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ARTICLES

Water Quality Response to Economic Development: Quantifying Environmental Kuznets Curve

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I

INTRODUCTION

The United Nations has announced this decade (2005-2015) as the International Decade for 'Water for Life' (UNEP, 2003). With human populations growing and freshwater demand increasing worldwide, the challenge of supplying adequate water to meet the societal needs is one of the most urgent problems (UNEP, 1999). Human activities on all spatial scales affect water quality (Norman, 2000). Despite several efforts, human health is at substantial risk due to water quality problems in many areas of the world (World Resources Institute, 1996). Water quality impairment is studied in scientific literature (Mankin *et al.*, 1999; Rudra *et al.,* 1999; Gardi, 2001) and is attributed to point and non-point sources of pollution (Pieterse *et al*., 2003; Dinnes *et al.*, 2002; Cessna *et al.*, 2001; Becher *et al*., 2000). The degree of influence of factors that impact water quality differs from local scale to macro scale. At the global scale, macro economic factor (income) and demographic factor (population) may be important in influencing water quality. The contamination levels in water can be used as the indicators of water quality impairment. This study focuses on examining the relationship between water quality degradation and income at a global level using cross-country panel data sets.

Water resource degradation is influenced by changes in the economic processes through scale, compositional, and technology effects (Grossman, 1995). The efforts on conservation of water resources are not on par with economic development in many developed as well as developing countries. The relationship between income and environmental quality is often studied through the Environmental Kuznets Curve (Panayotou, 1993), which can be used in environmental policy studies (Grossman and Krueger, 1991). Salvatore (2002) indicated that variables like income distribution, education, and information accessibility are also important and might play a fundamental role in determining environmental quality. Ervin and Daan (2001) studied the environmental degradation in developing countries using the

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Environmental Kuznets Curve (EKC). In this approach, it is hypothesised that in the early stages of economic growth, degradation increases up to a threshold and the trend reverses, where at high-income levels, economic growth leads to environmental improvement. This implies an inverted U-shaped function (Stern, 2003) - Model- B in Figure 1. In this model, the eventual decline of environmental degradation is explained by the structural change towards information-intensive industries and services, increased environmental awareness, environmental regulations, better technology, and higher environmental expenditures (Panayotou, 1993; IBRD, 1992; Beckerman, 1992; Shafik and Bandyopadhyay, 1992; Grossman and Krueger, 1991). Kaufmann *et al.* (1998) indicated that there is a U-shaped relation between income and atmospheric concentration of SO_2. Neha and Plassmann (2003) used this EKC approach to study the relationship between pollution and income in the US. Cole *et al.* (2001) examined the relationship between air pollutants and per capita income and their results suggested that global air pollutants either increase monotonically with income or else have predicted the turning points at high per capita income levels. Besides global level, some economists maintain the view that individual preferences explain the EKC, the relationship between rising income and environmental degradation (Jordi, 2003).

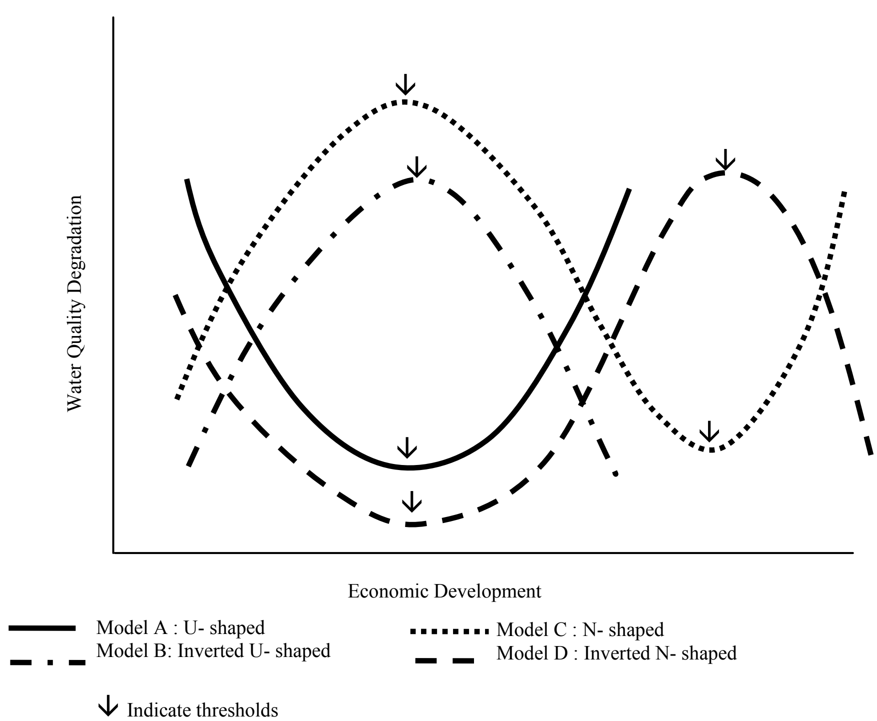

Figure1. Water Quality Degradation and Potential EKC

The U-shaped EKC has never been shown to apply to all pollutants or environmental impacts and recent evidence (Dasgupta *et al.*, 2002; Perman and Stern, 2003) challenges the notion of the EKC in general. In addition, the EKC for major water pollutants at the macro scale is rarely studied. In this context, the current study is appropriate on analysing the EKC, explaining the relationship between income and water quality, and identifying the water policy implications.

