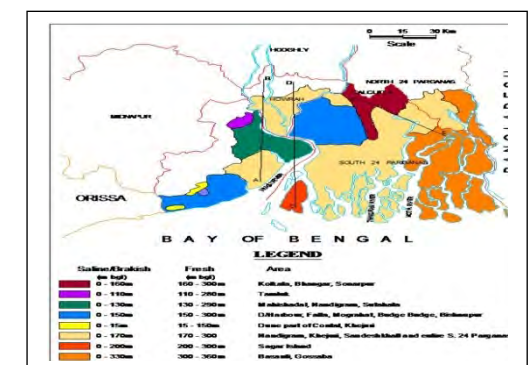
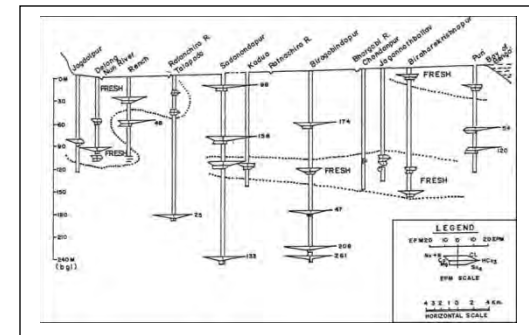
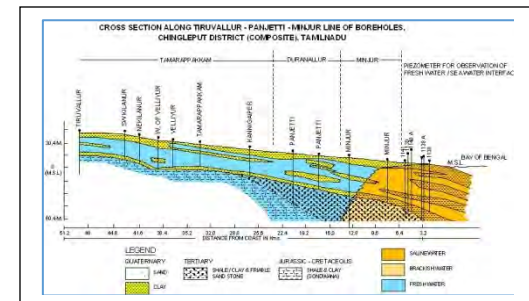
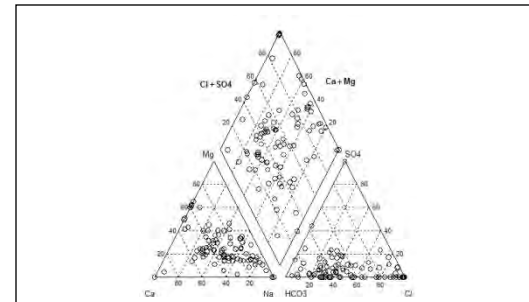
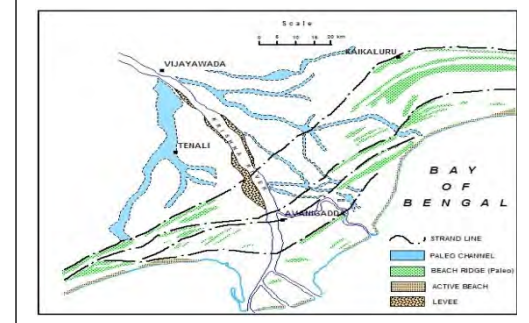




GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES
CENTRAL GROUND WATER BOARD

REPORT ON STATUS OF GROUND WATER QUALITY IN COASTAL AQUIFERS OF INDIA

FARIDABAD
FEBRUARY 2014





**GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES
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**REPORT ON
STATUS OF GROUND WATER QUALITY
IN COASTAL AQUIFERS OF INDIA**

**Bhujal Bhawan
Faridabad, Haryana
February 2014**

सुशील गुप्ता
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FOREWORD

The coastal stretches of India are among the most densely populated areas of the world. Ground water is an important source of water supply for various uses in the coastal areas of most of the States. Development of fresh water from aquifers in coastal areas of the country has increased manifold in the recent decades. Over exploitation of ground water from coastal fresh water aquifer systems, existing in delicate hydrodynamic equilibrium with sea water increases the risk of sea water ingress into these aquifers. Possible sea level rise due to global warming and climate change is likely to have serious implications for the ground water resources in the coastal aquifers of India.

Quality of ground water in coastal aquifers is constrained by several factors, both natural and anthropogenic. These include depositional environments, inundation during tides and cyclones, municipal and industrial contamination etc. A proper understanding of the quality aspects of ground water regime has a vital role in scientific management of ground water resources in coastal aquifers.

Central Ground Water Board and many other Central and State organizations have generated a vast amount of data on the quality aspects of coastal aquifer systems in India during various scientific studies over the years. The report entitled 'Status of Ground Water Quality in Coastal Aquifers of India' is probably the first attempt by any scientific agency in the country to systematically compile the available ground water quality data on the coastal aquifers in the country and to present it as a report. I am confident that this compilation will be of immense use to planners, professionals and researchers dealing with the water resources in the coastal areas of the country and will help in various endeavors aimed at ensuring the long-term sustainability of the precious and delicate ground water repositories. The efforts of Regional Directors, scientists and engineers of various Regions especially Dr. Nandakumaran. P of the Board in the collection, compilation and synthesis of data presented in the report are highly appreciated.

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CONSERVE WATER - SAVE LIFE

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Central Ground Water Board

Government of India

Ministry of Water Resources

PREFACE

India has a coast line of about six thousand kilometers and the coastal areas are home to some of the prolific aquifers catering to the increasing demands of fresh water for the dense population that inhabits it. In view of the increasing ground water development from the coastal aquifers and anticipated impact of climate change on the coastal ecosystems, a proper understanding of the quality aspects of the ground water in coastal aquifers systems becomes extremely important from the point of view of their scientific management.

The report on 'Status of Ground Water Quality in Coastal Aquifers of India' is the outcome of an attempt at compilation and synthesis of available scientific data on the ground water quality in the coastal aquifers of India, generated through years of scientific studies carried out by Central Ground Water Board and many other Central and State agencies. Details pertaining to east and west coasts have been dealt with separately as they have significant difference in origin, extents and characteristics. Various factors having a bearing on ground water quality such as drainage characteristics, climate, geomorphology, geological setting and hydrogeological framework have been described state-wise in detail. The section on ground water quality deals mainly with characterization of ground water quality, spatial and temporal quality variations, suitability of ground water for various uses, ground water contamination due to various chemical constituents etc. Critical areas and quality issues in coastal aquifer systems including fresh-saline water interface and status of sea water ingress have been dealt with separately.

This report has been compiled from the information made available by various Regional Offices of the Central Ground Water Board, supplemented with information available in reports and other published literature. I take this opportunity to appreciate the efforts of Dr.Nandakumaran. P, Regional Director, Central Ground Water Board, Kerala Region, Thiruvananthapuram, Kerala in compiling this report in a systematic manner. Thanks are also due to the Regional Directors of Central Ground Water Boards in the coastal States of the country viz. Tamil Nadu (SECR), , Andhra Pradesh (SR), Odisha (SER), West Bengal (ER), Karnataka & Goa (SWR), Maharashtra (CR) and Gujarat (WCR) for providing updated information on the status of water quality in coastal aquifers in their respective States. I hope Planners, Professionals and researchers, working on issues of ground water in coastal areas and all those concerned with the sustainable management of coastal aquifer systems will find this report useful,

(Dr.K.Md.Najeeb)

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“संचित जल, सुरक्षित कल”

"Save Water, Secure The Future"

STATUS OF GROUND WATER QUALITY IN COASTAL AQUIFERS OF INDIA

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1. INTRODUCTION

India has a dynamic coast line of about 7500 km length, including the main land coast line of about 5400 km. Nearly 25 percent of the total population of India resides in the coastal tracts of the country. A number of important towns and cities, viz., Mumbai, Goa, Cochin, Chennai, Visakhapatnam & Kolkata are located along the coast. More than 100 rivers, including 14 major and 44 medium rivers discharge into the sea along the entire length of the coast. The Indian coast with major drainage system outflowing to the sea is shown in Fig.1.1.

The eastern coast is generally characterized by a wider coast line when compared to its western counterpart. The evolution of the Indian coast has continued from continental plate movement through peri-cratonic basin formations during Mesozoic to the recent process of delta building. The east coast had a drastic change during Jurassic-early Cretaceous time (140 to 120 million years BP) with the separation of continents. Following the strong structural trends, the new coastline was formed, fringing the Indian Peninsula mainly towards south of Narmada-Son-Damodar graben. The tectonic movements also truncated the existing NW-SE trending Godavari and Mahanadi rift valleys by transverse faults and produced a coastal palaeo-slope in easterly direction. Gondwana sedimentation in the rift valleys ceased and shallow marine sedimentation started all along the newly formed passive margin. Because of the stretched crust in

this part and step-like faults causing easterly tilting subsidence NE-SW trending sedimentary basins, viz., Assam-Arakan, Bengal, Mahanadi, Krishna-Godavari, Palar-Pennar and Cauvery were initiated. These basins were connected to open sea in the east and were bordered on the west by highlands and discontinuous Eastern Ghats. Except for the Assam-Arakan basin, all other basins developed delta building process that has been continuously shaping up the east coastline of India since then. These basins are also the source of terrigenous clastic sediments to the coast and the

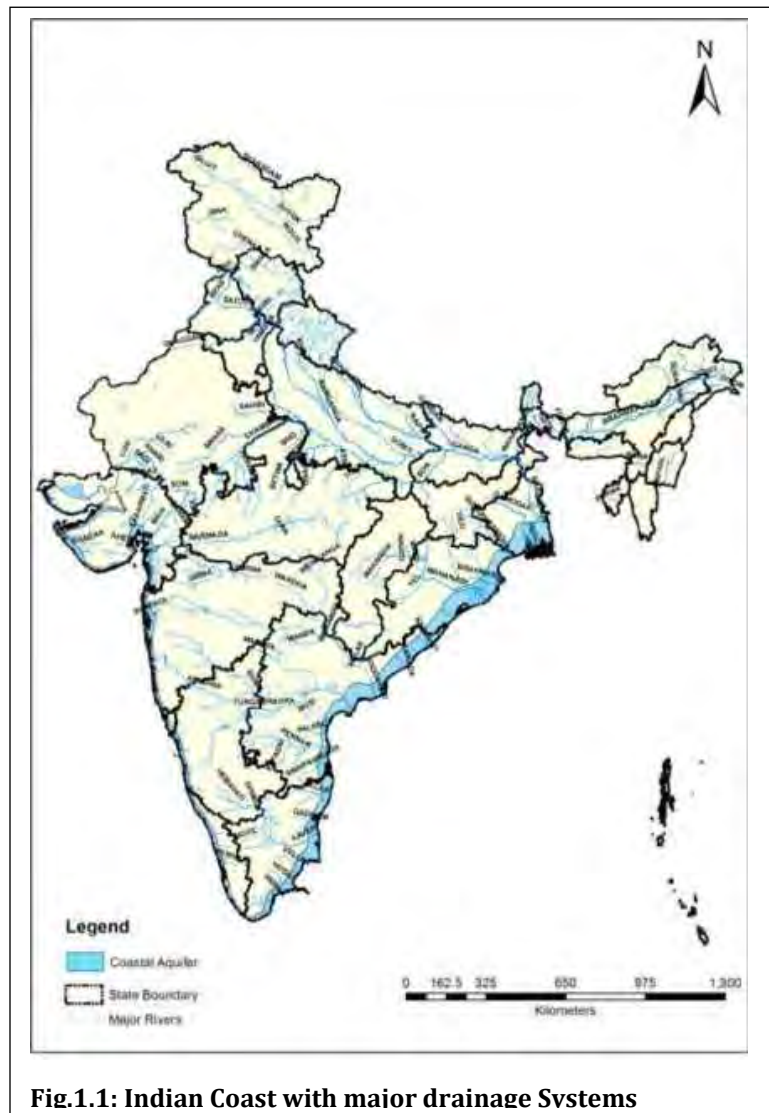


Fig.1.1: Indian Coast with major drainage Systems

Bay of Bengal.

The west coast originated subsequent to the east coast (Subrahmanya, 1998). It is partly limited by Western Ghats forming a prominent orographic feature along the western fringe of the peninsula. The edge of the continental shelf of the west coast is remarkably straight, representing a fault line that formed during Late Pliocene time. The block faulting and uplift of Western Ghats affected the coastal tract and got manifested through several major lineaments. The patchy occurrences of crystalline rocks and the sedimentary deposits are closely related to tectonics along the coast. In general, the west coast up to the Gulf of Khambat, is dominated by the presence of crystalline rocks with extensive linear fault systems parallel to the coast. Sediments on the west coast are minimal owing to the fact that only a limited part of the peninsula with high relief terrain is drained before being deposited into the Arabian Sea. Also, the shifting of the west coastline through geologic time was minimal. Further north, on the west coast, the Kathiawar sub-peninsula (Saurashtra) is underlain by sedimentary deposits and basaltic flows resting over the Proterozoic rocks. Sedimentary deposits controlled by tectonics and palaeo-climates got accumulated in the tectonic depression of Kachchh, Cambay and Narmada.

The Indian coastal tract is highly prone to cyclones. The onset of SW Monsoon during June to September brings high waves closer to the SW coast whereas the east coast faces the cyclones of NE monsoon during October-November. Besides, the tidal range varies from south to north. The southern coast has a tidal range of less than 1 m, while the northwest maximum is 11m and northeast is 4m.

1.1 Climate & Rainfall

Rainfall along the coastal tracts of Peninsular India is of monsoon type, normally spread over two seasons in a year. The southwest monsoon, from June to September, contributes bulk of the annual rainfall along the east and west coasts except for coastal areas of Tamil Nadu and Southern coast of Andhra Pradesh, where the maximum rainfall is from northeast monsoon during the months of October, November and December.

The southwest monsoon hits the Kerala coast by the end of May or beginning of June and advances towards northern parts of the country. Orographic influence is dominant in the distribution of rainfall in this season, as the prevailing winds blow almost at right angles against the Western Ghats. It brings copious rainfall along the west coast. But, the region of high rainfall along the west coast is limited to a narrow belt having steep slopes between the Western Ghats ridge and the coastal plain. Rainfall increases from the ridge of the Western Ghats towards the western steep slopes and rapidly decreases on the eastern lee side.

Along the east coast, the rainfall distribution is almost reversed, with higher rainfall of 600 to 1000 mm in the northern parts and relatively less in the southern parts within the range of 200 to 600 mm. The monsoon starts withdrawing gradually by early September and leaves the country by middle of October.

After the end of southwest monsoon, the northeast monsoon sets in and lasts for nearly three months, from October to December. It is relatively dry season with less rainfall as compared to the southwest monsoon. The entire coast of Tamil Nadu and southern coastal part of Andhra Pradesh are the main rainfall receiving areas during this season.

The annual normal rainfall distribution along the coastal tracts of the country (**Fig. 1.2**) is quite contrasting between the west and east coasts. The annual normal rainfall along the west coast ranges from 300 mm in the northern part of India and Northwestern parts of Gujarat to 2500 mm in the southern part, with a maximum of more than 5000 mm in some areas of the Western Ghats. It is the region receiving the season's second highest rainfall in the country. Annual normal rainfall in the eastern coastal tract is almost uniform from 1000 to 1500 mm except in some areas of Prakasam district of Andhra Pradesh and Tirunelveli district of Tamil Nadu.

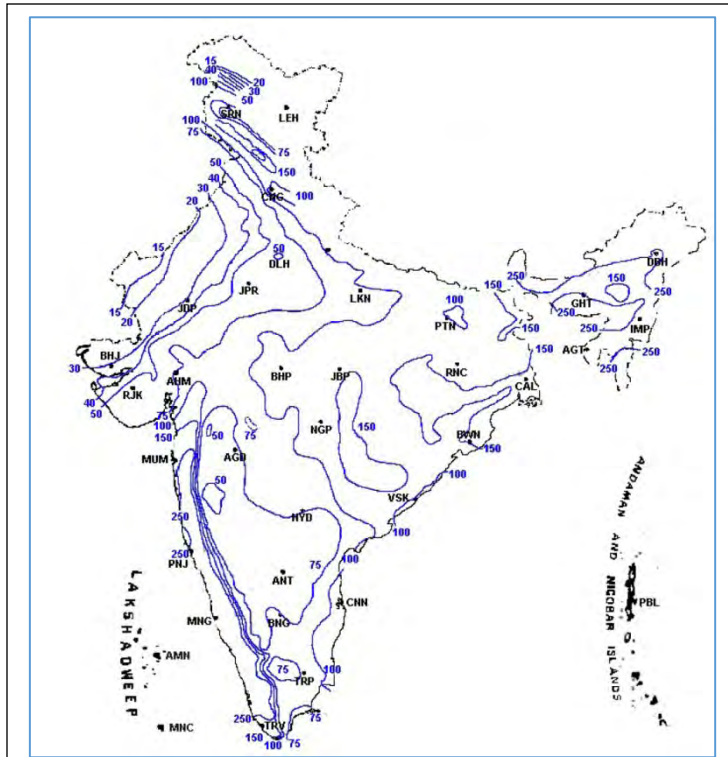


Fig. 1.2: Annual normal rainfall in India (cm)

(Source: India Meteorological Department web site)

The Bay of Bengal is a cyclonic belt with cyclones of varying intensity hitting the coast every year. The cyclonic storms are the low atmospheric pressure systems which form over the Bay of Bengal and move WNW towards the coast. The wind speed is more than 60 km/hr, generally more than 120 km/hr, and goes as high as 200 km/hr. The devastating cyclones are mainly observed in the winter months. The severe cyclonic storms create high tides near the coastline. These tidal waves inundate most of the low lying areas along the creeks, bays, lagoons, etc. and sometimes cover a large land area, as it happened in October 1864 when the tidal waves rushed up the Hooghly River along with the cyclone and flooded the neighboring lowlands. More than 80,000 persons lost their lives. After a few weeks in the same year another tidal wave, in the central part of east coast near Machilipatnam, Andhra Pradesh, engulfed the land ending the lives of 40,000 persons. In November 1977, huge tidal waves along with severe cyclonic storm engulfed and devastated Divi seema, the deltaic island of Krishna river, and other coastal areas of Krishna and Guntur districts of Andhra Pradesh even up to a distance of 20 km inland, and in the coastal districts of Nagapattinam and further south in Tamil Nadu. More than 15,000 persons and countless cattle perished. The coastal tract of Odisha is also one of the most disaster prone frequently subjected to cyclones as well as severe flooding induced by storm such as 1999 super cyclone that caused massive devastation of lives. The number of cyclonic disturbances (depressions and cyclonic storms) in a year ranges from 4 to 15. The frequent cyclonic storms create havoc in the coastal area causing the agricultural low-

lying areas submerged under a sheet of sea water for some time. It pollutes the near surface coastal fresh water aquifers and all the wells start yielding saline water.

1.2 Drainage Characteristics

Coastal streams, especially in the west, are short and episodic. The coastal areas of India show wide variations in drainage characteristics from place to place. In Gujarat, there are two distinct sets of rivers. The rivers Rupen, Saraswati and Banas in the NW part flows into the Rann of Kachchh, while the major rivers draining the central and southern coast of Gujarat, viz., Narmada, Tapi, Sabarmati and Mahi fall into the Gulf of Khambat. In Saurashtra, there are many intermittent rivers like Bhadar, Ojat, Madhyvanti, Noli, Megal, Hiran, Saraswati, Singwada, Singwadi, Rupen and Machundri carrying rain water to the sea. Out of these, river Bhadar is the longest. These rivers rise in the central plateau region of Saurashtra and meander in a radial pattern through the plains to meet the Arabian Sea. The narrowness of the river mouths and sandbars at their mouths impede the flow of floodwater causing inundation of the 'Ghed' and the coastal depressions. When the sandbars get breached by the accumulated flood water in the Ghed, tidal water from sea enters the Ghed and gets accumulated in its lower part. This phenomenon is noticed for Noli-Langri and Netravati rivers near Sil in Mangrol-Chorwad area. The entrapped sea water extends upto Shahpur and Khorada. In Kachchh area long draining rivers are absent except a few like Khari and Nagmati which joins the sea. The river Luni ends in the Rann of Kachchh. As such, the drainage pattern is braided in basalt, dendritic in upper reaches, karstic in Gaj Limestone and straight in Miliolitic Limestone terrain.

In Maharashtra State, the Konkan Rivers drain a relatively narrow strip of land and none of the rivers have a course more than 100 km. In north Konkan, Pinjal, Vaitarna, Bhatsai, and Ulhas rivers drain the area north of Thane creek and converge on Thane-Dharamtar creeks. The important rivers Amba, Kundalika, Savitri, Vashishti, Shastri, Kajvi, Waghothan and Gad of south Konkan coastal area carry heavy discharge. A number of creeks run from coast inland up to long distances carrying backwaters. Out of these, the Thane and Vasai creeks are quite prominent. The areas around these, in the lower reaches form typical marshy saline lands. Though the general slope is westward, a number of rivers and streams also have north-south alignment in certain stretches, displaying structural control. There are 14 rivers draining the Karnataka coast. The prominent are Netravati, Gurupura, Gangoli, Hangarkatta, Sharavathi, Aganashini, Gangavali and Kalinadi. The other rivers like Kumaradhara, Nandini, Shambavi and Swarna etc. also drain the coastal area. The two major rivers draining through Goa are Zuari and Mandovi. The coastal plain of Kerala is drained by a large number of rivers and their tributaries originating from Western Ghats. The main rivers which start from the Western Ghats are Chandragiri, Kuppam, Beypore, Bharatapuzha, Periyar, Meenachil, Pampa and Manimala etc. Out of these the river Bharatapuzha is the longest. The rivers viz., Periyar, Achankovil, Manimala, Muvattupuzha, Kallada, and Ittikara run for small distances and flow into the Vembanad or Ashtamudi lakes.

Bay of Bengal, along the eastern coast receives huge river water from many large river systems like Ganga-Brahmaputra, Mahanadi, Krishna, Godavari and Cauvery. They exhibit their matured nature before splitting into distributaries to form deltas. Besides, there are several important rivers that drain the plains of east coast. In West Bengal other than the Ganga-Brahmaputra system is the river Subarnarekha that originates from the Chhotanagpur plateau and drains the western most part.

The coastal plains of Odisha is drained by rivers of peninsular origin. The major rivers are Mahanadi, Brahmini, Baitarani, Rushikulya and Budhabalang. In Andhra Pradesh the major rivers draining the coastal area and nearby areas, in addition to Godavari and Krishna, are Nagavali, Vamsadhara, Yeleru, Gundlakamma and Pennar. The coastal area of Tamil Nadu is drained by several rivers. Amongst them the major rivers are Cauvery, Ponnaiyar, Palar, Vaigai, Vaippar and Tambrapani.

Drainage congestion is a common problem in coastal plains -the flat areas with flat slopes. In these areas, particularly in low lying coastal areas, disposal of surface runoff takes considerable time and surface drainage problem becomes acute. The accumulation of water affects the crops. Besides, the problem of water logging also exists in the coastal areas of West Bengal, Odisha and Andhra Pradesh (Planning Commission, 1981).

2. GEOMORPHOLOGY

The coastal region of India presents a variety of geomorphological units and landforms developed through several factors like rock types, tectonics, topography, land cover, climate and the fluvial, marine and aeolian actions. These processes also evolved the coastline and left their imprints as major geomorphic features. Various geomorphological units such as deltas, rocky cliffs, marine deposits, islands, gulfs, lagoons, tidal creeks, beach ridges etc. are encountered along the east and west coasts of the country. The coast line of India covers nine states and the Union Territories of Puducherry and Daman & Diu. Gujarat has the largest share of coast line, followed by Andhra Pradesh. The state wise distribution of coast line is given in **Table 1.1**(Kumar et al, 2006)

Table 2.1: State wise break up of coastline length and characteristic features

State	Length of coast (km)* / Coastal districts	Characteristic Features**
Gujarat & Daman & Diu	1224.2 Kachchh, Jamnagar, Porbandar, Junagarh, Amreli, Bhavnagar, Anand, Ahmedabad, Bhadodra, Bharauch, Surat, Navasari, Valsad	Gulf of Kachchh and Gulf of Khambat with extensive continental shelf area and shallow coast, sandy intertidal zone with vast stretches of muddy or sandstone areas
Maharashtra	652.6 Thane, Raigadh, Ratbagiri and Sindhudurg	Rocky coastal belt broken by small bays, creeks and fringed with islands, no major rivers
Karnataka & Goa	431.0 Goa, North Canara, South Canara and Udupi	Straight coastline broken at numerous places by rivers, rivulets, creeks and bays, northern part is rocky coast
Kerala	569.7 Kasaragod, Kannur, Kozikhod, Mallapuram, Alappuzha, Kollam, Thrissur and Trivandrum	Chain of brackish water lagoons and backwaters parallel to the coast, beaches and estuaries
Tamil Nadu & Puducherry	937.5 Tiruvallur, Kancheepuram, Villupuram, Puducherry & Karaikal, Cuddalore, Nagapattinam, Thanjavur, Tiruvarur, Pudukkottai, Ramanathapuram, Tuticorin, Tirunelveli and Kanyakumari	Narrow belt of sand dunes, low-lying beach, Plains mostly formed by rivers
Andhra Pradesh	973.7 Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasham and Nellore	Coastline is smooth with inundations, deltaic coast-Krishna and Godavari, marshy, muddy coasts
Odisha	476.4 Balasore, Bhadrak, Cuttack, Jagatsinghpur, Jajpur, Kendrapara, Puri, Khurda and Ganjam	Coast is depositional, formed by Mahanadi, Brahmani and Baitarani delta.
West Bengal	157.5 North 24 Parganas, South 24 Praganas, Haora, East Medinipur	Ganga and Brahmaputra river systems create large intertidal, deltaic mass. Hooghly mouth is uneven formed by massive sedimentation, coast sand riffed with innumerable tidal creeks and estuaries

* After Kumar et al 2006

**after S. Ramachandran, 2003

The west coast, to the south of Gulf of Khambat along NNW – SSE direction, is almost straight and crenulated with tidal creeks. It is generally referred as Konkan coast towards north and Kanara and Malabar coasts towards south. Almost parallel to the west coast, the Western Ghats is a prominent linear relief zone. It extends from Tapi valley located north of Mumbai, to the southern tip of Kanyakumari over a distance of 1600 km. The linear ridge acts as a major water divide, running parallel to the coast, between the east flowing Godavari, Krishna and Cauvery river systems and the short stretched west flowing minor rivers. The plateau escarpment is very prominent in the northern part. The Western Ghats, known as Sahayadris, Nilgiri Hills, Cardamom Hills, etc. in different parts of the coast, is the wettest region in the Peninsula with annual rainfall upto 5000 mm. The highest peak of the Peninsula is located at Anaimudi (2695 m above msl) in Kerala.

The coastal plain towards west of the Western Ghats reflects a distinct strip of low land interspersed by hills. It has, in general, a low topographic elevation within 10m above mean sea level. It is not well developed due to the absence of depositional actions of the fast flowing rivers originating from Western Ghats and is mostly confined to a narrow belt stretching from Surat in Gujarat to Trivandrum in Kerala. The fast flowing nature of the short length rivers from the Ghats resulted in formation of estuaries rather than deltas. Towards east of the coastal plain, all along the coasts, the Ghats present a steep rise like wall with a number of planation surfaces. The plains are essentially stepped plains of erosional surfaces, lateritic platforms and wave-cut terraces with eroded cliffs. Beach plains are confined at places as narrow discrete zones with number of tidal estuaries and lakes along the crenulated coastline. The other geomorphic features are sandy beaches, coastal sand dunes and mud flats, and alluvial tracts along the short stretched west flowing rivers.

In Gujarat, the wide semi-arid plains of Kachchh and Kathiawar peninsula existing as Rann are the prominent features. The Rann of Kachchh (about 22,000 sq. km) comprising Great and Little Rann with high tidal flats remains as saline desert for greater part of the year. Wide plains along the coast in NW-SE direction are formed by sedimentation around the Gulfs of Khambat and Kachchh. The Jakhau-Kandla segment of Kachchh coast line has irregular configuration. The Jamnagar-Okha segment of Saurashtra coast shows a crenulated rocky shoreline with channels, submerged islands, sand bars, dunes, mudflats and salt pans. The NW-SE trending Dwarka-Diu segment of the Saurashtra coast is straight. It has sandy beaches, tidal flats and estuaries. The Diu-Bhavnagar segment shows transition from open sea to gulf environment. There are 2-3 strand lines along the Saurashtra coast manifested by old Miliolite dunes.

The undulating low-land of Konkan coast is about 530 km long and 30-50 km wide. It encompasses the coastal tracts of districts Thane, Raigarh, Ratnagiri and Sindhudurg and Mumbai of Maharashtra state. It is wide in Mumbai-Thane area as a semi-circular basin of Ulhas river. Numerous hills and detached ridges dominate the low-land area. Flat shores with long sandy spits running into muddy shallows are found towards north of river Vaitarna. The southern part of the Konkan coast is more rocky and rugged. High hills and elevated plateaus cut by numerous creeks are found close to the coast. Further south, the coast around Goa is marked by deltaic deposits more than anywhere else in this region and is characterized by ria type wide estuaries.

The coastline of Karnataka is indented with a number of river mouths, creeks, promontories and cliffs. In northern Karnataka, the coastal low-land becomes narrow and gets confined to small

pockets along the lower courses of streams. Towards south, the low-land is somewhat wide, maximum about 70 km, near the port town Mangalore in Netravati valley. Three broadly parallel belts of landform are noted in Kanara coastal plain. Immediately adjacent the coast, a relatively narrow belt of Recent deposits form beach ridges, estuarine mud flats or marshes, backwater lagoons, pocket beaches, spit and bar systems and the valley plains. It is generally flat or gently sloping (elevation upto 30 m). The city of Karwar is on beach ridges. It is reported that the beach ridges are slowly vanishing along the coast especially at Karwar and Majali, owing to urbanization and other developmental activities (Hanamgond and Mitra, 2007). Rocky islands are present near the coast indicating submergent as well as emergent coast. This belt is followed by about 60 m high erosion platform, which is about 20 km wide in south and well dissected by steep sided valleys. Further inland, the third belt of isolated hills of height 91-305 m, are observed towards south east of Honavar and near Karwar.

Towards south, Malabar Coast in Kerala is about 5 to 35 km wide. It encompasses the districts of Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulam, Alappuzha, Kollam and Trivandrum (Thiruvananthapuram). Malabar Coast is prograding in nature. Sand dunes of peculiar form, locally called as 'Teris' are found all along the coast except south of Kovalam in Thiruvananthapuram district, where the rocks touch the sea. These dunes of Pleistocene and Recent Ages helped in formation of a large number of shallow lagoons and backwaters. Low laterite plateaus and foothills occur towards east of alluvial coast. The west coast of India terminates near the rock outcrops at Kanyakumari.

The east coast of peninsular India, stretching for about 3000 km is quite different from the west coast. The morphology along the east coast is in sharp contrast with that of the west coast. Unlike the west coast, the east coast is a curvilinear one with the maximum curvature near the mouth of Krishna River debouching into the Bay of Bengal. The well-developed river delta systems, vast coastal plains and extensive fluvial and marine sedimentary deposits, etc., from Sunderban to Kanyakumari indicate the prograding nature of the coast. Most of the major easterly and south-easterly flowing rivers, viz., Ganga, Mahanadi, Godavari, Krishna and Cauvery and a few minor rivers like Subarnarekha, Pennar, Palar and Vaigai have developed well-defined deltaic platforms at their mouths. These major rivers discharge large quantities of sediments near the shore. The sequential cyclic sedimentation and subsidence has taken place in some of the regions in a geosynclinal environment. Geophysical exploration and oil well drilling operations have proved the increasing thickness of Mesozoic, Tertiary and Quaternary sediments towards the shore and beyond. The seaward gently dipping marine sedimentary deposits, ranging in Age from Cretaceous to Pleistocene, that occur in disconnected patches from the coastal districts of South 24 Parganas and Medinipur in West Bengal to Pudukkottai and Ramanathapuram in Tamil Nadu speak of palaeo shallow sea environment in the present coastal land area. Some of the large lagoons and swamps namely, the Chilka lake in Odisha, Kolleru lake in Andhra Pradesh, Pulicat lake near Andhra Pradesh – Tamil Nadu State border also occupy the coastal plain. All these major geomorphic units with complex deep geologic structures play a vital role in the hydrogeological environment along the east coast of India.

2.1 Coastal configuration

The configurations of east and west coasts differ considerably from each other. The entire west coast is, in general, of submergence type with a number of islands, inundated stream courses near the coast, tidal creeks with rock-cut surfaces, etc. Submerged mythological city of Dwaraka is a classic example from Saurashtra coast. On the other hand, the west coast is rocky and pounded by big sea waves during monsoon. The sea is very deep near the coast. Three inlets on this coast – Mumbai, Goa and Cochin – form good natural harbours. There is no extensive sedimentary deposition along the west coast except few patches along Kerala and Maharashtra coast and the vast area filled up by thick pile sediments along the structural depression / ancient inland bay near Gulf of Khambat.

The vast coastal plains and the sedimentary deposits of the east coast were formed in marine environment, covering an area about 1, 50,000 sq.km. The plains, formed due to progradation process, are extensive repositories of ground water and other natural resources like lignite, oil and natural gas and radioactive minerals to some extent. The extensive alluvial deposits formed due to this prograding nature of the coast have provided confining conditions to the underlying aquifers in sedimentary formations resulting in high hydraulic pressures. Availability of huge water resources from major rivers and fertile soils has transformed the coastal plains into a major producer of food grains.

2.1.1 Submerged coast

The coastline of Maharashtra exhibits a crenulated, irregular outline with a number of stream courses submerged within the sea (Fig.2.1). Inter-stream areas project as ridges into the sea. Beach development is sporadic and disconnected. A number of creeks run from coast towards inland up to long distances carrying backwaters. The areas around these, in the lower reaches form typical marshy saline lands. There is less development of sand bars along the coast. Rocky



Fig. 2.1: Panoramic view of a part of west coast, Maharashtra

cliffs of basalt along the coast suggest that wave-cutting action is more prominent than the deposition by streams. In Karnataka coastal erosion and submergence of land have been reported at Ankola, Bhatkal, Malpe, Mulur, Mangalore, Honnavar, Maravante and Gokarn (Kumar et al, 2006).

Submergence and emergence of land along Tamil Nadu coast has also been reported (Gaur & Sundaresh, 2004).

2.1.2 Prograded coast

The prograded east coast exhibits number of deltas, sand bars, extensive deposits of marine sediments, etc. The coastline is very smooth with well-developed long beaches. A classic example of prograded coast is the Khejuri and Hijli areas of East Medinipur district, West Bengal. These two areas were non-existent about 400 years ago and got fully developed only about 250 years ago. Khejuri holds

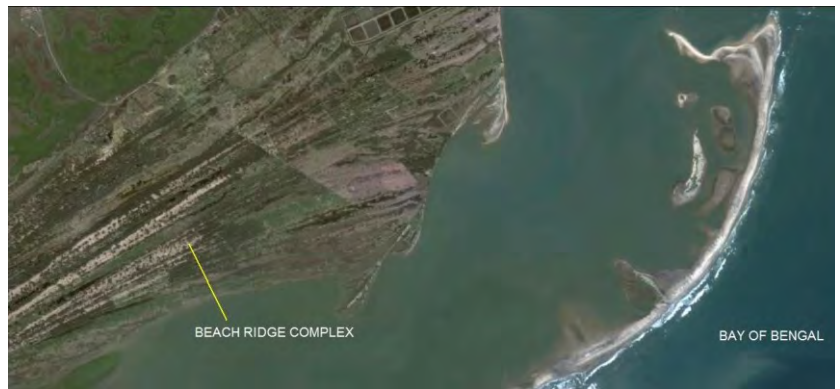


Fig. 2.2: View of prograding nature of east coast

30 to 40 m thick top fresh ground water. The prograding nature of the coastline has also left behind huge water bodies in the form of lakes and lagoons. The beach ridges (Fig 2.2 & 2.3), levees, palaeo



Fig. 2.3: Coastal plain with straight coast line and Sand dune, Tamil Nadu.

channels, etc. formed in the prograded coastal plain support fresh ground water aquifers.

2.2 Coastal Plain

2.2.1 West Coast

Coastal plain on the west coast from Gujarat to Kerala is confined to a narrow belt of about 10 to 35 km width, stretching between sea and Western Ghats. At the northern end this narrow strip merges with the Kachchh and Kathiawar peninsula with a vast plain.

Kachchh peninsula was once

an island surrounded by seas and lagoons until the Great and Little Ranns of Kachchh got silted up. Lack of rainfall in this region has given rise to arid and semi-arid landscape, and hence, coastal sand dunes, sandy plains and bare rocky hills are the characteristic physiographic features of the Kachchh peninsula. The Great Rann is a broad plain formed by dark silt with salt encrustation. The plain rises only a few metres above the sea level and at some places it is below sea level. The Rann gets flooded every year partly by river water and partly by tidal water. Kathiawar peninsula lies to

the south of Kachchh. The two Ranns- the Great and Little Ranns of Kachchh and the Gulf of Khambat – along with the Nal Lake nearly encircle the peninsula on the east and north-east. The Gujarat plains lie to the east of Kathiawar and stretch towards the interior uplands. The coastal tract of Gujarat, including the Rann of Kachchh, is stretched over 28,500 sq.km.

The Konkan coast, a geographic unit for more than 1000 km stretch between Gujarat plains in north and Malabar Coast in south, is characterized primarily by cliffs of basaltic trap rocks and Precambrian rock units with invasive estuaries. Beaches and narrow coastal plains having width up to 10 km are noticed as detached stretches in this unit. The rocky coast has a series of small bays and coves.

The Kerala coastal plain is comparatively much wide and less hilly. It is wide in the middle section and narrow in the southern as well as northern parts. The coastal plain has a width about 5 km in the southern part, whereas it goes upto 35 km around Cochin (Kochi) (Fig. 2.4). The maximum width is observed in the valleys of Beypore, Ponnai, Periyar and Pamba-Achankovil rivers. The width gets reduced to a few meters at the northern and southern ends. The crystalline rock exposures with small hillocks are seen all along the coast as isolated pockets like Kovalam-Vizhinjam area of Trivandrum district and Ezhimala of Kannur district. Steep to vertical cliff sections of the sedimentary formations are seen along the Karichal and Varkalai coasts (both in Trivandrum dist.), in Puliyoor (Alappuzha dist.) and in Charavathur (Kasaragod dist.). The midlands bordering the coastal plains along the east have an elevation of 6 to 40 m. and are characterized by undulating topography with the capping of laterites. A number of backwater (kayal) lakes lies along the coast. The largest is the Vembanad kayal which stretches for more than 250 km.

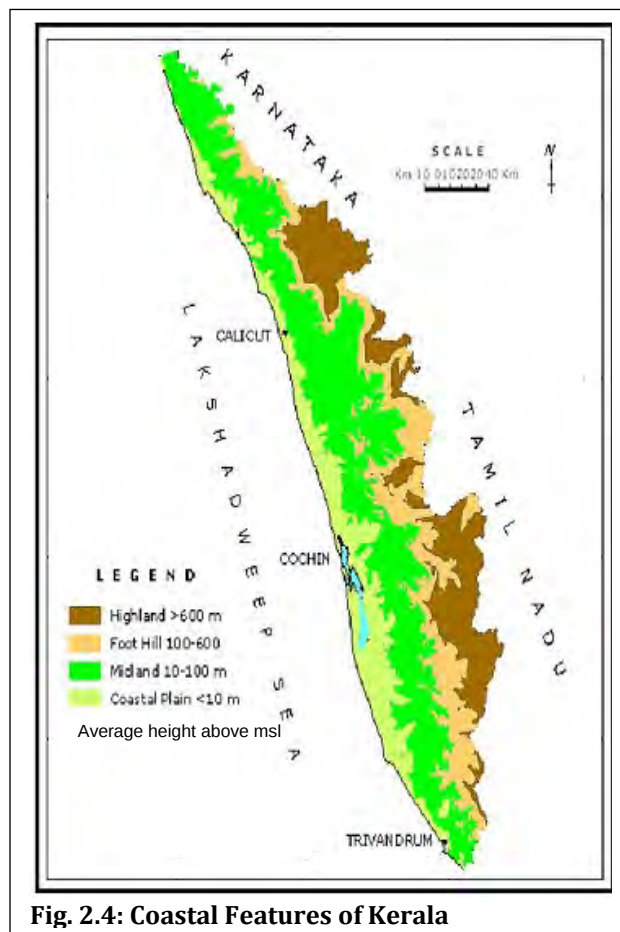


Fig. 2.4: Coastal Features of Kerala

2.2.2 East Coast

The coastal plain stretches in almost N-S direction from Kanyakumari to Krishna river mouth with an average width of 120 km. It takes a turn and extends in NE direction. Towards north of river Godavari, the coastal plain narrows down over a small stretch due to rocky coast and again widens towards north of Chilka lake in Mahanadi delta and Balasore coastal plain where they merge into the vast plains of Ganga- Brahmaputra delta system. The coastal plain in Tamil Nadu stretches from

Kanyakumari with a width of about 4 km and attains its maximum of about 150 km near Cauvery River and again narrows down towards Puducherry.

Singh and Swamy (2006) classified the eastern coastal plain into 10 zones, viz., the Ganga-Brahmaputra delta, Balasore coast, Mahanadi delta complex, Visakhapatnam coast, Krishna-Godavari delta complex, Southern Andhra Pradesh coast, Madras coast, Cauvery delta, Palk Bay coast and Gulf of Mannar coast as shown in Fig. 2.5.

The major coastal plain in Andhra Pradesh extends from Guntur district, across Krishna, West Godavari districts up to East Godavari districts up to East Godavari district. The other important coastal plain is formed in Nellore district near the mouths of Pennar, Swarnamukhi and Kandaleru rivers (Fig.2.6). The coastal plain of Andhra Pradesh is bordered by Archaean group of rocks on the west. The plain was formed under fluvial, fluvio-aeolian and fluvio-marine depositional environments. It was fluvial in the upper deltaic plain and along the river courses. In the lower deltaic plain, towards coast and other parts of the coast line, the fluvio-marine and fluvio-aeolian environments were dominant. In addition, the transgressive and regressive nature of the sea, especially in the middle part of the coastal tract of the state, has resulted in deposition of a complex sequence of formations, ranging from coarser to finer clastics often with rapid facies variation.



Fig. 2.5: East coast zones of India (After Singh and Swami, 2006)



Fig. 2.6: View of Krishna-Godavari coastal plain, Andhra Pradesh

The coastal plain is of prograding nature and formed due to shedding of sediment load by the mighty rivers Godavari and Krishna and other minor rivers. The presence of sand bars and spits all along the shoreline of the coastal plain, lagoons, inland lakes and tonal contrasts on satellite images due to sedimentation process in the areas where river water enters the sea are clear indications of prograding nature of the coast.

The striking feature in this area is the Kolleru natural lake. It formed as a natural inland bay when the shoreline was inland. The prograding process of the entire Godavari – Krishna coastal plain has left the Kolleru Lake in a land locked position. Due to the constant inflow of water from rivers like Tammileru, Budameru and other minor streams, the lake water has remained fresh. The marine landforms like beach ridge complexes, mud flats occur between the lake and the present day coast line.

2.3.Deltaic Plain

The east coast of India holds delta plains of major rivers developed near their debouching areas. These rivers drain large catchment areas and therefore have deltas of their own (Mahalik, 2000). The delta plains in the east coast are mostly of prograding nature. The huge catchment areas of the major rivers, viz., the Ganga-Brahmaputra (16, 56,000 sq. km), Mahanadi (1, 41,589 sq.km), Godavari (3, 12,812 sq.km), Krishna (2, 58,948 sq.km), Pennar (55,213 sq.km) and Cauvery (87,900 sq.km) contributed to the development of the extensive deltaic plains. These rivers particularly the Ganga-Brahmaputra system carry huge volume of sediments. The prograding nature of these deltas is clearly documented by the geomorphological processes through formation of various landforms, viz., levees, palaeo-channels and beach ridges. The deltas of Mahanadi and Krishna-Godavari are almost similar in mode of formation, have arcuate shape and differ from that of Ganga-Brahmaputra.

The landforms, which are highly permeable, are of great importance in hydrogeological environment.

2.3.1 Ganga Delta Plain

The Ganga delta is one of the largest deltas of the world. It is also known as Ganga-Brahmaputradelta and is formed by 3 main rivers, namely Ganga, Brahmaputra and Meghna. Out of these, the river Ganga makes the bulk of the delta system. There are a number of rivers joining

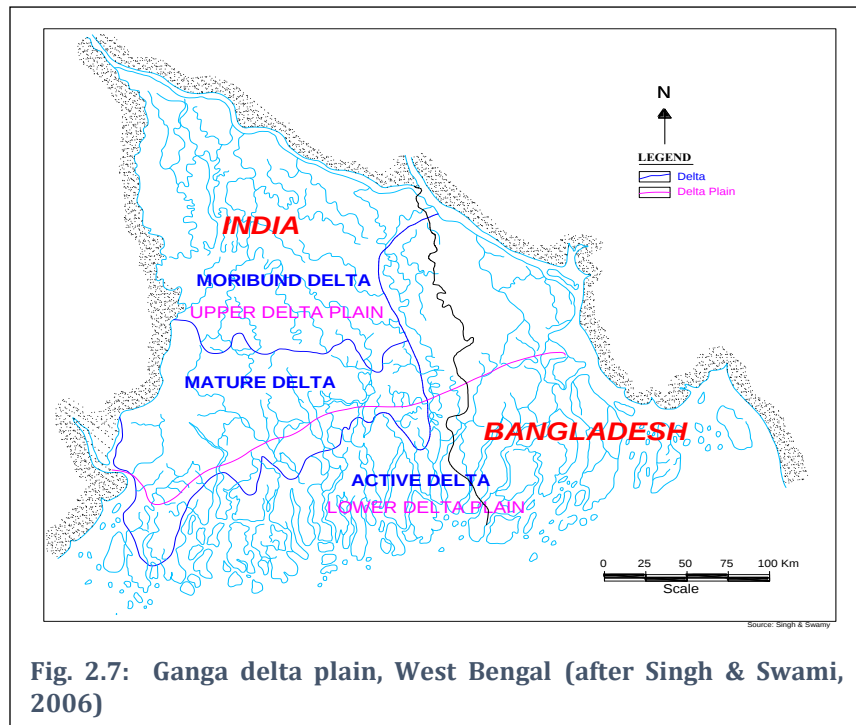


Fig. 2.7: Ganga delta plain, West Bengal (after Singh & Swami, 2006)

these major rivers to form the delta. The Ganga delta plain starts near Farakka. Saxena et al (1984) suggested that delta building was initiated during Oligocene period and west to east flowing proto Damodar River poured sediments from the peninsular shield. At present the deltaic region is flanked by the Pleistocene terraces in the north and west. Though the delta is of prograding nature the coast line is highly digitized. The upper delta plain has a maximum elevation of 15 m and is a fluvial flood plain. The lower delta plain has a maximum elevation of 12 m and is a tidal complex made up of tidal channels, creeks and flats and shows strong influence of tides. In most of the area the elevation is 3 m above mean sea level. Ganga delta shows numerous estuaries. There are a number of abandoned channels occupying the low lying areas to form lakes and marshes. The natural levees of the major rivers are quite prominent (Fig. 2.7).

2.3.2 Mahanadi Delta Plain

Mahanadi along with Brahmini and Baitarani rivers forms an arcuate shaped delta complex protruding for about 60 km into the Bay of Bengal. The Mahanadi delta was developed during Upper Pleistocene to Holocene and the deltaic sediments were deposited on the Mio-Pliocene floor. The delta plain of Mahanadi starts close to Cuttack, about 60 km from the coast line, while that of Brahmani-Baitarani

starts near Jajpur.

The upper delta plain displays anatomizing distributaries, flood plain and abandoned channels. The lower delta plain is characterized by tidal marshes and flats, tidal creeks, channels and estuaries and palaeo sand ridges etc. Almost up to 35 km inland palaeo sand ridges are present. There are four strand lines each consisting of a number of parallel ridges. The coastal lakes developed are

Chilka, Sar and Samang. Out of these the Chilka Lake occupies a large area. Flood plain in this delta is wide spread (Figs. 2.8, 2.9 and 2.10).

