RESEARCH REPORT

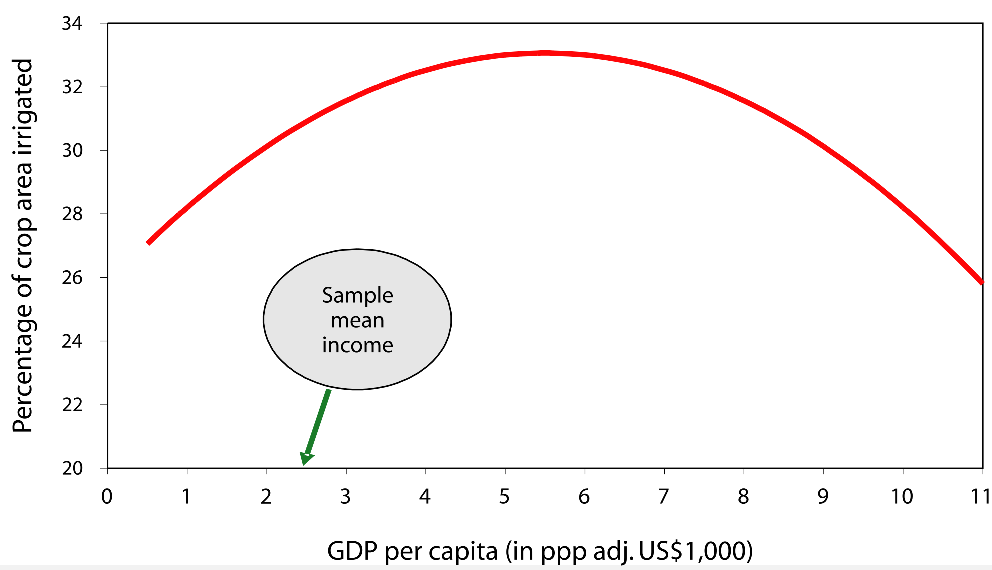
78

Irrigation Kuznets Curve Governance and Dynamics of Irrigation Development

A Global Cross-Country Analysis from 1972 to 1991

Madhusudan Bhattarai

Irrigation Kuznets Curve for Asia generated from the Asia model, 1972-1991.



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Research Report 78

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Madhusudan Bhattarai

International Water Management Institute
P O Box 2075, Colombo, Sri Lanka

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The author: Madhusudan Bhattarai is a Postdoctoral Scientist (Economist) at the International Water Management Institute (IWMI).

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Contents

Summary

This report verifies the Environmental Kuznets Curve (EKC) hypothesis for irrigation. The EKC hypothesis suggests for an inverse U-shaped (or concave) relationship between the level of environmental degradation and income in a given society. The EKC hypothesis also implies that some form of environmental deterioration appears inevitable during the initial stage of development, but subsequent increases in the societal income would generate enough incentives to improve the environmental quality. In line with this reasoning, the EKC relationship for irrigation (referred to here as Irrigation Kuznets Curve, or IKC) hypothesizes that the demand for irrigation is greater at the initial stage of development and that irrigation demand declines as societal income increases. This process subsequently gives rise to an inverted U-shaped relationship between the level of irrigation and the level of income. This information on EKC for irrigation has large implications for planning of irrigation and for analyzing demand for irrigation, and water uses and water reallocations across sectors.

To test the EKC hypothesis for irrigation, a statistical analysis was performed using spatial (cross-country) and temporal (over time) data from 66 tropical countries in Asia, Africa and Latin America over the period 1972 to 1991. The EKC analysis for irrigation was first carried out for 66 tropical countries as a whole (called the tropical-global model), and then separately for 13 countries from Asia (called the Asia model) where more than two-thirds of global irrigated land is located. Two measures of irrigation are used: "percentage of crop area irrigated" and "relative change in net irrigated area." In addition, the impacts of underlying institutions and structural factors on the spatial and temporal variation of irrigation development in the tropical countries were evaluated.

The empirical results suggest a confirmation of the EKC relationship for irrigation—that is, there is statistically verified evidence of the inverted U-shaped relationship between irrigation and income level across tropical countries. This is established for the two measures of irrigation noted above, and for both the tropical-global and the Asia models. The results imply that the demand for irrigation development in a country (region) is higher at the initial stage of development and will gradually decrease as the income increases, and subsequently gives rise to an EKC for irrigation (or inverted U-shaped) relationship in the economy. This means also that the income effect is one of the critical components in the irrigation development process across the countries.

In addition to income growth, we also found that other factors (other than income) also significantly affect the level of irrigation development at any point of time. They are institutions and public policy related factors such as macro economic policy, agricultural productivity, types of structural change in the economy, electricity use, and underlying public institutions and governance structures (quality of the governing institutions).

An important policy implication of the EKC for irrigation is that the irreversible damage to the water-sector environment, while allowing for a normal path of the irrigation development, can be potentially avoided by selecting appropriate policy and institutional tools. This allows for adjusting irrigation expansion below the ecological threshold limit of the region, and such policy-induced changes in irrigation will provide a *win-win* situation that is also consistent with the basic concept of sustainable development.

The information on the inverted U-shaped relationship between irrigation and income

established from the EKC analysis has also large implications in analyzing demand for irrigation in an economy. Past studies on irrigation demand have mostly assumed a fixed per capita requirement-based criteria and zero-income elasticity of irrigation, ignoring the income effects and the underlying societal trade-offs and substitution behavior. As opposed to that, the information on inverted U-shaped income elasticity of irrigation derived from the EKC analysis, if incorporated in irrigation forecasting models (or hydrological models), could greatly improve the accuracy and efficiency of irrigation demand estimation models. This information also has implications for public policy debates on water uses for food production versus environmental protection; and how irrigation and water (re)allocation decisions at any point of time are affected by income, policies, and underlying institutional factors.

Irrigation Kuznets Curve, Governance and Dynamics of Irrigation Development: A Global Cross-Country Analysis from 1972 to 1991

Madhusudan Bhattarai

Introduction

In the context 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 central point of discussion to resolve the water-scarcity problem. But, so far, very limited information is available on societal decisions for irrigation, and the factors affecting economy-wide demand for (or supply of) irrigation. In reality, the income effect of irrigation demand (supply) is very closely linked to the discussions on water uses and water (re)allocation across sectors, but these income effects of irrigation development have, so far, been inadequately addressed by past studies. In this context, this study evaluates the relationship between irrigation and income level using a cross-country analysis.

In particular, this report examines the relationship between irrigation development and the societal income level, and it evaluates how irrigation development in a region (nation) is affected by income, and by other policies, and institutional factors. The empirical analysis is done by adopting a recently developed analytical framework of the Environmental Kuznets Curve (EKC) of environmental economics, which provides information on the relationship between environmental quality and economic growth. The EKC hypothesis suggests that environmental quality deteriorates during the early stage of development and that it starts to improve when income reaches a critical level. Thereby, the EKC framework of analysis depicts the dynamics of the societal decision-making process and use of environmental resources; and it offers policy options for sustainable management of resources, including sustainable use of water resources.

Simon Kuznets in 1955 hypothesized an inverted U-shaped relationship between income inequality and economic growth. He said 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, leading to an inverted U-shaped relationship between the level of income inequality and income growth. This relationship became known as the Kuznets Curve for which Simon 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 the level of environmental degradation and income growth. This has become known as the Environmental Kuznets Curve (EKC),[1] particularly after the seminal work of Grossman and Kruger in 1991. For detailed discussions on EKC, see Grossman and Kruger (1991, 1995), Panayotou (1997, 2000) and Yandle et al. (2002).

Grossman and Kruger (1991) demonstrated that an inverted U-shaped relationship for air and water pollution indicators with income level for a set of countries. Following them, several studies have 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, see Shafik and Bandhopadhya 1992; Shafik 1994a; Grossman and Kruger 1995; Panayotou 2000; Yandle and Qin 1998); and for land use change and deforestation (Cropper and Griffith 1994; Shafik 1994a, 1994b; Bhattarai 2000; Bhattarai and Hammig 2001). Likewise, studies by Rock (1998) and Goklany (2002) 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 the EKC pattern for the irrigation level. This study specifically focuses on this point and it systematically tests the EKC relationship for the irrigation level using statistical analysis. This study also examines how the EKC relationship for irrigation is affected by selected policy and institutional factors in the economy, and their implications for irrigation development.

In terms of practical application of EKC analysis for irrigation, 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 income. This is equivalent to saying that irrigation development is affected by a *nonlinear (curvilinear) income effect*; i.e., irrigation development at any moment depends upon the level of societal income, and stage of development. This fact has large implications on analyzing the demand and supply of irrigation level in the economy, and on evaluation of the societal value and preference systems over the uses of water resources in agriculture and across sectors.

Until now, irrigation demand estimations have mostly been carried out using models that assume a constant per capita requirement by a linear projection of irrigated acreage on the basis of per capita requirement of food crops, and then adjusting that 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 sectors. But, a verification of the EKC for irrigation means that the income effect of irrigation is nonlinear and it is an important component of irrigation development. Absence of income effect in past irrigation studies (irrigation forecasting models) could be one reason for the lower scale of performance of these past irrigation models. Also, the forecasted results on irrigated areas greatly vary from study to study, which has created several controversies regarding the future needs of water for agriculture and irrigation demand (for a synthesis on performances of irrigation demand forecasting models, see Rijsberman 2000).

Because of these reasons, the improved quantitative information of EKC for irrigation, or the information on the inverted U-shaped relationship between irrigation and income, would contribute to a better understanding on societal decision for irrigation, and or factors affecting dynamics of irrigation development. This information is also critical for policy debates on finding out how much irrigation we need at any point in time, and where. In addition, the study

[1]The Grossman and Kruger 1991 study was the first empirical exercise to demonstrate a Kuzents curve type of relationship between environmental quality deterioration and level of income, which is now known as the Environmental Kuznets Curve in literature on environmental economics.

