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Analysis and Control of Saline Water Intrusion into Contai, West Bengal, India

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Abstract

Saline water intrusion into fresh groundwater aquifers takes place in the vicinity of coastal regions having hydraulic continuity with sea. India has significantly long coastal belt and contamination in the aquifers in these regions by saltwater intrusion has been seen. Such intrusion is likely to cause serious consequence if such aquifers are tapped for domestic water supply, irrigation or for any other specific purpose. This paper is based on extensive field study on subsurface and groundwater characterisation in Contai which is a small town near the coast of West Bengal, India. An innovative methodology was developed to control the saline water intrusion into coastal aquifers.

Introduction

In coastal areas like Contai, exploitation of groundwater for various human uses like agricultural, municipal and industrial applications are severely hampered by the encroachment of saline water in response to freshwater withdrawals. Sometimes, this may introduce serious adverse consequences.

The reasons by which freshwater aquifers are contaminated by saline water intrusion are numerous. Some of them are: pumping of freshwater initiating lateral or horizontal intrusion and vertical intrusion with upconing [1], cross-aquifer contamination caused by wells open to multiple aquifers, climate change initiating rise in sea water level, thereby pushing back the fresh water zones, etc.
The variability of hydrogeological settings, sources of saline water, history of groundwater withdrawals and freshwater drainage along different coasts around the world has resulted in different modes of saline water intrusion across the region. The same has been documented throughout the Atlantic coastal USA zone for more than 100 years initiating both lateral intrusion and upconing [2]. Similar adverse effects of saltwater intrusion in coastal area of Greek islands, Japan and Bangladesh have been reported and described by various researchers [3, 4, 5, 6, 7]. The country of India has a significantly long coastal belt of about 5700 km. The east coast (Coromandal) extends from the state of West Bengal to Kanyakumari, Tamil Nadu. The west coast (Malabar and Konkan), on the other hand, stretches from Kanyakumari to the state of Gujarat. It was observed [8, 9, 10, 11, 12] that the intrusion in the east coast is severe in comparison to the west coast except the state of Gujarat and a limited portion of the state of Maharashtra. The intensity of intrusion has been portrayed in Fig. 1.

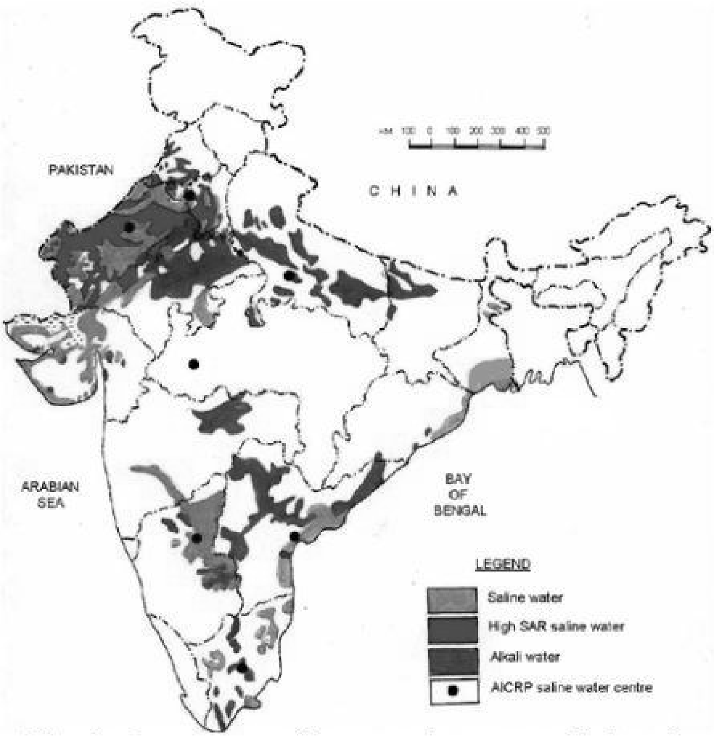


Fig 1: Intensity of groundwater salinity in India.

The work described in this paper is aimed towards conducting a thorough and in-depth field-based study on the extent and intensity of saline water intrusion in Contai which is a small town near the coast of West Bengal, India, by means of subsurface characterisation and water quality analysis and to discuss about the control methodologies.

