Original Research Article

Water Quality Response to Economic Development: Quantifying Environmental Kuznets Curve

ABSTRACT:

The study intendsto investigate the relationship betweenthe growth of the economy and surface water pollutants in Tamil Nadu using the concept of the Environmental Kuznets Curve (EKC). The study used cross-sectional time series (panel data) data for water pollutants such as Dissolved oxygen and conductivity, BOD, Total Coliforms and Fecal Coliforms across 16 districts in Tamil Nadu for the period 2003–2019. The findings of the study revealed that there was no indication of an EKC for Dissolved Oxygen and BOD; instead, Dissolved oxygen has a monotonically declining relationship while BOD has amonotonically increasing relationship, and the first turning point is yet to be achieved for both the water quality indices. The relationship between income and conductivity found a U-shaped relationship with the turning point on Rs.131.98 billion. The existence of an Inverted U-shaped *EKC*relationship *for Fecal coliforms and Total Coliforms with the turning point on Rs. 482.22 and Rs. 477.65 billion, respectively.*

Keywords: Economic growth, EKC, Panel data, Water pollution, Tamil Nadu.

INTRODUCTION

Withthe growing human population, urbanization, industrialization and raising freshwaterdemand around the world, one of the most challengingissues is supplying adequate water to meet societal needs. Water quality is influenced by human activity at all spatial scales. Pollution from both point and non-point sources is blamed for the decline in water quality. Discharge of industrial wastewater, untreated municipal sewage, solid waste dumping, agricultural runoff as well as human and animal fecal are the majorcauses of water contamination. Water contamination levels canbe used as indicators of deteriorating water quality.

Grossman and Krueger (1990) demonstrated an inverted U-shaped Environmental Kuznets Curve (EKC) to represent the relationship between economic growth and environmental degradation. Using cross-district panel data sets, this study examines the association between water quality degradation and income at a state level.Several literatures have found the EKCrelationship between several water quality indices and income. Inverted U-shaped function has been described for Nitrogen and Dissolved Oxygen (Pandit and Paudel, 2016) and BOD (Lee *et al*., 2009). N-shaped function has been reported for Fecal

Coliform and Dissolved Oxygen (Sekar *et al.*,2009), Phosphorus andMercury (Pandit and Paudel, 2016). Other forms reported in EKC studies include U-shaped function for Nitrogen, Phosphorus and Sediments (Sekar *et al.*,2009), increasing function for BOD (Sheikh and Hassan, 2020), decreasing function for BOD, COD and Fecal coliforms (Barua and Hubacek, 2009) and tilted S-shaped relationship for pH and BOD (Mythili and Mukherjee, 2011).

Given the variation in empirical results of variouswater quality indices, understanding the nature of EKC for major indicators isuseful.A substantial portion of the EKC literature was devoted to national-level research, which sometimes overlooks regional distinctions within a country or state. The association between pollution and income mightvary not justbetweencountries, but also between regions within the same country. A district-level investigation would have been more informative than a national or cross-country study because water pollution is local. The aim of the study is to determine the pattern of relationship between economic growth and water quality attributes as well as to quantify the EKC threshold levels and shapes for different water quality attributes. Dissolved oxygen (mg l^{-1}), Conductivity (µmhoscm^{-1}), Biological Oxygen Demand (BOD) (mg l^{-1}), Fecal coliforms (MPN/100ml) and Total coliforms (MPN/100ml) are identified as thesignificant determinants of water quality.

MATERIALS AND METHODS

Description of the study area:

The study was limited to the state of Tamil Nadu and was based on secondary data collected from the Statistical Handbook of Tamil Nadu and the Central Pollution Control Board, New Delhi from 2003 to 2019. Under Global Environmental Monitoring System (GEMS), the TNPCB (Tamil Nadu Pollution Control Board)monitors the inland water quality of major rivers and lakes in Tamil Nadu. With financial assistance fromthe Central Pollution Control Board in New Delhi, 79 stations are currently being monitored across Tamil Nadu. Data on water quality parameters are available on the basis of various locations of river basins and lakes in Tamil Nadu. The data were pooled from different stations and represented at the district level using a simple arithmetic mean. It reflects the average tendency of water quality of the district.The district included in the study are Thiruvallur, Cuddalore, Vellore, Salem, Namakkal, Erode, Coimbatore, Tiruppur, Karur, Trichy, Thanjavur, Nagapattinam, Tirunelveli, Thoothukudi, Dindugal and Nilgiris. The classification of various stations/locations based on district wise was given in Table 1.

