Hydrogeochemical evolution of groundwater of part of Ganges-Meghna Deltaic Plain.

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Abstract: The groundwater in the outcrop area appears to be an essentially NaHCO$_3$ type in nature but as it moves down gradient, hydrochemical evolution modifies the groundwater into a mixed NaHCO$_3$/Cl type. Three major and two minor ion exchange fields were identified. The expanded Durov plot was successful in identifying the existence of two different types of water, the dominant type being the ion exchanged water and the less dominant but equally well defined type being old brackish water accompanied by some reverse ion exchange water. The existence of reverse ion exchange water is further suggested by the changing chemistry in the direction of flow. The brackish waters are separated into a few discrete locations and are not linked to one another. Apart from the brackish water, the groundwater is found to be potable as well as suitable for irrigation usage. The saturation indices calculated by means of the PHREEQUE hydrochemical model for calcite and dolomite establish a unique linear relationship emphasising the older waters are mainly supersaturated and the younger waters undersaturated with respect to these minerals.

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Riassunto: *Le acque sotterranee nell'area di affioramento appaiono essere essenzialmente di tipo NaHCO$_3$ naturalmente, ma quando si abbassa il gradiente, l'evoluzione idrochimica modifica le acque sotterranee in un misto del tipo NaHCO$_3$/Cl. Sono stati identificati tre maggiori e due minori campi di scambio ionico. Expanded Durov Plot ha avuto successo nell'identificare l'esistenza di due tipi di acqua: il tipo dominante che è quello dell'acqua dove è presente uno scambio ionico e il minore, ma ugualmente ben definito che è quello dell'acqua salmastra accompagnato da qualche inversione di scambio ionico. L'esistenza di un'inversione di scambio ionico è ulteriormente suggerita dal cambiamento chimico nella direzione di flusso dell'acquifero. Le acque salmastre sono separate in piccole zone discrete e non sono collegate l'una con l'altra. A parte le acque salmastre, gli acquiferi sotterranei si possono considerare potabili così come adatti per l'irrigazione. L'indice di saturazione calcolato per mezzo del modello idrochimico PHREEQUE per la calcite e la dolomite stabilisce un'unica relazione lineare sottolineando che le acque più antiche sono nel complesso sovrasature e le più giovani sono sottosature rispetto a questi minerali. Complete analisi del principale elemento chimico su 48 campioni di acque sotterranee vengono considerate nella presente interpretazione geochimica. Queste sono il numero massimo di risultati analitici dei campioni di acque sotterranee disponibili. Il campionamento e le analisi successive sono state effettuate tra Marzo 1976 e Aprile 1988 in tre fasi diverse. La prima serie di analisi chimiche fu effettuata da UNDP per stazioni selezionate, durante un periodo compreso tra Marzo 1976 e Giugno 1979. L'organizzazione nazionale per la gestione delle acque e lo sviluppo in Bangladesh (BWDB) iniziò le sue analisi periodiche sistematiche nell'Ottobre 1979 in stazioni selezionate. Il secondo gruppo di analisi chimiche provenne da quella fonte. Il terzo gruppo di campioni venne raccolto in Febbraio e Marzo 1988 durante una campagna fatta dall'autore per integrare alcuni dati chimici insufficienti. Questi campioni furono analizzati nel laboratorio geochimico del Department of Geological Sciences nell' University College London. Una delle principali cause di preoccupazione è la presenza di acque sotterranee di bassa qualità e saline in diverse zone all'interno dell'area, che costituisce una seria minaccia alla qualità complessiva delle risorse delle acque sotterranee. L'obbiettivo di questo studio è stato capire il processo chimico attivo, per identificare i vari tipi di acqua presenti e il loro impatto sulle risorse delle acque sotterranee. Ancora più importante è il bisogno di capire l'estenzione dell'evento e il pattern di distribuzione delle acque sotterranee saline all'interno dell'area di studio.*

Introduction

Complete major element chemical analyses of 48 groundwater samples were considered in the present hydrochemical interpretation. These are the maximum number of analytical results of groundwater samples available. Sampling and the subsequent analysis were carried out between March 1976 and April 1988 in three stages. The first series of chemical analyses was carried out by the

UNDP for selected stations during the period between March 1976 to June 1979. The national organization for water management and development in Bangladesh (**BWDB**) started its periodic systematic chemical analysis in October 1979 for selected locations. The second group of chemical analyses came from that source.

The third group of samples were collected in February and March, 1988 during a field visit made by the author to supplement some inadequate chemical data. Those samples were analysed at the geochemical laboratory of the Department of Geological Sciences at University College London.

One of the most important causes of concern is the occurrence of poor quality and saline groundwater in several locations within the area which poses a serious threat to the overall quality of the existing groundwater resources. The objectives of this study are to understand the active chemical processes, to identify the existing water types and their impact on the groundwater resources. More importantly, there is a need to understand the extent of occurrence and the pattern of distribution of the existing saline groundwater within the study area.

Geology

The Bengal Basin, of which Bangladesh is part, is a large uplifted faulted block of Pre-Cambrian basement rocks covered in part by Cretaceous and Tertiary Shelf Sediments. The tectonic element of Bengal Basin (Fig.1) can be broadly divided into Shelf, Slope or Hinge, and Bengal Foredeep (Guha, 1978; Mirkhamidov & Mannan, 1981).

The present study area occupies the north-eastern part of the Barisal-Chandpur gravity high, the western part of the unfolded flank and the northern part of the Hatiya trough.