Study Area - Contai

Contai (also known as *Kanthi*) is headquarters of Contai subdivision in Purba Medinipur district, West Bengal, India. Kanthi means "Sand bound reefs" or sand walls. The latitude and longitude of the town is 21.78°N, 87.75°E. The town has an area of 17.25 km^2 and the population is 79954 with a density of population of 4635/km^2. Contai is about 160 km away from Kolkata, the capital city of West Bengal, 30 km from the coastal resort of Digha and about 6 m above the mean sea level. The town of Contai and its surrounding area comprise seven major administrative subdivisions, namely Contai-I, Contai-II, Contai-III, Khejuri-I, Khejuri-II, Ramnagar-I and Ramnagar-II. The geographical location of Contai area has been shown in Fig.2.

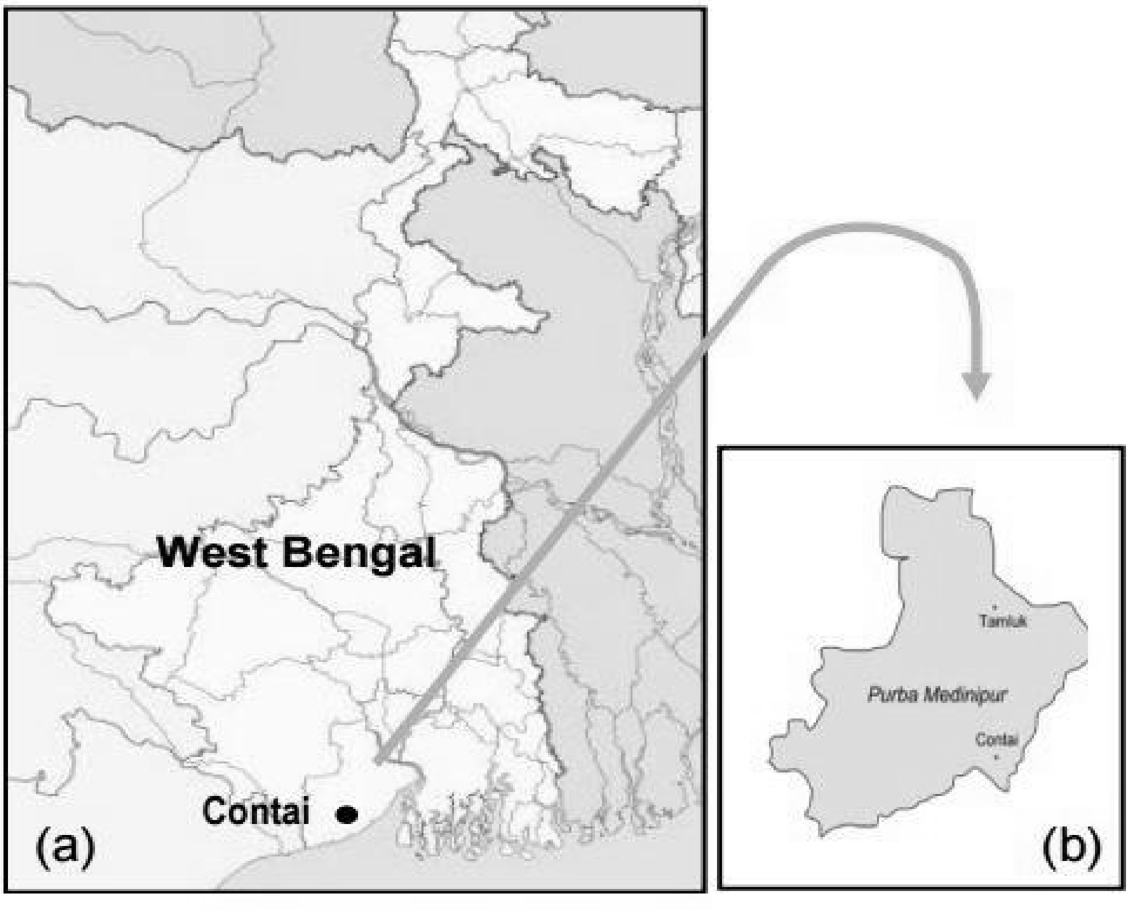


Fig 2: Geographical Location of Contai in the: (a) state of West Bengal
(b) district of Purba Medinipur