Table 1. District wise classification of various locations

Districts	Location
Thiruvallur	Poondi lake at Thiruvallur
	Redd hills at Thiruvallu
	Porur lake at Thiruvallur
	Pulicate lake at Thiruvallu
	Over head tank at tirur village, Thiruvallur taluk
Cuddalore	Veeranam lake at Cuddalore
Vellore	Palar river at Vaniyambadi
Salem	Cauvery at Mettur
	Thirumanimuthar, d/s of sago & textile dying industries, Salem
	Vasista, d/s of sago industries effluent, Salem
	Sarabanga, d/s of textile dyeing industries effluent, Salem
Namakkal	Cauvery at Komarapalayam,Nammakal
	Cauvery at Mohanur near Pattaipalayam
	Cauvery at Vairapalayam, Pamakal
Erode	Cauvery at 1km. D/s of Bhavani river confl.
	Cauvery at 1km. D/s of Bhavani riverconfl.
	Cauvery at Pallippalayam
	Cauvery at Erode near Chirapalayam
	Cauvery at Urrachikottai,Erode
	Bhavani at Bhavani sagar
	Bhavani at Pathirakaliammankoil
	Bhavani at Bhavani
	Bhavani at d/s of Bhavanisagar, Sathyamangalam
	U/s of Kalingarayan canal, Erode
	D/s of Kalingarayan canal, Erode
Coimbatore	Bhavani at Sirumugai
Tiruppur	Amravati at 1km d/s from eff.dis. Pt. At Madhuthukkulam
Karur	Cauvery at Thirumukkudal-confl.pt.of r. Amravati
	Cauvery at Pugalur,Karur
Trichy	Cauvery at Musiri
	Cauvery at Pettaivaithalai, Trichy
	Cauvery at Tiruchirappalli u/s
	Cauvery at Tiruchirappalli d/s
	Cauvery at Coleroon
	Cauvery at Trichy, Grand Anaicut
Thanjavur	Cauvery at Thanjavur
	Cauvery at Kumbakonam, Thanjavur
Nagapattinam	Cauvery at Mayiladuthurai, Nagapattinam

Thirunelvelli	Tambiraparani at Madura coats ltd.Papavinasam
	Tambiraparani at Cheranmadev
	Tambiraparani at Tirunelveli,collectorate
	Tambiraparani at Tappankulam
	Tambiraparani at Ambasamudam
	Tambiraparani at Kallidaikurichi, Tirunelveli
	Tambiraparani at Srivaikuntam, Tirunelveli
	Tambiraparani at Vellakoil, Tirunelveli
	Tambiraparani at Sivalaperi
	River Tamrabarani at Tirunelveli
Thoothukudi	Tambiraparani at Murappanadu
	Tambiraparani at Arumuganer
	Tambiraparani at ERAL, Thothukudi
Dhindugal	Kodaikanal lake
Nilgiris	Udhagamadalem lake (Ooty)

While assessing the variability in water quality parameters by evaluating regional changes in water quality is useful, we focuson the mean measure to describe the water quality of a district. Data on Net District Domestic Products (NDDP)for various districts were collected from the Statistical handbook of Tamil Nadu. The regional NDDP is measured in ₹ billions of constant prices at 2011-12base year.