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 basic social developmental needs and environmental management.

The second section of the report lays down the objectives and scope of the study. The third section illustrates the basic concept of EKC and its implications for environmental policy-making, including a synthesis of key past studies on EKC for water-sector issues. The fourth section points out possible reasons, as to why the EKC relationship should also apply for irrigation development. The fifth section describes the research methodology and analytical techniques adopted, the variables selected, nature of data and their sources. The sixth section illustrates the empirical findings of the study. These include recent trends in irrigated area and structural changes in selected countries, empirical results obtained from the cross-country statistical analysis (regressions model), and their implications. Conclusions and major implications of the study are provided in the last section of the report. Likewise, the annex section of the report provides findings of the closely related past EKC studies that theoretically contribute to the subject-area, and econometrics and technical issues involved in estimating the irrigation EKC model across the countries.

Objectives and Scope of the Study

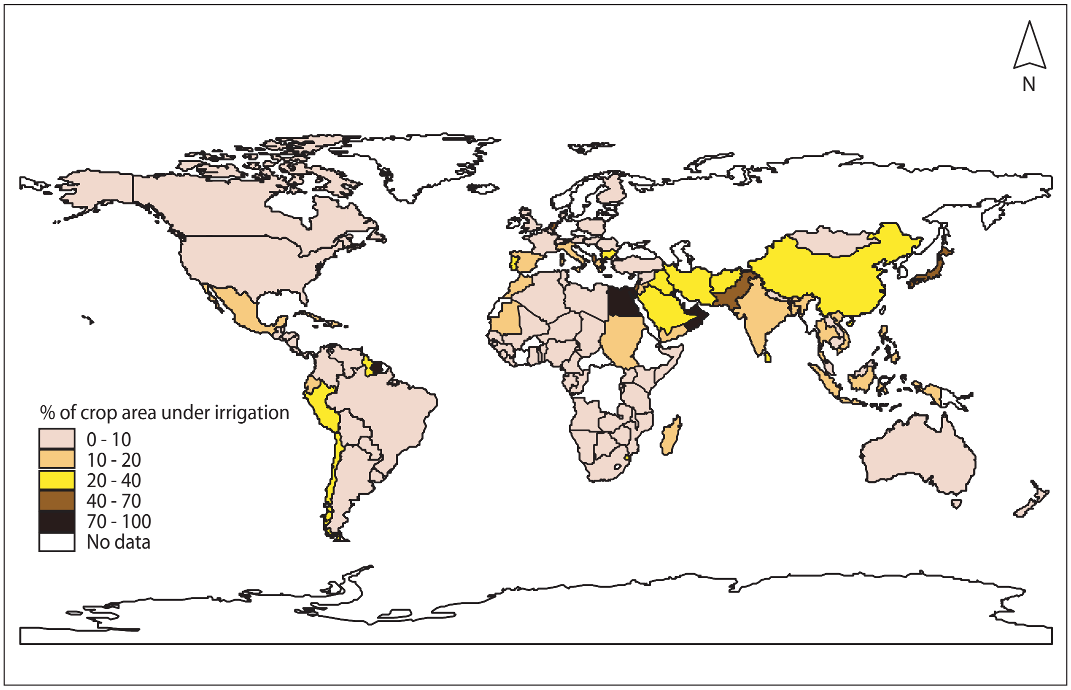
The major objective of this study is to empirically verify the presence of the EKC relationship for irrigation and to illustrate its policy implications. The specific objectives of the study are:

- 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.
- To evaluate and quantify the systematic relationship between irrigation level and per capita income level across tropical countries.
- To evaluate the impact of selected macroeconomic policy, structural and governance related factors affecting the irrigation-income relationship across the countries.
- To analyze policy implications of the empirical findings on EKC for irrigation.

The EKC relationship for irrigation is analyzed by taking data across 66 countries from Asia, Africa and Latin America, i.e., a sample of mostly developing or lower-middle income tropical countries.[2] This covers annual data over a 20-

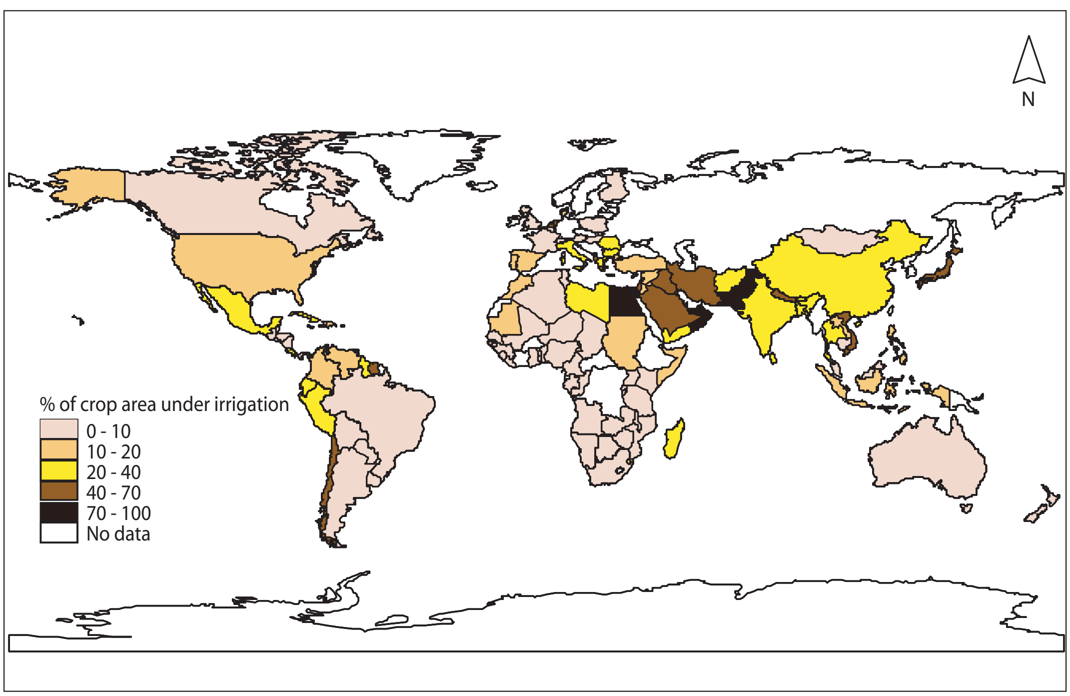
[2]The income level of developed countries is at a higher level, and the irrigated crop area in these countries is declining; which already illustrates the EKC type of relationship for irrigation in these countries. Whereas, this study excludes developed economies from North America, Europe and Australia; including Japan and Taiwan from Asia, and the Middle East and Northern African countries. The EKC relationship for irrigation in developing countries, or less-developed economies in the tropics, as selected here, is a more challenging and a policy-relevant task than the case of developed economies, where the irrigation level is already stabilized, and/or, on a declining trend.

FIGURE 1A.
Country-wise percentage of crop area under irrigation in 1970.



Source: World Development Indicator, 2001

FIGURE 1B.
Country-wise percentage of crop area under irrigation in 1990.



Source: World Development Indicator, 2001 year period from 1972 to 1991. The global percentage of crop area under irrigation in 1970 and in 1990 is illustrated in figures 1a and 1b, which shows the spatial distribution and pattern of irrigation development and its pace of change across the countries over the two decades.

Key Past Studies on EKC, Concepts, and Policy Implications[3]

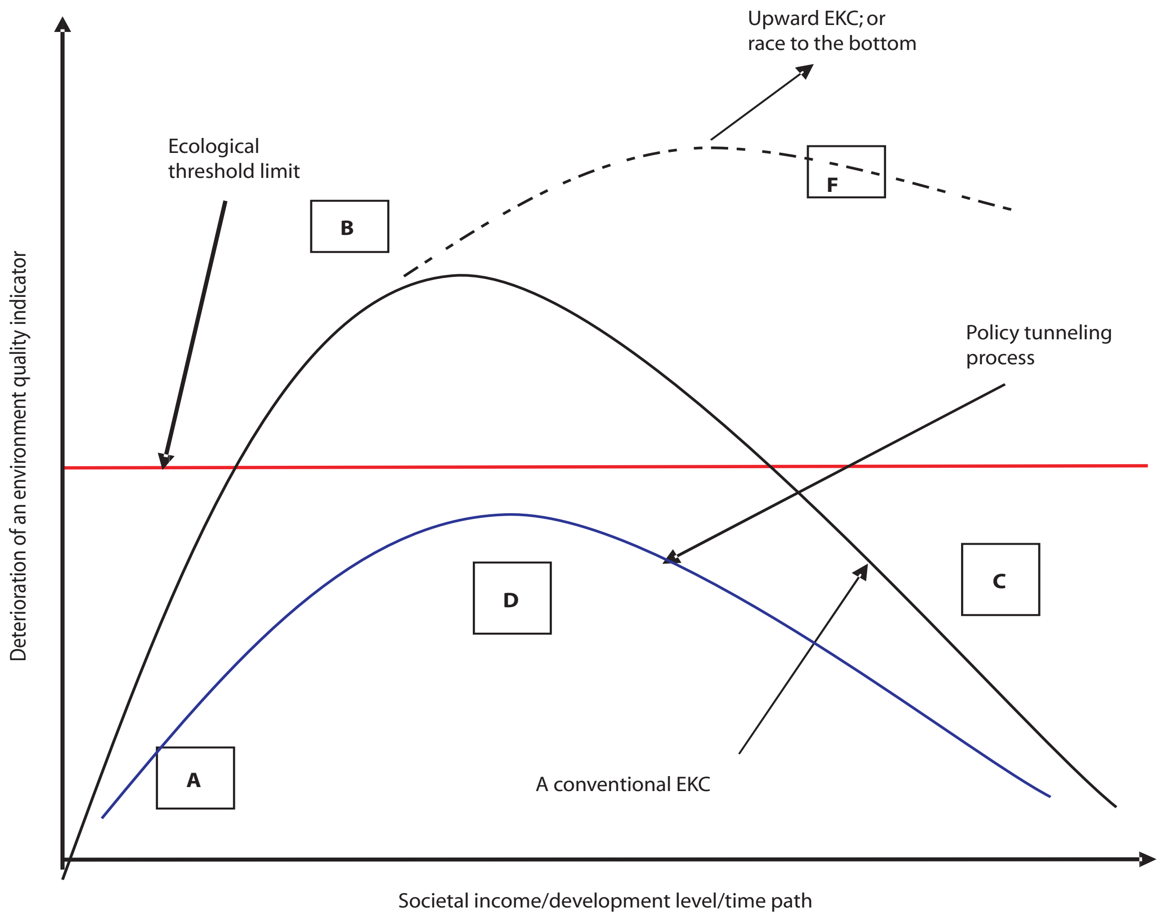
Past studies on EKC in the water sector have mostly focused on water-quality issues (e.g., Yandle and Qin 1998; Torras and Boyce 1998; Grossman and Kruger 1995; Vincent 1997; Hettige et al. 2000). More closely related to EKC for irrigation-related studies are Rock (1998) and Goklany (2002). Both provided a possibility for an inverted U-shaped relationship between per capita water withdrawal for agriculture and income level. The study conducted by Rock (1998) used a statistical analysis across states of USA, and across selected countries (mostly in developed contexts). Whereas, the study by Goklany (2002) used a qualitative assessment, over 100 years of a graphical trend at the global level, to illustrate the EKC type of pattern for water withdrawal in agriculture. The key findings of selected past EKC studies are summarized in annex note A and in annex table 2.

