WWC 2008-Abstract Identifier No ***: 613*** *(Language English)*

Environmental Kuznets Curve for Irrigation and its Implications for Agricultural Water Demands: a 20-years of Cross-Country Analysis for 65 Tropical countries

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ABSTRACT:

Using framework of Environmental Kuznets Curve (EKC) hypothesis, this paper evaluates relationship between irrigation and income across developing countries; and factors affecting the income-irrigation relationship. The EKC hypothesis for irrigation implies that irrigation demand will be greater at the initial development stage, but subsequently it declines as the income increases. The relationship between irrigation and income is analyzed across 66 countries from Asia Africa and Latin America and from 1972-92. The empirical results provide a strong evidence for an EKC type of relationship for irrigation (percent of crop area irrigated) for both Asia and combined of 66 countries, which implies that income elasticity of irrigated area is a nonlinear. This means that there is no leapfrogging type of jump in the irrigation and agricultural development process. The information on income elasticity of irrigation has huge implications for analyzing demand for irrigated area, deriving water demand in agriculture and other sectors, and for planning water uses (allocation) across sectors. This is also important for improved understanding of irrigation impacts in the societies.

1. Introduction

In the face of increasing water scarcity, sustainable management of limited available freshwater resources and their easy and equitable access to all are now major water sector public policy concerns. The irrigation sector, which consumes more than 80 percent of the total consumptive use of water worldwide, is a focus of discussion among water professionals worldwide to alleviate the water-scarcity problem. But, so far, very limited information is available on societal decision for irrigation, and how economic and institutional factors affect an economy-wide demand for (or supply of) irrigation and in turn demand for water uses. In reality, water uses and water (re)allocation across the sectors are linked with overall economic development level of a society; but these issues have, so far, been inadequately addressed in the literature. In this context, this study evaluates the relationship between irrigation and the societal income level using cross-country level of analysis across the 66 countries in the tropics.

The empirical analysis is done by adopting hypothesis and analytical framework of Environmental Kuznets Curve (EKC), which conjectures that environmental quality deteriorate at the early stage of development and it starts to improve when the societal income reaches a critical level. Earlier, Simon Kuznets (1955) proposed an inverted U-shaped relationship between income inequality and economic growth, and put forwarded a view that in the early stages of development, as societal income (per capita income) grows income inequality is hypothesized to increase, but beyond a critical income level the inequality would decline. Thus, this process leads to an inverted U-shaped relationship between level of income inequality and level of income in an economy, which is popularly known as the Kuznets Curve for which S. Kuznets was awarded the Nobel Prize in economics in 1971.

More recently, environmental economists have built on this notion by hypothesizing the same type of relationship between level of environmental degradation and income. This has become known as the Environmental Kuznets Curve (EKC), particularly after the seminal work of Grossman and Kruger in 1991. The EKC framework of analysis offers policy options on sustainable management of the resources, including use of water resources. For detailed discussions on EKC and its underlying concepts and theory, see Grossman and Kruger (1991, 1995), Panayotou (1997, 2000); Yandle, et al. (2002 and 2004).

Grossman and Kruger (1991) demonstrated an inverted U-shaped relationship of air and water pollution indicators with income level for a set of countries. Following their suit, several studies have then verified the inverted U-shaped relationship for other indicators of environmental quality such as sulfur dioxide ($S0_2$), river water pollutants, suspended particulates and certain other pollutants (for details reviews, see Bhattarai and Hammig 2001 and 2004). In case of water sector, Rock (1998) and Goklany (2002) studies provide evidence for the EKC type of relationship for per capita water withdrawal for the agriculture sector. However, there is no study yet that explicitly analyzes EKC pattern for the irrigation level. Considering this point, this study systematically validates the EKC relationship for irrigation level using statistical analysis. Then, it also examines how the EKC relationship for irrigation is affected by other policy and institutional factors in the economy, and their implications to irrigation development.

In most of the irrigation forecasting models, the irrigation demand is estimated assuming a constant per capita requirement and by a linear projection of irrigated acreage on the basis of per capita requirement of food crops; and then adjusting with the population growth over time (for example, see Gleick 1998; Seckler et al. 2000; Alcamo et al. 2000; Shiklomanov 2000; Rosegrant et al. 2002; FAO 2002). These studies assume a zero (or constant) income-elasticity of irrigation and water uses across the sectors. But, a verification of the EKC for irrigation means that an income effect of irrigation is nonlinear and it is an important component of irrigation development. Absence of income effect in the past irrigation studies (irrigation forecasting models) could be one reason for the lower scale of performance of these past irrigation models. Besides, the forecasted results on irrigated areas greatly vary from study to study, which has created several controversies on the future needs of water for agriculture and irrigation demand. (For review on performances of these models, see Rijsberman 2000).

