Impact of climate change on water availability: case study of a small coastal town in India

Rekha S. Nair, Dr Alka Bharat and Manu G. Nair

ABSTRACT

Climate change is presently causing a multitude of impacts in various sectors. Studies by the Intergovernmental Panel on Climate Change, the UN, and other agencies such as the Institute of Physical Geography, University College London show that there will be a significant impact on fresh water availability in the future due to climate change. The Cochin city region is an important port and commercial hub located on the south western coast of India. Average annual rainfall is 3,099 mm, yet there is an acute gap between the demand and supply of potable water. An assessment of the vulnerability of the city to various climate change parameters is important in formulating long-term strategies for sustainable development. This article examines the availability of water resources in the context of future requirements (2051), the expected impacts of climate change and its variability.

Research highlights:

- 99% of supply depends on monsoon fed rivers
- 100 years temperature shows an increasing trend with significant increase in later years
- 100 years rainfall shows increasing variability with significant increase in later years
- Sensitivity analysis and the environmental water requirement (EWR) approach indicate a 33% drop in reservoir water availability due to a 19% deficit in rainfall
- Based on climate change, vulnerability CVI for water availability computed
- 66% of population highly vulnerable.

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Key words | climate change, Coastal Socio Vulnerability Index, EWR, rainfall variability, temperature change, water availability

INTRODUCTION

Kerala, the southernmost state in India, experiences a severe shortage of drinking water availability and has one of the lowest per capita fresh water availability in India. The increasing population and the change in land use patterns led to a decrease in the availability of land for catchment, resulting in a shortage of water availability in the state.

Cochin city region is a part of Ernakulam district, located between northern latitude 9°47′ and 10°17′ and eastern longitude of 76°9′ and 76°47′. This town is the commercial port capital and is a hub of economic activity, thereby becoming the largest contributor to the Gross Domestic Product (GDP) in Kerala state (Economic Review 2010a, b). Cochin city region (study area; Figure 1) comprises of Cochin (Kochi) Corporation, two municipalities and 14 Panchayath, as mentioned in the Development Plan of Cochin city region 2031.

Physical characteristics

The topography of the study area is almost flat, except the eastern fringes. The eastern side has an average altitude of about 7.5 m above mean sea level (MSL) but towards the western most part of the city is only about 1.00 m above MSL. The area falls within the tropical climate, receives heavy rainfall of around 3,099 mm and lies in a perhumid climate (Thornthwaite 1948). According to hydrological records, the maximum recorded high tide level of +0.44 m (relative to

