Jal Vigyan Sameeksha—a publication of
High Level Technical Committee on Hydrology
Vol. II. No. 1, June 1987

Sea Water Intrusion in Coastal Unconfined Aquifers of South Western Peninsula-A Case Study

By

Dr. P. Basak
Executive Director-in-charge

M. Nazimuddin
Scientist

Groundwater Division
Centre for Water Resources Development and Management
Kunnamangalam (MBR), Kozhikode-673 571, Kerala

Abstract : *Seasonal increase in salinity in the wells near the sea shore is primarily due to salt water encroachment from the Arabian Sea which is hydraulically connected with the coastal aquifers running parallel to the ocean. The results from the field investigation carried out in this aspect with reference to coastal tracts in Malabar region are presented in this paper.*

Three years of observation on the coastal wells along Malabar region between Trichur and Kasaragod are analysed and correlated with depth to water level and distance of the well from the sea shore through a simple conceptual model. The model forwarded would be direct help to the well users to find out maximum quantity of water he can withdraw without adversely affecting the quality of water. It will also be of direct help in forecasting the likely level of salinity intrusion into the coastal aquifers and device possible remedial measures for the same.

1. Introduction

Salt water intrusion in the unconfined and confined aquifers along various coastal belts of Indian union are being increasingly reported. The problems are particularly severe in the coastal belts of Tamil Nadu, Kerala and Gujarat. Due to increasing demand of potable water resources caused by increased population and raised industrial activities, the limited ground water resources of this sensitive zone are being more extensively utilized compared to what used to be a decade back. In many places (particularly in Tamil Nadu Coast), this has resulted in a gradual lowering of water table causing the sea water wedge to intrude further inland.

Preliminary investigation (Bindu Madhav and Basak, 1982) indicates that 30,000 litres of groundwater per day per sq. km. of Kerala's coastal belts are withdrawn, namely through a large number of dug wells in this area (about 300 dug wells). Withdrawal of such fresh-water from the shallow unconfined aquifer adjacent to the shore, particularly in the absence of appropriate recharge in non-monsoonic seasons, causes lowering of the fresh water table. This lowering of water table is met with the landward advancement of the sea water interface and also partially increasing the salt content of the potable water due to transverse or lateral diffusion/dispersion of oceanic salts.

Since the time of Ghyben-Herzburg (Todd, 1959), the quantitative relation between the freshwater table depth and the position of sea water interface (Fig. 1) is well understood through the relation :

$$\frac{h}{H} = \frac{D_f}{D_s - D_f} \text{ in which (refer Fig. 1)}$$

h = Depth of fresh water in aquifer below the sea level

H = Depth of freshwater above the sea level

D_f = Density of freshwater (1 gm/cc)

D_s = Density of sea water (typically 1.025 gm/cc).

Physically, equation (1) signifies that for every unit drop of freshwater table, there is $(D_f/D_s—D_f)$ times rise of sea water interface then severely restricting the available quantum of fresh water. The typical value of the factor $(D_f/D_s—D_f)$ is of the order of 40. What happens to the quality of fresh water consequent upon this rise of sea water interface is neither properly understood nor adequately studied. Available literatures are very scanty and field observation on this particular aspect is also not well documented. The present paper aims to have a beginning in that direction.

2. Dynamics of Coastal Groundwater Quality : Basic Concepts

Ghyben Herzberg's concepts of sea water intrusions in coastal aquifer is shown in Fig. 1. The sharp interface between fresh and saline water as depicted is only simplification of actual situation. In reality, there exists a transition zone of certain width where the density varies between sea water to that of fresh water. The density of water is proportional to the dissolved salt content in it. This means TDS (total dissolved solids) chloride and other salt content distribution across the freshwater lens (Fig. 2) will also be of the same nature of that of density distribution. Hence, it is clear that average density (D) and consequently average TDS, chloride, and other individual salt contents of the floating freshwater lens will be dependent on the thickness of the fresh water table lens available at that point. Fig. 2 is self explanatory in this respect. Keeping this in mind, it is perhaps logical to expect the followings.