Hydrogeological Investigation

The *Purba Medinipur* district is situated in the south-western part of largest delta of the world [13]. This delta was formed by the deposits from innumerable river systems in the past, some originating from large track of Himalayan mountains, some from the old peninsular on the west and the others from Garo hills on the east. The long stretch of the Indo-Gangetic alluvial plains was formed and extended southwards gradually by the river systems of mighty Ganga-Brahmaputra and their tributaries. The sub-surface deposits in the region thus represent typical deltaic characters comprising sands, silts and clays with some sporadic organic concentrations down to great depths. To be precise, this region contains two types of deposits as: (i) normal silty clay deposits formed under back swamp condition, which cover most of the area, and (ii) sandy river belt deposits left by the ancient meandering rivers which occur in stretches . These subsurface characteristics have been depicted in Fig. 3.

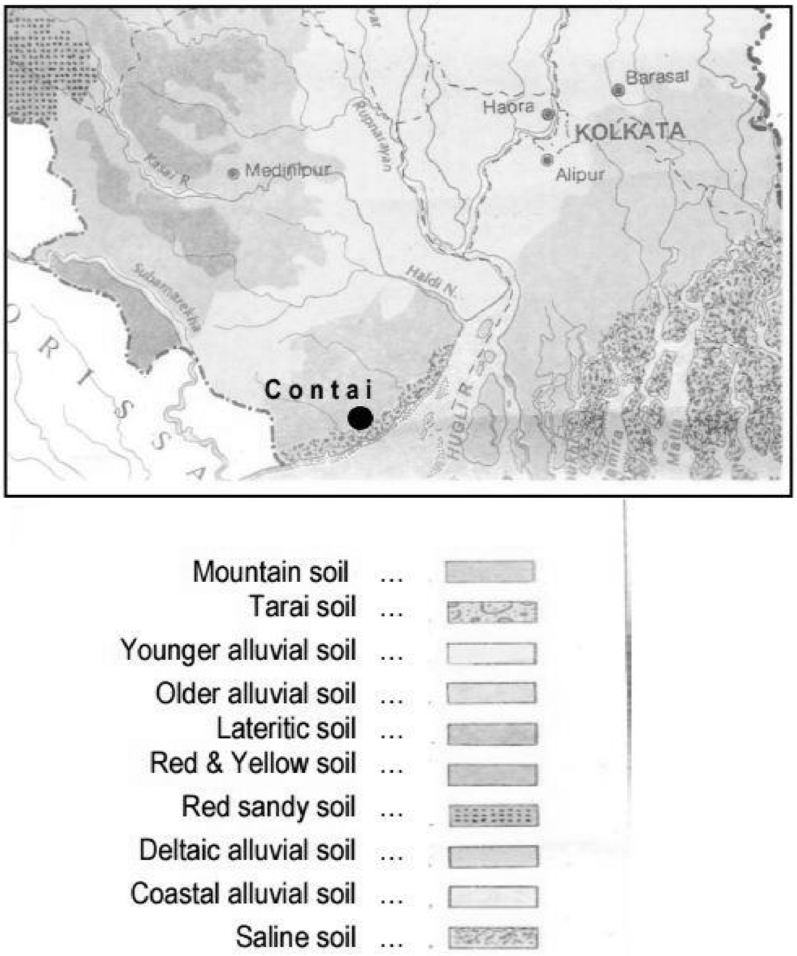
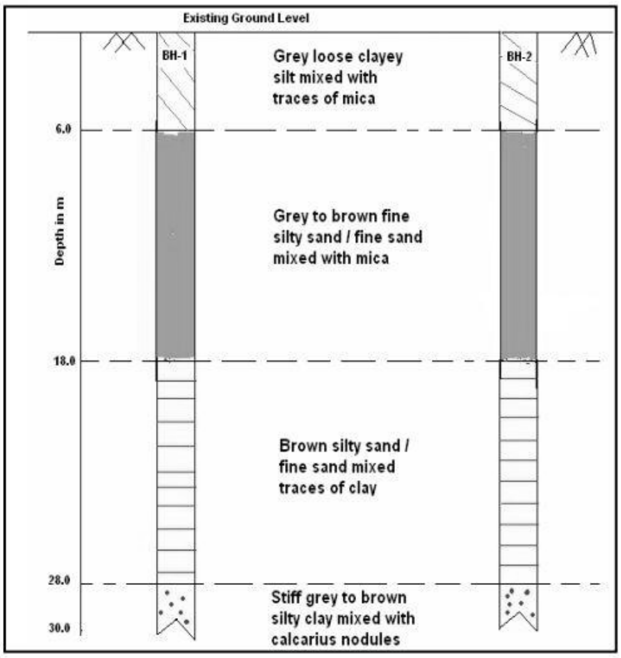