doi: 10.2166/wcc.2013.026

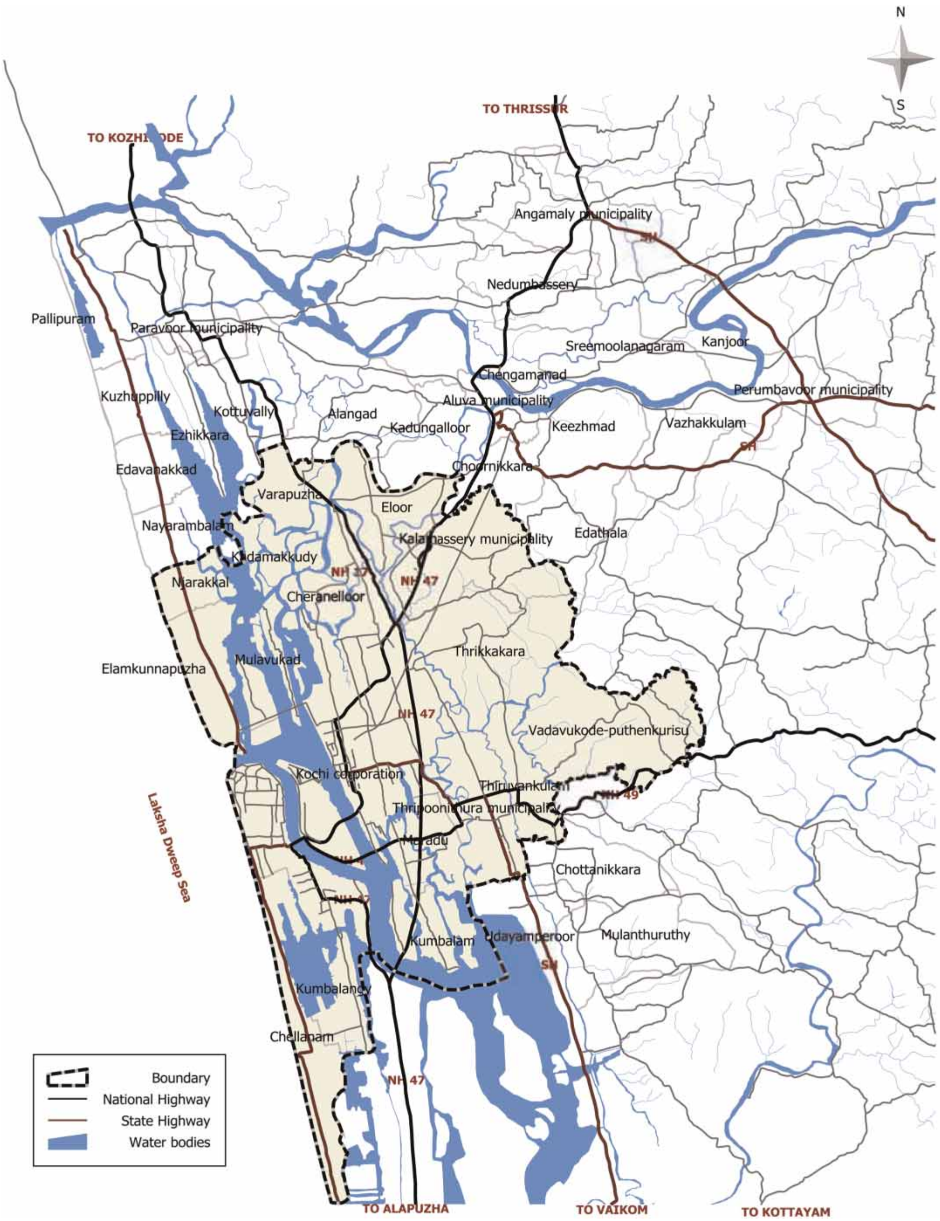

Figure 1 | Map showing the delineated study area.

MSL) was recorded in the rainy months of mid-May to mid-November (Nair 2010).

Demand and supply of fresh water in Cochin city region

Surface sources

The prime source of surface water is the Periyar river, approximately 20 km away from the city (Oak Ridge & CUSAT 2003). The river Periyar, the longest river of the state (PWD 1974), is considered to be the life line of Central Kerala with a total length of approximately 300 km (244 km in Kerala) and a catchment area of 5,396 km^2. The river is enriched with water of minor tributaries like Muthayar, Perunthuraiar, Chinnar, Cheruthony, Kattappanayar and Edamalayar at different junctures (Remani *et al.* 2005).

The increase in number of dams and manmade water reservoirs has resulted in a reduction of runoff from Periyar. Further, an increase in rainfall intensity and seasonal variability had led to increased sedimentation of riverbeds and reservoirs resulting in reduced holding capacity. Other factors like deforestation and change of land use with more impermeable surfaces also affected the runoff in the area. In Cochin, the increase of population has caused the per capita water availability to decrease to 1,365 m^3 from 3,780 m^3 in 100 years (Nair 2010).

There are two head works and treatment plants through which water is taken to Cochin from the Periyar river, one at Aluva with a capacity of 225 mld and the other at Chowwara (Table 1). The Chowwara scheme is diverted basically for serving rural areas. The supply of water for the study area, except Puthenkruz, comes from the Aluva water supply scheme (Development Plan Cochin – 2031, Vol. 1, 2010).

Underground sources

In some places where surface water is not available, the drinking water requirement is met through ground water sources such as dug wells, bore wells and tube wells. Many areas in the less affluent section of the city are dependent on wells for domestic water consumption. The dug wells range in depth from 2.14 to 13 m in general and have an average yield ranging from 15 to 20 m^3/day. Many dug wells are already contaminated by sea water intrusion and are not suitable for potable use (Shyam Anitha 2007). Study of simulation of sea water intrusion in Cochin Coast shows that the sensitive zone (salinity more than 500 mg/L) in this area is between 400 to 2,000 m from the high tide line (Bhosale Dipanjali & Kumar 2004).

Table 1 | Water supply schemes for Cochin

No	Source	Capacity	Year	Remarks
1	Periyar river	48 mld	1965	Implemented
2	Periyar river	72 mld	1969	Implemented
3	Periyar river	70 mld	1993	Implemented
4	Periyar river	35 mld	1995	Under implementation

Source: KSUDP (2005).

Challenges in the existing system

Population increase

The increase in population at the decadal rate of 14.5% per annum is causing pressure on the existing infrastructure of the region. In the past 30 years, the average decadal growth in Cochin Municipal Corporation was 7.83%, the nearby municipal areas registered decadal average of 18.65%, and the adjoining Panchayath had an average decadal growth of 12.13%.

Gap between demand and supply

Due to the lack of sufficient quantity, supply is limited from half an hour a day to 4 hours in different localities, while some areas receive water supply only twice a week.

Defects in pipes and salinity issues

Spot sources, such as open dug well, shallow tube well and ponds, are not feasible in the city centre and coastal areas, due to salinity. The existing pipes are old leading to the distribution not functioning satisfactorily. The iron pipes used for water supply mains corrode easily due to the high salinity in the soil. This, combined with high pressure, lead to frequent bursting of the mains.