1. At any point of time, average salt content of the fresh water lens should increase as one approaches the shore.
2. At all points in the coastal aquifers salt content should increase with the lowering of fresh water table.
3. The rate of increase of salt content with lowering of fresh water table should increase as one goes nearer to the shore.
4. Beyond a certain distance from the shore, the salt content of the fresh water lens should be independent of the depth to water table and its temporal fluctuations.

Field groundwater resources of a typical coastal aquifer in Malabar Region have to be studied to be studied to validate the concepts introduced and to quantity the parameters mentioned in points 1 to 4 above.

3. Groundwater Quality Behaviour in Coastal Aquifer of Malabar Region

Field Results and Interpretations

Spatial and temporal variations of ground water quality are being recorded in selected open wells along the coastal belts of Malabar region of the Kerala State. The study area and the location of experimental wells are shown in Fig. 3. This particular coastal belt has an area of 800 km² with width varying 0 4 kms to 8 kms and 300 km long, which is taken up for the present sea water intrusion investigations. The coastal belt of Malabar region comprises of five districts e.g. Trichur, Malappuram, Kozhikode, Cannanore and Kasaragod. The respective coastal stretches are named accordingly in Fig. 3.

The main source of drinking water is the freshwater lens in the shallow unconfined aquifer floating over the sea water wedge of

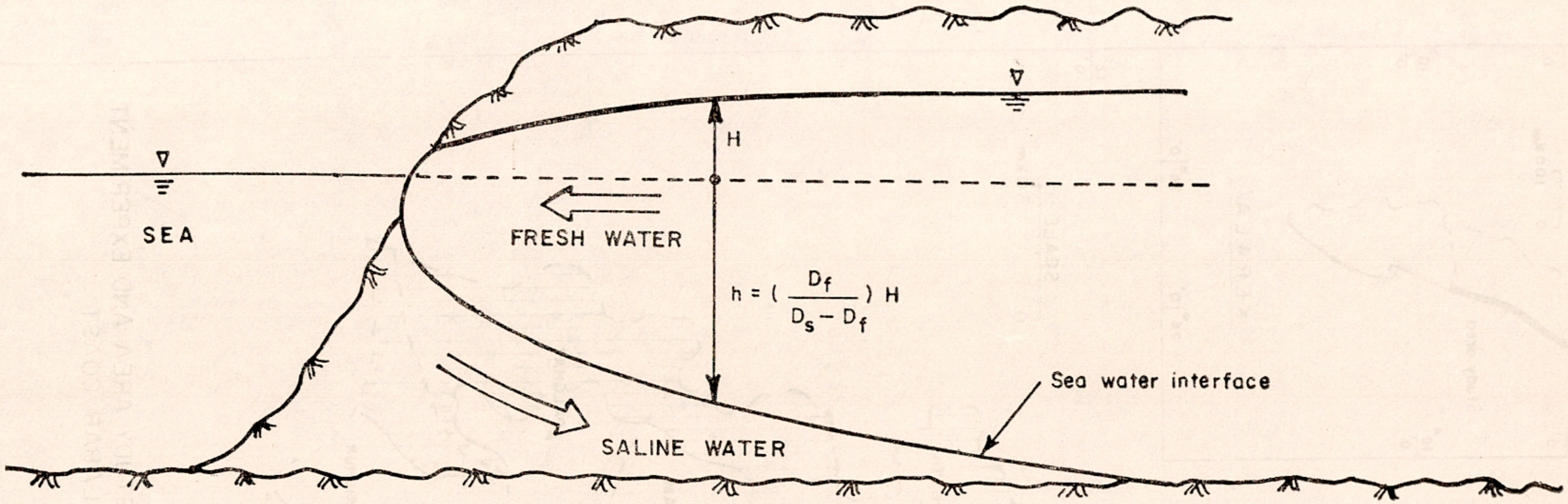


Fig. 1 : Sea Warer Intrusion in the Coastal Unconfined Aquifer and Ghyben Herzberg's Relation

