Research Article

Remedial measures for saline water ingression in coastal aquifers of South West Bengal in India

Abstract

Purba Midnapur, a coastal district of West Bengal in India, is under a serious threat concerning the deterioration of groundwater due to seawater encroachment. The upper soil horizon of Purba Midnapur consists of alternating deposits of clay and sand of marine origin. As with all marine deposits, rounded grains and high porosity are dominant characteristics. The coastal line upto 40 km wide tract is being contaminated due to the movement of saline water into aquifers of fresh water. Thus groundwater has become unfit for domestic uses and irrigation purpose. Due to extraction of groundwater, the water table is distorted like a cone of depression resulting in the associated risk like defunct well and making the abstraction uneconomical due to increased lift. Therefore immediate measures are required to control saline water ingression into the coastal aquifers. This paper suggests some measures for controlling saline water ingression in the area concern.

Keywords: coastal structures, controlling methods, saline water ingression, artificial recharge structures, rainwater harvesting technology, aquifer improvement plan

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Introduction

Various researchers have reported and described the adverse effects of saltwater ingression in coastal zones of different parts of world like Italy, Japan, Greek islands, Oman, Nigeria, Atlanta Coast USA, Turkey, Netherlands, Catalonia and Sardinia and various coastal areas of India.[1–35] India has long coastal line of 5700 km. The east coast (Coromandel Coast) extended from West Bengal to Kanyakumari, Tamil Nadu. The western coast (Konkan Coast) extended from Kanyakumari to Gujarat. Except Gujarat and little part of Maharashtra the ingression of saline water is severe in the eastern coast in comparison to west coast. Field-based studies have been conducted by various researchers.[1-16,18-20,23-27,30-32,34] The nature and position of interface and delineation of fresh groundwater and saline groundwater bodies at the aquifer of Digha beach at Purba Midnapur was studied. The depth of interface was found lesser than the interface calculated as per Ghyben-Herzberg principle.[16] Coastal aquifers of the Lagos metropolis, Nigeria were selected for an assessment of its groundwater quality and impact of saline water intrusion.[31] The coastal aquifers adjacent Lagos lagoon, Nigeria has experienced salt water intrusion, the geophysical and geochemical mapping techniques has been conducted. From this study, it was deduced that excessive groundwater extraction and possibly the reduction of groundwater gradients which allows saline-water to displace fresh water in the aquifer of the investigated area are responsible for the saline water intrusion as observed.[1] The change in behaviour of farmers as well as the development of appropriate management strategies, an empirical survey with stakeholders and physically based modelling of the groundwater-agriculture hydro-system interactions is taken into considerations. The study is exemplarily investigated for the south Batinah region in the Sultanate of Oman, which is affected by saltwater intrusion into a coastal aquifer system due to excessive groundwater withdrawal for irrigated agriculture.[20] The hydro-geological basis of seawater intrusion and describe specific cases in Catalonia and Sardinia, as examples of environmental problems and water management actions are reviewed. The origin of salinization and the hydro-geological details of each case, as well as the solutions were implemented to prevent groundwater salinization.[24]

The negative effects of using salt water on agricultural crops and seawater intrusion occurred because of excessive abstraction of water from the bore-holes located in the coastal plains of Hersek, Taşköprü and Altınova in Yalova region, Turkey. The depth of shallow wells ranged from 5 m to 20 m in depth and deep wells ranged between 16 m and 243 m have been studied. Seawater intrusion was found within a 1 km radius of the coastal line of the research area.[9] A viable solution for the prevention of saline water ingression into the inland fresh water aquifer is skimming well with horizontal collector system.[34] A model developed, was based on the studies of saline water ingression on aquifers of south Chennai, India.[23] A few predictions were made upto the year of 2010. As suggested, reasonable management strategies such as modernising the existing tanks, construction of a semi-pervious barrier and optimisation of pumping quantities would be of helpful in reducing the seawater ingression in the area. In the last century, many events such as land subsidence; land reclamation; and drainage; urban and industrial development; and gas and deep groundwater extraction; coastal dune destruction led to the intrusion of the large volume of brackish and saline groundwater in the Ravenna coastal area, Italy. This study is aimed at understanding how past and present human activities have affected the saltwater intrusion process in the phreatic aquifer and how the predicted future sea level rise will affect the salinization process. A numerical model was used here to quantify these effects on the density-dependent groundwater flow, hydraulic head and salinity distribution, seepage and salt load fluxes to surface water system. The simulation showed that over the last century artificial subsidence and heavy drainage started the salinization process in the study area and a relative sea level rise will accelerate the increase in salt load in the coming decades, affecting the entire aquifer.[18] In the last decades coastal dunes which protects coastline, have been removed or damaged by human activities in the Northern Adriatic Coast, Ravenna Area in Italy. The Restoration and subsequent management of coastal dunes alongside the Ravenna coast were initiated with the aims to identify dynamics, erosion and vulnerability of Northern Adriatic coast and associated residual dunes, and to define intervention strategies for dune protection and restoration. The methodology was based on a multidisciplinary approach that integrates the expertise of several researchers and investigates all aspects (biotic and abiotic), which drive the dune-beach system. All datasets were integrated to identify test sites for applying dune restoration.[19] Different management scenarios were proposed to prevent further ingress of saline water front in industrial part of Herakleio city in Greek islands.[32] Artificial recharge using fresh water was proposed as part of the solution. Purba Midnapur is situated in south-eastern part of West Bengal. The coastal district ofPurba Midnapur is adjacent to Bay of Bengal. The coastal lines of this district are approximately 150 km long and mean width is around 8 to 20 km towards inland. Irrigation, fish, agriculture and industrial trading are the chief source of earning of the common people of this district. Three rivers, Haldi and Rupnarayan to the north and Rasulpur to the south, allow for saline water ingress. Saline water also ingresses the aquifer through the highly porous coastal deposits near Contai and Digha area of Pruba Midnapur. The problem is intensive and urgent measures are essential to control and minimise the problems associated with groundwater extraction followed by saline water ingression. The main goal of this paper is some of the methods adopted here like creation of hydraulic barrier, harvesting of rainwater, artificial recharge and aquifers improvement plans have been discussed.

