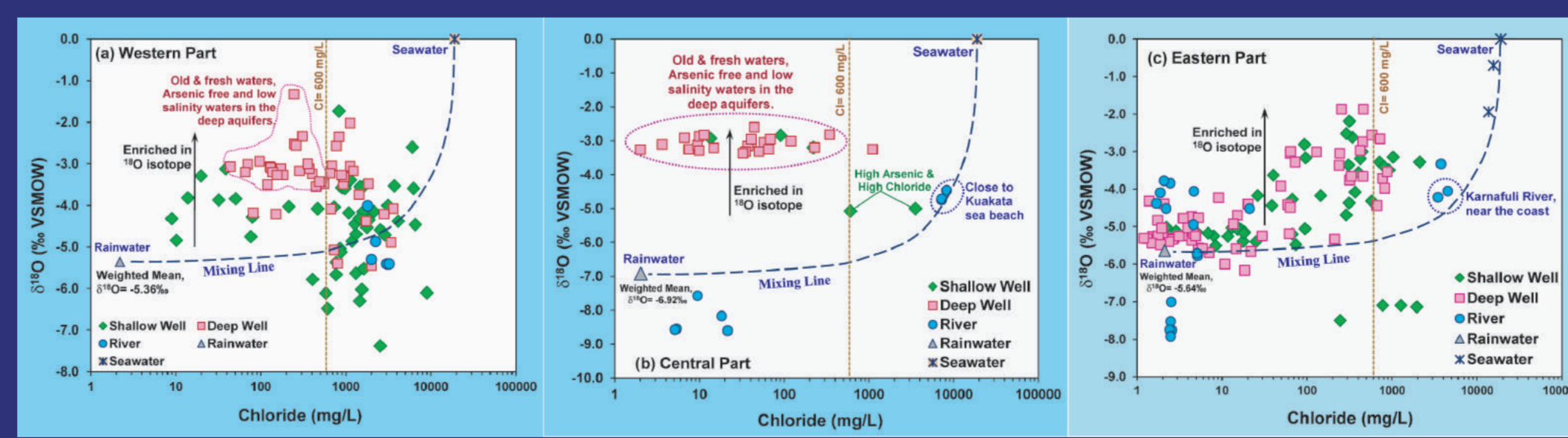


Figure 11: Relation between Oxygen-18 and Chloride in groundwater samples

### (i) Oxygen-18 and Deuterium Compositions in Groundwater Water

Most of the groundwater samples fall on, above and below the Global Meteoric Water Line (GMWL) ( $\delta^2\text{H} = 8\delta^{18}\text{O} + 10$ ) (Craig, 1961) which provides convincing evidence that all groundwater is derived from rainfalls and/or flood water and also indicates the effects of evaporation during infiltration (Fig. 7). The results of  $\delta\text{D}$  and  $\delta^{18}\text{O}$  have indicated that saline groundwaters are not much affected by seawater. The enriched stable isotope values of deep groundwaters of coastal area, as plotted on or below the meteoric water line, are not close to seawater.

The stable isotopes of Bhairab river waters are close to those of shallow groundwater at Bagerhat suggesting mixing with river water may be occurring. Both the river and shallow groundwaters have high chloride concentrations associated with high EC values. The salinity of these shallow groundwater samples most probably results from an admixture of marine water, which enters shallow aquifers indirectly by bank infiltration from Bhairab river or by flood water.

All the deep groundwater samples (depth 149–245 m) in the western part except three production wells (PW3, PW5 & PW6) at Bagerhat area have mostly intolerable limits of salinity (Cl<sup>-</sup> = 656–1436 mg/L). The  $\delta^{18}\text{O}$  values of these samples are high (-2.02 to -3.74‰ for oxygen) and plot below the meteoric water line, but not towards the sea water. It is assumed that these are pocket saline entrapped during late Pleistocene interglacial period, but they might be evaporated. The three production wells (depth ~305 m) at Satgambuj union are having exceptionally low Cl<sup>-</sup> concentrations ranging 260–357 mg/L and enriched oxygen-18 isotope (-2.34 to -3.00‰) indicating the paleo-water. The groundwaters from these three production wells with lower Cl<sup>-</sup> contents and arsenic free can be regarded as representative for safe drinking water.

In Madunaghat, Chittagong area, the  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  compositions of deep and shallow groundwater are overlapping. Deep (150–270m depth) groundwater has  $\delta^{18}\text{O}$  -3.98‰ to -6.17‰ and shallower (<70 m depth) groundwater has  $\delta^{18}\text{O}$  -5.00‰ to -5.41‰. These isotopic features suggest that most of the groundwaters result from a mixing between recent recharge and an older component recharge under climatic conditions cooler than at present. The isotope data suggest much of the water is derived from similar sources and has undergone evaporation.