The Bengal Basin, a major geosynclinals feature, began to form in the Late Cretaceous period (approx 70 million years ago) and continues subsiding today. Sediments washed from the surrounding hills have filled this geosynclinals basin to depths exceeding 18 kilometres (Fig. 1). No basement rock crops out within the study area (or in any part of Bangladesh as a whole) so that the surface and sub-surface geology consists of these recent geosynclinals deposits (Fig. 2). The Lalmai Hills are the only outcrop where all the rock types are exposed that make up the sub-surface geology down to an investigated depth of around 150 metres.
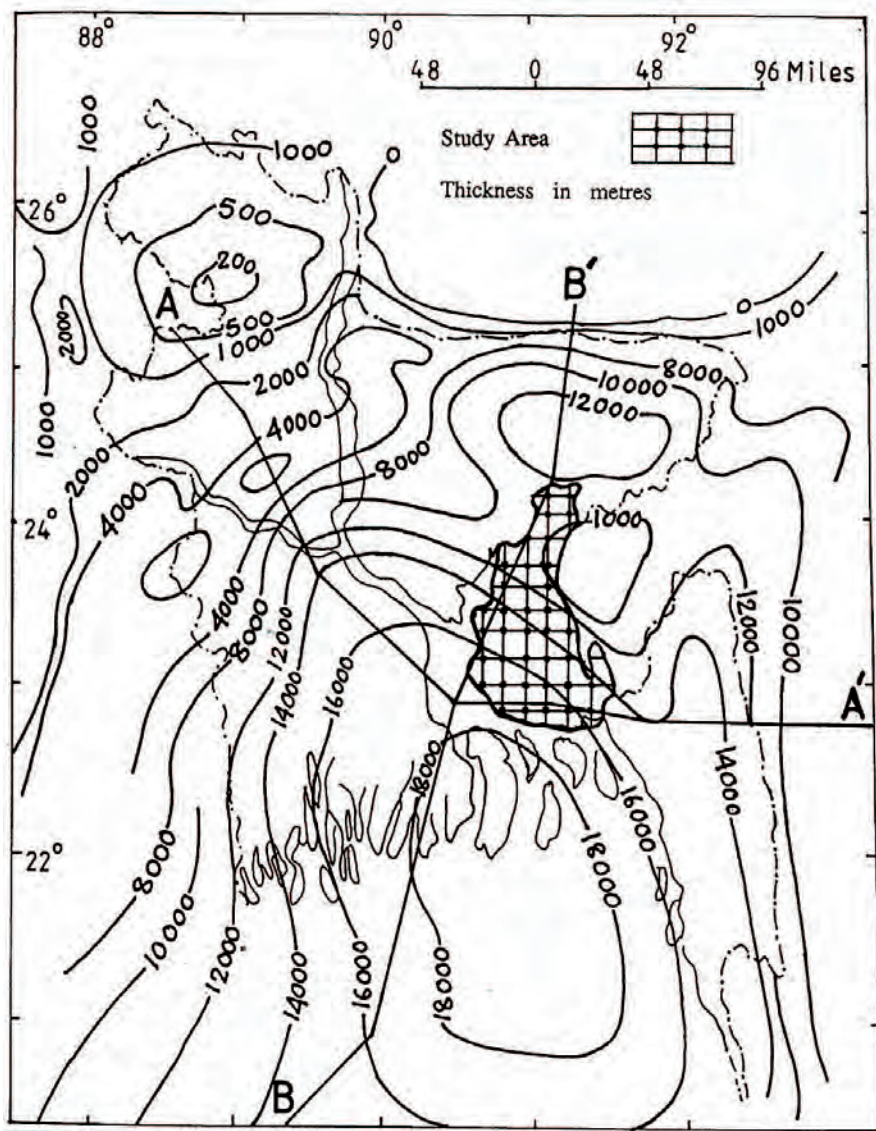

Fig. 1: *Location and sediment thickness of study area in tectonic map of Bangladesh (source: Guha, 1978; Mirkhamidov & Mannan.*
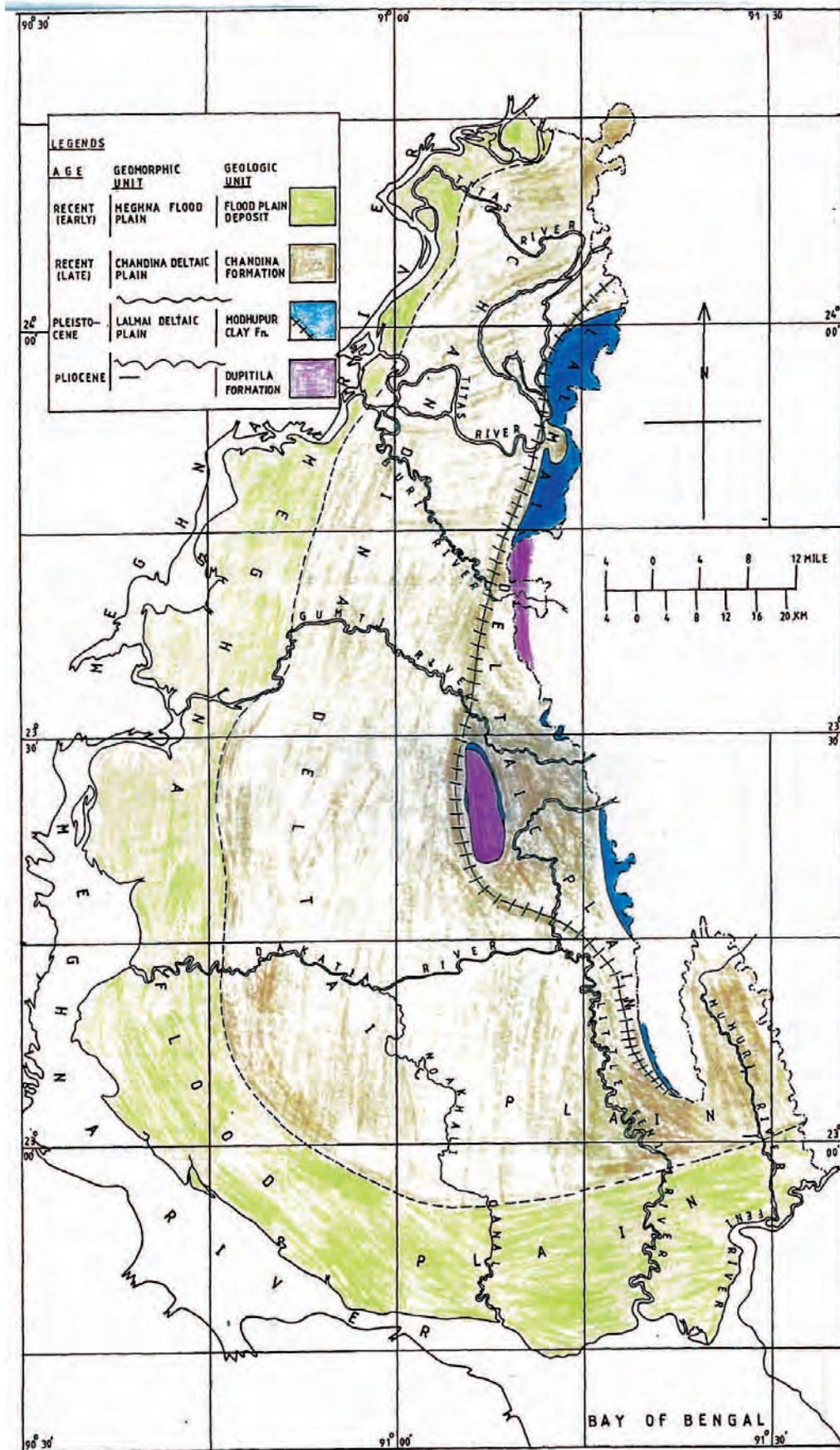
Fig. 2: *Location and sediment thickness of study area in tectonic map of Bangladesh (source: Guha, 1978; Mirkhamidov & Mannan.*

The existence of several deep seated structures (folds and faults) has been identified with the Lalmai Hills as the only exposed structures (Bakr, 1976; Morgan and McIntyre, 1959). All those buried structures have very little or no control on the formations of the main aquifer.