Fig.3. Hydrogeology of Purba Medinipur

In the Contai city, average subsurface characteristics have been investigated by several boreholes (Fig.4).



The subsoil consists of distinct four layers up to a depth of 30 m, denoted herein as zones1, 2, 3 and 4.

Fig.4. Subsoil profile in the study area

The characteristics of each layer have been described in Table 1 below.

Table 1: Subsoil characteristics

Zone	Average Depth (m)	Description	Hydraulic Conductivity (m/day)	Soil Properties
1	0-5	Soft to medium Clayey silt	4.23×10^{-5}	γ = 18.3 kN/m^3; c_u = 30 kPa $\Phi = 0$
2	5-16	Fine silty sand	1.84×10^{-2}	γ = 18.8 kN/m^3; $c_u = 0$ $\Phi = 32^0$
3	16-28	Fine sand with traces of silt and clay	1.94×10^{-2}	γ = 19.1 kN/m^3; $c_u = 0$ $\Phi = 34^0$

4	> 28	Sandy silty clay	$4.12x10^{-5}$	γ = 18 kN/m^3; c_u = 100 kPa $\Phi = 0$

Water Quality Assessment

At twenty selected locations in the Contai Municipality town area (see Fig. 5), water samples have been collected from shallow wells (average depth 2-3 m) with the assistance of State Water Investigation Directorate, Government of West Bengal, India, the following chemical tests have been performed: pH, turbidity, hardness, chloride, nitrate and iron contents, total dissolved solids and electrical conductivity. The relevant chemical analysis data (see Table 2) are utilised to draw the contours, as presented in Fig.6.

As observed, the chloride concentration varies from as high as 1100 ppm at Darua to as low as 20 ppm at Kanal-Parh and Digha Bypass. The variations of the chloride concentration in the aquifer at the depth taken were found to be quite irregular pattern. At some locations, the chloride concentration is quite high such as at Monoharchak (1000 ppm) and Mechada bypass (900 ppm). Conversely, at few locations, the chloride concentration is significantly low like Hatabari (20 ppm), Athelaguri (50 ppm) and Kumarpur (60 ppm). Within the Contai Municipality area, wide variation in salinity concentration has been observed which can be, at least partially, attributed to the high degree of spatial heterogeneity of the aquifer underlying the area.