Less coverage area

The existing as well as the proposed water supply scheme does not cover the entire area.

Huge unaccounted water

There is huge loss of water due to leaky pipe lines. The current estimated loss of water system due to leakage alone is 30% (Oak Ridge & CUSAT 2003; KSUDP 2005).

DEMAND FOR WATER

Current water demand

The current per capita demand and population for each region has been taken from the Development Plan of Cochin region. Estimates have shown that there is a deficit of 198 mld of water currently (see Table 2). Rural areas of Cochin city region are dependent on ground water to the extent of 80–90%.

Future water demand

The future demand (F_d) for water can be taken as

$$F_d = f(C_d, N_d)$$

where $C_d =$ industrial, commercial demand and $N_d =$ personal (non industrial) demand.

Here $N_d = f(E_p, P_d)$

where E_p is the estimated population of the city; P_d is the projected demand per day.

Here $E_p = f(R_p, F_p, M_p)$

where E_p is the estimated population of the city; R_p is the estimated residing population of the city; F_p is the estimated floating population of the city; and M_p is the estimated migrating population of the city.

The best fit curve method has been used to arrive at the estimated residing projection (R_p) for the population in 2051 (Table 3). In addition to the natural growth, there would be migrating and floating population which needs to be addressed. The percentage of migrating and floating population has been taken from the city Development Plan of Cochin.

The current supply of 225 mld to the city is through Periyar river. By 2031, an additional 285 mld from Periyar and also

Table 2 | Demand of water in Cochin city region as per 2001 census

Locality	Total population, inc migration and floating	Per capita water demand	Demand for personal use mld	Factor for industry and commercial use	Total demand mld	Current supply and deficit
Cochin M. Corp.	786,159	200	138	1.4	193	Periyar old: 225, Transport wastage: (68), Ground water: 2, Deficit = −198
Thripunithura	79,047	140	10	1.6	15	
Kalamasserry	98,461	240	19	1.6	30	
Maradu	58,647	140	7	1.6	11	
Thiruvankulam	28,666	70	2	1.6	3	
Thrikkakara	102,935	240	20	1.6	31	
Cheraneloor	31,579	150	4	1.6	7	
Eloor	46,245	120	5	1.6	8	
Varapuzha	31,881	120	3	1.6	5	
Kadamakudy	18,989	100	2	1.6	3	
Mulavukad	27,410	100	3	1.6	4	
Elamkunnapuzha	78,878	120	8	1.6	12	
Njarakkal	37,699	120	4	1.6	6	
Kumbalam	39,395	140	5	1.6	7	
Kumbalangy	31,993	140	4	1.6	6	
Chellanam	43,451	150	6	1.6	9	
Vadavucode-Puthencruz	41,668	120	4	1.6	6	
Total	**1,583,104**		**244**		**357**	

Table 3 | Population projection for 2051

Locality	Population ex migration and floating 2001	Projected population ex migration and floating (R_p) 2051	Projection method	*R*-Square (%)	% of migrating pop (M_p)	% of floating pop (F_p)	Total projected population (E_p) 2051
Cochin M. Corp.	595,575	1,011,578	Exponential	89	10	20	1,335,283
Thripunithura	59,884	135,463	Exponential	93	10	20	178,811
Kalamasserry	63,116	232,388	Exponential	95	30	20	362,526
Maradu	41,012	111,085	Exponential	93	30	10	158,852
Thiruvankulam	21,717	49,335	Exponential	89	10	2	65,122
Thrikkakara	65,984	300,504	Exponential	99	30	20	468,786
Cheraneloor	26,316	39,483	Exponential	100	0	20	47,380
Eloor	35,573	41,377	Logarithmic	99	0	30	53,791
Varapuzha	24,524	38,845	Exponential	94	30	0	50,499
Kadamakudy	15,824	23,725	Exponential	94	0	20	28,470
Mulavukad	22,842	25,459	Power	99	0	20	30,550
Elamkunnapuzha	50,563	63,069	Power	97	30	20	98,387
Njarakkal	24,166	32,500	Exponential	95	30	20	50,701
Kumbalam	27,549	53,744	Exponential	97	30	10	76,854
Kumbalangy	26,661	41,696	Exponential	95	0	20	50,035
Chellanam	36,209	60,960	Exponential	95	0	20	73,152
Vadavucode-	26,710	31,641	Logarithmic	98	30	20	49,361
Total	**1,164,225**	**2,292,853**					**3,178,559**

100 mld from Muvattupuzha river are expected. Transmission and distribution loss has been assumed to be 20% for the above calculation. By 2051, it is estimated that the demand will increase to 766 mld leading to a deficit of 276 mld of water, if only the proposed schemes are implemented (Table 4). Any disruption in supply of water due to climate change would exacerbate this water supply and demand mismatch.