Causes of saline water intrusion

The reasons, for which fresh water aquifers are contaminated by saline water intrusion, are listed below:

1. Pumping of fresh water increases the saline water intrusion.
2. Untimely water use, unplanned shrimp culture, insufficient management systems, inadequate or poorly maintained infrastructure and weak water governance systems at local.
3. Lateral or horizontal intrusion occurs when excessive water withdrawals from a coastal aquifer cause saline water from the coast to move towards the inland.
4. Vertical movement or upcoming of saline water can occur near a discharge well when water moves toward the well tip and saline water in the deeper aquifers rises up.
5. Cross-aquifer contamination can be caused by wells that are open to multiple aquifers or have casings that have been corroded or broken.

Factors affecting saline water intrusion

The following factors which affect saline water intrusion are listed below:

1. Type of aquifer and its geometry and geology.
2. Irrigation and agricultural practices.
3. Rainfall intensities and frequencies.
4. Total rate of groundwater withdrawals compared to recharge rates.
5. Presence of freshwater drainage canals that lack salinity control structures.
6. Distance of stresses, such as wells and drainage canals, from the source(s) of saline water intrusion.
7. Length of time for lowering of the aquifer levels.
8. Long-term changes in sea level initiated by the tidal fluctuations.
9. Seasonal and annual variations in groundwater recharge and evapotranspiration rates.
10. Geologic structures and the distribution of hydraulic properties of an aquifer including the presence of confining units which can prevent the saline water intrusion.

Ghyben-Herzberg relation

The relationship in a water table aquifer has been brought out by Ghyben- Herzberg formula. Saline water intrusion takes place in all coastal aquifers. Pumping of fresh water increases the saline water intrusion. This phenomenon is called saline water intrusion. The boundary between saline and fresh water is known as the "interface" (Figure 1). When equilibrium between saline water and fresh water in coastal aquifers is reached, the depth of the interface below Mean Sea Level is given by the Ghyben-Herzberg (1888) under the following assumptions:

The aquifer is homogeneous and unconfined.

Saline water- fresh water is separated by sharp interface.

There is no direct flow of fresh groundwater to the sea.

There is no mixing zone between the saline water and the fresh water.

Pressure of fresh water from water table is equal to pressure intensity of saline water from

Mean Sea Level at the same point of interface.

$$\rho_f g\left(h_s + h_f\right) = \rho_s g h_s \ (1)$$

$$\text{or,} \quad h_s = \frac{\rho_f}{\rho_s - \rho_f} h_f \ (2)$$

$$h_s = 40 h_f \ (3)$$

For, ρ_f=1, ρ_s=1.025 where ρ_s is the density of saline water, ρ_f is the density of fresh water, h_s is the Density of the interface below sea level, h_f is the elevation of the phreatic level above sea level and g is the acceleration due to gravity (Figure 1).

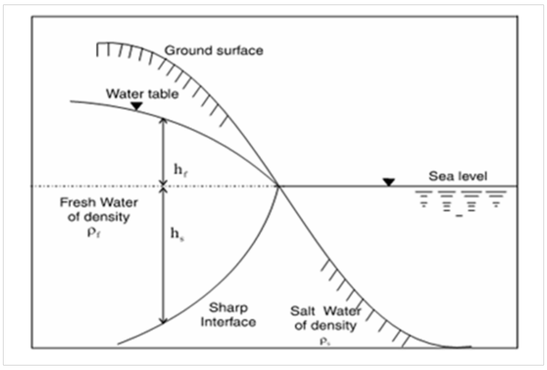

Figure 1 Schematic diagram of saline water and fresh water equilibrium in coastal aquifer with sharp interface between fresh water and saline water and no fresh water discharge directly into the sea.

Objectives

The objectives of this paper are enumerated below:

1. To study the sub-surface stratification, aquifer system and saline water intrusion in the study area, i.e., Purba Midnapur, West Bengal, India.

2. To develop Aquifer improvement plan, in turn, will help in recharging the aquifer, overcoming the threat of saline water ingression and improving the quality of groundwater.