The validation of the EKC relationship for irrigation level means accepting a nonlinear (i.e., inverted U-shaped) relationship between the level of irrigation and the income, i.e., irrigation development at any moment depends upon the level of societal income *(nonlinear income effect)*, and stage of development, and other policy and institutions related factors. This fact has large implications on analyzing demand and supply of irrigation level in the economy. This information is equally important for policy debates on how much irrigation do we need at any moment, and where? In addition, the study on EKC for irrigation also contributes to policy discussions and issues on water for food production versus environment protection. The same issues were also at the heart of the discussions at the Rio de Janerio conference in 1992 and the Johannesburg Earth Summit in 2002, and a search for the win-win path between the societal basic developmental needs and environmental management.

The second section of the paper lays down its objectives and scope. The third section illustrates reasons for emergence of EKC relationship for irrigation. The forth section describes the research methodology and analytical techniques adopted, the variables selected, data used and their sources. The fifth section illustrates the empirical findings obtained from the cross-countries statistical analysis and their implications. The last section provides conclusions and implications of the study-findings.

2. Objectives and Scope of the Study

The major objective of this study is to verify the presence (or absence) of the EKC relationship for irrigation and to illustrate its policy implications. The specific objectives of the study are:

1. To empirically verify the EKC hypothesis for irrigation-development. That is, to test whether an inverted U-shaped relationship exists between irrigation and income level?
2. To evaluate and quantify relationship between irrigation and income levels.

3. To evaluate impact of selected macroeconomic policy, structural and governance related factors affecting the irrigation-income relationship across the countries.
4. To illustrates implications of the study findings on demands for irrigation and water uses.

The EKC relationship for irrigation is analyzed taking data across 66 countries from Asia, Africa and Latin America, i.e., a sample of mostly developing or lower-middle income tropical countries. This covers annual data over the 20-years from 1972 to 1991, for which most of the other cross-country systemic data and policy variables are available with the author and the model structure from earlier constructed for his dissertation research purpose.

The EKC analysis provides a trade-off on different policy options on resources use. This is shown by the EKC path of ADC in figure 1, instead of the path followed by the ABC or ABF. The flattening and lowering of the EKC path by policy or institutional changes in figure 1 is also called *policy-tunneling* process in managing the environment (see Panayotou 1997, 2000; Yandle et al. 2002; Dasgupta et al. 2002). Intuitively, EKC analysis offers us a *policy tunneling* option by. Thus, if we identify the ecological threshold limit in a region (or ecosystem, or hydroecological basin) then the irreversible damage to the environment can be potentially avoided by keeping the environmental damage under the ecological threshold limit. This is illustrated by the ADC path of economy instead of ABC in figure 1.

3. Possible Reasons for the Emergence of EKC relationship for Irrigation

The income growth affects several facets of the economy, and including the societal water uses for irrigation vis-à-vis in other sectors. An economic growth involves transformation of the entire economy from an agriculture-based society at the early stage of development to an industry- and service-sector-based society in the later stage, as seen across the world over the last 300 years, since the industrial revolution time. More than one-third of the annual GDP income of some of the developed economy (UK and USA) now comes from service-sector activities, such as banking and financing (WB 2001). Such change in the structures of economy has large implications for the societal resources-use decisions and for the overall public-policy setting in a nation. (For related discussions, see Ruttan 1971; Samuelson 1976; Antle and Heidebrink 1995; Munasinghe 1999; Yandle et al. 2002.)

The increased income level also brings a major shift in the public-policy priority in the economy, including increasing concerns about environmental protection and value of environmental use of resources (see Yandle 1997). When environmental quality is considered as a luxury good with a high income elasticity , thus the demand for environmental needs of water proportionately increase more as the societal income rises, ultimately leading to the EKC in the economy (for detailed discussion, see Antle and Heidebrink 1995, and in Bhattarai, 2004).