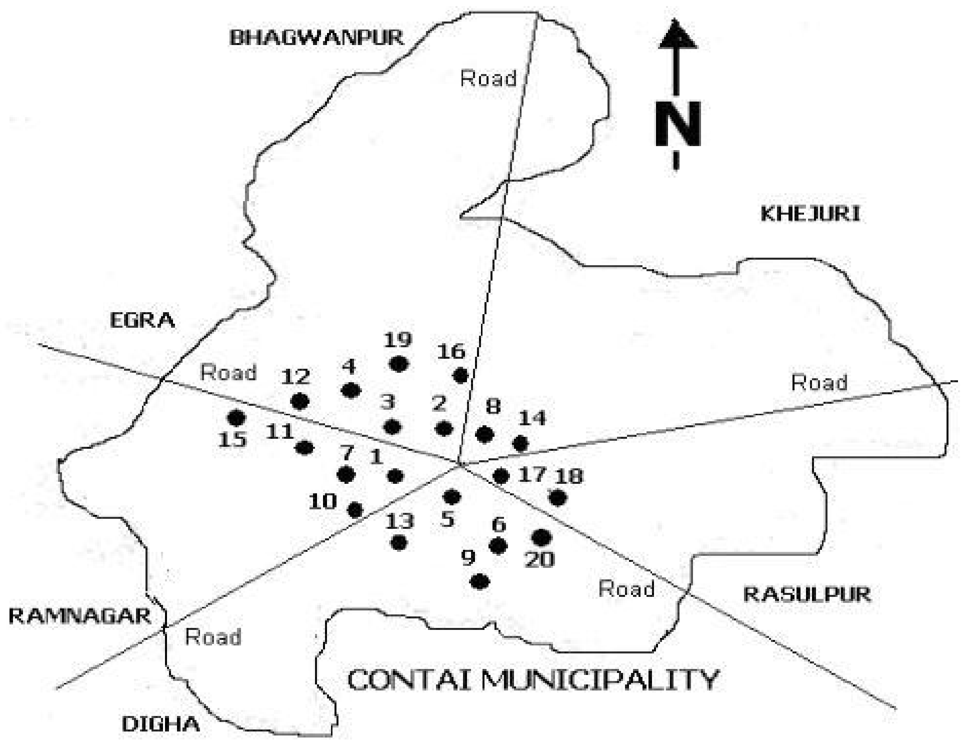


Fig 3: The Contai Municipality area with location of wells for collections of water samples

Table 2: Chemical analysis data

Well No.	Location of Tube well	pH	Turbidity Mg/L	Total Hardness Mg/L	Chloride Mg/L	Nitrate Mg/L	Iron Mg/L	TDS Mg/L	Electrical Conductivity
01.	Contai-Housing Complex.	6.73	0.48	216	159.00	-	0.04	1210	2440
02.	Contai-Central-Bus Stand	6.56	2.5	232	84.80	-	0.27	1100	2220
03.	Contai Police Station	6.85	0.71	340	254.40	-	0.18	1920	3830
04.	Athilagori near Kali Mandir	7.21	0.98	90	300.50	<0.90	0.34	910	890
05.	Krishnakanta Pukurpar	6.98	2.67	310	231.00	<0.90	0.42	750	1170
06.	Contai PHE Office	7.54	3.87	350	240.50	<0.90	1.47	710	1200
07.	Contai SDO Office	7.32	3.00	300	222.00	30.10	0.57	659	1300
08.	Canalpar (near Bhabatarini Mandir)	7.61	4.87	320	220.50	33.10	0.27	650	1400
09.	Contai SD Hospital	6.98	0.76	320	220.50	33.10	0.27	610	1890
10	Digha Bypass	8.21	0.87	980	1141.00	1.00	1.24	2130	1908
11	Contai PK College	6.81	5.00	110	35.00	16.70	0.03	201	1400
12	Kshetra Mohan High School	6.45	5.01	420	326.50	<0.90	0.89	910	1600
13	Contai High School	6.94	4.01	230	130.00	44.10	0.06	330	1700
14	Karkuli-near-Dr. G.K. Ghosh	7.01	3.78	330	691.00	<0.90	1.58	1800	1800
15	Kharagpur Bypass	7.30	3.67	570	339.00	<0.90	0.82	930	1980
16	Mechada Bypass	7.21	3.87	210	174.00	<0.90	0.48	630	2100
17	Susanta	8.43	3.89	160	212.00	39.60	0.18	630	2300

	Sarani Near Kali Mandir								
18	Padmapukuria Near Dr Bidhan Roy	6.86	4.89	170	57.50	<0.90	0.30	150	2400
19	Kishore-Nagar-High School	7.83	4.86	180	100.00	<0.90	0.56	210	2010
20	Municipality Dormitory	7.32	3.87	100	38.00	7.20	0.85	129	1890

Control Methodology

Coastal groundwater management aiming towards control of saltwater intrusion are carried out with the objective of limiting the fresh water withdrawal whereby preventing further encroachment of saline water into the freshwater zone. The conventional methods widely used around the world [14, 15, 16] include the following: (i) Creation of hydraulic barriers, (ii) Canal irrigation, (iii) Desalination and reverse osmosis, (iv) Rainwater harvesting and (v) Artificial recharge methods.

