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Contents

Review on Bacteria Based Cementitious Matrix for Sustainable Building Construction 1
Krishna Kumar Maurya, Anupam Rawat, and Rama Shanker

Physical and Mechanical Properties of Concrete Made with Glass Sand 19
Filipe Figueiredo, Rayssa Renovato Reis, and Lino Maia

Utilization of Waste Granite Powder in Cementitious Composites: Perspectives and Challenges in Poland 33
Slawomir Czarnecki and Lukasz Sadowski

Comparative Study on Fly Ash Based AAM Concrete with GGBS, Rice Husk Ash and Sugarcane Bagasse Ash 43
V. Poornima, K. Vasanth Kumar, and P. P. Hridhi Nandu

Self-consolidating Concrete Produced with Fine CDW 63
Stéphanie Rocha, Joice Soares, Thâwanne Costa, and Lino Maia

Fine Aggregates of CDW: Feasibility of Its Application in the Manufacture of Mortars for Laying 75
Nara Cangussu, Emanuel Silva, Rogério Borges, and Lino Maia

Evaluation of Barrier for Promoting Green Building Technologies in Coimbatore as Smart City 87
S. Hema, K. Poongodi, and P. Murthi

Cement After Expiry Date: Effect in the Concrete Properties 97
Stéphanie Rocha, Cássio Gonçalves, and Lino Maia

Problems and Prospects of Heritage Based City Development in India 105
Shipra Goswami and Ashwani Kumar

An Overview of Technique Used in Traffic Monitoring System 121
Parveen Berwal, Gopesh Kaushik, Kunal Chandra, Kirti Upadhaya, Deepak Gupta, and Rajesh Goyal

An Overview of Highway Failure and Its Maintenance on Old NH-2 133
Parveen Berwal, Maneesh Pal, Ishtiaque Ali, Shilpa Singla, and Rajesh Goyal

Effects of Soil Type on Contaminant Transport in the Aquifer System: A Numerical Investigation Using 2D Mobile-Immobile Model 143
Abhay Guleria and Sumedha Chakma

A Novel Plan for Gujarat to Mitigate the Effect of Flood, Drought and Salinity Using Interlinking of Canal and Rivers 155
Anant Patel, Upasana Panchal, and Neha Keriwala

Ground Water Potential Zone Mapping Using Remote Sensing and GIS in Saurashtra Region of Gujarat, India 169
Anant Patel, Kinjal Zala, and Krupali Solanki

Analysis of Spatial and Temporal Variability of Rainfall Using GIS in Rasipuram Taluk, Tamil Nadu, India 185
P. Mageshkumar, K. Angu Senthil, N. Sudharsan, K. Poongodi, and P. Murthi

Land Degradation in the Western Ghats: The Case of the Kavalappara Landslide in Kerala, India 199
Nirmala Vasudevan, Kaushik Ramanathan, and T. S. Syali

Study of Sustainability Aspects of Chambal River Linking System Using Reservoir Simulation Techniques 209
Rajesh Kumar Jain, Rajesh Goyal, and Dulal Goldar

Assessment of Environmental Flow Requirements Through Rainfall-Runoff Modelling for Hydropower Project 231
C. Prakasam, R. Saravanan, and M. K. Sharma

Assessment and Suitability Analysis of Water Quality of River Ganga in Patna, Bihar 251
Reena Singh and Saurabh Kumar

Filling the Health Gap in Energy Performance Certificates to Reduce Pulmonary Diseases Due to Bad Indoor Air Quality 259
Alexandre Soares dos Reis, Marta Ferreira Dias, and Alice Tavares

Impact of Covid-19 Pandemic Lockdown on the Managerial Aspects of Brick Manufacturing Unit—A Case Study on Post and Present Scenario 277
P. Murthi and K. Poongodi

The Impact of the COVID19 Pandemic on Shopping Trips Behavior in Urban Areas 289
Abeer K. Jameel, Wafaa Kh. Luaibi, and Iman Alghalibi