Irrigation is a human induced modification of the natural courses of water flows in a hydrological basin; and thereby, societal decision for irrigation inherently involves ecological and environmental consequences. In other words, the societal decision for irrigation is similar as like that of use other renewable natural resources such as the use of forest resources, fisheries, land resources, crop acreages, etc. From this line of reasoning, the EKC relationship is, at least in principle, also supposed to apply for irrigation, as like that of in the case of change in forest area, where the EKC relationship has very well been established (see Bhattarai and Hammig, 2001).

There is now a rising concern at the global public policy arena on maintaining a minimum "*environmental flow requirement*" in a river basin, which was not any more a water sector policy issue merely 2-3 decades ago (see WCD 2000; Vladimir 2003). The "environmental flow requirement" is now even increasingly being discussed in the middle income countries, but it is still more practiced in the relatively a higher income countries, *ceteris paribus*. The increased income also changes value systems in the society leading to change on perception on societal use of river water across the different sectors in the economy, including for maintenance of minimum ecological function in the river basin.

Instead of term EKC for irrigation, for convenience, we use here a new term "Irrigation Kuznets Curve (IKC)" for explaining the inverted U-shaped relationship between irrigation and societal income level. The author believes that this to be the first study which systematically validates the presence or absence of the environmental Kuznets curve relationship for irrigation, taking a global scale of assessment, and using a consistent statistical analysis. Moreover, we have hereafter interchangeably used in this report the nomenclature of "EKC for irrigation" and "IKC", both of the terms basically mean the same inverted U-shaped type of relationship between irrigation and income level in a society.

4. Methodology and EKC Models

We use *variables, each* reflecting the *underlying factors* associated with irrigation development, represented by broad public policies, institutions and structural factors. The *proximate factors* of irrigation are also important (e.g. market forces, inputs and output prices, and wage rates, etc.), but in reality, irrigation decision, compared to other commodities traded in the market, is almost everywhere decided more by the political market equilibrium and by the forces of interest group politics. Therefore, the selection of underlying factors best serves the study purpose and for policy modeling with factors determining the irrigation at moment.

4.1 Methodology

The EKC relationship is estimated here is a meta-relationship and it applies to an average situation observed across the countries and over the time period selected. At any point in time, the relationship among the variables in one country may differ from the average meta-relationship estimated here. But, the results derived from such meta-analysis are generic in nature and they apply to wider regions; and they are also more relevant for refuting any competing hypotheses. Policy recommendations (or competing hypotheses) that are tested only in the specific context of a country (or an irrigated system) may not equally apply for wider regions (systems) with vast differences on biophysical and socioeconomic characteristics. But, a well-designed cross-country analysis overcomes these limitations, and also helps to resolve the controversial policy debates on the EKC.

Within the short span of 20 years selected here, it is less likely that one would find all the required ranges of income level change and other income-induced changes on irrigation in one nation. Therefore, a technique of panel data analysis (cross-country and time-series) is adopted here to overcome these limitations of a specific country, and/or, a case study based analysis.

4.2 Analytical Models and Variables

The income-irrigation relationship is quantified in the EKC framework of analysis. This is done using annual observations collected from 66 countries in Asia, Africa and Latin America, and from 1972 to 1991. Two set of EKC models are analyzed, one using data from three continents (with 66 countries) called a *tropical-global model* and a second for 13 countries in Asia (called *Asia model),* where more than 60 percent of the global irrigated area is located.

Percent of crop area irrigated is used as measure for irrigation level and it is regressed with income per capita and other policy variables. To avoid the scale and size effects across the countries, the percentage change in crop area irrigated, instead of actual crop area irrigated, is used for analysis. Two forms of the regression model are used: i) Basic IKC and ii) Partial IKC.

Table 1. Description of variables used, expected relationship of explanatory variable with irrigation development, and their sample mean value.

Dependent and Explanatory Variable	Unit	Description	Expected Sign with Dependent Variable	Tropical Global Model Sample Mean	Asia Model Sample Mean
Dependent variables					
1. Percentage of crop area irrigated	%	(Total irrigated area/ Total crop area)*100		10	27.3
2. Relative change in irrigated land	M. ha	Log value of total Net irrigated crop (in million ha)		2	8.7
Explanatory variables					
GDP	US$1000	PPP adjusted per capita GDP 1985 US dollars (1 year lag)	Positive	2.5	1.7
GDP squared			No prediction		
Governance (quality of institutions, 2–14)	index	Sum of political rights and civil liberties indices (2–14). 2 = least freedom, and 14= most freedom	No prediction	7.8	7.3
Average cereal yield	(kg/ha)	National average cereal yield	No prediction	1870	2350
Ag. value added	%	Agricultural value added in the national economy	No prediction	23	32
Mang value added growth	%	Manufacturing value-added growth rate in the economy	Negative	4.5	7.8
Debt/GDP (Foriegn Debt burden)	%	Percent of external debt of country's annual GDP	No prediction	53	35
Enrolment in secondary schools	%	Percentage of eligible adult population enrolled in secondary schools	Positive	39	36
Economic growth rate	%	Annual percentage change in a country's GNP level, adjusted for inflation.	Negative	3.8	3.3
Annual inflation rate	%	Annual change in the GDP deflator	No prediction	94	10.5
Electricity use P. C.	K hr./year	Average electricity use per capita per year	Positive	495	272