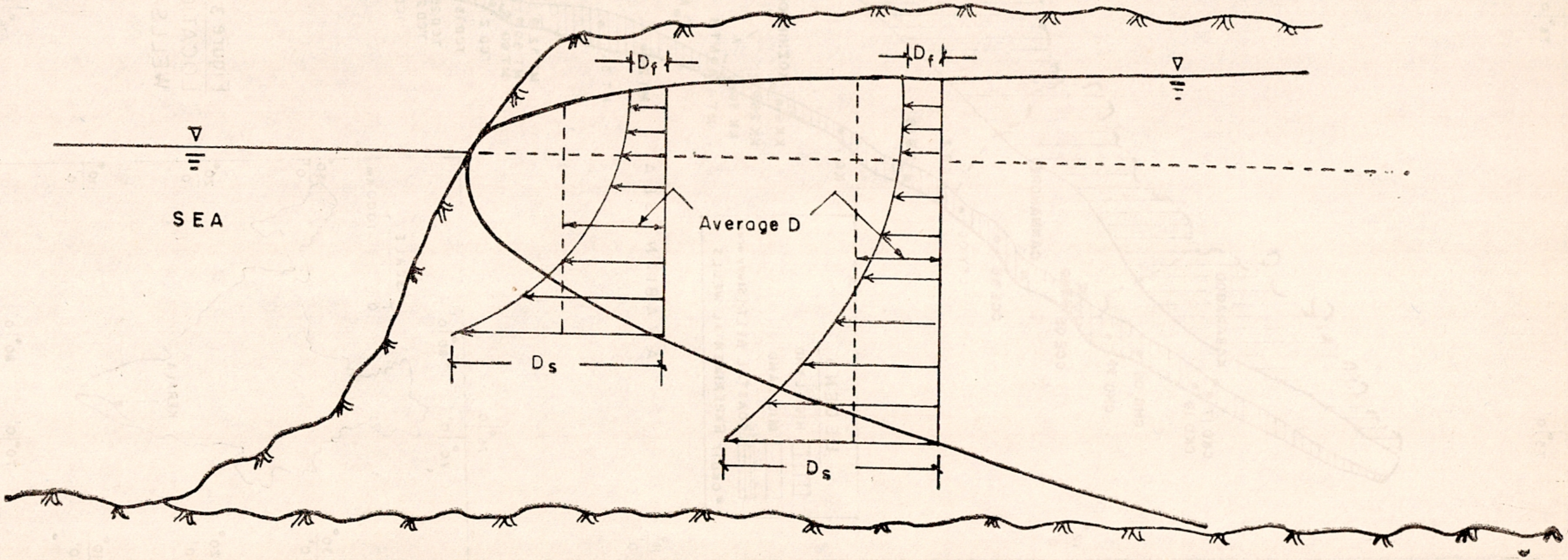


Fig. 2 : Probable Density Distributions in the Fresh Watet Lense above the Sea Water Interface