Hydrogeology

The occurrence of six well-defined potential aquifers (Fig. 3) has been identified down to a depth of >1800 metres. All these aquifers are made up of granular materials (Jones, 1985). The present work is entirely restricted to the delineation of the groundwater resources of the main aquifer (aquifer n°1). The distribution of the main aquifer in relation to the overlying aquiclude and the underlying clay aqui-tard outlining the recharge pattern are shown in an idealized sketck (Fig. 4). The main aquifer is distributed as a continuous, thick layer but is separated locally into two or more layers which are more pro-nounced in the south-west. It comprises primarily the sandy Dupitila Formation, of Pliocene age, which is composed of unconsolidated sands showing a gradation of grain size. Finer sands are at the top with the sequence coarsening downwards; the coarse sand at the bot-tom is usually associated with gravels and pebbles. The thickness of the aquifer ranges from 30 m to 120 m. The aquifer is almost entirely covered by a clay/silt aquiclude having a thickness ranging from <3 m to >300 m.

The loss of groundwater storage during the dry season is restored rapidly and regularly by the recharge during the following monso-on. The estimated total amount of recharge is about 1850 mm per annum about 95% of which originates from the infiltration of pre-cipitation through the surficial aquiclude. This is not unusual in an area which enjoys an annual rainfall (>3200 mm) which is one of the highest in the world. The complicated flow behaviour suggests that all the perennial rivers maintain direct hydraulic continuity with the groundwater. The regional flow is towards the west, south-west and south.

Borehole pumping tests indicate a truly confined condition for the smaller eastern part while leaky confined conditions prevail el-sewhere.

The transmissivity values range from 400 m^2/d <-> 1400 m^2/d while the storativity ranges from 4.1 x 10^{-3} <-> 3.7 x 10^{-4} and the maximum leakage (BL = 368 m) is recorded in the east central part (Alam, 1991).

Hydrochemical Evolution

Na/∑Cation Ratios And Ion Exchange

The ratio index values (Lloyd and Heathcote, 1985) obtained from the distribution map of the ration of sodium/∑cations (Fig. 5) indica-
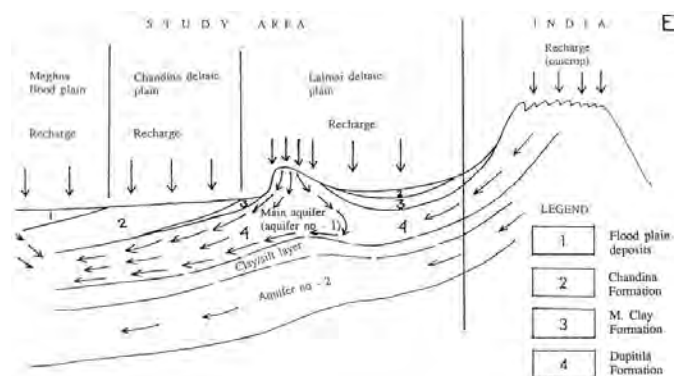

Fig. 4: *Idealized 'W -E' cross-sectional view of the main aquifer across the Lalmai hills showing recharge pattern.*
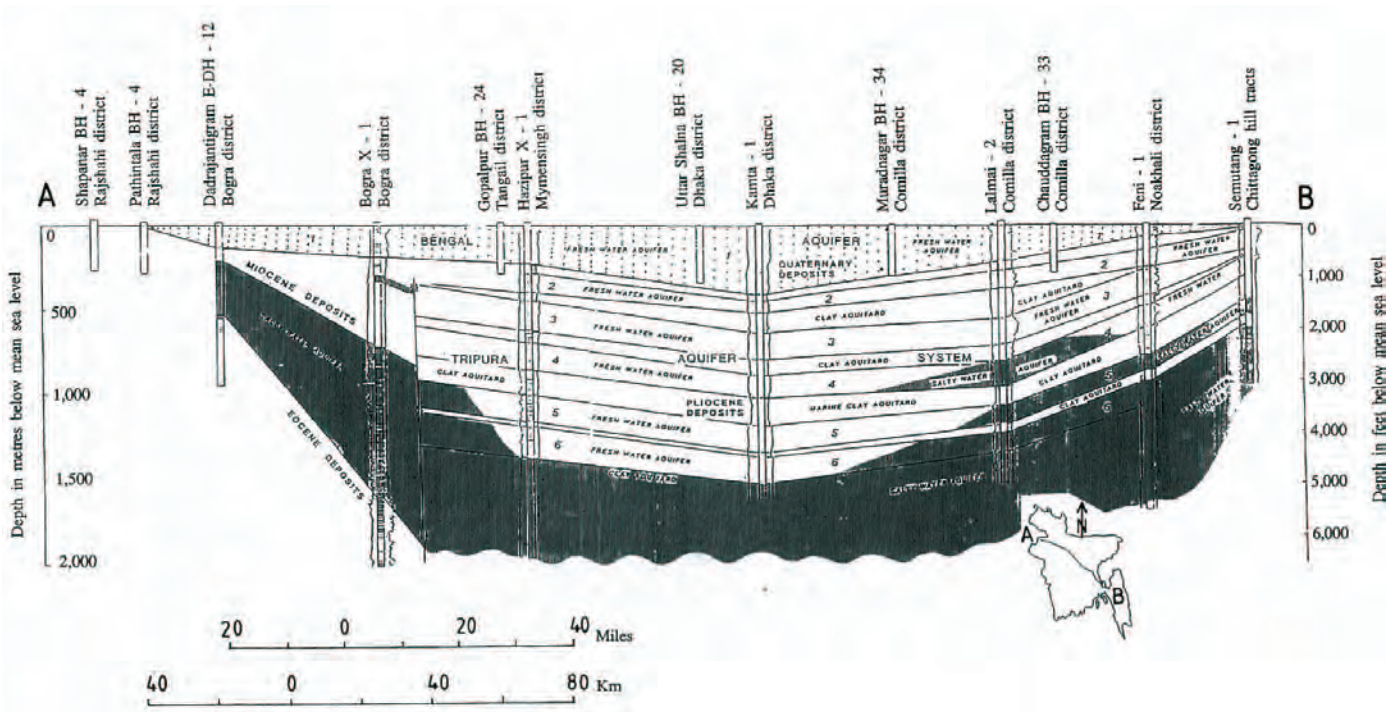