For water resources degradation, empirical evidence is mixed and many studies have reached conflicting results as to the shape and peak of the EKC (Borghesi, 1999). An N-shaped function was reported for Dissolved Oxygen (Torras and Boyce, 1998), Fecal Coliform (Shafik, 1994), Mercury (Grossman and Krueger, 1995; Grossman, 1995), Arsenic (Grossman and Krueger, 1994; Grossman, 1995), and Nickel (Grossman and Krueger, 1994). An inverted N-shape for Nickel (Grossman, 1995) and an inverted U-shaped function for Nitrates (Grossman and Krueger, 1994; Cole *et al.,* 1997) and Fecal Coliform (Grossman and Krueger, 1994) were reported. Other forms reported in EKC studies include U-shaped (Kaufman *et al.*, 1998), monotone decrease (Shafik, 1994), and monotone increase (Vincent, 1997).

Given the variation in empirical results of environmental parameters, understanding the nature of EKC for major indicators of water quality degradation is useful. Nutrient pollutants, sediments, and bacterial contaminants are identified as the significant predictors of water quality (National Sanitation Foundation, 2002). In this study, we include nutrient pollutants (nitrogen and phosphorous), sediments, bacterial contaminant (fecal coliform), and dissolved oxygen. EKC hypothesis of relating water quality degradation to the economic and demographic parameters is rarely tested and estimated using robust MM estimation methods.

The general objective of this study is to evaluate the relationship between water quality degradation and economic development using water quality attributes and income. The specific objectives are: (i) to examine the pattern of relationship between water quality attributes and per capita income; (ii) to quantify the threshold levels and shape of EKC of water quality attributes; and (iii) to identify the alternative reasons for differences in EKC of each attribute. Hypotheses that are tested include: (i) Water quality attributes exhibit different shapes in EKC behaviour depending on the indicator used; (ii) There exists thresholds in income for each water quality attribute; and (iii) The differences in EKC is influenced by scale, compositional, and technological factors.

II

METHODOLOGY

Data

Water quality data is compiled from the Global Environmental Monitoring System (GEMS/Water) dataset (UNEP, 2004). This dataset is a panel of ambient measurements from a number of stations across different countries around the world. The network consists of 865 stations that had been formally designated by the responsible national authorities in 76 countries (GEMS/Water Triennial Report). The number of stations range from 9 to 74 in each country. More information on the sites and frequency of data are presented in UNEP (2004). The protocols for sampling and quality control are followed as described in the GEMS/Water Operations Guide 3.1 (UNEP, 2004). The GEMS triennial data pertains to the years 1997-1999 and 1994-1996. Nitrogen, phosphorous, sediments, and dissolved oxygen are represented in mg per litre while fecal coliform is represented in number per mg. Water quality attribute data is pooled from different stations for each country and a simple arithmetic mean is used to represent the country level data. It reflects the average tendency of water quality of the region. While the evaluation of spatial changes in water quality is useful to assess the variability in water quality parameters, we focus on the mean measure to represent the water quality of a region, given the limitation in availability of data on a global scale. Data on per capita income (in US dollars[1]) for various countries is collected from World Development Indicators Database (World Bank, 2004). Population density is collected from World Population Database (UNPC, 2002) and is represented as population per square kilometer.

Methodology

It is assumed that water quality degradation is related to income through the EKC as a polynomial functional form as in (1).

$$F(x \mid A) = \beta_0 + \beta_1 x + \beta_2 x^2 + ... + \beta_n x^n \qquad ....(1)$$

Where, F(.) is the level of water quality degradation, *x* is income of the country, and A represents other variables. Different behaviours of EKC can be attributed to the order of the polynomial and the curvature properties of the function. Majority of the EKC shapes proposed in the literature can be estimated using the polynomial of the order 3 and less. For *n*=2, the EKC is quadratic in form and represents a U-shaped or inverse U-shaped function. For *n*=3, the EKC is cubic in form representing an N-shaped or inverted N-shaped function.