Author Index 303

A Novel Plan for Gujarat to Mitigate the Effect of Flood, Drought and Salinity Using Interlinking of Canal and Rivers

Anant Patel, Upasana Panchal, and Neha Keriwala

Abstract The rivers play a very important role within the lives of the people, because the Rivers are very much helpful in water supply, irrigation, water transportation, generation of electricity, and tourism. Most of the major cities are situated on the shores of holy rivers or near the coastal area. Depleting the status of water resources could also be one among the foremost critical resource problems with the twenty-first century. The country's rivers must be interconnected to provide water to the drought-prone areas. The method is designed to preserve river water that flows into the ocean every year during the monsoon season. The study focuses on interlinking key rivers in Gujarat to meet the requirements of regions with severe water shortage such as North Gujarat, Saurashtra, and Kutch. This article proposes a sustainable resilient strategy for river water interlinking, which helps manage surface water storage and salty water intrusion into coastal groundwater. The planned unlined canal is intended for low silting and scouring. The canal's bottom width is 152 m and its depth is 5.4 m. This canal will act as a multifunctional strategy to solve different water problems while also affecting the environment.

Keywords River interlinking · Saline water intrusion · Canal network · Drought & Flood · Water resources management

1 Introduction

Water is the most important asset on the earth for the survival of life. The importance of the water increases because of population growth in water scarce regions. In spite of the fact that freshwater is the most far reaching thing to be found in the environment, it isn't consistently disseminated all around the world [1]. Water requirement is crucial for daily life activities such as: cooking, sanitation,

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cleaning, bathing, drinking, agriculture, industry and many more endless other purposes. As opposed to reducing assets, worldwide interest for water is increasing [2]. Since the last five year the water demand is calculated six to seven times more than twofold the rate of populace development [3].

The environmental conditions of mouth items, as well as the economy of such regions, are severely harmed by seawater intrusion [4]. Seawater infiltration into river mouths causes salinization of surface water, groundwater, and soils, as well as affecting the freshwater biota and disrupting the natural environments of plants and wildlife that are not accustomed to salt or brackish water [5]. Seawater infiltration at river mouths results in the inflow of salt water onto water courses and bodies of water [6]. A saltwater wedge in the river mouth's bottom layer can obstruct sediment transport, resulting in silting of navigation canals, harbour ponds, and docks, as well as the accumulation of contaminants in bottom sediments [7]. River mouths (deltas, estuaries, lagoons, and limans) are currently among the most endangered geological features on the planet due to flooding, sea waves, and seawater penetration, which is becoming exponentially stronger and threatening [8]. When it comes to addressing hydraulic engineering, land reclamation, and environmental conservation issues in mouth zones, preventing these negative impacts is a top priority [9].

The rapid expansion of the economy and population in coastal areas has depleted freshwater supplies, resulting in a rise in seawater penetration [10]. As a result, groundwater supplies can be protected from saltwater contamination by employing appropriate steps. Since groundwater must be handled before it can be used, salinization is a restriction. Treatment of salt ground water can be costly and time-consuming depending on the source [11]. Different steps have been established to regulate Sea Water Infiltration in coastal aquifers. Todd discussed various methods for preventing salty water from contaminating freshwater supplies, including the relocation of pumping wells, the elimination of pumping prices, the usage of underwater walls, natural recycling, and saline water abstraction, artificial recharging, and hybrid strategies [12]. The Coastal aquifer is under severe hydrological stress as a result of overuse of the shallow groundwater table. The major cause of sea water infiltration into groundwater tables is a consistent drop in ground water levels over the last few years as a result of massive ground water use across the world [13].