Fig. 3: *geological cross-section along 'A-B? line showing the distribution of both the main aquifer and the deeper aquifers of Bangladesh (after: Jones, 1985).*
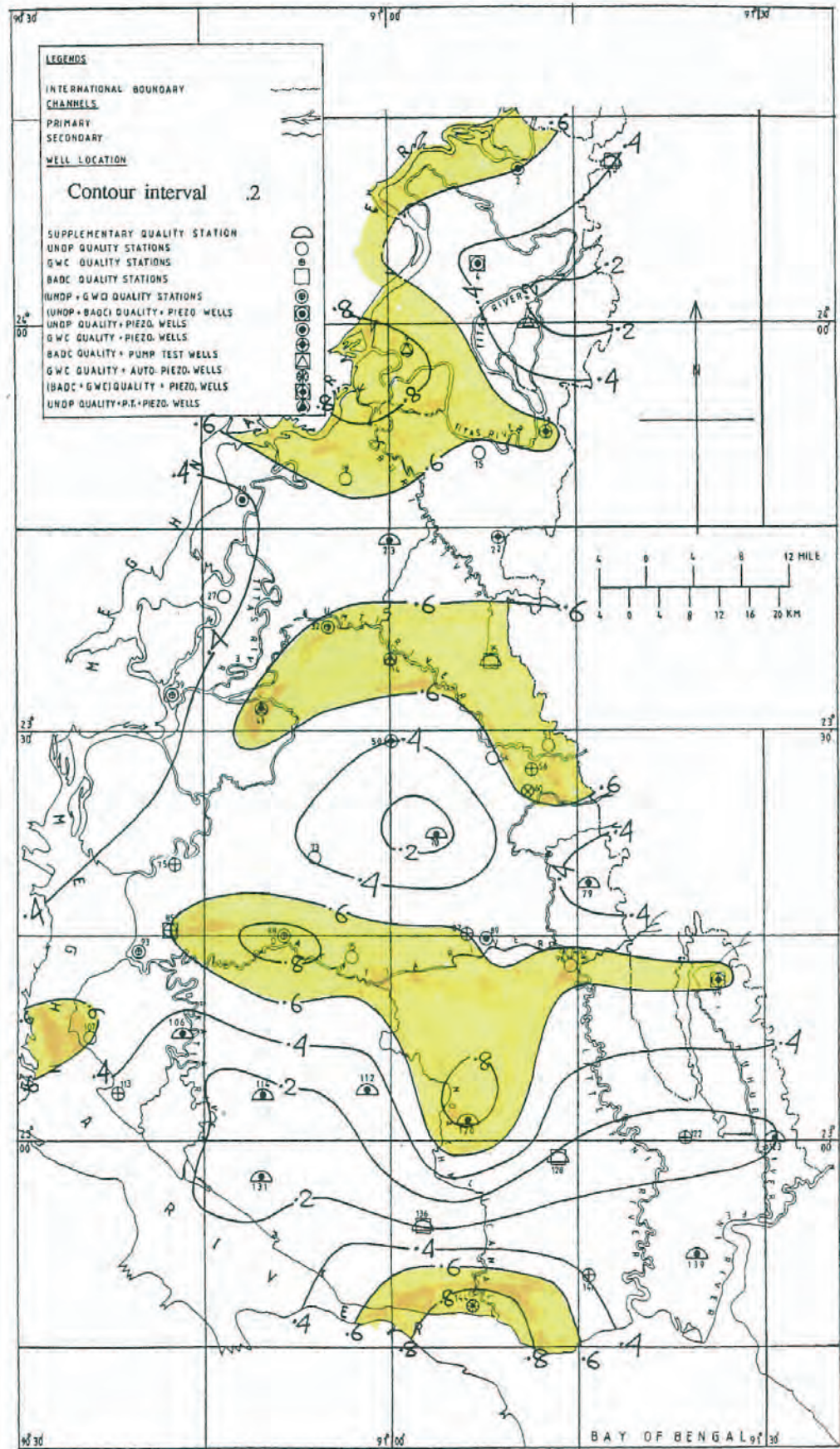
Fig. 5: *Hydrochemical ratio distribution of sodium to total cations and selected groundwater flow lines.*
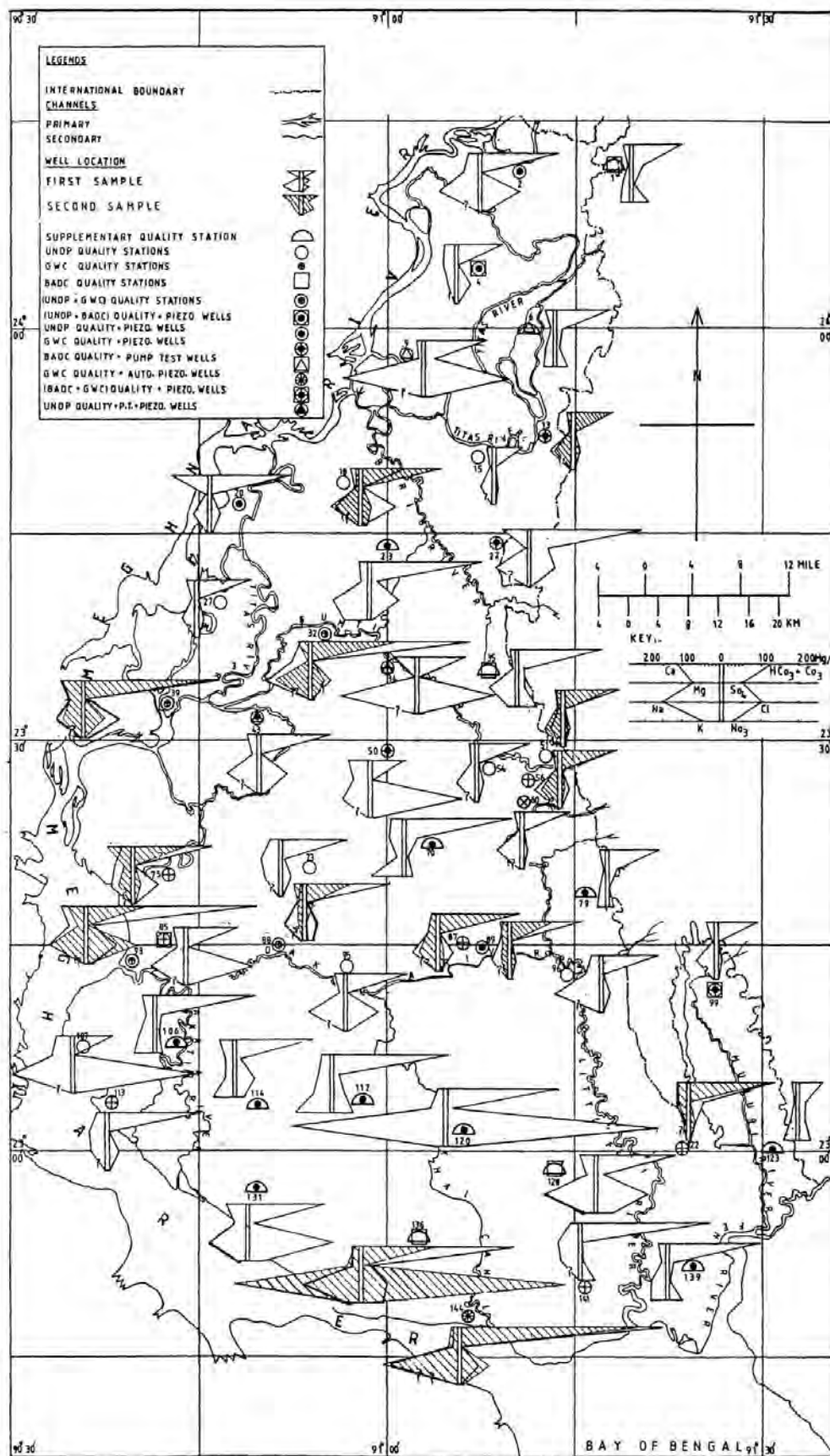
Fig. 6:*Patter distribution of major hydrochemical constituens.*