CLIMATE CHANGE

'Climate change is a significant change in the statistical distribution of weather pattern over a period of 30 years' (IPCC 2001, 2007a, b). The study focuses on the impact of climatic change parameters such as change in temperature, variability in rainfall and a rise in sea level on future water availability.

Increase in surface temperature

Data from IITM for the west coast of India were used for the analysis to find the surface temperature variability.

An increasing trend in maximum temperature is observed until 1940 with a steady increase from 1940 to 2000 and a sharp increase from 2000 (Figure 2). This has been confirmed by various studies, particularly by Kothawale *et al.* (2010).

Increase in sea level temperature

Reynolds sea surface temperature (SST) over the Arabian Sea and Bay of Bengal, available at the National Climatic Data centre, has been studied by Dash & Hunt (2007). The time series of SST indicates that over the last 100 years the SST has increased by 0.8 °C. The above rise in SST is 50% greater than that in the global ocean temperature.

Variability of rainfall

On analysing peninsular India rainfall, there has been a steady increase in the number of years having continuous rainfall deficit or excess. An analysis of the rainfall patterns over the past 100 years shows that the highest deficit of

Table 4 | Water demand for 2051

Locality	Total population inc migration and floating	Per capita water demand (litres)	Demand for personal use mld	Factor for industry and commercial use	Total demand mld	Future supply and deficit in mld
Cochin M. Corp.	1,335,283	200	235	1.4	329	Periyar old: 225
Thripunithura	178,811	140	22	1.6	35	Periyar new: 285
Kalamasserry	362,526	240	71	1.6	113	Muvatupura: 100
Maradu	158,852	140	19	1.6	30	Transport wastage: (122)
Thiruvankulam	65,122	70	4	1.6	6	
Thrikkakara	468,786	240	92	1.6	146	Ground water: 2
Cheraneloor	47,380	150	7	1.6	10	
Eloor	53,791	120	6	1.6	9	**Deficit** = **−276**
Varapuzha	50,499	120	5	1.6	8	
Kadamakudy	28,470	100	3	1.6	4	
Mulavukad	30,550	100	3	1.6	4	
Elamkunnapuzha	98,387	120	10	1.6	15	
Njarakkal	50,701	120	5	1.6	8	
Kumbalam	76,854	140	9	1.6	14	
Kumbalangy	50,035	140	6	1.6	10	
Chellanam	73,152	150	10	1.6	16	
Vadavucode-	49,361	120	5	1.6	8	
Total	**3,178,559**		**511**		**766**	

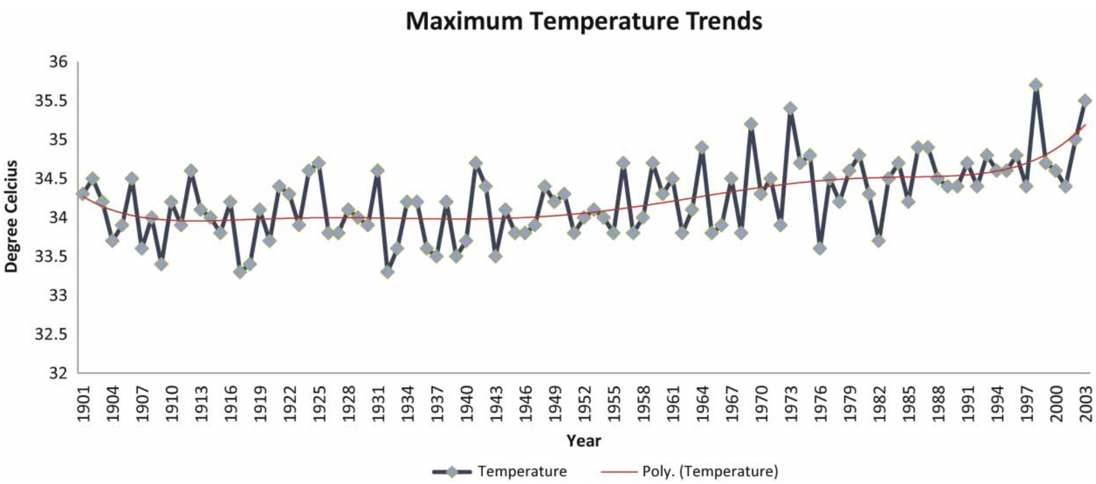

Figure 2 | Maximum surface temperature trends. *Source*: Homogeneous Indian Monthly Surface Temperature Data Sets, Indian Institute of Tropical Meteorology (2009).