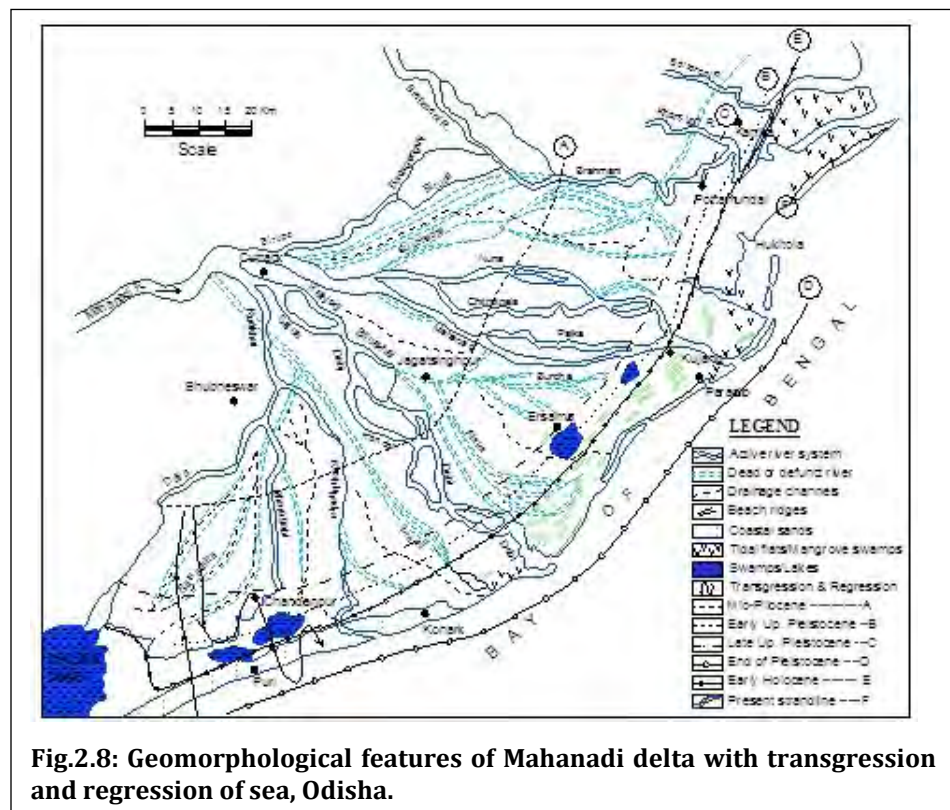


Fig.2.8: Geomorphological features of Mahanadi delta with transgression and regression of sea, Odisha.



Fig. 2.9: Coastal plain of Odisha with palaeo channel and migration of river.

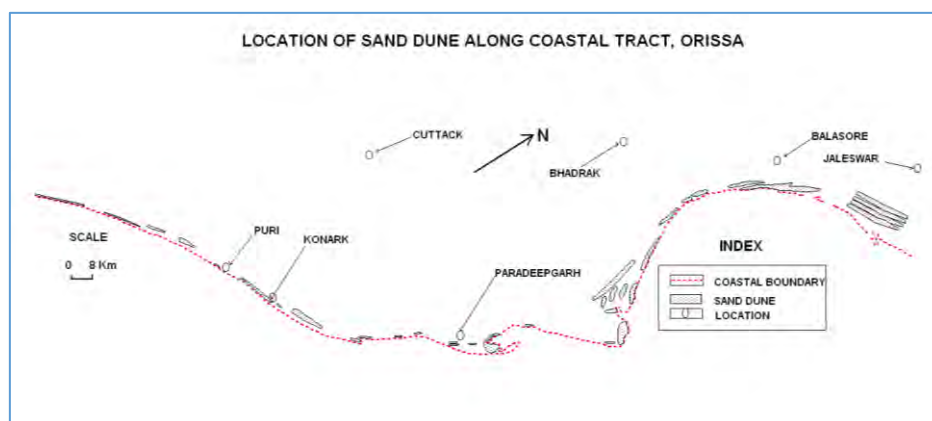


Fig.2.10: Sand dunes along Odisha coast

2.3.3 Godavari Delta Plain

Delta plain of the river Godavari occupies an area of 1700 sq.km. The present-day delta starts from Dhawaleswaram. River Godavari gets divided into two main distributaries, viz., Gautami and Vasishta. They are further sub-divided into minor distributaries before joining the Bay of Bengal. The delta is evolved in four stages and four major strand lines are deduced from reconstruction of beach ridges (Fig. 2.11). The oldest beach ridge is supposed to be in direct contact with the Tertiary sandstones. The deltaic alluvium comprises black, sticky clay, silt, sand and gravel in varying

proportions, often with rapid facies change, deposited under fluvial and marine environments. The levees and palaeo river channels, on the left bank, of river Godavari have a great effect on ground water conditions in the area.

2.3.4 Krishna Delta Plain

The Krishna River maintains a unique curvilinear path from its delta (old) head up to the coast. It forms a 95 km wide delta plain with a total area of 6322 sq. km. The delta plain, with its starting point at Vijayawada, is a fully developed one with huge distributary system, some of them crossing Tenali and others reaching Kaikaluru, which is evident from the distribution

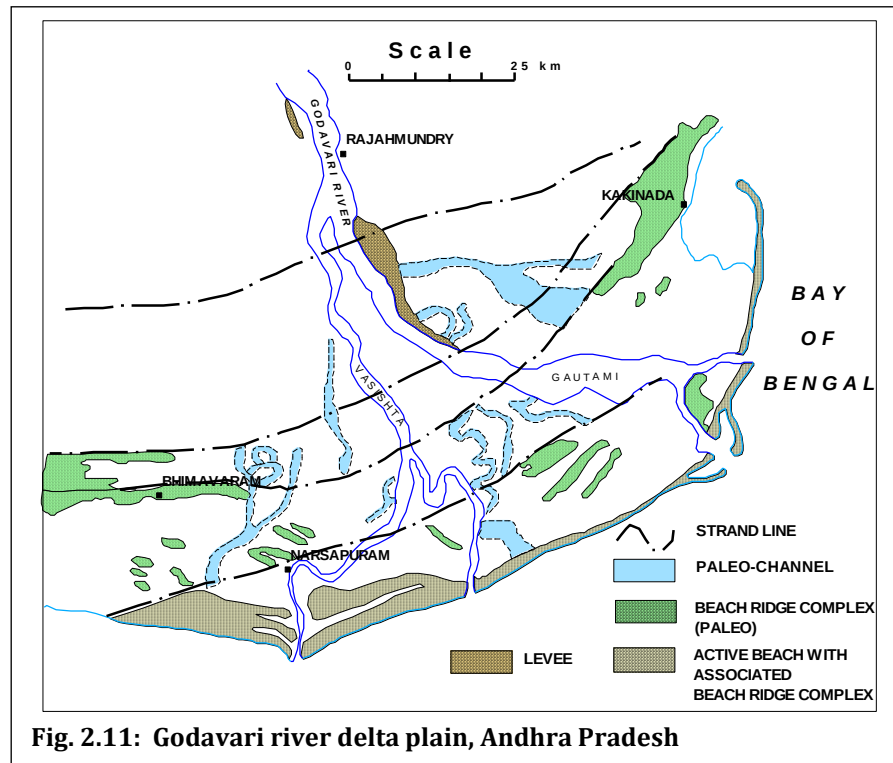


Fig. 2.11: Godavari river delta plain, Andhra Pradesh

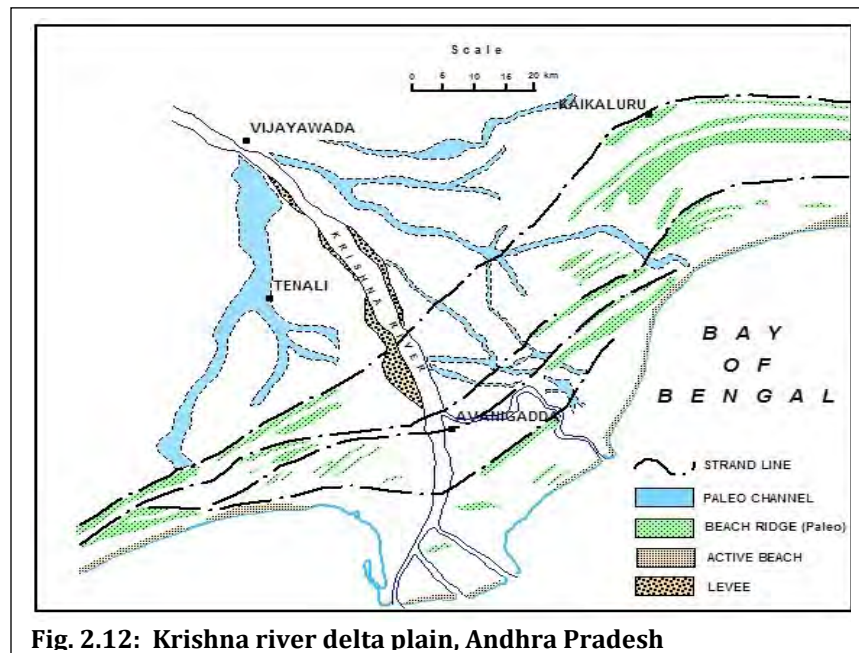


Fig. 2.12: Krishna river delta plain, Andhra Pradesh

of present day cusped shaped shoreline near Divi Seema.

The delta system appears to be more active on the left bank of the present day river channel. The levees, formed along the main river channel between Vijayawada and Avanigadda, support fresh

pattern of palaeo-river channels. The present day delta from Avanigadda covers an area more than 1000 sq. km. The first channel of the river starts near Avanigadda, but the 3 main distributaries of the present day river gets divided into the Golumuttapaya, Nadimieru and main channels just before entering the sea. It is estimated that there were four long duration shore-lines (leading to strand-lines) before the formation

ground water aquifers in the area. The palaeo-channels (Fig. 2.12) and beach ridges act as fresh ground water banks for the farmer communities in the Krishna deltaic plain.

2.3.5 Pennar Delta Plain

The third important delta plain in Andhra Pradesh is formed by the river Pennar in Nellore district. Though the river formed a well-developed delta earlier, there is no well-defined present day delta. The main river swings towards NE direction, as in the case of Cauvery (discussed latter), from Nellore onwards, and joins the Bay of Bengal directly without getting distributed into different river channels. The marine depositional landforms along the coast indicate that the coastal plain is prograding in nature. From the orientation of the beach ridges and other features, 3 major strand lines are traced. The lower plain around Escapable-

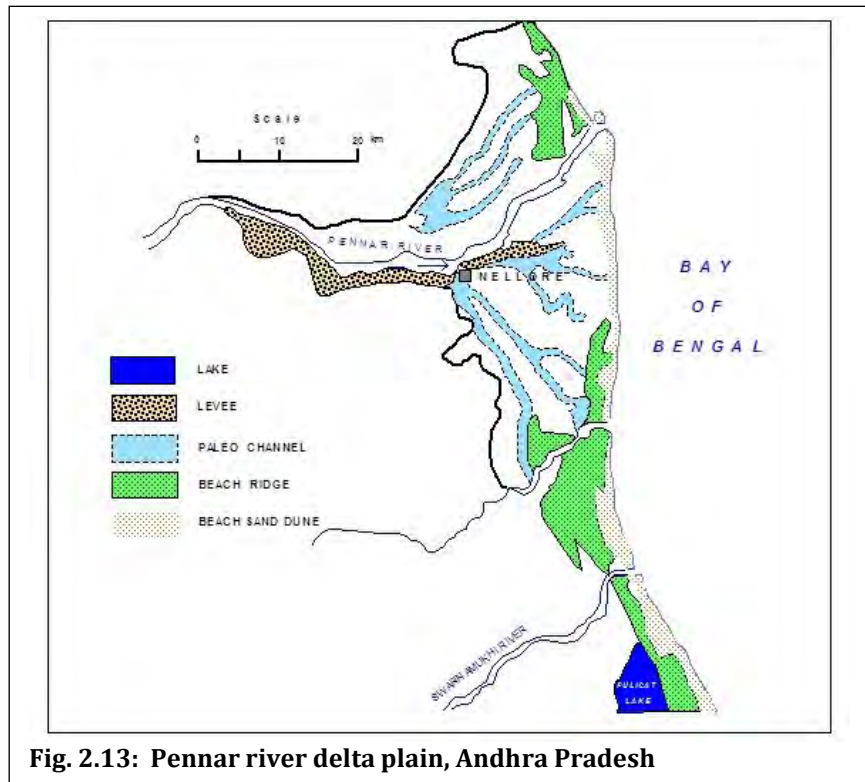


Fig. 2.13: Pennar river delta plain, Andhra Pradesh

Muthukuru-Nellore got developed in marine environment, while the upper deltaic plain in Sangam-Nellore, is developed in fluvial environment (Fig.2.13).

2.3.6 Cauvery Delta Plain

The Cauvery river delta plain is well developed and quite wide spread with straight coast line. The present day active distributary of the delta is located almost at its northern boundary created by the NE swing of the river and the site of active delta building has gradually shifted northwards probably due to siltation of channels and the flood plain (Fig 2.14). There are six distinct abandoned channel-belts indicating the stages of delta building. The western limit of this delta plain is in the upstream of Tiruchirappalli. The delta plain is characterized by a wide range of depositional environment. It is dominated by abandoned inactive distributary channels in its upper delta plain and by tidal flat, marshy lands, palaeo-beach ridges and levees in the areas close to the coast line. Narrow natural levees are developed along the distributary channels. The flood plain of the delta is well drained. Mangrove-marshes are not significant in the delta. They are developed along the tidal channels. Due to progradation of the delta palaeo sand ridges with dunes are well developed. At the back of the beach ridges a narrow belt of tidal flat is developed (Singh and Swamy, 2006).

2.4 Rocky Coast

The parts of Konkan and Kanara coast lines on the west coast exhibit mainly a rocky coast with wave-cut terraces / erosional platforms with sub-vertical eroded rocky cliffs of basalts, gneisses, etc. (Fig.2.15). On the east coast in Visakhapatnam and Srikakulam districts of Andhra Pradesh and Tirunelveli and Kanyakumari districts of Tamil Nadu crystalline rocks of khondalites and charnockites form the coastline (Fig. 2.16)? Rocky coast line is not noticed in the coastal states of Odisha and West Bengal. Kumar et al (2006) demarcated the rocky coast lines of India based on multi-band satellite data interpretations (Table 2.2).

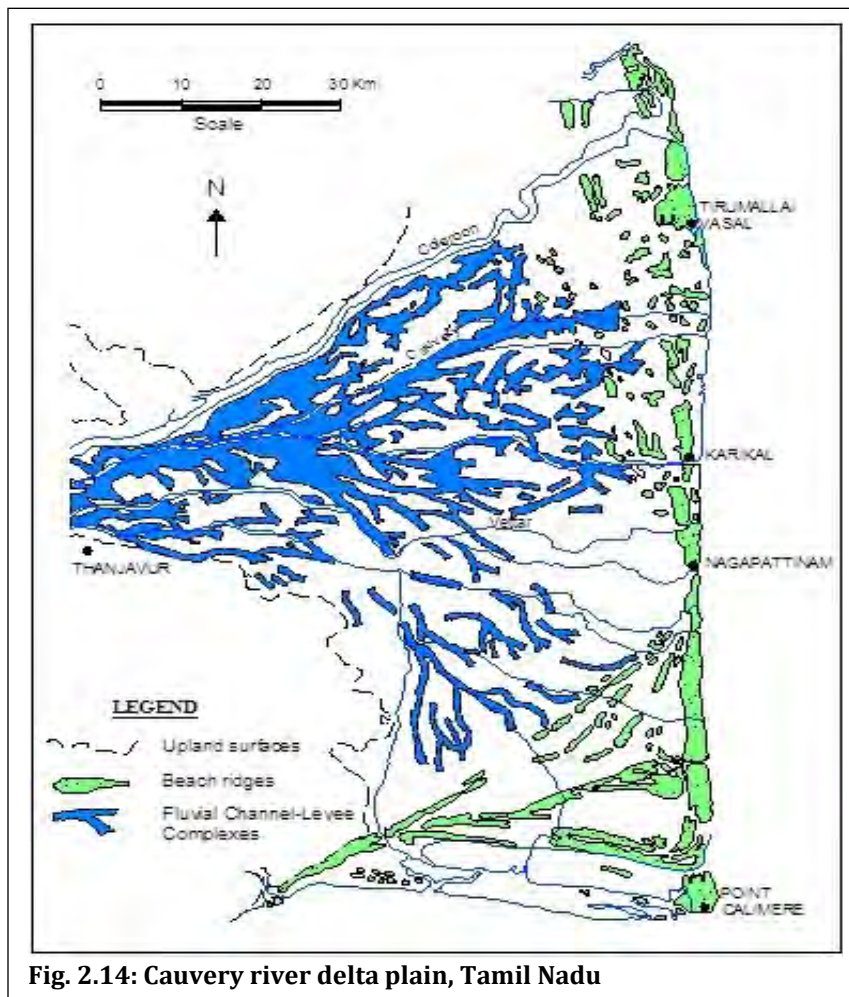


Fig. 2.14: Cauvery river delta plain, Tamil Nadu

Table 2.2: State wise break up of rocky coast line

State	% length of coast	State	% length of coast
Gujarat & Daman & Diu	21	Tamil Nadu & Puducherry	5
Maharashtra	37	Andhra Pradesh	3
Karnataka & Goa	15	Odisha	nil
Kerala	5	West Bengal	nil



Fig. 2.15: Rocky west coast, Maharashtra



Fig. 2.16: Rocky coastline of Visakhapatnam, Andhra Pradesh on east coast (Satellite & Terrestrial view)

3. GEOLOGICAL SETTING

Geological framework has an important bearing on the quality of ground water in the aquifer systems as various geological materials in contact with the formation water control its hydrochemical characteristics. The Indian subcontinent represents various geological formations ranging in age from Archaean to Quaternary. Coastal stretches encircling peninsular India consists mainly of Deccan Basalts and crystalline rocks. In the remaining area, the coastal regions are predominantly underlain by unconsolidated quaternary and tertiary sedimentary formations. A generalized geological map of the country depicting major geological formation is given in **Fig. 3.1**.

The geology of the coastal region of India is as varied as that of the Indian sub-continent with lithological units ranging from recent fluvial and marine deposits to Archaean Crystallines. The evolution of Indian coast has continued through geological past and the impacts of geotectonic movements have left their imprints on the coastal zone of the country. Existing river valleys were truncated, newer active sedimentation areas were created and older sedimentation areas were made passive due to geological and tectonic activities.

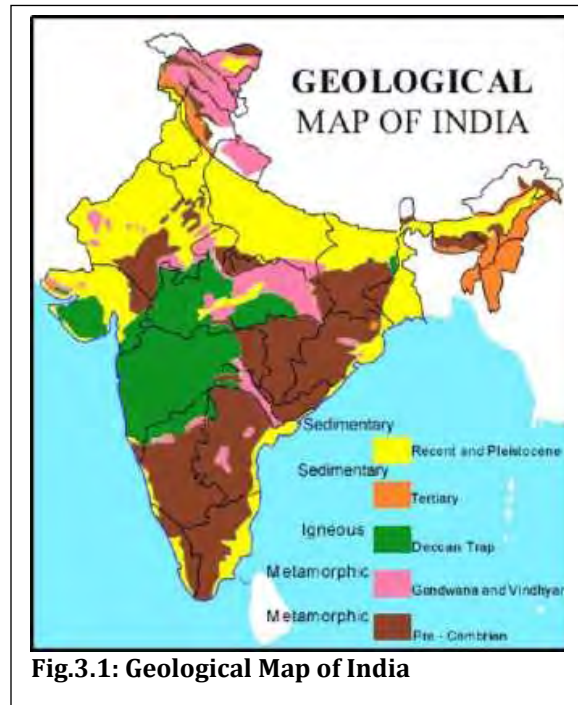


Fig.3.1: Geological Map of India

3.1. East Coast

On the east coast, thickness of alluvium is several hundred metres near the mouths of the major rivers like Cauvery, Krishna, Godavari, Mahanadi, Subarnarekha and Ganga. It decreases inland to a few metres near palaeo or existing delta heads where crystalline rocks occur. The alluvial plains with varying widths occur throughout the east coast up to Ramanathapuram in Tamil Nadu. Underlying the alluvium is a sequence of marine sandstone deposits of Miocene to Pliocene Age followed by basalt flows and Upper Gondwanas resting over the crystalline rocks - the Khondalites, Charnockites and granite gneisses. Important geological characteristics of the coastal zones in various districts along the eastern coast of India are described below in brief:

3.1.1 Tamil Nadu & Puducherry

More than 70 percent of the geographical area of Tamil Nadu State is underlain by crystalline formations comprising charnockites, granite gneisses, khondalites and mixed gneisses with intrusion of quartz veins, pegmatites, dolerite dykes and syenites etc. They mostly outcrop in the western and central parts. In the coastal areas, the crystallines are exposed mainly in the southern parts in the districts of Ramanathapuram, Tuticorin, Tirunelveli and Kanyakumari. The thickness of weathered zone in these crystalline areas varies from a few metres to tens of metres. Underlying the weathered zone in these rocks there are fractures and joints at places. The generalized

geological succession of Tamil Nadu coast is given in Table 3.1.

Table.3.1: Geological Succession along the Coastal Tamil Nadu

Epoch	Stage/Formation	Lithology
Recent Pleistocene		Soils, alluvium & beach sand, boulder conglomerate, Older alluvium and laterite
Pliocene	Karaikal beds	Sand and clay with fossils
Miocene	Cuddalore sandstone Niniyur Ariyalur	Mottled and friable sandstone, buff coloured, clay and gravel Arenaceous limestone and sandstone and clay
Cretaceous to Upper Carboniferous	Tiruchirappalli Uttatur Satyavedu Sriperumbudur	Sandstone, clay and shell limestone Basal limestone, coral clay and sandy bed Ferruginous sandstone and conglomerate Clay, shale and feldspathic sandstone
Unconformity		
Archaean		Gneissic complex, charnockite, granite and associated basic and ultra-basic intrusives

In coastal Tamil Nadu, Upper Gondwanas are found as patches in Tiruvallur, Kancheepuram and Ramanathapuram districts. They are spread in Uttiramerur-Madurantakam, Kancheepuram-Kottivakkam and Sriperumbudur-Satyavedu areas. Near Sriperumbudur, about 40 km WSW of Chennai, the Lower stage known as Sriperumbudur Beds are exposed. They comprise white to pink clays, shale and feldspathic sandstones. The Upper stage forms the Satyavedu Beds exposed 55 km NW of Chennai. The formations in this stage comprise purple mottled ferruginous sandstones and conglomerates. Further south the Upper Gondwanas are found in Tiruchirappalli district between Maruvattur and Neykulam. They comprise basal conglomerate, sandstone, micaceous shale and grit with calcareous concretions. In the southern coastal districts the Upper Gondwanas are encountered in Sivagangai district between Vaigai and Manimuktar rivers around Sivagangai-Tirupattur area. The sediments comprise basal boulder beds and conglomerates at the base followed by micaceous sandstones and alternating grits and variegated shales in the upper part (Krishnan, 1982; Balasubrahmanyam, 2006). Gondwanas have also been encountered in the deep boreholes in Pudukottai and Ramanathapuram districts.

Cretaceous formations are found in three patches in Tiruchirappalli-Cuddalore- Puducherry area. These exposures are separated by Vellar and Ponnaiyar rivers. Such formations outcropping in the northwestern part of Puducherry are Ramanathapuram Formation and Vanur Sandstone of Lower Cretaceous age and Ottai Claystone and Turuvai Limestone of Upper Cretaceous age. Ramanathapuram Formation comprises alternate layers of sands, sandstone and carbonaceous-claystone with thin seams of lignite. It is encountered in boreholes located north of Varahanadi River. The thickness of this formation ranges from 55 to 250 m. At Ramanathapuram it is unconformably overlain by the Tertiaries- the Cuddalore formation. In other areas Vanur Sandstone - the oldest Upper Cretaceous unit overlies the Ramanathapuram Formation. Vanur Sandstone comprises coarse grained friable grayish white pebbly sandstone, feldspathic at places.

Veins of aragonite and thin intercalations of dark grey to greenish grey shales are also present. Its thickness varies from 52 to 152 m in the boreholes drilled. The overlying Ottai Claystone is exposed in the area north of Gingee River. It comprises black to greenish grey claystone with a few bands of limestone and calcareous and micaceous silt and siltstone. Thickness encountered ranges from 88 to 231 m. The uppermost unit of Upper Cretaceous - the Taruvai Limestones is exposed and comprises fossiliferous, cement grey limestone with a few bands of sandstones. It is highly conglomeratic with pebbles of quartz at places.

In Cuddalore district also the Upper Cretaceous formations outcrop as isolated patches north of Vridhachalam. They comprise sandstone, shale and clays and are equivalent to Ariyalur stage of Tiruchirappalli district. A small patch of Cretaceous rock exposure is encountered west of Thanjavur also.

The Tertiary formations occupy the coastal strip of Puducherry, Cuddalore, Thanjavur and Ramanathapuram districts, attaining a maximum width about 75 km. In Puducherry area the Tertiary sequence overlying the Cretaceous formation is of Kadapperikuppam Formation, Manaveli Formation and Cuddalore Formation. The Kadapperikuppams of Paleocene age comprise yellowish gray to dirty white calcareous sandstone, with thin lenses of clay and shales and bands of shell limestone. They are exposed towards northwest of Puducherry. The Manavelis of Upper Paleocene age comprise yellowish brown calcareous sandy clay and shales with pieces of thin shell and limestone bands. They are exposed as a NE-SW trending 10-12 km wide strip west of Puducherry. The Cuddalores of Mio-Pliocene age comprise a thick succession of pebbly and gravelly coarse grained sandstone with minor clay and also with seams of lignite. They outcrop under a cover of ferruginous laterite at higher levels. Thickness of this unit varies from 30 to 450 m.

In Cuddalore district, the Tertiaries consist of red, yellow and mottled ferruginous Sandstones, clay and pebble beds. They are represented by Cuddalore sandstone resting over the Niniyur and Ariyalur formations of Cretaceous age forming the marker bed in the area.

Further south, in Karaikal area, the Tertiaries are represented by Karaikal Bed and Cuddalore sandstone. The Karaikal Bed outcrops only in localized patches in this area, overlying the Cuddalores. The Karaikals comprise alternating layers of sand and clay with gravel and pebbles at places. Within this, thin sandstone bands of argillaceous and conglomeratic characters at places are also noticed. The Tertiaries continue further south through Pudukkottai up to Ramanathapuram district exposed in the north-western parts as broad elevated high ground with a thick laterite capping.

The vast coastal plain in the Cauvery region, extending from Puducherry in the north to Gulf of Mannar in the south, has an alternating NE - SW trending depressions and ridges. From south to north, the Ramanathapuram depression, the Devakottai - Mannargudi Ridge, Kumbakonam - Shirkazhi Ridge in the interior, separates Thanjavur Depression and the Ariyalur - Puducherry Depression successively. Near the coast, the Tirutturaipoondi - Vedaranyam Ridge, Tirutturaipoondi Depression, Karaikal High, Tranquebar Depression and Madanam High occur successively. The basement depth contours are shown in **Fig. 3.2**.

In Tamil Nadu, there is a strip of alluvial cover all along the coast having a maximum width about 75 km in Cauvery delta between Cuddalore and Nagapattinam. The Quaternary sediments in the Tamil Nadu are represented by the laterite and older alluvium of Pleistocene Age and the Recent Alluvium, 'Teris' and coastal sands. Cauvery alluvium occupies a major part of Thanjavur and Nagapattinam districts. Besides, the prominent alluvial sediments occur in Tiruvallur, Kancheepuram, Vellore, Pudukkottai and Ramanathapuram districts. The river alluvium of Vaigai and Gundar rivers comprising gravel, sand, silt and clay, light to medium grey in colour was deposited under fluvial and fluvio-marine and aeolian environments. Its thickness varies from 15 to 75 m. Sub-Recent marine formations consisting of hard calcareous sandstone and grey clays are seen in Rameswaram Island and coastal area of Ramanathapuram district. In this area, alluvium occurs in tidal flat, estuary, lagoon, barrier ridge, mud flat, natural levee and flood plain. The Older alluvium with laterite granule and kankar occurs towards north of Vaigai river and Younger alluvium towards south.

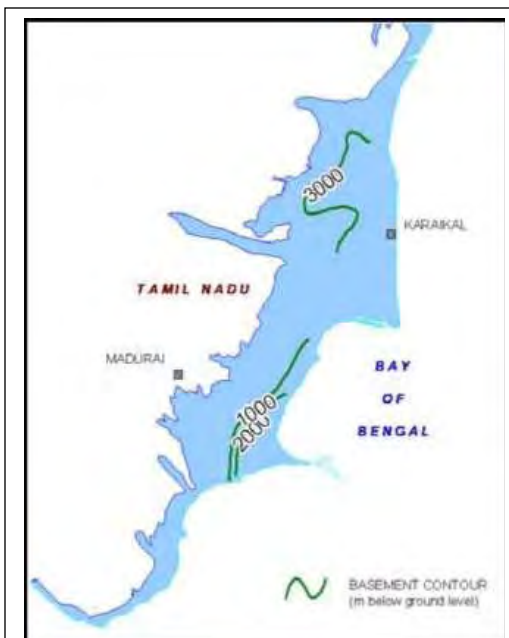


Fig.3.2: Depth to Basement in Cauvery Coastal Plain, Tamil Nadu

Another important Quaternary Formation is the aeolian deposit-the sand dunes and Teri dunes. They are common in the coastal area of Tamil Nadu. The extensive spread of dune complex is observed south of Nagapattinam, around Rameswaram Island, Mandapam, and Mangudi to Tuticorin. The Teri sands dunes also occur along the coast of Tirunelveli district.

3.1.2 Andhra Pradesh

The coastal tract of Andhra Pradesh is the receptacle of vast pile of sedimentation during recent age with several transgressions and regressions. The alluvium comprises a thick sequence of clay, silt, sand and gravel in various proportions, underlain by Tertiary sandstones at varying depths ranging from 9 m towards upper deltaic plain to 205m in central part of Godavari delta which is not encountered even down to 600 m near coast. However, in non-deltaic coast the alluvium directly lies in Archaeans, though at places rests on Tertiaries. The generalized geological succession in coastal tract and environs is given in **Table 3.2**.

The thickness of alluvium is more in Godavari and Krishna deltas ranging up to 600 m (basement not touched). This is underlain by Tertiary/Gondwana sediments. In Pennar delta its thickness ranges from 28 to 150m. However, it is limited in thickness towards north of Godavari delta viz., Visakhapatnam, Prakasam and Srikakulam districts. The width of alluvial plain varies from few meters to about 90 km. In three major deltas, the width is > 20 km. It is moderate in non-deltaic sedimentary areas viz. Srikakulam and Prakasam while it is thin in Vizianagaram and Visakhapatnam districts.

Table 3.2: Generalized Geological Succession of the Coastal Area, Andhra Pradesh

Age	Group/ Super Group	Formation	Areal distribution (districts)
Recent- Sub-Recent		Alluvium	All along the coast. Deltaic alluvium confined to Nellore, Guntur, Krishna, West Godavari and East Godavari.
Sub-Recent		Laterite	Nellore, Prakasam, Srikakulam
Mio-Pliocene		Rajahmundry	East Godavari, West Godavari
Lower Cretaceous	Upper Gondwanas	Tirupati Vemavaram Kandukuru	West Godavari, Nellore, Prakasam, Guntur.
Archaean	Eastern Ghats Dharwars Supracrustals	Khondalitic suite, Nellore schist belt, granites & associate groups	Nellore, Prakasam, Visakhapatnam, Vizianagaram, Srikakulam

3.1.3 Odisha

In Odisha, the coastal plain is bordered on the west by the Archaean crystalline basement rocks, viz., granite, gneiss, charnockite, khondalite and quartzite of the Eastern Ghats. The eastern boundary of the Eastern Ghats is believed to be a fault responsible for the formation of the coastal depression. In the deltaic plain and coastal tracts the basement tectonics are hidden under the thick cover of Quaternary and Tertiary sediments. The coastal tract has several ridge and depression structures which are possibly the surface expression of numerous fault zones (Om Prakash et al, 2001). The generalized geological succession of Odisha coast is given in **Table 3.3**.

Table 3.3: Geological succession of coastal Odisha

Age	Lithology
Quaternary	Dune sands, alluvium (clay, silt gravel and sand) and laterite
Tertiary	Clays, gritty sandstones, gravels, loosely cemented sandstones, arenaceous limestones and clay stones
Mesozoic	Sandstones, shales ,grits and conglomerates and coal seams
Archaeans	Granite, granite gneisses, charnockites and khondalites, schist, phyllite etc.

In coastal Odisha, the Upper Gondwanas locally known as Athgarh Beds are exposed in the western part, about 60 km west of the coast line near Athgarh located north of Bhubaneswar and west of Cuttack at the Mahanadi delta head. They comprise sandstones, grits, conglomerates and white or reddish clays. Upper Cretaceous formations are quite thick and the exposures are obscured by laterite and alluvium. They are traversed by basalt dykes. In coastal area of Odisha, the Tertiaries, known as Baripada Bed, occur 20 km inland as a coast-parallel 10 to 25 km wide strip, under a thin alluvial cover in Mayurbhanj district. They comprise loosely cemented sandstone, limestone and clay. According to Mahalik (2000) there was a lull in sedimentation during Upper Pliocene and early Middle Pleistocene due to the initiation of ice age. The regression exposed the Baripada Bed. It got eroded, weathered and lateralized. In Mahanadi delta the marine

Tertiaries occur under a thick sequence of Pleistocene sequence. The Tertiaries are dark gray in colour, overlying unconformably the Precambrian bedrocks in Delang to Bhagabanpur section. The Tertiary sequence thickens towards the coast. In the coastal tract of Odisha Recent to sub-Recent Sediments were deposited by various rivers to build up deltas at their mouths, which later on got combined. The lithology is characterized by cyclic sedimentation of sand and gravel with subordinate clay. Besides, alluvium of recent age occurs in numerous narrow disconnected pockets adjoining most of the river courses. The maximum width of the alluvial plain is about 100 km wide covering more than 20, 000 sq. km in Mahanadi delta area. The thickness of alluvium is about 150 m near the coast.

3.1.4 West Bengal

In West Bengal, Tertiaries are not exposed in the coastal area. They are encountered in deep bore holes as a thick sequence. They become thicker in southerly direction and the strata which are generally estuarine in north become progressively more marine towards south (Krishnan, 1982). Geological Succession of West Bengal Coast is given in **Table 3.4**.

Table 3.4: Geological Succession in Coastal West Bengal

Epoch	Formation	General Lithology	Depositional Environment
Recent/Pleistocene	Bengal Alluvium	Sand, clay, silt	
Pliocene	Debagram Formation	Claystone Siltstone	Marine deltaic
Miocene	Pandua formation	Shale	Estuarine to shallow marine
Oligocene	Memari formation	Shale, Sandstone	Burdwan formations are fresh water deposits of Oligocene- Miocene age.
Eocene	Upper Kopili formation Middle Sylhet formation Lower Jalangi formation	Shale Limestone, Sandstone, Carbonaceous shale	Brackish to shallow marine Shallow marine Top: Marine Middle: Fresh water Base: marine
Cretaceous	Upper Ghatal formation Middle Bolapur Lower formation	Shale, Calcareous Claystone Granite wash Trap wash	Brackish to littoral Estuarine at top rest Fresh water
Jurassic	Rajmahal formation	Basalt Trap	Sub aerial/volcanic

The thickness is about 5000 m near Port Canning and increases further south. In general, the sediments in coastal part of West Bengal thicken southeastwards with the basement surface dipping gently towards east with control of NNE to NE trending faults. The sediments are known to attain a thickness of more than 8000 m.

Recent findings (Sikdar, 2000) indicate the top of Tertiaries in and around Kolkata at depths beyond 150 m which increase towards the coast. Further, in East Medinipur district the exploration carried out under UNDP project indicates the presence of the grey clay Tertiary top at depths within 100 to 160 m below ground.

The Bengal basin is divided into 4 tectonic zones, viz., the basin margin, the platform slope, the hinge zone and the deep basin. The western margin of the basin is faulted-contact basin boundary with the peninsular shield. The platform part adjacent to the basin margin is characterized by the fluvial sedimentation. With the in southern in southern part of West Bengal progressive sinking of the basin Floor and the development of the basin boundary fault, basin assumed the shape of a graben like elongated trough. There was outpouring of lava flows from Middle Jurassic to Early Cretaceous period which formed the base for the Tertiary sedimentation. Deep basin towards east/southeast of the Kolkata-Ranaghat-Mymensingh hinge zone is characterized by rapid subsidence and thick filling of Tertiaries up to 7 km depth.

The geological formations in the coastal tract of West Bengal forming part of the Lower Ganga plain comprise sediments deposited under fluvial, lacustrine and marine environments. These sediments are of widely varying grain size depending on the palaeo depositional environment. The coarser material are usually derived from fluvial environment, while the finer material are usually deposited beyond the neritic zone in the deep seas. Deltaic sediments in the outfall area were formed by materials deposited both, in sub-aerial and sub-aqueous environment and therefore are of widely varying grain size from coarser than gravel to clay. Generally, material of the size of gravel and above are confined to the basal or lower part of the sedimentary cycle. Relatively coarse sediments are found in beaches, bars and open bays while the finer sediments are concentrated in active tributaries such as in marshes, stagnant bays and abandoned channels (Bhattacharya et al, 2004).

The thick pile of Quaternary sediments overlying the Tertiaries comprises sands of various grades, silt, clay and occasional gravel beds. Both Recent and Pleistocene sediments have been deposited successively by the river Ganga as flood plain deposits. The top of the Quaternary alluvium is, in general, capped by a thick (thickness varying from 20 to 60m) clay whose thickness increases towards south. Its age is considered to be Holocene. A thick grey to steel grey coloured clay bed generally occur beyond 200 m bgl. The age of this clay bed is considered as Pliocene (Upper Tertiary). The sediments overlying the grey clay up to the top (near surface) clay belong to Pleistocene. The Pleistocene sediments are coarse clastics comprising fine to coarse sand and gravel with clays occurring as lenses. The thickness of Quaternaries as recorded in ONGC boreholes in the coastal tract varies from 280 to 585m. It is 445 m at Raghunath, 459m (approximately) at Bakultala, 585 m at Diamond Harbour, 457 m at Port Canning, 365 m at Bodra and 280m at Deganga. The thickness of Quaternaries in Kolkata area is about 296 m (Chatterjee et al, 1959 and Sikdar et al, 2001).

In coastal part of Medinipur district, thickness of Quaternaries is around 150 to 180 m. The grey clay bed demarcating the top of the Mio-Pliocene deposit is persistent throughout the area and is considered as 'marker bed' which separate the Quaternaries from the Tertiaries. The Quaternaries have been classified as Older and Newer alluvia. The Newer alluvium is predominantly argillaceous and grey in colour. It comprises clay, silt and occasional fine sand. Its areal extent is limited to the coastal plains and in the marginal alluvial plains. Its thickness varies between 10 and 60m in the north west-south east direction. The newer alluvium is devoid of any significant granular zones. The older alluvium exhibits characteristic sheds of yellow to reddish brown. It comprises sand-silt and clay. It is quite extensive in coastal plains. Its thickness varies between 50m in the northwest and over 90m in the south east coastal plains.

3.2 West Coast

In general, the west coast up to the Gulf of Khambat in Gujarat is dominated by the presence of crystalline rocks with extensive linear fault systems parallel to the coast. Sediments on the west coast are minimal owing to the fact that only a limited part of the peninsula with high relief terrain is drained before being deposited into the Arabian Sea. Also, the shifting of the west coastline through geologic time was minimal. Further north, on the west coast, the Kathiawar sub-peninsula (Saurashtra) is underlain by sedimentary deposits and basaltic flows resting over the Proterozoic rocks. Sedimentary deposits controlled by tectonics and palaeo-climates got accumulated in the tectonic depression of Kachchh, Cambay and Narmada. Brief accounts of the geological framework of western coast are given below:

3.2.1 Kerala

A thick sequence of Tertiary formation is encountered in the coastal plains of Kerala. The oldest Tertiary sediments are known as Alleppey Beds. They are highly carbonaceous clay and sandy clay beds encountered in the depth range of 475 to 600 m bgl in boreholes drilled by CGWB at Nirkunnam, Trikunnapuzha, Kalarcode and Kattoor along the coast of Alappuzha (Alleppey) district. These beds contain fine to medium sands intercalated with dark brown to buff coloured clay which are carbonaceous and with thin seams of lignite. These are distinctly different from the overlying Tertiaries in their lithological character and could be easily identified in borehole lithological samples and electric log data. The exact age of this formation is not known since no systematic dating was carried out. However, the results of limited paleontological studies carried out by Birbal Sahni Institute indicate an interesting fossil assemblage belonging to Eocene Period. Since this formation is encountered only in the deep bore holes in and around Alleppey coast it was termed by CGWB as Alleppey beds. The geological succession is given in Table 5.7.

The Tertiaries immediately overlying the Alleppeys were earlier known as Warkali Beds. Detailed study through deep boreholes drilled by CGWB helped differentiate the bottom part as Vaikom Bed. These beds were earlier considered as Warkali Bed only due to its resemblance. This was first encountered in the deep boreholes drilled by CGWB in Alappuzha and Ernakulam districts. Vaikom Bed is found to be older than the Warkali bed underlying the Quilon limestone almost all along the sedimentary basin between Kollam (Quilon) and Cochin. Vaikom Bed was found to be older than the Quilon limestone. It outcrops all along the eastern peripheral area of the sedimentary basin. Since the type area of this formation was near Vaikom town, CGWB termed it as Vaikom Bed (Raghava Rao et.al, 1976). This is the only formation occurring almost all along the sedimentary basin north of Quilon. Later on ONGC referred it as Mayyanad formation (Mitra et al, 1983). It is made up of coarse to very coarse sands, gravel and pebble beds with alternating clay layers. Lignite is also encountered in this formation. The thickness of this formation ranges from a few meters to 238 m.

Overlying the Vaikom Bed is the Quilon Bed. It comprises a sequence of hard limestone, carbonaceous clay, and sand of marine origin which is seen south of Cochin and along the major portion of Kuttanad area. This bed is taken as a marker horizon for delineating the older Vaikom and younger Warkali beds by CGWB. The Quilon limestone is exposed in the cliff sections of Padappakara near Kundara, Paravur and in the well sections in and around Mayyanad area all in Quilon district. The bed dips towards NW to West and the thickness is between 6 and 125 m with

thickest portion seen in and around Nirkunnam. This is the only rock unit among the Tertiaries which are dated reliably by microfossil studies as Burdigalion age (Krishnan, 1988).

Table 3.5: Generalized geological succession along Kerala Coast

Period	Epoch	Formation	Lithology & areal distribution
Quaternary	Recent	Alluvium	Sand and clay seen along the coast and the flood plain deposits of Kuttanad and Kole lands.
	Sub-recent	Laterite	Laterite capping on the sedimentary formations.
Tertiary	Lower Miocene	Warkali	Sandstones and clays with thin band of lignite, south of Cochin all along the coast & western portion of Kuttanad.
		Quilon	Limestone and clays, south of Cochin
	Oligocene to Eocene	Vaikom	Sandstones with pebbles and gravel beds, clay and thin bands of lignite, all along the sedimentary basin.
	Eocene	Alleppey	Carbonaceous clay and sands, encountered only in boreholes in Alappuzha coast
Precambrian	Archaean		Crystalline basement of khondalites and charnockites.

The youngest among the Tertiary sequence is the Warkali Bed found south of Kochi. It is exposed in the cliff sections of Varkala beach in Trivandrum district, where it derived the name Warkali. The thickness of this formation ranges from 4 to 140 m and the thickest portion is seen around Alleppey. It is made up of fine to medium grained sand with clay and intercalation of lignite seams. The age of this formation is considered as Upper Miocene (Krishnan, 1982). Nair et al (1986) attribute Lower Miocene age to this bed. The paleontological studies made by Birbal Sahni Institute of Paleobotany on the samples from this horizon in Arthungal borehole indicates a Lower Miocene age (Ramanujan & Rao, 1975). Since the underlying Quilon bed is of Burdigalion age (Lower Miocene) it is inferred that the Warkali Bed might have been deposited during the Late Lower Miocene period. The geological cross-section showing the disposition of Tertiary beds is given in **Fig. 3.3** and the lateral extents is given in **Fig. 3.4**. The studies carried out in the coastal area of Kerala indicate that the sediments were deposited in a faulted basement. It is also inferred that there could have been lateral movements along existing weak planes, which brought thicker sediments by the side of thinner ones. Due to the near horizontal dip of the sediments this may not get reflected in the hydraulic continuity. It is also suspected that the basin was a sinking one with the sediment load. The sedimentary formation of this area is still unconsolidated and hence smaller movements subsequently might not have affected the beds. The studies carried out by ONGC along off shore Kerala have brought out valuable information on the basin configuration and tectonics. The sedimentary thickness increases from south to north in the off shore.

There is a major basin margin fault almost parallel to the coast in the off shore. Two principal faults run in NE- SW direction. Some of the NW- SE faults are observed to be disturbed by E-W faults. The alluvial formations are represented by back water and lagoonal deposit of black clay, fine to medium grained pure white quartzite sands, dirty white silt and silty sands of the flood plains, grey to dark grey beach sands and red Teri sands. These deposits have been brought down by the west flowing rivers which debouch into the back water lagoons and estuaries and get reworked by the waves and tides.

[illegible]

Laterite capping is wide spread and extensively developed. Its thickness is of the order of 5 to 15 m. In Malappuram district, laterite cappings upto a thickness of 20m are seen over the dissected plateau between Kottakkal and Manjeri. Laterites form a definite horizon in the geological sequence. At places part or the whole of the laterite has been eroded before the deposition of coastal alluvium.

3.2.2 Karnataka

The geological formations belonging to Archaean group of rocks in the coastal areas of Karnataka are composite gneisses, migmatites, granite gneisses and granites with occasional quartz veins. They show low degrees of metamorphism and are fine to medium in nature. The Dharwar rocks are represented by chlorite schist, amphibolite, quartzites, phyllites, limestones, dolomite and intrusives of basic nature. The coastal block faulting and uplift of Western Ghats left the effect of neotectonics in the coastal tract, resulting in several major lineaments. The Karwar coast is structurally controlled including the bays, beaches, drainage pattern and estuary. It is extensively affected by igneous activities. There are NE-SW trending dykes, crisscross pegmatite intrusions and folded granite gneiss. Hanamgond and Mitra (2007) identified a number of lineaments crisscrossing the area. They are of varied length and orientation. The lineaments are identified along the river course, creeks, hill ridges and they are linear and continuous. It was inferred that the coast is structurally controlled. The generalized geological succession is given in Table 3.6.

Table 3.6: Geological succession along Karnataka Coast

Epoch	Formation	Lithology
Recent		Alluvium - both coastal along the coast and creeks and fluviatile along all major drainage courses occur as narrow strips
Tertiary to Sub-Recent		Laterites
Archaean	Dharwar System	Volcanics and meta-sediments traversed by basic intrusive rocks
	Peninsular Gneiss	Gneissic Complex comprising of gneisses migmatites and granites traversed by basic intrusive rocks

3.2.3 Goa

Goa State has about 101 km long coast line distributed in two districts, viz., North Goa and South Goa. In the coastal areas geological formations range in age from Archaean to Sub-Recent and Recent. The geological succession of the area is given in **Table 3.7**. Goa is mostly covered by the rocks of the Goa group belonging to Dharwar super group of Archaean to Proterozoic age except for the narrow strip along the northeastern part occupied by the Deccan Traps. The rocks of Goa group are folded, faulted and intruded by granite gneisses, hornblende granite and porphyritic granites followed by basic intrusives of post Archaean ages. Seventy percent of the area is covered by laterite capping. The coastal alluvium occurring along the coastal plains constitute about 1% of the geographical area.

Table 3.7 Geological succession in Goa

Epoch	Formation			Lithology
Sub-Recent to Recent				Beach sand, alluvium and laterite
Upper Cretaceous to Lower Eocene	Deccan Trap			Basalt
Proterozoic (?)	Basic intrusive			Dolerite and gabbro.
Proterozoic	Acidic Intrusives.			Pegmatites, quartz veins, porphyritic granite, Feldspathic granite, granite gneiss.
Proterozoic to Archaean	DHARWAR SUPERGROUP	GOA GROUP	Valegeri Formation	Meta basalt, meta greywacke.
			Bicholem Formation	Banded ferruginous quartzite, manganeseiferous chert breccia with pink ferruginous phyllite, pink ferruginous phyllite, quartz chlorite amphibolite schist
			Sanvordem Formation	Argillite, quartzite, tilloid meta-greywacke.
			Barcem Formation	Meta gabbro, peridotite, talc chlorite schist. Variegated phyllite, quartz-chlorite schist, quartzite, quartz-sericite schist, phyllite, quartz porphyry, schistose and vesicular meta basalt.