Sources: 1. Percentage of crop area under irrigation, macroeconomic variables, GDP, Debt/GDP, inflation rate, and economic growth rate are obtained from the World Bank Growth Research Datasets, provided at http://www.worldbank.org/growth/index.htm. 2. Population growth, rural population density and enrolment in secondary schools are obtained from The World Bank's World Development Report, CD Rom data sets (1998). 3. Governance indices (quality of political institutions) are obtained from Freedom House (at http://www.freedomhouse.org). Higher governance index (14 index) means more political freedom and more civil liberty, which means good governance, and vice versa.

Basic IKC model

The basic IKC form of model includes variables is as given in equation [1].

$$\text{\% of Crop Area Irrigated}_{it} = \alpha_i + \beta_1 Y_{it} + \beta_2 Y_{it}^{\ 2} + \beta_3 T_{it} \qquad [1]$$

where,

% Crop Area Irrigated $_{it}$ = Percentage of crop area irrigated of county i^{th} at t^{th} period,

i $\Rightarrow$ 1…n = for number of countries used in the model (1………66)

t $\Rightarrow$ 1….t = for time period, continuous series, 1972 = 1 and 1991= 20.

α_i = Intercept term (one specific intercept for each country); this captures the country-specific time invariant factors' effects, as noted earlier.

β_i = The coefficient to be estimated from the panel regression model, where, B_i stands for B_1, B_2, and B_3.

Y_{it} = GDP per capita income (Purchasing Power Parity [PPP] adjusted to 1985 constant US$ value) of each country; and lag one period value is used.

T_{it} = Time trend 1 to 20 (1972=1 and 1991=20) to capture effect of any trend effects, and the effect of other time-dependent variables excluded from the model (e.g. interest rate, trade policies, agricultural prices, etc.).

Partial IKC model

A partial IKC model is constructed by adding one policy variable in the "basic IKC model" of equation [1] sequentially, i.e., one variable at a time, and as following the techniques adopted by Shafik 1994b (see in equation 2). The "partial IKC model" also minimizes the multicollinearity among the variables. Details on modeling related techniques are in Bhattarai (2004).

$$\text{\% of Crop Area Irrigated}_{it} = \alpha_i + \beta_1 Y_{it} + \beta_2 Y_{it}^{\ 2} + \beta_3 T_{it} + \beta_4 Z_{it} \qquad [2]$$

where,

All other terms in equation [2] are same as reported in equation [1] earlier, except Z_{it},

Z_{it} = Other policy variables, other than income, and they are the underlying factors such as macro policy, institutional, and structural variables (details are in table 1).

5. Results and Discussions

For both the tropical-global model and the Asia model, the percent of crop area irrigated is regressed first with the income and time trend in the EKC framework, called the "*basic irrigation Kuznets curve mode*l" (*or basic IKC model*); and later in the form of *partial IKC model* by adding one policy variable at a time in the basic model as noted in the earlier section.

5.1 Basic IKC model for percentage of crop area irrigated:

The regression results from the "basic IKC model" for irrigation (i.e., for percent of crop area irrigated) are reported in table 2. Results from both the tropical-global model and the Asia model are reported side by side. In table 2, the variable "time trend" is positive in both the models. This is a plausible result since the crop area irrigated is increasing in majority of the countries selected. The positive sign of time trend also indicates that other model-excluded variables, other than income, have also positively contributed for irrigation expansion during the period, which is a plausible result as irrigation is affected by several factors.

Table 2. Kuznetian relationship for the changes in percentage of irrigated cropped area and income for combined tropical countries (Model 1) and in Asia (Model 2), 1971–1991.