A typical EKC diagram is shown in figure 2. A study on EKC for environmental factors, including irrigation or water-sector issues, provides information on policies that help to move the economy to a sustainable path with least costs and potentially least damages to the environment. For the policy applications, EKC study offers options for a win-win situation (development options with minimum harm to environment) by restricting the damage within a ecological threshold limit of a region. The basic concept of EKC and its policy implications to environmental management and sustainable development issues are as depicted in the figure 2.

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 2, 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 2 is also called a *policy tunneling* process in managing the environment (see Panayotou 1997, 2000; Yandle et al. 2002; Dasgupta et al. 2002). Institutively, EKC analysis offers a *policy tunneling* option by flattening the EKC path. Thus, if we identify the ecological threshold limit in a region (or ecosystem, or hydroecological basin), irreversible damage to the environment can be potentially avoided by keeping environmental damage under the ecological threshold limit. This is illustrated by the ADC path of economy instead of ABC in figure 2.

[3]There is no study which specifically illustrates the EKC relationship for irrigation and, therefore, we have summarized here EKC-related studies on water-sector issues, and other related key studies. For discussions on important generic literature on EKC, see Panayotou 1997 and Yandle et al. 2002.

FIGURE 2.
A typical Environmental Kuznets Curve and its policy implications.



Policy Implications of EKC Analysis

- Tunneling policy by allowing the development (damage) within certain limit and below the ecological threshold limit; thus avoiding the irreversible damage in the ecosystem (economy).
- Flattening the EKC by policy and institutional changes, and providing economic development options with minimum possible damage to the environment.
- Policy options to achieve sustainable development in the long run by allowing economic development by limiting the environmental damage within threshhold limit (i.e., win-win situation).
- The importance of societal basic needs and achieving a minimum development level for better management of environment resources.

Possible Reasons for the Emergence of EKC for Irrigation

Societal perceptions of consumptive use versus environmental use of a resource is determined by societal value and preference systems, which in turn, are shaped by income level, and other underlying structural and institutional factors, and opportunities available for substitution of resources (see Samuelson 1976). Thus, the process of income growth affects several facets of the economy, including water uses for irrigation vis-à-vis in other sectors. In fact, economic growth (or economic development) also 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 at a later stage, as seen across the world over the last 300 years, since the time of the first industrial revolution. More than one-third of the annual GDP income of some developed economies (UK and USA) now comes from service-sector activities, such as banking and financing (WB 2001). Such changes in economic structures, brought about by income growth, has large implications for societal resources-use decisions and for the overall public-policy formulation process within a nation (for detailed 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 public-policy priority in the economy, including increasing concerns about environmental protection and the value of environmental uses of resources (see Yandle 1997). When we consider environmental quality as a luxury good, it has high income elasticity[4] which means the demand for environmental needs of water proportionately increase more as social income rises, ultimately leading to the EKC in the economy (for detailed discussion, see Antle and Heidebrink 1995, and in annex note B).

Moreover, irrigation is a human-induced modification of natural courses of water flows in a hydrological basin; and thereby, societal decisions for irrigation inherently involve ecological and environmental consequences. In other words, the societal decision for irrigation is similar like the use of other renewable natural resources[5] 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, like in the case of forest area changes, where the EKC relationship has been very well established (see Bhattarai and Hammig, 2001).

In real world observations, the fundamental issues and concepts discussed on EKC for irrigation are in fact consistent with the present water sector public policy debates. For example, there is now rising concern on the global public policy arena on maintaining a minimum "*environmental flow requirement*" in a river basin, which was an insignificant water sector policy issue merely 2-3 decades ago (see WCD 2000; Vladimir 2003). The "environmental flow requirement" is now ever increasingly being discussed in the middle income countries, but it is still practiced more in relatively higher income countries, *ceteris paribus*. The increased income

[4]In economics, the income elasticity (of demand) of a normal good is positive and less than one. When the income elasticity of a good is positive and more than one, the good is called a superior or luxury good. The elasticity term in economics is a unit-free measurement of a factor impact on a policy variable.

[5]A detailed recent review of theoretical literature on EKC can be found in Yandle, et al. (2002), and EKC for forests and natural resources are found in Bhattarai (2000); Bhattarai and Hammig (2001). Studies by Rock (1998) and Goklany (2002) illustrate the possibility of the EKC for water-withdrawal for agriculture uses (details of their findings are summarized in annx notes A and B).

growth and the associated changed value systems in society have lots to do with such changing perceptions on the societal use of river water across different sectors in the economy, including for the maintenance of minimum ecological functions in a river basin.

Instead of the term EKC for irrigation, here a new term "*Irrigation Kuznets Curve (IKC)*" is used for explaining the inverted U-shaped relationship between irrigation and societal income level. The author believes that this is the first study which systematically validates the presence or absence of the Environmental Kuznets Curve relationship for irrigation, taking a global scale of analysis, and using consistent statistical analysis. This new nomenclature of IKC is adopted here for convenience, however, "EKC for irrigation" and "IKC" are used interchangeably in this report. Both terms basically mean the same inverted U-shaped type of relationship between irrigation and income level.

Methodology and EKC Models

In this section, we first discuss a general methodology and framework of EKC analysis and the nature of data used. In the second part, we illustrate the analytical models used and variable specifications for estimation of IKC.

Methodology of EKC Analysis

To test the EKC hypothesis for irrigation, we adopt an *ex-post* cross-country level of analysis. Instead of a conventional consumer's utility maximizing model[6] with an assumption of the demand and supply equilibrium in a perfect marker condition, we use a reduced form of empirical model with broad-level economic and institutional factors, along with per capita income level, to explain the level of irrigation across countries. Many of these explanatory variables are non-market and higher order institutions by nature.

In reality, the level and process of irrigation development at any point in time is influenced by a host of factors, which can be broadly divided into two categories:

- Proximate factors: Those factors that are directly and immediately observed in irrigation development. For example, government investment (intervention) decisions in irrigation, or farmer investment in a tubewell. This also includes local and regional market forces (food prices, energy prices, crop prices, etc.).

- Underlying factors: Those factors that are associated with the ultimate reasons for the development of irrigation in a region such as, transformation of a regional economy, changes in demographic factors, changes in other socio-economic structures, and shifts in macroeconomic and regulatory policies.

[6]The conventional demand and supply equilibrium market model, with the price effects of consumer behavior, may not be appropriate when allowed for the overtime change in institutional and other structural factors. This is also the reason that past studies on EKC have adopted this kind of reduced form of analytical method (see details in Bhattarai 2000; Panayotou 2000; Bhattarai and Hammig 2001). This type of model is more relevant to irrigation, because irrigation largely set by political economy and institutional factors everywhere rather than by the changes in factor-inputs and crop-outputs prices.

These are not so apparently linked only to irrigation, but since time immemorial, they are the fundamental reasons for public sector involvement in irrigation all over the world.

In this study, we use *variables, each* reflecting the *underlying factors* associated with irrigation development. This includes factors represented by broad public policy, institutions and structural factors, mostly non-market elements in the economy. The *proximate factors* (e.g., market forces, inputs and output prices, and wage rates, etc.) of irrigation are also important, but in reality, irrigation decisions, as opposed to other commodities traded in the market, are almost everywhere decided more by the political forces and by the forces of interest group politics. Therefore, the selection of underlying factors best serves the study purpose and factors determining irrigation.

Because of the cross-country and time-series-data-set used, the EKC relationship estimated in this study is a meta-relationship, which applies to an average situation observed across 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 more generic in nature and they apply to wider regions; and they are more relevant for refuting any competing hypotheses. A policy recommendation (or competing hypotheses) that is tested only in the specific context of one country (or one irrigated system) may not equally apply for a wider region (systems) with different biophysical and socioeconomic environments. But, a well-designed cross-country analysis overcomes these limitations[7], and also helps to resolve controversial policy debates.

Within the short span of 20 years selected here, it is unlikely 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 cross-country and time-series analysis (panel data) is adopted in this study to overcome these limitations of a specific country based, and/or a case-study scale of analysis.