The water quality indicators considered in this study are physical (sediments), chemical (dissolved oxygen, nutrients), and biological (fecal coliform). We test the EKC relationship between water quality indicators and per capita income as well as population of different countries. The relationship between water quality degradation, per capita income, and population is specified in Equation (2). Population density is included (Ehrlich and Holdren, 1971) to quantify the extent of human impact on water quality degradation, especially urban impacts. It also resulted in a higher explanatory power of the model. D_i *is* used as indicator of F(.) in (1). If N, P, S, F, and O represent nitrogen, phosphorus, sediments, fecal coliform and dissolved oxygen, respectively, then D_i can be represented as:

$$D_i = \alpha_{1i} + \beta_{1i} Y + \beta_{2i} Y^2 + \beta_{3i} Y \cdot P + \beta_{4i} P + \beta_{5i} P^2 + \beta_{6i} Y^3 + \beta_{7i} P^3 \quad \ldots(2)$$

Where, i = {N,P,S,F,O}, D_i, is loading level of water quality indicator i, Y is per capita income in US $, P is population density per square kilometer and α_{1i}, β_{1i}, β_{2i}, β_{3i}, β_{4i}, β_{5i}, β_{6i} and β_{7i} are coefficients specifying functional forms. We assume that:

For Model- A, $\beta_{2i} > 0$ and indicate a convex function in Y.
For Model- B, $\beta_{2i} < 0$ indicating a concave function in Y.
For Model-C, $\beta_{2i} < 0$ and $\beta_{6i} > 0$ indicating a concave section followed by a convex section in Y.
For Model - D, $\beta_{2i} > 0$ and $\beta_{6i} < 0$ indicating a convex section followed by a concave section in Y.
For an N- shaped EKC, it is often multiple maxima or minima.

We hypothesise that nutrients (N and P) concentrations follow Model –A ($\beta_{2i} > 0$), sediment follows Model-B ($\beta_{2i} < 0$), and DO and fecal coliform follow Models C or D.

The empirical models are specified in equations (3) through (7). For these equations the degree of the polynomial function is identified to maximise the model explanatory power.

$$D_N = \alpha_{1N} + \beta_{1N} Y + \beta_{2N} Y^2 + \beta_{3N} Y \cdot P + \beta_{4N} P + \beta_{5N} P^2 \quad \ldots(3)$$

$$D_P = \alpha_{1P} + \beta_{1P} Y + \beta_{2P} Y^2 + \beta_{3P} Y \cdot P + \beta_{4P} P + \beta_{5P} P^2 \quad \ldots(4)$$

$$D_S = \alpha_{1S} + \beta_{1S} Y + \beta_{2S} Y^2 + \beta_{3S} Y \cdot P + \beta_{4S} P + \beta_{5S} P^2 \quad \ldots(5)$$

$$D_F = \alpha_{1F} + \beta_{1F} Y + \beta_{2F} Y^2 + \beta_{3F} Y \cdot P + \beta_{4F} P + \beta_{5F} P^2 + \beta_{6F} Y^3 + \beta_{7F} P^3 \quad \ldots(6)$$

$$D_D = \alpha_{1D} + \beta_{1D} Y + \beta_{2D} Y^2 + \beta_{3D} Y \cdot P + \beta_{4D} P + \beta_{5D} P^2 + \beta_{6D} Y^3 + \beta_{7D} P^3 \quad \ldots(7)$$

Robust regression analysis provides an alternative to a least squares regression model when fundamental assumptions are unfulfilled by the nature of data. This estimation provides resistant (stable) results in the presence of outliers. For estimating empirical models, Robust MM Regression was earlier used by Rousseeuw and Yohai (1984), Yohai *et al.* (1991), and Yohai and Zamar (1998). In our data set, we perceived the outliers in both the y-direction (response direction) and the x-space (leverage points), which lead us to use this estimation method. In addition to this, this method has several other advantages that include it minimises maximum possible bias of coefficient estimates, and the inference tools are based on large sample size approximations of test statistics.

If the model has the form: $y_i = x_i^T \beta + \varepsilon_i, i = 1, ..., n$ ….(8)

Where y_i is the response, x_i is s-dimensional vector of independent variables, $\beta = \beta_1, \beta_2, \ldots, \beta_S$ are coefficients, and ε_i are errors. The Robust M-estimate for $\hat{\beta}$ minimises the objective function in equation (9).

$$\sum_{i=1}^{n} \rho \left[\frac{y_i - x_i^T \beta}{\hat{S}} \right] \quad \text{….(9)}$$

Where, $\hat{s}$ is a robust scale estimate for the residuals and ρ is symmetric, bounded loss function. The estimation is done using S-PLUS software (Insightful Corp., 2001).