The area has undergone three sets of folding and deformation. The first fold movement resulted in the WNW-ESE trending roughly hinged asymmetrical fold confined to the south western parts of Goa. The second fold movement was the most powerful and was responsible for development of a series of NW-SE trending oppressed folds overturned to the south west and doubly plunging. The third movement is observed only in the north eastern part of Goa where the rocks have been folded in the form of a north westerly plunging up right open synclinal fold and exhibits a plunge of about 12° -15° due NNW. The straight coastline of Goa is suggestive of major fault along the west coast. Perpendicular to this fault a number of weak planes have been developed in west and WSW directions and along these planes, the rivers Terecol, Chapora, Mandovi and Zuari flow to meet the Arabian Sea. The Western Ghats also represent the prominent fault direction.

3.2.4 Maharashtra

The geological formations ranging from Archaean to Recent occur in the coastal region. A generalized geological sequence is given in Table.3.8.

Dharwarian meta-sediments belonging to the Lower Precambrian period are the oldest formation occurring in the Coastal Maharashtra. These are mainly found in the Ratnagiri and Sindhudurg districts only. These formations are represented by ferruginous phyllites, pink banded ferruginous quartzite, micaceous quartzite, mica schist, amphibolite, pegmatite, granite and granite-gneiss. These do not possess any primary porosity and permeability. The secondary porosity develops in these rocks by weathering and presence of joints & fractures. The ground water occurs under

unconfined conditions only in the weathered and fractured parts, which extend down to 10 to 15 m depth. Yield of wells in these formations range between 5 and 20 m³/day. Pumping test dugwells in these formations have indicated that the specific capacity ranges from 0.5 to 80 lpm/m. The permeability and transmissivity ranges from 8 to 56 m/day and 8 to 57 m²/day respectively.

Table 3.8: Geological succession along Maharashtra Coast

Recent to sub recent	Alluvium	Soil, Beach sand, River sand, Mud flats	
Pleistocene		Laterite	
Miocene	Tertiaries	Shale with associated peat and pyrite nodules	Ratnagiri District
Cretaceous to Eocene	Deccan Trap	Basalt and associate rocks	
Upper Precambrian	Kaladigas	Conglomerate, Cherty sandstone, Quartzite, Shale associated with Limestone	Ratnagiri and Sindhudurg Districts
Lower Precambrian	Dharwar System	Pegmatites, Quarts veins, basic dykes, granite gneisses, biotite & hornblende schiest, Mafic & ultra mafic rocks, amphiblites	Ratnagiri and Sindhudurg Districts

The Kaladgis, which overlie the meta-sediments, comprise of ortho-quartzite, sandstone, shale with minor intercalation of conglomerate and limestone. These formations also occur in Ratnagiri and Sindhudurg districts. Ground water in these formations occurs under unconfined conditions in the weathered mantle and long the joints in sandstone, shale and limestone. Yield of wells in Kaladgis range from 10 to 40 m³/day. The transmissivity of the near-surface aquifer is about 120 m²/day.

The Deccan Trap occurs in almost entire coastal tract. The Deccan Trap occurs in the form of lava flows, which are predominantly of “aa” type. The flows have a basal section of dense dark basalt and top section and top section with elongated vesicles and flow breccia. The ground water mostly occurs in the upper weathered and jointed/fractured parts, which generally extend down to 15 to 20 m depth. The Deccan trap generally forms good aquifer in the valleys. The confined aquifers below 30m depth occur at places. Yield of wells in jointed & weathered massive basalt range between 15 & 80 m³/day, whereas in vescicular & amygdaloidal basalts it ranges between 45 & 90 m³/day. Tansmissivity of these aquifers range from 18 to 38 m²/day. The discharge in deeper aquifers varies between 0.9 to 1.7 lps with drawdown ranging from 0.8 to 1.1 m.

Along the Konkan coast underlying the Beach deposits and at places exposed as outcrops along the coast, a semi consolidated calcareous sandstone occurs which is coarse grained and gritty. The cementing material is calcareous and the embedded drains are gravel-grade mixed with pieces and fragments of shell. These rocks are locally known as Karal and are Mio-Pliocene in the age. These are observed between Ratnagiri and Wada Mirva near Ratnagiri and other places along the coast. The observed thickness of the -formation is up to 10 m at places but may be more at some places. The ‘Karal’ forms a distinct local hydrogeological unit, which yields good discharge to dug wells. The quality of water is slightly brackish and is locally used for horticulture purposes

(Coconut/Arecanut gardens). The pumping test conducted on 2 dug wells indicated unit area specific capacity as 33.81 lpm/m.

All along the Konkan coast a narrow strip of unconsolidated beach sands, varying in width from a hundred metres where the hills form a sea face, to a few hundred metres where the coastline has flatter topography, occurs. Wherever the coastal topography is flatter the beach sands merge landwards into low-lying mud flats which may extend a few km. inland. The depressions in such mud flats form saline lands. The coastal alluvium, wherever locally extensive assumes importance as moderate ground water reservoir. In Thane district the coastal alluvium occurs from north of Chikhaley to Dahanu and extends to Palghar, Virar, Vasai and Nalasopara in the south. The beach sands are less than half km. wide but the mud flats have width up to 5 km. and thickness up to 36 m. It comprises clay, silt, sands, and gravel. The yield potential of dug wells range from 150 to 900 m³/day in winter and 100 to 230 m³/day in summer. The quality of the ground water is fresh in the elevated lands (EC 600 to 2000 μ mhos/cm) but brackish to saline (EC up to 4000 micro mhos/cm) in lowlands.

In Raigad district, significant coastal alluvium occurs only around Uran and Srivardhan, where it is 3 to 5 km. wide and less than 10 m. thick. Ground water in shallow dug wells is fresh to brackish and the yield less than 100 m³/day.

In Ratnagiri district beach sands occur as disconnected belt south of Raigad to Ratnagiri which is less than 300 m wide. The thickness varies between 1 and 8 m. The specific capacity of existing dug wells is reported to be around 200 lpm/m of drawdown and average permeability of 90 m/day. The quality of water is slightly brackish near creeks.

In Sindhudurg district significant coastal alluvium occurs south of Achra creek and extends through Malvan up to Devgad and Kelus to Shiroda. It comprises brownish buff coloured sands with thickness between 5 and 15 m. and maximum width up to 1 km. The yield of open wells is between 20 and 40 m³/day and the quality of water is fresh to brackish.

The fluvial alluvial deposits occur along river courses and are locally significant hydrogeological units wherever these have adequate thickness (10 m.) and some areal extent. These generally comprise silts, clays, sands, gravels and occasionally cobble beds. The coarser granular strata like sand, gravels, pebbles beds when occur below water table form productive aquifers but have generally limited areal extent as these form lenses embedded in finer strata. If the alluvium has considerable thickness say between 10 and 40 m the deeper sand lenses occurring below clay layers act as semi-confined aquifers. In many Kankar beds are a common occurrence within the alluvium. The quality of ground water in areas where alluvial thickness is small (less than 10 m) is generally fresh to slightly brackish but in areas where the alluvium is thicker and poorly drained the ground water quality is brackish or even saline.

In the Konkan coastal districts, local patches of alluvial deposits occur along the courses of Vaitarna and Ulhas Rivers (Thane). Patalganga. Amba and Kundalika rivers (Raigarh), lower reaches of Vaishishti, Shastri, Kajvi, Machkundi and Karni rivers (Ratnagiri) and lower reaches of Wagothan, God, Karli and Terekhol Rivers (Sindhudurg) and their tributaries. Due to higher topographic gradients the extent of alluvial deposits is rather restricted and the thickness along the riverbanks seldom exceeds 4 to 6 m.

3.2.5 Gujarat

The Jurassic and Cretaceous formations of Gujarat include Pachham, Chari, Katrol, and Bhuj (Umia) series in Kachchh, Dharangadhara and Wadhwan sandstone in NE Saurashtra and Bagh beds along Narmada River. The Bhuj series comprise dominantly friable and soft, medium to coarse grained sandstones. These formations cover a large part of Kachchh. In the coastal area they outcrop near Lakhpat in the extreme NW part and extends up to west of Anjar. In Saurashtra coastal area, these rocks outcrop NE of Morvi. The Tertiary formations are of marine shelf facies, attaining a thickness of 600 m towards south-west. The sequence comprises the following Series: Khari, Kankabati and Porbandar ranging in age from Miocene to Pleistocene. The generalized geological succession of Kachchh area is given in **Table 3.9**.

Table 3.9: Generalized Geological Succession of Kachchh, Gujarat

Age	Epoch	Series (Biostratigraphic units)	Formation (Lithostratigraphic units)
Tertiary	Plio-Pleistocene		Sandhan (unconformity)
	Middle Miocene		Chhasra
	Early Miocene		Khari nadi (unconformity)
	Oligocene		Manyara fort (unconformity)
	Middle Eocene to Early Late Eocene		Fulra Limestone
	Early Middle Eocene		Harudi (unconformity)
	Late Eocene to Early Eocene		Naredi (unconformity)
	Early Palaeocene		Matanomadh (unconformity)
Lower Cretaceous	Deccan Traps Unconformity		
	Albian to Neocomian	Umia	Bhuj
Upper Jurassic	Kimmeridgian to Tithonian	Katrol	Jhuran (unconformity)
	Callovia to Oxfordian	Chari	Jumaria+
Middle Jurassic	Bathonian to Aalenian	Pacham	Jhurio+
Lower Jurassic to Upper Triassic	Rhaetian to ?Lias		(Not exposed)
Unconformity			
Precambrian basement not exposed			

The Tertiary formations are exposed between Narmada and Tapi Rivers in parts of Bharuch and Surat districts in mainland Gujarat. In coastal parts of Saurashtra and Kachchh they are exposed as linear strips along the coastline of Surat-Bharuch-Khambhat and also in southern and eastern Kathiawar and in Kachchh. The full Tertiary succession overlies the Traps. In Khambhat trough the Tertiary sediments attain a thickness of nearly 2000 m and are gently folded. This unit extends up to the northern border of the Rann. The generalized geological succession of Saurashtra is given in **Table 3.10**.

The Tertiary strata are exposed in the south-west, south and east of Saurashtra along the coast. They generally dip at a low angle towards the sea. The sequence comprises Gaj Bed (L Miocene), Gogha Beds (Mio-Pliocene), Piram Beds (exposed in Piram island, Pliocene), Dwarka Beds (Pliocene), Porbandar Limestone/ Miliolitic Limestone (Pleistocene).

The coastal plain extends from Gulf of Khambhat in the south in a NNW - SSE direction to Kachchh.

It is bounded, on the east and west, with parallel fault systems as well as transecting faults. The basement has fault - bound uneven surfaces made up of horst and grabens. The sedimentary deposits are flanked by Deccan Traps towards west and Pre-Cambrian igneous and metamorphic rocks towards east with the Deccan Traps forming the base. The thickness of sediments is of the order of 3000 m as estimated by ONGC Ltd.

Table 3.10: Generalized Tertiary Succession of Saurashtra Region, Gujarat.

Epoch	Formation	Lithology
Pleistocene	Porbandar Limestone	Oolitic miliolite Limestone
(?) Pliocene	Dwarka Beds	Clays, silts , cherty limestone
Pliocene	Piram Beds	Conglomerates, grits and clays
Mio-Pliocene	Gogha Beds	Thin bedded grits and sandstones
Lower Miocene	Gaj Beds	Variegated clays, marl, impure limestone
Cretacio-Eocene	Deccan Trap	
Mid. Cretaceous		Light coloured & variegated sandstones
Cenomanian to Albian	Wadhwan Sandstones	Light sandstones with marine intercalations
Neocomian-Tithonian		Dark grey marls

In the coastal tracts of Gujarat, Deccan Trap basalts form the basement. In the southern part of Kachchh, Traps occur around 10 to 15 km inland as a 10 to 20 km wide strip elongated in E-W to NW-SE directions and disappear under the cover of younger sediments of Tertiary and Quaternary ages towards the Gulf of Kachchh. The basaltic lava flows are of Cretaceous to Eocene ages and have horizontal to near horizontal disposition. Infra-trappean sedimentary rocks very often underlie them. The intertrappean tuff and erosional products of traps and other rocks occur between successive flows at many places. Almost in the entire Saurashtra peninsula excepting the 10 to 30 km wide narrow coastal plain the Traps are exposed. In the Jamnagar-Okha segment the Traps occur on the coast line, while it lies a few km inland from the Gulf of Khambat. The Trap of Saurashtra are tholeiitic basalt with several intrusions of acidic, alkaline and mafic/ultramafic rocks (Merh, 1995).

In Thane district, the coastal alluvium occurs from north of Chikhaley to Dahanu and extends to Palghar, Virar, Vasai and Nalasopara in the south. The beach sands are less than half a km wide but the mud flats have width upto 5 km and thickness up to 36 m. They comprise clay, silt, sands, and gravel. In Raigad district, significant coastal alluvium occurs only around Uran and Srivardhan. In Ratnagiri district, beach sands occur as disconnected belt south of Raigad to Ratnagiri which is less than 300 m wide. The thickness varies from 1 to 8 m. In Sindhudurg district significant coastal alluvium occurs south of Achra creek and extends through Malvan up to Devgad and Kelus to Shiroda. It comprises brownish buff coloured sands with thickness between 5 and 15 m and maximum width up to 1 km.

4. HYDROGEOLOGICAL FRAMEWORK

Aquifers along the coastal tracts of India can be broadly classified into those in porous sedimentary formations and in fissured hard rock formations. The sedimentary tracts, all along the east coast and the coastal plains of Kerala and Gujarat are mostly occupied by 'porous' aquifers while a major part of the west coast and parts of Andhra and Tamil Nadu coast are occupied by 'fissured' aquifers. Aquifers in the sedimentary tract can further be grouped depth-wise into two main groups, viz., the shallow aquifers, mostly in the Quaternary alluvium and the deeper aquifers in the underlying sediments ranging in age from Tertiary to Permo-Carboniferous. The shallow aquifers are mostly separated from the underlying deeper aquifers by clay layers. In the hard rocks, the shallow aquifers are, in general, in the weathered zone and deeper aquifers are in the underlying fracture zones. General hydraulic gradient of the ground water table in the unconfined shallow aquifers and piezometric surface of the deep aquifers in the coastal tract is towards the sea. Aquifer zones as well as the fresh/saline ground water interface have been broadly demarcated based on the data collected from various investigations, which are described in brief below.

4.1 East Coast

4.1.1 Tamil Nadu

4.1.1.1 Porous Formations

In Tamil Nadu the coastal alluvial sediments are by and large the important repositories of ground water. The beds of sand and gravel and their admixtures form aquifers. Their water yielding capabilities also vary considerably. These coastal aquifers show wide variation in the water quality both laterally and vertically. Besides, the detailed hydrogeological surveys and exploratory drilling down to the depth of 777 m (maximum depth drilled) in the coastal tract of Tamil Nadu revealed the presence of a number of aquifers and their characteristic parameters. The hydrogeology of coastal Tamil Nadu is shown in **Fig. 4.1** and the range of aquifer parameters are given in Table **4.1**.

The sediments in the extreme northern coastal tract of Tamil Nadu in the districts of Tiruvallur, Kancheepuram and Chennai are represented by alluvium, both the young and old, boulder beds and the coastal sands of Quaternary age, underlain by a sequence of Tertiary sandstones, clays, shales and the Gondwana formations, mainly sandstones and shales. The area falls in the sub-basins of rivers Cooum, Kortalaiyar, Araniyar and Palar where recent alluvial deposits form important repositories of ground water.

The thickness of alluvium in Kortalaiyar-Araniyar sub-basin ranges from 9 to 50m. Earlier studies under UNDP delineated 3 potential areas, viz., Minjur, Panjetty and Tamaraipakkam for ground water development. Ground water occurs both under water table and confined conditions. An intensive development of ground water in Minjur area, to meet the water supply of Chennai city and industries, has led to the decline in water levels and also caused saline water ingress. The granular zones generally occur between 9 and 15 m and 20 and 47 m bgl towards Minjur area. The transmissivity and storage coefficient values for the aquifers in these three areas were estimated as 2046-3100 m²/day and 1.0x10⁻⁴ to 3.1x 10⁻³, 1017-3968 m²/day and 6.2x10⁻⁴ to 2.8x 10⁻³ and 1240-12400 m²/day and 7.022x10⁻⁴ to 2.74x 10⁻³ respectively.

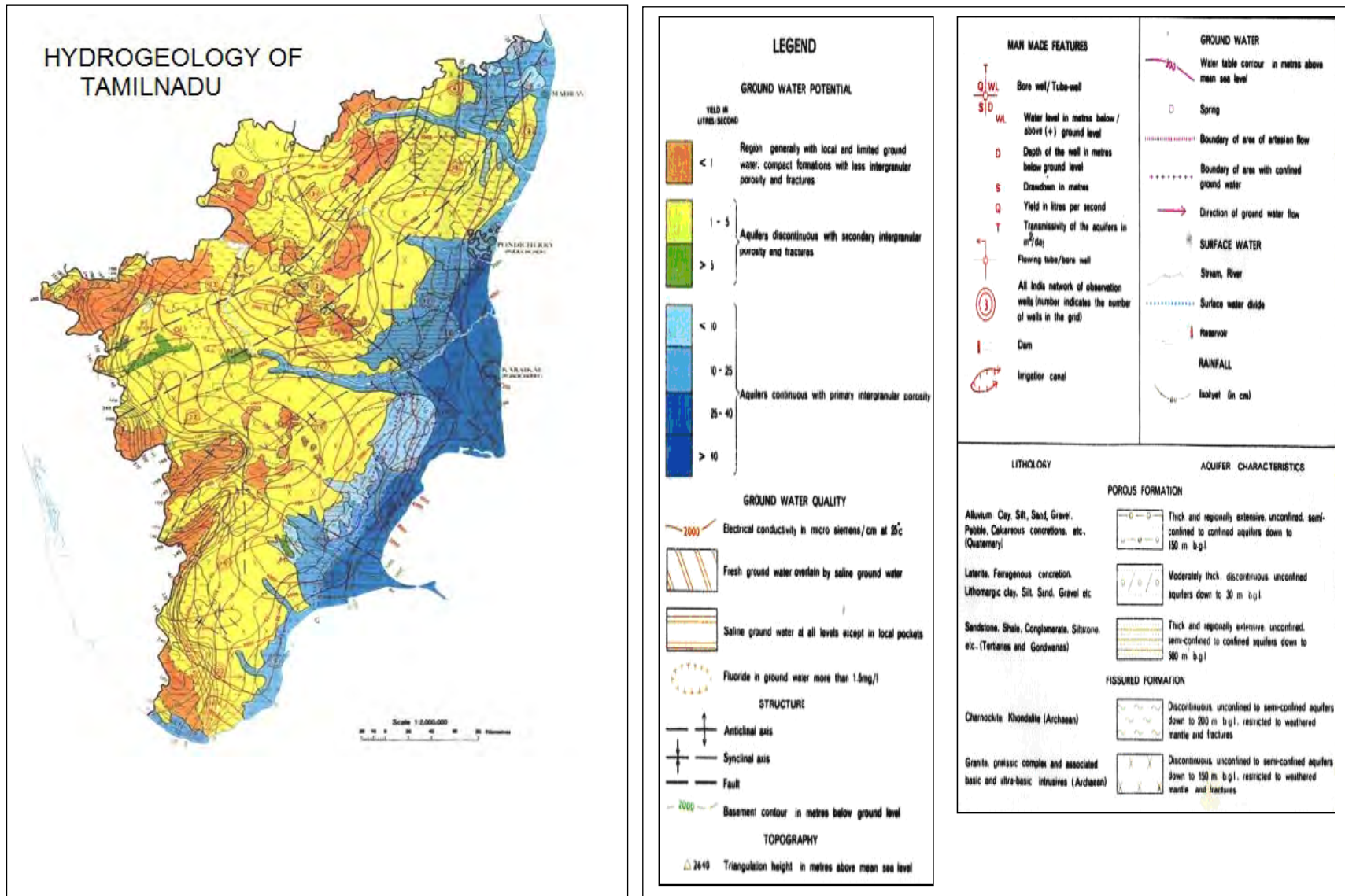


Fig. 4.1 Hydrogeology of Tamil Nadu & Puducherry

Table 4.1: Range of aquifer parameters in coastal areas of Tamil Nadu.

Aquifer	District	Depth (m bgl)	Yield (lps)	T (M ² /day)	S
Recent Alluvium	Trichy, Tuticorin, Ramanathapuram	10 - 30	2 - 4	100 - 1000	0.1
Older Alluvium	Thanjavur, Tiruvallur, Vellore, Pudukkottai, Madurai & Ramanathapuram	7 - 70	4 - 13	4800 - 10000	
Tertiary Sediments	Cuddalore, Villupuram, Thanjavur, Pudukkottai & Ramanathapuram	44 - 53	7 - 58	150 - 4000	5.5 X 10 ⁻⁵
Mesozoic Sediments	Tiruvallur, Vellore, Kancheepuram, Tiruchchirappalli, Cuddalore & Villupuram	30 - 50	1 - 5	2 - 150	5 X 10 ⁻⁴
Archaean Crystallines	All Districts except Cauvery Delta	100 - 150	2 - 10	< 1 - 10	

The yield of the shallow wells was 5.08 to 12.13 lps and that of wells in the depth range of 24 to 52 m varied from 19 to 39 lps for draw down of 2.4 to 10.7 m. A hydrogeological cross-section along Tiruvallur-Panjetty-Minjur is shown in **Fig. 4.2**. In this area the sedimentary column varies in thickness from 735 m at Kancheepuram to 790 m at Virapuram and 764m (crystalline not encountered) at Puduvoyal and rests over the crystallines. However, the depth to the crystalline bed rock in Tiruvanmiyur – Covelong – Kalpakkam coastal tract varies from 10 to 23 m bgl with exposures near Mahabalipuram and Covelong.

In Cooum sub basin, the yield of the open wells piercing through the unconfined aquifer in the alluvium varied from 3.3 to 10.42 lps and that of the tube well, constructed to the depth of 28 m was 16.8 lps for a drawdown of 1.67 m. The transmissivity and storativity values are 1001.8 m² per day and 2.29x 10⁻² respectively.

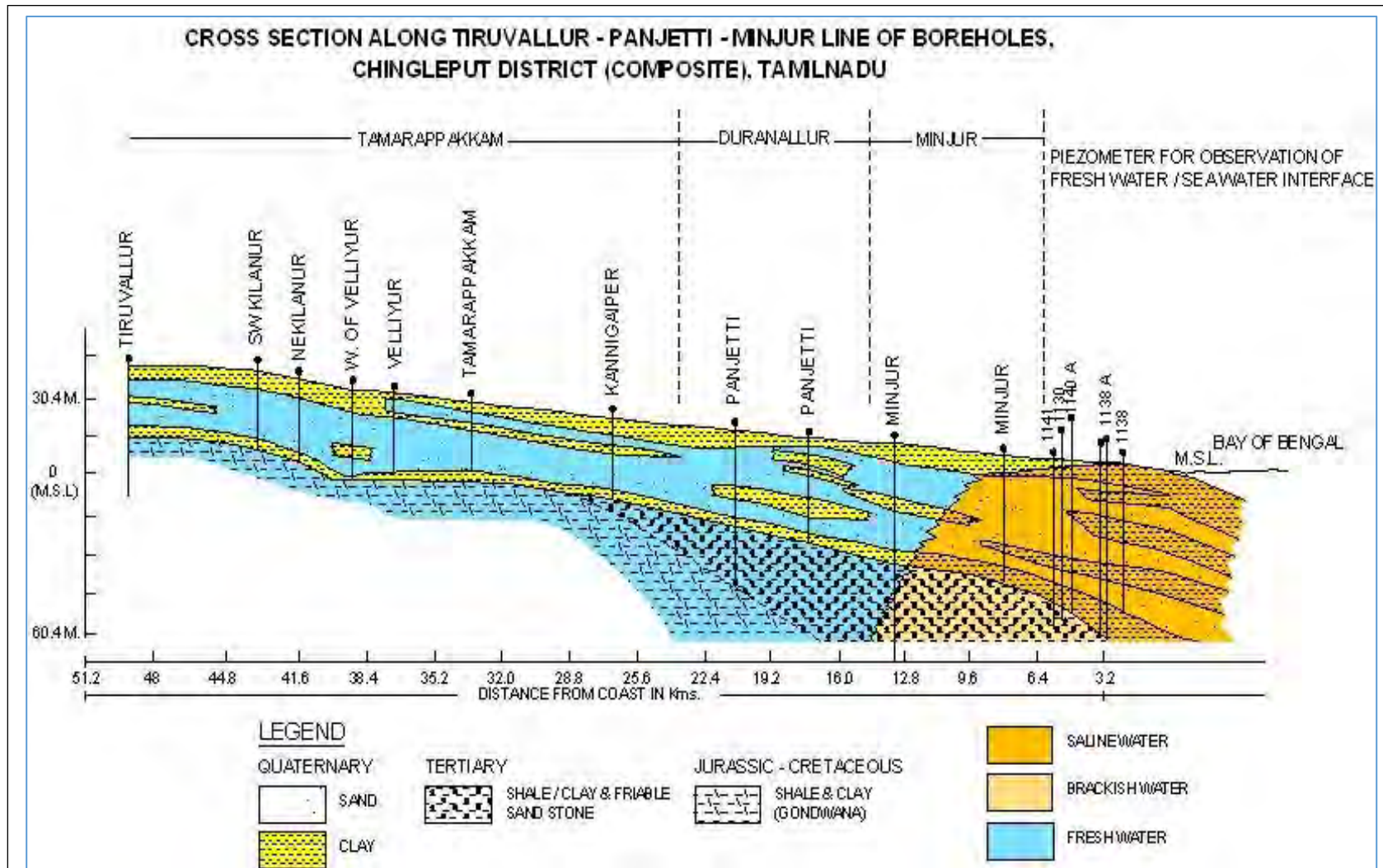


Fig. 4.2: Hydrogeological Cross Section along Tiruvallur - Minjur area, Tamil Nadu

In Palar basin, the yield of the open wells and shallow tube wells varied from 2 to 2.5 lps and 3.3 to 10 lps respectively. However, the yield of a well of 31 m depth was 31.6 lps for a drawdown of 2.3 m. The transmissivity value was 1271 m² per day. The yield varied from 3.3 to 10 lps for a drawdown of 2 to 5 m. The 3 potential areas identified through UNDP studies for groundwater development were Poini-Palar confluence, Chingleput Bridge and Paiganallur. The aquifers in Tertiaries and Gondwanas in this area do not have much potentiality. Aquifers in these formations tapped at Puduvoyal in the depth range of 206 to 625 m bgl had discharge of 5 lps for a drawdown of 42 m.

The coastal part of Ponnaiyar river basin, Cuddalore district has a typical hydrogeological set up. The non-productive zones are present towards north; highly productive zones are in the central part and fresh water aquifers overlain by saline water in the southern part. The bore wells are suitably designed taking care of effective sealing of overlying saline water zones to prevent vertical movement of saline water during pumping operation. In the northern part of the district the sedimentary rocks are exposed as a narrow strip whereas in the southern part it becomes wider and thicker. The thickness of sediments is estimated to be of the order of 4000 m (source – ONGC) in the geophysically delineated graben – horst structures, as in Cuddalore – Puducherry monocline, Chidambaram graben and Porto-Novu horst. The thickness of granular zones in the shallow aquifer group occurring within 100 m bgl ranges from 15 to 75 m whereas in deeper aquifer group between 100 and 450 m bgl it is of the order 30 to 304 m. There is a wide variation in lithology, hydrogeology and hydrochemistry of the coastal aquifers. The yield potential of the bore wells in the northern part of the basin, which has a sedimentary thickness of 300 to 400 m, is less than 70 m³ / hour. In the central part of the basin the yield potential of tube wells is high being 250 m³ / hour for drawdown of 3 to 5 m only. Localized patches of saline water are encountered but so far seawater intrusion into the coastal aquifers are not reported even due to heavy pumping in the nearby Neyveli area. Exploration by CGWB has also indicated the occurrence of saline water in the sediments encountered up to 200 m depth in the localized parts of the basin and comparatively fresh water in the depth range of 300 to 470 m bgl but with high hydrogen sulphide content.

In the area around Puducherry and Cuddalore, the sedimentary sequence rests over the Charnockites occurring at a depth about 448m bgl (Auroville). The potential aquifers in the area are confined to alluvium (Quaternary), Cuddalore Formation (Upper Tertiary - Miocene), Vanur Sandstone (Upper Cretaceous) and Ramanathapuram Formation (Lower Cretaceous). Locally, the Kadapperikuppam Formation and Manaveli Formation (Palaeocene) and Ottai Claystone (upper Cretaceous), hold less potential aquifers. Ground water occurs both under unconfined and confined conditions in these aquifers.

Alluvium consisting of fine to coarse grained sands forms the most potential shallow aquifers. The granular zones are often lenticular in shape and of varied thickness. In general, 30 % of the alluvial thickness forms the aquifer. The extreme cases are at Sathamangalam, where out of 51 m thick alluvium, 34 m (11 to 45m bgl) is saturated granular zone, while at Manapattu the 42 m thick alluvial cover has hardly any granular zone. The bottom aquifer in the alluvium is under confined condition. The areas around Tirukanji, Odiampet, Tavalapet, Villianur, Parayur, Konerikuppam, Mangalam and Sattamangalam, where thickness of alluvium is maximum, have potential alluvial aquifers. These aquifers are extensively developed. The transmissivity value ranges from 275 to 770 m² per day.

The Cuddalore Formation extends from Puducherry to Srimushnam in Cuddalore district. It occupies extensively, either exposed at the surface or underlying the thick alluvial cover. Its chief occurrence is around Cuddalore and Panruti towns. Cuddalore Formation constitutes 80% of the granular zones. The red, yellow and mottled ferruginous, sandstone and gravel in Cuddalore Formation constitute the aquifers. The thickness of this aquifer varies from 20 to 265 m and attains maximum thickness at Bahur, Ariyankuppam, Puducherry, Villianur, Manapattu and south of Gingee River. In most of the aquifers water is under confined condition and auto-flowing conditions were observed at a few places viz., Manapattu, Krishnapuram, Tengtatttu and Ariankuppam. Of late these auto flowing conditions have ceased. The yield of the tube wells ranges from 290 to 400 m³ /day for a drawdown of 5 to 10 m. Hydraulic conductivity of Cuddalore aquifer is of the order of 50 m/day with storativity ranging from 9.5×10^{-5} to 8.9×10^{-4} . The maximum and minimum transmissivity values are 8492 and 323 m²/day at Valaiyamadevi and Mettukuppam respectively. The average transmissivity is around 2000 m² /day. The lagoonal and marine deposits comprising grey to black sandy clay, plastic clay and fine sands, do not crop out but underlie the Cuddalore Formation along the coast from Markanam located between Mahabalipuram and Puducherry to Porto Novo.

The fine grained calcareous sandstone in Kadapperikuppam Formation (Palaeocene) forms the local aquifers with moderate yield. Better yields are obtained from bore wells located around Pillaiyarkuppam, Sedarapattu and in the northeastern part of the area. The limestone in this formation is devoid of water bearing zones. These aquifers occurring under thick alluvial cover are widely distributed around Mannadipet, south of river Gingee and towards west around Nettiappakkam. Towards the coast, i.e., down dip, the deeper aquifers have poor yielding capacity. The hydraulic conductivity ranges from 0.8 to 3 m/day only.

The Manaveli Formation (Upper Palaeocene) behaves as an aquitard but local granular zones yield moderately. It is tapped when the overlying Cuddalore aquifer thickness is less. The Vanur Sandstone (Upper Cretaceous) and Ramanathapuram Formation (Lower Cretaceous) occur at depths. They hold 38 to 92 m thick granular zones in the depth range of 65 to 400m with much lateral variation in their ground water potentiality. The yield varies from 1200 to 2200 m³ /day. The transmissivity ranges from 92 to 1925 m²/day and storativity ranges from 2.93×10^{-5} to 1.39×10^{-4} . The Ottai Claystone is mostly an aquitard but local granular zones of 42 to 56 m thickness yield 1500 to 3200 m³ /day for a draw down ranging from 6.6 to 25 m (as observed at Lake Estate). The hydraulic conductivity ranges from 2.5 to 11 m/day. The aquifer in Turuvai limestone has limited potentiality. The maximum cumulative thickness of granular zones encountered in Cretaceous and Palaeocene sediment at Madukkarai is about 144 m.

In this area, due to the high yield of fresh water aquifers, the water quality problem that is normally prevalent in the coastal deposits elsewhere is absent. Auto-flowing condition with piezometric head as high as 17 m agl at places and discharge upto 39 lps, is prevalent for the aquifers in Cuddalore Formation. It is observed for underlying Cretaceous aquifers also at Kopavallangudi and Rupnarayananalur in the depth range of 186 to 250 m bgl. The piezometric head for the non-flowing zone varies from 3 to 55 m bgl with yield ranging from 7.5 to 59 lps for an average drawdown of 6 m.

An important hydrogeological aspect in this area is the high pressure head of ground water in the Neyveli Lignite Field. The lignite bed occurs at a depth varying from 20 to 140 m bgl in Cuddalore Formation (Mio-Pliocene). The problem is of controlling the high pressured ground water flow from the 3 confined thick aquifers occurring down to the depth of 305 m bgl underneath the 28 m

thick (maximum) lignite beds of the heavy pumping in the Neyveli Lignite mines to control the pressure head might have influenced the auto-flowing waterwells tapping Cuddalore sandstones in the surrounding area, as manifested by the cessation of the auto-flowing conditions.

The large scale development of coastal aquifers in Puducherry region not only caused decline in water levels and/or piezometric heads but also caused deterioration in quality of water in both shallow and deep aquifers along the coast due to ingress of seawater in areas around Kalapet, Murugampakkam and Kirmanpakkam.

Further south, the Cauvery delta forms the coastal tract encompassing erstwhile Thanjavur composite district comprising Thanjavur, Tiruvarur and Nagapattinam districts. The area is underlain by geological formations ranging in age from Archaean to Recent. Extensive sedimentary deposits cover all the 3 districts almost entirely. The shallow aquifers occurring within 100m bgl have one to five granular zones with a total thickness of 3 to 54 m, while the deeper aquifer groups between 100 to 450 m bgl have one to five zones with a cumulative thickness of 11 to 103 m. The alluvial deposits occupy the northern and eastern parts with maximum thickness of 50 m near the coast. The aquifers in alluvium have transmissivity in the range of 20 to 1120 m²/day and storativity in the range of 5.0x10⁻⁴ to 2.0x 10⁻³. The quality of water in alluvial aquifers deteriorates towards the coast. The sedimentary sequence holds potential fresh water aquifers except in the eastern and southeastern parts nearing the coast. In comparison to Cuddalore district, the transmissivity of Pliocene aquifers is, in general, reduced here, to the range of 35 to 1300 m²/day. Higher transmissivity value of 3002 m² per day was obtained only at Pattam. Auto-flowing condition was observed in a number of wells with piezometric head of 2.4 to 4.5 m agl for the aquifers in the general depth range of 190 to 350 m bgl. Aquifer in the depth range of 500 to 524 m bgl tapped at Thiruthuraipoondi had pressure head of 12.3 m agl, indicating an increase in pressure head with depth. However, the exploration carried out in Vedaranyam and Tirutturaipoondi taluks, down to 666 m bgl reveals deterioration of quality of formation water at depth.

The coastal tract of Pudukkottai and Ramanthapuram districts is underlain by sediments of Cretaceous to Recent Ages. In the coastal tract of Pudukkottai district near Vallar River, the thickness of sediments varies from 300 to 450 m. It is 453 m at Kattumavadi. The thickness gradually increases to 3000 m towards south as estimated in deeper investigations for oil. Detailed exploration by the CGWB has established the presence of deeper aquifers down to 524 m (at Manamelkudi). The yields of these aquifers range from 50 to 80 m³ / hour.

In Pudukkottai district, adjoining the Archaean crystallines in the western uplands the Cretaceous formations - oldest sedimentaries occur in a 6 to 10 km wide belt. They comprise mainly intercalated coarse grained sand, clayey sandstone and mottled clay occasionally associated with kankar, gravel and greyish silty clay. Fibrous limestone is noticed in association with reddish silty sandstone. The thickness of the sedimentary column is 453 m at Kattumavadi on the coast. In the coastal tract of the district the coarse grained sandstone with grey clay intercalations encountered below the fibrous limestone (Cretaceous) in the general depth range of 267 to 400m bgl at Pandipattiram, Karuvur, Vilianur, Ambalabananendal, Manamelkudi hold fresh to marginally fresh water aquifers under auto flowing condition. The piezometric head was 1.25 to 5.2 m agl with higher head of 13.49 m agl (in the year 1980) at Manamelkudi and 11.32 m agl (in the year 1981) at Kattumavadi. While the EC of the water was 1200 to 1725 μ S/cm at other sites, at Manamelkudi it

was 2010 μ S/cm. At Kattumavadi, though flowing condition was observed the quality of water was poor (EC: 4070 μ S/cm). The aquifers tapped are mostly in the depth range of 267 to 400m bgl, except at Manamelkudi where aquifers in the depth range of 300 to 524 m were tapped. The yield of these wells varied from 16.7 to 168.3 lps for a draw down varying from 12 to 26 m. The transmissivity of the aquifer ranges from 30 to 2640 m^2 per day. It has revealed that the deeper Cretaceous aquifers are under high hydrostatic pressure which increases with depth and the quality deteriorates towards the coast. Also, in the coastal tract of this district the Quaternary and Tertiary aquifers up to a depth of 190 m hold, in general, poor quality water (EC: 4075 to 27000 μ S/cm).

The Vaigai basin of Ramanathapuram district, is completely influenced by marine environment. Though there are number of water-bearing zones, the quality of formation water is highly saline with TDS values in the range of 1000 to 37000 ppm. Fresh water pockets in palaeo channels occur about 25 km inland from the coast. In Vaippar and Gundar basins of Ramanathapuram and Tuticorin districts, the thickness of the sediments at Sikkal is estimated to be around 2500 m whereas at Mandapam it is 1650 m which shows a basin high in the eastern part of the basin. Thickness of sediments in the southern part of the basin is only 30 to 60 m with a width of about 5 km. Fluvial, fluvio-marine, marine and aeolian landforms support fresh ground water pockets down to 10 m in this area. The area is bestowed with a number of tanks, ponds and 'Ooraries' which form as surface storage reservoirs for rainwater. The permeability of the surface layers over the major part of the basin is very poor. The wells are generally shallow. Water levels are within 2 m in monsoon season whereas in summer season the wells become dry. The deepening of these dry wells ended up in saline water zones.

The eastern coastal part of Ramanathapuram district has a similar sedimentary sequence like Pudukottai, comprising Recent, Pleistocene, Tertiaries and Cretaceous resting on the Archaean crystallines which are exposed in the extreme western part and occurs beyond 600 to 700 m depth in the eastern coastal part. The thickness of alluvium in the extreme eastern part is 109 m (Mandapam). The Gondwanas occurring in the adjacent Sivagangai district has poor ground water potentiality due to the presence of fine sand and clay as evidenced by the bore well at Amaravathipudur where the zone between 86 and 185m bgl tapping the Gondwana sandstone and shale yielded only 4.15 lps for a drawdown of 31.33 m. Gondwanas are not encountered in the eastern coastal tract. The Lower Cretaceous sediments overlying the Gondwanas are not exposed anywhere in this area and were encountered in ONGC borehole at Pondikkomoy in the depth range of 355 to 890 m bgl. They comprise sandstone, clay and shale and limestone. The Upper Cretaceous sediments having 2 lithofacies, the top unit forming the marker limestone bed and the bottom unit of sandstone, clay and shale, hold thick fresh water aquifers. The aquifers showed auto-flowing condition with piezometric head of 6 to 13.25 m agl. The transmissivity of the aquifer varies from 56.17 to 594 m^2/day (hydraulic conductivity: 2.8 to 27.3 m/day). These aquifers in the Sivagangai district showed higher drawdown for similar discharges.

The overlying Cuddalore Sandstone occurring at depths ranging from 15 to 75 m bgl in this area comprises sand, sandstone, gravel and clay and constitutes the potential aquifer. It is extensive, 20 to 70 m thick and in the eastern part occurs under a thick cover of alluvium. Auto flowing conditions were recorded for Cuddalore aquifers. The transmissivity ranges from 5.5 to 3616

m²/day. The alluvial aquifers are discontinuous lenses and are influenced by numerous surface tanks. Over all in the eastern coastal part the wells tapping 3 to 8 granular zones in the above sedimentary sequence up to 450 m depth showed auto-flowing condition with a maximum head of 13.24 m agl. The yield ranged from 2.08 to 187.5 lps for drawdowns varying from 4 to 50 m. Further east, the formation water is highly saline down to the depth of 750m bgl.

As compared to Ramanathapuram district the thickness of sediments in the coastal tract of Tamraparni basin in Tirunelveli and Tuticorin districts is drastically reduced. It is underlain by 50 to 150 m thick sedimentary formations. The area is underlain by Panamparai Sandstones of Tertiary age and sediments of Sub-Recent age. It is drained by Nambiyar River and other minor rivers. The quality of formation water is generally of poor. Fresh ground water is available only as lenses at shallow levels in the sandy layers of the coastal beach ridges. The thickness of sediments decreases towards south and the crystalline hard rocks are exposed on the coast at Kanyakumari, the southern tip of the country. The area is known for its aeolian and marine landforms. Active beach ridges and sand dunes are present in this belt. The older sand dunes are locally known as 'Red Teris', which possess fresh water pockets. However, yield of the open wells is low due to poor permeability of the underlying compact sandstones. The deeper aquifers in the depth range of 50 to 150 m are saline in the northern part of the area. The Sub-Recent sediments show beach uplift and the sediments at Tiruchendur temple show a reversal of dip. This structural feature also helps in preserving the rainfall recharge as fresh water pockets and 'Nalikinaru' at the temple is one such pocket. This is not affected by the sea water. In certain pockets in the sedimentary tract of Tirunelveli district, like Kuttam area, seawater intrusion is reported due to over extraction of fresh ground water from the 'Teri' sands.

In the southernmost Kanyakumari district, the sedimentary sequence is mostly absent and the crystallines are exposed. However, the patches of sedimentary column of alluvium, Tertiary sandstone and shell limestone resting over the crystallines form the fresh water aquifers whose cumulative thickness varies from 25 to 60 m. These are mostly capped by 7 to 15 m thick 'Teri' sand. The yield of wells tapping these aquifers varied from 1.4 to 6.8 lps for a drawdown ranging from 3.5 to 18.2 m. The transmissivity values range up to 1070 m² per day with storativity between 1.32×10^{-3} to 1.98×10^{-3} . Deterioration in quality of water is reported at Nalumulaikinar (EC: 2590 μ S/cm) on the coast for the aquifers tapped in the depth range of 29 to 42 m bgl. The crystallines, in general, hold fresh water in the saturated fracture zones except at a few places viz., Taruvai (EC: 3620 μ S/cm), Sattankulam (EC: 4200 μ S/cm) and Vilattikulam (EC: 2860 μ S/cm) where the water is reported to be brackish in the fracture zones.

Large stretches of wind-blown sand deposits in the form of irregular low dunes ranging in width from a few meters to above a kilometer occur all along the coast except where they are interrupted by the river outlets.

A small fresh water spring is present, at about 10 m inside the sea, at Villundi Theertham, about 7 km from Rameswaram temple in Ramanathapuram district. A ring well was made at this point to withdraw fresh water. Such fresh water discharge in the sea may be due to the presence of nearby sand dune with sufficient fresh water storage and movement towards the sea.

In some areas of the coastal tract, sand dunes are the only source for fresh water. The Rameswaram Island dunes, Mandapam – Manargudi dune, Periyapattinam dune, Kanjirankudi Kilakkarai dune, Narippaiyur – Selvalpatti dune and Valinikkan – Oppilan dune are the important landforms identified as sources for fresh ground water. Saturated column in these landforms generally varies from 6 to 10 m during monsoon season and 2 m in summer season. Close monitoring and careful management is required in these areas while developing the resource since overdevelopment of fresh water resource may end up in the upcoming of saline water which damages the fresh water sources permanently. The design of feeder and collector well system is already in place to develop the fresh water resource without disturbing the sensitive fresh – saline water interface. But, a methodical approach in enhancing the fresh water resource through artificial recharge is required in these areas.

4.1.1.2 Fissured Formations

In coastal tracts of Tamil Nadu the granite gneisses and charnockites are exposed in Villupuram, Tuticorin, Tirunelveli and Kanyakumari districts. The boreholes drilled to a depth around 205 m in Villupuram district encountered shallow as well as deep fracture zones in the depth ranges of 26 to 28m, 68 to 71 and 80 to 82 m bgl. The cumulative yield varied from 25 to 100 m³/day. The depth to water level (year 1993) was within 2.7 to 5 m bgl. The major rock types encountered in coastal part of Tuticorin district are biotite gneiss, charnockite and khondalite. In this area the thickness of weathered zone ranges from 10 to 42m. In the maximum explored depth of 200m, 1 to 6 saturated fracture zones were encountered within 100 m bgl with discharge varying from less than 85 to 1400 m³/day during drilling. At a few sites the boreholes drilled were dry. Also in some of the boreholes caving was encountered during drilling within 33 m depth. The discharge of successful wells varied between 6 and 330 m³/day for a drawdown of 1.4 to 9.2 m. The quality of formation water in the deeper aquifers varied widely with EC values ranging from 550 to 4200 µS/cm. Further south in the crystallines of Tirunelveli district, the yield of the fracture zones encountered during drilling ranged up to 1000 m³/day. The successful wells had yield between 85 and 390 m³/day for a drawdown in the range of 2.6 to 41.8 m. The EC values of formation water ranged from 487 to 3620 µS/cm. In the southern most Kanyakumari district the yield of the well varied between 17 and 1200 m³/day during drilling. The yield of successful wells varied from 140 to 1000 m³/day for a drawdown ranging from 2.5 to 33 m. Though the quality of water is, in general, fresh, a few well encountered water with very high salinity with EC values ranging from 4900 to 21,200 µS/cm in the depth ranges of 43 to 46m, 77 to 78m and 120 to 121 m bgl.

4.1.2 Andhra Pradesh

A generalized hydrogeological map of coastal Andhra Pradesh is shown in **Fig.4.3**. The coastal area of Andhra Pradesh has been classified into i) Deltaic sedimentary coast, ii) Non-deltaic sedimentary coast and iii) Rocky coast based on certain unique characteristics and the hydrogeological framework of each has been described in the following sections:

4.1.2.1 Porous Formations

Deltaic Sedimentary Coast

Deltaic sedimentary coast include the deltas of Pennar, Krishna and Godavari rivers (**Table 4.2**). These present varied depositional environments with the fluvial environment in the upper deltaic plains changing to fluvio-marine and fluvio-aeolian environments in the lower deltaic plains towards coast. This has given rise to a complex sequence of sedimentary deposits ranging from coarser to finer clastics often with rapid facies variation.

Ground water occurs under water table and semi-confined conditions in the recent alluvium and under confined conditions in the underlying Rajahmundry/Gondwana sandstones. Most of the deltaic area is under surface water irrigation projects. The water levels are shallow and either seasonal /perennial water logging or prone to water logging conditions exist in significant part. The depth to water levels generally lies within 4 m bgl and the seasonal fluctuation is of the order of 1 to 3 m. Generally, the ground water development is limited and is confined to certain fresh water zones. The depth to filter point wells vary from 6 to 30 m, while the depth of dug wells vary from 5 to 12m. The discharge of filter point wells vary from 3 to 15 lps. The hydrogeological details of deltas are given in **Table 4.3**.