te that a considerable amount of ion exchange has occurred in combination with other processes responsible for the modification of calcium and sodium ions concentration as they become predominantly affected by the ion-exchange phenomena. A contour interval value of 0.2 was used to construct the ration map and the area with >0.6 index value has been singled out to locate the area where a significant amount of ion-exchange has taken place. Four major and one minor ion-exchange areas have been identified. Both the northern-most and the southern-most ion exchange areas demonstrate that the increasing amount of exchange activity is coincident with the increasing flow distance. But the centrally located ion-exchanged areas demonstrates that the exchange activities increase towards the centre of each block from all directions.

Even though the study aquifer in most cases appears to be composed of dominantly sandy and gravelly particles, up to 15 percent by weight of clay/silt materials are associated with the arenaceous materials. It was mentioned previously that the major part of the groundwater recharge takes place by direct infiltration of rain water by inter-granular flow. As the fresh recharge water passes through the sequence some ion-exchange activity takes place which increases significantly when the recharge water comes in contact with connate and saline water.

Pattern Diagram

Hydrochemical facies (Stiff, 1951; Back, 1966; Lloyd and Heathcote, 1985) variation across the study area is presented in Figure 6 as patterns for each well. The following comments can be made about the distribution:

- with the exception of a few wells, the Anion group is dominated by HCO_3 ions, though this tendency is superseded in the south by an increasing amount of chloride.

- the analytical results clearly demonstrate that the groundwater is dominated by sodium with some influences from calcium, magnesium and potassium ions.

- the groundwater towards the outcrop appears to be essentially $NaHCO_3$ type in nature but as it moves towards the west, south-west and south hydrochemical evolution modifies the groundwater into a mixed $NaHCO_3/Cl$ type because of ion exchange and mixing with connate water.

Chemical Evolution Along Direction Of Flow

Four different flow lines were selected to demonstrate the pattern of hydrochemical changes (Piper, 1944, Back, 1966) and the groundwater sampling locations falling along or close to each of the flow lines were considered.

The major ionic contents of the groundwater samples along a particular flow line were plotted in separate trilinear diagrams as Figure 7 in which the flow directions are indicated by arrowheads. The general rule about the ionic concentration under normal simple flow conditions is that the amount of total dissolved solids is expected to increase with increasing flow distances (Back, 1966; Hem, 1985; Lloyd & Heathcote, 1985). Because of the complex flow pattern this rule has not been maintained in any of the flow lines.

The natural flow lines are distorted by over-pumping as also are the active processes. A reverse ion-exchange process may be explained by flow lines 2 and 3 where both the wells 18 and 50 indicate end-point waters and a progressive increase of unstable ions (Ca and Mg) is observed at the expense of stable ions (Na and K). Wells 23, 35 and 51 along flow lines 2 can be regarded as a group so also the wells 54 and 60 along flow line 3. The sequential direction of flow in flow line 1 looks rather unlikely as a chemical evolution. The plot of wells 89, 106 and 112 can be best described as a group rather than a chemical evolution. The dominance of calcium in wells 20, 22, 39 and 75 and magnesium in wells 4, 70, 73, 113 and 141 is indicative of limited chemical dissolution of associated calcitic and dolomitic materials. The interactions between the oxygen rich fresh water and the reducing aquifer matrix are responsible for the redox phenomena, so that a certain amount of reduction is likely.
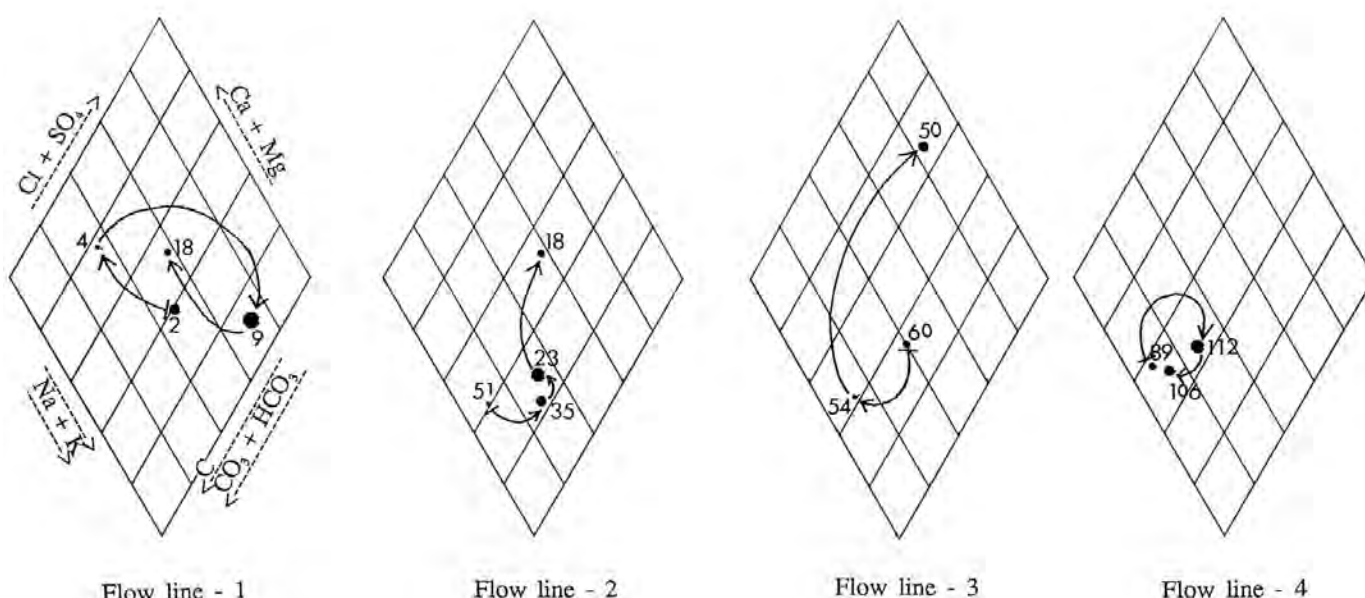