III

RESULTS AND DISCUSSION

The descriptions of different water quality attributes, per capita income, and population density of different countries are presented in Table 1. The highest per capita income in the data set is in Luxembourg at $43,940 (1 US $ = Rs. 40 at current exchange rate), while the lowest is in Cambodia ($310). Water pollutant rates vary among countries. For instance, nitrogen rate ranges from 3.5 mg/l in Poland to 0.01 mg/l in Finland. Phosphorus pollution rate varies from 0.46 mg/l in Lithuania to 0.01 mg/l in Finland and Canada. Sediments range from 213.59 mg/l in Pakistan to a low of 1.90mg/l in Canada. Fecal coliform values range from 9887 No./mg in Spain to the lowest of 13 No./mg in Hong Kong.

The estimated results of the polynomial model using Robust MM method are presented in Table 2. It is observed that the behaviour of the EKC varies among various water quality attributes. These are discussed in detail in following sections. The EKC relationships between water quality degradation and per capita income are presented in Figure 2. The shape of EKC of water quality indicators like nitrogen, phosphorus and sediments follow a U-shaped function as compared to the common expected inverted-U shaped curve. The EKC follows an N- shaped function, for rest of the indicators like fecal coliform and dissolved oxygen. This is consistent with the observations and results of the past literature on fecal coliform (Shafik, 1994) and dissolved oxygen (Torras and Boyce, 1998). The following sections present results of each water quality attribute in detail.

TABLE 1. INCOME AND WATER QUALITY IN SELECTED COUNTRIES

			Water quality attributes				
Country (1)	Per capita income ($) (2)	Population density (3)	Nitrogen (mg/l) (4)	Phosphorus (mg/l) (5)	Sediments (mg/l) (6)	Fecal ColiformN/m (7)	Dissolved oxygen (mg/l) (8)
Cambodia	310	63	-	-	56.30	-	-
Ghana	320	73	0.97	-	95.78	16	5.12
Bangladesh	400	857	1.95	-	59.39	699	6.70
Pakistan	470	157	1.73	0.38	213.59	3,236	6.61
Vietnam	480	220	-	0.02	-	-	0.69
India	530	283	1.05	0.23	-	-	6.53
Senegal	550	42	3.17	-	-	-	-
Philippines	1080	228	-	-	45.11	-	7.42
China	1100	127	1.48	0.28	-	-	8.51
Jordan	1850	48	2.94	-	183.00	326	-
Russia	2610	9	0.41	0.06	17.99	-	9.49
Argentina	3650	13	-	0.07	77.50	475	8.55
Lithuania	4490	55	-	0.46	-	-	6.34
Poland	5270	119	3.50	0.29	26.53	-	10.02
Korea	12,030	455	0.35	-	7.70	1,202	10.49
Portugal	12,130	107	-	-	-	3,575	15.98
Greece	13,720	79	-	-	-	3,372	14.86
New Zealand	15,870	13	0.21	0.05	-	-	10.73
Spain	16,990	79	-	-	-	9,887	15.56
Italy	21,560	190	-	-	-	-	20.56
Canada	23,930	3	-	0.01	1.90	38	8.13
Germany	26,250	229	-	-	-	2,880	10.07
Netherlands	26,310	378	0.02	-	8.02	-	-
Hongkong	25,430	5543	-	0.05	-	13	7.96
Austria	26,720	96	-	0.08	-	902	10.46
Ireland	26,960	51	-	-	-	6,812	11.24
Finland	27,020	15	0.01	0.01	3.13	-	11.24
UK	28,350	236	-	-	7.71	-	-
Denmark	33,750	121	-	-	-	397	10.18
Japan	34,510	332	1.58	0.05	-	292	10.01
US	37,610	29	0.89	0.13	12.51	452	10.14
Switzerland	39,880	172	1.01	0.06	28.30	-	11.03
Luxemburg	43,940	157	-	-	-	-	12.13

Source: Estimated derived from GEMS panel data (1994-1999), UNEP, 2004; World Development Indicators Database, World Bank, 2004 and World Population Database, UNPD, 2002.