−19% (in 2002), as well as the highest excess rainfall of 25% (in 2010), occurred in the last decade (see Table 5). The increase in temperature (IPCC 2007c) and other global factors, such as El Nino, etc., could be the reason for such increases in rainfall variablity.

Sea level rise

The study by Unnikrishnan *et al.* (2006, 2007) shows a sea level rise at the rate of 70 mm by 2051 (Table 6). However, the predictions for the future from the Global Climatic

Table 5 | Rainfall variability for the peninsular of India

Deficit rainfall	1904–1908	1926–1929	1950–1953	1971–1974	1984–1989	1999–2003	2002	
Average rainfall	978	978	978	978	978	978	978	
No of continuous years	5	3	3	5	6	5	1	
Average monthly deficit (mm)	(117)	(90)	(123)	(44)	(77)	(102)	(186)	
Deficit (%)	−12	−9	−13	−4	−8	−10	−19	
Excess rainfall	**1913–1915**	**1929–1933**	**1958–1962**	**1977–1979**	**1990–1994**	**1996–1998**	**2005–2008**	**2010**
No of continuous years	3	5	5	3	5	3	4	1
Average monthly excess (mm)	91	82	81	102	43	127	125	247
Excess % over mean	9	8	8	10	4	13	13	25

Source: Indian Institute of Tropical Meteorology (2009).

Table 6 | Sea level rise predictions

Station	No of years of data	Trends (mm/year)	GIA (glacial isostatic adjustment) corrections	Net sea level rise (mm/year)
Cochin	54	1.31	−0.44	1.75

Source: Unnikrishnan *et al.* (2006, 2007).

Models suggest that the averaged sea level will rise significantly by 2051, perhaps by 0.5 m.

IMPACT OF CLIMATE CHANGE ON WATER AVAILABILITY

Impact of increased temperature on water availability

Warming accelerates the rate of surface drying, leaving less water moving in near-surface layers of soil (Table 7). Less soil moisture leads to reduced downward movement of water and so less replenishment of ground water supplies (Dash & Hunt 2007). Increased runoff at the expense of rainfall infiltration is a major cause of declining ground water, as less water is then available to percolate through the soil down to the ground water, i.e. less recharge occurs (Nearing *et al.* 2005). These will cause a decrease in the yield of water from the dug wells in Cochin.

Impact of variability in rainfall on water availability

Relationship between water availability and rainfall

All the rivers in Kerala are monsoon dependent. Analysis was carried out to find the interdependency between water availability and rainfall. Table 8 shows a 100% relationship between the rainfall and water availability in India.

Table 7 | Impact of increasing temperature on water supply

Climate parameter	Predicted change	Intervening parameter	Impact on potable water availability	Impact probability
Temperature	Increase by 1–2 °C within 50 years	High evaporation rate	Reduced water availability due to high evapotranspiration rate	•
		Reduced percolation into the soil	Surface and ground water loss	•

• Least; •• Less; ••• Moderate; •••• High; ••••• Very high.

Table 8 | Relation between water availability and rainfall

Per capita water availability in litres/day in Kerala			
Year	**Rain**	**Surface water**	**Ground water**
1901	49,609	6,556	3,095
1911	44,718	5,909	2,790
1921	40,705	5,379	2,539
1931	33,421	4,416	2,085
1941	28,863	3,814	1,801
1951	23,518	3,108	1,467
1961	18,786	2,482	1,172
1971	14,906	1,969	930
1981	12,500	1,672	780
1991	10,762	1,422	672
2001	94,50	1,022	590
Co-relation		100%	100%

Here, it is important to note that only 2% of the total potable water demand in the Cochin region is met by ground water.

Impact of variability on water availability using sensitivity analysis and environmental water requirement method

The Periyar river average annual runoff is 12,300 Mn M^3. The basin has nine irrigation schemes and 16 hydroelectric projects. The total capacity of all the reservoirs is 3,280 Mn M^3 (CESS 1984).

The 'environmental water requirement' (EWR), a synonym to environmental flows, is an ecologically acceptable flow regime designed to maintain a river in an agreed or predetermined state. A threshold of 10% of the mean annual runoff (MAR) reserved for an aquatic ecosystem was considered to be the lowest limit (category C onwards – corresponding to severe degradation of a system) for EWR recommendations. Fair/good habitat conditions could be ensured if ~35% of the MAR is allocated for environmental purposes (category B). Allocations in the range of 60–100% of the MAR represent an environmental optimum (category A). It has been established that for the Periyar region to be in 'A' category the EWR is 62.9% of the MAR, based on the Tenant method (Smakhtin & Anputhas 2006; Smakhtin et al. 2007).

From Table 8, it has been established that there is a 100% relationship between the surface water and rainfall. Further, Table 5 shows that that the rainfall variation is between −19 and +25%. The MAR in the catchment area is 12,300 M^3 and applying the EWR of 62.9% would lead to a 33% deficit in reservoirs in extreme rainfall deficit (−19.2%) conditions, as illustrated in Table 9.