Study area

The Purba Midnapur district (Figure 2) in West Bengal is located to the southwest of Calcutta and shares the western border of the state of Orissa. The district comprises 6724 km2 area and bordered by Paschim Midnapur and Bankura districts of West Bengal in the North, Hooghly, Howrah and 24-Paragnas districts of West Bengal in the East, Bay of Bengal in the South and Mayurbhanj and Balasore district of Orissa in the Southwest. The district lies roughly between 21031′ to 23000′ N and 86045′ to 88000′ E. The district is very much populous, population being 5,095,875 persons enumerated in 2011 census. The district is subdivided into five subdivisions namely Haldia, Contai, Tamluk, Egra, Panskura. Several major and minor rivers traverse the district. River Kasai traverses through the Panskura town and the industrial town of Haldia. Kasai River after its confluence with Kalaghai River is known as Haldi River and it ultimately joins the river Hooghly. Rupnarayana River flows in Eastern border of the district and joins Bay of Bengal. The groundwater basins of the district mostly to the Ganga basin except for are covering the Subarnarehka River which forms the separate basin. The Purba Midnapur has been formed in the last few thousands of years by the continuous supply of sediments loaded from huge catchments which is deposited into a subsiding basin, partly fluvial and partly marine, under varying energy conditions. The study area is divided into six zones on basis of depth of the aquifers, status of piezometric surface and predominant soil type as shown in Figure 2 & 11.

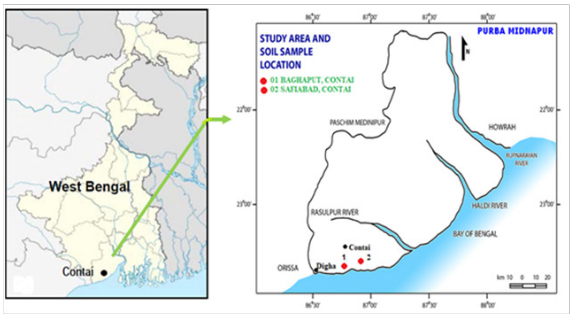

Figure 2 Soil sampling locations at Baghaput and Sofiabad.

Subsoil profile log at Baghaput and Sofiabad areas in Purba Midnapur

In the Purba Midnapur coastal area, average subsurface characteristics have been investigated by analysing the data collected from several bore holes (B.H.) (Figure 2) of Baghaput and Sofiabad areas in Contain. The subsoil consists of distinct four layers upto 30 m depth, denoted herein as zones I, II, III and IV. The characteristics of all subsoil layers have been described in Tables 1 & 2 and Figure 3 & 4.

Table 1 Subsoil characteristics of Baghaput

Zone	Average Depth (m)	Description of Stratum	Hydraulic Conductivity (m/Day)	Soil Properties		
				γ (kN/m^3)	Cu (kPa)	Φ (°)
I	0 - 0.8	Very loose yellowish grey silty fine sand	4.13 ×102	18	30	28
II	8.0 - 2.8	Soft to medium light silty clay with sand	4.12 × 10-2	18.3	0	0
III	2.8 - 13.0	Medium whitish grey silty fine sand	4.12 × 10-1	18.8	0	32
IV	13.0 - 30.6	Stiff to very stiff light yellowish to bluish grey sandy silty clay	4.14 ×10-2	18.9	100	0

Note: γ is the bulk density of soil; Cu is the unconfined compressive strength of soil and Φ is the angle of internal friction of soil.

Table 2 Subsoil Characteristics of Sofiabad

Zone	Average Depth (m)	Description of Stratum	Hydraulic Conductivity (m/Day)	Soil Properties		
				γ (kN/m3)	Cu (kPa)	Φ(°)
I	0 - 6	Grey loose clayey silt mixed with traces of mica	4.11 ×10-5	19.2	35	0
II	18-Jun	Grey to brown fine silty sand/fine sand mixed with mica	4.31 × 10-1	19.8	0	32
III	18 - 28	Brown silty sand/fine sand mixed traces of clay	1.94 × 10-2	18.1	80	33
IV	>28	Stiff grey to brown silty clay mixed with calcarius nodules	4.12×10-5	19	90	0

Note: γ is the bulk density of soil; *Cu* is the unconfined compressive strength of soil and Φ is the angle of internal friction of soil.

Methods for controlling saline water ingression

Saline water intrusion is controlled by maintaining the appropriate balance between water being extracted and the quantity of water recharging into aquifers. Regular monitoring of saline water interface is essential in calculating the accurate management technique. In many of case colony people who face a saline water intrusion problem, layout new extraction wells advance inshore direction. This merely complicated the problem. The goal of any controlling method should be to prevent further encroachment of saline water and if achievable to lessen the area already intruded by saline water.

Six methods are normally recognized as methods for controlling or preventing saline water ingression. They are categorised by

a. Keeping basin water level high,

b. Creating a fresh water ridge near sea,

c. Creating pumping trough or extraction barrier trough,

d. Developing artificial subsurface barriers,

e. Adopting rainwater harvesting technology and artificial recharging structures and (f) implementing aquifer improvement plans.

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Keeping basin water level high: Although it is manifested that reduction in pumping draft would tend to affect a rise in groundwater levels, additional comment if warranted regarding effects of arrangement of pumping pattern. If the site of major withdrawals is transferred from the coastal segment of a basin to an area further inland, the landward hydraulic gradient inland from the trough would be increased. Such a condition would tend to halt or slow the inflow of saline water. Groundwater levels in the overdrawn aquifers can be raised and maintained above sea level through artificial recharge utilizing surface spreading, injection wells otherwise both.

Pros: Managed groundwater replenishment *area* must be appropriately sized to provide accommodation the *higher* water in the basin, control saline water intrusion or halt the inflow of saline water.