TABLE 2. ESTIMATED ROBUST MODEL RESULTS OF WATER QUALITY INDICATORS WITH INCOME AND POPULATION

(1)	Nitrogen (2)	Phosphorus (3)	Sediments (4)	Fecal Coliform (5)	Dissolved Oxygen (6)
Intercept	4.2850*	0.0606**	40.5402*	-2295.0777*	4.3084*
	(13.038)	(2.268)	(5.048)	(-5.492)	(2.952)
Income (β_{1i})	-0.0004*	-6.6251×10^{-6}**	-0.0039*	0.6664*	0.0016*
	(-9.594)	(-2.405)	(-5.132)	(7.241)	(6.124)
Income^2 (β_{2i})	7.0360×10^{-9}*	2.1400×10^{-10} *	9.5410×10^{-8} *	-3.8229×10^{-5}*	-8.0300×10^{-8}*
	(7.934)	(3.148)	(4.791)	(-6.239)	(-5.517)
Inc Vs Pop (β_{3i})	3.4050×10^{-7}*	-6.4080×10^{-8}*	-1.4049×10^{-6}	-0.0006*	-4.2763×10^{-7}
	(6.979)	(-8.731)	(-0.759)	(-6.456)	(-1.113)
Population (β_{4i})	-0.0215*	0.0021*	0.0502	38.1661*	0.0240***
	(-6.196)	(9.591)	(0.753)	(8.911)	(1.598)
Population^2 (β_{5i})	3.4840×10^{-5}*	-9.1830×10^{-8}*	-3.1464×10^{-5}	-0.0471*	-9.3913×10^{-5}***
	(4.686)	(-4.870)	(-0.439)	(-8.804)	(-1.862)
Income^3 (β_{6i})	-	-	-	5.8600×10^{-10}*	1.0000×10^{-12}*
				(5.482)	(4.899)
Population^3 (β_{7i})	-	-	-	7.6522×10^{-6} *	7.9883×10^{-8} ***
				(8.682)	(1.859)
R^2	0.74	0.42	0.71	0.49	0.58

[t- values are presented in parentheses. *, ** and *** indicates significance at 1, 5 and 10 per cent level, respectively.