Analytical Models and Variables

The statistical analysis (regression analysis) is done using annual observations collected from 66 countries in Asia, Africa and Latin America from 1972 to 1991. The name of the country included along with its GDP per capita income (in 1990) is listed in annex table 1. Two sets of EKC models are analyzed, one using data from all three continents (with 66 countries) called a *tropical-global model* and a second for Asia alone (with 13 countries) called the *Asia model*, where more than 60 percent of the global irrigated area is located.

Two measures of irrigation are used to test the EKC for irrigation that are comparable across countries, these are:

- Percentage of crop area irrigated.
- Relative changes in irrigated land (log value of irrigated land).

To avoid scale and size effects across countries, the relative change in irrigated land (log value), instead of actual irrigated land area, is used in the EKC model. Each of these two measurems of irrigation is regressed with income per capita and other policy variables using the framework of the EKC analysis.

[7]This kind of cross-country analysis is also useful for better isolating the net effect of broad-level institutional and macro policy factors, for a short span of time, they are usually constant within a system or country. But, even these factors largely vary across countries at any given time, and the pace of change also varies greatly. Therefore, a well-designed cross-country analysis (or a panel analysis) better captures the impact of higher order institutions and policies on changes in irrigation than the model based on commodity-prices equilibrium.

Irrigation Kuznets Curve for percentage of crop area irrigated

Two forms of the regression model are used: i) basic IKC and ii) partial IKC. Both forms of the models are specified as the fixed effects form of panel model, with one intercept for each country to control the effects of state-specific factors. In particular, the country-specific intercept term here controls the effects of country-specific policy and institutional factors on temporal and spatial variation of the irrigation-income relationship The model is estimated as weighted least squared (WLS) technique (or Generalized Least Squares, GLS). Details on econometrics and the estimation techniques are reported in annex note C.

Basic IKC model

The basic IKC form of the model includes variables like income, income square, a time trend, and a country-specific intercept. The model is as given in equation [1].

$$\text{Percentage of crop area irrigated}_{it} = \alpha_i + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 T_{it} \qquad [1]$$

where,

Percentage of crop area irrigated $_{it}$	=	Percentage of crop area irrigated of county i^{th} at t^{th} period,
$i \Rightarrow 1 \ldots n$	=	for number of countries used in the model
$t \Rightarrow 1 \ldots . t$	=	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][8] adjusted to 1985 constant US$ value) of each country; and lag one period value is used
T_{it}	=	Time trend, ranging from 1 to 20 (1972=1 and 1991=20) to capture the effect of any trend effects, and the effects of other exogenous time-dependent variables that are excluded from the model but they effect irrigation (e.g. interest rate, trade policies, agricultural pricing policies, etc.).

Partial IKC model

To construct a partial IKC model, one policy variable is added in the "basic IKC model" of equation [1] sequentially, i.e., one variable at a time. This is done following the techniques adopted by Shafik (1994b). The partial IKC model is used as in equation [2].

[8]PPP US dollar value represents the value of local currency expressed in Purchasing Price Parity adjusted to US dollar values that are internationally comparable across countries, estimated based on the basket of the goods that the local currency can purchase at the local markets (WB 2001).

$$\text{Percentage of crop area irrigated}_{it} = \alpha_i + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 T_{it} + \beta_4 Z_{it} \qquad [2]$$

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 as noted above. They include macro policy, institutional, and structural variables. More specifically, they are variables like cereal yield, electricity use per capita, inflation rate, agricultural value added in the economy, growth in manufacturing sector value added, rural population density, population growth rate and governance-related and institutional-related factors. Detailed specifications are given in table 1.

This type of "partial IKC model" better isolates the net effect of the each of the policy factors on irrigation controlling for the income-effect. To the extent that these policy variables (Z_{it}) influence the percentage of crop area irrigated (or irrigated land), they influence the irrigation-income relationship (or IKC). Hence, from the pubic policy perspectives, the results from the "partial IKC models" carry significant implications. Besides, the "partial IKC model" also minimizes the multicollinearity problems among the variables selected.

Irrigation Kuznets Curve for change in irrigated land

The IKC for irrigated land area, i.e., EKC for relative change in net irrigated land area, is analyzed using a similar IKC framework of analysis as applied in equation [1] earlier for change on percentage of crop area irrigated. The model is as given in equation [3].

$$\text{Change in irrigated land area irrigated}_{it} = \alpha_i + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 T_{it} \qquad [3]$$

The dependent variable of equation 3 is the log value of net irrigated area instead of the percentage of crop area irrigated used in equation [1] earlier. The irrigated land area largely varies across countries depending upon the scale and size of the countries, whereas, the "log value of irrigated land" represents a proportionate change in the irrigated land, and it is free from the scale and size of the countries and so comparable across all counties. All other techniques applied, and variables like income and time trends used in the IKC model for changed in irrigation land area in equation [3] are similar to that of IKC for the percentage of crop area irrigated discussed in equation [1] earlier.

TABLE 1.
Descriptions of variables used, expected relationship of explanatory variable with irrigation development and their sample mean values.

Dependent and explanatory variables	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 irrigated crop (in million ha)		2	8.7
Explanatory variables					
GDP	US$1,000	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	1,870	2,350
Ag. value added	%	Agricultural value added in the national economy	No prediction	23	32
Manuf. value added growth	%	Manufacturing value-added growth rate in the economy	Negative	4.5	7.8
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, inflation rate, and economic growth rate are obtained from the World Bank Growth Research Datasets, at http://www.worldbank.org/growth/index.htm.

2. Population growth and rural population density 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.

Results and Discussions

This section is divided into three sub-sections. First, we provide a descriptive analysis on how the irrigated area and structure of the economy would change when income grows, by taking examples from some of the East Asian countries such as Taiwan and Japan, and its implications for emergence of the EKC for irrigation. In the second part, we provide temporal changes in trends of irrigated area in selected countries and its implications for the EKC for irrigation. In the third part, we provide empirical results on EKC for irrigation from the statistical analysis (regression models).

Structural Changes in the Economy and Implications for Irrigation

Irrigation demand is in principal a derived demand affected by the type of crops grown, extent of crop area, and the structure of the economy. Declining irrigated area in Western Europe and North American countries, and a similar trend recently seen in developed Asian economies like, Japan, Taiwan, South Korea and The People's Republic of China clearly suggest the possible existence of an inverted U-shaped (concave shape) relationship between irrigation and income level. For example, in Taiwan, the total crop area has declined from 1.52 million ha (M ha) in 1955 to 0.96 M ha in 1999 (CEPD 2000), a decline of over 37 percent during the 45 years (see table 2). Similarly, the net irrigated area of Taiwan has also declined over the period, as Taiwan's per capita income grew. A quick glance at changes in the structure of Taiwan's agrarian economy overtime, as its income grew, is given in table 2.

Table 2, clearly illustrates how irrigation land and the agriculture sector, in general, shrunk in Taiwan's economy as income grew; over time, and the share of agriculture in its national economy declined and the concurrent decrease in population dependent on agriculture, and the net irrigated land area in the country (for details, see annex table 3 and Levine et al. 2000).

During the last five decades in Taiwan, the net paddy land area declined by 15 percent, but the second season paddy area declined by over 50 percent (table 2); which means that the second season paddy fields have been diversified to other higher-value crops[9] because of the changes in the economic structure of the country. All of these indicators point to the existence of an EKC for irrigation in Taiwan.

Recently, over the last two decades, a similar type of change has also been emerging in mainland China (PRC), where the net rice area has declined from 33.8 M ha in 1980 to 31.3 M ha in 1999 but the rice yield has increased from 4.2 t/ha in 1980 to 6.4 t/ha in 1999 (FAO 2001), overcoming the negative impact of loss of aggregate crop area on rice production (for more discussions, see in annex note B and annex figure 3).

Over time as an economy grows, the share of farm household population declines, both in absolute and relative terms (see table 2), which is also visible in the Japanese economy (see table 3). Most of the farmers in Japan, and in Taiwan, are now part-time farmers, where the farming households engaged in agriculture declined from 5.6 million in 1965 to 2.8 million in 1999—a decline from 24 percent share of the total national households in 1965 to merely 6.6

[9]The changes in type of crops grown, and the extent of crop acreage, obviously have a significant implication on irrigation demand in the economy. In the case of USA, where the land is not a scarce factor as in Taiwan and Japan, irrigated land in the southern part of USA, where rice and cotton used to be grown earlier, until 4 to 5 decades ago, are now either kept as fallow land or transformed into forestry and wood plantations (author's personal observations). These changes are due to changes in the labor market and other sectoral shifts brought on by income growth.

TABLE 2.
Some of the structural changes in the Taiwan agrarian economy over the last five decades.

Year	Per capita GNP at current price (US$)[1]	Net irrigated area (1,000 ha)	Agriculture share (%) in national GDP	Total crop area (1,000 ha)	Total paddy fields (1,000 ha) (net crop land)	Total rice planted area (1,000 ha) (gross crop area)	Agricultural population as a percentage of total population	Total agriculatural household polulation (in millions)
1952	196	——	32	1,521	534	778	52	4.38
1965	217	490	24	1,680	537	773	45	5.74
1971	443	430	13	1,620	526	753	40	5.96
1981	2,670	410	7	1,398	503	669	28	5.10
1991	8,980	390	4	1,127	473	429	21	4.21

Sources: 1. Taiwan Food Statistics Book, 1997. Department of Food, Republic of China.
2. Agricultural Production Statistics Abstract, Republic of China, 1996.
3. Taiwan Statistical Data Book, Council for Economic Planning and Development (CEPD), 2000.