Flow line - 1   Flow line - 2   Flow line - 3   Flow line - 4

Fig. 7: *Variation in groundwater chemistry (arrow represent sequential direction of flow).*

Water Types And Processes By Expanded Durov Diagram

The plotted points in the expanded diagram (Fig. 8) fall into two fields (Durov, 1948), suggesting the existence of two different types of groundwater. More than 77 percent (38 data points) of the waters plot in the second and third fields with a majority lying in the third field. Those lying in the second field show the dominance of Mg and HCO₃ but at the same time Ca and Na are also important parts of their concentration and suggestive of partial ion-exchange accomplishment. On the other hand, those falling in the third field exclusively, show the dominance of Na and HCO₃ which normally indicates a strong ion-exchange potential. Therefore, the water in the second and third fields would normally be classified as **ion-exchanged waters** (Durov, 1948; and Lloyd and Heathcote, 1985). The second major group of water samples plotted in the ninth field indicates the dominance of Na and Cl ions. Waters having such features are usually regarded as end-point waters which often suggests the existence of older waters in the aquifer. Only two water samples plot in the eighth field suggesting Cl ion dominance and no dominant cations which is a positive indication that the water may have experienced **reverse ion-exchange processes** from previously Na-Cl rich waters. Waters in both the eighth and ninth fields jointly can be classified as **Old Brackish Water** where some reverse ion-exchange processes have taken place.

The expanded classification (Durov, 1948) strengthens the idea that the scatter distribution of the brackish water within the major ion-exchanged waters neither represents any distinct pattern nor does it indicate any link with brackish waters. Therefore, it may be concluded that the saline water entrapped in the southern region at shallow depth is because of sea water intrusion from the Bay of Bengal. However, the isolated locations of saline groundwaters in the northern and central parts may be due to the trapping of connate brackish water with some possible segregation of Na, K and Cl ions by ion-exchange processes.
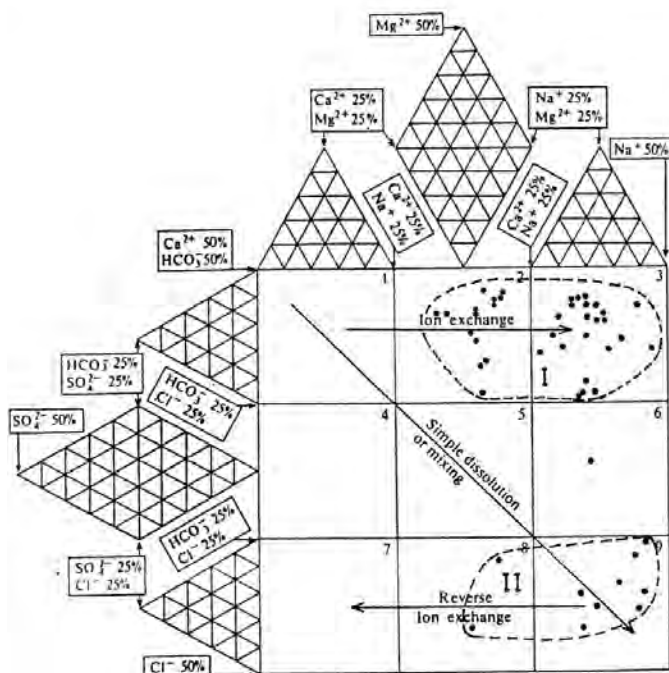
Phreeque Hydrochemical Model And Chemical Equilibrium

The assessment of the groundwater equilibrium state with respect to soluble solids as a result of the continued action of chemical processes has been made in terms of saturation indices (SI). To perform such a calculation the hydrochemical model **PHREEQE** (Parkhurst et al, 1985) has been used. The model calculates the distribution of species in the water. The saturation index (SI) of a water is defined by the expression: $SI = Log\ ([IAP]/[K])$ where, IAP = ion activity product and K = equilibrium constant. A water is in equilibrium with a mineral when the Saturation Index is zero. When this index is negative, the water is under-saturated and mineral dissolution may occur. When the Saturation Index is positive the water is super-saturated and mineral precipitation may occur. The saturation indices (SI) of certain important minerals are summarized to provide information on their saturation states. It should be mentioned that any interpretation on the basis of saturation is only meaningful for sparingly dissolved minerals. Therefore, to demonstrate any possible relationships only calcite, dolomite and siderite saturation indices were used to construct the X-Y plots. The calcite against siderite plot (figure not included) demonstrates a wide variability of SI values and are randomly scattered in all four quadrants. The distribution is probably meaningless.