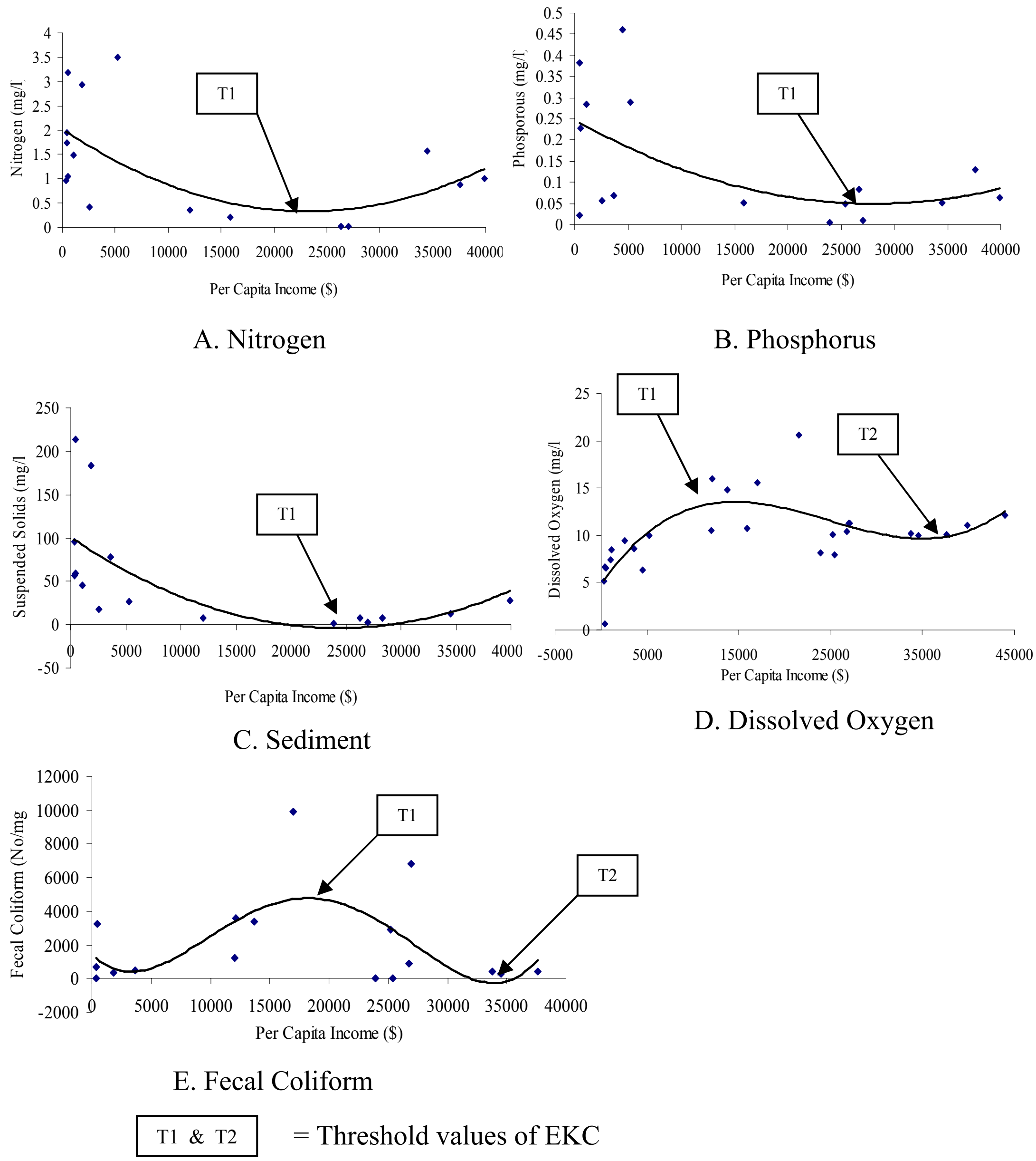

Figure 2. Environmental Kuznets Curves for Water Quality Attributes

Nutrients

Nitrogen and phosphorus are the nutrient contaminants that could impact the quality of water and result in water quality degradation. The result obtained from the nitrogen model show that nitrogen level decreases with rising per capita income and starts to increase after the threshold range of US$ 20,000 to 25,000 of income (T-1). The EKC follows a U- shaped curve (Panel A of Figure 2) that is weaker in slope and convex to the origin. This indicates that water quality improves and then deteriorates after a threshold income. This could be because of change in economic activities (compositional effect) through reduction in agricultural activities and increase in industrial and service sectors. This change is often associated with reduction in nutrient use in agriculture, a major contributor to non-point source pollution. The robust modeling estimates of EKC for nitrogen and their significance levels are presented in Table 2. The explanatory power of the nitrogen model is 0.74, indicating that 74 per cent of the variation is explained by the model specification. The estimate of the income coefficient ($\beta 1_N$) is -0.00034 that is highly significant at one per cent level indicates that a general decrease of 0.34 mg/l for each increase of $1000 in income. The sign of second order coefficient (β_{2N}) is positive indicating a convex function in income. The estimate of coefficient for population (β_{4N}) is negative at -0.0214 indicating that there is a decrease of 0.02 mg/l of nitrogen for each unit increase in population density. This is often because of shifts from agriculture to urban land uses as population densities increase. The second order coefficient for population (β_{5N}) is positive indicating a convex function in population.

Phosphorus is one of the primary nutrients used in crop production in the agricultural sector. In phosphorus model, the pollution rate decreases with increases in income up to the range of US$ 25,000 to 30,000 (T-1) and eventually increases with income. The phosphorus model also registers a U-shaped EKC (Panel B of Figure 2) with weaker slope and convexity. This is also due to adjustments in economic components through reduction in agricultural activities to industrial and service sectors. The explanatory power of the phosphorus model is 0.42, indicating a 42 per cent of variation explained by the model specification. As presented in Table 2, the estimate of the income coefficient (β_{1P}) is significant at 5 per cent level and indicates a decrease of 0.6 mg/l in phosphorus contamination for each increase of US$100,000 in per capita income. The sign of the second degree coefficient (β_{2P}) is positive indicating a convex function in income. The estimate of the coefficient for population (β_{4P}) is positive indicating an accrual of 0.0021 mg/l for each unit increase in population density. This implies that increase in population density adversely impact water quality. The second order coefficient for population (β_{5P}) is negative indicating a concave function in population.

Sediments

The EKC curve for sediments is U-shaped as presented in Panel C of Figure 2, implying that sediment loadings decline initially with income and reach a low in a range of US$ 24,000 to 27000 (T-1) and increase further. This could be because of reduction in soil loss as countries decrease their agricultural activities at a developing phase of an economy. However, there is an increase after reaching a threshold and the later increase could be explained by the potential increase in impervious area as a result of urbanisation that increases sediment loading (Randhir, 2003). The proportion of variation explained by the sediment model (R^2) is 0.71, indicating high explanatory power. The coefficient of income (β_{1S}) for sediment is estimated at -0.0039, which is significant at one per cent level. This implies a decrease of 0.39 mg/l in sediment pollution for every $100 increase in income. In other words, water quality improves in general with an increase in income. This is also due to compositional or technological effect on sediment loading. The sign of second order coefficient (β_{2S}) is positive denoting a convex function in income. The estimate of coefficient for population (β_{4S}) is 0.0502 indicating that there is an increase of 0.05 mg/l of sediments for each additional increase in population density. This is expected because of human influence on landscape alteration that enhances sediment loading. The second order coefficient for population (β_{5S}) is negative indicating a concave function in population.

Dissolved Oxygen

Adequate levels of dissolved oxygen are necessary to sustain aquatic ecosystems and to maintain good water quality. Hypoxic and anoxic conditions are not good for aquatic health. In dissolved oxygen model, the EKC follows an N- shaped portraying varying slopes (Panel D of Figure 2). Dissolved oxygen increased for initial increase in income. The maximum point of deflection (T-1) of income is in a range of $ 13,000 to 17,000 and after this point the curve starts declining and eventually climbs up after T-2 ($ 28,000 to 38,000). Dissolved oxygen is a function of the type and the amount of pollutants that are accumulated in water bodies. It also depends on decomposition of organic matter. During developing phase in an economy, the physical (sediments) and chemical (nutrients) pollutants in water decrease as noticed in previous models (sediment, nitrogen and phosphorous). Reduced levels of these pollutants result in less Biological Oxygen Demand (BOD) in the initial phase. The dissolved oxygen levels start to decline after T-1, which could be arisen from substantially large additions of organic and industrial wastes. The composition effect from urban and industrial activities can lead to high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) resulting in a declining level of dissolved oxygen. After T-2, dissolved oxygen levels improve, which could be because of efforts concerted on reducing the physical and chemical pollutant loads in water.