Econometric framework:

The study employed a quadratic kind of model to investigate the pollution-income relationship.

$$WQ_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + U_{it}$$

WQ_{it} = Water Quality Indicators. Y_{it}= NDDP, Y_{it}^2= Square of NDDP, U = Stochastic term, t =time/year, i = regions (district), β's = parameters to estimated. The estimated curve has a turning point of NDDP level calculated as$\left(-\frac{\beta_1}{2\beta_2}\right)$. The shape of EKC model is decided by the sign of coefficients in the estimated equation. There are several kinds of relations in the equation between water pollution and economic growth as follows.

1. β_1=β_2= 0 indicates that economic growth and water pollution are unrelated
2. $\beta_1 > 0 \; and \; \beta_2 = 0$ indicates a monotonically increasing relationship between economic growth and water pollution
3. $\beta_1 < 0 \; and \; \beta_2 = 0$ indicates a monotonically declining relationship between economic growth and water pollution
4. $\beta_1 < 0 \; and \; \beta_2 > 0$ shows a U-shaped relationship between economic growth and water pollution

5. $\beta_1 > 0$ *and* $\beta_2 < 0$ shows an Inverted U-shaped relationship (EKC) between economic growth and water pollution

The aforementioned quadratic equation is estimated separately for all the water quality variables using panel data regression since the data includes16 districts of pooled cross section and 17 years' time series (2003-19). Panel data regression can be done in two ways:

A regression model with a *fixed effect* is one in which the group means are fixed (non-random). This model assumes that differences in constant terms can describe changes across cross-sections.

Random effect in which the group means are a random sample from a population. This model is based on the assumption that there is only one intercept and that the model can be estimated using generalized least squares (GLS).

The Hausman test is used to determine which estimation technique is most appropriate. This test verifies the null hypothesis that the coefficients estimated by the efficient random effects estimator and the consistent fixed effects estimator are the same. It is safe to employ random effect if the p-value are insignificant*i.e.,*Prob >chi2 larger than 0.05. Fixed effect must be used if the p-value is significant.

RESULTS AND DISCUSSION

Table 2 shows the designated best use of different water quality parameters under various class of water.

Table 2. Criteria for designated best use water quality

Category	Class of water	Water quality indicator	Range
Drinking water after disinfection without conventional treatment	A	Total Coliforms	Shall be less than 50 MPN/100ml
		pH	Between 6.5 and 8.5
		Dissolved Oxygen	More than or equal to 6 mg l^{-1}
		Biochemical Oxygen Demand	Less than or equal to 2 mg l^{-1}
Outdoor bathing	B	Total Coliforms	Shall be less than or equal to 500 MPN/100 ml
		pH	Between 6.5 and 8.5
		Dissolved Oxygen	More than or equal to 5 mg l^{-1}
		Biochemical Oxygen Demand	Less than or equal to 3 mg l^{-1}
Drinking water source after disinfection and conventional treatment	C	Total Coliforms	Shall be less than or equal to 5000 MPN/100 ml
		pH	Between 6 to 9
		Dissolved Oxygen	More than or equal to 4 mg l^{-1}
		Biochemical Oxygen Demand	Less than or equal to 3 mg l^{-1}
Fisheries and Wild life	D	pH	Between 6.5 to 8.5

Propagation		Dissolved Oxygen	More than or equal to 4 mg l^{-1}
Controlled Waste disposal, Irrigation and Industrial Cooling	E	pH	Between 6.0 to 8.5
		Electrical Conductivity	Maximum of 2250 mhos cm^{-1}

Source: Tamil Nadu Pollution Control Board, GOTN

In Tamil Nadu, CPCB has identified six numbers of Polluted River Stretches for exceeding the prescribed standard limit of BOD during the period of 2011 to 2015 namely River Sarabanga, Vasista, Thirumanimutharu, Cauvery under priority-I (BOD > 30 mg l^{-1}), River Bhavani under priority-IV (BOD - 6 to 10 mg l^{-1}) & River Thamirabarani under priority-V (BOD - 3 to 6 mg l^{-1}) (TNPCB, 2020). Moreover, as these rivers runs through manydistrictsin Tamil Nadu,each district with its individual socio-economic and cultural variety, the sources of pollution change from one district to the other.

