



# Urban Hydrogeological Scenario of Kochi Urban Area, Central Kerala under Coastal Plain, South India

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## Abstract

The urban hydrogeological scenario of Kochi Urban area in Central Kerala, India has been carried out. The Kochi (Cochin) Corporation having an area of 97.88 km<sup>2</sup> bordering Arabian Sea is noticed for its scenic beauty and tourism potential. The surface water sources of the Kochi Corporation area is contaminated with salinity-brackishness and also polluted by various anthropogenic activities. The water requirements of over 6 lakh city population are catered through abstracting the Tertiary confined aquifers of Vaikom and Warkali Formations. Against the present need of 500 MLD the Kerala Water Authority is supplying 400MLD water to Kochi. For the sustainability of water resources of the Kochi Corporation various supply side management interventions and demand side management measures is proposed in the study.

**Keywords:** Tertiary Aquifer; Hydrogeology; Hydrochemistry; Supply Side Management; Demand Side Management

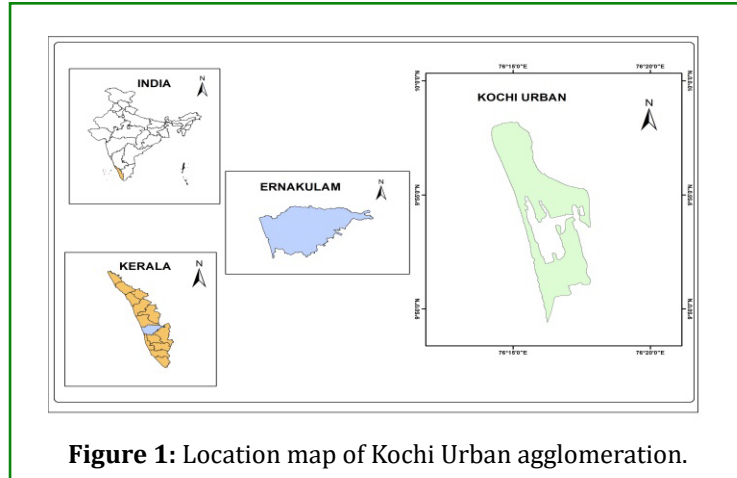
## Abbreviations

CGWB: Central Ground Water Board; DTW: Depth to the Water Table; PRM: Pre-Monsoon; PSM: Post Monsoon; VES: Vertical Electrical Sounding; KWA: Kerala Water Authority; MLD: Litre Per Day; WUE: Water Use Efficiency.

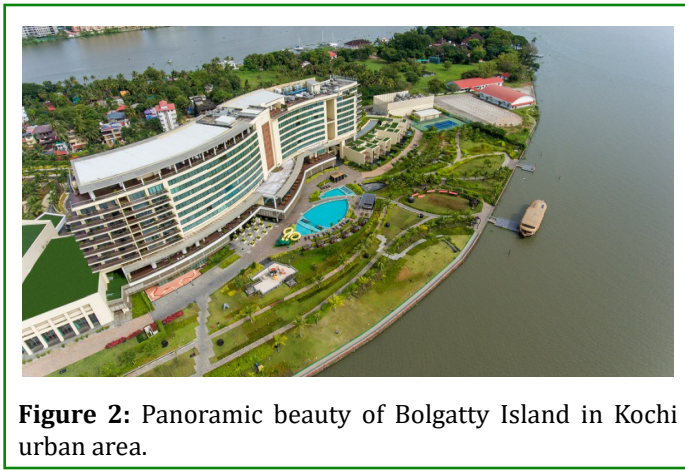
## Introduction

The Kochi (Cochin) Corporation occupies an area of 97.88 km<sup>2</sup> lies between 76°14' and 76°21' East long. and 9°52' and 10° 1' North Lat. (Figure 1) and is divided into 74 Corporation wards and having population of 602046 with density of population 6287/km<sup>2</sup>. The Kochi Corporation lies in the Ernakulam dist. of Central Kerala and includes areas of Kanayannur and Kochi Tehsils. The Kochi is also known as the 'Queen of the Arabian Sea' (Figure 2) and was attracted