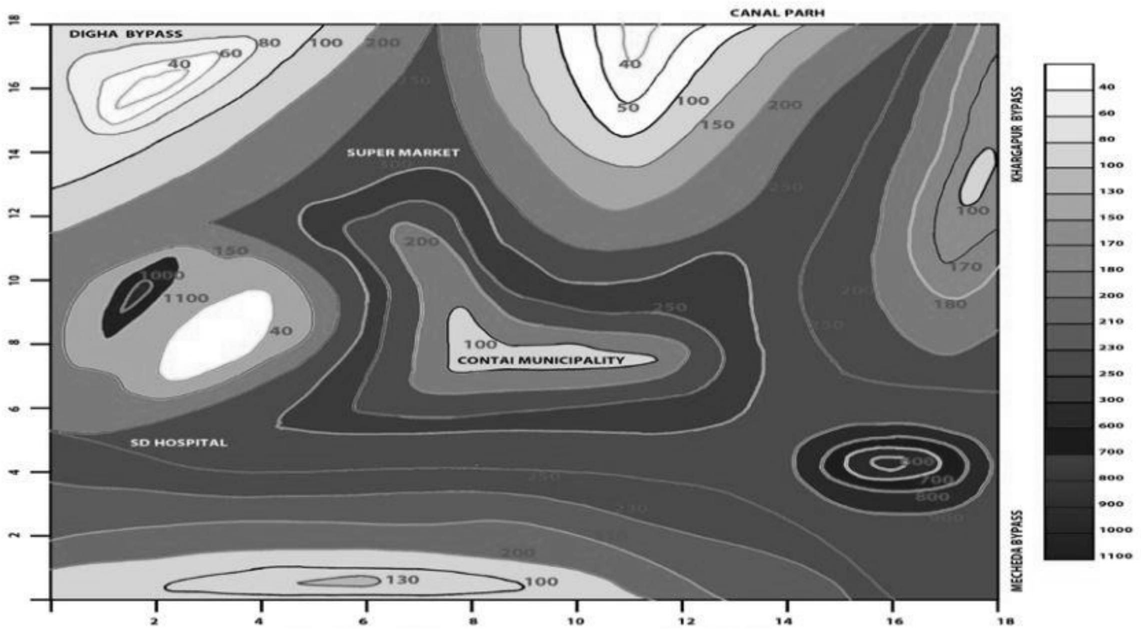


Fig 6: Chloride contours in the study area

The hydraulic barriers are created by keeping the basin water level high, initiating a fresh water ridge near the sea, creating a pumping trough or extraction barrier trough or development of a semi pervious barrier.

Canal irrigation is one of the principal methods used for improving the growth of the crop. Adopting this irrigation technique not only can eliminate the use of deep tube wells for irrigation, but also the seepage of fresh water into the ground push back the saline water while controlling the upcoming.

Owing to its cost, desalination is considered only when all the other methods have been ruled out for various reasons. There are several methods of desalination such as distillation, vapour compression, solar distillation, freezing and reverse osmosis.

Rainwater harvesting and conservation involve direct collection of rain water. The rain water so collected can be stored in the surface or subsurface for future usage with the aim to minimise the loss due to surface runoff through drains and drainage channels to the nearby rivers and/or sea.

Artificial groundwater recharge is a process by which the groundwater reservoir is augmented at a rate exceeding those under natural conditions of replenishment. The various methods of artificial recharge include spreading, recharge shafts, injection wells, induced recharge, etc. The choice of a particular method is governed by local topography, hydrogeology and availability of freshwater for recharge. The lead author has developed a cost-effective and convenient methodology for coastal groundwater management. While the details of the model have been published elsewhere [17], the salient features are described here. The methodology is suitable specifically for coastal regions having significant annual precipitation, good hydraulic conductivity of the aquifer, low depth of fresh groundwater and not very urbanised area. The technique (see Fig.7) involves: (i) withdrawal of freshwater by qanat-well structure since shallow wells are unsuitable because of their low yield and adoption of deep tube wells initiates the problem of upconing, and (ii) groundwater replenishment by rainwater through recharge ponds and recharge wells.

For optimum usage of this innovative technique, adequate balance should be maintained between the withdrawal of freshwater and the recharge by precipitation and drainage of used water. This demands a value of factor of safety slightly above unity. The factor of safety is defined as the ratio of water available for recharge to that of withdrawal in a specified period.