The explanatory power (R^2) of the model is 0.58 implying that 58 per cent of variation in dissolved oxygen is explained by the model in the study. The estimate of coefficient for income (β_{1D}) is 0.0016, which is highly significant at one per cent level, indicating that there is an increase in 0.16 mg/l dissolved oxygen for each increase in \$100 income. This could be because of changes in technology resulting in less BOD and COD. The second order coefficient of income (β_{2D}) is negative implying a concave function in income. The estimate of coefficient for population (β_{4D}) is 0.024 indicating an increase of 0.024 mg/l dissolved oxygen for each increase in population density. The second order coefficient of population (β_{5D}) is negative implying a concave function in population. The third order coefficients of income (β_{6D}) and population (β_{7D}) are positive implying a non-linear function with a maxima and minima for income and population.

Fecal Coliform

The EKC for fecal coliform follows an N- shape as in Panel E of Figure 2. The curve initially increases and eventually decreases at a range of US \$ 17,000 to 21,000 (T-1). This could be because of less investment in treatment technologies to reduce coliform levels. As economy grows, conscious efforts and adequate investments in treatment facilities and sanitary improvements result in reduction in the level of fecal coliform after T-1. There is a slight increase after the second threshold income range of US\$ 33,000 to 36,000 (T-2) lesser capacity or Combined Sewer Overflows (CSO). The explanatory power of the fecal coliform model (R^2) is 0.49, indicating that 49 per cent of the variation is explained by the model specification. The estimate of coefficient for income (β_{1F}) in the fecal coliform model is 0.67, which is highly significant at one per cent level, indicating an increase of 0.67 No. /mg for each unit increase in income. This implies that water quality impairment due to fecal coliform occurs with income. The estimate of second order coefficient of income (β_{2F}) is negative indicating a concave function. The estimate of coefficient for population (β_{4F}) is positive at 38.17, which is highly significant at one per cent level, explaining an increase of 38.16 No./mg of fecal coliform for each unit increase in population density. The second order coefficient of population (β_{5F}) is negative indicating a concave function in population. The third-order coefficients of income (β_{6F}) and population (β_{7F}) remain positive and indicate non linearity and two inflection points.

IV

POLICY IMPLICATIONS

The results imply that as transition takes place from agrarian to industrialised economies, the loading rate of water pollutants such as nitrogen, phosphorus and sediments become lesser. However, after attaining a threshold income level, the rates of these pollutants increase probably because of urban effects. In other words, water quality improves and then deteriorates after a deflection point of income. The decline in pollutant loads is explained by Stern (2004) that developing countries are addressing the environmental issues, sometimes adopting developed country standards with a short time lag and sometimes performing better than some wealthy nations. However, the rise in later phase is a cause of concern as agriculture still continues to be the mainstay of post-modern economy of many developing countries. It is reported that intensive crop production is not sustainable because they lose excessive amounts of nitrogen (N) to the environment. Vegetable crops like spinach grown in fields, where residual soil mineral nitrogen exceeds 200 kg N ha^{-1} (Neeteson and Carton, 2001) have evidently showed a huge loss of nitrogen to the environment. It calls for policy reforms to use appropriate best management practices (BMPs) and adopt efficient nutrient management.

As an economy moves towards an industrialised economy, it paves the way for emanating more of these pollutants. This can have adverse impacts in surface water bodies more particularly through eutrophication, which occurs because of imbalanced nitrogen and phosphorus ratio. The nitrogen can also have the externality impact on ground water, which in turn can have far reaching impacts. A policy package on environment and technology can lessen the load of these pollutants in surface and ground water. The model also estimated that there is an increase of sediments for each additional increase in population density, which is expected because of anthropogenic disturbances on landscape. In the developing phase of an economy, the increase in these pollutant loads is attributed to potential increase in impervious area as a result of urbanisation that increases sediment loading. This observation is in conformity with the findings of Randhir (2003). Urbanisation increase can lead to more impervious area and more run-off. When run-off hydrology changes, it is possible that sediment particles carry adsorbed phosphorus molecules along during run-off. Therefore, efforts are needed to harness run-off water through rain water harvesting techniques. A technology policy on this front would reduce run-off and sediment load as well as the adsorbed nutrients in sediment particles. It is also required to have an appropriate policy which can keep a check on population growth rate because anthropogenic factors are mainly responsible for landscape disturbances.