by voyagers and traders in the past and at present the city is noted for its scenic beauty and tourism potential especially backwater tourism. The Kochi Corporation experienced a mean decadal population growth of 7.83% whereas the nearby urban agglomeration registered 18.65% growth, and that of adjacent panchayaths 12.13%. The literacy rate of the Kochi corporation is 95.5%. The population is mainly doing commercial activities and others in service sector. The urban area comprises mainly of soft rocks. Exploratory works in the sedimentaries was done during the Field Season Programme of the Central Ground Water Board (CGWB) during 1965-66, 1974-75, 1989-90, 1998-2001 and 2001-02. Various hydrogeological studies were made in Ernakulam dist. by S/ Sh. K.Md. Najeeb (1981-82, 87-88) and V. Dhinakaran (1995-96). Earlier reports of groundwater resources development potentials of Ernakulam give an account of all these studies by CGWB.



**Figure 1:** Location map of Kochi Urban agglomeration.



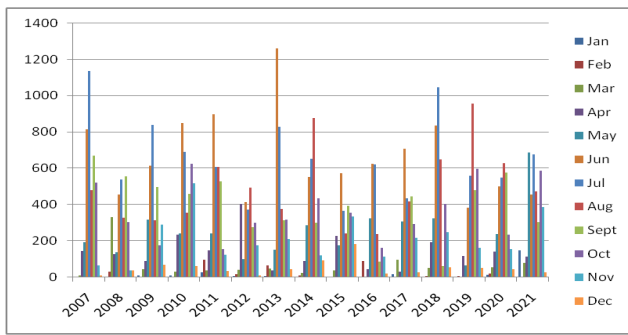
**Figure 2:** Panoramic beauty of Bolgatty Island in Kochi urban area.

### Climate and Water Resources

The urban agglomeration of Kochi is experiencing tropical monsoon with humid climate. The Kochi urban area is receiving heavy rainfall from SW monsoon (June- August)/Edavapathi accounting for 55% of the total rainfall and NE monsoon (September –November)/Thulavarsham 29%. The remaining rainfall is from summer showers (Mango shower). The annual rainfall varies in study area from lowest 2326.3 mm in 2016 and highest 4074 mm in 2010 during 2007 to 2021 (Table 1) and is shown as Figure 3 depicting 15 year average rain fall 3335 mm. Maximum rainfall occurs in June or July with June 2013 recorded max. monthly precipitation of 1258.7 mm whereas min. rainfall in Jan. or Feb.

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
2007	1.9	1.4	9.2	146.5	193.5	815	1133	480.1	667.3	522	66.1	9.8	4045.8
2008	3	30.8	329.6	129.1	137.7	455.1	539	326.2	555.1	304	37.4	36.9	2883.21
2009	10.4	0	45.8	89.5	315.7	615.1	839	312.2	497.4	177	290	70.1	3262.2
2010	9.8	0	30.5	233.8	239.9	849.9	691	356.5	456.9	625	517.5	63.2	4074
2011	26.3	98.2	37.3	147.1	241	897.5	605.4	605.5	527.8	156.5	123.8	34.3	3500.7
2012	7.1	18	43	401.8	100.9	414.1	370.9	494.7	274.6	299.4	176	9.7	2610.2
2013	6.3	65.3	48.8	37.8	151	1258.7	826.5	374.7	314.2	318.7	211	45.2	3658.2
2014	0	11.1	22.4	90.7	287.9	550.1	650.2	877	298.8	434.8	119	94	3436
2015	2.4	0.5	37.2	229.3	176.2	573.9	367.2	241.2	393.8	355	333	182	2891.7
2016	0.4	91.4	3.4	43.8	322.8	624.6	620.4	238.7	85.7	160.5	115	19.5	2326.2
2017	16.8	0	97.9	31.4	306	706.3	435.4	415.8	445.3	293	217.8	28.1	2993.8
2018	1.4	7.1	52.5	193.2	324.9	833.5	1044.2	648.4	63.1	402.7	246.9	56.6	3874.5
2019	0	7.2	4.6	117.6	64.8	382.1	558.8	956.6	478.5	597.1	162.4	51.1	3380.8
2020	15.6	21.3	53.7	140.7	237.2	501.5	549.9	628.6	576.3	233.9	155.8	43.6	3158.1
2021	149.2	0	79.5	115.4	684.7	455.7	674.3	472.1	301.8	585.2	386	28.1	3932