Cons: There will be constant demands of fresh water supply required in order to maintain groundwater high above sea level in the overdrawn aquifers.

Cost: Cost of Percolation Pond INR 200000 to 700000 and Artificial Recharge by Injection well INR 15000 for confined aquifers; Surface spreading [such as stream channels, ditches, and furrows, as well as flooding] INR 300000 for unconfined aquifers.

Application: Saline water intrusion affected coastal zones.

Creating a fresh water ridge near the sea: The method would require the continuous maintenance of a fresh water ridge in the principal water bearing deposits along the coast through the application of water by surface spreading or injection wells otherwise both. Effects of a fresh water ridge or mound on seawater ingression are shown in Figure 5(a) and Figure 5(b) for unconfined aquifer and confined aquifer, respectively. The actual formation of a ridge along the coastal segment of a groundwater basin by use of injection wells otherwise surface water spreading or combination of both would depend on whether free groundwater or pressure condition exists, as determined by geologic and engineering investigations.

Pros: Injection of water through wells can pressurize a confined aquifer continually along a coastal zone, thereby reversing any pre-existing landward gradient and preventing further seawater intrusion.

Cons: Constant supply of water is required; water for injection must be compatible chemically with native waters and must be treated to avoid clogging the aquifer. Chloride dosages of between 5 and 10 ppm are necessary to prevent slime growth and maintain transmissibility. The freshwater to be recharged must be of better quality than the water used in the artificial recharge methods.

Cost: Cost of injection well INR 15000.

Application: At the coastal aquifers where salt water intrusion severe, this method is used both unconfined and confined aquifers. Waters of varying qualities are injected to create salt water intrusion barriers, including untreated surface water, treated drinking water, and mixtures of treated municipal wastewater and ground or surface water (Figure 5).

Creation of pumping trough or extraction barrier trough: Development of an extraction barrier would require retaining a continuous pumping trough near ocean. Pumping trough can be created and developed by means of a row of pumping wells, properly located along the seacoast. The wells would create a mix of fresh and saline water and could result in the waste of substantial quantities of fresh water. Hydrologic conditions with an extraction type of seawater barrier in unconfined aquifer and confined aquifer are depicted in Figure 6(a) and Figure 6(b), respectively.

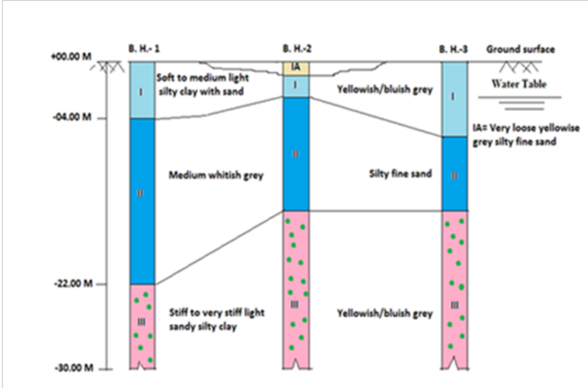

Figure 3 Subsoil profile log of Baghaput.

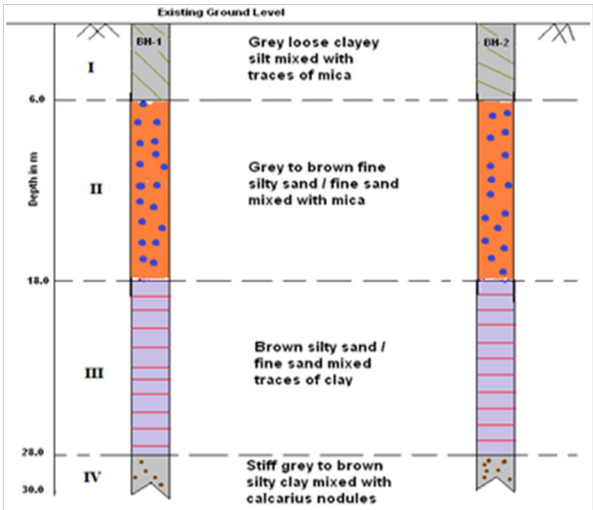

Figure 4 Subsoil profile log of Sofiabad.

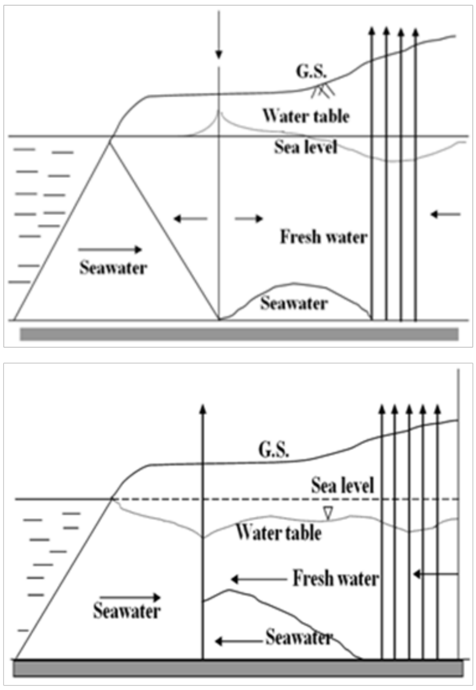

Figure 5 a & b An injection ridge seawater barrier and an extraction type of seawater barrier in unconfined and confined groundwater basins, respectively.