The rise of these pollutant levels in the later phase of economy can have indirect impact too. Algae bloom in surface water bodies can have an adverse impact on eco-tourism revenue and also impact on aquatic ecosystems. The model suggested that dissolved oxygen increases with initial increase in income and start declining and eventually rise. The models suggested a congruity in their behaviour. Dissolved oxygen model can be associated with these nutrient pollutants and sediment model. During the developing phase of an economy, the decline in these pollutant levels tends to have less Biological Oxygen Demand (BOD) and therefore more availability of dissolved oxygen in the initial phase. The dissolved oxygen levels start to decline which could be due to substantially large additions of organic and industrial wastes.

Rothman (1998) also examined the hypothesis of an EKC and of the view that environmental impact increases in the early stages of development followed by decline in the later stages. The driving forces appear to be clean technology diffusion, and new approaches to pollution regulation in developing countries (Dasgupta *et al.,* 2002). Composition effect from urban and industrial activities can lead to high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) resulting in a declining level of dissolved oxygen. Further improvement in dissolved oxygen levels could be because of efforts taken on reducing pollutant loads in water. It is important that countries that are in a developing phase should devise a suitable technology policy which can ensure a stable level of BOD and COD. There is also a need for an environmental policy, incorporating the key features of technical progress in abatement and an explicit role for policy in determining costs and pollution over time (Anderson and Cavendish, 2001). During the developing phase, relatively less investment in treatment technologies to reduce fecal coliform levels and less importance given to curb biological contamination, has led to initial rise in coliform levels. As economy grows, conscious efforts and adequate investments in treatment facilities and sanitary improvements result in reduction in the level of fecal coliform. However, a slight rise in the later phase can be due to lesser capacity or Combined Sewer Overflows (CSO). The model implies that water quality impairment due to fecal coliform is more in relation to income. Appropriate technologies are required to be put in place for the treatment of impaired water bodies so that availability of safe and clean water to human beings become a reality. It is important to continue and expand the treatment phases as economies grow. There is also a critical need for supply of information, imparting education and creating awareness on water resource protection.

V

CONCLUING COMMENTS

While the demand for fresh water is increasing continuously, the availability of fresh water is declining around the world. Water quality problems are attributed to many factors that include nutrient, sediment, and bacterial contaminants. Evaluating relationship between water quality and income will be useful in the development of appropriate policies for sustainable water resource management. This study aims at relating various water quality indicators with income using the Environmental Kuznets Curve. Polynomial model is used to fit the data on water quality attributes and income of various countries. MM Robust regression is used to estimate the parameters and to test the hypothesis. The estimation results show that the behaviour of EKC curve has different shapes for different water quality indicators. For nitrogen, phosphorous and sediments, the shape of the EKC curve is U- shaped. But in fecal coliform and dissolved oxygen models, the behaviour of EKC is N- shaped. It is observed from the empirical relationship of nutrient and sediment contamination with income that the levels of these pollutants are lowered as economy develops. This could be possibly because agriculture being the major source of these kinds of water pollutants, the loadings is high during the initial phase and it turns less when the countries move towards industrial and urbanising economies. However, the levels of nutrient pollutants start increasing after reaching the threshold level of income and it is important that progressive economies mitigate the impacts of urbanisation.

The EKC for dissolved oxygen exhibits an N- shaped behaviour, which indicates that dissolved oxygen increases for initial increase in income, then starts declining after the first threshold point and eventually climbs up after the second threshold income. An adequate level of DO is essential for a healthy aquatic ecosystem. Appropriate policies are therefore needed to introduce reforms in technologies that could reduce the multiple demands arising from compositional and scale effects of the system. The EKC for bacterial contaminant (fecal coliform) also follows an N-shape. The initial increase could be because of lower investments in technologies reducing coliform loadings in water, which is potentially a case in low income countries. From the estimates of the model, there is an increase of 0.66 No./mg for each unit increase in income, implying that water quality degrades with income during the initial phase. The declining phase could be attributed to investments made in treatment facilities and improvements in sanitary facilities as countries become better off in their economic status. However, it is important for urbanised countries to continue with the efforts of water quality improvement and also to expand the levels of technology in controlling bacterial contamination.

In sum, the behaviour of each water quality attribute can be evaluated using EKC. As transition takes place from agrarian to industrialised economies, nutrient and sediment pollution become higher although it is less at the initial stages. This calls for reforms of nutrient management and soil loss management in urbanising countries, through appropriate changes in BMPs (technologies) that could be applied at a watershed scale. Dissolved oxygen needs more focus in the declining phase, which could be through efforts in reducing industries that increase BOD and COD of water. There is also a need for countries to continue expanding treatment phases as economies grow. Providing education and information on protecting water quality is also important for sustaining water resources.

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NOTE

1. One US dollar is equal to Rs. 40 at current exchange rate.

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