**Table 1:** Variation of Rainfall (mm) in the study area (2007 -2021).



**Figure 3:** Rainfall (mm) variation in the study area (2007-2021).

The ave. monthly max. temp. varies between 28.1 and 31.4°C and min. 23.2 to and 26°C. The higher temperature experiences in March, April and May and the lowest in Dec. and Jan.. The humidity varies from 68 to 89% during morning hrs. and 64 to 87% during evening. The max. humidity is experienced during May to Oct.. Evaporation is high during Jan. to April and it is low during May to Aug..

The Periyar is the longest river in Kerala and is originating from the cardamom hills of the Western Ghats and enters the Ernakulam at Neriamangalam, Kochi is situated along Periyar River. The river is finally debouching into the Arabian Sea.

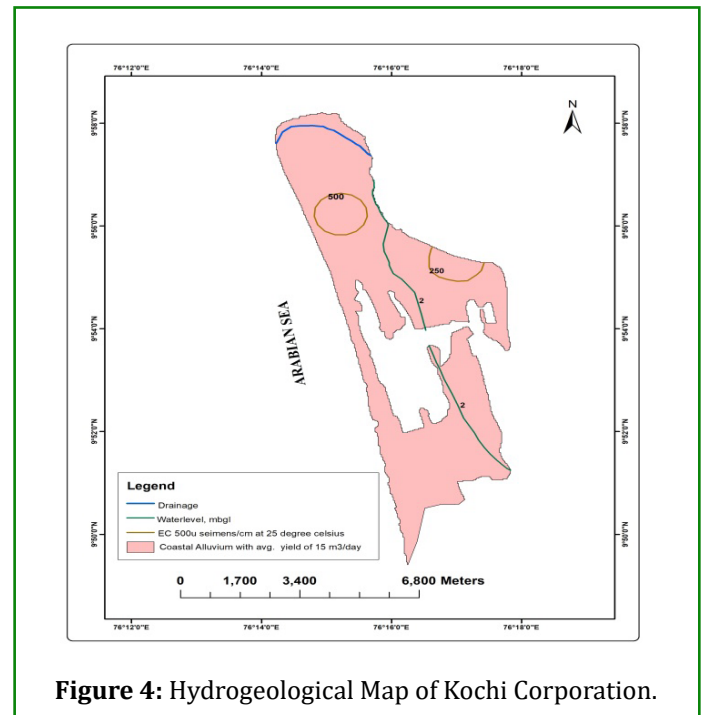
## Hydrogeological Set Up

### Geology and Geomorphology

The deep seated crystalline rocks of Archaean gneissic complex forms the basement in the study area. The basement is overlain by Tertiaries of Vaikom beds constituting gravel, sand, clay and lignite with stratigraphic range varies between Eocene and Oligocene and is overlain by Lower Miocene Warkali Formations of sand, clay and lignite. The Sub-Recent primary laterite derived from Tertiaries and Crystallines are exposed in road cuttings, well sections and river beds. The sand, silt and black clay deposited as alluvium is the Holocene or Anthropocene youngest formation of the study area.

The study area is separated into two physiographical zones viz. low lands and mid lands on the basis of altitude with respect to mean sea level. The altitude of the lowlands is <7.6 m. amsl and that of midlands ranges between 7.6 and 76 m. amsl. The Kochi Corporation area is mainly coming under coastal plains. The coastal plain is flecked with a number of islands like Vypin island, Mulavukad, Vallarpadam, and Willingdon Island. The longest Cherai Beach is occupying the western coast of Vypin and its northern end of Vypin has

the largest fishing harbour (Munambam). Vypin is noted for harbour affiliated industrial plant like Kochi Refineries and LNG Terminal. The Hydrogeological map of the depicted as Figure 4.