Large-scale study has been undertaken to explore Sea Water Infiltration in coastal aquifers. However, only a small amount of research has been done on the control of SWI. To monitor SWI, existing control methods depend on the above-mentioned steps [12]. The aim of lowering the abstraction rate is to save money by using other water supplies and lowering pumping rates [14]. Seawater cannot drain through the basin because of subsurface barriers. The aim of natural recharge is to bring more surface water to rivers [15]. Artificial recharge can help raise groundwater levels by using surface dispersal for unconfined aquifers and recharge wells for restricted aquifers. Water for injection may come from surface water, treated wastewater, groundwater, or desalinated water [16]. Fresh water injection and salt water withdrawal together decrease salt water levels while increasing fresh water levels [15, 17].

The Gujarat Water Resource Development Corporation, Gujarat has identified the limits of ground water salinity in terms of Total Dissolved Solids (TDS) in the coastal region of Kutch and Saurashtra. Ground water with TDS more than 6000 ppm is considered highly saline, 4000–6000 ppm as medium saline, 2000–4000 ppm as low saline and below 2000 ppm as fresh water.

Fluctuation in the salinity of groundwater in these coastal regions is a complex phenomenon. On the whole, it fluctuates with the geological formations and their disposition along the coast. There are various factors such as infiltration of sea water, inherent salinity and the structural properties of the formations deposited underneath marine conditions which will affect the groundwater [18]. To solve this problem it is essential to interlink all the rivers within the whole country to supply water to the deficit area. The approach is made to store river water which discharges an ample amount of water every year during monsoon season into the ocean. The main priority is given for interlinking of the Gujarat state major rivers to fulfill the needs of the areas which are facing the severe water scarcity In this paper a sustainable resilient plan is suggested for river water interlinking, which is helpful in control of surface water storage and saline water intrusion into the ground water along the coastal area.

2 Study Area

Different researchers have observed and described the worst effect of saline water intrusion in coastal zones of various parts of the globe like the Coast of USA, Japan, Italy, Greek Island, Oman, Atlanta, Netherlands, Turkey, Nigeria, and coastal areas of India. India has a long coastline of 5700 km [19–21]. Gujarat has the longest coastline in India having 1600 km length, having the Gulf of Cambay and Gulf of Kutch situated in the southern and western part of Gujarat. For this research study area has been taken as the Gulf of Cambay (Khambhat) and rivers which are draining their water into the Gulf of Cambay. A quadruplet coastal sector of western coastline furnished with an engrossing variety of geological features is formed at the entrance of the Arabian Sea. The Gulf frames a funnel-like shape at the entrance of the Arabian Sea and is positioned in continental shelf which is the widest portion of the western coast. The river sediments carried by the currents from the mainland contaminate the water of the Gulf of Cambay to an extraordinary degree, and the water is continuously churned up by the tidal currents. The Gulf of Cambay shoreline is attributed by variety of deltas, salt marshes, islands, cliffs, mangrove forest and mud flats [22]. The perceptible deltas are the Tapi, Narmada, Mahi, Sabarmati, Bhogavo, Shetrunji, Bhadar, Sukhbhadar, Sani and Saraswati. There has been considerable infilling in the estuarine and rivers which diverge around the islands. Aside from the islands, there are numerous shores found in the Gulf, especially at the opening of estuaries (Fig. 1).