Independent variable	Tropical-global Model (Model 1)	Asia Model (Model 2)
Time trend (1 to 20)	0.004 (13.22)***	0.28 (13.04)***
GDP per capita (lag one period)	0.05 (3.45)***	2.64 (4.40)***
GDP per capita squared (lag one period)	-0.009 (2.44)**	-0.24 (3.42)***
Adjusted R^2 (unweighted value)	0.95	0.96
Number of countries	64	13
Number of observations	1210	246
Turning Point Income (TPI) of the basic EKC model	$2,800	$5,500

Notes:

1. Values in parentheses are absolute t-statistics; ***, **, and * means significant at 1, 5, and 10%, respectively. F statistics of all the above models are significant at 1% level.
2. Both models are estimated as a fixed effect form of panel data regression allowing a separate intercept term for each country included, and the results from WLS and iterated converged models are reported.
3 Country-specific intercept term involved they are not reported here to save space in the table. Details on country-specific intercept values can be obtained from the author upon a request at <madhu.bhattarai@netra.avrdc.org.tw>
4 The basic form of the EKC model is estimated with only income to better analyze net income effect on irrigation.
5. Turning Point Income (TPI) is the income level associated with the turning point of the inverted U-shaped curve.

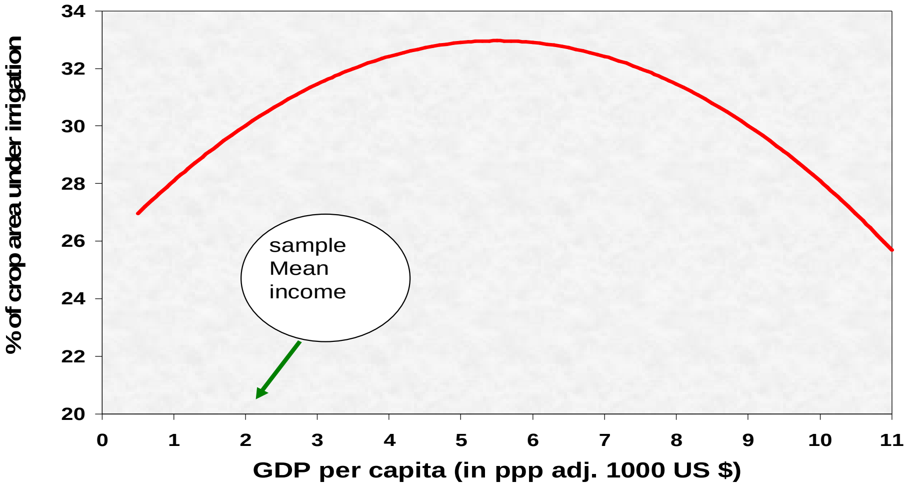
In table 2, a highly significant and positive sign for GDP per capita and the negative sign for GDP per capita squared variable, in both the tropical-global model and the Asia model, suggest that irrigation level rises with the income, and it declines when income reaches to certain critical level. That is, there is an inverted U-shaped relationship between irrigation and income level across the countries. This result provides for a statistically verified EKC type of relationship between the irrigation and the per capita income (i.e. IKC), as hypothesized in this study earlier. The EKC for irrigation holds for both the models.

The high value of adjusted R^2 in both models in table 2 suggest for better explanatory power of the regression models estimated in this study. The model reported in table 2 also includes a separate intercept term for each country, called the state-specific intercept term (used as a country dummy), which captures the effect of country-specific time-invariant factors (e.g. institutional, structural and historical factors) affecting irrigation development over the 20 -years period. To save the space in table 2, the country-specific intercept values are not reported. (The detailed state-specific regression results can be obtained from the author upon request).

Figures 2 and 3 illustrate the IKC diagrams generated from the regression coefficients of the Asia IKC model (table 2) and the Tropical-global IKC model (table 3), respectively. These figures are simulated IKC diagrams and they show a possible scenario of what would happen to the irrigation when the per capita income increases. These IKC diagrams are generated at the sample mean value of intercept, time trend, and with increasing value of the per capita income from US$500 to US$11,000.

The presence of an IKC pattern is obvious in both the Asia model and in the tropical-global model; however, the IKC relationship is more noticeable in the case of the former case (figure 2) than in the case of later case (figure 3). In truth, the inverted U-shaped relationship depicted in figure 2 is more evident than EKC patterns for other environmental factors (such as S02, air and water pollutions, water quality, deforestation, etc) as estimated in the past studies (see, Shafik and Bandhopadhya 1992; Shafik 1994a; Grossman and Kruger 1995; Panayotou, 1997; Bhattarai and Hammig, 2001).