**Figure 4:** Hydrogeological Map of Kochi Corporation.

### Aquifer Type And Character With Water Level And Its Trend

In the study area of Kochi Corporation ground water is situated in water table condition in the Recent alluvium and semi-confined to confined in Tertiaries. The open dug wells tapping phreatic aquifer in the island and coastal plain of Kochi Corporation having the depth to the water table (DTW) < 2.0 m.bgl and in laterites about 4.0 m.bgl and the fluctuation remains in 0.5 and 2 m and most of the areas with fluctuation values less than 1.0 m.

The dug and filter point wells (shallow tube wells) are the common extraction structures in Kochi Corporation and the filter point wells are feasible where sand thickness is high (more than 10m) and depth of wells varies from 1.10 to 9.40 m.bgl. The bulk of open dug wells in Kochi Corporation with depth of < 3 m.bgl and in the laterites it is deeper. The diameters of dug wells are <1.5 m. The groundwater level in the phreatic aquifer in the area is mainly influenced by infiltration and percolation from precipitation. The long-term trend analysis (2009-2018) shows that in pre-monsoon (PRM) has observed maximum rise of 0.311 m/yr and maximum fall of (-)0.3962 m/yr and in post-monsoon (PSM) 0.2239 m/yr to (-) 0.1977 m/yr in the district of Ernakulam. A well hydrograph in the coastal alluvium at Mallipuram

is depicted in Figure 5 [1]. The water level in the ground water monitoring station of CGWB at Vytila within the Kochi Corporation is compiled (Table 2).

Location	Apr.19	Aug.19	Nov.19	Jan.20
Vytila	2.38	0.78	1.18	1.98

Table 2: Depth to the water level (mbgl) at Vytila.

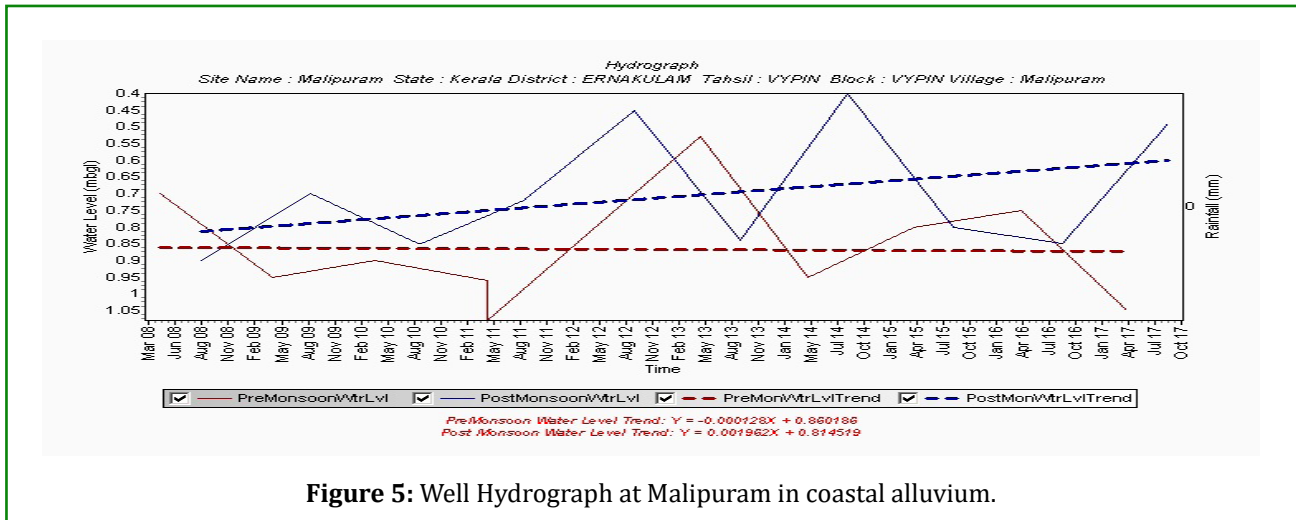


Figure 5: Well Hydrograph at Malipuram in coastal alluvium.