Table 3. Statistical description of variables for the pooled data (2003-19 for 16 district)

Parameters	Observation	Mean	Std. dev.	Minimum	Maximum
Dissolved oxygen	272	5.78	1.05	2.47	9.65
Conductivity	272	1281.74	2764.91	2.00	27122.25
BOD	272	5.94	17.13	0.13	166.78
Fecal Coliform	272	1270144.56	10832910.38	2.00	117645506.38
Total Coliform	272	3871000.96	34584283.73	10.00	453771216.00
NDDP	272	240.70	175.17	28.43	1144.76

Table 4 shows the descriptive statistics for different water quality parameters and NDDP. The descriptive mean value of NDDP for different districts from 2003 to 2019 found that highest NDDP is inTiruvallur(₹ 502 in billions), while the lowest is in The Nilgiris(₹ 61.10 in billions) (Table 2). Water quality attributed varyamongdifferent districts. For instance, dissolved oxygen ranges from 5.5 mg mg l^{-1} in Vellore to 7.5 mg mg l^{-1}in Thanjavur. Conductivity rate varies from 164.3 µmhos cm^{-1}in Tirunelvelito 9824 µmhos cm^{-1}in Tiruvallur. BOD range from1.5 mg l^{-1}in Tirupur to a high of 40.65 mg l^{-1}in Salem. Fecal and Total Coliform values was found to be highest MPN/100ml in Salem district whereas lowestinTirunelveli and Thoothukudi (Table 4).

Table 4. Mean and Compound annual growth rate of water quality parameters (2003-19)

District	A. Dissolved Oxygen		B. Conductivity		C. BOD		D. Fecal Coliform		E. Total Coliforms		F. NDDP	
	Mean	CAGR	Mean	CAGR	Mean	CAGR	Mean	CAGR	Mean	CAGR	Mean	CAGR
Thiruvallur	7.2	-3.68	9824.66	4.38	4.96	4.23	2114.25	-8.03	7582.75	-14.30	502.90	12.98
Cuddalore	7.1	-0.78	540.31	0.79	3.71	0.61	5663.54	-20.65	12369.93	-20.94	188.88	9.33
Vellore	5.5	-3.09	795.13	2.35	3.15	-2.44	271.51	-12.15	616.31	-2.81	364.09	10.38
Salem	6.2	-0.62	1341.88	13.92	40.65	34.94	13945925.22	112.84	45134216.38	108.14	307.54	8.34
Namakkal	6.7	-1.28	622.20	-0.43	2.50	1.76	1103.39	9.13	3083.72	8.44	218.98	9.57
Erode	6.8	0.97	427.88	0.71	3.42	-0.82	15474.90	5.71	22834.40	2.53	252.71	9.59
Coimbatore	7.3	-0.57	175.76	3.19	1.64	-5.64	1369.25	2.62	2841.10	2.43	395.19	11.04
Tiruppur	7.5	-1.06	267.62	1.91	1.50	-2.38	311.15	-7.68	723.55	-8.28	273.71	11.30
Karur	7.2	-2.05	620.13	8.55	1.74	2.67	723.51	9.40	1774.68	10.77	103.89	10.38
Trichy	7.0	-1.59	2933.95	7.74	3.00	2.12	12763.80	19.50	42736.27	18.54	323.28	11.03
Thanjavur	7.5	-0.77	568.35	-1.37	1.72	2.17	446.41	4.25	820.83	0.12	157.62	8.85
Nagapattinam	6.7	-0.99	475.59	-0.37	1.45	1.21	2751.12	-22.05	513.01	0.29	110.64	6.38
Thirunelvelli	6.9	-0.66	164.29	1.38	3.71	3.02	54.47	-3.69	144.09	-5.34	256.05	8.61
Thoothukudi	6.8	0.10	1215.49	8.52	8.17	1.11	61.97	2.47	141.46	-1.79	172.14	8.15
Dindugal	6.4	0.39	181.44	-7.85	5.30	-3.81	1598.41	-23.18	4972.80	-30.68	162.51	8.80
Nilgiris	5.6	-2.35	353.18	8.87	8.49	8.54	6331680.12	41.41	16700644.01	48.03	61.10	8.27