Notes: [1]PPP adjusted per capita income of Taiwan in constant dollar values is not available in the cross-countries comparable publications of the World Bank and other agencies. This is also the reason for exclusion of Taiwan in cross-countries level of the statistical analysis discussed in the next section. But, Taiwan case is important for the discussion on issues related to EKC for irrigation, because of the fast pace of income growth, from developing to a developed economy, within a short span of time.

percent in 1999 (see table 3). Such income-induced structural changes have large policy implications for irrigation and other rural-sector planning and investment decisions. All the data in tables 2 and 3 support the existence of an EKC hypothesis for irrigation.

Not only aggregate country-level indicators, but some of the village-level indicators from Southeast Asia have also shown such structural changes in the rural economy as income grew, as shown in table 4 below. During a 10-year period (1985/1987 to 1995/1997), the percentage share of income from rice as well as from other farming sectors declined in all three surveyed villages in the Philippines and Thailand. This is consistent with the typical changes in the structures of the rural economy in Asia in general, mostly seen during the post Green Revolution period. In table 4, the income from the non-farm sector has in general increased in all three types of villages, more in the case of irrigated villages than the other two types of villages.[10] This extent of transformation in a village economy within a decade, further provides evidence on the working of the IKC relationship in Asia.

Despite the reduction in total irrigated land in some East Asian economies (Taiwan, Japan), and more recently in Malaysia, the overall agricultural production and productivity in these countries has dramatically increased in the recent past, mainly due to timely policy and institutional changes. In fact, the process of change in these institutions and polices is endogenously determined, as postulated by the induced innovation hypothesis, by the changes in income and availability of technology factors (see Ruttan and Hayami 1998). More discussions on related issues and other agrarian policy changes in these Asian countries can be found in Kaosa-ard and Rerkasem (2000); Rosegrant and Hazell (2000); Barker and Dawe (2001).

[10]The two upland villages in Thailand are exceptional cases, where the non-farm-sector income has not been increased to such a noticeable scale, but has rather decreased marginally over the selected period. For a detailed discussion on these issues, see Barker and Dawe 2001.

TABLE 3.

Agricultural sector and demographic changes in Japan from 1965 to 1993.

Structure of population by type		Year	
		1965	1993
1.	Total population (in millions)	98	125
2.	Total farming population (in millions)	30	13
3.	Farmers' family share in total national population (%)	31	11
4.	Total households number (in millions)	24	43
5.	Total farming households number (in millions)	6	3
6.	Share of farm households in total national-level households (%)	25	7

Source: JSDRE (Irrigation and Drainage in Japan), 1995.

Note: This table shows the demographic shift in the population as the country's income rises over time.

TABLE 4.

A decade-wise change in percentage of rural household income from rice and other farming and non-farming sectors in selected villages in the Philippines and Thailand.

	Irrigated		Rain-fed		Upland	
Philippines	1985	1997	1985	1997	1985	1997
Rice	42	29	55	41	25	17
Other farming	18	6	26	10	42	22
Non-farm	40	65	19	49	33	61
Thailand	1987	1995	1987	1995	1987	1995
1. Supan Buri						
Rice	56	21	53	17	53	27
Other farming	36	31	27	18	8	36
Non-farming	8	48	20	65	39	37
2. Khon Kaen						
Rice	46	8	28	8	30	19
Other farming	10	5	14	7	19	32
Non-farming	44	87	58	85	51	49

Source: Adapted from Barker and Dawe 2001, which gives a more detailed discussion on these recent structural shifts in the Asian rural economy.

Note: Both Philippines and Thailand are middle-income countries.

On the other hand, in the case of India and Pakistan, in spite of the massive expansion in irrigation over the last few decades, the overall aggregate agricultural productivity (measured by the level of cereal yield) of these two countries has not been improved to the level prevailing in East Asian or South East Asian countries (for related discussions, see Kalirajan and Shind 1997; Kaosa-ard and Rerkasem 2000; FAO stats 2001). Similar to agricultural productivity, the income level has also not been improved in these two countries, and in South Asian countries in general, over the last few decades, as is the case in East and South East Asian countries.

Trend in Irrigation Development across the Selected Countries

A four-decade trend in irrigation level (percentage of crop area irrigated) in selected countries from Asia is illustrated in figure 3. The irrigated crop area trend of developed economies like Japan has been decreasing since the mid-1960s. In China, it has been almost flat since the mid-1980s, whereas, irrigation is showing an increasing trend in Thailand, India and Pakistan.

The IKC cannot be more clearly evident than in the case of Thailand and Japan, as shown in figure 4. The irrigated land in Japan began declining in 1966, but shows a rising trend in Thailand (figure 4). This absolute decline in irrigated area in Japan, and in Taiwan as noted earlier, could be due to land conversion from the food crop production to urban housing or industrial development, or for farm forestry or recreation purposes because of rising income; or it could be because of conversion to rainfed farming (at margin) due to increased water-scarcity and increased demand for intersectoral reallocation of water in the economy.

Likewise, figure 5 illustrates the change in irrigated land and income in a single country (Taiwan). Taiwan stands out as an exceptional country that has dramatically increased its per capita income over the last 20 years, an increase from US$4,000 in 1980 to over US$13,000 in 1995 (both are in constant values), as shown in figure 5. The absolute decline in irrigated area in Taiwan, (a greater decline since 1980) is very clear evidence of the emergence of the IKC relationship in Asia.

Instead of the qualitative trend analysis as shown in the figures 3 to 5, a statistical analysis can provide more systematic and consistent evidence of the impacts of factors on irrigation level, including the impact of income, which are free from country-specific anecdotal factors. Therefore, for validating the IKC relationship across countries, a regression model based statistical analysis is used. Detailed results are provided in the next section.

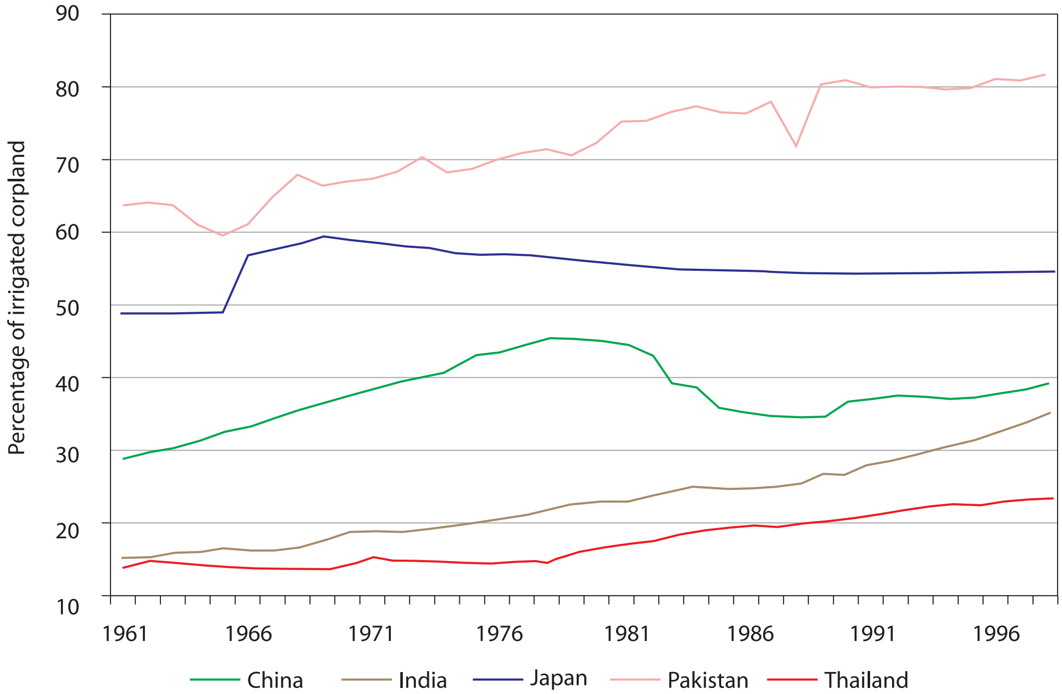
Cross-countries IKC Model

Based on the measures of irrigation used, this section is further divided into two sub-sections.

IKC for percentage of irrigated crop area

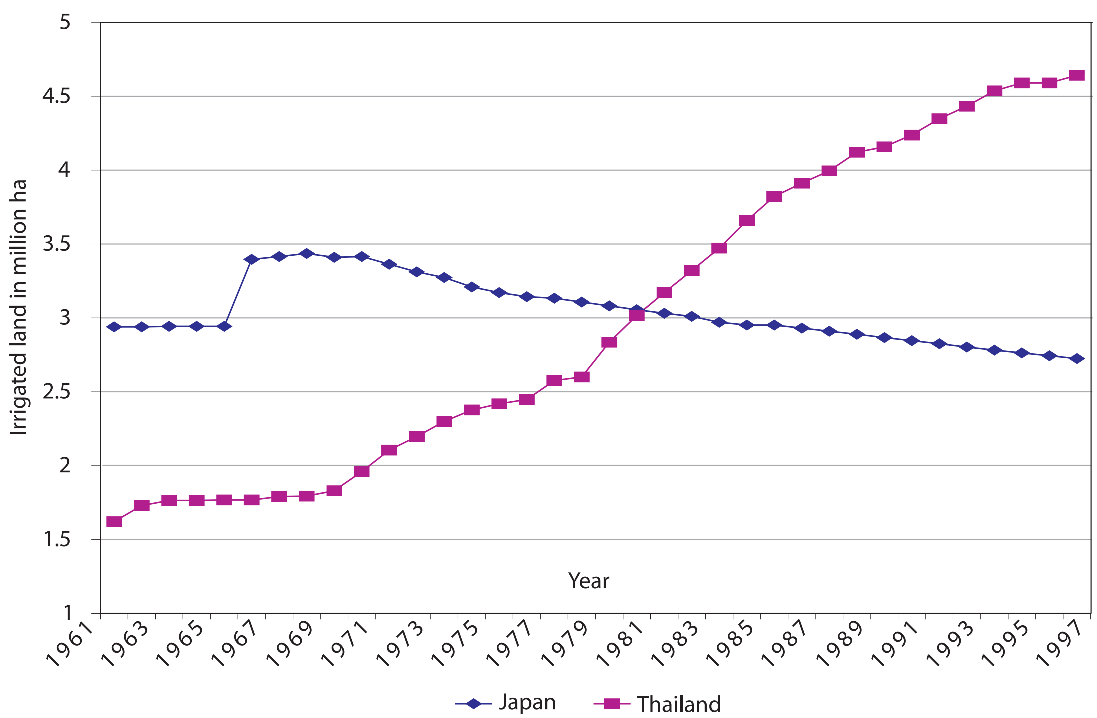
For both the tropical-global model and the Asia model, the percentage of crop area irrigated is regressed first with the income and time trend in the EKC framework, called the “basic irrigation Kuznets curve model” (or basic IKC model), and later in the form of a partial IKC model. The detailed techniques are as noted in the methodology section and in equations [1] and [2] in the earlier section.