**Surface And Sub-Surface Geophysical Results**

Surface and subsurface geophysical investigations were performed in the coastal plain. There were 45 vertical electrical sounding (VES) conducted at 24 sites in the coastal plains of Ernakulam by CGWB to delineate fresh water

pockets in the area. On the basis of analysis of VES data, various ranges were brought about for various formations and on the basis of results proper sites were recommended for exploratory drilling and the details are compiled (Table 3).

Resistivity range (Ohm m)	Inferred lithology
0.1 – 0.7	Clay with minor sand saturated with saline water
9-Jan	Clay/sand saturated with fresh/brackish water
12-86 (occasionally more than 100 ohm m)	Sand with fresh water(Shyam [2])

Table 3: Resistivity range and Probable lithology of the area.

The sub-surface GP studies revealed that fresh water is found at deeper aquifers (Vaikom Formation) in southern part of Vypin and Willington islands. The interpretation of GP logs and VES data generalize that fresh water bearing Vaikom beds found between 95 and 105 mbgl. Pallurutty in Mattanchery Island revealed the occurrence of brackish water. The gamma log at Pallipest, northern part of Vypin Island and at Cochin Port Trust infers that the Vaikom sands are highly enriched with radioactive minerals and the basement is dipping towards south or south west at depth range of 100 and 300m [2].

**Aquifer related studies: Dug and Tube well zones**

The Vaikom and Warkali beds forms semi-confined to

confined aquifers of the coastal plain The piezometric head lies between 2-20 m.bmsl. The deeper Vaikom Formation with discharge of 1-57 lps. Whereas the Warkali occurring at shallow depth compared with the Vaikom, it is the most developed with piezometric head 3 m.amsl to 10 mbmsl with discharge of 3-14 lps. A few drilling carried out by CGWB within the Kochi Corporation reveals that static water level varies from 0.34 to 9.18 mbgl with discharge 0.5-3.7 lps. Depth of drilling, zones tapped, discharge and T values computed are compiled (Table 4). The lithological units encountered were clay and sand and even free flow well is also obtained during the drilling.

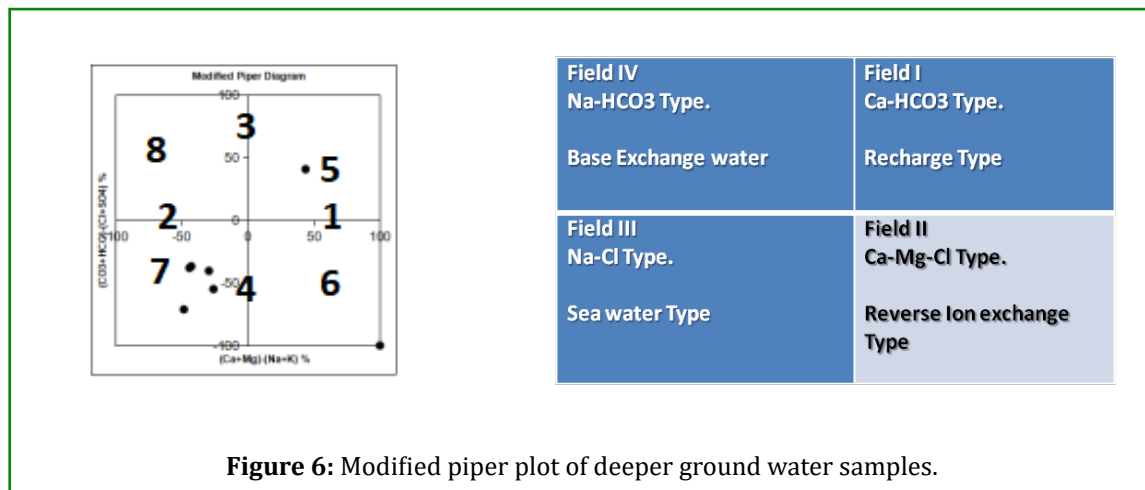
#	Location	Depth , m bgl	Zones tapped	SWL, mbgl	Discharge, lps	T m <sup>2</sup> /day
1	Wellington -1	116.5	97-103	5.18	1.2	
2	Wellington -2	54.66	42-45	0.34	2.5	
3	Wellington -3	133.5	96.0-102.0	1.7	3.14	
4	Vaittila	54.66	42-45	0.34	2.5	
5	Subash Park	200	81.0-84.0 90.0-93.0	4.25	3	
6	Thevara	127	85.0-97.0	5.5	3.7	28.07
7	Mundanveli	207	109.0-118.0	1.2	3.1	89
8	Fort Kochi-1	198	166.0-178.0	9.18	0.5	
9	Fort Kochi -2	202	174-180	Free flowing		