Figure 2. Irrigation Kuznet Curve for Asia generated from the Asia model, 1972-91.

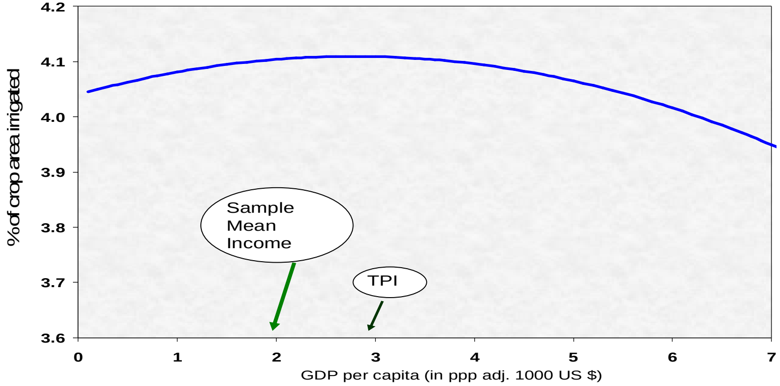


Note: The IKC diagram generated in figure 2 is estimated taking the regression coefficients from the Asia model reported in table 2, with an income range selected from US$500 to US$11,000 with an interval of 100. The average intercept value of 13 countries of the Asia model is 23, which is used to generate this policy-simulated IKC.

The turning point income (TPI) associated with the IKC model varies depending upon the sample of countries (or regions) selected (see figures 2 and 3). In this case, the TPI of the Asia model is US$5,500, which is higher than that of the tropical-global model (US$2,800), and is also consistent with the real-world observations. Out of 66 countries of the global-tropical model, more than 33 countries are from the Africa region (appendix table 1), and 13 are from Asia and remaining 20 from Latin America. The average percentage of crop area irrigated in Asia is very high than in Africa and Latin America, as over 60% of the global irrigated area is in tropical Asia (table 1). Thereby, the global-tropical model is more skewed towards the lower mean average irrigation level than in the case of the Asia model.

Figures 2 and 3 also imply that there is no constant or a unitary value of income elasticity as usually presumed in the past irrigation demand studies (see Glieck 1998; Postel 1999; Seckler et al. 2000; Alcamo et al 2000; Shiklomanov, 2000; Rosegrant, et al 2002). In all of these global irrigated demand studies, the demand for irrigation (water uses for agriculture) is done by multiplication of per capita use of food (or cereal grains) with the population level forecasted. Then, the water scarcity level in a region is then derived comparing this forecasted water demand with the annual renewable water resources naturally available in a future specified time period. The neglect of this curvilinear relationship between irrigation and income (and the substitution effects) could be the one reason for the lower degree of performance of the irrigation projection models constructed so far (finding of these models, see Rijsberman 2000).

Figure 3 Irrigation Kuznets Curve for tropics simulated from the tropical-global model,1972-1991.



Note: As in figure 2, the average of all the intercepts estimated (with value of 4) out of 66 countries in the tropical-global model is used to generate the policy simulated IKC diagram in figure 5.

Partial IKC model for percentage of crop area irrigated

The net impact of each of the policy variables selected on irrigation-income relationship is estimated by including one policy variable (Z_{it}) at a time in the basic IKC model, which is called as partial IKC model, as discussed in equation [2] earlier. The main results from the partial IKC model (both tropical-global and Asia models) are summarized in table 3, and for evaluation, the detailed results of the tropical-global model are separately reported in appendix table 3.

The basic concept of EKC relationship (the income positive and income squared negative, i.e., inverted U-shaped relationship) is observed in each of the partial IKC models reported in table 3. To minimize the space, only the sign (positive or negative) of the marginal impact of the policy factors (Z_{it}) and their significant level are reported in table 3. The sign of some policy variables differ in the Asia model from those of the tropical-global model; which is a plausible result considering the vast differences in the country's characteristics, irrigation and income level, and other institutions and policy factors across the countries in the regions. Key implications of the results in table 3 are summarized below.

The impact of electricity use per capita on irrigation is positive in both the tropical-global and the Asia models, which means that the increased electricity availability have positively contributed to the expansion of crop area irrigated in the recent past. This is a plausible result considering the increasing importance of groundwater irrigation in the recent past, more so in Asian countries; and a very close nexus of energy and groundwater uses (see Shah 2001, 2003).