### (ii) Carbon-13 on Dissolved Inorganic Carbon (DIC)

The  $\delta^{13}\text{C}$  values in deep groundwater samples of western part range from -13.34 to -2.31‰ VPDB with an average value of -6.87‰ VPDB. Methanogenesis are active in the anoxic deep Bengal Delta aquifers (Dowling, 2003), which accounts for the depletion of  $\delta^{13}\text{C}$ . The positive  $\delta^{13}\text{C}$  values (+1.87 to +14.02‰) for the shallow samples at Bagerhat are due to high bicarbonate (660, 1448, 839 and 738 mg/L respectively) fraction of groundwater (Clark & Fritz, 1997). Considering the compositions of  $\delta\text{D}$  and  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$  compositions of saline waters are expected to have higher than those of non-saline waters. However, the  $\delta^{13}\text{C}$  for saline groundwaters have ranges of -20.9 to -2.31‰ VPDB and they are similar to those of non-saline waters (Fig. 8). The  $\delta^{13}\text{C}$  values in non-saline groundwater have ranges of -23.3 to -1.29‰ VPDB (Izbicki, 1996). This result suggests that  $\delta^{13}\text{C}$  values of saline groundwater mostly in deep aquifer are affected by dissolution of carbonate minerals to enrich the amount of  $^{13}\text{C}$ .

### (iii) How old are the Deep Groundwaters ?

Mostly the deep groundwater samples have isotopically enriched O-18 values ranging from -1.87‰ to -4.83‰ VSMOW, less -ve compared to shallow samples (Fig. 9). The zero or low tritium (<1 TU) and low C-14 (1.8 – 43.8 pMC) contents indicate predominance of older water being recharged during the Pleistocene and Holocene periods. The apparent radiocarbon age ranges from 6,000 to 24,000 years BP. So, the deep groundwaters in the coastal area appear to have been recharged from local rains during or soon after the last glacial maximum (about 20,000 years BP) when the oxygen isotopic composition of local rains is likely to have been about 1‰ less -ve than the present rains (Aggarwal et al., 2000). These groundwaters appear to be the end member of the deep groundwater flow systems in Bengal Delta, where it mixes with the chloride rich (average 502 mg/L) water. This deep water salinity can possibly be attributed to contribution of salts from the marine connate water.

### (iv) Isotopic Evidence of Salinity

The -ve correlation between  $^3\text{H}$  and Cl<sup>-</sup> (Fig. 10) indicates that the deep groundwaters acquire salinity progressively as its residence time increases, suggesting that gradual dissolution or reaction with aquifer materials is the dominant mechanism. A few deep groundwaters in the western and eastern part crossing the permissible limit (600 mg/L) of drinking quality have +ve  $^3\text{H}$  values (0.04–23.3 TU) indicating sub-modern to modern recharge. These groundwaters contain high Cl<sup>-</sup> content (960–2830 mg/L) implying the salinity is due to the dissolution of salts in the aquifer during recharge in long time ago. The water with low salinity and arsenic free in two production wells (PW5 & PW6) at Satgambuj, Bagerhat has almost zero  $^3\text{H}$  and low C-14 values, and is considered to be reliable for safe drinking purpose.

In most cases, the waters from the deep and shallow wells do not fall on the mixing line (Fig. 11), which confirms that the enrichment of the heavy oxygen isotope in these samples is due to evaporation effects (Rozansky & Fröhlich, 2001). A few shallow samples of western part (Shyamnagar, Mongla and Batiaghata) having Cl<sup>-</sup> >600 mg/L fall on the mixing line. A few deep samples of eastern part (Chittagong) having Cl<sup>-</sup> <600 mg/L fall on the mixing line. The presence of halite within the deposits suggests dissolution of evaporites could be responsible for the high Cl<sup>-</sup> in the groundwaters. This fact provides a direct isotopic evidence that the salinity is not of marine origin.

## Conclusions

- In accordance with the geological and lithological features of the study area,  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$ ,  $^3\text{H}$  and Cl values in deep groundwater suggest that dissolution of evaporate deposits is responsible for the composition of Na-Cl brackish water. Some samples show a clear tendency of chloride and oxygen-18 increases indicating that evaporation is an important process, in particular, for near surface groundwater samples.
- There was no relationship between isotopic enrichment and increasing salinity. The salinity in the groundwater is due to the dissolution of soluble salts in the soil. These salts could have originated from marine aerosols which upon evaporation became solid.
- A few shallow groundwater samples show some tendency of mixing with sea water that fed through the marine rivers due to backwater effect. The shallow aquifers are prevalent with arsenic contamination.
- The water with low salinity and arsenic free in the deep aquifers at Satgambuj, Bagerhat is considered to be reliable for safe drinking purpose.

## Acknowledgements

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