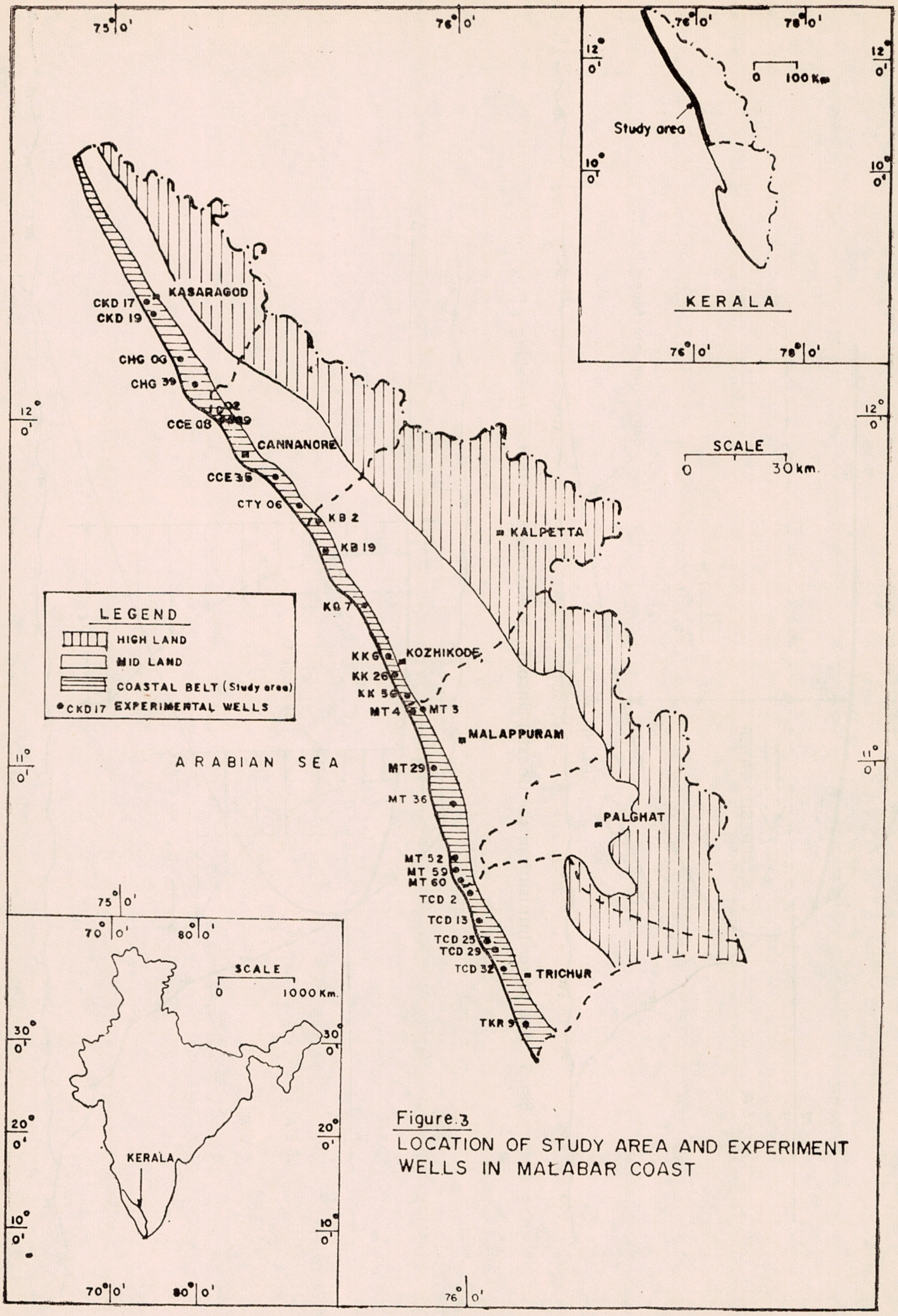


Figure. 3
LOCATION OF STUDY AREA AND EXPERIMENT WELLS IN MALABAR COAST

the type described in Fig 2. General direction of fresh water flow is from eastern uplands to the Arabian ocean in the west.

The depth to groundwater table and two water quality parameters e.g. T.D.S. and chloride contents were measured during three times in a year, summer (April–May), monsoon (July–August) and postmonsoon (December-January).

For each depth to water table measurement corresponding T.D S. and chloride values are plotted to various coastal belts. A typical plot and chloride vs depth to water table in different coastal districts in Malabar region are shown in Fig. 4 & Fig. 5. The slope of these plots indicate rate of salinity (TDS or Cl_2) change with change of depth to freshwater table and are termed here as "Quality-Depth Index QDI"). These indices tell the well user, the likely amount of rise or depth of salinity per unit lowering or rise of depth to water table. Higher QDI indicates higher sensitivity of the freshwater towards the change in depth to water table. The distance of the observation wells from the sea shore are plotted against the QDI for TDS and chloride and are shown in Fig. 6.

From figures 4, 5 and 6 it is seen that quality parameters (TDS and Cl) in the coastal aquifer vary linearly with the depth to water table and is associated with deterioration of quality. Experimental area shows the QDI variation between 8900 ppm/m to 16 ppm/m for TDS and 1900 ppm/m to 6 ppm/m for chloride. Near the well to the coast, higher the value of QDI. At higher distance from the shore, it is seen that QDI is insensitive to the change in depth to water level. This is in conformity with the basic concepts mentioned earlier.

The plots of QDI versus well distance (from the sea shore) indicate as exponential decrease of QDI with distance. As seen from the plots, the coastal aquifers may be divided in 2 zones, e.g.