Table 4.2: Details of deltas in coastal Andhra Pradesh

Delta	Area (sq. km.)	Districts covered	Shore in length (km.)	Number of strand lines deciphered
Godavari	6322	East Godavari (Eastern delta) and West Godavari (Western delta)	150	4
Krishna	5476	Krishna (Eastern delta) and Guntur (Western delta)	125	4
Pennar	1470	Nellore	54	3

Table 4.3: Hydrogeological Details of Deltas in Coastal Andhra Pradesh

Delta	No. of EWs drilled by CGWB	Total depth drilled (m bgl)	Depth constructed (m bgl)	Yield range	Cumulative thickness of granular zones (m)	Remarks
Godavari	20	27-650	22-258	0.7-30	3-54	11 wells abandoned due to poor quality. Thickness of alluvium from 9 to 205m. followed by Tertiaries down to 647 m. at Tanuku. Tertiaries not encountered down to drilled depth of 295 m. in lower deltaic plain.
Krishna	39	172-600	18-153	15-22	12-47	85% of wells abandoned due to quality hazards. The thickness of alluvium 42-600 m (basement not encountered).
Pennar	9	43.56-457.2	60.76-84.27	8.36-38.6		6 wells abandoned due to poor quality. Thickness of alluvium 28-120 m followed by Tertiaries. Swarnamukhi alluvium also included.

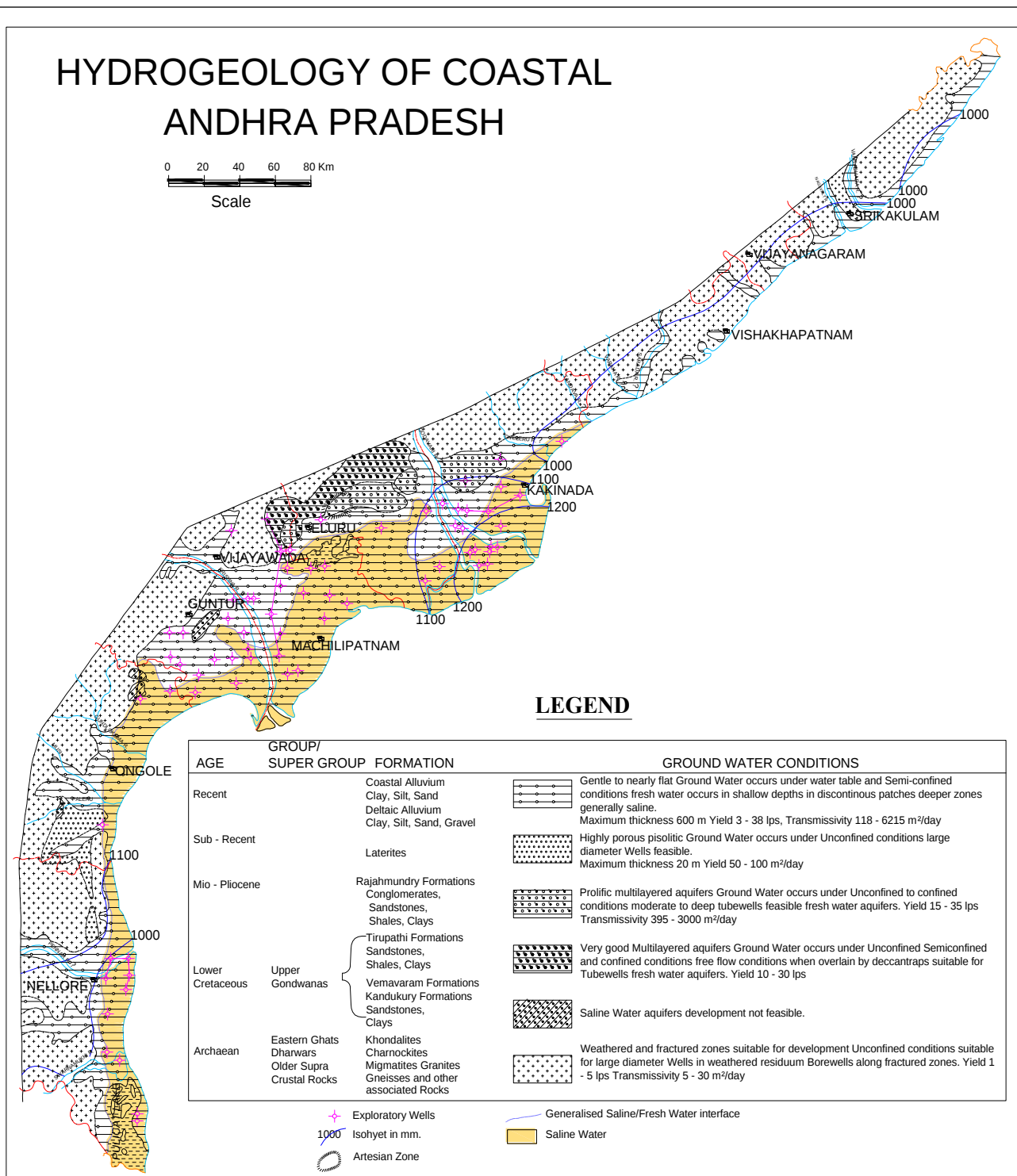


Fig.4.3: Hydrogeology of Coastal Andhra Pradesh

Non-deltaic Sedimentary Coast

The non-deltaic environment exist mainly in Srikakulam and Vizianagarm districts in northern and Prakasam district in the southern coastal area.

Srikakulam district has a coast line of about 175 km. The ground water is developed by means of dug wells and filter point wells. The depth of dug wells mostly range between 2 and 10 m and the depth of filter point wells vary from 6 to 20 m. with discharges varying between 5 and 8 lps. In northern part of the district (Uddanam area), wind-blown sands down to a depth of about 80 m occur at high elevation adjacent to the coast. The water levels are very deep ranging up to 30 m. The exploration (4 wells) indicated that the thickness of granular zones is less and the yields are negligible. Ground water extraction is mostly by means of dug wells and bore wells fitted with hand pumps and is used for drinking purpose. The ground water development is meager.

In Vizianagaram district the area is devoid of major rivers and has a coast line of about 25 km. A thin coastal plain occurs with a limited thickness of alluvium. Ground water development is limited to beach ridges and dunes, where the water is fresh.

Prakasam district has a coast line of about 100 km. The exploratory data of three tube wells (Karamchedu, Inkollu and Ulavapadu) in alluvial plain down to 200 m revealed that water is saline down to depth of 200m with negligible discharges. However, in Ulavapadu which has yielded about 2 lps. It is observed that though the water was fresh, the water became saline as the pumping progressed. The exploration in Beach Ridge-Sand Dune Complex (2 wells) which lies parallel to the coast, the water is fresh down to a depth of about 20 m and electrical logging has indicated moderately fresh water to a depth of 40 m. The development was used to be shallow dug wells locally known as daruvus. However, the development has increased considerably through power driven filter point wells with depth ranging between 8 to 30 m. The discharge of these wells varies from 2 to 5 lps. Ground water development in the alluvial plain is negligible due to salinity and fairly good in beach ridge-sand dune complex.

Rocky Coast

Rocky coast (hard rock with intermittent alluvium) exists only in Visakhapatnam district. The district has a coast line about 140 km. and coastal plain is relatively narrow with a maximum width of 3.5 km. The eastern part is characterized by high relief, structural hills with narrow valleys with thin coastal plain. The central and western parts are marked by mud flats. The unconsolidated aquifers are mainly made of shallow beach ridges, fluvial borne alluvial plain and highly dissected red sediments. The ground water is developed through dug wells, shallow bore wells and filter point wells. The ground water development is limited in this coastal tract.

4.1.2.2 Fissured Formations

The basaltic Traps in West Godavari district exposed as an isolated patch do not form a good aquifer system. In East Godavari district, Traps exposed in a relatively large area, are tapped for ground water through dug wells / shallow bore wells for water supply and irrigation on a limited scale.

From the northern part of Visakhapatnam to Srikakulam district, along the coast, the crystalline rocks of khondalite group occupy the coastal tract without giving much scope for the development of coastal plain. The weathered and fractured zones in these garnet – sillimanite – gneissic rocks support as aquifer system with low to moderate potentials. Dug wells in these formations have

yield varying from 40 to 120 m³/day, in the winter months and 10 to 30 m³/day in the summer months. The exploration in Srikakulam and Vizianagaram districts up to a maximum depth of 200m bgl revealed the fracture zones up to 100m depth having yield less than 170 m³/day and those beyond 100m depth have 170 m³/day to 430 m³/day. The transmissivity of these wells range from 0.5 to 36 m²/day but in most cases it is between 5 and 20 m²/day. The colluvial deposits near the foot-hill zone of these rocks serve as good recharge area for down the hill weathered and fractured systems.

4.1.3 Odisha

4.1.3.1 Porous Formations

In the coastal tracts of Odisha, the sand and gravel layers in alluvium and the semi-consolidated or loosely cemented sand and gravel layers of the underlying Tertiary (Mio-Pliocene) deposits form the prolific aquifers. The shallow or phreatic aquifers occur more or less throughout the coastal tract. The phreatic aquifers in the western part, are generally formed by the older alluvium while in the eastern part they are formed by the younger alluvium. The phreatic aquifers in the older alluvium extend down to an average depth of 10 to 14 m and the same in the Younger alluvium to an average depth of 8 to 10 m. Ground water extraction from phreatic aquifers is mainly through dug wells and hand pumps fitted shallow filter point tube wells. The yield of the dug wells in older alluvium generally varies from 40 to 50 m³/day, while in the Younger alluvium it varies from 50 to 60 m³/day. The average yield factor in older alluvium generally ranges from 2 to 3 litres per minute per metre of

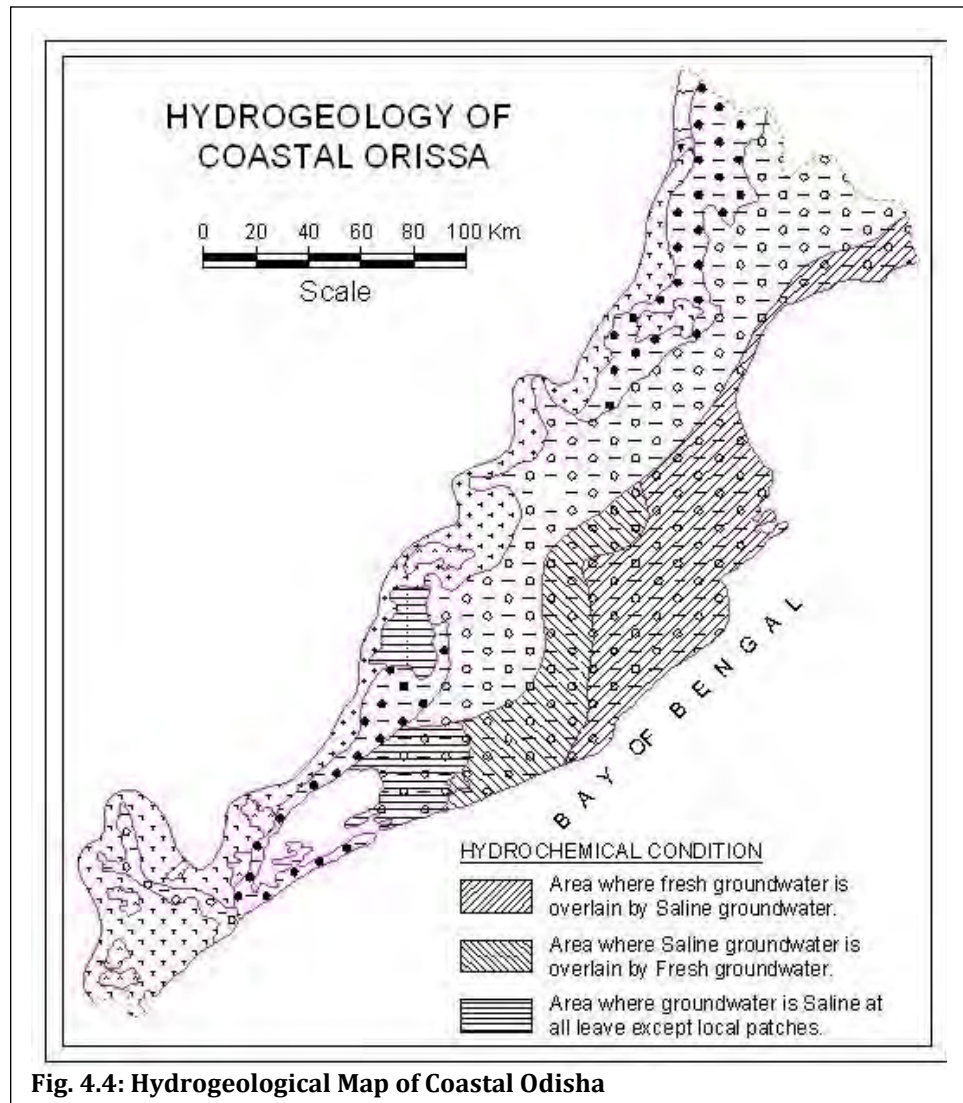


Fig. 4.4: Hydrogeological Map of Coastal Odisha

to 10 m. Ground water extraction from phreatic aquifers is mainly through dug wells and hand pumps fitted shallow filter point tube wells. The yield of the dug wells in older alluvium generally varies from 40 to 50 m³/day, while in the Younger alluvium it varies from 50 to 60 m³/day. The average yield factor in older alluvium generally ranges from 2 to 3 litres per minute per metre of

drawdown for unit cross sectional area (sq.m), while the same in Younger alluvium it is up to 4 litres/m/m/m². The range is 3 to 43 lpm/m/m². Hydrogeological map of coastal Odisha is shown in **Fig 4.4**.

The deeper aquifers of coastal tract have been explored extensively by CGWB, drilling down to a maximum depth of 600m. More than 300 boreholes have been drilled. Thick alluvial deposit generally facilitates formation of high yielding aquifers. The alluvial deposit extends down to 50 to 60 m in the western part and to 150m in the eastern coastal tract. The sand and gravel layers in alluvium and the semi-consolidated or loosely cemented sand layers in the underlying Tertiary deposits form the prolific aquifers at depth. The deeper aquifers in the alluvial deposits in eastern coastal tract open up in the inland areas towards west. The aquifers become thick as well as dip towards the coast. The aquifers are regionally extensive, often interconnected and display wide variation in texture. The deeper aquifers are under confined condition due to the presence of confining clay beds extensively. The yield factor of Tertiary aquifers is less than the alluvial aquifers and ranges from 1 to 11 lpm/m/m².

The drilling reveals the predominance of coarser clastic (sand and gravel) in Subarnarekha and Mahanadi-Brahmani-Baitarani delta areas occupying the extreme northern part and central and south-eastern part of the coastal tract respectively. The cumulative thickness of aquifers as well as the thickness of Quaternary alluvium is more in these two deltas. The finer clastics (clay and silt) are predominant in the area between Balasore and Bhadrak towns. The characteristics of the aquifers in alluvial formations are distinct from those in the Tertiary deposits (**Table 4.4**). The alluvial aquifers have higher transmissivity and hydraulic conductivity values in comparison to the Tertiary aquifers.

Table 4.4: Aquifer characteristics in Coastal tracts of Odisha

Aquifers	No. of Wells	Aquifer thickness (m)	Static water level (mbgl)	Discharge (lps)	Drawdown (m)	Yield factor (lpm/m/m ²)	T (m ² /d)	K (m/d)	S
Quaternary alluvium	40	10-55	0.8-7.6	18-75	3.1-13.1	2.9-42.8	1000-8198	9-330	1.3x 10 ⁻³ to 7.5x10 ⁻⁵
Tertiary sediments	27	8-76	1.2 m agl to 4.5 m bgl	8.5-45	10.3-25.3	0.73-11.1	151-1900	4-60	8.9x10 ⁻⁴ to 1.9x10 ⁻⁶

The hydraulic conductivity values vary with the nature of the sediments and their sorting. It reflects the complex influence of provenance and depositional environment that varied from continental to marine in late Tertiary and Quaternary times due to repeated marine transgressions and regressions. The continental influence predominated more in the inland areas in post Tertiary times. This has created remarkable inhomogeneity in the nature and distribution of sediments and hence the aquifers thereby show sharp variations in the aquifer potentialities which are further

complicated by irregular occurrence of saline water zones due to preferential flushing. In general, towards coast finer sediments progressively dominate.

The alluvial aquifers occurring in parts of Mahanadi and Brahmani basins are generally of the flood plain deposits and are of coarser material with higher hydraulic conductivity than those in Budhabalang and Jamira basins (except extreme northeastern part of Balasore district) where finer sediments prevail and potential deep aquifers occur in semi-consolidated Tertiary sediments.

The storativity values of the deep aquifers in Quaternary alluvial deposits (Table 6.6) indicate that the aquifers are mostly under unconfined to semi-confined conditions. The storativity values for aquifers in Tertiary deposits indicate their semi-confined to confined conditions. The wells in the outfall areas of the rivers Baitarani, Brahmani and Mahanadi indicated auto-flowing condition.

In general, well yields vary from 25 to 35 lps for Tertiary aquifers for a cumulative tapped thickness of 35 to 45 m within 300m depth. The yield of Tertiary aquifers progressively reduces with increase in depth. While the yield of wells tapping 35 to 45 m thickness in Quaternary alluvial deposits within 150 m depth is 50 lps or more.

Sand dunes are common in the coastal tracts of Odisha. Sand dunes of height ranging from 6 to 22 m, are observed along the coast. These dunes exist as thin elongated bands parallel to the coast. Dunes occur along the riverbeds and are more prominent at the mouth of the major rivers joining the sea. Long stretches of sand dunes are interpreted from the satellite imagery near Chandipur area, Dhamra- Basudevpur section, Puri- Balighai- Konark section, Brahmagiri- Puri section and along a length of Krushnaprasad block adjoining the coast. Some of the dunes are very long and corroborate with the strand line.

In Puri district, sand dunes cover larger areas and such dune occurring between Brahmagiri and Puri has maximum height of 22m near Balichandi, followed by one adjacent to the Lord Jagannath Temple in Puri (height 18m). The general ground water level is 2m bgl in this area but in the dunes the ground water level is at 15m bgl. At Ramchandi the dunes are as thick as 9 m, having a ground water level at 6m bgl. A few sand dunes in Bhadrak district are conspicuous since the entire habitation is along the sand dune parallel to the coast and the dunes are the only shallow fresh ground water source in these areas.

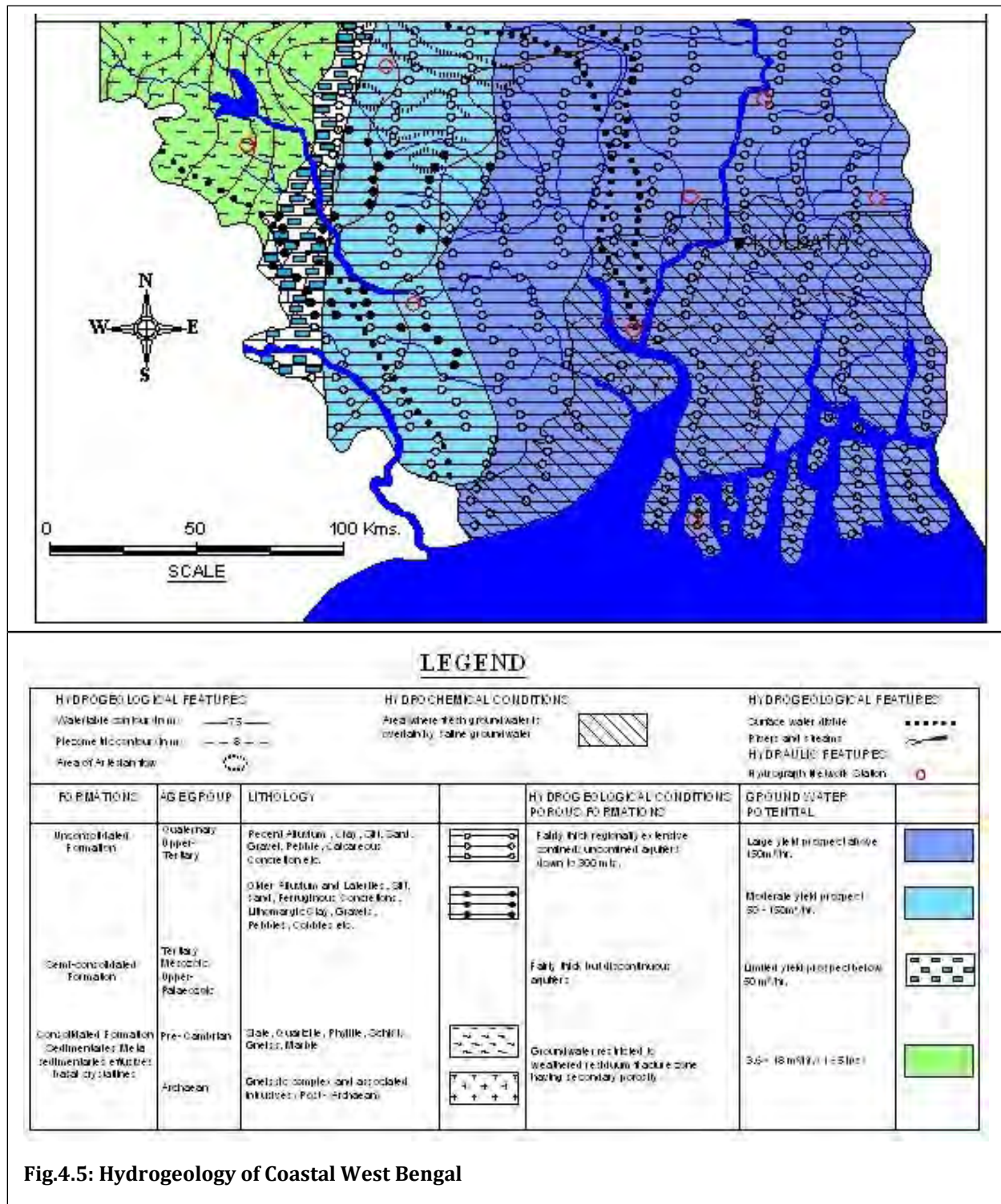
4.1.3.2 Fissured Formations

In the southernmost part of the coastal tract of Odisha, in Khurda district the crystallines are exposed towards north of Chilka lake. Except a few patches of khondalite rocks, the area is mostly occupied by granites and granite gneiss. The occurrence of ground water is restricted to the weathered residuum and the underlying fracture zones. The boreholes drilled to the depths ranging from 200 to 300m in general encounter 2 to 5 fracture zones within 200m depth. The yield of these fracture zone varies over a wide range from 1 lps to a maximum of 10 lps. The average yield of the fracture zone in khondalites is less than those in granites and granite gneisses.

4.1.4 West Bengal

In the coastal tract of West Bengal encompassing the districts of S 24 Parganas, N 24 Paraganas (part), Haora (part) and East Medinipur (part), alluvium of Recent to Pliocene ages and the Tertiary sediments form the principal aquifers. The alluvium comprises sands of varying

grades with gravels and kankar. The sands are mostly fine to very fine grained. At some places the sands are mixed with broken Pelecypoda shell fragments. The nature of aquifer material as well as the geometry of aquifer changes spatially. In general, there is a thick blanket of clay at the top whose



thickness varies from 15 to 76 m with increasing thickness towards south. Also, a thick basal clay bed occurs at depths ranging from 152 (N 24 Parganas district) to 414 m (Kolkata area). The aquifers in between these shallow and deep clay layers in the general depth range of 70 to 360 m bgl are under confined condition and are mostly tapped either for irrigation or drinking water supplies. These are expected to be Quaternary aquifers as the top of Upper Tertiary is the basal clay bed fixed around 296 m to 414 m in Kolkata area (Sikdar, 2000). The basal clay bed was encountered at a depth of 300m in a borehole in Haora district and found to continue even beyond 548 m bgl (Mishra, 2007). The hydrogeological map of coastal West Bengal is shown in **Fig 4.5**.

In the northern part of S 24 Parganas district, however, there exists a shallow aquifer system within 50 m bgl mostly tapped for domestic use by shallow tube wells. It is followed by second and third aquifer systems in the depth ranges of 70 to 160m bgl and 170 to 400 m (depth explored) respectively. Each aquifer system comprises one or several interconnected aquifers.

The first aquifer system within 50 m bgl is restricted to recent levee deposits and is not regionally extensive. It consists of 2 to 3 aquifers. The thickness of these aquifers ranges from 10 to 30 m. The aquifers are separated by thin clay layers. These clay layers also do not extend regionally. The aquifer material is fine to very fine-grained sands in the upper part and medium grained in the lower part. The first aquifer system occurs in Baruipur, Bhangar, Bishnupur, Budge Budge, Diamond harbour, Falta, Joynagar, Mograhat, Thakurpukur-Mahestala and Sonarpur blocks. Ground water occurs under unconfined condition. This aquifer is extensively developed through low duty small diameter tube wells for domestic use capable of yielding 20 to 40 m³ per hour for 0.9 to 2.5 m drawdown. The transmissivity and storativity values for this aquifer are 500 to 2000 m² per day and 0.3×10^{-1} to 0.5×10^{-2} respectively.

The second aquifer system in the depth range of 70 to 160 m bgl is separated from the overlying first aquifer system by a 10 to 30 m thick clay layer. Mostly, it consists of 1 to 2 aquifers whose individual thickness varies from 5 to 30m and are separated by thin clay layers which are again not regionally extensive. The aquifer material is medium to coarse grained and belongs to alluvial deposits of Pleistocene age. The aquifer is regionally extensive and has prominent gravel horizon at its base particularly in the southern part of Diamond Harbour area.

The third aquifer system exists in the depth range of 170 to 360m bgl. It is separated from the second aquifer system by 10 to 30 m thick regionally extensive clay layer. The aquifer material is medium to coarse grained sands, at places enriched by gravels. The aquifer system is supposed to be of Pleistocene alluvium and Tertiary deposits. It consists of 5 to 30 m thick aquifers. The aquifer system is tapped for 30 to 35 m aquifer-thickness by heavy duty tube wells yielding 50 to 120 m³ per hour for 6 to 12 m drawdown. The transmissivity and storativity values for this aquifer are 915 to 3000 m²/day and 0.3×10^{-3} to 1.1×10^{-3} respectively.

In the southern part of the district, i.e., up to Sunderban and Sagar Island, the first and second aquifer systems cannot be separated and as such 2-aquifer system exists in the depth ranges of 22 to 168 m bgl and 160 to 360 m bgl. These aquifers are separated by thick, laterally extensive clay layer.

The deeper aquifer system consists of 4 aquifers in the depth range of 180 to 490m bgl. They are 10 to 30 m thick and separated by 40 to 150 m thick clay layer. Out of the 4 aquifers the upper 3 extend towards Rudranagar-Kakdwip-Mathurapur-Kultali. In Canning town, there are 5 aquifers in the depth range of 160 to 400 m bgl. Out of these, the bottom one continues up to Gosaba towards east and attains a thickness of 45 m and the other 4 aquifers pinch out towards southeast. In Ganga Sagar Island the deeper aquifers occur in the depth range of 200 to 320m bgl. The wells tapping these aquifers show a discharge around 80 to 90 m³ per hour for a drawdown of 6.5 to 11.8 m. The transmissivity of the deeper aquifers in Ganga Sagar Island ranges from 400 to 500 m² per day. In comparison to the transmissivity of deeper aquifers in northern part of the district and in the contiguous areas of North 24 Parganas (more than 5000 m² per day). The deeper aquifers tapped in southern part including Ganga Sagar island show lesser transmissivity values. The aquifer characteristics are given in **Table 4.5**.

Table 4.5: General characteristics of aquifers in coastal area of West Bengal

Aquifer	Depth of wells (m)	Discharge of wells (m ³ /hour)	Draw down (m)	Transmissivity(T) (m ² / day)	Storativity (S)
Shallow	30-50	25-40	0.9-2.5	500-2000	0.3x10 ⁻¹ to 0.5x10 ⁻²
Deep	100-350	100-120	6-12	900-3000	0.3x10 ⁻³ to 1.1x10 ⁻³

Towards west of river Hooghly, in the coastal tracts of East Midnapur district, the Quaternary sediments (Newer and Older alluvium) also termed as Upper Lithosystem are underlain by Upper Tertiary (Mio-Pliocene) semi-consolidated sediments- the Lower Lithosystem. Quaternaries consist of quartzo-feldspathic unconsolidated sediments. Its thickness varies considerably from 120m in the west to over 150m in the east, and 150m in the northwest to 180m in the southeast direction. The thickness of Quaternary alluvium is comparatively less than that in South 24 Parganas district. It is predominantly arenaceous in the north and northwest and mostly argillaceous in the south and southwest, i.e., towards the coast.

The Newer alluvium is predominantly argillaceous and grey in colour. It comprises clay, silt and occasional fine sand. Its areal extent is limited to the coastal and marginal alluvial plains. Its thickness varies from 10 to 60m in the NW-SE direction. The Newer alluvium is devoid of any significant granular zones.

The Older alluvium exhibits characteristic shades of yellow to reddish brown. It comprises sand-silt and clay. It is quite extensive in alluvial and coastal plains. Its thickness varies between 50m in the northwest to over 90m in the south eastern coastal tract. The Older alluvium comprises two prominent granular zones forming productive aquifers in the alluvial and coastal plains.

The Tertiaries comprise alternations of graded sand - silt - clay sequence suggesting cyclic sedimentation. In contrast to the Quaternaries, the Tertiary sediments are grey in colour with deeper facies being steel-grey. A perusal of subsurface data reveals the presence of a multi-aquifer system down to the depth of 423m (depth explored) in the Quaternary (Newer and Older Alluvium) and Upper Tertiaries.

The near surface aquifer of Newer Alluvium occurs in the depth range of 5 to 20m bgl. This aquifer pinches towards northwest and the same gets split owing to the appearance of clay beds towards southeast. This is followed by a 15 to 25 m thick clay bed, which is persistent throughout the area. Underlying the clay bed 2 prominent aquifers occur in the depth ranges of 55 to 110m and 70 to 140 m bgl in the Older alluvium, out of which the deeper one is characterized by the presence of gravel at its bottom. Overall the granular zones in the Quaternary sediments occur between 37 and 147m bmsl. It is underlain by a 20 to 40 m thick clay bed, grey in colour, in the depth range of 67 to 150m bgl (61 to 147m bmsl). This clay bed has been designated as the 'Tertiary clay' at the top of Mio-Pliocene sediments. Appearance of this monotonous thick bedded 'steel grey clay' marks the end of granular zones of any significance. The grey clay bed demarcating the top of the Mio - Pliocene sediments is persistent throughout the area and is considered as 'marker bed' which separates the Quaternary and Tertiaries identified in the area. It is encountered in all the boreholes and occurs at different elevation in different areas. At Debra, it lies at bmsl 150m, Daspur at 149m bmsl and Jalchak at 220m bmsl. Underlying the Tertiary clay 2 to 3 more aquifers occur in the depth ranges of 100 -120m and 200 to 240m bgl or in the altitude range of 184 to 343m bmsl. The aquifers in the Tertiaries comprise sand, medium to coarse mixed with gravels and also gravel bed at places and occasionally fossiliferous zones of bivalve shells. Thickness of aquifer ranges from 20 to 30 m. Due to the argillaceous nature and presence of thick clay beds, ground water in the Upper Tertiary as well as Quaternary sediments in the coastal tract is under confined condition. In the coastal plains the well discharge varies from 2 to 37 Ips for a drawdown of 10 to 15 m. Transmissivity values vary between 300 and 800 m²/day. At Khejuri the discharge recorded was 61 Ips with 18 m of drawdown and transmissivity value as 2300 m²/day. The aquifer parameters are given in **Table 4.6**.

Table 4.6: Aquifer parameters in coastal tracts of East Medinipur

Well location	Aquifer Depth range (m) bgl	Thickness tapped(m)	Discharge (Ips)	Transmissivity (m ² /day)	Storativity	Hydraulic Conductivity (m/day)
Upper Litho-system(Quaternary)						
Negua	20-57.5	14	13.6	1700-2500	4.2-7.7x10 ⁻³	18
Daspur	45-157	27	44.15	3800	3.8x10 ⁻⁵	34
Jalchak	47-65	18	14	700-800	5.7x10 ⁻⁴	43
Lower Litho-system (Tertiary)						
Negua	101-200	47.5	65.01	3700-4500	1.1x10 ⁻³ - 8.3x10 ⁻⁴	45
Kapasariya	240-346	28	28.39	300	4.9x10 ⁻⁵	3
Jalchak	143-164	21	61.7	1800	1.3x10 ⁻⁴	84
Haldia	187-202	12	25.3	800		34
Khejuri	234-291	30	53.44	2400-2800	3-6.8x10 ⁻⁴	43
Sarasankha	79-220	48	44	2400-3500	1.1x10 ⁻² 8.1x10 ⁻³	72

In the coastal tracts of East Medinipur district, several alignments of sand dunes are observed near Digha, Kanthi and Khejuri. These sand dunes are the major shallow level sources of ground water in these areas.

4.2 West Coast

4.2.1 Kerala

A generalized hydrogeological map of the State is shown in Fig.4.6

4.2.1.1 Porous Formations

In coastal plains of Kerala the alluvial deposits form the most potential phreatic aquifer in the state. It is being tapped by dug wells and filter point wells extensively. The density of open wells in the coastal tract is 200 per sq.km (Kerala SCSTE, 2008). In general the dug wells are sunk up to 10m depth.

The maximum thickness of alluvium is about 100 m around Kattoor. At places where the thickness is large it is tapped by shallow tubewells. The depth to water level ranges from less than a metre to about 6 m that comes to around 1 to 6 m amsl. Filter point wells are feasible wherever the saturated sand thickness exceeds 5 m within a depth of 12 m bgl.

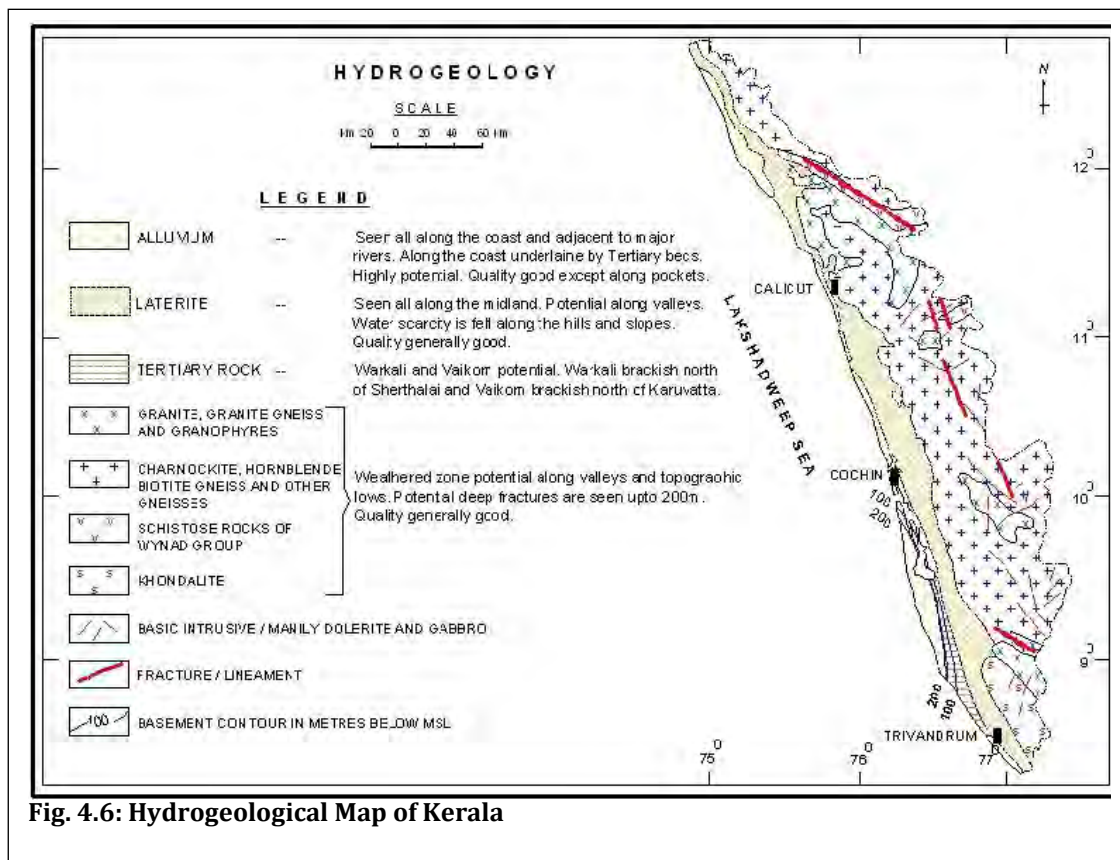


Fig. 4.6: Hydrogeological Map of Kerala

The areas around Iravipuram, Chavara, Kayamkulam, Alappuzha, Cherthala, Vypin, Ponnani and Tirur are promising for filter point wells. The yield of the shallow dug wells ranges from 15 to 50 m³/day, while that of filter point wells ranges from 20 to 60 m³/day. Tube wells constructed in

alluvium at Purathoor taps total granular thickness of 22 m and the transmissivity of the aquifer is 168 m²/day.

Laterite forms potential aquifers along valleys and topographic lows, where the thickness of saturated zone is more and can sustain large diameter open wells. The depth of wells ranges up to 20 m bgl. The yield of the wells ranges from 0.5 to 6 m³/day. The laterites occurring at higher elevations and on slopes get de-saturated in summer.

In the underlying Tertiary sediments ground water occurs under unconfined to confined conditions. The disposition of the Tertiary formation is shown in Fig.6.3. Out of the Tertiary formations, viz., Warkali, Quilon, Vaikom and Alleppey, the Warkali and Vaikom hold the most potential aquifers. Warkali is the extensively developed aquifer amongst the Tertiaries. Aquifers in Warkali bed are mainly composed of medium to fine grained sands. The granular zones encountered range in thickness from 5 to 40 m. The yield of the wells ranges from 3 to 14 lps (259.2 to 1209.6 m³/day). The piezometric head ranges from 2.8 m amsl in Kandiyoor area to 10 m bmsl in Alleppey town. The transmissivity value ranges from 130 to 710 m²/day. It is minimum around Quilon and eastern parts and maximum between Karunagapalli and Alleppey towards north. The hydraulic conductivity ranges from 6.69 to 33.89 m/day. The water supply system between Quilon and Ernakulam mostly depends on this aquifer. Tube wells of 150 m depth tapping this aquifer for the water supply of Alleppey town and nearby villages are pumped for 8 to 24 hrs a day. Due to heavy draft and concentration of wells with short inter-spacing the water level has gone down beyond 10 m bmsl in the town and the flow in the aquifer converges towards Alappuzha.

Quilon Bed even though contains a limestone bed, it reflects a poor quality aquifer. Tapping this limestone only a few wells have been constructed. The thickness of the granular zone varies from 6 to 16 m. The piezometric surface rests between 1 and 4 m amsl. The transmissivity and hydraulic conductivity values are 28.22 m²/day and 1.09 m/day respectively.

Vaikom Bed constitutes prolific aquifer system amongst the Tertiaries. In and around Vaiyankara in Quilon district, the piezometric surface in wells tapping this aquifer was recorded as 18 m amsl (19.96 m bgl) during 80's. It was recorded 1 m amsl (4.97m agl-auto flowing) in and around Karuvatta in Alleppey district. However, the piezometric surface was around 18 m amsl in and around Peruvazhi.-Pallikal area in Quilon district and it slowly decreased towards west and northwest. In and around Karumadi it was 4.8 m amsl and decreased to 1.0 m amsl around Cochin. A sag in the piezometric surface was observed around Kuttanad area and north where it was 1 m amsl. Around Quilon the piezometric surface was 5.0 m bmsl. This may be due to the intensive pumping going on in the area. This unit forms the auto flow zone between Karunagapalli (Kollam district) and Nattakam (Thrissur district). The thickness of the granular zone ranges from 6 to 65 m and the yield ranges from 0.73 to 57 lps. The transmissivity value ranges up to and 3855 m²/day at Karuvatta. The hydraulic conductivity ranges from 0.5 to 68 m/day. The storativity ranges from 2.5x 10⁻⁵ and 4.1x10⁻³. The Alleppey Bed holds brackish formation water as indicated by the electrical logging of the boreholes encountering it. The ranges of aquifer parameters are given in **Table 4.7.**

Table 4.7: Summarized Aquifer Parameters in coastal plains of Kerala

Aquifer	Thickness range tapped (m)	Discharge (lps)	Drawdown (m)	Transmissivity (m ² /day)
Recent Alluvium	3-18	1.29-16.76	3.08-6.93	34.02-530
Warkali	6-36	3.3-15	2.52-8.85	130-711.61
Quilon	16	5	7.4	28.23
Vaikom	5.5-65	0.73-30	2.2-18.18	11.85-3855.6

In the coastal plain of Kerala auto flow conditions were observed during the years 1986-88 in some of the wells tapping Vaikom aquifer. The areas with auto flowing condition extend from Quilon to Cochin and near Thrissur along the coast. Eastward it is traced up to Kottayam. The piezometric head varied from 1.63 to 4.4 m agl.

4.2.1.2 Fissured Formations

Along the coastal tract of Kerala the khondalite, charnockite and migmatite groups of rocks of the Western Ghats form the eastern boundary of the coastal plain. In the northern part they occur close to the coast line under a capping of laterite. The shallow aquifers in the weathered and fracture zones in these formations occur in general within 20 m depth. The wells have a very wide variation in their water yielding capacity ranging from 40 to 300 lpm. Also, deep fracture zones are encountered up to 200 to 240m depth. The fracture zones were encountered up to a maximum depth of 200m in Kasaragod district of north Kerala. The quality of water in the fracture zones are, in general, potable.

4.2.2 Karnataka

A hydrogeological map of coastal Karnataka is shown in **Fig.4.7**

4.2.2.1 Porous Formations

Along the 225 km long coast line of Karnataka in the 3 districts of Uttara Kannada, Dakshina Kannada and Udupi there occurs a narrow strip of coastal alluvium underlain by the Precambrian crystallines. Its width varies from a few metres to 4 km at places. Tertiary laterite

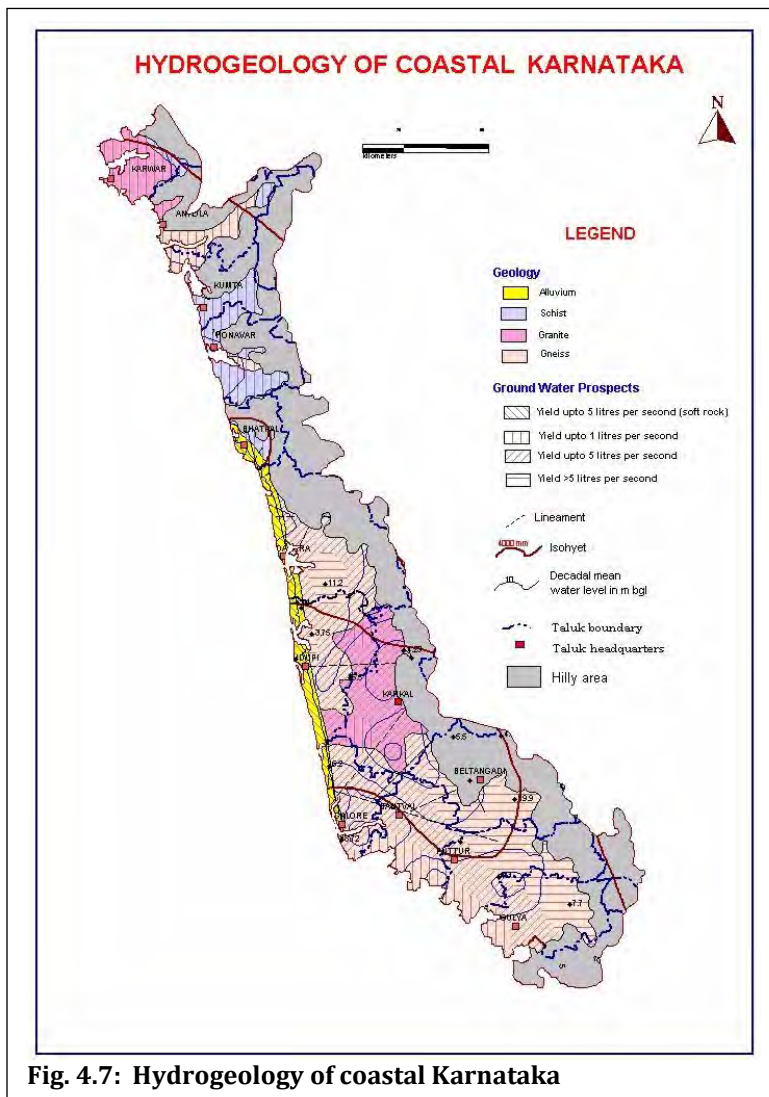


Fig. 4.7: Hydrogeology of coastal Karnataka

cappings on schists and granites are seen at places. These are residual formations. The maximum thickness is about 25m around Bhatkal and Kumta areas in Uttara Kannada district. The laterites are characterized by tubular pores and at depth grade into lithomargic clay.

Coastal alluvium comprises fine to medium grained sand, clay and gravels. The thickness of alluvium is around 35 to 45 m near the coast and gradually decreases landward up to 10 m. In the alluvial areas ground water occurs under water table condition. A well-defined clay layer at places has induced the semi-confined to confined ground water conditions in the alluvial aquifers. Hydrogeological map of coastal Karnataka is shown in Fig.6.2.

The yield of the dug wells ranges from 1.8 to 297 m³/day in sand and 18 to 36 m³/day in clay. The specific capacity of the dug wells tested ranges from 4.32 to 1198 m³/day/m for sand, 4.32 to 230 m³/day/m for sandy-clay and 4.32 to 44.64 m³/day/m for clay. The transmissivity values range from 37 to 781 m² /day for sand, 24 to 132 m² /day for sandy clay and 2 to 20 m² /day for the clayey beds. The hydraulic conductivity values range from 6.7 to 1323 m/day for sand to 0.6 to 6.30 m/day for clay.

In laterites, ground water occurs under unconfined condition. Laterites form productive aquifers in areas close to valley portions. The laterite plateaus are generally characterized by thick overburden gradually grading into lithomargic clay. The underlying clay wherever present, is of caving nature and constrains deepening of dug wells. The specific capacity of the wells in laterites in Uttara Kannada districts varies from 32.69 to 57.6 m³/day/m. The specific capacity of these formations in Udupi and Dakshina Kannada districts ranges from 10.9 to 572 m³/day/m. The transmissivity ranges from 385 to 4348 m² /day. The hydraulic conductivity values range from 0.6 to 311 m/day. The yield of wells in laterites ranges from less than 2 to 280 m³/day.

4.2.2.2 Fissured Formations

The coastal Karnataka occupied by the Dharwarian group of rocks is represented by chlorite schist, amphibolite, quartzites, phyllites, limestones, dolomite and intrusives of basic nature. In these formations ground water occurs under unconfined conditions in the weathered mantle. In the underlying deeper fractures ground water occurs under confined or semi-confined conditions. In Uttara Kannada district the yield of the wells of 15 to 24 m depth varies from 3.14 to 3.86 lps. The specific capacity of these wells ranges from 20 to 139 m³/day/m drawdown. While in Udupi and Dakshin Kannada the specific capacity of wells ranges from 10.9 to 572 m³/day/m drawdown. The transmissivity values range from 3.85 to 4348 m²/day and the hydraulic conductivity values range from 0.60 to 311 m/day. In granitic gneiss in shallow weathered zone ground water occurs under water table conditions. The specific capacity values range from 0.2 to 19.5 lpm.m/m². The transmissivity values range from 5 to 141 m²/day and the hydraulic conductivity values range from 1.8 to 86 m/day. The yield of the wells ranges from 14 to 85 m³/day. The specific capacity values for the dug wells vary between 5.04 and 83.52 m³/day/m drawdown.

4.2.3 Goa

A generalized hydrogeological map of Goa is shown in **Fig. 4.8**.

4.2.3.1 Porous Formations

In coastal Goa, the recent alluvium and the thick laterite cappings form potential aquifers. The fine to coarse sand, gravel with intercalation of sandy loam in the alluvium, constitute the aquifers.

Thickness of alluvium varies from a few meters to about 22 m. Exploratory wells constructed in the coastal alluvium vary in depth from 15.5 to 22 m. The thickness of sand and gravel bed varies from 3 to 3.5 m in the depth range of 10 to 20 m bgl. The yield ranges from 155 to 260 m³/day. The specific capacity varies from 27.1 to 200.8 m³/day/m. The transmissivity values range from 25 to 178 m²/day.



Laterites also constitute important water bearing formations in Goa. The laterites are either insitu particularly in plateau areas or detrital origin generally occupying the valley portions. Besides inherent porosity the laterites are highly jointed and fractured which control their water bearing capacity. The topographic setting of laterite controls its ground water potential. The thickness of laterite extends up to 30m. The depth to water level in laterites varies from 1.21 to 9.54 m.bgl.