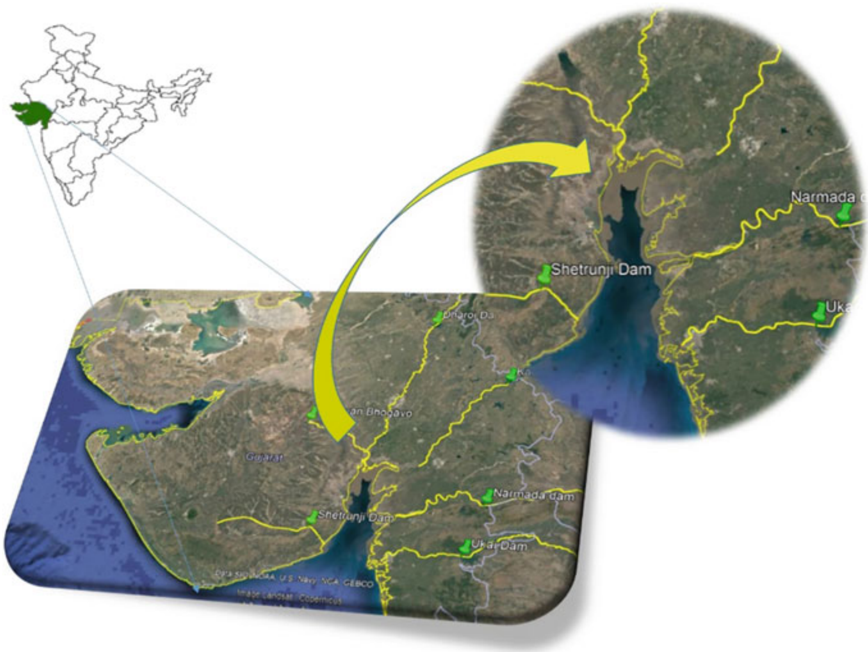

Fig. 1 Location map of rivers of Gujarat

3 Methodology

The maximum emphasized water sources of the world are Coastal aquifers. 70% of the world's general population is inhabited in coastal areas. Rise in population in the coastal area clearly results in over exploitation of groundwater resources. The herbal equilibrium inside the coastal aquifer reverses because of immoderate depletion of groundwater and outcomes in salinity ingress [23]. On the other hand, flood frequency for the various rivers is consistently increasing year by year. Rivers and reservoirs are getting filled up by sediment load which tends to increase flood frequency. For this study past flood & drought history and effect of salinity in Gulf of Cambay location have been amassed and analyze for better planning and control of water resources available on the earth surface. Rainfall data has been accumulated from the State Water Data Center, SWDC, Gandhinagar, Gujarat. Rainfall facts of the last 30 year have been collected for major river basins like Tapi, Narmada, Mahi, Sabarmati, Bhogavo and Shetrunji River. Every basin having a different number of rain gauge stations and annual average rainfall of each major region of Gujarat state have been calculated through thiessen polygon method and based on that average annual rainfall was carried out (Figs. 2 and 3).

Many damaging floods were seen in the history of Gujarat. In the state all major rivers pass through a wide stretch of very flat terrain (frequently in the way of fifty