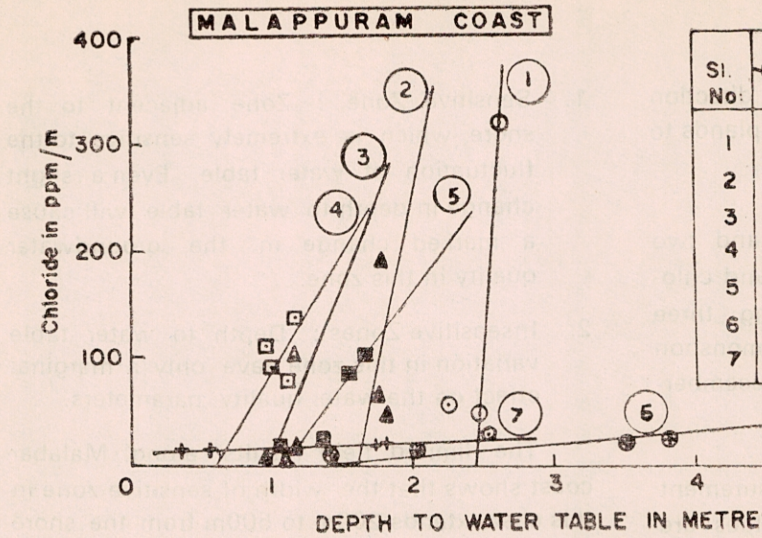
1. Sensitive Zone : Zone adjacent to the shore which is extremely sensitive to the fluctuation of water table. Even a slight change in depth to water table will cause a marked change in the groundwater quality in this zone.
2. Insensitive Zones : Depth to water table variation in this zone have only a marginal effect on the water quality parameters.

The limited field results along Malabar coast shows that the width of sensitive zone in this cost extends 200m to 500m from the shore in different coastal belts. Identification of the sensitive zone is extremely important because much care has to be taken to maintain minimum possible depth to groundwater table. This can be achieved by a combination of restrictive groundwater withdrawal and appropriate recharging in this zone.

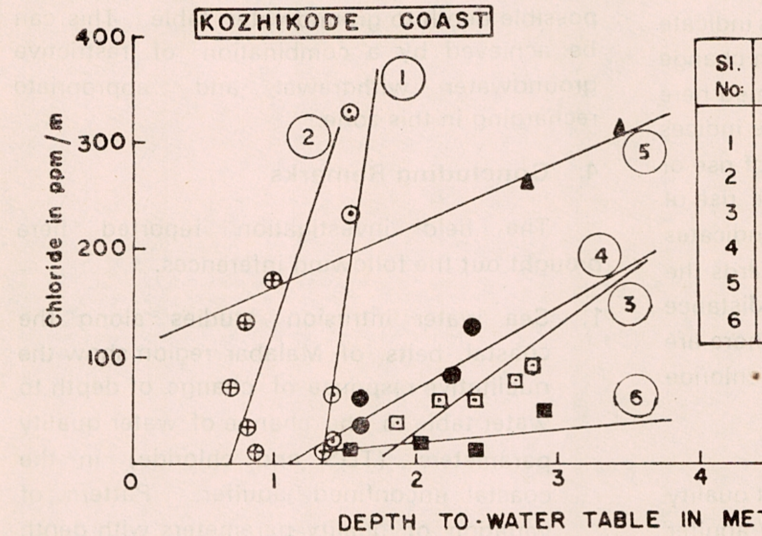
4. Concluding Remarks

The field investigation reported here brought out the following inferences.