Table 5. Panel data result for the relationship of water quality parameters with NDDP (2003-19)

S.No.	Particulars	A. Dissolved Oxygen		B. Conductivity		C. BOD		D. Fecal Coliform		E. Total Coliforms	
		FE	RE	FE	RE	FE	RE	FE	RE	FE	RE
1	NDDP	-0.004***	-0.003***	-1.764	-1.561	0.03	0.030*	9399.7	7615.9	29052.91	26638
2	$NDDP^2$	1.01E-06	5.33E-07	0.007***	0.007***	-1.51E-05	-1.59E-05	-8.89	-7.897	-28.206	-27.885
3	Intercept	7.589***	7.481***	1114.82***	1028.331**	0.037	0.177	-205560	135912	-625617	-72787.3
4	F stat/ Wald Chi^2	29.760***	51.99***	25.610***	60.28***	3.440**	7.020**	0.26	0.44	0.24	0.53
5	Prob > F /Prob>Chi^2	0	0	0	0	0.034	0.03	0.77	0.802	0.785	0.766
6	Hausman t test (Prob>Chi2)	0.006		0		0.78		0.925		0.95	
7	No. of observation	272		272		272		272		272	
8	No. of groups	16		16		16		16		16	
9	Obs. per group	17		17		17		17		17	

Note: FE- Fixed effect; RE-Random effect

* Significant at 10 per cent level

** Significant at 5 per cent level

*** Significant at 1 per cent level

Dissolved oxygen

Table 4 showed that Vellore, Salem and Nilgiris were found to be highly polluted with their mean values below 6.5 mg $l^{-1}$and the compound annual growth rate showed that there was a decreasing trend in all the district which means that all the district were found to have increasing pollution level over a period of past 17 years (2003-17) except in Erode, Thoothukudi and Dhindugal. There was no indication of an EKC for Dissolved Oxygen in panel data regression; instead, there tends to monotonically decreasing relationship. Since the low level of dissolved oxygen indicates pollution to the environment, the efforts have been taken to improve the level of dissolved oxygen, consequently reducing the physical and chemical pollutant loads in river water. The estimated coefficient for NDDP is -0.004, which is highly significant at one per cent level, indicating that there is a decreasing in 0.004 mg l^{-1}dissolved oxygen for each unit increase in NDDP (Rs. billion). The second order coefficient was found to be approximately zero (Table5).

Conductivity:

The summary statistics of conductivity was given in the table 4. The district wise mean value of conductivity for Thiruvallur was 9824.66 µS/cm, which considered as highly polluted, followed by Trichy (2933.95 µS/cm). CAGR on conductivity was found to be increasing trend in all the district except in Thanjavur, Nagapattinam and Dhingal district.

According to the statistical result in table5, EKC has a U-shaped relationship between economic growth and conductivity, implying that conductivity declines initially with increasing income, reaches a low in the range of ₹ 131.98 billion, and then raises again. The coefficient of NDDP for conductivity is estimated to be -1.764. This means that for every one unit raise in economic growth, conductivity drops by 1.764 µS/cm. The second order coefficient is positive, with the value of 0.004 which is at one per cent significant level and its sign that shows a convex function in income.

Biological Oxygen Demand:

The result of the summary statistics in table 4 showed that B.O.D level for the districts Thirvallur, Cuddalore, Vellore, Salem, Nammakkal, Erode, Trichy, Thirunelveli, Thoothukudi, Dhindugal and Nilgiris were found to be more than 2 mg l^{-1}. The result also shows mean value for the river Thirumanimutharu, Vashista and Sarabanga in Salem district were found to be 40.65 mg l^{-1} which is due to textile and sago industrial effluents mixed into the river without proper treatment led to increased water pollution and it alters the characteristics of ecosystem. Farmers are using these effluents for irrigation and found that agricultural productivity and soil health are reduced and also creates a major negative impact on cropping pattern, health of people, livelihoods and animal health etc. Already, the government ensures the installation of zero liquid discharge system in almost all the bleaching and dyeing units and several action plan like Municipal Solid waste Treatment facility. Government of Tamil Nadu in the year 2014 has announced the formation of common effluent treatment plants and identification of land is under progress.