The sign of variable "cereal yield", a proxy for the overall productivity and technical change in agriculture, is positive in the global model but negative in the Asia model. This means that the improvement of agricultural productivity and technical changes (HYV adoptions, modern inputs use, etc.) in the past also positively contributed for irrigation expansion, when we consider all the tropical countries together. This is also because of the economy-wide additional demand created for irrigation as technology advances. The case is different in the Asia because of already a high level of irrigation in Asia compared to that of the countries from Latin America and Africa. In Asia, the agricultural yield level is not necessary high in the country with high level of irrigation development. For example, in 1990, more than 80 percent crop area in Pakistan is under irrigation, but the cereal yield level there is at much lower compared to the other countries in Asia with much less scale of development of irrigation.

Table 3. Kuznetian relationship for the changes in percentage of crop area irrigated across the tropical countries, 1971 to 1991.

Independent Variable	Topical-global model	Asia model
Electricity use per capita	Positive (***)	Positive (***)
Cereal yield (kg/ha)	Positive (***)	Negative (***)
Ag. value added (%)	Positive (***)	Negative (***)
Manuf. value added growth rate	Negative (*)	Positive (N.S.)
Economic growth rate	Negative (**)	Positive (N S.)
Inflation rate (%)	Negative (**)	Negative (N.S.)
Rural population density	Negative (***)	Positive (***)
Governance (Civil + Political rights)	Positive (**)	Positive (***)
Governance*GDP PC	Positive (**)	Positive (***)

Note:

1. Partial regression model is estimated by adding one variable at a time to the basic EKC model (with time, income, and income squared) as in equation 2 earlier. All explanatory variables are lag of one period (i.e., $t\text{-}1^{th}$ period).
2. Values in parentheses are absolute t-statistics; The sign ***, **, and * are means significant at 1, 5, 10%, respectively. N.S. Not significant at 10%. F statistics of all the above models are significant at 1% level.
3. The basic EKC models are significant in all cases, hence only the significance of other policy variables is reported in this table. To screen out the strength of each variable in influencing the irrigation development and to minimize the multicolinearity problem, one variable is added at one time sequentially to the basic EKC model.
4. In table 1, definition and units of the variables are reported, such as, i) Electricity use per capita = Electricity use per capita per year (in Kh unit/hr), ii) Manuf. Value Added Growth Rate = It measures the manufacturing value added annual growth rate in %. iii) Ag. Value Added % = Agricultural value added % of GDP. iv) Governance is the sum of political liberty and civil liberty levels in a year, and details are in Gastil (1987). iii) Governance*GDP per capita measures the effects of interaction between GDP and governing institutions on irrigation development.

The sign of the variable “agricultural value added” is positive in the tropical-global IKC model, which means less need for irrigation expansion as the agriculture sector shrinks in the economy. The reasons for different result in Asia model from that of tropical-global model are as explained earlier. In fact, the negative sign of the variable “manufacture value added growth rate” in the tropical-global model furthermore supports the “structural change” based explanation of the emergence of the IKC relationship. That is, the economy-wide demand for irrigation is more influenced by underlying structural changes in an economy caused by the income growth. In summary, our empirical results here also support for the structural changed hypothesis-induced by income growth- for emergence of the IKC in the economy (see in Bhattarai, 2004).

The impact of variable “economic growth rate” is negative and statistically significant at 5 % level in both the models, which means a faster rate growing economy requires less and les need for expansion of the irrigated cropland. This again validates the IKC hypothesis. However, its impact is not significant, nor the meaning is so straightforward, in the case of Asia model.

In table 3, the sign of “inflation” variable is negative in both the models, but it is statistically significant only in the case of tropical-global model. This implies that the irrigation development in the past was high in a low-inflationary economy, which is a plausible result considering the huge financial investment required for the irrigation development, and long-gestation period needed to realize benefits of irrigation investment. The discussions on marginal impacts of each of the other policy variables in table 3 are detailed illustrated in Bhattarai 2004.