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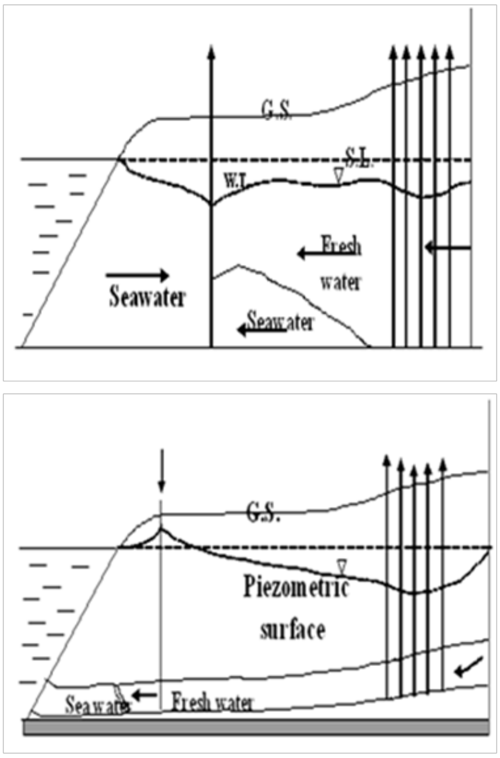

Figure 6 a & b Hydrologic conditions with an extraction type of seawater barrier and an injection ridge seawater barrier in an unconfined and confined groundwater basin respectively.

Pros: The most effective method is trough the natural recharge from the rain, so decrease the impermeabilization of the soil in the coastal zones, combined with the monitoring of the water pump using mathematical models, can be an economic and efficient way to face the salt intrusion. Pumping trough reduces the usable storage capacity of the basin.

Cons: It is costly to install and operation. Amount of freshwater that can be extracted must be reduced. Without reducing the pumping rate, it is impracticable for accomplish equilibrium.

Cost: Cost of Submersible Pumping, 200 mm Casing, 5 HP Pump INR 1778280.

Application: Coastal aquifers have been facing salt water ingression.

Development of artificial subsurface barriers: This method involves the establishment of a subsurface barrier to reduce the permeability of water bearing deposits sufficiently to prevent the seawater inflow into fresh water strata. This reduction in the permeability could be achieved by the construction of a subsurface barrier of sheet pilling or other form of physical structure as depicted in Figure 7. Emulsified asphalt, plastics and other materials might be injected to form a vertical zone of reduced permeability that would retard or prevent seawater ingression into freshwater portions of aquifer.

Pros: Although initial costs are very high, the subsurface barrier method often a potential permanent solution to the seawater intrusion problem in narrow coastal groundwater basins with relatively shallow aquifers, Banks & Richter.[2] Todd[35] and Bruington[3] also noted that the subsurface barrier is a viable solution to the seawater intrusion problem

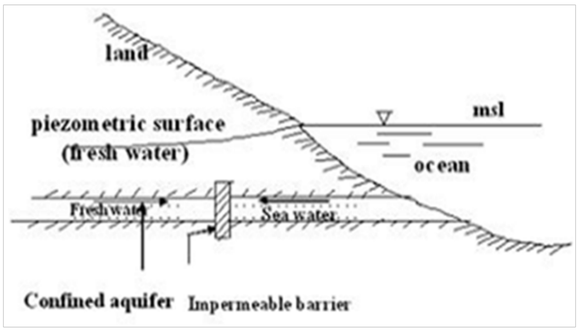

Figure 7 Subsurface barrier.

Cons: This method has limited applicability for very shallow aquifers and is expensive initially. Subsurface barriers present procedural difficulties of a political, social, and economic nature. Resistance to earthquakes and to chemical erosion is major issues confronting implementation of the subsurface barrier method

Cost: The *cost* is highly dependent on the depth of cut-off, length of wall and specific material availability.

Application: It is also known as sealing wall method has been used extensively open mines cast to prevent seepage of saline water or reduce it to an insignificant amount.

Rainwater harvesting technology: Rainwater is the foremost appearance of water into hydrological cycle and a major source of water. Oceans, rivers, lakes, ponds and groundwater are secondary resources of water. The present situation is much more dependent on secondary resources of water. Rain is only resource to feed all these secondary sources. The meaning of rainwater harvesting is to collect rain and runoff in towns and villages while taking suitable measures to not allow the polluting agents to mix with clean water in catchments. Rainwater harvesting provides many purposes. It may provide irrigation water and drinking water; reduce storm water discharge, floods in urban area and overcapacity of sewage handling plants; enhance groundwater recharge; lessen saline water ingression in coastal aquifer, etc.

Urban scenario

The rainwater endowment of a region is the full quantity of water received as rainfall in the area. The potential of rainwater harvesting is that share of water which will be effectively harvested (Figure 8). The potential of rainwater harvesting is described as the product of rainfall in mm and collection efficiency. A theoretical example that emphasizes the vast potential for rainwater harvesting, is given here. Let us assume a roof area of 210 m2, average rainfall of 280 mm and collection efficiency of 85% during monsoon month. Therefore the capacity of water will be harvested during monsoon month is 0.85 m × 0.28 m×210 m i.e. 49.98 m3. Nineteen m3 of water may be utilized during monsoon month for cleaning and toilet use. So 30.98 m3 may be stored for future. Thus, a 70 m3 capacity reservoir (4.5 m × 7.5 m × 2.1 m) may be constructed to hold the two months surplus of water. Evaporation loss can be minimised to this extent. Cost of 70 m3 storage tank is INR 130000 and cost of accessories is INR 25000.