4.2.3.2 Fissured Formations

Ground water occurs under unconfined to semi confined and confined conditions in the weathered and fractured zones of granites, granite gneisses. The depth to water level in these rocks varies from 2.12 to 7.27 mbgl. The water level in the exploratory bore wells in granite and granite gneiss

drilled to 71 to 124 m range from 3.9 and 6.7 mbgl. The transmissivity varies from 0.9 to 35 m²/day.

The dugwells tapping metavolcanics and metasedementaries have average depth of about 9.00 mbgl. The depth to water level ranges from 2.12 to 7.27 mbgl. The depth of exploratory bore wells ranges from 37 to 200 m and yield range from as low as 16 to 2200 m³/day. The transmissivity values range from 0.25 to 346 m²/day. The aquifer parameters are summarized in **Table 4.8**.

Table 4.8: Aquifer parameters of shallow aquifers, South Goa (after Adyalkar)

Aquifer	Hydraulic Conductivity (m/d)	Saturated thickness (m)	Specific capacity (lpm/m)	Specific yield (%)
Alluvial sand	99.2	1.2	101.5	-
Beach sand	10.0	2.2-2.4	46.2	1.1
Laterite	109.4	1.1-2.8	262.0	3.5-4.1
Laterite (underlain by weathered granite or mica schist)	13.8	2.0-2.5	48.2	4.1
Weathered granite	57.6	1.4	169.0	-

4.2.4 Maharashtra

4.2.4.1 Porous Formations

In Maharashtra, semi-consolidated calcareous sandstone occurs along the Konkan coast underlying the beach deposits and at places exposed as outcrops. It is coarse grained and gritty with fragments of shells. It is locally known as Karal and of Mio-Pliocene age and found in Ratnagiri & adjoining Sindhudurg districts between Ratnagiri and Wada Mirva and other places along the coast. The area covered by this formation is about 1200 sq. km. The observed thickness of the formation is up to 10 m at places but may be more. The Karal forms a distinct local hydrogeological unit, which yields good discharge to dug wells. The quality of water is slightly brackish and is locally used for horticulture purposes (coconut / arecanut gardens). The pumping test conducted on dug wells indicated unit area specific capacity as 33.81 l lpm/m/m².

Laterites, both primary and secondary, occupy extensive areas of low-lying tracts, coastal parts and high plateau of Sahyadri ranges, concealing the underlying Dharwars, Kaladgis and Deccan Trap. The laterites are product of leaching process acting on Deccan Traps and Precambrian rocks. The laterites have better porosity due to intricate network of sinuous conduits formed during leaching process. The ground water occurs in network of such conduits. The lithomargic clays occurring at the base act as an aquiclude restricts downward percolation of ground water and at places springs emerge at the contact zones due to lateral movement of ground water. However, due to limited thickness and quick draining of ground water, the laterites do not constitute potential aquifers.

In the coastal areas of Ratnagiri district, marked by extreme laterite capping, both primary and secondary laterite form potential shallow aquifer. A detailed study carried out in Sivjartali-Akloli section in Ratnagiri district (Saha, 1998) reveals the depth to water level as varying from 1.1 to 15.7 m bgl with an average of 6.99 m bgl. Pumping test of open dug wells reveals the range of unit area specific capacity as 1.5 to as high as 43.7 lpm/m/m². The permeability of hard rocks ranges from

0.6 to 37.0 m/day but mostly it remains within 7 m/day. The rate of inflow which is an indicator of potentiality of the aquifer ranges from 0.7 to 14.9 m³/hr.

All along the Konkan coast a narrow strip of unconsolidated beach sands occurs, varying in width from a few tens of metres where the hills form a sea face, to a few hundred metres near the coastline having flat topography. Wherever the coastal topography is flat the beach sands merge landwards into low-lying mud flats, which may extend a few km inland. The depressions in such mud flats form saline lands. The coastal alluvium, wherever it is locally extensive, assumes importance as moderate ground water reservoirs.

In Thane district, the coastal alluvium occurs from north of Chikhaley to Dahanu and extends to Palghar, Virar, Vasai and Nalasopara in the south. The beach sands are less than half a km wide but the mud flats have width upto 5 km and thickness up to 36 m. It comprises clay, silt, sands, and gravel. The yield potential of dug wells ranges from 150 to 900 m³/day in winter to 100 to 230 m³/day in summer. The quality of the ground water is fresh in the elevated lands (EC 600 to 2000 μ S/cm) but brackish to saline (EC up to 4000 μ S/cm) in lowlands.

In Raigad district, significant coastal alluvium occurs only around Uran and Srivardhan, where it is 3 to 5 km wide and less than 10 m thick. Ground water in shallow dug wells is fresh to brackish and the yield is less than 100 m³/day.

In Ratnagiri district, south of Raigad up to Ratnagiri, beach sands occur as less than 300 m wide disconnected belts. The thickness varies between 1 and 8 m. The specific capacity of the existing dug wells is reported to be around 200 lpm/m and the average permeability is 90 m/day. The quality of water is slightly brackish near the creeks.

In Sindhudurg district significant coastal alluvium occurs south of Achra creek and extends through Malvan up to Devgad and Kelus to Shiroda. It comprises brownish buff coloured sands with thickness between 5 and 15 m and maximum width up to 1 km. The yield of open wells is between 20 and 40 m³/day and the quality of water is fresh to brackish.

The fluvial alluvial deposits occur along river courses and form locally significant hydrogeological units wherever they have adequate thickness (more than 10 m) and considerable lateral extent. The alluvium generally comprises silts, clays, sands, gravels and occasionally the cobble beds. The coarser granular layers like sand, gravels, pebbles beds when occur below water table form productive aquifers but have generally limited geometry, as these form lenses embedded in finer sediments. If the alluvium has considerable thickness, say between 10 and 40 m, the deeper sand lenses occurring below clay layers act as semi-confined aquifers. Occurrence of Kankar beds is common within the alluvium. The quality of ground water in areas where alluvial thickness is small (less than 10 m) is generally fresh to slightly brackish but in areas where the alluvium is thick and poorly drained the ground water quality is brackish or even saline.

In these Konkan coastal districts, local patches of alluvial deposits occur along the courses of Vaitarna and Ulhas Rivers (Thane), Patalganga, Amba and Kundalika rivers (Raigarh), lower reaches of Vaishishti, Shastri, Kajvi, Machkundi and Karni rivers (Ratnagiri) and lower reaches of Wagathan, God, Karli and Terekhol Rivers (Sindhudurg) and their tributaries.

Due to higher topographic gradients the extent of alluvial deposits is rather restricted and the thickness along the riverbanks seldom exceeds 4 to 6 m. Separate observations on the yield of alluvial aquifers and aquifer parameters are very few. The quality of ground water in areas experiencing tidal backwater effects is brackish or saline but in other areas it is fresh.

4.2.3.3 Fissured Formations

In the coastal parts of Maharashtra, Dharwar meta-sediments of Lower Precambrian period occur in Ratnagiri and Sindhudurg districts. They comprise ferruginous phyllites, pink banded ferruginous quartzite, micaceous quartzite, mica schist, amphibolite, pegmatite, granite and granite-gneiss. These formations do not possess any primary porosity and permeability. The secondary porosity develops in these rocks by weathering and presence of joints & fractures. The ground water occurs under unconfined conditions in the weathered and fracture zones, which extend down to 10 to 15 m depth. Yield of wells in these formations ranges between 5 and 20 m³/day. Pumping test of dugwells in these formations indicates specific capacity of 0.5 to 80 lpm/m. The hydraulic conductivity and transmissivity range from 8 to 56 m/day and 8 to 57 m²/day respectively.

Overlying the meta-sediments, the Kaladgis are exposed over a small area in the coastal tract of Ratnagiri and Sindhudurg districts. They comprise ortho-quartzite, sandstone, shale with minor intercalation of conglomerate and limestone. Ground water in these formations mostly occurs under unconfined conditions in the weathered mantle and along the joints in sandstone, shale and limestone. The occurrence and movement of ground water in the Kaladgis are controlled by the fracture porosity due to its indurated nature. Karsts in the limestones form good aquifers. Yield of the wells of depths less than 100 m in fractured and karst limestones may range up to 600 m³/day. Yield of shallow open wells is maximum up to 100 m³/day. The transmissivity of the near-surface aquifer is about 120 m²/day.

A large part of the coastal tract of Maharashtra is occupied by the lava flows of basaltic rocks- the Deccan Traps. The Traps are often affected by sheet jointing and columnar jointing. Also in each flow, generally the top 1/3rd of the flow-thickness is occupied by vesicles. Ground water in these basaltic rocks occurs mostly in the upper weathered and jointed/fractured zones, generally up to 15 to 20 m depth. The interconnected vesicles also form potential aquifer just like the aquifer system in sedimentary formation. The vesicular layer of the deeper flows gets recharged through columnar or vertical joints present in the massive basalt part. In fact, the aquifer system in Traps behaves as multi layered aquifers where potential vesicular layers are inter-layered with massive basalt. The Deccan trap generally forms good aquifer in the valleys. At places, the confined aquifers occur below 30 m depth. The confined aquifers, below 30m depth, occur at places. Yield of wells in jointed & weathered massive basalt ranges from 15 to 80 m³/day, whereas in vesicular & amygdaloidal basalts it ranges from 45 to 90 m³/day. The transmissivity of these aquifers range from 18 to 38 m²/day. The permeability varies from 0.4 to 1.1 m/day (Saha and Agrawal, 2006). The discharge from deeper aquifers varies from 75 to 145 m³/day with drawdown ranging from 0.8 to 1.1 m.

4.2.5 Gujarat

A generalized Hydrogeological map of Gujarat is shown in **Fig. 4.9**

4.2.5.1 Porous Formations

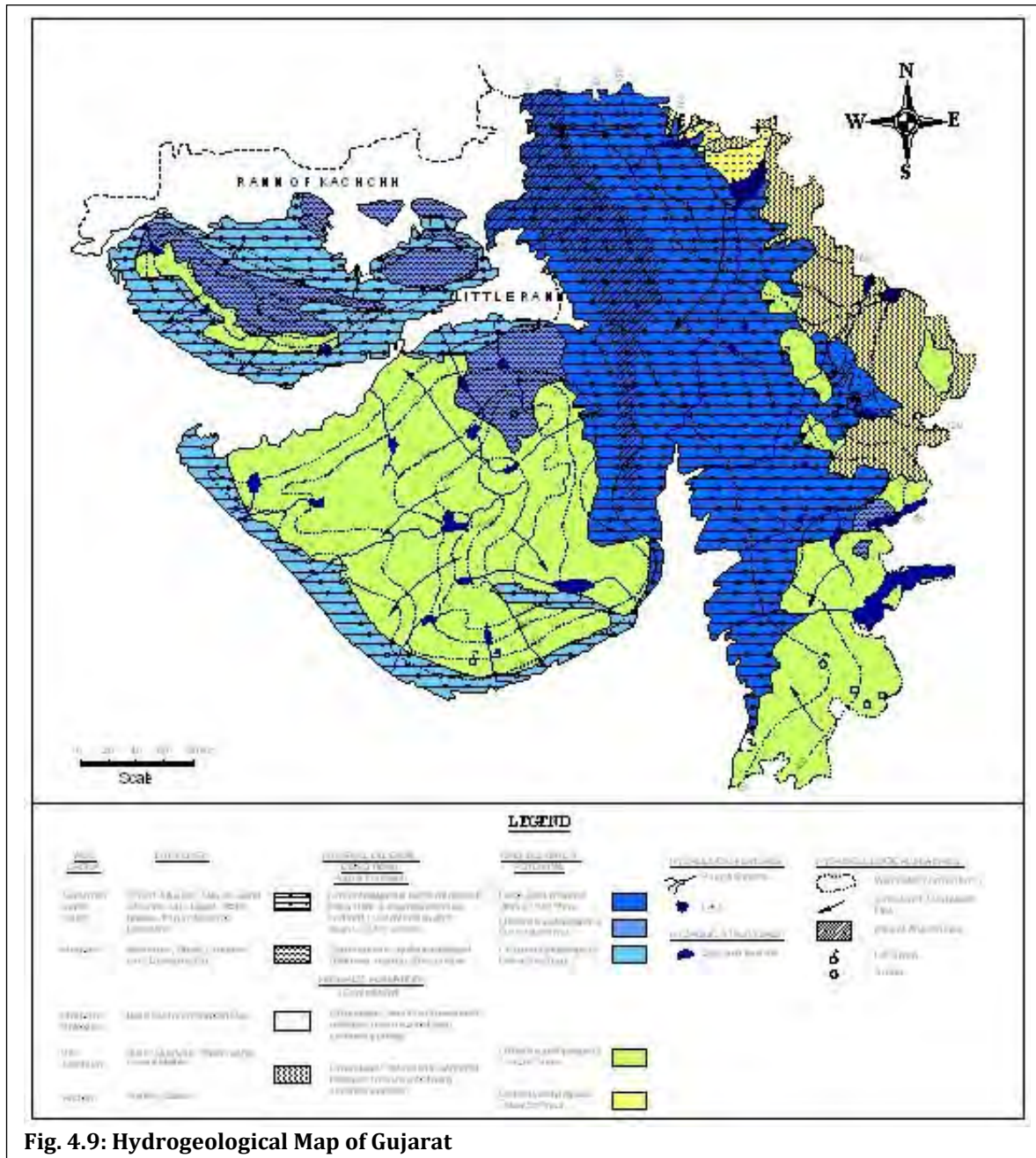
Along Gujarat coast, the sedimentary formations ranging in age from Upper Cretaceous to Quaternary form the aquifers. They occur under unconfined to semi-confined conditions. In general, the unconfined aquifers occur up to 40 m bgl, whereas the semi-confined to confined aquifers extend from 30 m to more than 200 m bgl (the general depth of drilling). The salient features of the aquifers are given in **Table 4.9** and shown in the hydrogeological map of the State (**Fig. 4.9**).

Geological formation	Aquifer material	Nature of the aquifer	Max. thickness (m)	Nature of porosity	Thickness of saturated zones	Quality of ground water	Remarks
Recent	Alluvium	Unconfined	20- 30	Primary Porosity	15 to 20m	Good	
Manchar	Sand, Clay, Conglomerate	Unconfined		Primary Porosity		Good	
Miliolite	Limestone	Unconfined	More than 40	-do-	15 to over 20m	Good to bad. Quality below 40m not known	Yield prolific around Barda Hills and between Mangrol and Veraval, less so elsewhere
Gaj	Limestone, Grit and sand stone	Upper unconfined	30	Primary and secondary (Pores, fractures and solution cavities)	—	Good to bad. Lower aquifer reported saline	Productive in Kodinar-Una area, less productive else where
Deccan Trap	Massive and Amygdaloidal basalt	Upper unconfined Lower confined	20 25	Secondary (Weathered material, fractures shears)	5-15 m in places unsaturated	Good	Productive in Kodinar-Una area, less productive else where

Table 4.9: Salient features of aquifer system (GWRDC, Gujarat)

The Kachchh coast largely comprises mud and marshy lands. The alluvium and wind-blown sand deposit along Malia – Lakhpatt reach is 15 to 40m thick (Tahal, 97) and form the unconfined aquifer. The Miliolite limestones of Pliocene age exposed along the coastal tracts of Kachchh and Saurashtra form potential aquifers because of their highly pervious nature that resulted from the caverns in them. The porosity as well as thickness of the Miliolite aquifer decrease inland. In the coastal tract of Kachchh, the sediments grouped as Manchar Series (Tertiary) also form the unconfined aquifer. The depth to water level varies from 3 to 10 m bgl in general. Exploratory drilling in the depth range of 150 to 458 m bgl carried out in this area has revealed the existence of confined aquifers of limited thickness. The quality of ground water in deeper aquifers is saline, except a small pocket around Kapaiya in Mundra-Mandvi area. The quality of water in the shallow aquifer is also saline with few localized pockets of brackish to fresh water.

Tubewells ranging in depth from 116 to 169 m bgl tapping the aquifers in Tertiary sandstones of Manchar series, yield 1600 to 3200 m³/day. The yield of Tertiary aquifers tapped in Mandvi area in the depth range of 14 to 50 m is also considerably high.



The aquifers, underlying the Tertiaries, in the Upper Bhuj formation, comprising medium to coarse grained soft sandstone are the most productive. Tubewells constructed to a depth of 200m tapping Upper Bhuj aquifers yield 240 to 9000 m³/day for a drawdown of 10 m. The quality of formation water deteriorates towards the coast.

Along Saurashtra coast the Quaternary alluvial cover is pervious to semi-pervious except where it occurs as marshy land. The coastal alluvium, comprising sand and clay in parts of Jamnagar, Junagadh, Amreli, Bhavnagar and Rajkot districts, overlying the Tertiary deposits, in general, forms aquifer of limited nature and is poorly developed because of brackish to saline water saturation.

The limestone in the area has wide range of permeability depending on their compaction or cavernous nature. The underlying Gaj and Dwarka Beds have low to moderate permeability due to their clay content. The Supra-Trappeans and the Deccan Trap forming bed rock in the coastal tract have low permeability due to their secondary porosity. These are qualitative generalized characteristics of the aquifers in these formations and may marginally vary locally.

The thickness of the sediments in the exploratory boreholes drilled by CGWB in the coastal area, ranges from 190 m to more than 300m. The Miliolitic Limestone thickness ranges from a few metres to 45 m. Thickness of the Gaj formation encountered in the boreholes varies from 158 m to more than 300m. According to Arun & Parchure (2002), the coastal sands and alluvium hold 5 to 10 m thick aquifer.

The Miliolitic limestone occurring all along the southern and western part of Saurashtra coast, underlying the beach sands is the most potential unconfined aquifer. The depth of wells ranges up to 40 m and depth to water level varies from 5 m to 27 m bgl. The Miliolite limestone forms high yielding aquifer due to its cavernous nature. The average yield is more than 200 m³/day. It has permeability in the range of 25 to 200 m/day. These form locally very useful aquifers as they are the repositories of potable ground water in the otherwise saline water coastal tract of Saurashtra. The quality of ground water in the Miliolite limestone is good but mostly in areas 2 to 4 km inland from the coast. The sea water ingress in Miliolitic limestone is due to its easy access in the caverns and the overexploitation of ground water.

The Tertiary (Miocene) Gaj Bed consisting of limestone, clay, and grit with minor sand also form aquifers in the coastal tract but has low permeability (25-60 m/ day). Miliolite and Gaj Bed occur in belts parallel to the coast. The ground water occurs under unconfined to confined conditions. The wells tapping Gaj Bed vary in depth from 4 m to 64m bgl, with depth to water level ranging from near surface (in depressions) to 26 m bgl. The wells have an average yield of about 200 m³/day. It has been observed that yield does not increase with increase in depth of wells. The quality of formation water is, in general, marginally fresh due to inherent salinity of formation water and intercalation of clays. The tube wells tapping the aquifers in Dwaraka beds show yield about 20 m³/day. The dug wells have a bit higher yield of 27 m³/day.

In the mainland coastal tracts of southern Gujarat the aquifers in the Tertiaries, of maximum thickness 100 m of sandstone, shale, limestone and gravel, yield moderately through shallow tubewells. However the water is mostly brackish to saline.

4.2.5.2 Fissured Formations

In the coastal tract of Jamnagar district along Gulf of Kachchh the Deccan Trap basalts are exposed over a large area. The thickness of Traps is 100 to 150 m in Kachchh to more than 1000 m in the main land. It holds aquifers in fracture zones with low permeability (25 m/day). The yield from aquifers in Trap is in general meager but at places it is upto 90 m³/day or more in cases of wells located on fractures/joints. The quality of ground water in Deccan Traps is in general fresh except the places where sea water has intruded through large creeks into fractures and joints.

5. STATUS OF GROUND WATER QUALITY OF IN COASTAL AQUIFERS

Coastal aquifers are mostly characterized by the confrontation between marine and continental conditions. Ground water quality in coastal aquifers is largely influenced by the interaction between the sea and the bordering aquifer systems. This may result in the salinization of fresh aquifers, or conversely, the freshening of saline aquifers. Salinization can be induced by natural events, such as marine transgressions and flooding, or by anthropogenic causes, such as overexploitation of the aquifer. Freshening can have natural origins, such as the development of dune belts along the coastline, or it can be triggered by man by artificial recharge. Each of these mechanisms has its own time scale, and the present fresh/salt water distribution in a coastal aquifer is very often determined by the long-term hydrogeological and physiographical history of the region.

Quality of ground water in coastal aquifers is governed by both natural and anthropogenic factors. The most important factor affecting the quality of ground water in coastal aquifers is the sea water, which contains a number of chemical constituents in very high concentrations as compared to groundwater (**Table.5.1**).

Salinity in coastal aquifers is mostly due to the sea water (as connate water) with different degrees of salinity either getting entrapped in aquifer zones during marine transgressions or through deposition of sediments under marine depositional environments. Other possible sources of salinization include seepage from

Table 5.1: Major ionic composition of sea water	
Constituent	Concentration (mg/l) in Sea water
Chloride	19,000-23,000
Sodium	10,000-16,000
Sulphate	2,600-3,200
Magnesium	700-1800
Calcium	200-500
Potassium	200-450
Bicarbonate	140-145
Strontium	>10
Bromide	70-150
Borate	25-70
Fluoride	1.0
Silicate	1-1.5
Iodide	<1-2

navigation canals and salt pans along the coast, evaporation of saline surface water; large-scale flooding of coastal areas during cyclones & tsunamis etc. Tidal influxes in rivers and streams may also cause deterioration of quality of ground water for considerable distances from the coast depending on the topographical settings. Anthropogenic factors affecting quality of ground water in coastal aquifers include over-exploitation of fresh water aquifers leading to ingress / upconing of saline water, dumping of domestic / municipal wastes and industrial effluents.

The quality of ground water in the shallow aquifers is studied from the analytical results of ground water samples collected from shallow dug wells whereas water quality of deeper aquifers are deciphered from the analytical data of samples from bore/tube wells. The salinity of ground water is normally measured in terms of its Specific Electrical Conductance (EC) and Chloride (Cl) content. Analysis of ground water samples collected from the observation wells of CGWB indicate that EC of shallow ground water is less than 750 $\mu\text{S}/\text{cm}$ in a major part of the west coast between Dadra & Nagar Haveli (UT) and Trivandrum except in a few patches around Raigarh in Maharashtra and Udipi in Karnataka with higher EC upto 3000 $\mu\text{S}/\text{cm}$. Further north, along the coast of Gujarat the EC of shallow ground water, in general, ranges from 1500 to 4500 $\mu\text{S}/\text{cm}$ except in the area between Sikka and Hadiyana of Jamnagar coast. However, there are strips of Kachchh and Saurashtra coasts and parts of Gulfs of Kachchh and Khambat where EC values are above 4500 $\mu\text{S}/\text{cm}$. It is upto about

20000 $\mu\text{S}/\text{cm}$ near Vinjhan (Kachchh coast), 6000 $\mu\text{S}/\text{cm}$ around Dwarka, 15000 to 18000 $\mu\text{S}/\text{cm}$ around Mangrol-Veraval (Saurashtra coast), 11000 to 12000 $\mu\text{S}/\text{cm}$ near Shikarpur-Kumbhariya (Gulf of Kachchh) and 6000 to 12000 $\mu\text{S}/\text{cm}$ near Jantram and Bhavnagar (Gulf of Khambat).

Along east coast, the EC of groundwater in the near surface aquifers varies, in general, from 750 to 3000 $\mu\text{S}/\text{cm}$ except a few patches with EC less than 750 $\mu\text{S}/\text{cm}$ around Digha on the coast of West Bengal and Kendrapara and Puri on the coast of Odisha. In the northern part of Andhra Pradesh coast the EC is mostly in the range of 750 to 1500 $\mu\text{S}/\text{cm}$, while in the southern part it is mostly in the range of 1500 to 3000 $\mu\text{S}/\text{cm}$. Along east coast also there are patches with EC values in the range of 3000 to 4500 $\mu\text{S}/\text{cm}$ on the coast of Andhra Pradesh and Tamil Nadu. Shallow aquifers with very High EC water, in the range of 7000 to 22000 $\mu\text{S}/\text{cm}$ are encountered only in the southern coastal districts of Tamil Nadu, viz., Pudukkottai, Ramanathapuram, Tuticorin and Tirunelveli.

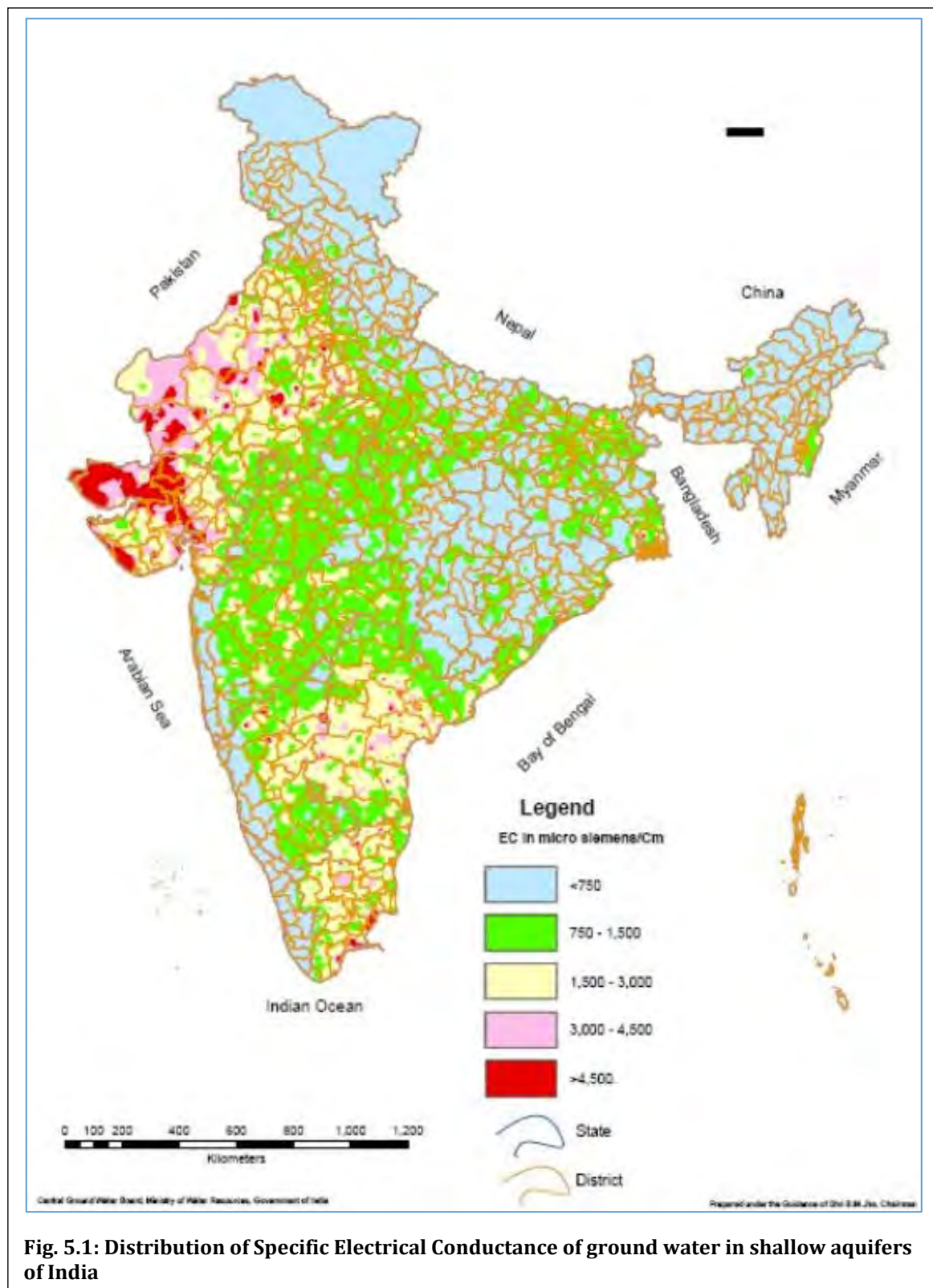
Along Konkan and Malabar coasts on the west, Chloride content of shallow groundwater zones is mostly less than 250 ppm, whereas along Gujarat coast, it is, in general, more than 500 ppm. In some patches on Saurashtra coast, Kachchh coast and Gulf of Kachchh the chloride content is higher, even more than 2000 ppm. On the east coast, the Chloride content of shallow ground water zone is less than 250 ppm only in the coastal tract of Odisha and in the southwestern part of the coastal tract of West Bengal. Along the coast of Andhra Pradesh and Tamil Nadu, Chloride content generally ranges up to 1000 ppm with patches of higher Chloride content up to 2000 ppm. In Tamil Nadu patches with Chloride content higher than 2000 ppm in shallow ground water zones are encountered in the southern districts viz., Pudukkottai, Ramanathapuram and Tuticorin. Maps showing the spatial distribution of Specific Electrical Conductance (EC) and Chloride (Cl) in ground water in shallow aquifers of India are shown in **Figs. 5.1 & 5.2** respectively.

Quality of ground water in coastal aquifers show considerable variation from place to place, depending on a host of factors including climate, geomorphology, geology, hydrogeological setting and extent of human interference. Status of ground water quality in coastal aquifers are described state-wise in some detail in the following sections

5.1 East Coast

5.1.1 Tamil Nadu & Puducherry

Detailed hydrogeological studies and ground water exploration by CGWB in the coastal tract of Tamil Nadu State and U.T. of Puducherry reveal the presence of multi-layered aquifers with wide variations in quality. Electrical. These aquifers contain fresh water ($\text{EC} < 750 \mu\text{S}/\text{cm}$), brackish (EC between 750 to 2250 $\mu\text{S}/\text{cm}$) /saline water ($\text{EC} > 2250 \mu\text{S}/\text{cm}$) and also brine at places. Packer tests conducted for different granular zones at varying depths have revealed the vertical considerable variation in hydrochemistry. The fresh water and saline water system in the sub-surface co-exist in a characteristic hydrodynamic equilibrium and the exploration has indicated the following:



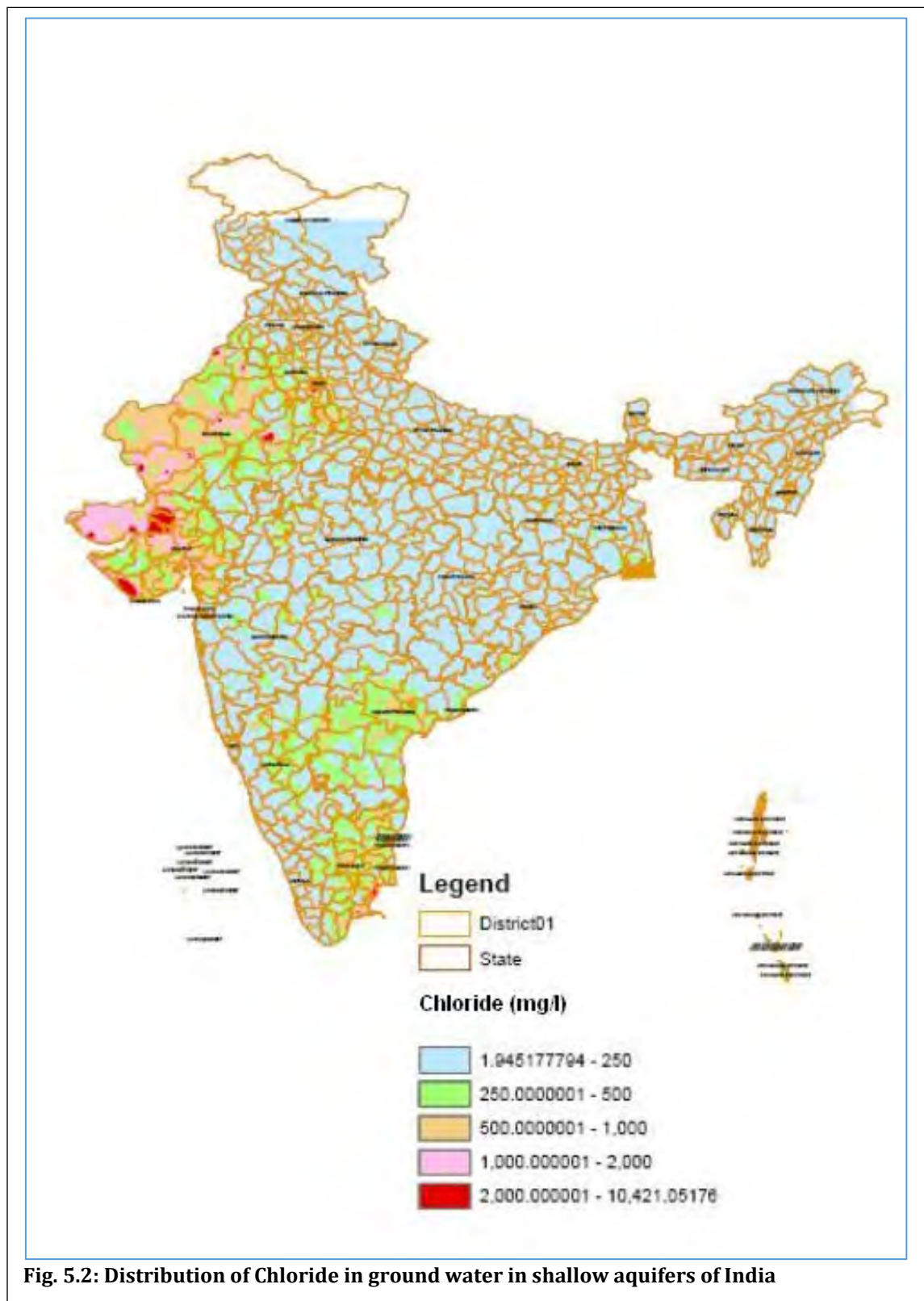


Fig. 5.2: Distribution of Chloride in ground water in shallow aquifers of India

Depending on the hydrogeological and hydrological conditions, a wide variation occurs in the disposition of fresh and saline ground water as given below.

- 1) Fresh water underlain by saline ground water in a homogeneous and isotropic medium under water table conditions
- 2) Saline water underlies comparatively fresh ground water, the two zones being separated by a semi-pervious layer.
- 3) Saline water overlies comparatively fresh ground water, the two zones being separated by a semi pervious layer.
- 4) Fresh ground water laterally grades into saline water occurring either under water table confined or semi confined conditions.

The quality of ground water is observed to be potable in Korattalaiyar – Araniyar basin falling in Tiruvallur-Kancheepuram districts and in areas north of Ponnaiyar River including Puducherry region. In Cuddalore district, the ground water in the shallow aquifer group is in general good and EC is below 1100 $\mu\text{S}/\text{cm}$ and, in general, between 100 and 600 $\mu\text{S}/\text{cm}$. The depth zone between 100 and 300 m bgl in the Bhuvanagiri- Chidambaram- Porto Novo belt is highly saline with Total Dissolved Solids (TDS) in excess of 30000 ppm as observed in the exploratory well at Puduchattiram.

The areas south of Ponnaiyar River, especially south of Porto Novo up to river Coleroon, south of Tranquebar (Tharangambadi) up to the area south of Nagapattinam district including Karaikal region of UT of Puducherry and area south of Pattukottai in Thanjavur district, up to Tiruvadana and Thondi in Ramanathapuram district exhibit the occurrence of saline aquifer down to a maximum depth of 300 m bgl. Aquifers with potable ground water occur at deeper levels below 300 m bgl. However, as an exception in Kottucherry area of Karaikal region, potable water is found between 110 and 240 m bgl.

In Nagapattinam district the quality of water in the deeper aquifers towards the coast is in general poor. On the other hand, the coastal alluvium of Thanjavur district mostly holds fresh water with some quality deterioration towards the coast, e.g., in the shallow aquifers in Shiyak and Pattukottai taluks, the alluvial aquifers hold saline water. The Tertiary and other older sediments explored down to a maximum depth of 244 m bgl contain potential fresh water aquifers. The EC of water in Pliocene aquifers ranges from 156 to 1931 $\mu\text{S}/\text{cm}$. Higher values are observed near the coast.

Further south, in the eastern part of Ramanathapuram district near surface fresh water aquifers are available in the beach ridges and sand dunes all along the coast line. In the near surface aquifers water has EC in the range of 570-20000 $\mu\text{S}/\text{cm}$ with higher values towards the eastern coastal part. As such there is no definite pattern in the water quality variation. In the northwestern part of the district, only at Tiruvadana the aquifers in the depth range of 351-378 m bgl immediately overlying the crystalline bed rock and at Andavurani in the depth range 347-375 m bgl hold fresh water of EC 1280-1260 $\mu\text{S}/\text{cm}$. Also, these wells showed auto-flowing conditions with piezometric head 7.6 to 13.25 m agl. In these wells the overlying granular zones contain saline water of EC 5100-8200 $\mu\text{S}/\text{cm}$. However, in southern part near the coast, all deep wells (with maximum depth of 777 m bgl at Periya Ayakkudi) in which the crystalline basement was not encountered even at that depth has revealed the presence of saline water throughout (for depth range 0-172m bgl : EC 3800 $\mu\text{S}/\text{cm}$,

172-310m bgl : EC 2200-2500 $\mu\text{S}/\text{cm}$, 341-479 bgl : EC 4500 $\mu\text{S}/\text{cm}$ and 510- 728m bgl : EC 3000-5000 $\mu\text{S}/\text{cm}$).

The coastal tract of Tuticorin district, on the contrary, exhibits fresh water aquifers at the top up to a depth of 45 to 55 m bgl followed by saline aquifer at the bottom in the comparatively lesser thickness of sedimentary formations (125 m bgl).

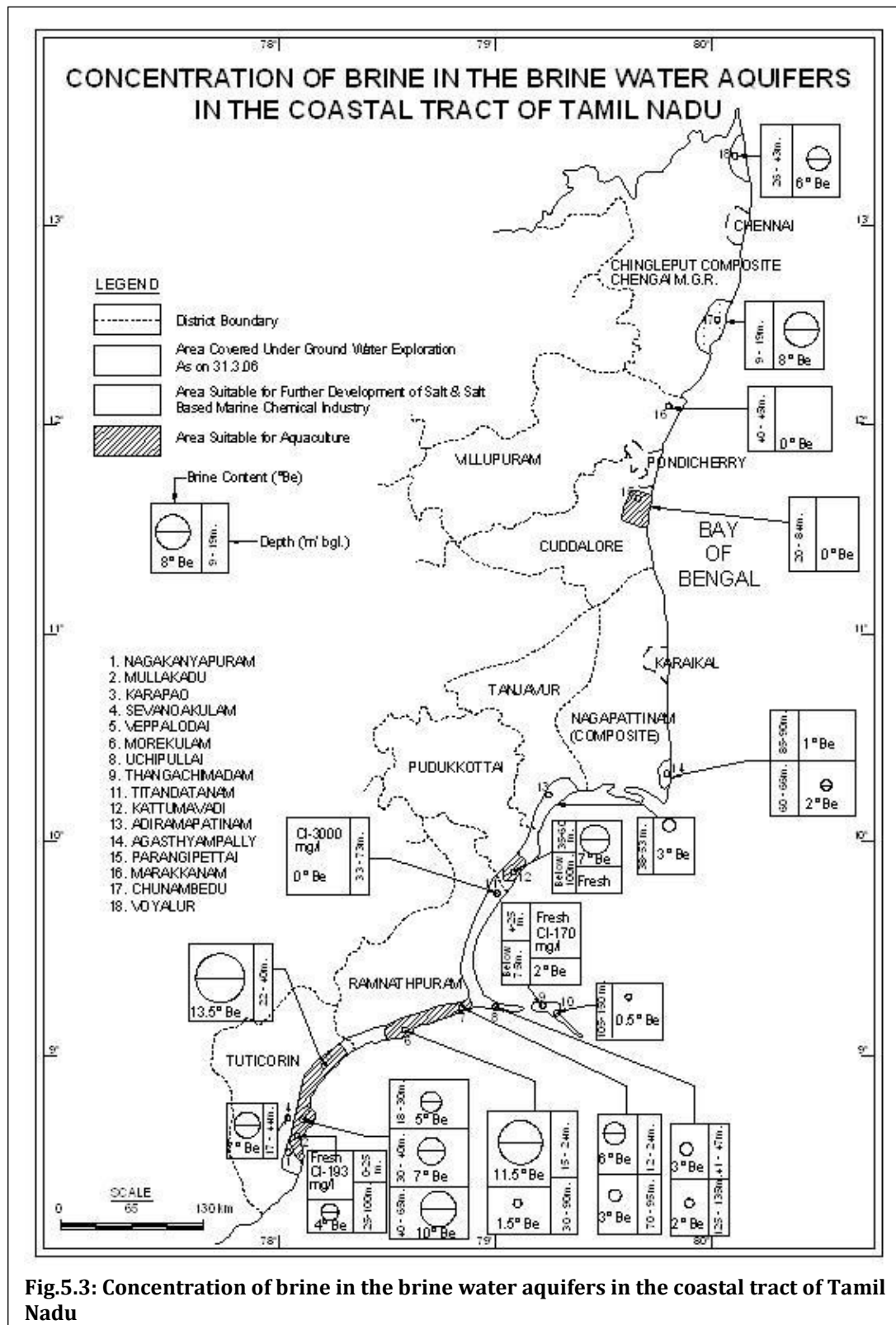
Studies conducted by CGWB on brine concentration by drilling a number of wells along the coast line of Tamil Nadu reveal the range of concentration varying from 0.5 $^{\circ}\text{Be}$ to 13 $^{\circ}\text{Be}$ in the depth range of 4 to 200m bgl. The EC values range from 11000 to as high as 1,36,800 $\mu\text{S}/\text{cm}$ and Chloride concentration ranges from 4000 to 74,000 ppm. High concentration were observed in the extreme north and south of the state in Tiruvallur and Tuticorin districts. If the concentration of brine is up to 3 $^{\circ}\text{Be}$, it is suitable for the development of aquaculture. Higher concentrations are suitable for development of salt and salt based marine chemical industries. The details of sites are shown in **Fig. 5.3**.

In Puducherry Region, the coastal aquifers can be broadly divided into three groups, viz., Recent, Tertiary and Cretaceous. The thickness of recent alluvial aquifers ranges from 5 to 34m. These aquifers are tapped by wells in the depth range of 25 to 50m. The cumulative thickness of aquifer varies from 20 to 245 m in Tertiary formations and is tapped by wells in the depth range of 27 to 366 m bgl. In Cretaceous formation, the cumulative thickness of aquifer varies from 38 to 92 m and the depth of the wells tapping this aquifer varies from 65 to 400 m bgl. The exploration revealed that in general, ground water encountered down to 300 m bgl, is of good quality with EC less than 600 $\mu\text{S}/\text{cm}$, while the zones beyond 300 m has EC about 1500 $\mu\text{S}/\text{cm}$.

In general, the quality of the formation water in alluvial aquifers is good and has EC less than 750 $\mu\text{S}/\text{cm}$. However, at Murungapakkam, Kirumampakkam, Kilparikelpet and Uchimedu, along the coast, at about 5 km from the coast, the EC was more than 10000 $\mu\text{S}/\text{cm}$ recorded during May 2002. It was also reported that the deterioration in quality at these places might have been due to seawater intrusion.

The quality of ground water in Tertiary aquifer is good and has EC less than 750 $\mu\text{S}/\text{cm}$, except along the coast at Murungapakkam (8280 $\mu\text{S}/\text{cm}$), Kilparikelpet (6800 $\mu\text{S}/\text{cm}$) & Uchimedu (5100 $\mu\text{S}/\text{cm}$). Similarly, the quality of ground water in Cretaceous aquifer is also good and has EC less than 750 $\mu\text{S}/\text{cm}$ except a patch at Madagadipet where EC was recorded as 7280 $\mu\text{S}/\text{cm}$.

The disposition of fresh and saline water reveals that from Marungapakkam to Kilparikalpet, along the coast, the formation water has turned brackish in both recent alluvium and Tertiary aquifers in recent years, probably due to seawater ingress. While, the poor quality of the formation water in Madagadipattu in Cretaceous sediments may be due to in-situ salinity.



5.1.2 Andhra Pradesh

Ground water in the coastal aquifers varies widely from fresh to saline. In general, the shallow ground water varies from fresh to saline while the deeper aquifers are saline. There is considerable heterogeneity in distribution of quality both vertically and spatially.

5.1.2.1 Shallow Aquifers

The shallow ground water in the coastal tract of Andhra Pradesh is generally alkaline in nature. The EC varies from 280 to 16000 $\mu\text{S}/\text{cm}$. The Chloride ranges between 20 and 4600 ppm and sulphate between 1 and 980 ppm. Broadly, the fresh water is confined to palaeo-channels, levees and palaeo beach ridges of sand dune complex. Saline water occurs in tidal flats, mangrove swamps, back swamps. In the beach ridge – sand dune complex located close to the coast in Prakasam district, the water is fresh having EC of 280 $\mu\text{S}/\text{cm}$ down to 18m depth and geophysical logging indicated moderate fresh water down to a depth of 45 m bgl.

The unsuitability of shallow aquifers for drinking purpose (BIS, 2003) is mainly due to Nitrate (NO_3^-) and electrical conductivity (EC). The ranges of different chemical constituents of ground water samples (district-wise) along with % of wells exceeding permissible limit (PL) of drinking water standards (BIS, 2003) are given in **Table 5.2**.

The majority of samples are Ca - HCO_3 type followed by Na – Cl type. Most of the water samples are of C3S1 class and varying from high Salinity - low Sodium hazard (C3S1) to very high Salinity – medium Sodium hazard (C4S2) as per their plotting positions in U.S. Salinity Lab diagram. In the beach ridge-sand dune complex, located close to coast in Prakasam district, the water is fresh having EC of 280 micro Siemens/cm at 25°C down to depth of 18 m.

5.1.2.2 Deep Aquifers

In order to study the quality of deeper aquifers, hydrochemical data of exploratory wells constructed by CGWB (96 wells) were utilized. It reveals that wells constructed beyond 100 m in deltaic aquifers are invariably saline, with maximum EC of 46000 $\mu\text{S}/\text{cm}$. However, EC is less in very few wells like Pedapurapudi (EC of 1517 $\mu\text{S}/\text{cm}$ at 25°C), Musalipadu (EC of 2200 $\mu\text{S}/\text{cm}$ at 25°C) in Krishna delta. In wells constructed in palaeo-channels in Godavari delta, the water is fresh down to depths varying from 8 to 70 m, with EC of 810 to 2130 $\mu\text{S}/\text{cm}$ at 25°C, below which saline water occurs. However in paleo-channels of Krishna delta, the fresh water is limited to much shallower depths of 20 m. It is also observed that the EC is found to increase with depth at few places. For instance at Pullaparru in Krishna delta the EC is 10,400 $\mu\text{S}/\text{cm}$ at 25°C at depth range of 29-33 m which increases to 77,950 $\mu\text{S}/\text{cm}$ at 25°C at depth range of 44-45m. Generally HCO_3 -Ca+Mg facies dominates towards inland while Na-Cl facies dominates towards coast. The ranges of chemical constituents of the water samples collected from exploratory wells district-wise are given in **Table -5.3**.

The ranges of chemical constituents of the deep aquifers, formation-wise are given in **Table: 5.4**. It can be seen that average concentrations of electrical conductivity, sodium are high in unconsolidated formations (mostly deltaic) suggesting that degree of salinity of high.

Order of abundance of ions in consolidated, semi-consolidated, unconsolidated formations is $\text{Na} > \text{Mg} > \text{Ca}$; $\text{Cl} > \text{HCO}_3 > \text{SO}_4$, $\text{Na} > \text{Ca} > \text{Mg}$; $\text{Cl} > \text{HCO}_3 > \text{SO}_4$ and $\text{Na} > \text{Mg} > \text{Ca}$: $\text{Cl} > \text{HCO}_3 > \text{SO}_4$ respectively. Geochemically ground water can be classified in general as Na K – Cl SO_4 type (**Fig.5.4**).