FIGURE 3.
Percentage of irrigated cropland in selected countries in Asia, 1961-1997.



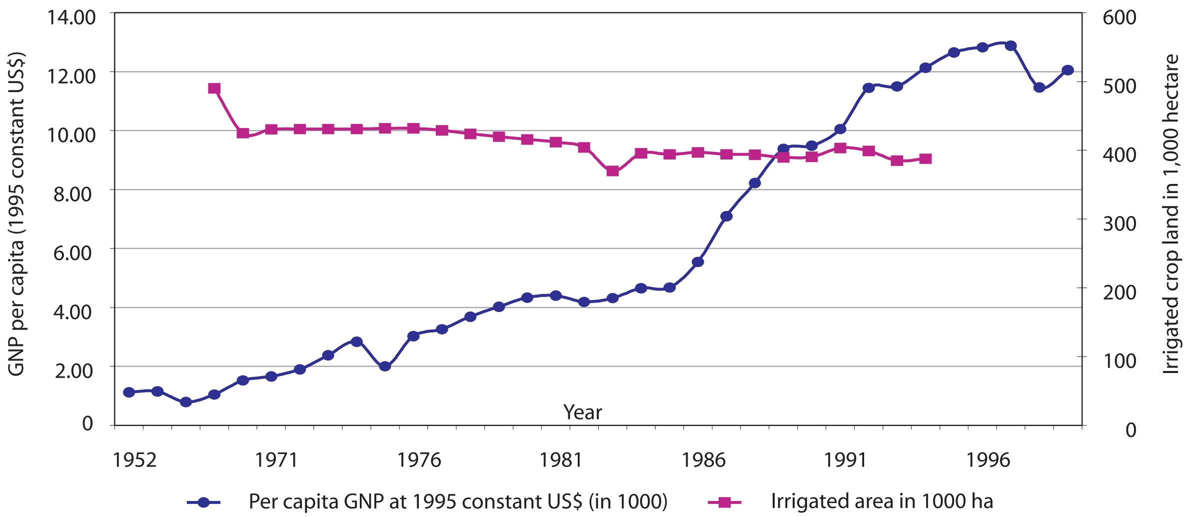
Source: FAO stat, 2000.

FIGURE 4.
Three decades of trends in irrigated land in Japan and Thailand, 1961-1997.



Source: FAO stat, 2000.

FIGURE 5.
Changes in irrigated land and income in Taiwan, 1952-1996.



Basic IKC model for percentage of crop area irrigated:

The regression results from the “basic IKC model” for irrigation (i.e., for the percentage of crop area irrigated) are given in table 5. Results from both the tropical-global model and the Asia model are reported side by side.[11] In table 5, the variable “time trend” is positive in both the tropical-global and Asia models, which means that the percentage of crop area irrigated has been increasing across the selected countries. This is a plausible result since the irrigated crop area has been increasing in a majority of the tropical countries selected here. This result also indicates that other model-excluded variables, over time, have also positively contributed to irrigation expansion, which is a plausible result as irrigation is affected by several factors, not only the income.

In table 5, 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 income, and that it declines when income reaches a certain critical level. In other words, there is an inverted U-shaped relationship between irrigation and income level across the countries. This result also provides for a statistically verified EKC relationship between the irrigation and income (i.e., IKC), as hypothesized in this study earlier. In table 5, the IKC relationship holds for both the models, as reported in the past studies for other environmental factors, such as forest area changes, water quality and air quality indicators as already discussed in the earlier sections.

[11]There are more than 64 countries, and therefore, the intercept value of a country is not reported in table 5 to save space. In table 5, each country has a separate intercept value, with its average value of 4 for the tropical-global model (across the 64 countries) and 23 for the Asia model (across 13 countries). Two countries were dropped during GLS modeling stage because of the missing observations for a longer period of time for these countries.

TABLE 5.
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	0.004	0.28
(1 to 20)	(13.22)***	(13.04)***
GDP per capita	0.05	2.64
(lag one period)	(3.45)***	(4.40)***
GDP per capita squared	-0.009	-0.24
(lag one period)	(2.44)**	(3.42)***
Adjusted R^2	0.95	0.96
(unweighted value)		
Number of countries	64	13
Number of observations	1,210	246
Turning point income (TPI)	US$2,800	US$5,500
of the basic EKC model		

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. Because of the large number of country-specific intercept terms involved they are not reported here to save space in the table. Details on country-specific intercept values, however, can be obtained from the author upon request: M.Bhattarai@cgiar.org
4 The basic form of the EKC model is estimated with only income variables to assess the net income effect on the relative change in irrigated area.
5. Turning point income (TPI) is the income level associated with the turning point of the inverted U-shaped curve.

The high value of adjusted R^2 (unweighted value) in both models in table 5 suggest a better explanatory power of the regression models estimated in this study. The model presented in table 5 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 a 20-year period. To save space, country-specific intercept values are not given in table 5 (the detailed state-specific regression results can be obtained from the author upon request).

Figures 6 and 7 illustrate the IKC diagrams generated from the regression coefficients of the Asia IKC model and the tropical-global IKC model (table 5), respectively. These figures are simulated IKC diagrams and they show a possible scenario of what would happen to the irrigation level when the per capita income increases up to US$11,000.[12] These IKC diagrams are generated at the sample mean value of intercept and time

[12]The maximum income associated with the sample of countries used in Asia is about US$ 6,700 (per capita income of South Korea in 1990), and the projected downward sloping shape of the EKC in figure 6 beyond the income range of US$6,700 is based on the simulated (generated) income level. The same case applies for figure 7 after income range of US$7,800. The sample mean level of income shown in figures 6 and 7 is average per capita income of sample countries selected in 1990.

FIGURE 6.
Irrigation Kuznets Curve for Asia generated from the Asia model, 1972-1991.

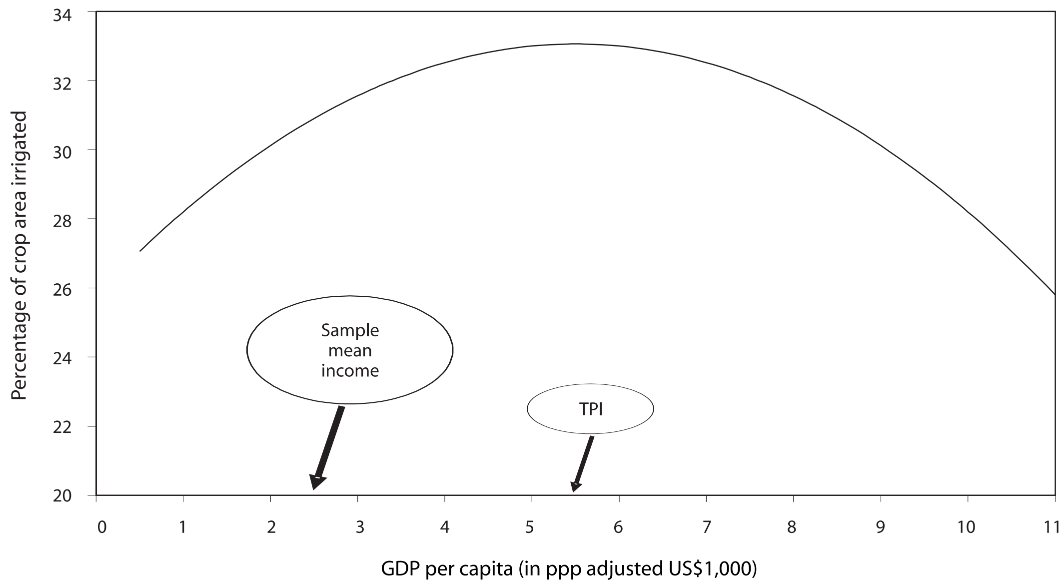
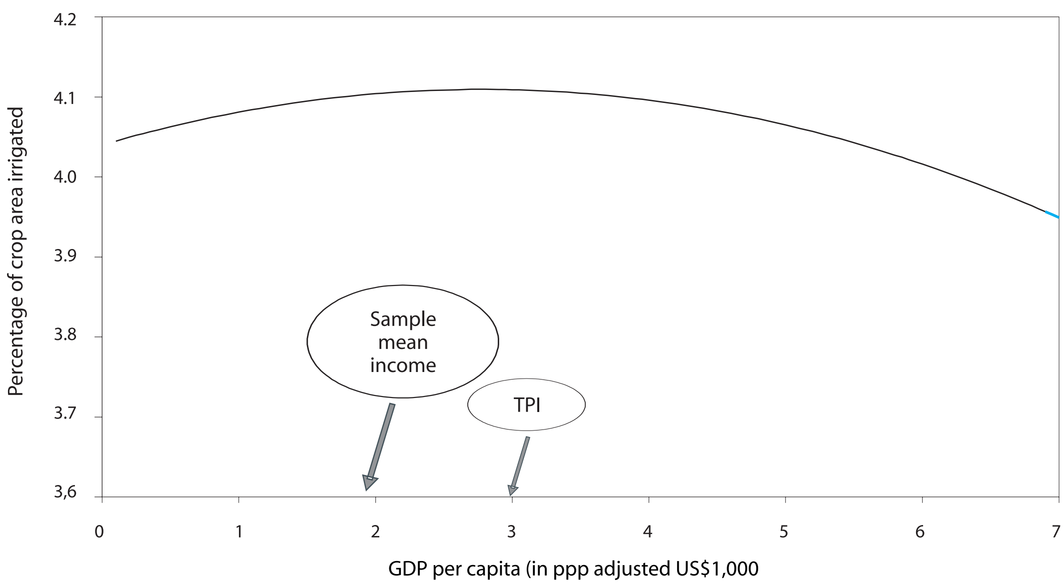


FIGURE 7.
Irrigation Kuznets Curve for the tropics, simulated form the tropical-global model, 1972-1991.