Hence, we can see that variability in rainfall (there are long continuous period of deficit and excess rainfall) could significantly reduce the water in the reservoirs and would exacerbate the drinking water deficit in the region (Table 10).

Impacts of sea level rise

Seventy percent of the study region is just above sea level (0.5–1.5 m above the MSL). An increase in sea level by 0.5 m will cause inundation of many areas, along with percolation of salt water in many ground water aquifers (Table 11). The area of influence of salt water infiltration may be much more depending on the hydrology of the soil. A detailed analysis based on the hydrological characteristics of the soil has not carried out in this study.

Table 9 | Impact of rainfall variability on water availability based on the EWR approach

Rainfall variability (%)	**Total water in periyar catchment (Mn M^3)**	**EWR in lower areas (Mn M^3)**	**Reservoir capacity (Mn M^3)**	**Water deficit in reservoir (Mn M^3)**	**% deficit in reservoir**
−19.2	9,944	7,749	3,280	(1,085)	−33
−12.6	10,747	7,749	3,280	(282)	−9
−10.4	11,016	7,749	3,280	(13)	−0.4
−7.9	11,324	7,749	3,280	–	0
−4.5	11,745	7,749	3,280	–	0
0	12,300	7,749	3,280	–	0
4.4	12,840	7,749	3,280	–	0
8.3	13,324	7,749	3,280	–	0
10.5	13,593	7,749	3,280	–	0
13.1	13,906	7,749	3,280	–	0
25.4	15,426	7,749	3,280	–	0

Table 10 | Impact of rainfall on water availability

Climate parameter	Predicted change	Intervening parameter	Impact on potable water availability	Impact probability
Rainfall	Reduced rainfall by 8 mm/year	Increased evaporation	Reduction in supply of surface water	•••
	Increase in intensity of rainfall in 24 hours	High runoff rate	Reduction in the amount of percolated water and thus decreased recharging of ground water	•••
	Increase rainfall variability	Increased evaporation	Difficulty in planning water supply schemes	•••

• Least; •• Less; ••• Moderate; •••• High; ••••• Very high.

Table 11 | Impact of sea level rise on water availability

Climate parameter	Predicted change	Intervening parameter	Impact on potable water availability	Impact probability
Sea level change	Increase in sea level of the rate of 1.5 mm/s	Salt water infiltration of ground water	Reduced supply of pure water from wells	•••••
		Increased salinity of soil	Corrosion of water carrying pipes due to increase in salinity of soil	••••
		Inundation	Water supply pipes may come under the sea level	••

• Least; •• Less; ••• Moderate; •••• High; ••••• Very high.

RELATIVE VULNERABILITY OF THE STUDY REGION TO CLIMATE VARIABILITY

An attempt has been made to assess the relative vulnerability of the various localities in the study region. The relative vulnerability is addressed in the form of a CVI (Coastal Vulnerability index). The steps followed in the process are:

1. Selection of variables
2. Assigning values (indexing)
3. Weighing of indices
4. Relative vulnerability score.

Selection of variables

The major factors which determine the vulnerability of water availability due to climate change factors were found to be population of the area, the location, the condition of ground water and the piped municipal water supply (Table 12).

Population

The population predicted in 2051 in the ward is taken as the index number for assessing vulnerability of water supply due to climate change.

Location

The areas near the sea will be facing more problems due to climate change because of salt water infiltration, inundation, etc.

Ground water

The present quality of ground water is taken as critical, semi-critical and safe (as mentioned in the ground water booklet of Ernakulam district) for vulnerability assessment.