Table 5.2: Range of Different Chemical Constituents in Shallow Aquifers of Coastal Andhra Pradesh

	pH	EC	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F
		µS/cm	(mg/l)										
Entire Coastal Aquifers 85 samples)													
Maximum:	8.29	15950	3570	334	665	2737	411	60	964	4566	978	540	1.63
Minimum:	5.20	274	80	22	6.0	10	1.9	0	24	18	0.10	0	0.02
Average:	7.69	2322	465	96	55	287	56	1	409	437	136	79	0.36
% wells above BIS(PL):	1	25	15	5	60	--	--	--	--	7	5	40	1
Srikakulam District (11 samples)													
Maximum:	8.18	2350	540	140	63	391	47	0	543	496	144	149	0.70
Minimum:	7.33	274	80	22	6	10	4	0	31	18	5	2	0.05
Average:	7.80	1440	323	79	30	179	22	0	342	242	65	60	0.38
% wells above BIS(PL):	0	0	0	0	45	--	--	--	--	0	0	55	0
Vizianagaram District (3 samples)													
Maximum:	7.91	1400	375	76	45	147	24	0	360	191	86	110	0.80
Minimum:	7.27	1110	340	62	45	106	20	0	329	128	72	64	0.28
Average:	7.69	1510	443	109	42	105	76	0	327	164	205	68	0.47
% wells above BIS(PL):	0	0	0	0	67	--	--	--	--	0	0	67	0
Visakhapatnam District (8 samples)													
Maximum:	8.02	4540	1020	216	117	598	109	0	531	1064	180	400	0.67
Minimum:	7.28	356	110	28	10	30	4.7	0	98	28	4.8	0	0.21
Average:	7.63	2250	441	101	46	277	53	0	320	453	90	140	0.36
% wells above BIS(PL):	0	9	25	25	75	--	--	--	--	13	0	63	0
EG District (18 samples)													
Maximum:	8.18	5950	650	152	102	1047	126	0	964	1631	207	302	0.57
Minimum:	7.45	650	185	32	13	59	1.9	0	314	27	0.1	0.0	0.15
Average:	7.91	1869	375	83	41	229	42	0	515	317	42	28	0.34
% wells above BIS(PL):	0	15	6	0	61	--	--	--	--	6	0	6	0
WG District (7 samples)													
Maximum:	8.20	15950	1711	152	323	2737	243	0	805	4566	425	540	0.44
Minimum:	7.43	926	243	58	24	45	6	0	61	74	6	0	0.23
Average:	7.95	3958	662	120	88	561	73	0	458	934	196	98	0.31
% wells above BIS(PL):	0	8	29	0	57	--	--	--	--	14	29	29	0
Krishna District (11 samples)													
Maximum:	8.29	6320	681	100	114	1119	105	60	854	1078	978	150	0.38
Minimum:	7.54	910	205	28	19	110	4	0	122	103	13	2	0.06
Average:	7.86	2572	361	64	48	407	29	5	519	420	209	45	0.22
% wells above BIS(PL):	0	70	9	0	64	--	--	--	--	9	9	36	0
Guntur District (8 samples)													
Maximum:	8.19	5580	1211	192	177	684	175	0	622	1400	490	150	0.69
Minimum:	7.32	1100	120	28	12	96	3	0	293	121	1	4	0.21
Average:	7.94	2249	405	68	57	298	64	0	446	393	169	42	0.44
% wells above BIS(PL):	0	70	13	0	13	--	--	--	--	13	13	25	0
Prakasam District (5 samples)													
Maximum:	7.98	3666	841	164	112	428	411	0	476	893	240	500	0.58
Minimum:	6.95	960	275	72	12	77	28	0	275	106	31	10	0.11

Status of Ground Water Quality in Coastal Aquifers of India

	pH	EC	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F
		µS/cm	(mg/l)										
Average:	7.50	2505	542	118	60	256	113	0	394	445	149	166	0.27
% wells above BIS(PL):	0	0	60	0	60	--	--	--	--	0	0	60	0
Nellore District (14 samples)													
Maximum:	7.62	12630	3570	334	665	1233	129	0	732	4113	384	180	1.6
Minimum:	5.20	410	95	24	9	25	2	0	24	64	1	5	0.0
Average:	6.96	2543	638	120	82	270	30	0	361	567	104	67	0.4
% wells Crossing BIS(PL):	7	57	21	14	50	--	--	--	--	7	0	64	7

Table 5.3: Range of Different Chemical Constituents in Deeper Aquifers of Coastal Andhra Pradesh

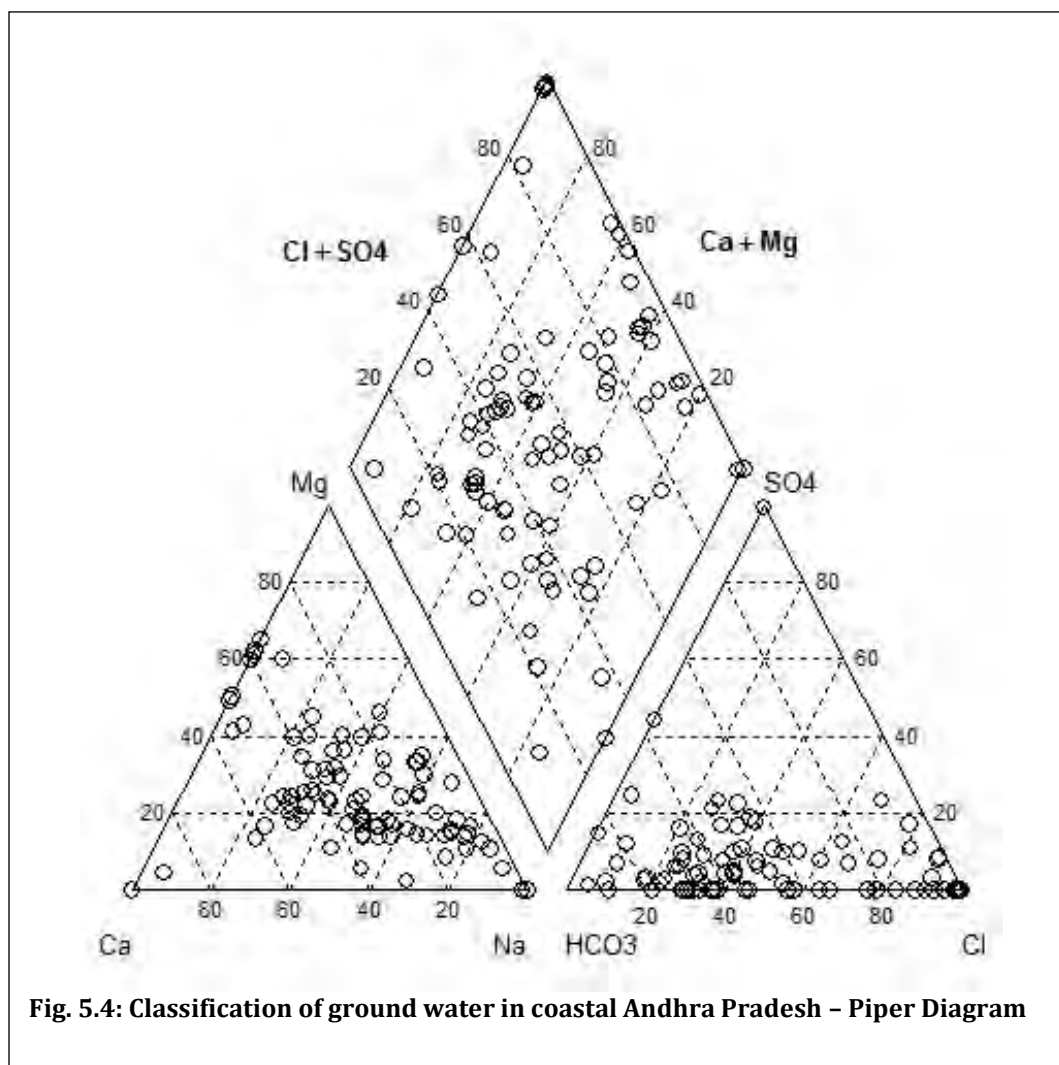
Area	pH	EC	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F
		µS/cm	(mg/l)										
Entire Coastal Area (96 samples)													
Maximum:	9.00	46100	17320	2443	2771	5175	460	405	1040	10650	787	682	1.31
Minimum:	6.50	165	5	9	2	7	0	0	29	0	3	0	0.17
Average:	7.73	3897	855	139	98	421	16	11	284	749	82	57	0.55
% of samples > BIS Limits:	6	21	24	11	12	--	--	--	6	16	2	13	0
Srikakulam District (4 samples)													
Maximum:	8.50	1614	365	56	66	205	8	12	275	383	178	65	0.52
Minimum:	7.10	203	65	16	6.0	12	1	0	29	14	10	3	0.34
Average:	7.64	722	179	32	24	82	5	3	113	131	62	26	0.43
% of samples > BIS Limits:	25	0	0	0	0	--	--	--	0	0	0	25	0
Vizianagaram District (1 Sample)													
	8.14	690	255	42	36	35	2	0	317	43	10	6	1.01
Visakhapatnam District (11 samples)													
Maximum:	8.51	6915	1541	152	297	895	39	12	488	2021	370	126	1.19
Minimum:	7.10	210	70	16	2	16	1	0	55	7	7	0	0.17
Average:	7.62	1646	386	69	52	200	9	1	274	352	75	32	0.69
% of samples > BIS Limits:	9	9	18	0	9	--	--	--	0	9	0	27	0
East Godavari District (26 samples)													
Maximum:	8.35	19370	5620	560	1027	3250	460	78	1040	5760	386	26	1.31
Minimum:	6.50	300	75	14	4	12	0	0	85	0	5	0	0.25
Average:	7.62	2129	585	96	79	264	34	7	342	484	58	11	0.53
% of samples > BIS Limits:	0	21	20	5	5	--	--	--	15	5	0	0	0
West Godavari District (12 samples)													
Maximum:	8.40	6925	1520	276	202	889	24	171	412	1889	34	0	0
Minimum:	6.75	648	5	40	14	49	0	0	146	67	11	0	0
Average:	7.63	1688	388	93	46	199	11	22	279	342	22	0	0
% of samples > BIS Limits:	0	15	8	8	8	--	--	--	0	8	0	0	0
Krishna District (13 samples)													
Maximum:	9.00	31200	5720	1192	658	5175	29	405	387	10650	787	0	0.55
Minimum:	6.75	407	40	9	2	75	2	0	170	19	91	0	0.50
Average:	7.63	12133	2142	284	129	1267	14	41	268	2069	439	0	0.53

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% of samples > BIS Limits:	10	62	60	40	20	--	--	--	0	40	10	0	0
Guntur District (11 samples)													
Maximum:	8.25	19370	5620	560	1027	4100	460	78	1040	6090	386	26	1.31
Minimum:	7.50	300	75	14	4	28	1	0	85	0	10	0	0.25
Average:	7.95	3753	643	110	85	621	33	7	322	1015	105	11	0.52
% of samples > BIS Limits:	0	55	60	20	20	--	--	--	30	50	0	0	0
Prakasam District (10 samples)													
Maximum:	8.90	2240	716	114	105	273	9.0	24	689	241	62	682	0.65
Minimum:	7.26	300	70	12	6.0	21	0.7	0	104	21	13	4.0	0.18
Average:	8.09	924	219	40	29	107	4	6	265	85	33	98	0.46
% of samples > BIS Limits:	10	0	10	0	10	--	--	--	10	0	0	20	0
Nellore District (8 samples)													
Maximum:	8.50	46100	17320	2443	2771	2620	25	30	689	3607	202	486	1.00
Minimum:	7.12	165	50	12	3.6	7.3	0	0	43	18	3.0	2.0	0.18
Average:	7.69	8688	2781	405	436	686	7	4	278	1134	70	105	0.49
% of samples > BIS Limits:	14	50	43	14	29	--	--	--	14	29	0	14	0

Table 5.4: Ranges of Different Chemical Constituents Formation-wise in Deeper Aquifers, Coastal Andhra Pradesh.

	pH	EC	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F
		µS/cm	(Mg/l)										
Consolidated (20 samples)													
Min	7.10	203	65	12	2	12	1	0	29	1	7	0	0.17
Max	8.90	6915	1541	152	297	895	78	24	689	2021	370	126	1.19
Avg.	7.82	1254	300	54	39	152	12	3	264	227	59	27	0.61
Semi Consolidated (35 samples)													
Min	6.5	165	55	12	4	7	1	0	3.9	6	3	4	0.18
Max	9	23650	4320	276	202	911	8	405	689	4700	134	486	1.31
Avg.	7.65	2411	467	76	37	154	3	21	256	407	41	59	0.46
Unconsolidated(41 samples)													
Min	6.75	205	5	0.5	0.4	3	0.04	0	3	0	3	0	0.23
Max	8.50	46100	17320	2443	2771	5851	25	171	689	36079	14770	486	1.00
Avg	7.68	8533	2089	252	259	976	5	13	248	2734	1019	76	0.52



The saline ground water at moderate to deeper levels is observed to be due to resident saline sea water present at the time of deposition of sediments. Quality of this in-situ saline water in the aquifers has not changed much over a period of time due to less hydraulic gradient in the coastal plains. But, in the parts of coastal plain East Godavari district some improvement in the quality of ground water is observed, may be due to flushing of in-situ saline water with the continuous irrigation by Godavari canal water over a period of more than 100 years or by the river itself.

Deeper aquifer systems in the alluvial tract, nearer to the uplands where these are exposed, are observed have recorded lowering of piezometric surface. Intensive development of ground water from Tertiary and Upper Gondwana Sandstones in the upland areas, adjacent to the alluvial plain, has lowered the pressure heads. With the result, the piezometric surface, of these aquifers, which was observed to be above ground level in the coastal alluvial plain has been reduced far below the ground level. Lowering of hydraulic pressure in the deeper aquifers of coastal alluvial plain is likely to invite seawater ingress and create a situation for permanent contamination of fresh water aquifers.

Sea water ingress, near the coast, do happen locally where saline ground water is pumped for various activities like aquaculture, and other infrastructural activities. But, there is no extensive problem due to sea water ingress even in the areas of urban settlement, Visakhapatnam. It may be due to less transmissive nature of the underlying crystalline rocks or steep hydraulic gradient.

In Andhra Pradesh, the coast was subjected to marine transgressions and regressions in the past as seen from strand lines and the deltas are of prograding nature indicating that they were submerged under sea. Thus the salinity could be imparted during the time of deposition of sediments. It is clear from the exploration that there is a lot of heterogeneity in quality of water both spatially and depth-wise. The complexity in distribution of salinity both vertically and spatially can be attributed to depositional environment and hydrogeological frame work. Thus, it could be inferred that the geomorphic evolution of the coast had an impact on the occurrence of aquifer zones. However, ground water abstraction, aqua-culture practices, tides/cyclones have also provided to be factors responsible in causing localized salinity problems.

5.1.2.3 Fresh – Saline Ground Water Interface

Along the coastal tract of Andhra Pradesh, the interface between fresh ground water and the underlying saline ground water exists at shallow levels and is very sensitive to external factors like development. Intensive development of fresh water would result in the upconing/ migration of saline water to shallow levels permanently.

The interface of fresh and saline ground water at deeper levels was not studied in detail. Ground water exploration by CGWB down to a depth of 300 m at several places and of 600 m at some places in the coastal tract has revealed a broad picture of interface at deeper levels. The presence of fresh and saline ground water interface is noticed deep inland in the Krishna and West Godavari district border area. Fresh ground water is observed along the Godavari River due to flushing of saline ground water in shallow zones. The deep aquifer system down to a depth of 600 m in Krishna deltaic plain is found to contain saline ground water.

The studies reveal that major part in Godavari and Krishna deltas do not contain fresh water aquifers at depth, except locally at the top down to 20 to 25m bgl in the palaeo channels and nearby levees and sand dunes as elongated fresh water bodies with rapid change in water quality. In the rest of the area, in tidal-flats, mud-flats, back-swamps and in the areas adjacent to creeks with tidal water, the ground water is saline. The salinity in coastal tract is spread over 0.5 million ha.

Generally, the ground water in the aquifers below 30 m is saline mostly due to inherent salinity attained during the deposition of the aquifer beds in the marine environment of the prograding coast. The limited exploration for ground water between 30 and 300 m did not reveal any change or improvement in the quality of ground water. The deltaic plain is prone to frequent cyclonic storms. During the cyclonic storms, high tidal wave enters deep inland, along the tidal creeks, the influent seepage from which increases the salinity of ground water.

Ground water at shallow depths, at places, has become fresh over period of time due to constant flushing by the applied irrigation water through canal system. Ground water is fresh at shallow depths down to 10 m in stabilized beach ridges found up to 15 km inland from the shoreline. High chloride concentration more than 600 ppm is observed in shallow ground water at Tallarevu, Ainavalli, Alamuru, Antervedi, Nagaram and Kumargiripatnam of East Godavari district.

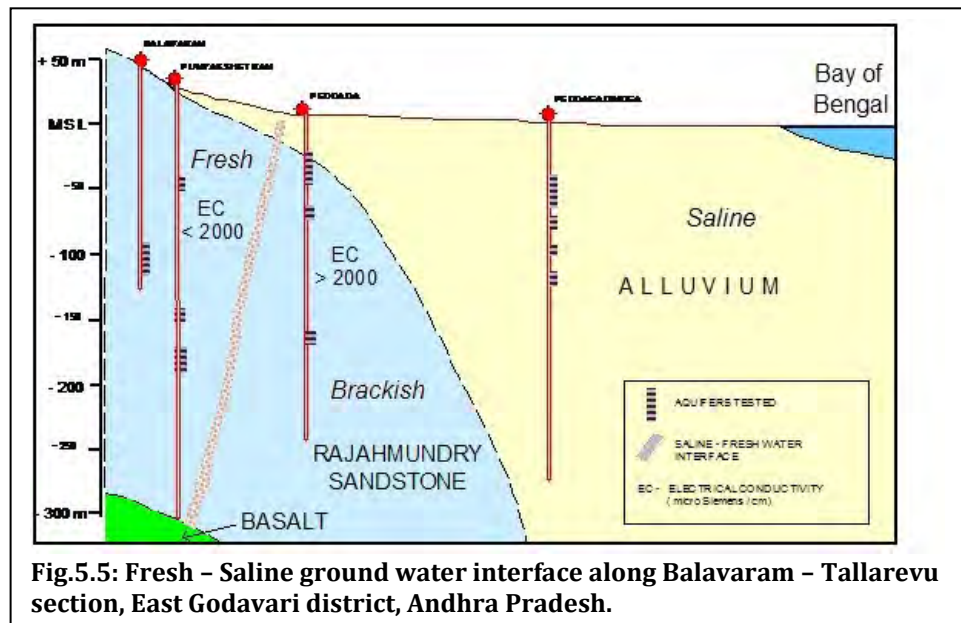
The waters in deeper aquifers beyond 94 m depth down to explored depth of 300m are invariably saline as is evidenced by boreholes at Peddada, Amalapuram, Dangeru, Cheyyeru and Peddagadimoga in East Godavari district with depth to fresh/saline water interface varying considerably.

In West Godavari district also, the fresh water is limited to shallow depths locally. The deep aquifers up to the explored depth of 300m at Kesavaram, Jakkaram, Nidamaru and Medapadu hold saline water.

The quality of ground water is good in both shallow and deep aquifers of Rajahmundry (Tertiary) and Tirupati (Gondwana) sandstones with EC less than 1000 micro Siemens/cm at 25°C in the upland areas of the coastal tract. However, in Rajahmundry sandstones, ground water in deeper depths at Oduru and Bikkavolu is brackish to saline with chloride content 879 and 617 ppm respectively. Similarly, the water in deeper depths in Gondwana sandstone at Alamuru has 934 ppm chloride indicating brackish to saline conditions at depth. The data reveals that the water from deep aquifers except at Oduru, Tallarevu, Kumargiripatnam, Antarvedhi and Peddada is suitable for irrigation purpose.

A cross section along Balavaram – Tallarevu is presented as **Fig. 5.5**. The quality of ground water in the Tertiary Sandstones and Gondwana Sandstones, lying below the alluvium, beyond 300 m, was not explored in detail towards the coast. In some of the areas, the Tertiary Sandstones are observed to contain saline ground water. But, the Gondwana aquifers, which are proved to be potential in the upland areas, were not explored below the basalts at depths beyond 600 m in the coastal plain.

In parts of Krishna delta, wide variation in water quality occurs in shallow aquifers in the alluvium. The fresh water aquifers in the eastern part of this delta occur down to a depth of about 20m in natural levees and beach ridges. The fresh water pockets are close to the course of river Krishna which is an influent river in this area. As such there is no extensive fresh water aquifer at shallow depths.



A number of boreholes drilled in parts of Krishna delta were abandoned due to the salinity of formation water at depths. A few wells were constructed tapping deeper fresh water aquifers either close to Krishna River or in Krishna eastern delta. The Krishna River is an influent river and the shallow aquifers adjoining the river are mainly recharged by it. Fresh ground water is found to occur down to 200 m in the alluvium and Tertiary sandstones towards the inland area of the coastal plain. In Angaluru well the electrical conductivity of water was 1770 $\mu\text{S}/\text{cm}$ with 337 ppm chloride for the zone tapped at 232-242 m bgl. Ground water in the southern part of the plain is mostly brackish to saline (EC upto 60,000 $\mu\text{S}/\text{cm}$ at 25°C) except along the palaeo

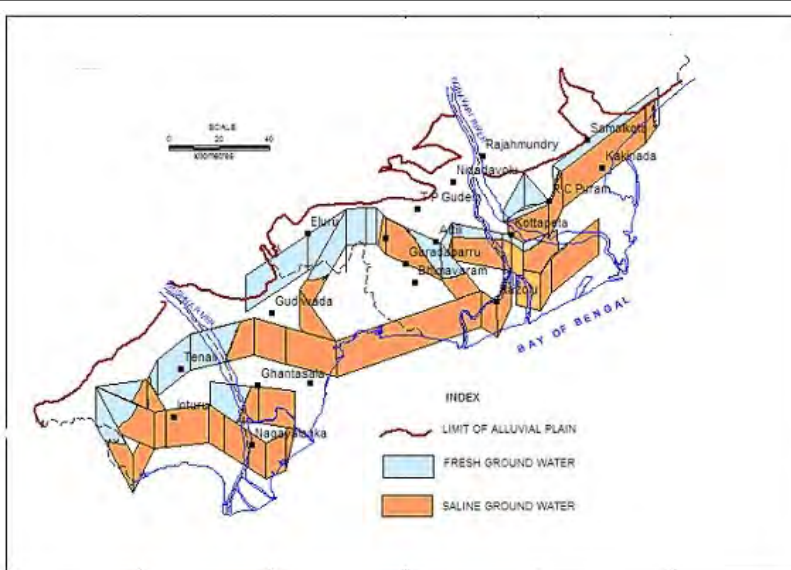


Fig.5.6: Distribution of Fresh – Saline Ground Water in Krishna-Godavari Plains, Andhra Pradesh.

channels where sandy aquifers are found to contain fresh ground water. Vertical distribution of fresh and saline ground water is presented as **Fig.5.6**.

Beach sand dunes all along the coast line of Pennar delta area occur as narrow strip of width varying from a few metres to 4 km with thickness varying from 6 to 7 m. These dunes form potential perched fresh water aquifers. These sand dunes are underlain by a clay zones and the sediments below it contain brackish to saline water. The paleo-channels in the Pennar deltaic plain are proved to be highly potential (upto 10 lps) and have been developed extensively.

Pennar delta in Nellore district holds potential fresh water aquifers in Pennar, Swarnamukhi and Kandaleru alluvium upto a depth around 85m. The exploration down to depth ranging from 120 to 457m has revealed highly saline water in deeper aquifers underlying the alluvium at Kudithipalem, Devispet, Mypad, Veguru and Chinnapallepalem. At Devispet the entire depth column holds saline water. At Sriharikota Island also the deeper aquifers hold saline water upto the depth explored around 350m. Fresh water is available only in the near surface aquifers in the sand dune deposits.

In Prakasam district ground water is saline up to 200 m bgl. Also, the quality of water deteriorates with pumping at some places (Ulavapadu). Along the coastal tract, sand dunes are the repositories for fresh ground water at shallow depths. These sand dunes, occurring parallel to the coast, extend from a few metres to 20 km in length, are extensively developed through shallow wells down to a depth of 30 m and electrical logging has indicated moderate fresh water to depth of 45 m bgl.

In Srikakulam district alluvial formations occurring all along the lower reaches of the rivers Nagavali and Vamsadhara contain fresh water and its thickness varies from place to place with a maximum thickness of 20 m. In Visakhapatnam district the coast is mainly underlain by crystalline rocks with a thin strip of alluvial plain. The ground water is relatively fresh in the areas underlain

by crystalline rocks (Khondalites). Ground water is brackish to saline with maximum reported EC around 9600 $\mu\text{S}/\text{cm}$ and chloride around 3200 ppm in the areas underlain by the unconsolidated sediments which are not extensive in the district.

5.1.3 Odisha

Ground water in the coastal tract of Odisha varies widely from calcium-bicarbonate type in the inland areas to Sodium-chloride types near the sea. Depth-wise too, the hydrochemical quality profile is non-uniform. The residence time of ground water in the aquifers, cation exchange process in clays, seawater contamination and sulphate reduction by sulphate reducing bacteria modify the quality. The range of chemical constituents in the shallow and deep aquifers is given in **Tables 5.5&5.5**. The types of water and irrigation class are depicted in **Fig. 5.7**. The quality of ground water along Puri-Delang sector has been shown in **Fig.5.8**.

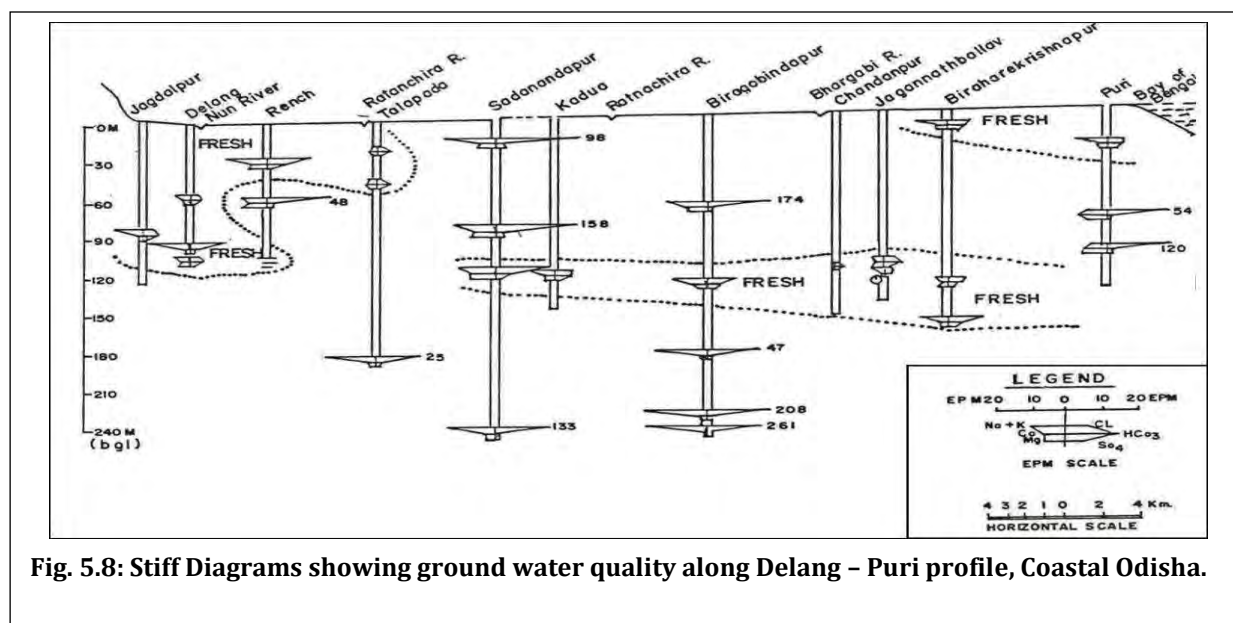
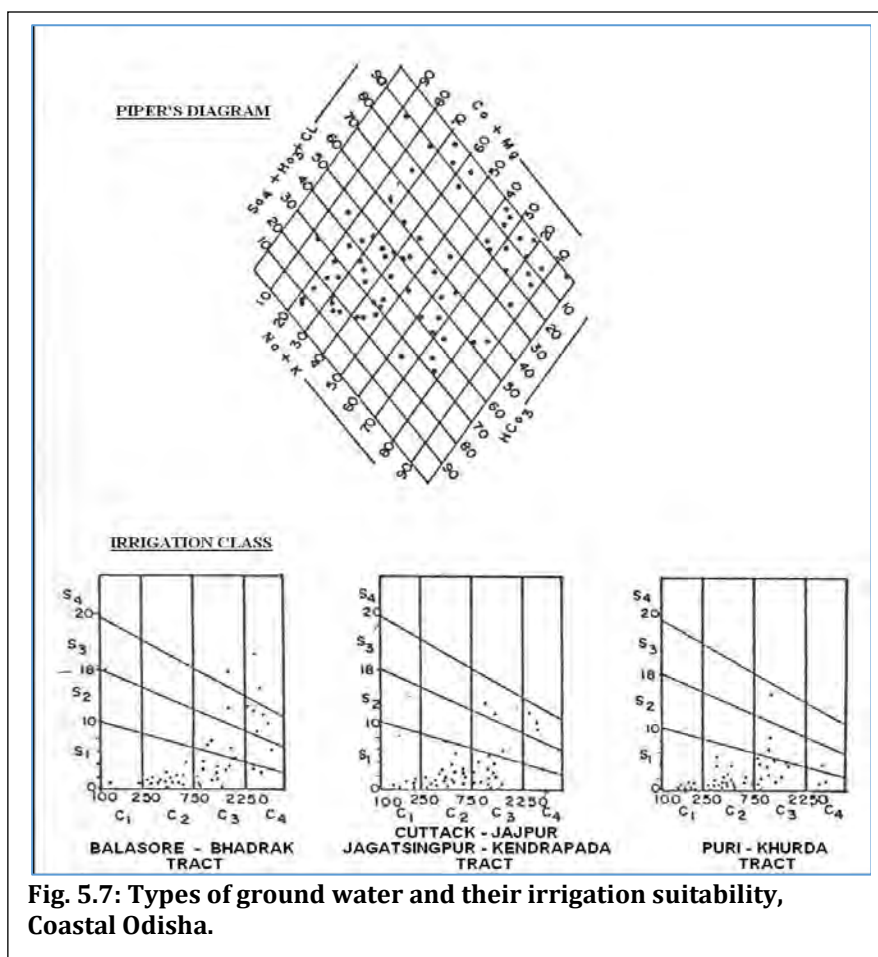
Table 5.5: Range of different chemical parameters in shallow coastal aquifers in Odisha

Chemical Parameter	Unit	Balasore (undivided) Bhadrak, Balasore	Cuttack (undivided) Cuttack, Jajpur, Jagatsinghpur, Kendrapada	Puri (undivided) Puri, Khurda, Nayagarh
pH		7.1-8.2	7.1-8.2	6.4-8.2
Electrical Conductivity	$\mu\text{S}/\text{Cm}$ at 25°C	203-2350	74-14406	134-5338
HCO ₃	mg / L	24-836	18-433	18-525
Cl	mg / L	21-549	7.1-4538	7.1-932
NO ₃	mg / L	Nil-80	0.4-345	Nil-119
F	mg / L	0.1-8.3	0.08-6.9	0.07-7.5
TH(as CaCO ₃)	mg / L	45-740	30-2125	25-535
Ca	mg / L	8.0-202	6.0-393	6.0-144
Mg	mg / L	6.1-92	2.4-359	2.4-73
Na	mg / L	12-299	1.0-2300	6.9-403
K	mg / L	122-1410	0.8-174	1.2-458

Table 5.6: Range of different chemical parameters in deep coastal aquifers in Odisha.

Chemical Parameter	Units	Balasore (undivided)	Cuttack (undivided)	Puri (undivided)
pH		6.8-8.45	7.1 - 8.4	7.3-8.6
E.C.	$\mu\text{S}/\text{Cm}$ at 25°C	350-2449	133-3292	542-2063
HCO ₃	mg / L	92-793	92-390	125-478
Cl	mg / L	11-383	7.1-922	60-447
TH(as CaCO ₃)	mg / L	20-280	75-1101	40-380
Ca	mg / L	6.0-56	6-240	8-80
Mg	mg / L	5.0-39	3.6-121	4.9-44
Na	mg / L	32-586	6.9-385	90-322
K	mg / L	1-7.8	1.7-25	4.7-8.2
NO ₃	mg / L	-	-	0.8-18

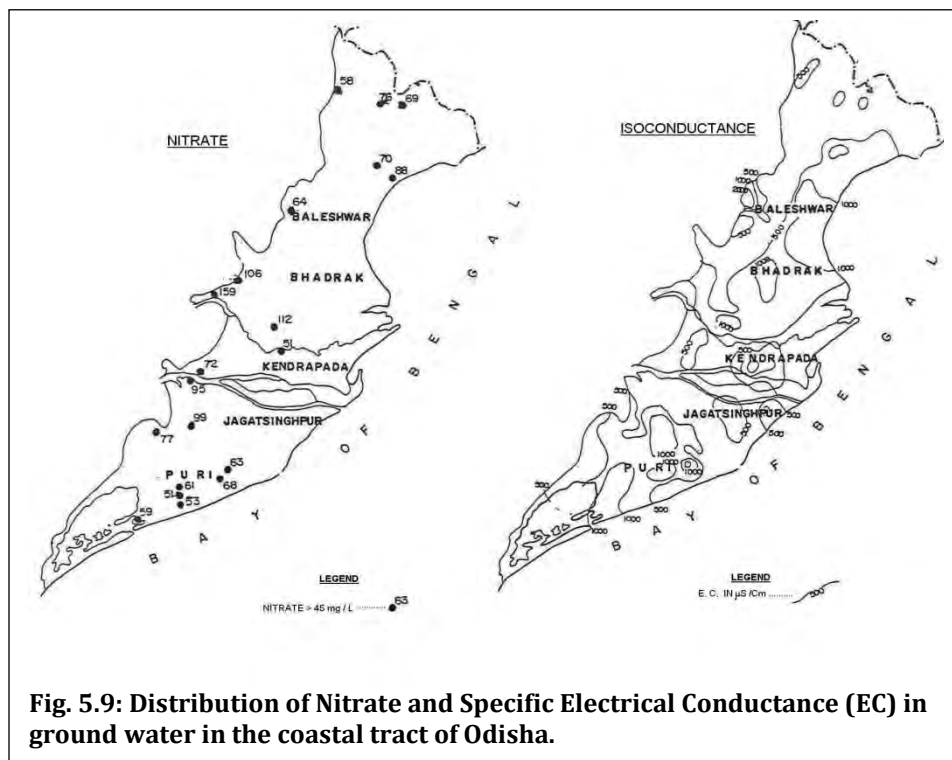
E.C. : Electrical Conductivity ; T.H. : Total Hardness



The quality of ground water from shallow aquifers is highly variable from calcium- bicarbonate type of water to Sodium-Chloride type of water. The other chemical faces encountered are Sodium-Bicarbonate, Calcium-Magnesium-Bicarbonate and mixed type. The electrical conductance values range from extremely fresh (EC 74 $\mu\text{S}/\text{cm}$ at Kalrangi) to extremely saline (EC 14406 $\mu\text{S}/\text{cm}$ at Rajnagar). The EC of most of the water has been found below 1600 $\mu\text{S}/\text{cm}$ at 25° C (1000 mg/l T.D.S.), although high values have been found at Jagatpur (8440) in Cuttack, Morad (4338), Gopinathpur (2358) in Puri and Bahanga (2350) in Balasore district. The chloride and Sodium contents have been found below 50 mg/l. The Sodium-Chloride type of water is rare. Hardness varies from moderately hard to very hard.

In general ground water in shallow aquifers of coastal Odisha, within a depth of 60 to 80m, is suitable for drinking and irrigation. The most common irrigation class of water is C₂S₁ (49%), but C₁S₁ and C₃S₁ types of water also occur.

The chemical quality of deeper aquifers also varies from fresh to extremely saline. Electrical conductance of deeper fresh aquifer is mostly below 1200 $\mu\text{S}/\text{cm}$ at 25°C. The hydrochemical profile does not follow any fixed trend. The chloride concentration varies from 43 mg/l at Nischintakoili in Cuttack district in depth range of 98-110m to 17573 mg/l at Arilo in Cuttack district in depth range of 315-325m. Sodium and chloride are the dominant cations and anions, and account for more than 80% of TDS(Total Dissolved Solids) in saline water. But the composition of saline water is not identical to seawater, because of the Base Exchange reactions and sulphate reduction occurring in the aquifers. The chemical types available in the area are Sodium-chloride, Sodium-bicarbonate, Sodium-Chloride-bicarbonate, mixed cation bicarbonate and mixed types of water.



Maps showing distribution of Nitrates and Specific Electrical Conductance (EC) in the coastal tract of Odisha is presented in **Fig. 5.9**. Some characteristics hydro-chemical features of coastal ground water are discussed below

Salinity: In coastal Odisha, there is variation in salinity and the lack of uniformity in aerial and vertical distribution of mineral content and also of type of water. Sea water is the major pollutant in

the coastal tract. The influence of sea water reduces with distance from the coast. All saline water in the coastal area is of Na-Cl type. Fresh sodium-bicarbonate water is encountered at deeper zone near the seacoast while much interiors to the coastal line saline water occur in the upper and deeper zones. Lacuna in well construction may result in leakage of saline water and contamination of fresh water aquifer. With continued pumping in a well at Panchtukri, the initial EC of $2400\mu\text{S/cm}$ at 25°C , changed to $9560\mu\text{S/cm}$ making well water saline. Overexploitation of ground water or clustering of wells may also lead to salinisation of aquifer due to sea water ingress.

Iron: Iron occurs in ground water in ferrous state, which in contact of air converts into ferric iron and get precipitated as hydrated oxide. The high iron contents renders water non-potable. Recently high iron has been linked with Haematochromatosis (accumulation of high iron in lungs, livers, pancreas, etc.). Some of the high values found in the area 9.7 mg/l in Gaumat Mahapada, 7.0 mg/l Gobindpur, 19.9 mg/l Bimukundpur, Bhatpada 17.3 mg/l etc. The high iron in ground water is due to the presence of organic matter in deltaic sediments creating reducing environment. Presence of Ironreducing bacteria has been reported in the area. The ferrous content of ground water has not been found constant in well water which might be due to inhomogeneity of aquifer material so that finer pores can retain the water for large time and perhaps enriched the iron content.

Nitrate: High concentration of Nitrate is potentially hazardous pollutant, in drinking water. It causes disease known as haemoglobinemia in infants specially that taking artificial milk feed. In shallow coastal aquifer in Odisha it is generally found below 20 ppm but higher values (above 45ppm) have also been found at places such as Jagganthpur(66ppm) , Jagatpur-II(345 ppm), Sardeipur (155 ppm) in Cuttack districts, Jalani (179ppm), Chandanpur (67ppm) in Puri Districts and Chandipur (80ppm), Chandbali in Balasore district. Fertilizer pollution of shallow ground water has been detected in the irrigated tract of Mahanadi delta. The ground water contains high values of fertilizer related chemicals like Nitrate, phosphate and potassium as at Alipur with 280ppm Nitrate, 8.5 ppm phosphate, 133 ppm mg/l potassium 525 mg/l chloride and 509 ppm sulphate.

5.1.4 West Bengal

The salinity problem in coastal aquifers of West Bengal is mostly due to the presence of sea water (as connate water) with different degrees of salinity getting entrapped during marine transgression or through deposition of sediments under marine depositional environment. Slow movement of groundwater in coastal area with a long residence time in contact with a stationary coast-ward salt water body also causes quality deterioration. The coastal areas are prone to frequent cyclonic storms. During the cyclonic storms, high tidal waves enter deep inland and also along the tidal creeks, the influent seepage from which also deteriorates the quality of ground water.

In South 24 Parganas District, Ground water from shallow aquifers (dug well zone), in general, is fresh with neutral to mildly alkaline (pH ranging from 6.5 to 7.8), medium EC (331 to $3540\mu\text{S/cm}$ at 25°C), medium Chloride (99-916 mg/l), except at Budge-Budge, Barisha, Mograhat, Falta and Bishnupur. Concentration of Calcium, Magnesium, Bicarbonates & Iron vary from 2 to 116, 2.7 to 228, 92 to 567 and BDL to 4.47 mg/l respectively. Ground water in Kolkata city area particularly north of Taratala-Kasba-Santoshpur tract within the depth span of 60-125 m bgl contain high chloride (284-657 mg/l) and high total hardness (460-775 mg/l) having more than 1,000 mg/l dissolved solids.

Ground water in the western and south central part of Kolkata city is primarily a Ca-Mg-HCO_3 type. Chloride content and Total Dissolved Solids are low ranging from 11 to 67 mg/l and 500 mg/l

respectively. South of Behala-Sonarapur-Bhangar area, aquifers within the depth range of 150 m bgl is brackish, except in a linear tract of 2 – 3 km wide (Adi Ganga channel) from Garia to Joynagar. The EC and Chloride values range from 5,960 to 41,350 $\mu\text{S}/\text{cm}$ at 25°C and from 1,750 to 6,300 mg/l respectively. This may be the connate water which is not suitable for drinking and agricultural purposes. In the linear tract, fresh ground water occurs within 50 m bgl. However, in the shallow aquifer, concentration of arsenic has been found to the tune of <0.001 to 3.2 mg/l. The sporadic occurrence of arsenic in ground water above permissible limit (0.05 mg/l) in some places of Kolkata Municipal Corporation has also been reported. The concentration of arsenic varies from 0.054 to 0.70 mg/l. Apart from Arsenic, Fluoride content in shallow aquifer in general ranges from less than 0.01 to 1.01 ppm. The Iron concentration in water of shallow aquifer is highly sporadic and is generally related to Arsenic concentration. The general range is 0.01 to 7.67 ppm. However, in the extreme southern part, the upper limit of Fluoride and Iron concentrations are 0.88 and 3.31 ppm respectively.

The deeper aquifers, occurring in the depth range of 180 to 360 m bgl contain fresh water. The pH ranges from 7.4 to 8.3 and is slightly alkaline in nature. Iron concentration is high in isolated patches (0.01 to 3.09 ppm) and Arsenic concentration is below detection limit. The EC ranges from 714 to 2,692 $\mu\text{S}/\text{cm}$ with Chloride ranging from 14 to 596 mg/l. The water in deep aquifer is mainly Ca-HCO₃ type with very low sulphate, chloride and fluoride. In the extreme southern part, the EC in deep aquifer increases to 915-3960 $\mu\text{S}/\text{cm}$ with Chloride content in the range of 64-1255 ppm. The ranges of chemical constituents, obtained by analyzing the water samples collected from ground water observation wells are given below (**Table 5.7**).

Table 5.7: Major Ionic composition of ground water from Kolkata city & South 24 Parganas district, West Bengal

Chemical Constituents ($\mu\text{S}/\text{cm}$ /ppm)	Kolkata City	South 24 Parganas
pH	6.8-7.7	6.5-7.8
EC	785-2100	434-3540
Cl	71-657	99-916
HCO ₃	116-256	92-567
Na	92-194	65-696
Ca	14-64	2-116
Mg	19-177	2.7-228
Fe	BDL-1.5	BDL- 4.47
SO ₄	15-58	BDL-99
K	0.9-1.5	0.6-43
F	BDL-0.2	BDL-0.18

In the southern part of Haora district also, brackish water (EC up to 6,830 $\mu\text{S}/\text{cm}$) zone occurs down to a depth around 160 m followed by fresh water aquifers down to 300 m depth. It has been observed that the water of the dug wells, adjacent to the River

Ganges, is fresh due to flushing. The ranges of chemical constituents obtained by analyzing the water samples collected from GWMS are given in **Table 5.8**. Sporadic occurrence of arsenic above permissible limit has been reported from the shallow tube wells in Uluberia II & Shyampur II blocks.

In North 24 Parganas District, the upper most fresh water aquifer exists within the depth range of 160 – 250 m bgl occurs in Sandeshkhali where it attains a thickness of 90 m. Fresh water aquifers occur in the depth range of 160 to 215 m bgl at Hingalganj and 430 to 480 m bgl at Hasnabad.

In coastal plain of Purba Medinipur district, the fresh ground water occurs within the depth span of 120-300 m bgl. Chemical analysis shows that the water is neutral to slightly alkaline. The EC and

Table 5.8: Major Ionic composition of ground water from Haora district, West Bengal

Chemical Constituents ($\mu\text{S/cm}$ /ppm)	Coastal Area of Haora District	
	Shallow Tube well/ Dug well	Deep Tube well
pH	7.6-8.0	8.1
EC	3450-6830	1600
Cl	401-2052	270
HCO ₃	220-946	214
Na	460-920	189
Ca	22-34	16
Mg	43-196	36
Fe	BDL-1.86	0.91
SO ₄	102-385	0.74
K	11-42	5.2
F	0.16-0.72	BDL

Chloride value ranges to the tune of 300-1,200 $\mu\text{S/cm}$ and 128-461 mg/l respectively. The bicarbonate value ranges from 305 to 549 mg/l and that of Iron varies from <0.01 to 0.24 mg/l. But in few places in Mahisadal and Ramnagar blocks, Iron content is high. Quaternary aquifers occurring up to a depth of 200 m bgl hold brackish ground water in general with patches of fresh water with EC varying from 211 to 830 $\mu\text{S/cm}$. Also, there are patches of high salinity of ground water with EC ranging from 5,500 $\mu\text{S/cm}$ (Tamluk) to 8,000 $\mu\text{S/cm}$ (Narghat). The underlying Tertiary aquifers in the depth range of 60 to 400 m bgl hold fresh water with EC in the range of 272 - 1,990 $\mu\text{S/cm}$. However, in the area around Kanthi, except the top fresh water aquifer in the coastal sand dunes, the entire column up to the depth of 300 m bgl holds

brackish/saline ground water (Fig.5.10). Further west, at Digha only, the top 10 m holds fresh ground water within the coastal sand dunes. The saline/fresh ground water interface along the Haldia-Digha coastal tract is at a depth ranging from 40 to 60 m, except at Junput where it is 135 m, perhaps indicating the coast-ward extension of the palaeo-lagoon at Kanthi. The EC of water in the

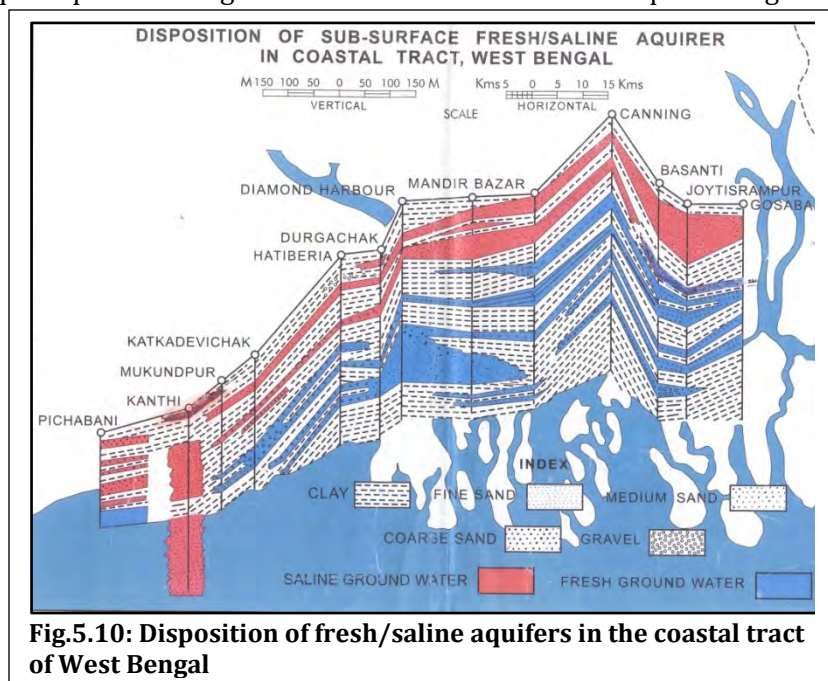


Fig.5.10: Disposition of fresh/saline aquifers in the coastal tract of West Bengal

brackish/saline ground water zones in the Quaternary and Tertiary sediments ranges from 16,000 to 24,000 and 9,000 to 26,000 $\mu\text{S/cm}$ respectively.

The analytical results of the ground water samples from the exploratory wells/piezometers along the coast of Medinipur district do not indicate sea water intrusion down to the explored depth of 400 m. However, inherent salinity in the ground water up to a depth of 300 m has been observed in and around Kanthi. The brackish/ saline

water zone is limited, laterally as well as at depth. The maximum salinity has been observed in and around Kanthi where flushing of entrapped sea water was obstructed due to the reversal of palaeo-

topographic (low) in the coast parallel palaeo-lagoon with connection to the sea near Junput, as indicated by hydrogeological, geophysical and hydrochemical studies.