Rural scenario

Rainwater harvesting done by the community in rustic areas of Purba Midnapur - the past concept has enough strength today as it did before. Only based on this technology, the people are able to survive in water scarce area. In early times our ancestors used to harvest water in many ways. First rain drops are harvested directly. Then from rooftops, water is collected and conserved in tanks. From open neighbourhood lands, rainwater is collected and conserved in artificial wells. In monsoon season, runoff water is captured in swollen streams and it is stored in different form of water bodies. Lastly water is harvested from flooded rivers.

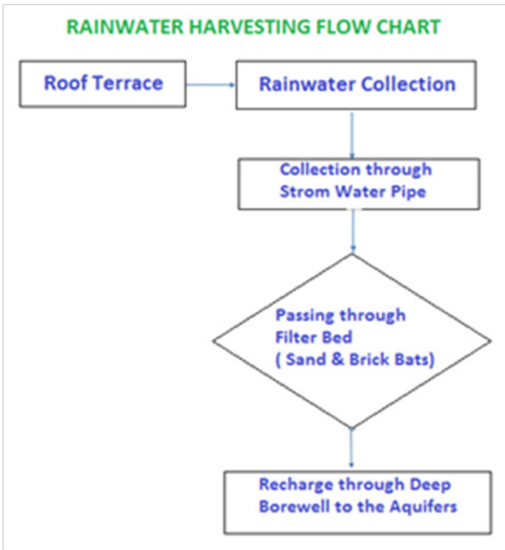

Figure 8 Rainwater Harvesting Flow Chart.

Causes of contamination of rainwater storages and health risk

The main causes of contamination storage of rainwater as follows:

1. Wind-blown dirt, leaves, faecal droppings from birds and animals, insects contaminated harvested rainwater, leading to health risks from the consumption of contaminated water from storage tanks.
2. Storage tanks can present breeding sites for mosquitoes, including species that transmit dengue virus.
3. Poor hygiene in storing water in and abstracting water from tanks or at the point of use can also represent a health concern.
4. Microbial contamination of collected rainwater indicated by E. coli (or, alternatively, thermotolerants coliforms) is quite common. Pathogens such as Cryptosporidium, Giardia, Campylobacter, Vibrio, Salmonella, Shigella and Pseudomonas have also been detected in rainwater.

Increase healthcare in different Ways

However, risks from these hazards can be minimized by good design and practice.

a. Well designed rainwater harvesting systems with clean catchments.

b. A detachable down-pipe can be used manually; storages will require periodic cleaning to remove sediment. Storages without covers or with unprotected openings will encourage mosquito breeding and sunlight reaching the water will promote algal growth.

c. Cracks in the tank and withdrawing of water using contaminated pots can contaminate stored water. Storages should preferably be fitted with a mechanism such as a tap or outlet pipe that enables hygienic abstraction of water. Some households incorporate cartridge filters or other treatments at the point of consumption to ensure better quality of drinking-water and reduce health risk.

d. The first flush of rainwater carries most contaminants into storages. A system is, therefore, necessary to divert the contaminated first flow of rainwater from roof surfaces. Some devices and good practices are available to divert the first foul flush of rainwater.

e. Materials used in the catchment and storage tank should be suitable for use in contact with drinking-water and should be non-toxic to humans

f. Care should also be taken to avoid materials or coatings that may cause adverse taste or odour, and some metals can dissolve to give high concentrations in water. Regular cleaning of catchment surfaces and gutters should be undertaken to minimize the accumulation of debris. Wire meshes or inlet filters should be placed over the top of down-pipes to prevent leaves and other debris from entering storages. These meshes and filters should be cleaned regularly to prevent clogging.

g. The physical quality of rainwater (turbidity, colour and smell), the level of pH should be monitored frequently in case of new concrete or masonry storage tanks. The levels of lead, zinc or other heavy metals in rainwater should also be measured occasionally when it is in contact with metallic surfaces during collection or storage .Microbial quality of rainwater needs to be monitored as part of verification.

h. Pros: Easy to Maintain, Reducing Water Bills, Suitable for Irrigation, Reduces Demand on Ground Water, Reduces Floods and Soil Erosion, Can be used for Several Non-drinking Purposes.

i. Cons: Unpredictable Rainfall, Initial High Cost, Regular Maintenance, Certain Roof Types may Seep Chemicals or Animal Droppings, Storage Limits

j. Cost: Cost of 70 m3 storage tank is INR 130000 and cost of accessories is INR 25000.

k. Application: In the some part of India and Southern part of West Bengal.

Artificial recharging structures: Groundwater recharge is of two types:

a. Natural recharge and

b. Artificial recharge.

When natural recharge is reduced, artificial recharge is needed for application. Artificial recharging methods are adopted to increase fresh water head that is groundwater table, which is slowly declining due to overdraft and thereby *saline water ingression* is prevented. In coastal zones, groundwater drawdown can reverse the natural movement of groundwater towards sea and cause saltwater ingression of inland aquifer. Water quality degradation will be prevented as the artificial recharge endows with valuable hydraulic barrier in the aquifers.