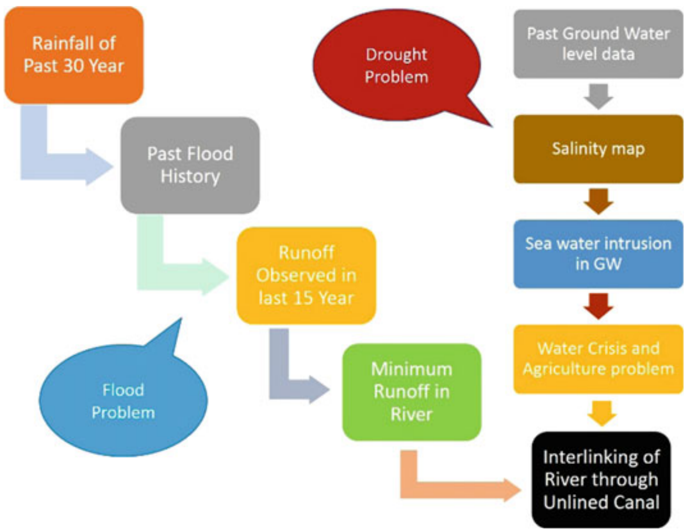

Fig. 2 Methodology plan to mitigate risk of flood & drought

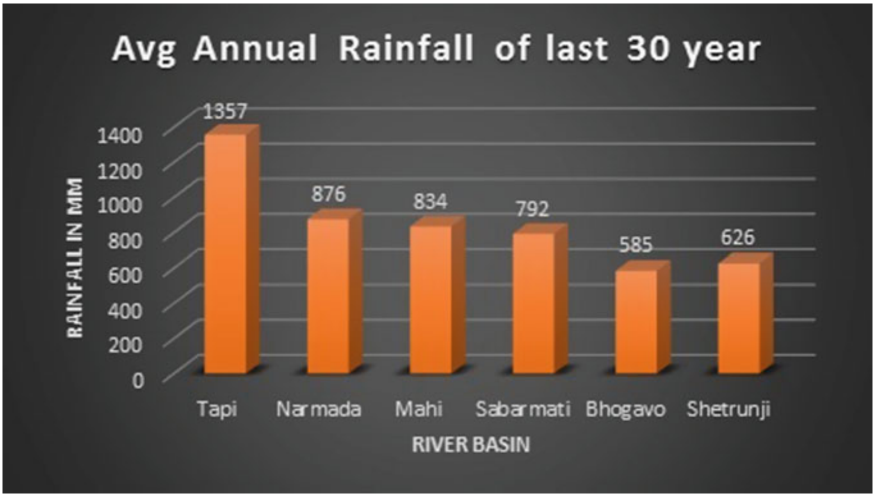

Fig. 3 Average annual rainfall of last 30 year for Gujarat state

km) before reaching the sea. Flooding may occur rapidly in these flat lowlands of lower river basins [24]. Periodical cyclones and depressions additionally cause serious downfall in large parts of Saurashtra, Kutch, central and northern parts of Gujarat. The urban cities like Ahmedabad, Surat, Vadodara and Bharuch are also placed on the flat alluvial plains of enormous rivers and are susceptible to flooding. Table 1 shows past flood history in Gujarat state (Fig. 4).

Table 1 Past flood history in Gujarat State

Sr. No.	Month and Year	Flood region	Sr. No.	Month and Year	Flood region
1	June, 2018	Surat and Saurashtra	10	2004	Narmada, Tapi
2	July, 2017	Banaskantha	11	1998	Surat, Tapi
3	Aug, 2016	Surat and Valsad	12	1994	Surat, Tapi
4	June, 2015	Amreli, Bhavnagar	13	1983	Shetrunji river
5	Sept, 2014	Vadodara	14	1979	Surat, Tapi
6	Aug, 2013	Bharuch, Narmada	15	1977	Mahi river
7	Sept, 2007	Mahi river	16	1973	Sabarmati river
8	Aug, 2006	Surat, Tapi	17	1970	Narmada river
9	July, 2005	Surat, Tapi	18	1968	Tapi river

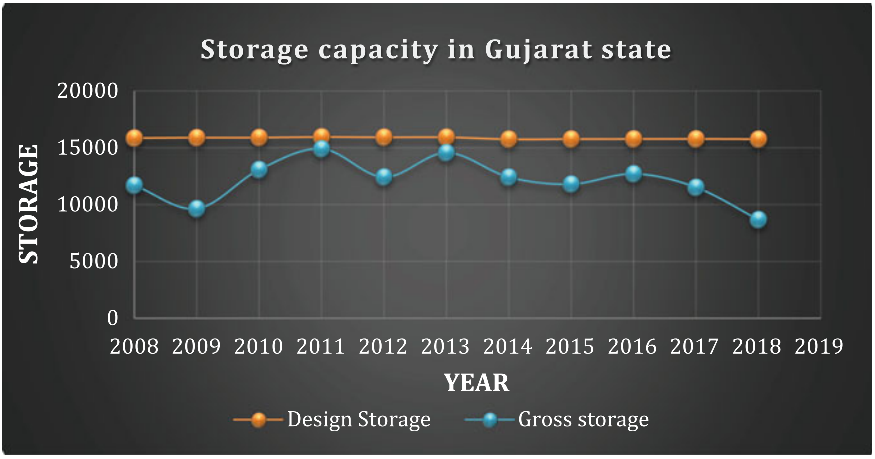

Fig. 4 Surface water storage in Gujarat State

Flood and drought both are unpredictable as it is a natural disaster [25]. Table 2 shows that in Gujarat state in the last 10 year there are both situations were reported i.e., Flood & Drought in some of the locations. Runoff collected at the estuaries of the river needs to be measured through discharge at a particular section. For this research, discharge data at the estuaries of rivers was collected and an average daily discharge was identified for each river.