Table 12 | Analysis for computing impact of variables in various localities

Name of local body	Location	Existing condition of ground water	Water supply, existing and proposed (proposals in italics)
Cochin Corporation	Low lying almost all areas below 1.5 m from MSL	Critical	Piped water mainly with present supply of 70 Lpcd. Few wells. Water supply inadequate. Location far away. Demand is much more than supply. *New project in process*
Kalamassery Municipality	Mid land area	Safe	Present supply of 140 Lpcd. Improving and using the existing schemes, but many wells are present with good quality water
Thripunithura Municipality	Low lying , not coastal	Semi-critical	Present supply of 40 Lpcd *KWA's Chowra and Chundi schemes, when implemented, would solve the water problem faced by Thripunithura and neighbouring areas*
Elankunnapuzha Panchayath	Coastal	Safe	Present supply of 40 Lpcd
Njarakkal Panchayath	Coastal	Safe	Present supply of 40 Lpcd
Mulavukadu Panchayath		Safe	Present supply of 35 Lpcd
Kadamakkudy Panchayath	Low lying, not coastal	Safe	Present supply of 30 Lpcd. *Special water supply scheme from Periyar river*
Cheranallur Panchayath	Low lying, not coastal	Safe	Present supply of 50 Lpcd. *Special water supply scheme from Periyar river under process*
EloorPanchayth	Industrial, medium elevation	Semi-critical	Present supply of 40 Lpcd. *Special water supply scheme from Periyar river*
Varapuzha Panchayath	Low lying, not coastal	Semi-critical	Present supply of 40 Lpcd
Thrikkakara Panchayath	Medium elevation; not coastal	Safe	Present supply of 120 Lpcd
Thiruvankulam Panchayath	Medium elevation, not coastal	Semi-critical	Present supply of 25 Lpcd. Many wells
MaraduPanchayath	Low lying	Critical	Present supply of 40 Lpcd
KumbalamPanchayath	Medium elevation	Critical	Present supply of 40 Lpcd
KumbalangiPanchayath	Low lying	Safe	Present supply of 15 Lpcd
ChellanamPanchayath	Low lying coastal	Safe	Present supply of 15 Lpcd
Vadavucode-Puthenkurisu	High elevation	Safe	Present supply of 75 Lpcd. Many wells. Puthenkurisu depends on Muvattupuzha river

Sources: City Development Plan 2005–2012 (2005); KSUDP (2005); Shyam Anita (2007); Development Plan for Kochi City Region 2031 (2010).

Water supply

The dependency on the water supply on rainfall will depend mainly on the existing, and proposed, schemes and availability of water in Periyar river.

Assigning values (indexing)

Population (P_p)

The percentage of the population to the total population present in the area is taken for index for population component 1. High (>25% population), 2. Medium (5–25% population), 3. Low (<5% population). Determines the user group.

Location (P_l)

The location will determine the impact of sea level rise. Based on maps using geographic information system co-ordinates, the values given are: 1. High (low lying, almost all areas below 1.5 m from MSL), 2. Medium (low lying, not coastal), 3. Low (mid land area, high elevation).

Table 13 | Indexing of variables

Name of local body	% Population in 2051	Vulnerability due to location	Dependability on ground water	Vulnerability due to dependency on rainfall
Cochin Corporation	High	High	Low	High
Kalamassery Municipality	Medium	Low	High	Low
Thripunithura Municipality	Medium	Medium	Medium	Medium
Elankunnapuzha Panchayath	Medium	High	High	Low
Njarakkal Panchayath	Low	High	High	Low
Mulavukadu Panchayath	Medium	Low	High	Low
Kadamakkudy Panchayath	Low	Medium	High	Low
Cheranallur Panchayath	Low	Medium	High	Low
EloorPanchayth	Low	Low	Medium	Medium
Varapuzha Panchayath	Low	Medium	Medium	Medium
Thrikkakara Panchayath	Low	Low	High	Low
Thiruvankulam Panchayath	Low	Low	Medium	Medium
MaraduPanchayath	Low	Medium	Low	High
KumbalamPanchayath	Low	Low	Low	High
KumbalangiPanchayath	Low	Medium	High	Low
ChellanamPanchayath	Medium	High	High	Low
Vadavucode- Puthenkurisu	Low	Low	High	Low

Low 1, Medium 2, High 3.

Ground water (P_g)

Dependability on ground is indexed as: 1. High, 2. Medium and 3. Low, based on the existing ground water availability scenario.

Dependability on rainfall (P_r)

Dependability on rainfall is taken on the basis of existing and proposed water supply and is indexed as: 3. High, 2. Medium and 1. Low, based on the existing and proposed water supply schemes (Table 13).

Weighing of indices and relative vulnerability score

The different indices do not contribute equally to the vulnerability of the area. The major factor will be the dependency of rainfall. Hence, 45% weightage is given for rainfall component, 25% for locational aspects, 25% for population and 5% for ground water dependency (ground water

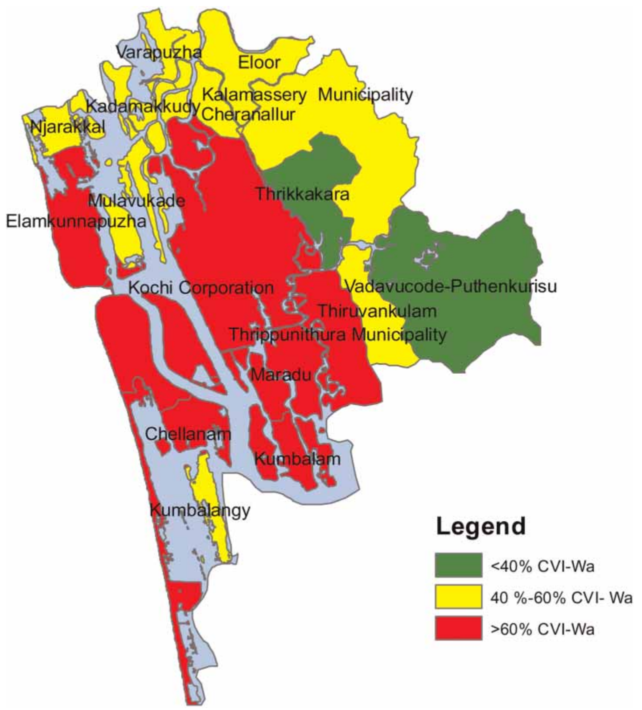

Figure 3 | Relative vulnerability of water availability in Cochin area due to climate change.