The growth rate of BOD by district wise from 2003-19 was found to be increasing trend in all the district with the positive values except in Vellore, Tiruppur, Coimbatore and Dhindugal as shown in the table 2. Salem district has experienced higher growth rate of 34.94 per cent per year among all the districts in Tamil Nadu.

Panel data regression analysis found that there was an increasing relationship of BOD with economic growth. We find that the coefficient of NDDP was positive with the value of 0.03 which is at 10 per cent significant level and the second order coefficient was found to be approximately zero. This means that as income increases, BOD also increases and the turning point yet to occur (Table 5).

Fecal Coliforms and Total Coliforms

Starting with the summary statistics in table 4,we found the mean values of fecal and total coliforms in Thiruvallur, Cuddalore, Salem, Trichy, Nagapatinam and Nilgiris district are more than the maximum permissible limits. The growth of fecal and total coliforms in Salem and Nilgiris district was found to have increasing trend with the very high growth rate per annum.

The results of panel data analysis (Table 5), confirm the existence of an EKC (Inverted U-shaped relationship) for Fecal coliforms and Total Coliforms, respectively, with the turning point at₹ 482.22 and ₹ 477.65 billion. This means that, in the earlier phase of economic growth, raising income is linked with growing levels of Fecal and Total Coliforms until it reachesNDDP of ₹ 482.22 and ₹ 477.65 billion, respectively. It is possible that this is due to a lack of investment in treatment technologies to reduce coliforms levels. As the economy grows, deliberate efforts and adequate investments intreatment facilities and sanitary improvements result in decrease in coliform levels. This could be due to the Swachh Bharat Mission, which began in the Cuddalore and Coimbatore districts of Tamil Nadu in 1999 and expanded to all other districts by 2004, with the goal of enhancing overall quality of rural life by encouraging cleanliness, hygiene and eliminating open defecation.

CONCLUSIONS

The EKC relationship between water pollutants such as Dissolved oxygen, Conductivity, BOD, Total Coliforms, Fecal Coliforms and net district domestic product was investigated with a panel of 16 districts of Tamil Nadu for the period 2003–2019. In order to determine the relationship between economic growth and water pollution for the given dataset, the study used the panel data analysis. There is no indication of an EKC for Dissolved Oxygen and BOD; instead, there is a monotonically declining relationship for Dissolved oxygen and a monotonically increasing relationship for BOD, with the first turning point yet to be reached. EKC relationship between income and conductivity found U-shaped relationship with the turning point on Rs.131.98 billion. The results of panel data analysis, on the other hand, confirm the existence of an EKC (Inverted U-shaped relationship) for Fecal coliforms and Total Coliforms, with the turning point being Rs. 482.22 and Rs. 477.65 billion, respectively.

As a country's economy grows more industrialised, more of these water contaminants are released into the environment. As a result of this, both surface and groundwater could be harmed. A policy package focussing on the environment and technology can help to lessen the burden of these pollutants in surface and groundwater.

To manage the pollution at the source, all the polluting industries should install Effluent Treatment Plant (ETP). Sewage Treatment Plants (STPs) are also required in all towns and cities to clean up sewage effluents. In agricultural sector, sprinkler and drip irrigation should be encouraged to make the optimum use of water; avoidance ofoveruse of various chemicals like fertilizers, pesticides and herbicides as well as organic methods of farming should be adopted. The polluter pays principle should be implemented so that that the polluters are the ones who bear pollution expenses by paying the pollution cost. Ultimately, the polluter pays principle should be structured to discourage people from polluting and encourage them to act responsible towards the environment.

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