3.1 Effect of Salinity in Coastal Region of Gujarat state

Ground water is not equally distributed throughout the globe relying upon various climatic conditions such as moderate zones with enormous rainfall providing an

Table 2 Discharge of major river of Gujarat

River	Maximum discharge reported	Daily average discharge	% Weightage assigned
Tapi	42,475 cumec	470 cumec	21.8
Narmada	69,400 cumec	1200 cumec	35.7
Mahi	33,000 cumec	250 cumec	17.0
Sabarmati	14,150 cumec	186 cumec	7.3
Bhogavo	1886 cumec	80 cumec	1.1
Shetrunji	7,080 cumec	150 cumec	3.6
Sukh Bhadar	10,700 cumec	180 cumec	5.5
Bhadar	5,667 cumec	110 cumec	2.9
Sani	7,019 cumec	130 cumec	3.6
Sarasati	3354 cumec	90 cumec	1.7

essential renewable recharge to the aquifers which act as a vital role together with surface water, guaranteeing a good year to year management in case of drought [26]. Infiltration or intrusion of surface water and rainfall through permeable layers gives great quality of groundwater; which results in easy access to groundwater in numerous regions of the world, clarifies the extensive utilization of ground water for human water sources covering greater than 58% of human needs. Ground water is frequently over-utilized particularly in arid zones bringing down the water table level [27]. The areas which are densely populated across the world are coastal areas. In this area, the consumption of water is amplified due to an increase in population. As a result, the aquifers in coastal zones are being over exploited. Sea water intrusion in aquifers can be caused due to over exploitation of groundwater [28]. The water level increase due to global warming and other occurrences are increasing rapidly as a result the intrusion factor of salty water in coastal aquifers also increases. The groundwater discharges into the sea and a natural gradient exists towards the coast, at the junction of groundwater aquifers with the coastline. Fresh water is 1.025 times lighter than sea water; it meddles in coastal area groundwater aquifers forming a wedge between saline and freshwater [29] (Fig. 5).

According to the Ghyben-Herzberg connection seen in Fig. 6, the interfacing layer resides at a depth lower than sea level, h2, which is 40 times the height of freshwater above sea level, h1. As sediment from a well in a coastal aquifer is expelled. Due to heavy groundwater injection, the normal hydraulic gradient reverses, and the aquifer can become saline. Bore-wells are evacuated when the saline content exceeds a certain tolerance level. A seaward hydraulic gradient should be maintained to regulate seawater penetration, and a portion of the natural freshwater recharge should be permitted to flow into the shore.