**Table 4:** Salient features of tube wells drilled by CGWB in Kochi Corporation.

### Assessment of Ground Water Quality and its Suitability

The hydrochemical parameters analysed using Modified Piper diagram [3]. It is found that majority of the samples are falling under Field 7 with Na-Cl hydrochemical facies and coming under sea water type (Figure 6) and the analytical

data is compiled (Table 5). The analysis of the data by using Gibb's plot [4] revealed that rock-water interaction responsible for ground water hydrochemical parameters and precipitation and evaporation played meagre role. The water of the Tertiaries is worthy for drinking and agricultural purposes.



**Figure 6:** Modified piper plot of deeper ground water samples.

#	Location	pH	EC	TH	Ca	Mg	Na	K	CO <sub>3</sub>	HCO <sub>3</sub>	Cl	SO <sub>4</sub>	NO <sub>3</sub>	F	SAR	%Na	PI
1	Wellington 1	7.37	1380	190	46	18	206	17	0	256	298	33	8.5	0.43	6.51	71	86
2	Wellington 2	8.18	1360	170	42	16	192	17	0	254	305	33	8.2	0.43	6.39	72	88
3	Subash Park	7.76	1370	205	48	21	167	11	0	281	355	41	1.4	0.82	5.05	65	83
4	Thevara	7.69	1638	240	44	32	178	18	0	207	369	61	12	0.39	4.98	63	76
5	Mundanveli	8.4	2980	200	40	24			0		888			0.72	0	0	
6	Fort Kochi 1	7.15	1810	235	60	21	300	19	0	159	512	50	0.4	0.52	8.48	74	82



7	Fort Kochi 2	7.98	423	146	51	4.4	24	3.7	0	176	27	22	7	0.22	0.86	28	69
Ave.		7.79	1566	198	47	19	178	14	0		393	40	6	0.5	4.61	53	69
Min.		7.15	423	146	40	4	24	4	0		27	22	0	0.22	0	0	0
Max.		8.4	2980	240	60	32	300	19	0		888	61	12	0.82	8.48	74	88
SD		0.44	76234	34	7	8	89	6	0		262	14	4	0.2	3.09	28.29	31.24

**Table 5:** Hydrochemical characteristics of Tertiary aquifer of Kochi Corporation area.

## Ground Water Resource Management

### Ground Water resource availability

The ground water resource of the area is determined by CGWB & SGWD based on GEC 2015 methodology as on 2020 March and is compiled (Table 6) . The parts of Kochi urban area coming under the blocks of Palluruthy and Vypeen

constituting coastal alluvium (sand, silt and clay) deposited by the coastal processes of waves and currents. The ground water extraction stage in Palluruthy and Vypeen blocks are 24.17 and 63.76 per cent respectively. The stage of ground water extraction in the urban area is < 70% and comes under safe category and other details are shown in Table 7.