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 former case (figure 6) than in the latter one (figure 7). In reality, the inverted U-shaped relationship depicted in figure 6 is more evident than EKC patterns for other environmental factors estimated in past studies (e.g., Shafik and Bandhopadhya 1992; Shafik 1994a; Grossman and Kruger 1995; Panayotou 1997; Bhattarai and Hammig 2001).

The turning point income (TPI) associated with the IKC model varies depending upon the sample of countries[13] (or regions) selected (see figures 6 and 7). The same pattern of variation on TPI across the models (regions) is also seen in past studies on EKC for deforestation and other environmental factors (see Grossman and Kruger 1995; Bhattarai and Hammig 2001; Yandle, et al. 2002;). The TPI of the Asia model is US$5,500, which is higher than that of the tropical-global model (US$2,800), which is in fact also consistent with real-world observations. Since, the average percentage of irrigated crop area in Asia is much higher than in Africa and Latin America (see table 1). Here, out of 66 countries in the global-tropical model, more than 33 countries are from the Africa region (annex table 1), and 13 are from Asia and the remaining 20 are from Latin America—showing that the global-tropical model is more skewed towards the lower mean average irrigation level (and also to lower mean income) countries than the Asia model (see table 1 and annex table 1). Therefore, the variation of the variables' impact in these two models in table 5 is a plausible result.

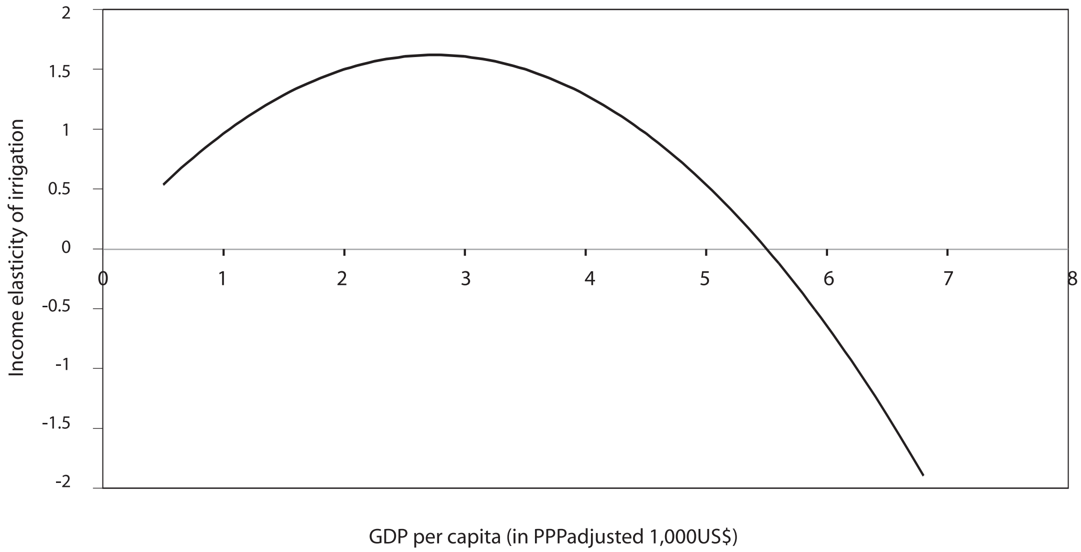
Figure 8 shows the income elasticity of irrigation, a relationship estimated in a unit free measurement, estimated from the Asia model in table 5; which suggests that the income elasticity of irrigation is nonlinear in nature and its value starts to decline in Asia as early as at an income level of US$2,500 (PPP adjusted US$). It also suggests that the percentage of irrigated crop area in Asia becomes an inferior commodity, and an absolute negative trend, once the income reaches the critical limit of US$5,500 (see figure 8).

The income level of US$5,500 shown in figure 8 (or the TPI income in table 5) was equivalent to the income level of Malaysia in 1990, but it was lower than the per capita income of South Korea in the same year. The recent decrease in net irrigated land in Malaysia and South Korea (FAO stat 2001), and in Taiwan since early 1970 (figure 5), reveals an IKC type of relationship even in some of these middle-income countries in Asia.

This curvilinear (nonlinear) nature of income elasticity between irrigation and income shown in figure 8 has another major implication for forecasting of irrigated land, and of water uses for agriculture and for other sectors. Figure 8 implies that there is no constant or 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 studies, the demand for water uses for agriculture is calculated by multiplication of per capita use of food (or cereal grains) by the population level forecasted; the water scarcity level in a region is then derived comparing this

[13]The regression analysis shows the relationship on variation among the variables at the sample average, and the magnitude of regression coefficient depends upon the sample range, the sample numbers, etc. There is a large variation on average per capita income and irrigation development level across the countries selected (see table 1 and annex table 1), hence the variation on parameters in the Asia and tropical-global model is a plausible result.

FIGURE 8.
Variation in income elasticity of irrigation value with income level in Asia, 1972-1991.



forecasted water demand with the annual renewable water resources naturally available in a specified future time period. Neglecting this curvilinear relationship (inverted U-shaped) between irrigation and per capita income (and the substitution effects) could be one reason for the lower degree of performance of these irrigation projection models adopted in the past (for a synthesis on the performance of these past studies, see Rijsberman 2000).

Partial IKC model for percentage of crop area irrigated

The net impact of each of the policy variables selected on the irrigation-income relationship is estimated by including one policy variable (Z_{it}) at a time in the basic IKC model, which is called a partial IKC model[14], as discussed in equation 2 earlier. The main results from the partial IKC model (both tropical-global and Asia models) are summarized in table 6. For evaluation, the detailed results of the tropical-global model are separately reported in annex table 5.

The basic concept of the EKC relationship (or the income term positive and income squared term negative, i.e., inverted U-shaped relationship) is observed in each of the partial IKC models reported in table 6 and in annex table 5. Therefore in table 6, only the sign (positive or negative) of the marginal impact of the policy factors (Z_{it}) and their statistically significant level are provided[15]. In table 6, the sign and the significant level 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 across the countries between Asia and the other two regions (Africa and Latin America). Some of the policy implications of the results in table 6 are discussed below.

[14]The main purpose of the EKC analysis here is to test the presence or absence of the EKC hypothesis in irrigation but not to develop a global model with determinants of irrigation development. Thereby, the "partial EKC model" best serves the purpose of assessing the relative strength of the policy variables (see Shafik 1994b).

[15]To avoid a repetitive and long list of parameter values, only sign of the policy variable (Z_{it}) from partial IKC models are presented in table 6, and the detailed results of tropical-global model are in annex table 5. Further information in this respect, i.e., the detailed results of partial IKC models, can be obtained from the author (email: M.Bhattarai@cgiar.org).

TABLE 6.
Kuznetian relationship for the changes in percentage of crop area irrigated across countries, 1971 to 1991.

Independent variable	Topical-global model	Asia model
Electricity use per capita	Positive (***)	Positive (***)
Cereal yield (kg/ha)	Positive (***)	Negative (***)
Agriculture value added (%)	Positive (***)	Negative (***)
Manufacturing 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 (***)

Notes:

1. Partial regression model is estimated by adding one policy variable at a time to the basic EKC model with time trend, GDP per capita, and squared of GDP per capita. This is done as illustrated in equation 2 earlier. All of the explanatory variables are used as lag of one period (i.e., t-1th period). .
2. Signs in parentheses are level of significance. The sign ***, **, and * means significant at 1, 5, 10%, respectively. N.S. means 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 multi-colinearity problem, one variable is added at one time sequentially to the basic EKC model.
4. In table 1 earlier, definition of the variables is detailed provided. 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 of a nation. iv) Governance is the sum of political liberty and civil liberty variables 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. Other variable definitions are self-explanatory, and details are given in table 1.

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

The sign of the variable “cereal yield”, a proxy for the overall productivity and scale of the 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 positively contributed to irrigation expansion—when all the tropical countries are considered together. This is because of the economy-wide additional demand for irrigation created by new technology, and the synergy effects of input use in farming. But the situation is different in the Asia model because of a already high level of irrigation development (crop area under irrigation) in Asia compared to that of countries from Latin America and Africa. When the data within Asia is closely examined, the agricultural yield level is not necessarily high in a country with a high level of irrigation access. For example, in 1990, more than 80 percent of the crop area in Pakistan was under irrigation, but the cereal yield level in Pakistan was much lower compared to other countries in Asia with a much smaller scale of development in irrigation.[16]

The sign of the variable “agricultural value added” is positive in the tropical-global IKC model, which means that there is less need for irrigation expansion as the agriculture sector shrinks in the economy. This result supports the structural-change-based explanation of the emergence of IKC in an economy, but the variable has a reverse sign in the Asia model. The reasons for the difference in result between the Asia model and the tropical-global model are due to the factors explained earlier. In fact, the negative sign of the variable “manufacture value added growth rate” in the tropical-global model further supports the “structural change” based explanation for the emergence of the IKC relationship. That is, the economy-wide demand for irrigation is more influenced by underlying structural changes in an economy, which in turn, are affected by income growth. In summary, our empirical results here also support the structural change based hypothesis (induced by income growth) for the emergence of the IKC in the economy (see, annex section B).