Table 14 | Computing CVI for various localities

Name of local body	Vulnerability due to population (P_p)	Vulnerability due to location (P_l)	Dependability on ground water (P_g)	Vulnerability due to dependency on rainfall (P_r)	Coastal vulnerability index for water availability (CVI –Wa)	Vulnerability (high if CVI > 60%, 60–40% medium, <40% low)
Relative weightage (R_w)	25%	25%	5%	45%		
Cochin Corporation	3	3	1	3	97	High
Kalamassery Municipality	2	1	3	1	45	Medium
Thripunithura Municipality	2	2	2	2	67	High
Elankunnapuzha Panchayath	2	3	3	1	62	High
Njarakkal Panchayath	1	3	3	1	53	Medium
Mulavukadu Panchayath	2	1	3	1	45	Medium
Kadamakkudy Panchayath	1	2	3	1	45	Medium
Cheranallur Panchayath	1	2	3	1	45	Medium
EloorPanchayth	1	1	2	2	50	Medium
Varapuzha Panchayath	1	2	2	2	58	Medium
Thrikkakara Panchayath	1	1	3	1	37	Low
Thiruvankulam Panchayath	1	1	2	2	50	Medium
MaraduPanchayath	1	2	1	3	72	High
KumbalamPanchayath	1	1	1	3	63	High
KumbalangiPanchayath	1	2	3	1	45	Medium
ChellanamPanchayath	2	3	3	1	62	High
Vadavucode- Puthenkurisu	1	1	3	1	37	Low

dependency of future will be closely related to locational aspects). Based on the weighted average score CVI: (W_{wa}) (for water availability) has been computed.

$$W_{wa} = \sum_{n=1}^{m} (R_w * P_v) \Big/ \sum_{n=1}^{m} [R_w * \mathrm{Max}(P_v)]$$

where R_w = relative weightage; P_v = vulnerability factors; m = number of factors considered. Hence (W_{wa}) = (45%*P_r + 25%*P_p + 25%*P_l + 5%P_g)/(45%*Max (P_r) + 25%* Max (P_p) + 25%*Max (P_l) + 5%Max (P_g)) (Figure 3, Table 14).

CONCLUSION

- The population of Cochin area has been estimated for 2051 using the best fit curve method to be around 3,178,559, resulting in 766 mld of water demand. The current supply schemes and projects under implementation would be able to supply only 490 mld of water leading to a 276 mld deficit of water if no further supply schemes are planned. Moreover, out of 489 mld of water supply, 487 is dependent on monsoon (rainfall) fed rivers. This shows the dependency on rainfall for sustenance of population.
- The analysis of the past 100 years temperature has shown an increasing trend with a significant increase after the year 2000. Further, on analysing the past 100 years rainfall data, it has been deduced that there has been an increase in variability in rainfall with the highest deficit of 19% and highest excess of 25% (with respect to the average in the past 100 years) occurring in the last decade. A sensitivity analysis carried out based on the EWR approach has indicated a 33% reduction in reservoir water availability if there is a 19% deficit in rainfall, leading to exacerbation of a water deficit situation in Cochin. Moreover, 70% of the study region is just above the sea level (0.5–1.5 m above the MSL),

hence an increase in sea level will cause inundation of many areas, along with percolation of salt water in many ground water aquifers.

- Further, the areas in the study region have been categorised into high, medium and low based on the CVI computed for water availability derived from population, locational aspects, ground water dependency, dependency on rainfall (based on current water supply and existing plans to meet future water demand). The CVI for water availability indicates that 66% of the population are in the highly vulnerable category, 31% in medium and the remaining 3% are in the low category. Hence, focus areas have been determined where immediate climate change impact mitigation plans have to be formulated.
- The study points out that it will be prudent for the municipal corporation to begin planning for the climate variability through adaptation measures that can build resilience against its negative impacts on potable water availability. Investment in cost-effective and adaptive water management practices, such as rainwater harvesting, ground water recharge, waste water recycling and technological development for planned reductions in water use will be beneficial for the future water security of the area.

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First received 31 May 2012; accepted in revised form 5 January 2013. Available online 25 March 2013