Recharge through a recharge well with pressure filter

This method is suitable for areas with low groundwater tables, when ground profiles involve large depths of impervious strata, making groundwater infiltration difficulty under simple force of

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gravity, at the rate of rainfall. In this method the rainwater is first collected into an underground tank, from where it is lifted up by a pump through a filter and pressured down into a recharge well (Figure 9). The shaft or well is drilled up to the groundwater level or just above the normal tube well withdrawal level, may be made by lowering galvanised iron (GI) tube well type pipe into a bore hole of 0.15 to 0.3 m diameter depending upon porosity of the receiving strata. The pipe to be lowered in the bore must be slotted in the bottom part of shaft to enable permeability in the groundwater table. Also the slots in the upper length may be located to coincide with favourable permeable strata, if any. The details of other types of recharge well are shown in Fig. 10. The settlement tank of size varying from 1.5 to 5 m3 is usually constructed for collecting the rain fed surface runoff. A dual media pressure filter is utilized to filter the collected water and then pump it into the ground.

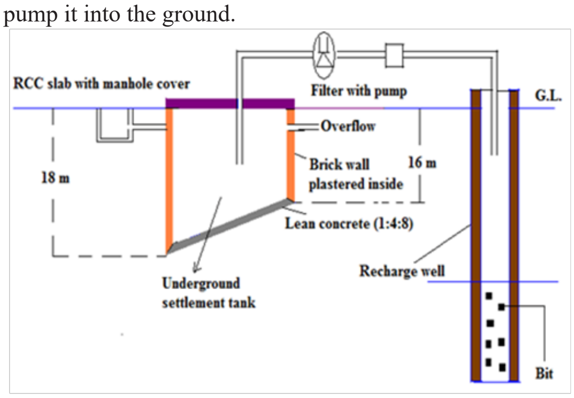

Figure 9 Percolation of runoff water to the underground reservoir by a recharge well with pressure filter.

Pros: Enhance the groundwater yield in depleted the aquifer due to urbanization. Conservation and storage of excess surface water for future requirements. Improve the quality of existing groundwater through dilution. Remove bacteriological and other impurities from sewage and waste water by natural filtration, so that water is suitable for re-use. Control saline water intrusion.

Cons: As for the disadvantages of surface water sources for artificial infiltration, they may be more susceptible to variations in discharge during the year. Another disadvantage is the more prominent chemical, microbiological, biological and physical instability of surface water as opposed to ground water. In this respect, it is important to be more cautious and its parameters during artificial infiltration must be observed. The disadvantages concern the fact that the intake structure and the pumping station may be demanding in the space requirements. Another disadvantage is the relatively high initial and operational costs.

Cost: The cost of Recharge structures: Percolation Pond INR 475102; Injection well, tube well INR 15000

Recharge shaft INR 130210; Dugwell INR 10000.

Application: Artificial recharge structures such as Ditch, Percolation Tank, water spreading, recharge through pits, shafts, wells, Induced Recharge Injection wells etc. have been successfully use to the area of West Bengal where over extraction of groundwater lowering of groundwater levels and intrusion of saline water in coastal areas have been detected (Figure 10).

Aquifer improvement plan

Unplanned and rampant groundwater exploitation has resulted in lowering the water levels and consequently saline water ingression in rural and urban areas in most part of coastal areas of Purba Midnapur. With the increasing population, the water demand in agriculture, industrial and urban sectors has enlarged manifold in the past decade. Groundwater, which is once thought as the steady source of water, is now no more a reliable source due to faster lowering in water table. The outcome of which is well-known as water scarcity. So water conservation and thereby rainwater harvesting provides a solution to the present crisis. Rapid industrialization coupled with indiscriminate tapping of groundwater has led to a steady decline in the groundwater table by 10 m here, threatening to turn the area into a saline-prone zone within a few years if the subsidence of the groundwater level continues. A development plan of the aquifers of Purba Midnapur district has been chalked out (Figure 11) based on depth of the aquifers, status of piezometric surface and predominant soil type. Based on these parameters, the study area has been divided into six zones and the recommendations for groundwater improvement in each of these zones are listed in Table 3

Table 3 Aquifer improvement plan

Zone	Depth of aquifer (m)	Status of interface between saline water and fresh water	Predominant soil type	Development plan
I	90 - 120	The interface of fresh and saline water is near 90 m below ground level (bgl)	Clayey sand from sandy clay	No groundwater abstraction, surface water supply system may be used from river
II	100 - 150	The interface of fresh and saline water is near 87 m bgl	Sand, medium to coarse, white	No groundwater abstraction
III	160 - 183	The fresh and saline water interface is near 138 m bgl. Zone upto 90 m contains high salinity. groundwater while zone upto 138 m contain comparatively less saline water	Very coarse sand	No groundwater abstraction in the saline zone. Deep tube well may be installed outside the saline zone.
IV	161 - 185	The granular zone above 60 m contains inferior quality groundwater	Medium sand, greyish	No groundwater abstraction, withdrawal to be regulated by reducing tube well operation time
V	205 - 252	The groundwater contained upto 123 m bgl is inferior in nature and best portion available for tapping lies in between 216 m - 249 m bgl and hence	Fine to medium sand, greyish	Additional tube wells may be installed for future groundwater abstraction
VI	110 - 170	The interface of fresh and saline water is near 85 m bgl	Clayey sand from sandy clay	Additional tube wells may be installed for future groundwater abstraction