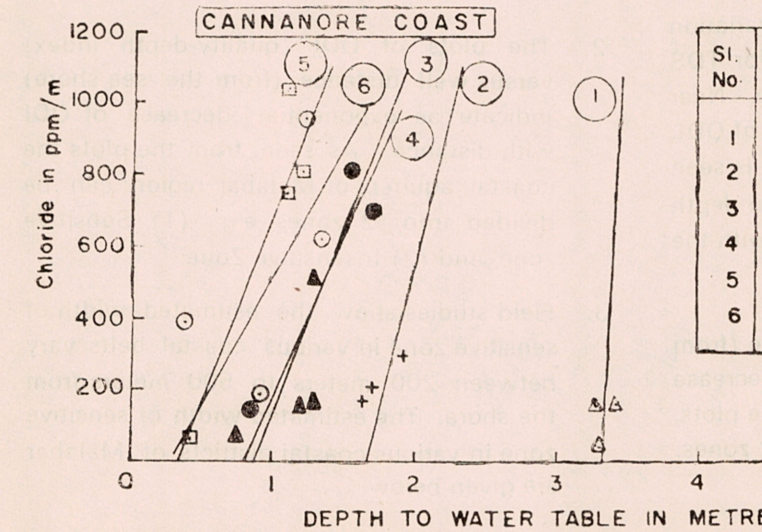
1. Sea water intrusion studies along the coastal belts of Malabar region show the qualitative response of change of depth to water table to the change of water quality parameters (TDS and chloride) in the coastal unconfined aquifer. Pattern of variation of quality parameters with depth to water table are expected to be in the similar lines in all similar coastal aquifer.
2. The plots of QDI (quality-depth index) versus well distance (from the sea shore) indicate as exponential decrease of QDI with distance. As seen from the plots the coastal aquifers of Malabar region can be divided into 2 zones e.g. (1) Sensitive zone, and (2) Insensitive Zone.
3. Field studies show the estimated width of sensitive zone in various coastal belts vary between 200 meters to 500 meters from the shore. The estimated width of sensitive zone in various coastal districts of Malabar are given below.



Sl. No.	Symbol	Well No.	Distance from shore in metres	QDI in ppm/m
1	⊙	MT 4	45	1900
2	▲	MT 60	138	613
3	△	MT 29	240	264
4	⊡	MT 52	440	200
5	■	MT 59	860	140
6	⊕	MT 3	1000	6
7	+	MT 36	2300	2



Sl. No:	Symbol	Well No:	Distance from shore in metres	QDI in ppm/m.
1	⊙	KK 52	60	800
2	⊕	KQ 7	70	475
3	⊡	KB 19	100	95
4	●	KK 26	200	75
5	▲	KK 6	600	58
6	■	KB 2	1500	14

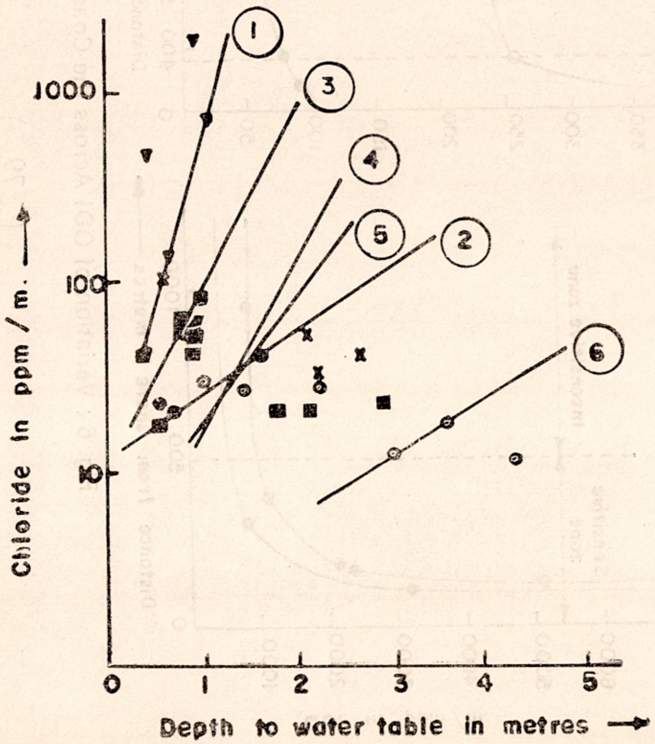


Sl. No.	Symbol	Well No:	Distance from shore in metres	QDI in ppm m
1	△	CKD 17	125	5360
2	+	CCE 35	190	2160
3	▲	CCE 02	380	1080
4	●	CKD 04	950	926
5	⊡	CCE 18	1650	914
6	⊙	CHG 39	2750	770

Fig. 4. : Variation of Chloride with Depth to Water Table

Sl. no	Symbol	Well. no	Distance from Shore in metres	QDI in ppm/m
1	▼	TKR 09	50	1967
2	●	TCD 29	90	67
3	⊡	TCD 32	220	800
4	x	TCD 25	250	195
5	■	TCD 03	400	103
6	⊙	TCD 02	530	23