The analytical results show higher values of EC and Chloride towards the southeastern part of the coastal plain and abnormally high values around Kanthi. The ground water is generally Ca-Mg-

HC03 type except in the confining layer. The relation between Chloride and Na/Cl ratio shows that the ground water is fresh and does not have any affinity with seawater. The concentration ratios of Bromide/Chloride (8.47×10^{-3} to 1.2×10^{-2}) and Iodide/Chloride (6.29×10^{-6} to 3.85×10^{-3}) in the ground water under semi-confined condition indicate marine depositional environment, but the same in the phreatic zone in the area of recharge are beyond traceable limit. The concentration of chemical constituents in brackish/ saline ground water zone is shown in **Table 5.9**.

Table 5.9: Concentrations of chemical constituents in brackish/saline ground water zones in coastal West Bengal

Constituents		Tertiary (Lower Lithosystem)		Quaternary (Upper Lithosystem)	
		Pre-Monsoon	Post-Monsoon	Pre-Monsoon	Post-Monsoon
pH		7.12 - 8.82	8.13-8.64	7.25 - 9.53	7.8-8.7
EC ($\mu\text{S}/\text{cm}$ at 25° C)		9337 - 26000	9013 - 20698	16700 - 24000	16709 -19745
TH (as CaCO_3)		4.0 - 5880	350 - 735	35 - 3540	920 -1225
mg/l	NO ₃	0.5 -12.2	3.2-5.2	1.7 - 5.2	2.5 -17.2
	F	0.06 - 7.3	3.2-5.2	0.03 - 0.29	0.04 - 0.06
	Cl	355 - 10281	3297 - 7657	638 - 9288	5743 -7444
	SO ₄	35.40 - 250	28.00 - 200	6 - 1040	60 - 278
	CO ₄	9	96	9-24	9-12
	HCO ₃	18 - 531	24 - 67	18 - 1 40	18 - 37
	Ca	14 - 1152	40 - 222	8 - 600	140 - 440
	Mg	1.2 - 782	42.77 - 60.8	3.6-610	30.4 -137
	Na	420 - 5000	2050 - 4900	300 - 8850	3300 - 4700
	K	1 0 - 1 04	24 - 39	3.3 - 96	32 - 38
	Fe	0.094 - 0.866	-	0.046 - 0.453	-
	SiO ₂	0.5 - 4.5	2-6	0.5-4	2
	Br	1 .56 - 39	21 - 42	2.6 - 46	34 - 42
	I	0.03 - 0.76	0.26 - 0.46	0.04 - 2.3	0.53 - 0.66
	B	0.1-1.06	0.06 - 0.74	0.20 - 0.92	0.20 - 0.60

10-6 to 3.85×10^{-3}) in the ground water under semi-confined condition indicate marine depositional environment, but the same in the phreatic zone in the area of recharge are beyond traceable limit. The concentration of chemical constituents in brackish/ saline ground water zone is shown in **Table 5.9**.

The process of refreshing of initial salinity in the marine sediments was accelerated with the uplift of the Chotanagpur Plateau and simultaneous shifting of shorelines south eastwards. As a consequence, the flushing of saline/ brackish water in the marine sediments was intense in the platform terrain, moderate in alluvial and poor in the coastal plains. In and around Kanthi, the flushing of saline/brackish water was obstructed due to the reversal of palaeo-topographic low as indicated by hydrogeological, geophysical and hydrochemical studies.

5.2 West Coast

5.2.1 Kerala

5.2.1.1 Shallow Aquifers

In Kerala coastal plain, the electrical conductivity of shallow ground water, which is the index of mineralization, is in the range of 10 to 700 $\mu\text{S}/\text{cm}$, except in certain pockets close to back water channels. Some of the areas are Chellanum in Ernakulam district and Azhikode in Thrissur district. However, the values rarely exceed 3000 m $\mu\text{S}/\text{cm}$. The Fluoride content of the shallow ground

water is well within the limits and is generally less than 0.5 ppm. The studies on long term ground water quality variation also indicate noconspicuous change. However, slight quality variations are seen in the wells located adjacent to backwater channels, which are under the influence of tides.

5.2.1.2 Deeper Aquifers

The water from the Tertiary aquifers are characterized by higher concentrations of Bicarbonate, Fluoride and Iron compared to the water from the phreatic zones and also compared to that of the deeper aquifers in the hard rock areas. This is due to the combination of biological and geochemical processes that continued during the long residence time of water in Tertiary aquifers.

The Warkali aquifers yield fresh water with Chloride content between 10 and 200 ppm. A noted exception is the exploratory well at Mancombu, south of Alleppey, where the Chloride concentration is 720 ppm. The Fluoride content of water from these aquifers is in the range of 0.3 to 2.6 ppm, with higher values (1.4 to 2.6 ppm) observed in the wells around Alleppey. Sulphate is below the detection limit. The Iron content is in the range of 0.1 to 14.0 ppm with a mean of 2.2 ppm. The insitu pH of water from the wells in Kuttanad region is in the range of 6.3 to 6.8, while that from the wells in the area further west (close to the coast) is in the range of 7.0 to 7.5. The lower values in Kuttanad area are due to higher contents of CO₂. The Nitrate content in Kuttanad region is in the range of 5 to 17 ppm (mean: 11 ppm) whereas that in the area further west is in the range of less than 0.1 to 2.2. ppm (mean : 0.6 ppm).

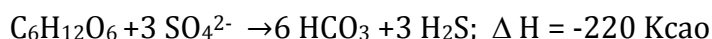
Fresh water of Ca-HCO₃ type occurs in Karunagapalli-Kayamkulam sections. The profile further north shows a decrease in Calcium accompanied by an increase in Sodium. Magnesium also decreases but the decrease is not as pronounced as that of Calcium. The anion type continues to be HCO₃. The Kayamkulam-Ambalapuzha zone has water of mixed cation HCO₃ type. North of Ambalapuzha, the water becomes Sodium dominant and the water in the Ambalapuzha- Alleppey zone is of Na-HCO₃ type. Further north, the electrical conductivity increases as slightly brackish water of mixed cation Chloride or Na-Cl type results. The change in degree and type of mineralization of water in the Warkali aquifer can be explained as reflection of different stages of inter action of recharging fresh water with the sediments deposited under the marine environment.

Initially, Ca-HCO₃ type water was formed by the chemical action of rainwater, containing CO₂ on CaCO₃ bearing minerals in the recharge zone. The Calcium rich water during its movement released Sodium by ion exchange from clay minerals (under marine conditions the clay minerals became Sodium rich). This resulted in Na-HCO₃ type of water, which also explains the higher Fluoride content, since the alkaline waters depleted in Calcium are effective in releasing Fluoride from the minerals like Flour-Apatiites. Further north, where the freshening is incomplete, hard brackish water of Ca-Mg-Cl or Na-Cl type occurs. The process is similar to the one observed in parts of Sweden by Agerstrand et.al. (1981). The above-mentioned freshening process is responsible for the presently observed zonation of water types.

The chemical analysis data of water from aquifers in Quilon bed is meager, since the wells tapping this formation are very few in numbers. The EC at Karthikapalli is 560 μ S/cm, while the Chloride and Fluoride are found to be 18 ppm and 0.1 ppm respectively. The well at Kandankari yields water with EC of 980 μ S/cm with Chloride content of 156 ppm and Fluoride of 0.8 ppm.

The ground water in the Vaikom aquifers is fresh in the southern part, i.e., south of Karuvatta in Alappuzha district. The EC is in the range of 30 to 670 μ S/cm and the Chloride varies from 4 to 75 ppm. The well at Nallanickal yields water of higher EC (1840 μ S/cm) and Chloride of 400 ppm and this is considered as an exception. The Fluoride content of Vaikom is in the range of 0.3 to 1.2 ppm, while Iron ranges between 0.05 and 5.6 ppm. The waters in these aquifers in Kuttanad and further north are more mineralized with EC in the range of 1500 to 8000 μ S/cm.

The water of Vaikom aquifers, south of Kuttanad is of CaCO₃ type, whereas in the northern parts it is of NaCl type. The water is under reducing conditions as evidenced by the low Sulphate content, Iron in ferrous form and presence of H₂S. The H₂S content of water in the exploratory well at Pattanakad is 3.2 ppm and the water temperature is 38o C. A clay sample from the Tertiary aquifer in Kuttanad has about 25% combustible organic matter and 10 mg of Iron per kg. of the sample which is released on digestion with distilled water. This phenomenon can be explained as Sulphate reduction in these aquifers. Anaerobic micro-organisms activate the exothermic process of oxidation of organic matter by Sulphate and thrive on the energy thus released. Ferric iron also apparently acts as an oxidant along with Sulphate resulting in dissolved Fe⁺⁺.



During the sedimentation process the organic matters in the sediments became rich in Iodide due to biological fractionation. Subsequent movement of water through the aquifer matrix released Iodide into solution along with other soluble matter. Thus iodide can be used as a key parameter in tracing the origin of dissolved matter in ground water (Lloyds et al, 1982).

The brackish water from Vaikom aquifers has 700 ppm of Chloride and 0.12 ppm of Iodide on an average. A mixture of sea water and fresh water to bring Chloride concentration of 700 ppm would contain only 0.0004 ppm of Iodide. The brackish water of Vaikom aquifers contains high Iodide concentrations of about 300 times that of fresh water – sea water mixture. This criterion clearly shows that the brackishness is not due to mixing of sea water (past sea water intrusion) with fresh water but due to the dissolution of Iodide rich substance from the organic matter in the sediments by the recharging fresh water. By this process the recharging fresh water gets enriched in Iodide, Chloride, Sodium and other ions.

5.2.1.2.1 Changes in Ground water Quality with Time

The low tritium content (<1 T.U.) in the water from Tertiary aquifers indicates that those aquifers are not getting rapid recharge from the overlying surface water bodies. The surface waters are separated by a thick clay layer from the Tertiary aquifers. In Kuttanad region, where the surface water bodies are extensive, the intervening clay layer is 20 to 50 m. thick. Thus, the water in Tertiary aquifers is not affected by the quality of surface water or that in the phreatic zone. The chemical composition of water from Tertiary aquifers is stable.

Studies conducted in the SIDA assisted Coastal Kerala Ground Water Project (1983-88) indicate no conspicuous variation in chemical quality of water in the deep aquifers with time and pumping. This was confirmed through a few selected water supply tube wells in the Alleppey town having large ground water withdrawal by testing immediately after the start of pumping and again before the end of continuous pumping for 20 hrs.

Ground water from the exploratory tube well at Pattanakad coast (Alleppey district) which was under auto-flowing conditions had a TDS of 1500 ppm and Chloride of 625 ppm at the time of construction in December 1973. During November 1985 the EC was 2600 $\mu\text{S}/\text{cm}$ (corresponding to a TDS of 1600 ppm) and Chloride concentration was 662 ppm. The well was flowing during the period from 1973 to 1985.

5.2.2 Karnataka & Goa

In the coastal plains of Karnataka water in the shallow aquifers is, in general, fresh with EC less than 1000 $\mu\text{S}/\text{cm}$, except localized pockets in and around Hangarkatta in Kundapura block of Udipi district where EC and Chloride was recorded as 4230 $\mu\text{S}/\text{cm}$ and 980 ppm respectively. The water in the aquifers in beach sand has EC in the range of 132-744 $\mu\text{S}/\text{cm}$. Relatively higher EC of water in some wells in beach sand is due to contamination by high tides. It is observed that water in laterites have less EC than that from beach sand. The chemical analysis of the water samples collected during November 2007 are in acceptable levels in the coastal areas of Goa.

5.2.3 Maharashtra

In the coastal districts of Maharashtra, the overall range of pH of ground water indicates that it is weakly acidic to weakly alkaline in nature while the average value shows that the ground water is alkaline in nature. The average value of EC (Electrical Conductivity) and TDS (Total Dissolved Solids) suggests that the ground water in the shallow aquifers is not highly mineralized. Except a few samples from Thane and Raigarh districts, the total dissolved solids in groundwater is less than 500 ppm indicating minimum mineralization. This is due to the physiographical, climatic and hydrogeological conditions existing in the area. It is mainly hilly, covered by porous laterite capping and receives high rainfall. Due to steep topographic gradient existing in the area, the ground water gets minimum residence time and the flushing of aquifer is regularly going on due to the heavy rainfall. The average concentration of major ions also indicates that they are mainly originating from the natural source. The higher concentration of these ions in a few ground water samples of Thane and Raigarh districts may be due to anthropogenic sources. The ground water samples having high Sodium also indicates that mixing of seawater with ground water is taking place at a few locations. Spatial distribution of EC & Chloride in coastal Maharashtra is shown in Figs. 5.11 and 5.12.

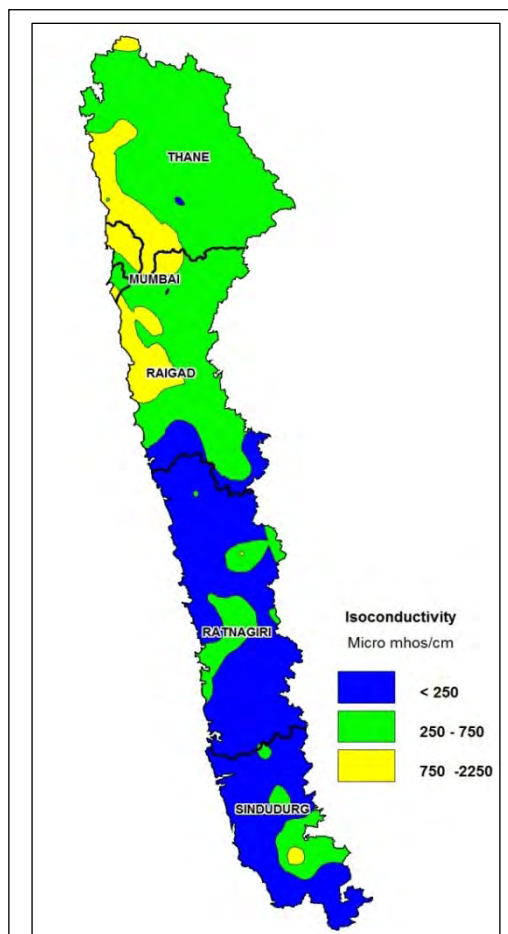
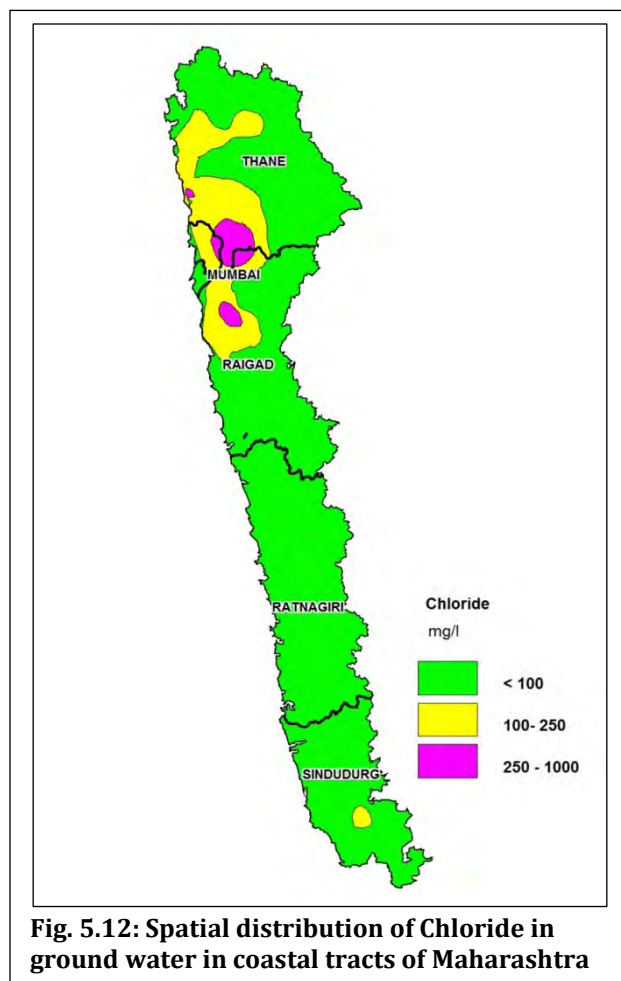


Fig. 5.11: Spatial distribution of EC in ground water in coastal tracts of Maharashtra.



Fluoride content in ground water is below 1.5 mg/l in all the aquifers in the coastal tract. Nitrate content in ground water is also found to be within permissible limit of 45 mg/l in the major part of the coastal tract, except in isolated urban areas where it is above this limit, probably due to anthropogenic activities.

Ground water in almost the entire coastal area is of Ca-HCO₃ type, indicating predominance of recharging waters in determining its hydrochemistry.

5.2.3.1 Suitability of ground water for various uses:

The standards proposed by the Bureau of Indian Standards (BIS) for drinking water (IS-10500-91, Revised 2012) were used to decide the suitability of ground water. The classification of ground water samples collected during May 2012 was carried out based on the desirable and maximum permissible limits for the parameters viz., TH, SO₄, NO₃ and F prescribed in the standards and is given in **Table 5.10**. The analysis indicates that shows the concentrations of all the parameters in most of the samples are within the maximum permissible limit of BIS standards.

Classification of ground water based on Specific Electrical Conductance (EC), shown in **Table 5.11** indicates that ground water in the major part of the coastal area has low to medium salinity hazard and is suited for irrigation applications in most soil types.

5.2.3.2 Presence of Heavy Metals

Studies on the presence of select heavy metals in ground water in the coastal area of Maharashtra indicated the presence of Copper in traces but well below the acceptable limit of 0.05 mg/l. Iron was found to exceed the acceptable limit of 0.3 mg/lit in parts of Ratnagiri, Thane, Sindudurg and Mumbai districts in Basalt and Laterite aquifers. Lead (Pb) was also found at Agashi (Thane districts) in excess of the acceptable limit i.e. 0.03mg/l. Zinc (Zn) was also found in traces but below acceptable limit at places. Presence of Manganese exceeding permissible limit of 0.3 mg/l was found in basalt aquifers of Thane, Raigadh, Sindudurg and Ratnagiri districts.

5.2.4 Gujarat

In the coastal tracts of Kachchh and Saurashtra, GWRDC, Gujarat has defined the ranges of ground water salinity in terms of Total Dissolved Solids (TDS). Ground water with TDS less than 2000 ppm is considered fresh, 2000-4000 ppm as low salinity, 4000-6000 ppm as medium salinity and more than 6000 ppm as high salinity. Accordingly, the iso-TDS contour of 2000 ppm defines the areas with ground water salinity. Variation in the salinity of ground water in these coastal tracts is a complex phenomenon. Broadly, it varies with geological formations and their disposition with reference to the coast. It is influenced by factors like sea water ingress, inherent salinity of the formations deposited under marine conditions and the structural features. Also, several creeks under tidal influence allow the sea water to invade and deteriorate the ground water quality in the phreatic aquifers. The ground water salinity is a combined effect of a) inherent formation water salinity, b) sea water ingress, c) tidal water, d) saline water percolation in low lying marshy lands inundated by sea water, e) irrigation with saline water and f) salt laden winds. Along Saurashtra coast, the Bhavnagar-Una section is affected by sea water ingress and inherent salinity and the Una-Madhavpur section has prominent sea water ingress while the Madhavpur-Maliya section has the effects of all factors like inherent salinity, sea water ingress, tidal inundation, marshy land seepages and saline alluvium. In Kachchh area the Maliya-Lakhpur section also has all the factors causing salinity (**Table 5.12**).

Besides these, overexploitation of ground water causes up-coning of saline formation water at depths and also makes the lateral invasion easier. The marine Tertiaries and the Mesozoic formations of Kachchh hold saline ground water. The upper or near surface part of the formations receiving monsoon recharge gets flushed and holds fresh water in storage moderately. A vast low lying tract in the Central Gujarat, the structural trough filled up with very thick Tertiary sediments and alluvial cover, holds saline ground water as well as pockets of brine. It causes sub-surface outflow of highly saline ground water to the adjoining areas of Saurashtra and Kachchh.

In the coastal part of mainland Gujarat occupied by poorly permeable basalts, ground water is affected by salinity over a limited area. However, in the low lying coastal tracts of Surat, Bharuch and Vadodra districts with rivers under tidal influence, the ground water is saline. In coastal Saurashtra an increase in the ratio of $\text{Cl}/\text{CO}_3 + \text{HCO}_3$ is also noticed towards the coast indicating considerable mixing of sea water with the local ground water. (**Fig.5.13**). This ratio in water also increased during pumping for a few hours, indicating up-coning or lateral movement of sea water locally.

In Kachchh area, the ground water salinity due to ingress is restricted to the narrow coastal strip and the low lying Bani plains. However, the inherent formation water salinity prevails almost everywhere except the central uplands. The EC of water from deeper confined aquifers (beyond 100 to 200 m depth) in unconsolidated and semi-consolidated formations is, in general, more than 1500 $\mu\text{S}/\text{cm}$ while it is less than 1000 $\mu\text{S}/\text{cm}$ in basalts. The ground water at depths being brackish/saline, the lowering of piezometric head in the wells tapping deeper aquifers by overexploitation may cause up-coning of saline water. Fluoride rich ground water gets restricted by the dykes. Higher concentrations of Fluoride are also observed in limited patches in basaltic areas of Kachchh, Surat and Bharuch districts.

Table 5.10: Suitability of ground water in coastal tract of Maharashtra for Drinking

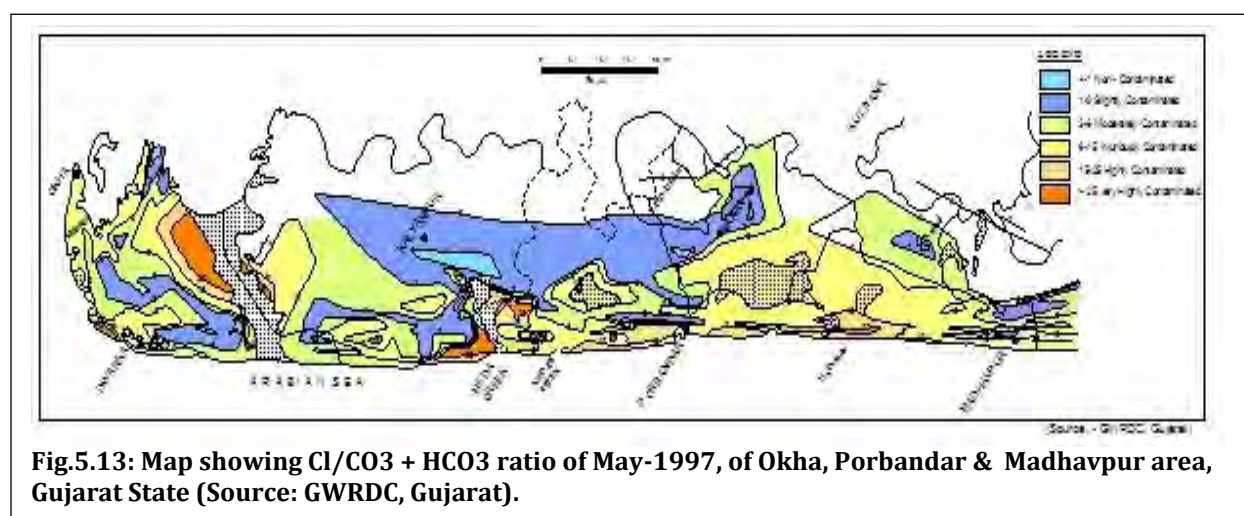
Parameters	BIS Standards (IS-10500)		Basalt			Laterite			Granite			Sand			Compact Sand Stone		
	Desirable Limit (DL)	Max. Permissible Limit (MPL)	< DL	DL-MPL	> MPL	< DL	DL-MPL	> MPL	< DL	DL-MPL	> MPL	< DL	DL-MPL	> MPL	< DL	DL-MPL	> MPL
TH (mg/L)	300	600	53	7	1	21	1	-	3	1	-	1	2	1	2	-	-
SO ₄ (mg/L)	200	400	60	1	-	22	-	-	4	-	-	1	3	-	2	-	-
NO ₃ (mg/L)	45	No relaxation	60	-	1	22	-	-	4	-	-	4	-	-	2	-	-
F (mg/L)	1.0	1.5	60	1	-	22	-	-	3	-	-	4	-	-	2	-	-

Table 5.11: Classification of Ground water in coastal tracts of Maharashtra based on EC.

Type of Salinity	EC (µS/cm) Range	Aquifer									
		Basalt		Laterite		Granite		Sand		Compact Sand Stone	
		No. of Samples	% of Samples	No. of Samples	% of Samples	No. of Samples	% of Samples	No. of Samples	% of Samples	No. of Samples	% of Samples
Low Salinity Water	<250	24	39	19	86	2	50	-	-	2	100
Medium Salinity Water	250-750	29	48	3	14	1	25	1	25	-	-
High Salinity Water	750-2250	8	13	-	-	1	25	3	75	-	-
Very High Salinity Water	>2250	-	-	-	-	-	-	-	-	-	-
Total		61	100	22	100	4	100	4	100	2	100

Table 5.12: Causes of ground water salinity in taluks in different sections, coastal Saurashtra and Kachchh (after Tahal, 1997)

Cause of salinity	Bhavnagar-Una	Una-Madhavpur	Madhavpur-Maliya	Maliya-Lakhpat
Inherent salinity	Bhavnagar Talaja Mahuva Rajula Jafrabad Una		Porbandar, Ranavav Kalyanpur Okhamandal Jodia Morvi Maliya	Bhachau Anjar Mundra Abdasa Lakhpat Rapar
Sea water ingress	Bhavnagar Ghogha Mahuva Talaja Jafrabad Una Rajula	Mangrol Maliya Veraval Kodinar Una	Porbandar	Mundra Mandvi Anjar
Tidal inundation			Khambaliya Lalpur Jamnagar Jodia Kalyanpur	Bhachau Anjar Mundra Mandvi Abdasa Rapar
Marshy area			Dwarka Jamnagar Jodia	Bhachau Anjar Mundra Mandvi Abdasa Lakhpat Rapar
Alluvial saline			Porbandar Maliya	



The presence of Fluoride in ground water is prominent in areas occupied by basalts. In several parts of Amreli district, Saurashtra, where thin alluvial cover derived from eroded and weathered basalts and the dykes are present, the concentration of Fluoride is in the range of 4 to 10 ppm. Flushing of

5.3 Critical areas & quality Issues in Coastal Aquifers

5.3.1 East Coast

5.3.1.1 Tamil Nadu

On the basis of exploration and Ground water management studies of Central Ground Water Board and studies undertaken by other government and non-government agencies for sustainable management of ground water in Tamil Nadu, following areas have been identified as critical areas. The area can be critical in reference to Chemical quality of water due to anthropogenic reasons or due to insitu salinity problems. Such areas are given below.

- 1) Minjur area, North of Chennai city, Chennai District: Sea water intrusion problem
- 2) Tiruvanmiyur- Kovalam Tract, Southern part of Chennai City: Seawater intrusion reported.
- 3) Cuddalore Coast: Seawater intrusion reported due to heavy pumping at SIPCOT and Insitu salinity.
- 4) Ramanathapuram, Nagapattinam, Thanjavur Tiruvarur & Tuticorin Districts: Insitu salinity problem.
- 5) Kuttam- Radhapuram area, Tuticorin District: Seawater intrusion reported.

In the coastal tract of Tamil Nadu and Puducherry, the location of fresh-saline ground water interface has varied with time depending on the exploitation of ground water and the recharge conditions. For example, in Minjur area, located north of Chennai city the interface was about 3.5 km inland in 1972. It has moved to about 15 km inland at present.

Data collected during exploratory drilling programme of CGWB in the coastal area of Tamil Nadu has been allayed to have a better understanding of the fresh and saline water interface in the aquifers. The granular zones encountered in the sediments are grouped depth zone wise viz., 0 to 100m bgl, 100 to 300 m bgl and 300 to 500 m bgl and analyzed for their water quality and the fresh-saline water interface for these depth zones have been demarcated (**Figs. 5.14**). Comparison of interface in 0-100m depth range with that in 100-300m depth range indicates that the interface in shallow aquifers is relatively more inland that for the deeper aquifers in which it is closer to the coast line. Further deep, for the aquifers in the depth range of 300-500m bgl, again the interface is relatively more inland in comparison to that in the depth zone of 100-300m, but less than that in the depth zone of 0-100m.

5.3.1.2 Andhra Pradesh

5.3.1.2.1 Ground Water Salinity

The saline ground water at moderate to deeper levels is observed to be due to resident saline sea water present at the time of deposition of sediments. Quality of this in-situ saline water in the aquifers has not changed much over a period of time due to less hydraulic gradient in the coastal plains. But, in the parts of coastal plain East Godavari district some improvement in the quality of ground water is observed, may be due to flushing of in-situ saline water with the continuous irrigation by Godavari canal water over a period of more than 100 years or by the river itself.

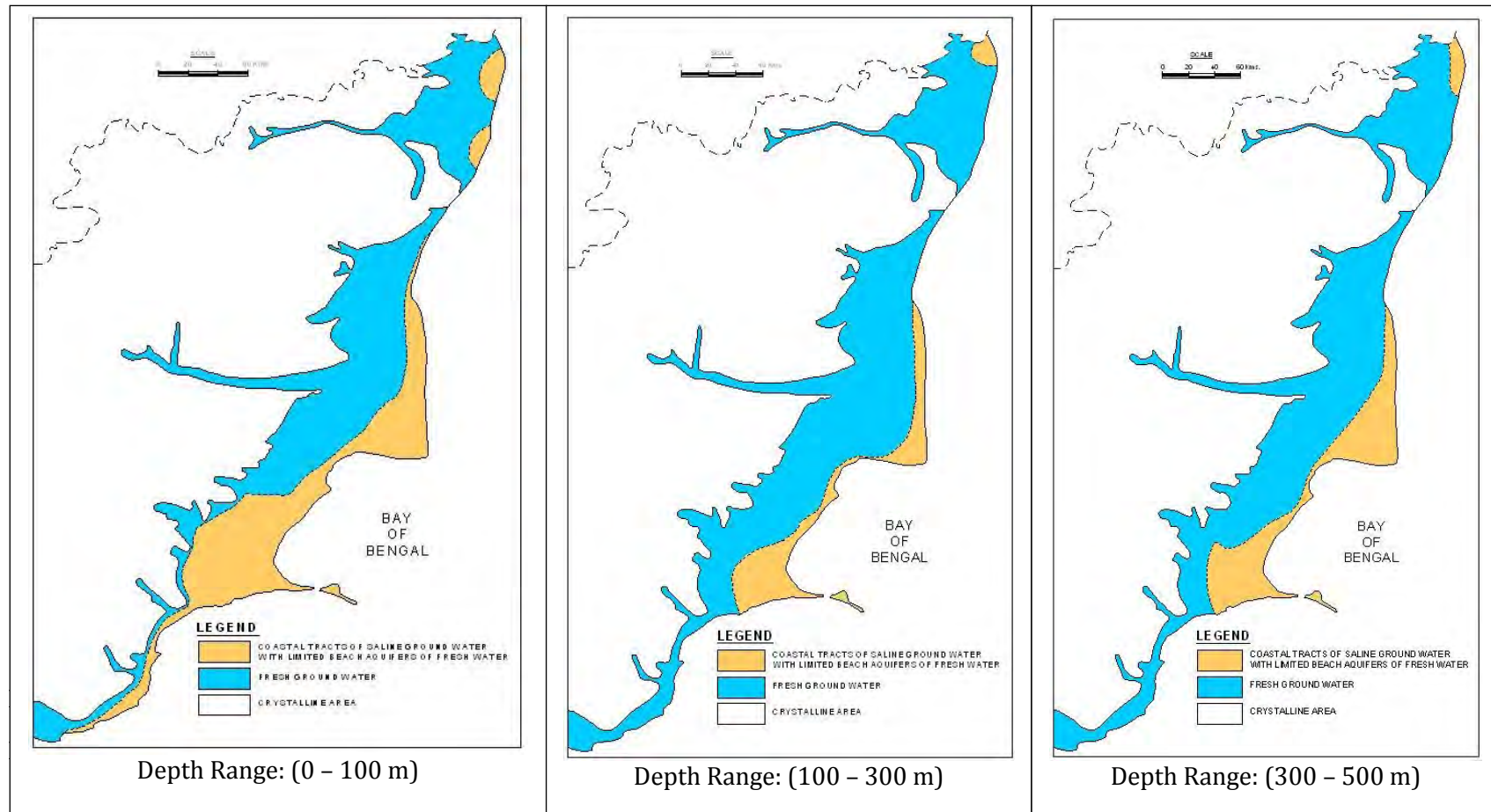


Fig. 5.14: Fresh water – Saline water interface for different depth zones in the coastal aquifers of Tamil Nadu

Deeper aquifer systems in the alluvial tract, nearer to the uplands where these are exposed, are observed have recorded lowering of piezometric surface. Intensive development of ground water from Tertiary and Upper Gondwana Sandstones in the upland areas, adjacent to the alluvial plain, has lowered the pressure heads. With the result, the piezometric surface, of these aquifers, which was observed to be above ground level in the coastal alluvial plain, has been reduced far below the ground level. Lowering of hydraulic pressure in the deeper aquifers of coastal alluvial plain is likely to invite seawater ingress and create a situation for permanent contamination of fresh water aquifers.

Sea water ingress, near the coast, does happen locally where saline ground water is pumped for various activities like aquaculture, and other infrastructural activities. But, there is no extensive problem due to sea water ingress even in the areas of urban settlement, Visakhapatnam. It may be due to less transmissive nature of the underlying crystalline rocks or steep hydraulic gradient

In Andhra Pradesh, the coast was subjected to marine transgressions and regressions in the past as seen from strand lines and the deltas are of prograding nature indicating that they were submerged under sea. Thus the salinity could be imparted during the time of deposition of sediments. It is clear from the exploration that there is a lot of heterogeneity in quality of water both spatially and depth-wise. The complexity in distribution of salinity both vertically and spatially can be attributed to depositional environment and hydrogeological frame work. Thus, it could be inferred that the geomorphic evolution of the coast had an impact on the occurrence of aquifer zones. However, ground water abstraction, aqua-culture practices, tides/cyclones have also provided to be factors responsible in causing salinity though locally.

5.3.1.3 Odisha

5.3.1.3.1 Disposition of fresh and saline water aquifers

Paleodepositional history has determined occurrence and distribution of the coastal aquifers. Land slope, rainfall geological setup tectonic history marine transgression and regression including sea level changes in the geological past, tidal effects, natural changes in river courses influence the saline and freshwater distribution.

In the coastal tract of Odisha, an area around 8575 sq.km in the districts of Balasore, Bhadrak, Jajpur, Kendrapara, Jagatsinghpur, Cuttack, Puri and Khurda suffers from ground water salinity hazard. It is confined to the east of Kasba Kumurda - Balasore- Gopalpur - Basudevpur- Kothar - Chandikhole - Salepur - Raghunathpur - Niali - Pipli - Chilka up to the coast line. The saline ground water zone in the coastal tract has a width around 15 km in the extreme NE around Karanjasole, 1.5 to 5 km in the northern part between Balasore and Saud/Kalyani sector and maximum of 75 km in the central part of the Mahanadi delta. In the extreme south east it extends for 2 to 3 km around Chilka Lake. The salinity of ground water is prominent in the deltas of Mahanadi-Brahmani, Subarnarekha and Burhabalang and the most prominent ground water salinity hazard are found in the central part of the coastal tract. However, the shallow/phreatic fresh water aquifers as localized pockets occur within the palaeo and recent coastal sand dunes and palaeo channels throughout the coastal tract.

Within the depth explored occurrence of fresh and saline water zones are not uniform. Four types of interface relations of fresh/saline ground water are found, viz., i) fresh water zone overlying saline water zone, ii) saline water zone overlying fresh water zone, iii) alternate fresh and saline water zone and iv) saline water all through. Sector wise distribution of fresh ground water zones is given in **Fig: 5.15**. The condition of fresh water aquifers overlying the saline water zone occurs prominently in Cuttack and Puri districts and also in parts of Kendrapara, Jagatsinghpur and Jajpur districts. The condition of saline water zone overlying fresh water aquifers exists prominently in Balasore, Bhadrak, Kendrapara, Jagatsinghpur and Jajpur. Within this saline/fresh condition, a few metres thick fresh water aquifer at the top and also alternate saline and fresh water zone in pockets at depth exist. The condition of saline water throughout down to the explored depth of 600m is conspicuous in Puri district and also in pockets of Kendrapara and Jagatsinghpur districts. Within this, very thin and discontinuous fresh water aquifers with chloride content 250 to 430 ppm occur as pockets.

In Balasore district salinity hazard occurs in a narrow elongated tract along the coast and the rest of the holds fresh water. The salinity is conspicuous in the northern most part, along Karanjasul/Chandaneswar to Chandipur. The width of the saline water zone at Karanjasul is 10-12 km and at Chandipur 6-7 km and further south it reduced to about 3 km along

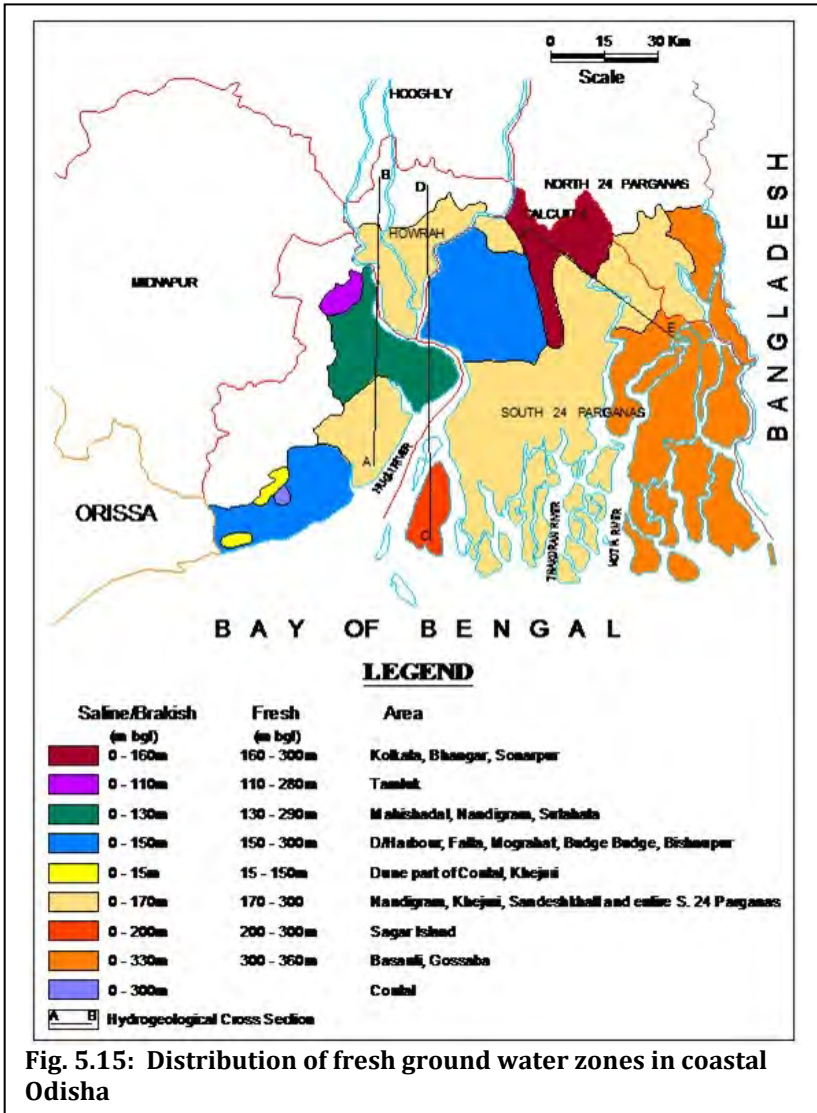


Fig. 5.15: Distribution of fresh ground water zones in coastal Odisha

the coast. In this section fresh water aquifers are sandwiched between saline water zones. The bottom saline water zone extends down to 600m depth. Barring a 10 to 12m thick, maximum up to 30m, fresh water aquifer in the sand dunes, the top saline water zone in the area (a) Karanjasul-Chandaneswar-Narayan Nohanti Poria extends down to 70 m and in the area (b) Chandipur down to 150 m depth. Underlying this saline water zone, thick fresh water aquifers occur down to 300 to 350 m depth in area (a) and relatively thin within 250 m depth in area (b). The water in the near

surface fresh water aquifer as well as the bottom fresh water aquifer has 350 ppm chloride, while the intermediate level aquifer has 250 ppm chloride. At Kalyani, 30 km south of Chandipur all the aquifers down to the depth of 240 m are fresh water bearing. Towards west, i.e., further inland, isolated pockets of brackish/ saline water occur near Jaleswar, Basta, Brahmpur-Pokarisahi and Sunhat at depths within the general range 110-250 m bgl.

Towards south, in the eastern and southeastern parts of Bhadrak, eastern part of Jajpur and in Kendrapara district the thick fresh water aquifer either underlies the saline water zone or is sandwiched between saline water zones. In Bhadrak district the top saline water zone including a few metres of near surface fresh water extends down to 65-100m. The maximum thickness of the near surface fresh water aquifer is 37 m at Tihidi. In Dhusuri-Tihidi-Pirhat-Aradi area 42-77 m thick, deeper freshwater aquifer, generally occurring within 200m depth, underlies the saline water except in and around Suryapur where it is sandwiched between saline water zones. In Harsingpur-Nalgunda-Chandbali-Dhamra-Matto area the top saline water zone (including a few metres of near surface fresh water) extends down to a maximum depth of 206m. The underlying 40-45 m thick fresh water aquifer extends to 300 m depth. In Jajpur district the top saline water zone is 48 to 100 m (Singhpur) thick. It includes near surface fresh water pockets of maximum thickness 48m (Binjharpur). The underlying deeper fresh water aquifers of maximum cumulative thickness 75 m is encountered up to the bed rock encountered at a depth around 200 to 300m. Towards coast in Kendrapara district mostly the similar conditions prevail. The thick fresh water aquifer underlying the saline water zone commences in the depth range of 90 to 190 m. The deeper fresh water aquifer extends to depths, at places beyond 300m. The cumulative thickness of the deeper fresh water aquifer ranges from 47 to 166 m in Patamundai-Rajnagar-Basantapur towards the coast to 22 to 66 m in the inland areas of the district. In the southwestern part of the district alternate zones of fresh and saline water is encountered to a maximum depth of 528m (depth explored). That is, underlying the fresh water aquifer at depth as described above, there exists another two deeper fresh water aquifers, each being separated from the other by a saline water zone. The depth ranges for the fresh water aquifers are 66-254m, 304-421m and 460-528 m bgl. While in the extreme southeastern part of Masakani- Dasarajpur near the coast, the entire column to depths beyond 300m holds saline water.

In Cuttack district, 45-55 m thick fresh water aquifer occurring within 90-100m depth is underlain by saline water zone extending beyond 300m depth. Reversal of this is also seen in some parts where the top 130-150 m of saline water including pockets of fresh water (up to 40m depth) is underlain by deeper fresh water aquifer extending to depths beyond 300m. Like Cuttack district, in Jagatsinghpur district located east of it, also holds fresh water aquifer at the top up to a depth of 50 to 100m bgl with increasing depth towards south. This is underlain by saline water zone to depths beyond 300m (Arilo-Balikuda-Machhagaon). Towards north, around Tirtol, another 25-35 m thick deep fresh water aquifer underlies the saline water zone as observed in Kendrapara district. However, towards the coast, SE of Tirtol around Ersama-Banipath-Manijang area the deeper fresh water aquifers occurring in the depth range of 73-340 m bgl are again underlain by saline water. As moved towards the coast the thickness of the deeper fresh water reduces and around Chatua-Paradwipgarh the water throughout the entire depth column becomes brackish to saline.

In Puri district, major part of the coastal alluvium suffers from salinity hazard. In Puri district also,

the fresh/ saline water zones occur in 3 modes, viz., fresh water aquifers overlying the saline water zone, alternate fresh/saline water zone and saline water zone throughout the depth. In the northern and eastern parts the fresh water aquifers overlie the saline water zone. The 6 to 34 m thick fresh water aquifer occurs in the depth range of ranges of 11m (Astarang) to 110 m (Charichak). However, the area around Gundi-Dasbatia holds saline water throughout the depth up to 300m. The sequence alternate fresh water /salinewater are observed in a narrow stripe along the coast between Puri and Ramchandi. The top fresh water aquifer (cumulative thickness 6 to 10 m) extends down to 40-46m at Puri and 15-18m around Ramchandi. The deeper fresh water aquifer occurs in the depth range of 160 to 240 m in Puri town and 218 to 228 m bgl at Ramchandi. The maximum thickness of the deeper aquifer is 40 m at Puri and it reduces to almost negligible around Ramchandi. While in Brahmagiri and large part of Kanas block, except a few metres of fresh water at the top the entire column down to 300m or the bed rock is saline. In Satyabadi and Pipili area the top fresh water zone up to a depth of 8 to 12 m is underlain by saline water zone. Unlike other areas this saline water zone is underlain by a brackish water zone in the depth range of 62 to 200m bgl. In southern part of Khurda district, adjacent to Puri district the fresh water aquifers are underlain by saline water zone up to the bed rock at 200 to 230 m bgl. The saline water zone is expected to be the northern extension of the one encountered at 110 m bgl in Nimapara-Charichak area of Puri district or encountered at 90 m around Madhav on Cuttack district. Fresh to brackish water aquifers down to 108 m depth at Orakhand is underlain by saline water.

In the narrow tract close to coastal line extending from Chandaneswar in Balasore district to Brahmagiri in Puri district aquifers are found to be saline at different depths giving rise to following four varied situations.

- Area without salinity hazard
- Area with fresh water underlain by saline water
- Area with fresh water overlain by saline water.
- Saline ground water with or without fresh water aquifers (<4 m thick)

The general disposition of different aquifers in the tract is presented in **Figs. 5.16 and 5.17.**

In Balasore and Bhadrak Tract, in a 10-km wide strip along the coast, aquifers are generally saline at the top and fresh water aquifers occur at depths. At Karanjasole fresh water aquifers occur below 165-m depth. Further south in Ghanteswar- Chandbali- Krushnapur area fresh water occur below 165 to 173 m depth and tapped through deep tube wells. In the remaining part of the district adequate thickness of fresh water aquifer occur within 300-m depth. In the Jaleswar-Basta- Baliapal Remuna- Balasore tract a group of fresh water aquifers occurs within 100-m depth. In the western fringe of Nilgiri, Oupada, Khaira, Bonth and Bhandaropokhari blocks the bed rock is encountered at shallow depths (within 134 m depth).

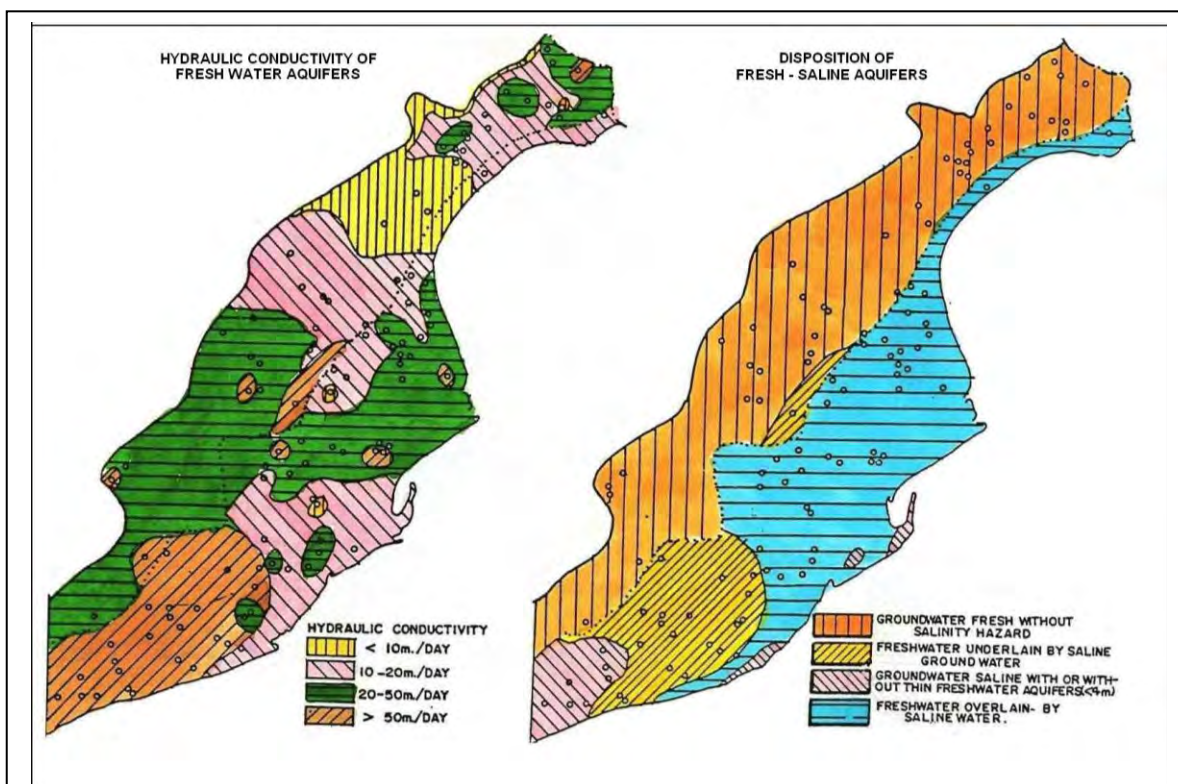


Fig. 5.16: Characteristics of fresh water aquifers and disposition of fresh –saline aquifers in coastal Odisha.