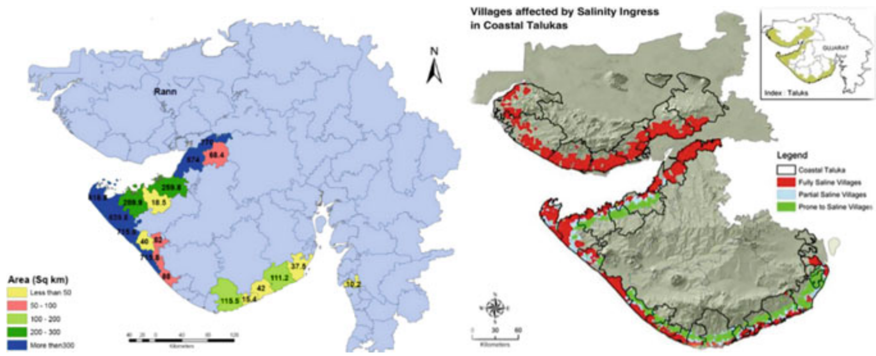

Fig. 5 Salinity affected region of Gujarat state

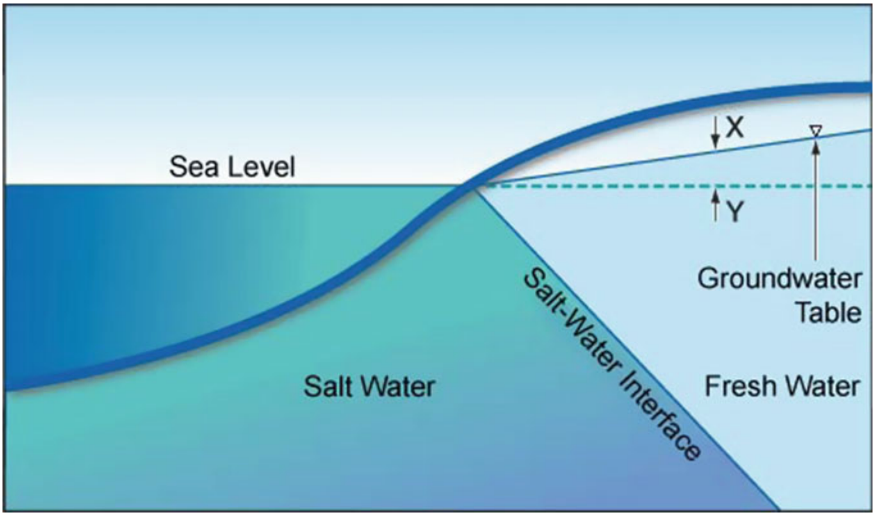

Fig. 6 Sea water interface with fresh water in coastal area

4 Results and Discussions

After analysis of past flood history, drought history, rainfall and average daily discharge in rivers for the study area, a sustainable plan is proposed to mitigate risk of flood and drought. Fresh river water barrier in terms of an unlined canal has been proposed as a mitigation structure which will help in reduction of salinity and also recharge the groundwater table.

Design of Alluvial Canal

Those canals which are excavated in alluvial soil, such as silt, and carry a lot of silt along with water. The boundary or perimeter of such a canal is therefore made of

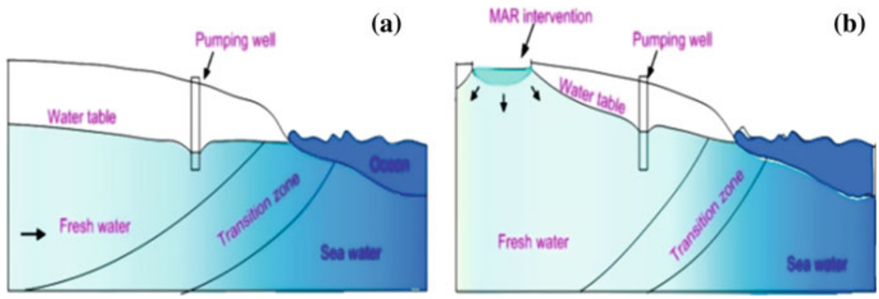

Fig. 7 Conceptual cross section showing **a** seawater intrusion due to over pumping and **b** Fresh water barrier for mitigation

silt, commonly known as "Alluvium". Design of the canal is done based on "Non Silting & Non-Scouring Velocity". The main benefit of this canal is that water can easily percolate inside the ground and thus ground water recharge becomes easy. Also this canal is more cost effective compared to lined canal (Fig. 7).

The designed canal has to draw a fair share of silt flowing in the river. This silt is carried along the bed of the canal or in suspension. Silt load carried by the canal is a challenging problem in canal design in alluvial soil. According to Lacey Regime Theory "Silt is kept in suspension by the vertical component of eddies generated at all points of forces normal to the wetted perimeter".

For canal design an average daily discharge is taken as 1200 cumecs.