Calcite Versus Dolomite Si Plot

A plot of calcite SI versus dolomite SI (Fig. 9) is effectively linear, passing through the points of mutual equilibrium and shows 73 percent of the water to be over-saturated with respect to both minerals. The linearity of the plot suggests that: 1) the degree of saturation of the water with respect to the minerals tends to increase with increasing distance from the outcrops with a few exceptions. Some of the wells in figure 9 have been numbered to illustrate this trend; and 2) the increasing depth of water also clearly demonstrates an increase in degree of saturation with even fewer exceptions.
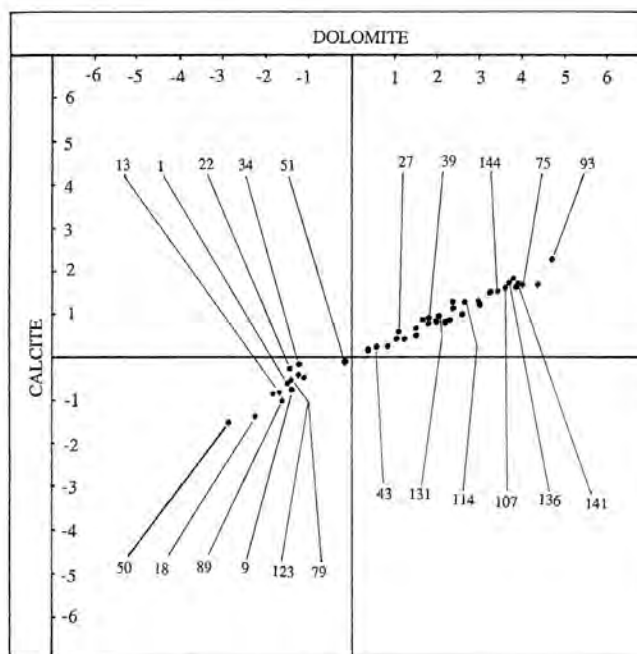

Fig. 8: *Classification of groundwater types using the expanded Durov diagram: (I) Ion exchange water; (II) Old brackish water.*

Fig. 9 : *Plot showing the linear relationship between calcite and dolomite SI value.*

Groundwater quality

Drinking Water Quality

The potability of a groundwater is partly dependant on the concentration of soluble solids and partly on the mineralogical content (EEC, 1975; WHO, 1984, USEPA, 1988; Sayre, 1988). International agencies (**EEC, WHO and USEPA**) have recommended certain standards or limits for most of the dissolved materials. The obtained maximum and minimum concentrations for the measured ions are compared with the three different major international standards in Table 1 to visualise the status of the quality aspect of the groundwater in the area being examined. To assess the potable quality of the present groundwater, a comparative study of more important major ionic concentrations is presented below.

TDS: The measured TDS concentration is well below the recommended limit. The high TDS value at shallow depth is because of the very high concentration of **Na and Cl** ions derived from the sea water intrusion and is not representative of the main aquifer.

pH: A **pH** of **10.00** is recorded in a number of wells which is above **MAC** limit. The majority of the remaining wells recorded a **pH** of **8.0 and above**, indicating that the solution is increasingly basic.

SILICA (SiO_2): The range of concentration of silica most commonly observed in natural waters is from **1 to 30 mg/L.** The maximum (74.1 mg/L) and minimum (15.0 mg/L) silica contents from the study area indicate that they are on the very high side.

MAJOR IONS: The chemical analysis suggests that in most cases calcium, magnesium, sodium, iron, sulphate, chloride and nitrate levels are well below the **EEC** recommended safety limits except for a few instances. The analytical results revealed that wherever an analysis of potassium and manganese is available, the **MAC** level has been exceeded in the case of potassium for all wells and with the exception of very few wells, the manganese level is also much higher than the **MAC.**

MINOR IONS: Of the **two** minor ions analysed, the fluoride level is much lower than the lower range of the **MAC** limit in all the analyses, and **phosphate** concentrations in excess of the **MAC** limit were noted in a few wells.

Tab. 1: *Comparative tabulation of potable water quality in terms of various ions with selected international standards.*

ITEM	WHO	(1984)	USEPA	(1988)	EEC	(1975)	STUDY	RESULTS
---	MAC	MRC	MAC	MRC	MAC	MRC/GL	MAX.	MIN.
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TDS	1000	---	500	---	1500	---	1180	102
Pb	6.5-8.5	---	6.5-8.5	---	---	6.0/6.5-8.5	10.0	6.5
SiO_2	---	---	----	---	---	----	74.1	15.00
Ca	100-300	---	---	---	---	10/100	68.00	7.5
Mg	---	---	---	---	---	5/30	54.0	3.0
Na	200	---	---	---	100	--/20	400.0	4.6
K	---	---	---	---	12	--/10	92.6	16.8
Fe	0.3	---	0.3	---	0.3	--/0.1	9.6	0.0
Mn	0.1	---	0.05	---	0.05	--/0.02	0.79	0.0
Co_3	---	---	---	---	---	10/35	46.00	0.0
HCo_3	---	---	---	---	---	--/30	532.00	59.0
So_4	400	---	250	---	250	--/5	46.1	0.0
Cl	250	---	250	---	250	--/25	562.0	0.8
No_3	44	10 (GL)	---	---	50	--/25	50.00	0.0
Po_4	---	---	---	---	2	--/0.3	13.2	0.72
F	1.5	---	2.0	---	1.4-2.4	--/0.7-1.2	0.53	<0.1
Ec	---	---	---	---	1250 μScm^{-1}	--/400 μScm^{-1}	1920 μScm^{-1}	146 μScm^{-1}

MAC – Maximum Admissible Concentration
MRC – Minimum Required Concentration
GL – Guide Level

Tab. 2: *Comparative study of irrigation water quality in terms of various types of hazards.*