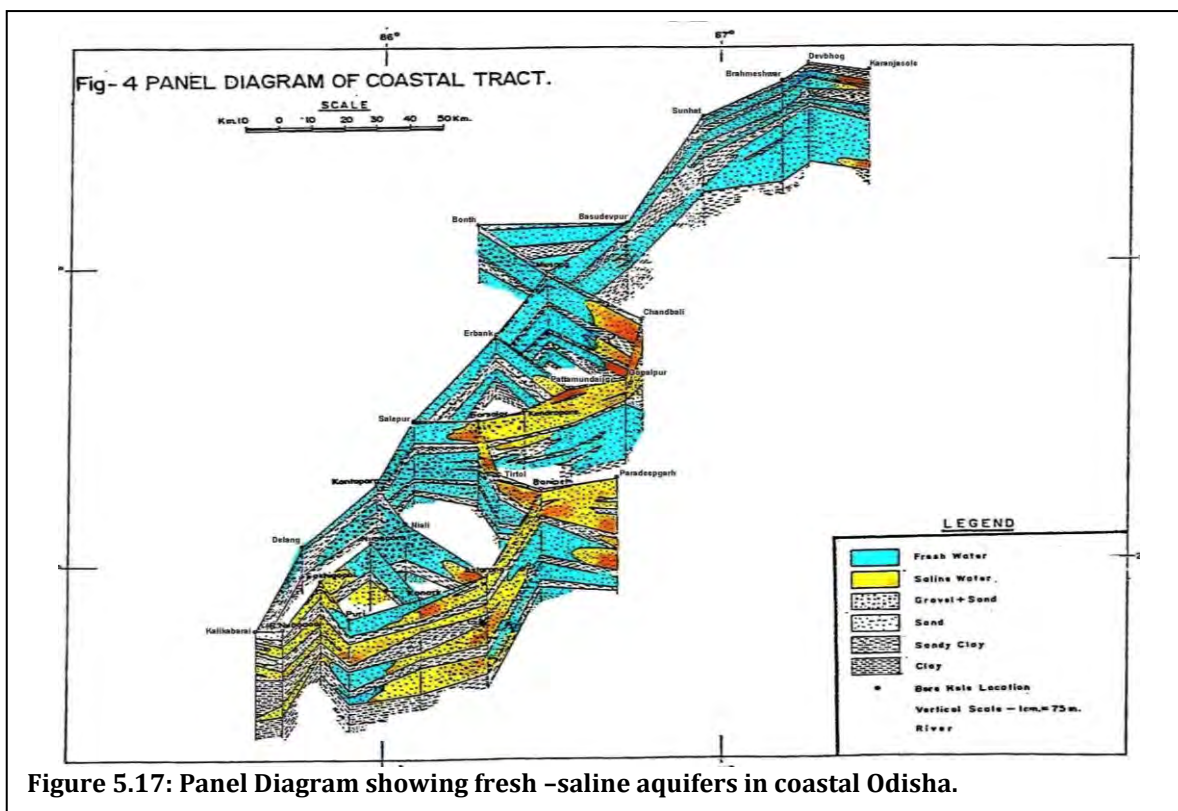


Figure 5.17: Panel Diagram showing fresh -saline aquifers in coastal Odisha.

In Cuttack – Jagatsinghpur-Kendrapara and Jaipur tract, In large areas falling in Rajkanika – Aul – Rajnagar –Pattamundai – Kendrapara-Marshaghai, Mahakalpara, Kujang, Patkura and Ersama blocks aquifers down to a depth of 60 to 320m are saline to brackish in nature, and fresh water aquifers occur below this depth. The depth to fresh water horizon gradually increases towards the coast. In areas to the west of the saline tract, fresh water aquifers occur within 100 to 150m depths and both shallow and medium deep tubes well are feasible. In the saline tract only deep tubewells are feasible. At Tirtol shallow freshwater (within 52m depth) is underlain by brackish to saline aquifer down to a depth of 160m, below which, second group of fresh water aquifer occurs. At Khandatari about 10 km west of Tirtol no saline aquifer was encountered within 184m depth.

In Puri and Khurda Tract, the aquifer and the aquiclude disposition is very irregular and erratic. In the eastern part of Puri district falling in parts of Nimapara, Gop, Balipatna, Kakatpur, Astarang (West) blocks, fresh water aquifers occur within a depth of 100m below which formation water is brackish to saline in nature. In the Puri-Brahmagiri-Siruli tract aquifers are generally saline, at all depths down to the bedrock except in local pockets. In the area around Sakhigopal, ground water is slightly brackish to saline down to the bed rock (282m). In the Tolapada- Delang area fresh water aquifers occur at shallow depths (30 to 100 m). At Puri town fresh water aquifers occur in shallow (within 40m depth) as well as deeper horizons (135-200 m depth). The deeper fresh water zone pinches out towards northeast. At Astarang only the dug well zone (within 15-m depth) contains freshwater, beyond which aquifers are brackish to saline. In Pipili area only shallow tubewells are feasible. The disposition of aquifers around Puri has been depicted in **Fig. 5.18**. The geochemical profile based on geophysical logging along Delang -Puri has been given in **Fig. 5.19**.

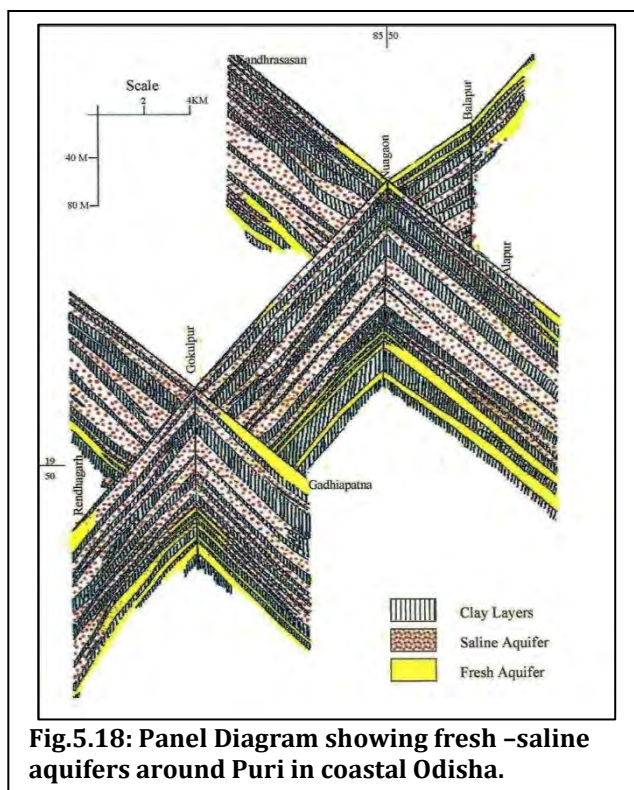


Fig.5.18: Panel Diagram showing fresh –saline aquifers around Puri in coastal Odisha.

5.3.1.4 West Bengal

In the coastal tracts of West Bengal, the following water quality issues may be mentioned:

- Salinity Hazards/ Ingress
- Arsenic Pollution
- Industrial Pollution
- High Iron in Ground Water

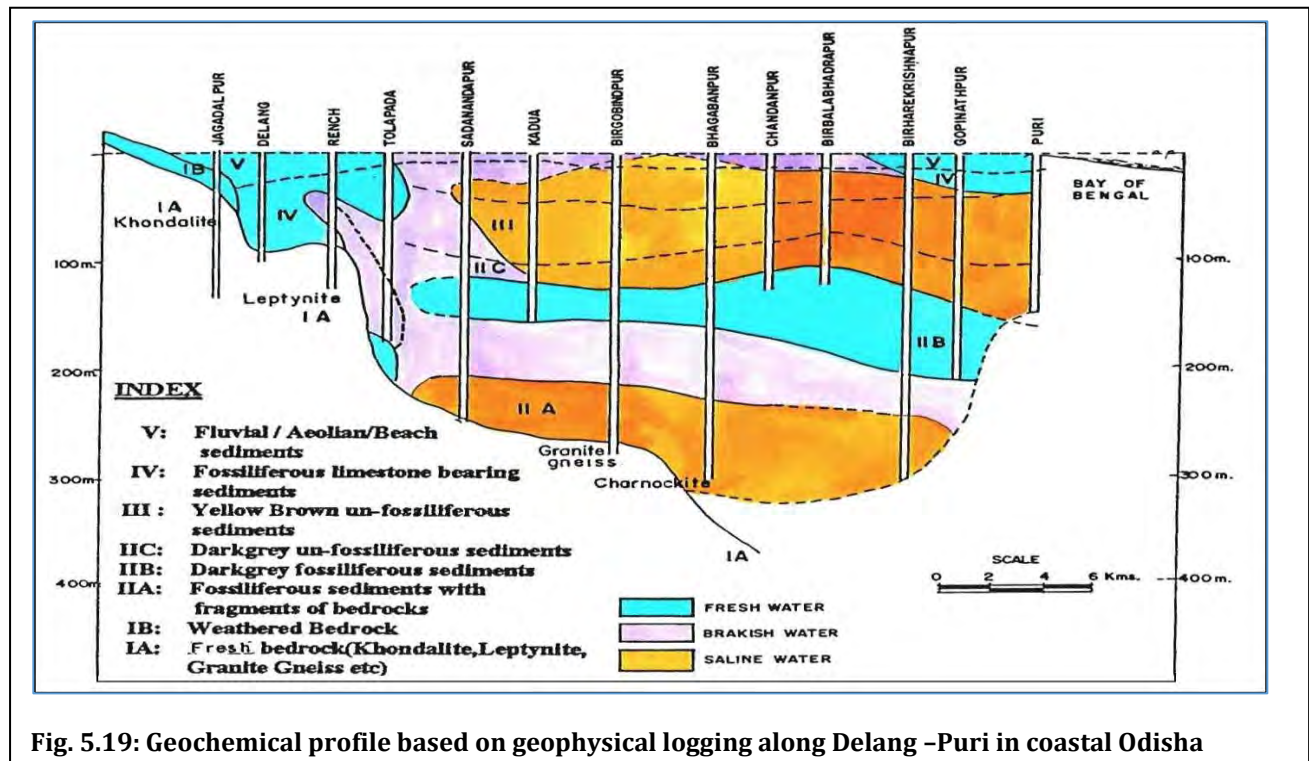


Fig. 5.19: Geochemical profile based on geophysical logging along Delang -Puri in coastal Odisha

5.3.1.4.1 Salinity Hazards/ Ingress

Based on the geophysical surveys and ground water exploration, brackish to saline and fresh water bearing aquifers have been deciphered in the different depth zones in Kolkata Municipal Corporation area, South 24 Parganas and in parts of North 24 Parganas, Haora and Purba Medinipur districts.

Considering the findings of surveys and exploration, tube wells were constructed in the fresh water bearing aquifers with proper design including cement sealing which played an important role in safe withdrawal of water from the deeper aquifers preventing saline water from the upper saline aquifers to percolate down to the deeper fresh aquifers.

i) Kolkata Municipal Corporation (KMC) Area, Kolkata

In consequence to the rapid growth of population and urbanization in KMC area, depletion of piezometric level occurs in KMC area due to heavy withdrawal of ground water possibly more than the replenishment. Consequent to the significant fall in the piezometric level especially in the central and south-central part of Kolkata, a ground water trough is formed. As a result, the ground water flow direction which was originally towards south and southeast became convergent displaying reversal of ground water flow in the southern part. Due to the lowering of the piezometric surface, possibility of ingress of the 'brackish' ground water in to the fresh aquifer in KMC area exists. Considering the ground water condition, KMC Authority has decided to lower the stress on ground water development. They have decided to cover more and more area under surface water supply

and to reduce the ground water supply gradually. In this way, formation of ground water trough will be checked and intake of arsenic contaminated ground water will also be avoided.

Monitoring of water level at regular interval in salinity prone areas and monthly monitoring in KMC areas are being done by CGWB for suggesting measures that need to be taken from time to time to arrest the salinity ingress, if any.

ii) Haldia Industrial Area

The Haldia industrial complex falling under the Haldia Development Authority forms a part of the coastal plains of Purba Medinipur district. The study reveals a steep fall in water level (piezometric level) to the tune of 5 to 7 m during the last 3 decades due to over development of ground water for industrial and domestic uses in Haldia and the adjacent industrial area. The draft of ground water in the area is more than the ground water inflow in a year. As a result, an imbalance of ground water withdrawal vis-à-vis replacement has taken place that could trigger the ingress of the sea water into fresh water aquifers because of the close proximity of the area to the Bay of Bengal.

In this area, ground water draft for domestic and industrial uses from existing ground water structures has been estimated as 6 MGD (Million Gallon per Day). Fifteen (15) MGD water is being supplied to the industrial area from Hugli River after its treatment at Geonkhali by PHED (Public Health Engineering Department), Govt. of West Bengal. In order to combat the salinity problem of Hugli River water due to tidal effect during summer months (particularly during mid-March to mid-June), 5 MGD fresh ground water is being withdrawn from 15 nos. of deep tube wells (PHED) located between Mahisadal and Chaitanyapur and after mixing with 15 MGD treated surface water, the total 20 MGD is supplied during the above mentioned period. In addition to that, the major industries like IOC, HFCL, CPT, etc. have their own ground water abstraction structures and according to their requirement, they are withdrawing the fresh ground water. The 17 piezometers drilled up to the depth zone of 164 to 213 m in the Haldia-Panskura area recorded piezometric head in the range of 6.0 m a MSL to 7.0 m below MSL during pre-monsoon 2002. During 2011, it was recorded in the tune of 8.0 m below MSL. In view of distinct declining trend of the piezometric head in the industrial belt, the future water requirement of nearly 30 MGD would be met from Hugli River source at Uluberia (Haora district) as decided by HDA.

Since Namkhana, Kakdeep, Sagar island areas which are located south of Haldia industrial belt, no deterioration in quality of the deeper fresh water bearing aquifers has been noticed yet, the interface is expected to be far south of the Sagar Island. However, keeping in view of the long-term sustainability of the ground water quality, it was felt essential by the CGWA to regulate indiscriminate withdrawal of ground water. As a result, the entire Haldia Municipal area covering 103 Km² consisting of 97 Mouzas has been notified under Section 5 of the Environment Protection Act by CGWA on 22.08.2000 and later modified and re-notified in January 2003.

Based on the notification, the ban has been imposed on large-scale withdrawal of ground water from heavy-duty tube wells from zones beyond 120 m depth.

iii) Arsenic Pollution

Sporadic occurrence of arsenic in ground water above the permissible limit (>0.05 mg/l) has been observed in shallow aquifers in parts of South 24 Parganas, North 24 Parganas and Haora districts. The arsenic contamination in ground water from the tube wells in KMC area has also been reported by KMC.

iv) Industrial Pollution

a) Haldia Industrial Area

Untreated or partially treated industrial effluents are major sources of surface and ground water pollution in and around the industries. The result of chemical analysis of water samples for determination of trace elements in ground water in Haldia industrial area is given in Table 6 and it is observed that concentration of manganese exceeds the stipulated standard.

b) Haora Industrial Area

The chemical analysis of water samples, collected from Haora Industrial area is given in Table 7 and it is observed that concentration of manganese and iron exceed the stipulated standard. In Haora, high nitrate concentration of 46 ppm in shallow ground water has been reported.

c) Kolkata Municipal Corporation (KMC) Area

In the eastern part of KMC area, near Tangra-Topsia-Tiljala, toxic trace element like Cr and Co was found in excess of 0.01 mg/l in the shallow aquifers within 20 mbgl, which is under semi-confined conditions. Leather industries were present in those areas. Ground water here occurs under semi-confined condition, as a result of which polluted water from the surface finds its way to reach this shallow aquifer. Presence of thick clay layer does not permit these pollutants to go further below. In the deeper aquifers below 80 mbgl Cr, Co and other heavy metals are below permissible limit.

In Dhapa and nearby area in Eastern part of KMC, the chemical analysis of water samples, collected from surface water bodies, dug wells and tube wells is given in the Table 8. It has been observed that both surface and ground water in the Dhapa is alkaline in nature. High chloride, iron, total hardness and EC are present in water in the area. Amongst heavy metals, manganese and lead are found above permissible limit. Arsenic is found beyond detectable limit.

High Iron in Ground Water

Iron above permissible limit is found in ground water in shallow aquifers in South 24 Parganas and Haora district.

5.3.2 West Coast

5.3.2.1 Kerala

In the coastal area of Kerala, saline ground water is encountered in localized areas in both shallow and deeper aquifers. The cause of ground water salinity has been attributed to the marine depositional environments of the aquifer material. Seasonal salinity of ground water in areas adjoining rivers and streams in the coastal area, caused by the tidal ingress of sea water upstream for distances up to about 10 km is a common problem. The ground water, which turns brackish/saline during summer season, becomes fresh again with the onset of monsoon, due to the flushing of aquifers. No major ground water quality issues have been reported from the coastal area of the State, except for localized occurrence of fluoride in excess of permissible limits (1.5 mg/l) in the deeper sedimentary aquifers in part of Alappuzha district and isolated patches presence of salinity. Trace elements associated with industrial effluents around Chavara in Kollam district. No incidence of sea water intrusion has so far been reported from the coastal area of the State.

The quality of water in the Tertiary aquifers indicates that the relative concentrations of major ions and trace elements are different from that obtainable by seawater dilution. The parameter to indicate the long term processes of freshening or intrusion in coastal aquifers is the NaCl ratio (Jacks, 1987 and Mercade, 1985). In the course of sea water intrusion part of the sodium ions is exchanged for Calcium and Magnesium ions which are the predominant cat ions in the exchange sites of clay minerals in fresh water aquifers. The resulting water will be depleted in sodium. The chloride ions continue to remain in solution since chloride does not undergo ion exchange precipitation complex oxidation-reduction or biological reactions (Hem, 1970). Thus the NaCl mole ratio during the intrusion will be less than 0.85, the mole ratio in the sea water. When freshening of saline aquifers occurs, the direction of cation exchange is reversed and the opposite trends will be effective and NaCl ratio will be higher than that in sea water.

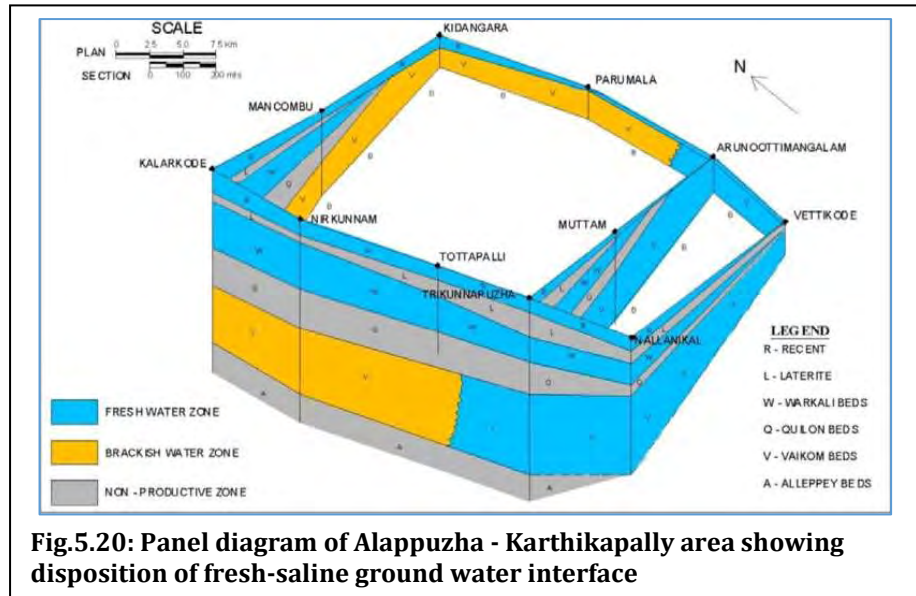


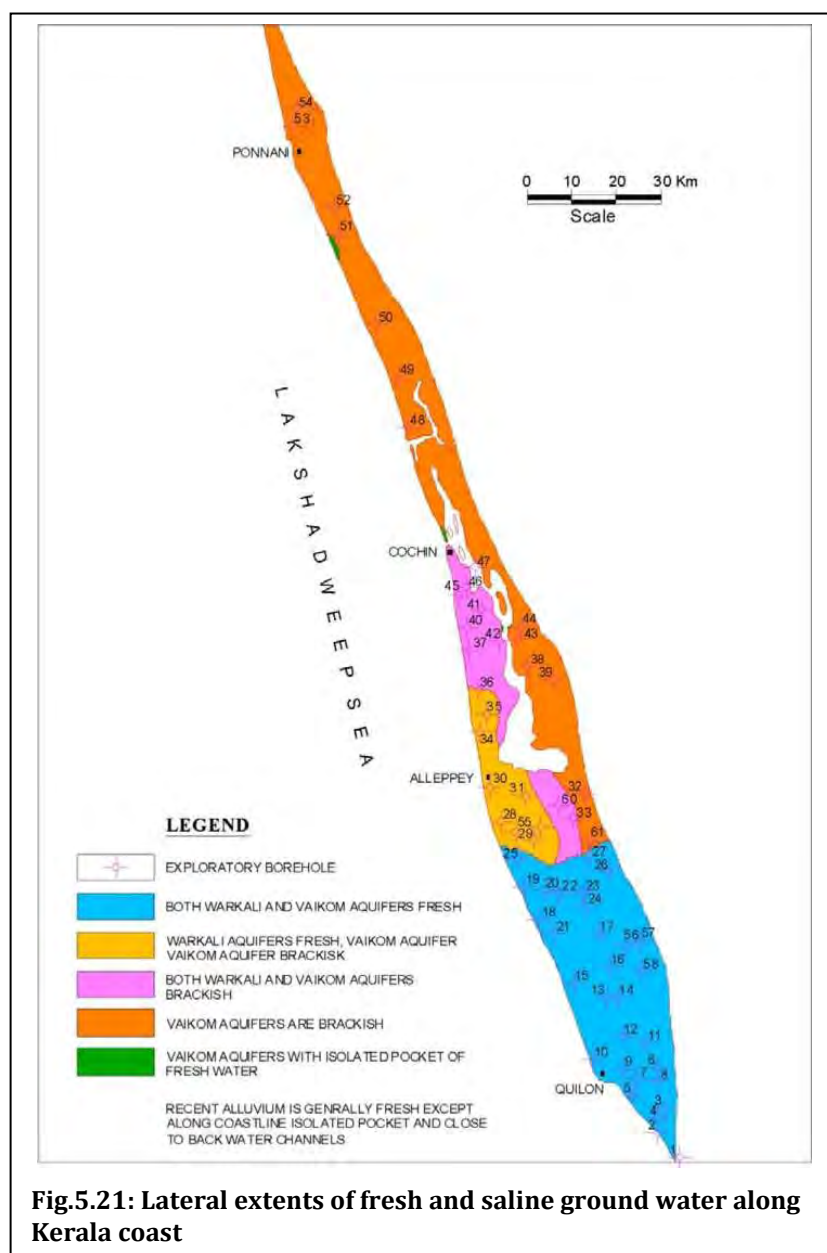
Fig.5.20: Panel diagram of Alappuzha - Karthikapally area showing disposition of fresh-saline ground water interface

The NaCl ratio of the water from the Tertiary aquifers is plotted against the chloride content. The size of the loops of the NaCl ratios depends on the ion exchange capacity of the aquifer material. It is seen that the NaCl ratio for most of the samples is higher than that in sea water fresh water mixture and that these plot is in the field of freshening. This indicates a freshening process of the formation water over a period of time and not sea water fresh water mixing. The fresh saline ground water interface in Alappuzha- Karthikapally area is shown in **Fig. 5.20** and its lateral extents are shown in **Fig. 5.21**.

5.3.2.2 Karnataka & Goa

No major issues related to ground water quality have been reported from the coastal aquifers of Karnataka and Goa, except for salinity caused by marine depositional environment and tidal influence in rivers/ streams.

In the coastal tract of Karnataka, the fresh-saline ground water interface is observed very close to the coast line with in a kilometer and primarily due to tidal waves. The interface is at a distance of about a kilometer in sandy areas and about 500m from the tidal tract of estuaries (Environment Report, 2003). Since the coastal districts of Karnataka receive an annual rainfall more than 3000 mm. salinity is not noticed during monsoon period due to dilution by heavy rains (Planning Commission Report, 1981). The interface is noticed is noticed in the months from October onwards



5.3.2.3 Maharashtra

All along the Konkan coast brackish to saline ground water is obtained in the beach sands and mud flats forming the coastal alluvium. The topographic depressions in mud flats form saline lands. In the coastal alluvium in Thane district, quality of ground water is fresh in the elevated lands (EC 600 to 2000 $\mu\text{S}/\text{cm}$) but brackish to saline (EC up to 4000 $\mu\text{S}/\text{cm}$) in the lowlands. In Raigad district ground water in shallow dug wells is fresh to brackish. In the beach sands of Ratnagiri district the quality of water is slightly brackish near the creeks. In the coastal alluvium of Sindhudurg district south of Achra creek in Malvan - Devgad - Kelus - Shiroda area the quality of water is fresh to brackish. The EC ranges from 70 to 4400 $\mu\text{S}/\text{cm}$ and Chloride ranges from 7 to 450 ppm, with their average values as 441 $\mu\text{S}/\text{cm}$ and 43 ppm.

The fluviatile alluvial deposits along river courses generally hold fresh to slightly brackish groundwater where alluvial thickness is small (less than 10 m) but in areas where the alluvium is thicker and poorly drained the ground water quality is brackish or even saline. Also the quality of ground water in areas with rivers experiencing tidal backwater effects is brackish or saline.

Underlying the beach sand and mudflats, in the semi consolidated, coarse grained and gritty calcareous sandstone of Mio-Pliocene Age, the quality of water is slightly brackish and is locally used for horticulture purposes (Coconut / Arecanut gardens).

The average value of EC and TDS in ground water suggests that it is not highly mineralized. The TDS is less than 500 except at few places of Thane and Raigarh districts, which indicates that mineralization of ground water, are minimum.

5.3.2.4 Gujarat

The Gujarat Government constituted a High Level Committee (HLC) to address the basic issues of salinity ingress and set up the priorities for salinity control measures along the coasts of Kachchh and Saurashtra. The fresh-saline ground water interface along Kachchh and Saurashtra coast is being studied and periodically monitored by GWRDC, Gujarat since 1976. The fresh-saline ground water interface is defined by the TDS of ground water and the 2000 ppm TDS is taken as the lower limit of ground water salinity. Ground water with less than 2000 ppm TDS is considered as fresh. The fresh- saline ground water interface along the coast in terms of 2000 ppm TDS is discussed below. It was traced maximum 25 km inland on Kachchh coast.

Lakhpat-Naliya-Mandvi-Mundra-Gandhidham (Kachchh coast)

Along this section on Kachchh coast, in the year 2004, the 2000 ppm iso-TDS contour was traced about 25 km inland in Lakhpat-Naliya area and 10-15 km in Mandvi area. Near Gandhidham the 2000 ppm TDS contour was traced near Anjar located about 22 km inland. Near the creeks and along the coastline the TDS was upto 10,000 ppm. However, patches of ground water zones with TDS less than 2000 ppm were traced near Jakhau, Vadapaddhar-Lathedi, Bhujpar, and Mundra, located about 10 to 5 km inland.

Okha-Maliya (Gulf of Kachchh)

Along this section, the 2000 TDS contour was traced in 2004 by GWRDC. It was almost parallel to the coast line and 10 to 20 km inland. The contour was traced closest to the sea between Khambaliya-Jamnagar where basalts are exposed. On the coast line the TDS goes up to 6000 ppm. Okha-Porbandar-Madhavpur (Saurashtra coast) Along this section the fresh-saline ground water interface was traced and monitored by GWRDC since 1980 by conducting VES and measurement of depth to water level and quality of water from observation wells along profiles perpendicular to the coastline. Two such profiles along Dwarka- Ladwa and Gorsar-Hantarpur (near Madhavpur) are shown in **Figs. 5.22 and 5.23** respectively. The fresh-saline interface was 4 to 7 km inland in 1986-87. Along Okha-Madhavpur section the 2000 ppm iso-TDS contour in 1997 was, in general, 10-12 km inland. However, all along this section there were patches with less than 2000 ppm TDS very close to the coast line.

Una-Bhavnagar (Gulf of Khambhat)

Along Una-Bhavnagar section the iso-TDS contour of 2003-04 is quite close to the coastline indicating near-coast fresh-saline ground water interface. Even presence of fresh ground water was

observed near the coast at Jaspara.

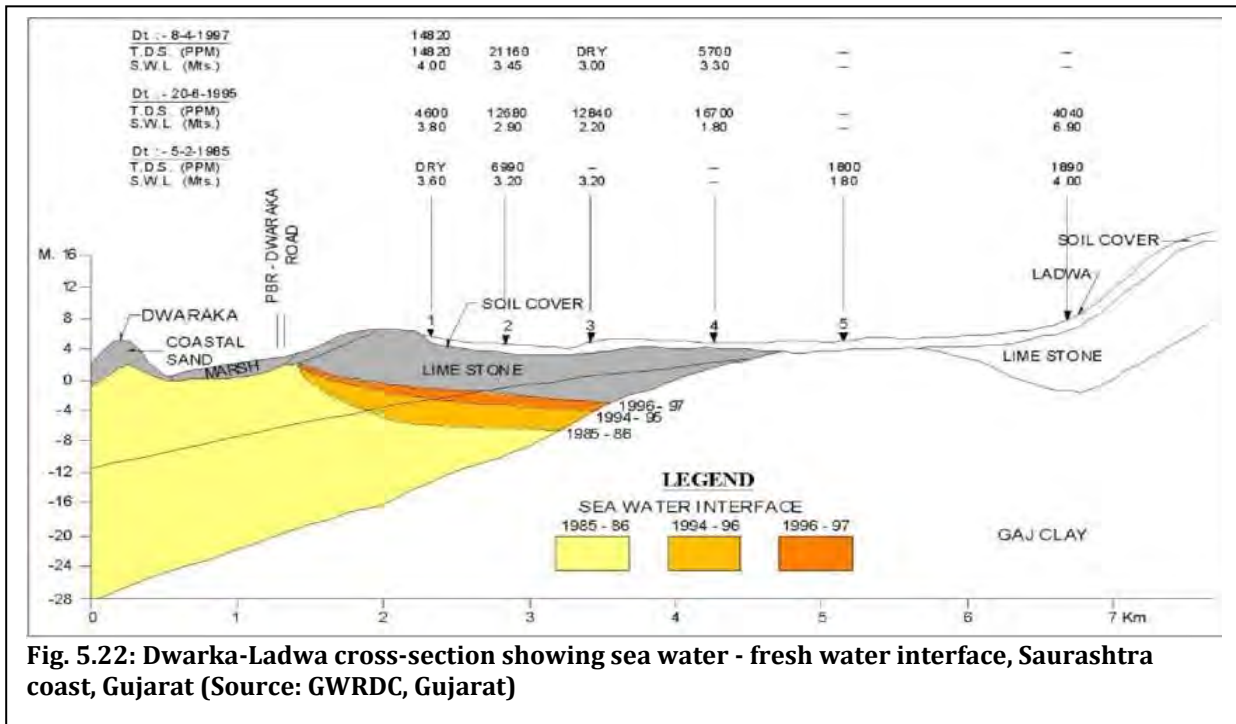


Fig. 5.22: Dwarka-Ladwa cross-section showing sea water - fresh water interface, Saurashtra coast, Gujarat (Source: GWRDC, Gujarat)

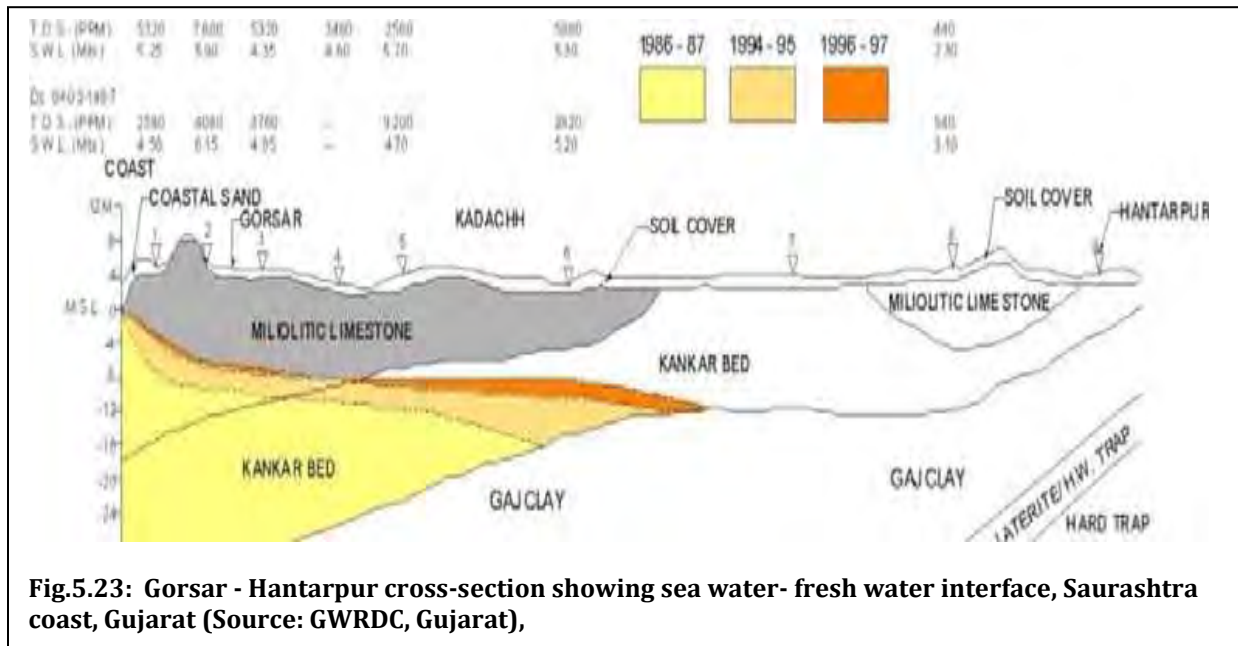


Fig.5.23: Gorsar - Hantarpur cross-section showing sea water- fresh water interface, Saurashtra coast, Gujarat (Source: GWRDC, Gujarat),

6. CONCLUSIONS

1. The coastal region of India has a variety of geomorphological units and landforms developed through several factors like rock types, tectonics, topography, land cover, climate and the fluvial, marine and aeolian actions for over the geologic past. The coast line of India covers 9 states and one union territory. The west coast, to the south of Gulf of Khambat along NNW - SSE direction, is almost straight and are characterized by a number of tidal creeks. The Western Ghats, almost parallel to the west coast is a prominent linear relief zone and acts as a major water divide, between the east flowing Godavari, Krishna and Cauvery river systems and the short stretched west flowing minor rivers. Unlike the west coast, the east coast is a curvilinear one with the maximum curvature near the mouth of river Krishna debouching into the Bay of Bengal. The well-developed river delta systems, vast coastal plains and extensive fluvial and marine sedimentary deposits, etc., from the Sunderbans in West Bengal to Kanyakumari in Tamil Nadu, which are characteristic features of the east coast, indicate its prograding nature.
2. Rainfall along the coastal tracts of Peninsular India is of monsoon type, restricted to two seasons in a year. The southwest monsoon, active from June to September contributes the bulk of the annual rainfall along the east and west coasts, except in the coastal areas of Tamil Nadu and Southern coast of Andhra Pradesh, where the bulk of the rainfall is from northeast monsoon. The annual normal rainfall along the west coast ranges from 300 mm (north & northwest), to 2500 mm (south), while in the eastern coastal tract, it is generally in the range of 1000 to 1500 mm except in some areas of Andhra Pradesh and Tamil Nadu.
3. The coastal tracts of India have a complex geology, with lithological units ranging from recent fluvial and marine deposits to Archaean Crystalline rocks. On the east coast, thickness of alluvium is several hundred metres near the mouths of the major rivers like Cauvery, Krishna, Godavari, Mahanadi, Subarnarekha and Ganga. It decreases inland to a few metres near palaeo- or existing delta heads where crystalline rocks occur. The alluvial plains with varying widths occur throughout the east coast up to Ramanathapuram in Tamil Nadu. The western coast, on the contrary has a narrow strip of recent alluvium and older unconsolidated deposits for a major part of its length.
4. Aquifers along the coastal tracts of India can be broadly classified into those in porous sedimentary formations and in fissured formations. The sedimentary tracts, all along the east coast and the coastal plains of Kerala and Gujarat are mostly occupied by 'porous' aquifers while a major part of the west coast and parts of Andhra and Tamil Nadu coast are occupied by 'fissured' aquifers. In the hard rocks, the shallow aquifers are, in general, in the weathered zone and deeper aquifers are in the underlying fracture zones. General hydraulic gradient of the ground water table in the unconfined shallow aquifers and piezometric surface of the deep aquifers in the coastal tract is towards the sea.
5. In Tamil Nadu, the coastal aquifers show wide variation both laterally and vertically. The sediments in the extreme northern coastal tract of Tamil Nadu in the districts of Tiruvallur, Kancheepuram and Chennai are represented by alluvium both younger and older, boulder bed and the coastal sands of Quaternary age, underlain by a sequence of Tertiary sandstones, clays and shales and the Gondwana sandstones and shales. The area falls in the sub-basins of rivers

Cooum, Kortalaiyar, Araniyar and Palar and the alluvium forms the important repository of ground water. Ground water occurs both under water table and confined conditions. The aquifers in Tertiaries and Gondwanas in this area have only limited yield prospects. The coastal part of Ponnaiyar river basin, the nonproductive zones occur towards north, highly productive zones in the central part and fresh water aquifers overlain by saline water in the southern part. In the area around Puducherry and Cuddalore, the potential aquifers in the area are confined to alluvium, Tertiaries & Cretaceous formations. Ground water occurs both under unconfined and confined conditions in these aquifers. Further south, the Cauvery delta forms the coastal tract. The shallow aquifers occurring within 100m bgl have one to five granular zones with a total thickness of 3 to 54 m, while the deeper aquifer groups between 100 to 450 m bgl have one to five zones with a cumulative thickness of 11 to 103 m. The quality of water in alluvial aquifers deteriorates towards the coast. The Vaigai basin of Ramanathapuram district is completely influenced by marine environment and there are a number of water-bearing zones but the quality of formation water is highly saline. In the southernmost Kanyakumari district, the sedimentary sequence is mostly absent and the crystallines are exposed. In some areas of the coastal tract, sand dunes are the only source for fresh water as in Rameswaram, Mandapam etc.

6. In Andhra Pradesh, coastal areas of East and West Godavari districts have exposures of Tertiary sandstones-Rajahmundrys. Due to highly porous and permeable nature, these sandstones hold potential aquifers in parts of West Godavari district. In the upland areas towards east of Godavari river, Tertiary sandstones are more of fine-grained nature holding poor aquifer system. Towards south, in the lower deltaic plain of Pennar River, Tertiary sandstones occur in the depth range of 150 to 450 m bgl and hold potential aquifers. The Upper Gondwanas, forming potential aquifers in the upland areas, where they are exposed, occur at depths beyond 600 m in the coastal plain underlying the crystalline basalts. The unconsolidated sediments constituting the coastal and deltaic plains, are highly porous and permeable with sustainable ground water resource consisting Gravel, sand and silty sand. Ground water in the shallow layers of these sediments occurs under unconfined conditions whereas at deeper levels it develops high pressure heads due to confining conditions. Dunes, consisting mainly of sand are formed near the sea coast of Andhra Pradesh due to aeolian action across the coast. These sand dunes, which are linear and formed parallel to the coast line, are found all along the coastline.
7. In the coastal tracts of Odisha, the sand and gravel layers in alluvium and the semi-consolidated or loosely cemented sand and gravel layers of the underlying Tertiary (Mio-Pliocene) deposits form the prolific aquifers. The shallow or phreatic aquifers occur more or less throughout the coastal tract. The phreatic aquifers in the western part, are generally formed by the older alluvium while in the eastern part they are formed by the younger alluvium. Ground water extraction from phreatic aquifers is mainly through dug wells and shallow filter point tube wells. The alluvial deposit extends down to 50 to 60 m in the western part and to 150m in the eastern coastal tract. The sand and gravel layers in alluvium and the semi-consolidated or loosely cemented sand layers in the underlying Tertiary deposits form the prolific aquifers at depth. The alluvial aquifers occurring in parts of Mahanadi and Brahmani basins are generally of the flood plain deposits and are of coarser material with higher hydraulic conductivity than those in Budhabalang and Jamira. Wells in the outfall areas of the rivers Baitarani, Brahmani

and Mahanadi indicated auto-flowing condition. In general, the well yield varies from 25 to 35 lps for Tertiary aquifers for a cumulative thickness tapping of 35 to 45 m within 300m depth. The yield of Tertiary aquifers progressively reduces with increase in depth. Sand dunes are common in the coastal tracts of Odisha and exist as thin elongated bands parallel to the coast.

8. In the coastal tract of West Bengal encompassing the districts of S 24 Parganas, N 24 Paraganas (part), Haora (part) and East Medinipur (part), alluvium of Recent to Pliestocene ages and the Tertiary sediments form the aquifers. The alluvium comprises sands of varying grades, micaceous, with gravels and kankar. The sands are, in general, fine to very fine. Medium to coarse grained sands are of limited occurrences. In general, there is a thick blanket of clay at the top whose thickness varies from 15 to 76 m with increasing thickness towards south. Also, a thick basal clay bed occurs at depths ranging from 152 (N 24 Parganas district) to 414 m (Kolkata area). The aquifers in between these shallow and deep clay layers in the general depth range of 70 to 360 m bgl are under confined condition and are mostly tapped either for irrigation or drinking water supplies. In the northern part of S 24 Parganas district, however, there exists a shallow aquifer system within 50 m bgl mostly tapped for domestic use by shallow tube wells. It is followed by second and third aquifer systems in the depth ranges of 70 to 160m bgl and 170 to 400 m (depth explored) respectively. Each aquifer system comprises one or several interconnected aquifers. The ground water resource availability in these coastal districts constitute about 12.7 % of the utilizable dynamic ground water resource annually available in the country.
9. In coastal plains of Kerala, the recent alluvial deposits form the most potential phreatic aquifer in the state. It is being tapped by dug wells and filter point wells extensively. Laterite forms potential aquifers along valleys and topographic lows, where the thickness of saturated zone is more and can sustain large diameter open wells. In the Tertiary sediments, ground water occurs under unconfined to confined conditions. Out of the Tertiary formations, viz., Warkali, Quilon, Vaikom and Alleppey, the Warkali and Vaikom hold the most potential aquifers. Warkali constitute the most extensively developed aquifer amongst the Tertiaries. The water supply system between Quilon and Ernakulam mostly depends on this aquifer. Limestone beds in Quilon formation forms local aquifers of low yield. Vaikom Bed constitutes prolific aquifer system amongst the Tertiaries.
10. Along the 225 km long coast line of Karnataka, in the three districts of Uttara Kannada, Dakshina Kannada and Udupi, there occurs a narrow strip of coastal alluvium underlain by the Precambrian crystallines. Its width varies from a few metres to 4 km at places. Tertiary laterite cappings on schists and granites are seen at places. Coastal alluvium comprises fine to medium-grained sand, clay and gravels. The thickness of alluvium is around 35 to 45 m near the coast and gradually decreases landward up to 10 m. The yield of the dug wells ranges from 1.8 to 297 m³/day in sand. Laterites form productive aquifers in areas close to valley portions. The yield of wells in laterites ranges from less than 2 to 280 m³/day.
11. In coastal Goa, the recent alluvium and the thick laterite cappings form potential aquifers. The fine to coarse sand, gravel with intercalation of sandy loam in the alluvium, constitute the aquifers. Thickness of alluvium varies from a few meters to about 22 m. Exploratory wells constructed in the coastal alluvium vary in depth from 15.5 to 22 m. Laterites as well as

fissured crystalline formations constitute aquifers of importance in the State.

12. In Maharashtra, semi-consolidated calcareous sandstone occurs along the Konkan coast underlying the beach deposits and at places exposed as outcrops. The thickness of this formation is up to 10 m at places but may be more, which yields good discharge to dug wells. Laterites, both primary and secondary, occupy extensive areas of low-lying tracts, coastal parts and high plateau of Sahyadri ranges. All along the Konkan coast a narrow strip of unconsolidated beach sands occurs, varying in width from a few tens of metres. The coastal alluvium, wherever it is locally extensive, assumes importance as moderate ground water reservoirs. In coastal Goa the alluvium and the thick laterite capping form the potential aquifer. The fine to coarse sand, gravel with intercalation of sandy loam in the alluvium, constitute the aquifers. Thickness of alluvium varies from a few meters to about 22 m. The thickness of sand and gravel bed varies from 3 to 3.5 m in the depth range of 10 to 20 m bgl. The yield ranges from 155 to 260 m³/day. The laterites are another most important water bearing formation. The laterites are either insitu, particularly in plateau areas, or detrital in origin generally occupying the valley portions. The thickness of laterite extends up to 30m.
13. Along Gujarat coast, the sedimentary formations ranging in age from Upper Cretaceous to Quaternary form the major aquifer systems. They occur under unconfined to confined conditions. In general, the unconfined aquifers occur down to 40 m bgl, whereas the semi-confined to confined aquifers extend from 30 m to more than 200 m bgl. The major aquifers are formed by Miliolitic Lime stone (Recent), Manchar Series (Tertiary) and alluvium and blown sands. The quality of water in the shallow aquifer is also saline with few localized pockets of brackish to fresh water. Miliolitic Lime stones form prolific aquifer but are effected by poor quality due to proximity of sea. Manchar Series also have moderate to high yield at economical drawdown. The quality of ground water in deeper aquifer is saline in large parts.
14. Quality of ground water in coastal aquifers varies considerably depending upon various factors such as climate, disposition fresh and saline water zones in multi-aquifer systems, ground water development scenario etc. Ground water quality variations are more predominant along the eastern coastal tract when compared with its western counterpart. Quality of ground water in a major part of both the coastal tracts is potable. Major issues related to water quality encountered in the coastal aquifers include salinity and presence of chemical constituents such as iron, nitrate etc. Documented cases of sea water ingress in coastal aquifers are restricted to Minjur near Chennai, Puducherry and Tuticorin in Tamil Nadu and Mandvi-Mundra and Okha-Madhavpur areas of Kachchh and Saurashtra coasts of Gujarat. Freshwater-saline water interface has been demarcated in the Saurashtra coast along Okha-Maliya (Gulf of Kachchh), which was 10-20 km inland parallel to the coastline in 2004, while along Okha- Madhavpur section, it was 10-12 km inland. In Madhavpur-Una section (Saurashtra coast), it was 2 to 10 km inland and in Una-Bhavnagar section (Gulf Khambhat), it was close to coast. In Minjur area near Chennai, the fresh water-saline water interface is currently about 16 km inland, due to over-exploitation ground water from alluvial deposits near the coast. Localized contamination of ground water due to industrial effluence has also been reported from the coastal areas of West Bengal, Tamil Nadu and Kerala.

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