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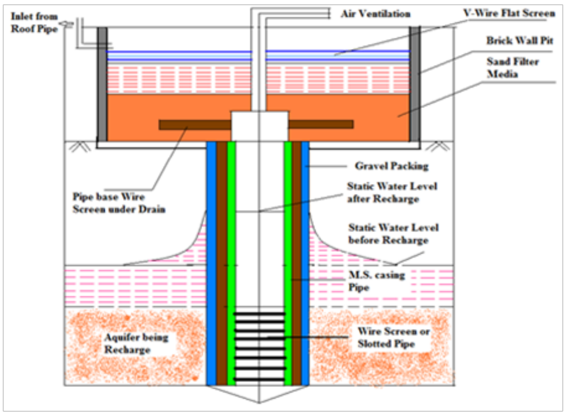

Figure 10 Section of recharge well to be adopted for percolation arrangements.

Pros: Aquifer Improvement Plan of the Purba Midnapur district is divided into six zones and imposing certain restricting of abstracting and use of ground water and as a result water table has risen considerable and saline water interface movement towards inland is prevented further

Cons: Lack of political wills, awareness amongst the farmers, and non- availability of any other source of water supply in some areas have been the main hurdle in implementing Aquifer Improvement Plan.

Cost: Groundwater regulation Act has been maintained properly.

Application: Purba Midnapur, West Bengal, India.

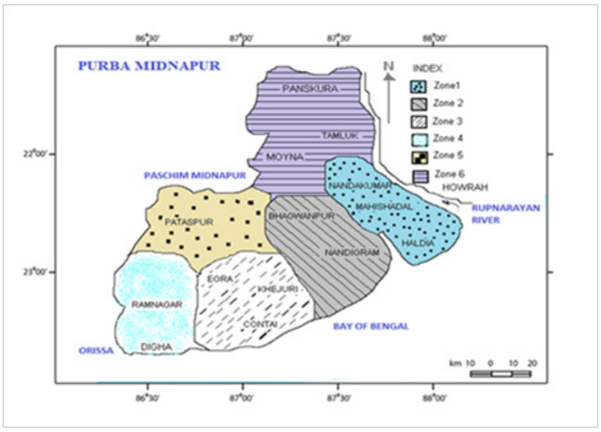

Figure 11 Separated zones of study area for aquifer improvement plan.

Discussion interpretation

The coastal district of Purba Midnapur in the state of West Bengal is affected by salinity and hence has been studied in details. Arsenic is absent in the coastal tracts. Saline water intrusion in the coastal aquifers is intense and causing problems, particularly as these areas are very fertile and there is intensive cultivation in winter as well. Saline water ingression into fresh water aquifer occurs in Purba Midnapur district. For deterrence and control of saline water ingression, the following measures are to be employed: Artificial recharge to create a freshwater ridge by injection wells or water spreading are implemented over the whole coastal basin. Improvement of pumping trough in the region between exploitation areas of coastal blocks. Artificial recharge of fresh groundwater into the coastline tracts of Purba Midnapur district using injection wells is an expensive but technically sound method of recharging the freshwater in coastal aquifer. A less costly method is to provide for sinking pits of a fairly large (about 1 to 2 m) diameter by digging such a pit down to a suitable depth and filling it with coarse gravel and sand of high hydraulic conductivity so that in the monsoon season, rainwater may infiltrate into aquifer and saline water is driven back. This method is eminently suitable for rural areas. In urban areas, of course, rooftop rainwater harvesting is the best option. Aquifer development plan, in turn, will help in recharging the aquifer, overcoming the threat of saline water ingression and improving the quality of groundwater. The study also reveals that only in restricted regions of Purba Midnapur, groundwater may be safely withdrawn. Therefore, to ensure steady water supply for the growing population in a sustainable manner, the regional water supply authority should look for alternative resources. They are periodical increase in capacity of the surface water (Rupnarayan and Haldi River) supply system; aquifer artificial recharge; rainwater harvesting, improvement in operation and safeguarding of the water supply system and reduction in wastage of water through leakage and illegal tapping, desalination plant and underground water storage reservoirs are the permanent and unique solutions for the concerned coastal area.

Conclusion

In the coastal area of Purba Midnapur, the southern part of West Bengal, India is severely hampered by the encroachment of saline water intrusion into the fresh water aquifers due to over-exploitation of groundwater for several human uses like agricultural, municipal and industrial application. In the summer season, heavy drawdown of water table is observed which results in acute scarcity of fresh groundwater in the regions surrounded by Rupnarayan River, Rasulpur River and Haldi River, as a result the interface of saline water progressively moves towards inland direction. An Improvement plan of the aquifers of Purba Midnapur district has been chalked out and divided into six zones, in turn, will help in recharging the aquifer, overcoming the threat of saline water ingression and improving the quality of groundwater. This plan is productive when restriction of withdrawals from coastal aquifers and groundwater regulation act has been maintained. Other plan of solution to meet future fresh water demand in the area, using alternative freshwater sources has also been encouraged, by constructing small height dam across the existing small rivers/canals of Purba Midnapur and in the monsoon season accumulated rainwater are collected and distribution to the various purpose after proper treatment.

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Conflicts of interest

None.

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