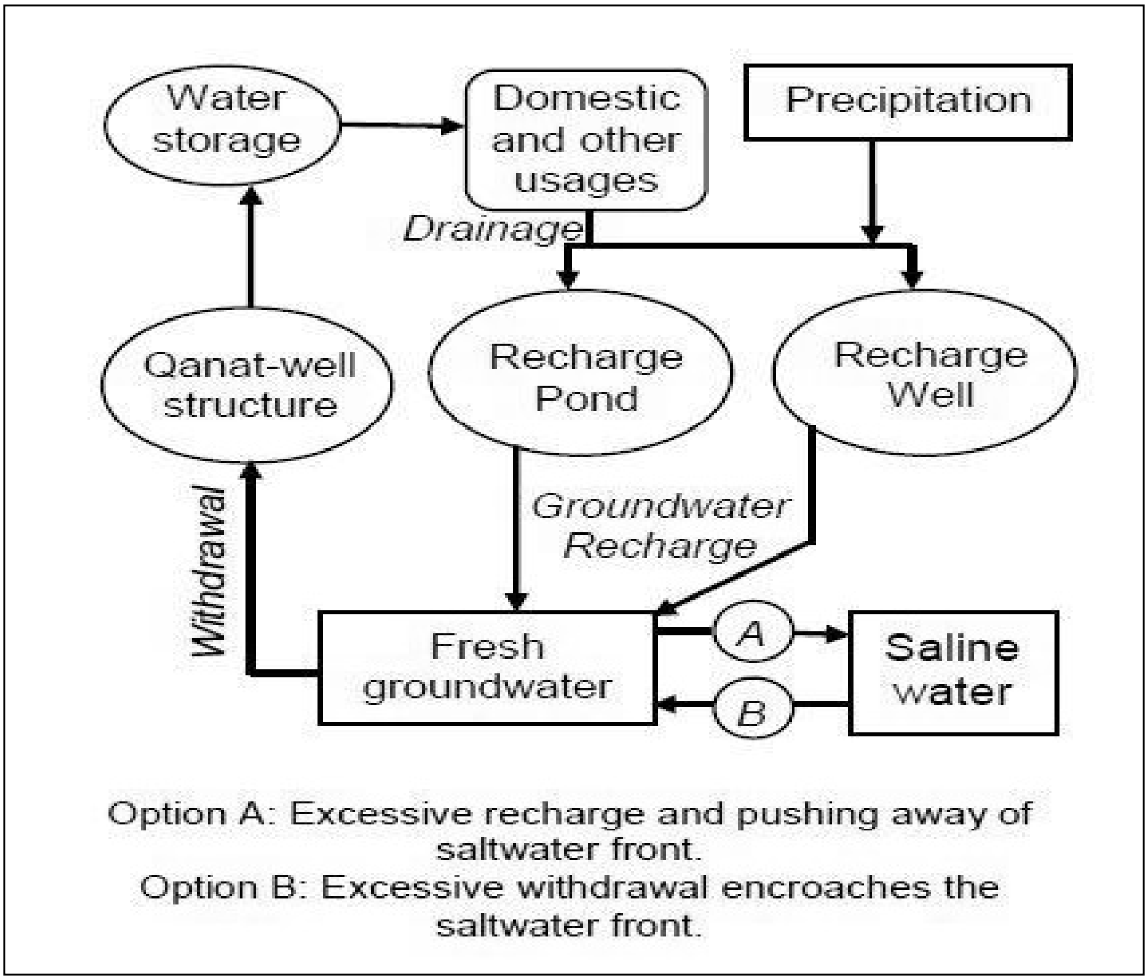


Fig 7: The control methodology developed

Conclusion

To mitigate the problem of saline water intrusion in places like Contai, it is important to analyse and control the saline water intrusion into the underlying aquifers. Contai has been chosen as the study area and relevant hydrogeological investigations and groundwater assessments have been made. The observed wide variation in saline concentration revealed high degree of spatial heterogeneity of the aquifers. Although different techniques are available, a convenient methodology for coastal groundwater management has been developed by the lead author which involves freshwater withdrawal by qanat-well structure and subsequent rainwater recharge.

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