WELL NO.	SAR	SAR HAZARD	RSC (meql^{-1})	RSC HAZARD	MHaz (meql^{-1})	MHaz HAZARD
1	0.931	LOW	0.296	Suitable	49	Harmless
2	3.028	"	-1.290	"	71	Harmful
4	0.697	"	-0.820	"	88	"
6	0.973	"	0.706	"	31	Harmless
9	11.782	Medium	1.400	Marginal	46	"
13	2.739	Low	0.600	Suitable	41	"
15	1.724	"	-0.084	"	52	Harmful
18	2.137	"	-1.030	"	59	"
20	1.183	"	-0.415	"	36	Harmless
22	2.651	"	1.043	"	09	"
23	3.650	"	2.440	Marginal	53	Harmful
27	1.482	"	0.392	Suitable	36	Harmless
32	3.124	"	1.700	Marginal	77	Harmful
34	6.984	"	-1.10	Suitable	08	Harmless
35	4.001	"	2.627	Unsuitable	45	"
39	4.088	"	0.263	Suitable	51	Harmful
43	3.321	"	0.751	"	42	Harmless
50	1.686	"	-4.662	"	54	Harmful
51	2.404	"	0.595	"	45	Harmless
54	2.373	"	0.694	"	59	Harmful
56	3.456	"	1.104	"	47	Harmless
60	3.122	"	0.603	"	42	"
70	0.666	"	0.558	"	66	Harmful
73	1.011	"	-2.292	"	76	"
75	1.431	"	-1.361	"	76	"
79	0.934	"	1.011	"	28	Harmless
85	3.178	"	-0.803	"	50	Harmless
87	1.744	"	0.896	"	72	Harmful
88	11.748	Medium	2.445	Marginal	69	"
89	1.619	Low	0.815	Suitable	72	"
93	2.233	"	0.868	"	52	"
95	4.028	"	0.480	"	42	Harmless
96	3.537	"	-1.963	"	74	Harmful
99	2.339	"	0.148	"	35	Harmless
106	1.298	"	1.403	Marginal	49	Harmless
107	3.830	"	-4.415	Suitable	69	Harmful
112	1.470	"	1.318	Marginal	70	"
113	1.132	"	-0.738	Suitable	76	"
114	0.709	"	-0.017	"	48	Harmless
120	12.784	Medium	1.117	"	77	Harmful
122	0.318	Low	0.327	"	64	"
123	0.957	"	0.193	"	38	Harmless
128	4.085	"	-0.345	"	48	"
131	2.523	"	-2.181	"	50	"
136	5.734	"	4.082	Unsuitable	62	Harmful
139	1.782	"	2.079	Marginal	47	Harmless
141	1.210	"	0.048	Suitable	80	Harmful
144	8.825	"	6.818	Unsuitable	65	"

Irrigation Water Quality

The selected indices for irrigation water quality are the sodium absorption ration **(SAR) = [Na / {(Ca + Mg)/2}$^{1/2}$]** (Richard, 1954), residual sodium carbonate **(RSC) = [(CO$_3$ + HCO$_3$) – (Ca + Mg)]** (Eaton, 1950), and magnesium hazard **(MHaz) = [{Mg / (Ca + Mg)} x 100]** (Szabolcs and Darab, 1964)**.** All these indices were calculated by meq/l units which provide a good practical guide to water suitability in terms of **major ions** summarized in Table 2 which compares the agreement between different types of hazards. For the present set of data, **'Low Hazard' and 'Suitable'** conditions for most of the wells are indicated by the **SAR** and **RSC** indices respectively rather than the **MHaz** hazard. The U.S. Department of Agriculture (Richards, 1954) has considered **SAR** in combination with **EC** which has proved very convenient and is widely used in assessing irrigation water quality. The calculated **SAR** values and measured **EC** values (EC values were considered only for those water samples analysed at (UCL) suggest that with the exception of only four wells, all the water belongs to a **Low to Medium Salinity Hazard Rating (Fig. 10)**

Of the exceptions, well 121 located on the edge of the Meghna estuary indicates a high salinity condition which is primarily due to salinity intrusion along the coastal belt and not surprising being so close to the Bay of Bengal. The other wells (112, 120 and 128) having higher hazards indicate isolated representation rather than being part of a pattern or trend. On the basis of the above explanation of the different categories of **hazards,** it may be concluded that the **most of the waters are suitable for most crops.** Nevertheless, selective cropping patterns would be more appropriate in areas having high sodium and high salinity hazard.
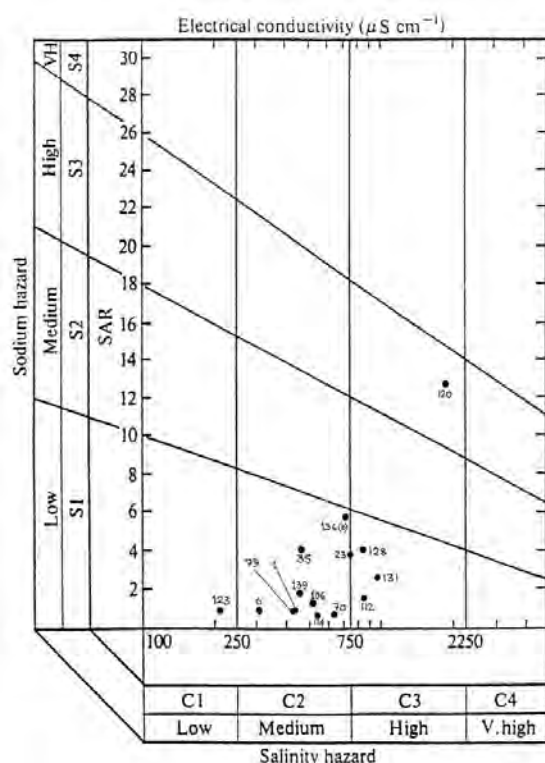
Conclusions

On the basis of the analysis of various graphical and geochemical parameters the following conclusions can be drawn about the hydrochemical evolution and the quality of groundwater in this part of Bangladesh.

- The general value for dissolved solids is very low (<600 mg/L) although the TDS concentration is occasionally unusually high in comparison with the rest of the groundwater, yet even that concentration is below EEC safety limit.

- The groundwater in its initial stage appears to have been an essentially NaHCO$_3$ type but as it moves in different directions hydrochemical evolution modifies the groundwater into a mixed NaHCO$_3$/Cl type by ion-exchange and mixing with connate water.

- The hydrochemical evolution is found to have been dominated by ion-exchange processes though other processes particularly mixing, dissolution, and reverse ion exchange, also play important roles in producing the water types. The combined action of these processes has given rise to two distinct types of water. The first is ion exchanged water while the second is old brackish water; the first type dominates the second.

- The X-Y plot of Calcite and Dolomite revealed that the degree of saturation of the water tends to increase with increasing distance from the outcrops, and the degree of saturation also increases with increasing depth of water.

- Although at present most of the groundwater in its natural state does not provide any injurious effects on health, its long-term potability is questionable with a rising concentration for some of the constituents in some of the wells, particularly **potassium,** manganese, phosphate and silica. From the irrigation point of view most waters are suitable for most crops, except in a few wells where the mixing of groundwater with connate water and sea water has initiated the deterioration of the water quality,and will require regular monitoring.

Fig. 10 :*Plot showing the range of combined sodium and salinity hazard for classification of irrigation water quality*

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