7**. Conclusions and Implications**

Using the EKC framework of analysis, this study illustrates how irrigation development at any point of time is affected by the level of per capita income, and by other policies and institutional and structural factors. Using statistical analysis, we verified the “EKC” relationship for irrigation (i.e., percent of crop area irrigated), which is called here as “EKC for irrigation”, and/or, “Irrigation Kuznets Curve” (or “IKC” in short). The EKC based explanation of irrigation suggests that societal demand for irrigation is higher at the initial stage of development, and when the income reaches a certain critical level then the societal demand for irrigation gradually ceases. That is, there is an inverted U-shaped relationship between irrigation and income level. In other words, after reaching a certain income level, the net irrigated area in an economy may decline, as already seen in some of the fast growing countries in Asia (Taiwan, Japan, etc.).

One of the reasons for emergence of the IKC relationship in an economy is due to structural changes brought by the income growth. Once the development occurs (increased income), the water needs for industrial and service sectors, including the water demands for environmental services, grow more than that of the agriculture sector. This brings water sector public policy and priority shifts, change in water uses, changes in the relative value (price) of water across the sectors, and contributing for emergence of an IKC relationship in an economy.

After empirically validating the EKC hypothesis for irrigation, this study evaluates also the effects of selected policy and institutional and structural factors on variation of irrigation development. The analysis was done by taking national level annual data from 66 tropical countries for the 20-year period of 1972–1991, once for all the 66 countries, called tropical-global model, and another for 13 countries in Asia, called Asia model.

The basic idea of the EKC relationship was observed for both the tropical-global and the Asia models. The level of Turning Point Income (TPI) however varied by the regions (countries) selected.. In conclusion, the statistically verified inverted U-shaped relationship between irrigation and societal income confirms the existence of an IKC relationship.

Our study also showed for the importance of public policy and institutional factors for flattening the EKC path and potentially in avoiding the irreversible damage to the environment. The empirical results show that the IKC relationship is conditioned by the country’s macroeconomic policies, as well by the level of technologies available, and the underlying governance factors (i.e., quality of governing institutions). All of these mean that there is an important role of the institutions and of the public-policy factors for the sustainable management of irrigation and water uses in an economy; and to ensure the irrigation level (and level of environmental damage) below the ecological threshold limit through policy-induced changes.

A practical application of the results derived here is in deriving irrigation demand in an economy. For estimating irrigation demand, past studies have mostly adopted fixed water requirement of population, and with one to one mapping to the demand for irrigated land on the basis of population growth (for example, see Alcamo et al. 2000; Gleick 1998; Postel 1999; Seckler et al. 2000; Shiklomanov, et al. 2000; Rosegrant et al. 2002). Instead of that, our study here statistically validates for a curvilinear relationship between irrigation and income level, which suggests that it is not only the level of population, which matters for the demand for irrigated area, but also the level of income and other policies and institutional factors. Hence, projection of the irrigation land (or demand for water uses) should be done taking into account the nonlinear income effects and other substitution processes, which would improve the accuracy and overall performance of the irrigation-forecasting models.

The empirical findings of this study contribute to the improved understanding of global irrigation requirement, and the search for an answer to the question, how much more irrigation do we really need at any moment of time? For any given country, our empirical analysis suggests that the irrigation demand depends upon several underlying factors and economic conditions. These include: the country's development stage, income level, institutions, over-time change on structures of the economy -brought about by the increased income. For sustainable use of irrigation and water uses for agriculture, these above factors need to be considered into the planning and management of irrigation

Because of the aggregate scale of analysis, the parameters estimated here should be interpreted cautiously as these estimates of IKC do not represent any specific country case (or irrigation system) where operational-level of irrigation policy are implemented. However, these results, from cross-national analyses, are very useful for validating or refuting the contestable hypothesis and policy prescriptions that are application to wider regions. Since, a cross-country scale of assessment provides information on policy recommendations that are applicable to wider regions and are free from the context-sensitive and anecdotal evidences. This is not the case with the single country, and/or single system level case study.

Acknowledgement:

- This research was carried out when the author was working as a Postdoctoral fellow with International Water Management Institute (IWMI), Colombo, Sri Lanka. The author is grateful to Prof. Randolph Barker, David Molden, and other researchers in IWMI for reviewing the original research report in the past and for their valuable comments and inputs to improve its quality. The author thanks two anonymous reviewers of the draft research report of IWMI, who earlier read the draft report thoroughly and provided very valuable comments and suggestions, which greatly helped in improving quality of this paper. However, the author alone is responsible for any remaining errors in this paper.
- This paper is a summary of findings with selected results of a larger version of research report by the author and published by International Water Management Institute, Sri Lanka. (R. R. No 78) in 2004.

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