S. No	Block	Annual Extractable GW Recharge, Ham	Current Annual GW Extraction (Ham) Irr. Use	Ind. Use	Dom. Use	Total extraction	Net GW availability for future use	Stage of GW Extraction (%)
1	Alangad	2062.11	421.74	46.87	954.01	1422.61	227.11	68.99
2	Angamaly	4658.57	739.77	46.11	999.16	1785.03	2441.63	38.32
3	Edappally	3831.76	168.38	10.89	2091.69	2270.97	656.61	59.27
4	Koovappady	5727.98	763.18	13.02	855.41	1631.6	3726.61	28.48
5	Kothamangalam	4161.89	645.08	2.42	1146.6	1794.1	1872.15	43.11
6	Moovattupuzha	3513.61	994.99	8.48	1186.13	2189.6	811.27	62.32
7	Mulamthuruthy	2859.67	687.04	10.24	1192.48	1889.76	454.43	66.08
8	Palluruthy	1483.79	150.18	9.29	199.18	358.64	1039.05	24.17
9	Pampakkuda	3565.12	751.08	5.15	666.35	1422.59	1854.49	39.9
10	Parakkadavu	2272.21	760.02	8.11	817.98	1586.12	332.5	69.81
11	Paravoor	1886.26	593.68	14.4	305.9	913.99	840.03	48.46
12	Vadavukodu	4187.66	497.52	3.84	829.16	1330.52	2498.72	31.77
13	Vazhakkulam	4744.19	945.06	6.62	1532.52	2484.2	1597.52	52.36
14	Vypeen	1004.77	49.96	0	590.7	640.67	108.75	63.76
Total (ha.m)		45959.59	8167.69	185.44	13367.28	21720.4	18460.87	47.26
Total (MCM)		459.6	81.68	1.85	133.67	217.2	184.61	47.26

**Table 6:** Dynamic Ground Water Resources of the Ernakulam district.

### Ground Water Quality Issues

The various types of quality issue have been reported in the case of phreatic aquifers. These include salinity ingress due to tidal effect and the impact of back waters bordering the urban areas of Kochi Corporation. The nitrate pollution

and localized iron have also been reported in the case of phreatic aquifers. Since the quality of water is generally poor in many parts of the island areas, wells are generally used for non-potable purposes especially in Willington Island due to high EC and high salinity. The well water nearer the salt water bodies and close to canal and drainage carrying saline

water turns brackish during summer. It is noticed that the deeper aquifers of the area are relatively free from all types of contamination. The occurrence of nitrate in ground water can be eliminated by reverse osmosis, distillation, or through ion exchange resin. salinity ingress due to tidal effect and the impact of back waters bordering the urban areas of Kochi Corporation can be reduced by restricting withdrawals from coastal aquifers and increased use of roof top rain water harvesting and its collection in storage tanks.

### Ground Water Recharge Action Taken and Future

In the urban area of Kochi Corporation the water table is < 2.0 m.bgl in the coastal alluvium and in laterites > 4.0 m.bgl. The ground water fluctuation between PRM and PSM varies between 0.5 and 2 m and most of the areas with fluctuation values less than 1.0 m. As the water table is situated at shallow depth (less than 6 m), no action has been taken till date to recharge the shallow aquifers. The piezometric head is also at shallow depth, recharging the tube wells of Tertiaries is also problematic. Hence no ground water recharge action has been taken by the Central and State organizations, NGOs or common man.

### Discussions

The surface water sources especially the drainages are either salty or brackish in nature. The influence of tidal effect and sewages from hotels and other commercial establishments made the surface water sources totally unfit for various types of domestic and non-domestic purposes. The phreatic aquifers of the area are polluted as the thickness of it is meager. The deeper Tertiary aquifers of Vaikom and Warkali are developed for the domestic and non-domestic purposes

The Kerala Water Authority (KWA) is mainly engaged in meeting the water requirements of the settled and floating population of the Kochi Corporation. The demand of the water to the Kochi Corporation is more than 500 Million Litre per Day (MLD). The KWA could be able to provide less than 400MLD water and the different parts of the area is now facing acute water shortage.