TRICHUR COAST



Sl. no	Symbol	Well no	Distance from Shore in metres	QD in ppm/m
1	●	CKD 17	125	94
2	x	CHG 06	320	85
3	⊙	CKD 19	1900	30
4	▼	CHG 39	2750	39

KASARAGOD COAST

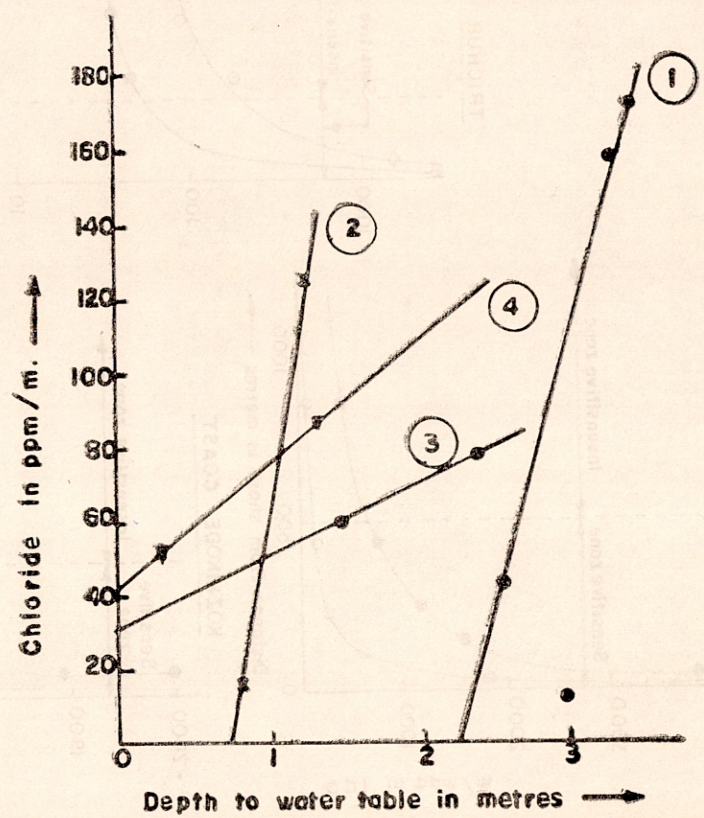


Fig. 5 : Variation of Chloride with Depth to Water Table

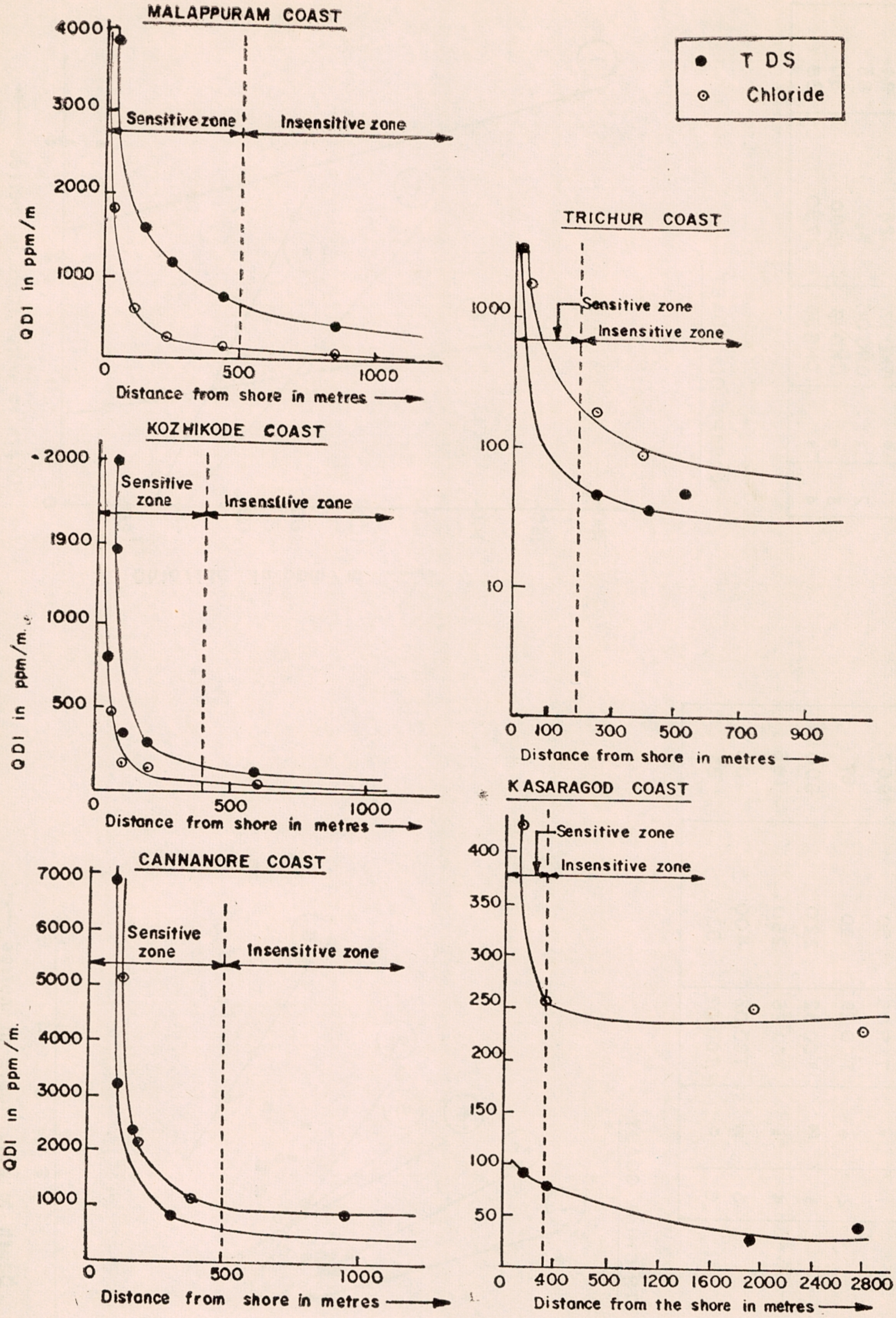


Fig. 6 : Variation of QDI Across the Coastal Aquifers

Name of the coastal belt	Estimated width of sensitive zone from the shore (in meters)
1. Trichur	200
2. Malappuram	500
3. Kozhikode	400
4. Cannanore	500
5. Kasaragod	320

From the users point of view, the parameter QDI introduced is extremely important. Given the value of QDI in a locality, the well users can themselves find out the maximum amount of water he can withdraw, without jeopardising the health or potability of this well water. From the point of view of optimum development of groundwater resources of coastal aquifers, the planners and executing hydrogeologists would be able to effectively plan if the parameters QDI and width of sensitive zone are known apriori.

5. Acknowledgement

The data used here have come out of the research project on "Open Well" in the ground water division of CWRDM. Authors are grateful to all scientific and technical staff involved in the project for collection, generation of data and other field work.