Step-1 Assume the silt factor:- f = 1.0

Step-2 Calculate the velocity of Flow:- $V = \left[\frac{Qf^2}{140}\right]^{1/6}$, $V = 1.43$ m/s

Step-3 Calculate cross sectional area (A):- Q = A × V, A = 840 m^2

Step-4 Calculate perimeter:- P = 4.75 × $Q^{1/2}$, P = 165 m

Step-5 Assuming the side slopes of the channel 0.5:1 (H:V)

- $A = BD + D^2/2$ & $P = B + D\sqrt{5}D$
- $D = \frac{P - \sqrt{P^2 - 6.944A}}{3.472}$,
- D = 5.41 m
- $B = P - 2.236D$, B = 152 m
- $R = A/P = 4.45$, $R = \frac{5V^2}{2f} = 5.11$ R = 5.11

Step-6 Calculate bed slope:- $S = \frac{f^{5/3}}{3340Q^{1/6}}$, S = 1 in 10,888

Number of barrages and weirs are required to construct for the proposed plan of interlink major rivers to mitigate risk of drought and flood in the Gujarat state. This interlinking canal will connect important rivers of Gujarat. Distance between Barrage Mugdhalla on Tapi river and Bhadbhut Barrage on Narmada river is 60 km. Distance between Bamangam Barrage on Mahi river and Bhadbhut Barrage on Narmada river is 67 km. Distance between Barrage Bamangam on Mahi river

Fig. 8 Proposed route of Unlined Canal for river interlinking

and Vataman Barrage on Sabarmati river is 69 km. Distance between Pipali weir on Bhogavo river and Talaja weir on Shetrunji river is 140 km. Huge volume of water can be stored through this canal which can helpful in drought as well as flood situation also (Fig. 8).

Advantages of Proposed Canal: (i) Sea water intrusion decreases, Runoff will reduce [5] (ii) Water will be easily available for irrigation [30] (iii) Saline land will be converted into cultivable land [9, 31] (iv) Water will be equally distributed to nearby areas. (v) Connectivity will be increased between villages and cities [32] (vi) It will create employment and help in socio economic development of people [19].

Disadvantages of Proposed Canal: (i) the available elevation is not feasible for flow of rivers hence pumping is required [19, 33] (ii) Land acquisition is required and it will take longer time [24] (iii) Rehabilitation of some villages is required where canal is aligned [26, 27] (iv) Political support is also necessary for inter-linking as it needs concordance among districts of state for land acquisition [26].

5 Conclusion

In the southern part of Gujarat, the coastal area of Gulf of Cambay and western part the coastal area of Saurashtra and Gulf of Kutch, is extremely set out by the sea water intrusion into the fresh water aquifers due to overuse of groundwater for numerous human uses like farming, civil application and commercial application. Heavy drawdown of water table is observed in the regions surrounded by Tapi, Narmada, Sabarmati, Mahi, Bhadar, Machhu and Bhogavo River during summer season which results in drastic scarcity of fresh groundwater, as a result the boundary of saline water steadily move towards inland direction. A resilient proposal for water resources management has been proposed through an unlined canal which connects different rivers to mitigate the risk of drought and flood in Gujarat state. The main agenda is to recharge the aquifer with fresh water, improving the quality of groundwater and repress saline water ingression threat. This plan is productive when restriction of withdrawals from coastal aquifers and groundwater regulation act has been maintained. This research proposed an unlined canal having a minimum average discharge of 1200 cumecs. This canal is designed based on the non silting and non scouring velocity concept. Designed velocity for the canal is 1.43 m/s, perimeter is 165 m, cross sectional area of canal is 840 m^2, hydraulic mean depth is 5.11, bottom width of canal is 152 m, canal bed slope is 1 in 10,888 and depth of canal is 5.4 m. This canal will be solution for the many of the problems faced by the Gujarat state and it having many advantages of this proposed interlinking canal plan.

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