### Prospects of Future Development and Supply and Demand Side Management

The meeting the water requirements of the population is really a threat faced by the Kochi Corporation. For solving the grave situation in the water sector, some supply and demand side management measures have proposed in the study. The supply side management is intended to increase availability of water and various recommendation under this include Regular de-silting and renovation of the tanks and ponds, public tube wells can be used for public water supply schemes

and tube well recharge through rainwater harvesting. By demand side management, Kochi Corporation can decrease the use of water. The various demand side management interventions include adopting Water Use Efficiency (WUE) practices like implementation of drip irrigation or micro drip irrigation, roof top rainwater harvesting through storage tanks, Myawaki afforestation measures in open spaces in education institution, government office, vacant land of the public and private lands and organising various capacity building measures to the stakeholders on water and crop management. The conjunctive use practice of surface and sub-surface waters also recommended.

### Conclusion

The various urban hydrogeological problems and prospects of Kochi Urban area in Central Kerala have been examined. The city of Kochi ('Queen of the Arabian Sea') was attracted by voyagers and traders in the past and at now noted for its scenic beauty and tourism potential especially backwater tourism with the literacy rate of t 95.5%. The annual rainfall varies from lowest 2326.3 mm (2016) and highest 4074 mm (2010) during 2007 to 202. The deeper aquifers of the area belonging to the Tertiaries of Vaikom (gravel, sand, clay and lignite) and L.Miocene Warkali Formations (sand, clay and lignite) and the Holocene or Anthropocene coastal alluvium acting as phreatic aquifer (sand, silt and clay). The phreatic aquifers are extracted by the dug and the filter point wells are feasible where sand thickness more than 10m and depth of wells varies from 1.10 to 9.40 m.bgl. The water table in the coastal alluvium is < 2.0 m.bgl and that in laterites about 4.0 m.bgl. The long-term water trend analysis (2009-2018) reveals that in PRM with maximum rise of 0.311 m/yr and maximum fall of (-)0.3962 m./yr and in PSM 0.2239 m/yr to (-) 0.1977 m/yr in the district of Ernakulam. The GP studies revealed the occurrence of fresh water at deeper aquifers (Vaikom Formation) in southern part of Vypin and Willington islands and fresh water bearing Vaikom beds found between 95 and 105 mbgl. The piezometric head the Vikom and Warkali lies between 2 and 20 m.bmsl & 3 m.amsl to 10 mbmsl respectively and that of discharge 1-57 lps & 3-14 lps respectively. The study area comes under Safe category of ground water extraction and hydrochemical studies revealed that ground water in the area belonging to Na-Cl hydrochemical facies. The rock-water interaction was responsible for evolution of ground water. The ground water of Tertiaries is fit for potable and irrigation purposes. As Kerala Water Authority could be able to supply 400MLD water to Kochi against the present need of 500 MLD, some management interventions have been proposed. Regular de-silting and renovation of the tanks and ponds, public tube wells can be used for public water supply schemes and tube well recharge through rainwater harvesting (supply side

management interventions), adopting Water Use Efficiency (WUE) practices like use of drip irrigation or micro drip irrigation, roof top rainwater harvesting through storage tanks, Myawaki afforestation measures in open spaces in education institution, government office, vacant land of the public and private lands and organising various capacity building measures to the stakeholders on water and crop management (Demand side management). The conjunctive use practice of surface and sub-surface waters is also recommended in Kochi agglomeration.

### Way Forward

The supply side management interventions (Regular desilting and renovation of the tanks and ponds, public tube wells can be used for public water supply schemes, tube well recharge) and demand side management interventions (WUE practices like drip or micro drip irrigation, roof top rainwater harvesting through storage tanks, Myawaki afforestation measures, capacity building measures to the stakeholders on water and crop management and conjunctive use practice) are to be implemented in the Kochi Corporation in a scientific and systematic manner at an early date [5,6].

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