6. References

1. Todd, D.K. 1959 : "Ground Water Hydrology" Wiley International Edition, Toppan Company Ltd., Tokyo, Japan.

2. Basak, P. and Sabu Abraham, 1983 : "Salt water Intrusion in Coastal Aquifers of Malappuram District". Research Report No. GW/R-54/83, CWRDM, Kozhikode-673 571. Kerala, India,

3. Basak, P. and Sabu Abraham, 1983 : "Salt water Intrusion in Coastal Aquifers of Cannanore District", Research Report No. GW/R-70/83, CWRDM, Kozhikode-673 571, Kerala, India.

4. Basak, P., and Vasudev S., 1983 : "Salt water Intrusion in Typical Aquifers of Kerala". Paper presented in the Workshop on Recent Advances in Groundwater Exploration and Management" at NGRI. Hyderabad, 27-29 January, 1983.

5. Basak, P., Nazimuddin. M. and Latha, P. 1985 : "Saltwater Intrusion in Coastal Aquifers of Kasaragod District". Research Report No. GW / R-70 / 83, CWRDM Kozhikode-673 571, Kerala, India.

6. Basak, P., Nazimuddin M. Santhi A, and Sree Vallabhan S. 1987 : "Saltwater Intrusion in Coastal Aquifers of Trichur District", Research Report No. GW/R-193/87, CWRDM, Kozhikode-673 571, Kerala, India.