The impact of variable “economic growth rate” is negative and statistically significant at 5 percent level in the tropical-global model, which means a fast-growing economy requires less and less expansion of irrigated cropland. This again validates the IKC hypothesis. However, its impact is negative and not significant, nor is the meaning so straightforward in the Asia model.

In table 6, the sign of “inflation” variable is negative in both the models, but it is statistically significant only in the case of the tropical-global model. This implies that irrigation development in the past was high in a low-inflationary economy, which is a plausible result considering the huge financial investment required for irrigation development, and the long-gestation period needed to realize benefits of irrigation investment. The impact of inflation is however not significant at 10 percent in the Asia model, which is due to a lower level of inflation rate in Asia compared to that of Latin America and Africa. The sample mean annual inflation rate in

[16]Because of the same difference in the level of irrigation development across countries (regions), the sign of the other variables also varies between the tropical-global and the Asia models reported in table 6.

Asia is $1/9^{th}$ times than that of its value in the tropical-global model (see table 1).

The impact of "rural population density" on irrigation is significant in both models (table 6), but its signs are reversed—it is negative in the tropical-global model and positive in the Asia model. This result implies that irrigation development in Asia in the past was influenced by increased rural population pressure, because of increased stress to feed the growing rural population. But, this was not the case when we look irrigation development process across Africa and Latin America. Nonetheless, in Asia, the political economy of excessive rural population pressure (mass-scale rural poverty, unemployment and food scarcity) was one of the major underlying factors for the large-scale public investment on irrigation during the 1960s and the 1970s (for details of the geo-politics of irrigation development in Asia, see Barker and Molle 2002). Here, the opposite impact of the rural population variable in the tropical-global model from that of the Asia model is a plausible result because of the different population pressures across the continents (see table 1).

To analyze the impact of institutions on irrigation, we included a "governance" variable in table 6 created by summing up political freedom and civil liberties (see table 1).[17] The governance variable in the partial IKC model particularly evaluates the impact of the "quality of a country's governing institutions" on irrigation. The impact of the "governance" variable is positive and statistically highly significant in both the tropical-global and Asia models, which implies that irrigation development in the past also depended upon the quality and effectiveness of underlying governing institutions of the country. In fact, this result is consistent with the situation of everywhere large extent of involvement of public agencies in the irrigation, the extent of the government investment and controls, and the level of collective action needed for development and management of irrigation. This result provides strong support for the institutions-based explanation of irrigation development and the importance of the governance factor—quality of governing institutions—in irrigation, and for the emergence of the IKC relationship in the economy. This result also means that the governance factor cannot be undermined while talking about irrigation and rural development and its consequences in the underlying economic activities, environment management, and development process as such.

To further examine the impacts of the joint effect (or interaction effect) between income and institutions on irrigation development, a separate interaction term of income and institutions (multiplicative of governance and GDP Per capita) is included in the partial IKC model. In table 6, this interaction term is positive and significant in both the models, which means that the income effect on irrigation also depends upon the level of institutional development, or *vice versa*. That is, the higher the income level the greater the marginal impacts of governance (or governing institutions) in irrigation, and *vice versa*. In summary, the results of institutions-related variable suggest that irrigation planning in a nation should not be done in isolation, neglecting the underlying economic factors and governance structures.

IKC for Change in Net Irrigated Land

After modeling IKC for crop area irrigated across countries, we analyzed an IKC for net irrigated land, i.e., the relationship between income and relative changes in the net irrigated land (log

[17]The "governance" variable (index 2 to 14) here includes political and civil rights related factors. Each of the civil liberty and political rights factor is created by summing 25 different indices in each country (for details, see Gastil, 1987; also available at www.Freedomhouse.org). In the IKC model used here, higher index of governance (14) means more freedom and better quality of government institutions (i.e., better rule of law), and vice versa.

value of irrigated land). This is done by adopting the "basic IKC model" approach, as discussed in table 5 earlier. The detailed results are provided in table 7. All methodologies and estimation techniques followed in table 7 are similar to that of the procedures used in table 5, as discussed earlier. We have estimated the IKC for net irrigated land in both the framework of "basic EKC" and "partial EKC" models, where we have got almost similar results as in the case of the IKC model for percentage of crop area irrigated, as noted in tables 5 and 6 earlier. To avoid duplications, in table 7, we have provided only the results from the "basic IKC model" for net irrigated land.

The positive time trend coefficient in both IKC models in table 7 implies that the average irrigated land in relative terms (weighted average across the countries) is increasing across the selected countries, as also noted earlier in the case of table 5.

In table 7, the GDP income is positive and the GDP income squared is negative in both models, which suggests that the basic idea of IKC is clearly observed for both the tropical-global and the Asia models. Here, the main logic of IKC is not necessarily that the level of irrigated land declines as income increases, but that the rate of growth in the level of irrigated land would decline after achieving a certain stage of development (i.e., an inverted U-shaped relationship). In table 7, this is illustrated by the negative coefficients of the income squared terms in both the models.

TABLE 7.
Kuznetian relationship for the changes in the net irrigated land for the tropical-global model (model 3) and for the Asia model (model 4), 1971-1991.

Independent variable	Tropical-global model (model 3)	Asia model (model 4)
Time trend	0.005	0.008
	(32.78)***	(8.58)***
GDP per capita	0.054	0.035
(lag one year)	(7.60)***	(1.77)*
GDP per capita squared	-0.006	-0.006
(lag one year)	(6.34)***	(2.72)***
Adjusted R^2	0.98	0.98
(un weighted value)		
Number of countries	64	13
Number of observations	1207	246
Turning point income (TPI)	US$4,500	US$3,000
of the basic EKC model		

Notes:

1. Dependent variable: Logarithm value of irrigated cropland in country i^{th} in year t^{th}.
2. Values in parentheses are absolute t-statistics; ***, ** and * means significant at 1%, 5%, and 10% level. N.S. means not significant at 10%. F statistics of all the above models are significant at 1%.
3. Both models in table 7 were estimated as the fixed effects form of panel regression method using the WLS technique. The intercept term for each country is not reported in table 7, the reasons are as discussed earlier in table 5.

The TPI level estimated in table 7, similar to the results in tables 5, differs in the tropical-global model from that of the Asia model; but its value is now more in the tropical-global model than in the case of the Asia model. The percentage of irrigated crop area and the relative change in net irrigated area are two completely different measures of irrigation. Therefore, the variation on TPI of the IKC models with these two different indicators of irrigation, and across regions, is an expected result. This is also due to a large variation in policy and underlying institutional factors across the countries (regions) included in these models, as noted earlier.

The level of TPI of IKC, in both the Asia and the tropical-global models in table 7, and in table 5 earlier, is more than the sample average income level of the countries selected (see annex table 1). This means that there will be an absolute increase in irrigated land (also, percentage of crop area irrigated) in several of these selected countries when the country's present level of income increases. It may take a while for a majority of these tropical countries to raise their per capita income to the estimated level of TPI and to achieve the reverse trend for irrigation, as explained in the IKC models here.

Conclusions and Implications

Using the EKC framework of analysis, this study illustrates how irrigation development at any point in 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 two measures of irrigation (i.e., percentage of crop area irrigated, and net irrigated area), which is termed the "EKC for irrigation", and/or, "Irrigation Kuznets Curve" (or "IKC"). The EKC-based explanation of irrigation suggests that social demand for irrigation is higher at the initial stage of development, and when income reaches a certain critical level, the demand for irrigation in an economy gradually ceases. In other words, there is an inverted U-shaped relationship between irrigation and income level. At a certain income level, the net irrigated area may decline in absolute terms, as already observed in some fast-growing countries in Asia (like Taiwan, Japan, etc.).

One of the reasons for the emergence of the IKC relationship in an economy is due to structural changes brought on by income growth. Once development reaches a certain stage (increased income), water needs for industrial and service sectors, including water demands for environmental services, overtake that of the agriculture sector. This results in public policy and priority shifts in the water sector and water uses in an economy because of the changes in the relative value (price) of water across sectors. All of these changes will contribute to the emergence of an IKC relationship within an economy.

After empirically validating the EKC hypothesis for irrigation level, this study evaluated the effects of selected policy and institutional and structural factors on temporal (over time) and spatial (cross-country) variation of irrigation development. The analysis was done by taking national-level annual data from 66 tropical countries for a 20-year period from 1972 to 1991. Two models were developed: one for all 66 countries, called tropical-global model, and the other for 13 countries in Asia, called the Asia model. Two measures of irrigation were used in this analysis: the percentage of irrigated crop area and the relative change in net irrigated land area (i.e., log value of net irrigated land).

From the empirical results of this study, the basic idea of the EKC relationship was observed for the two selected indicators of irrigation, and for both the tropical-global and the Asia models. This means that the societal demand for irrigation grows with income at the initial stage of development, and its growth rate declines as the societal income (per capita income) reaches a certain critical level (i.e., TPI). The level of TPI however varied depending on the measures of irrigation used and the regions (countries) selected for the analyses. The statistically verified inverted U-shaped relationship between irrigation and societal income estimated in this study confirms the existence of an IKC relationship. This means that the nonlinear nature of the income effect (inverted U-shape) is critical for planning, and managing irrigation systems.

Our study also revealed the importance of public policy and institutional factors for flattening the EKC path and potentially avoiding 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 technology available, and by the underlying governance factors (i.e., quality of governing institutions). This means that there is an important role for institutions and public-policy factors in the sustainable management of irrigation and other water uses in an economy; and to ensure that the irrigation level (and level of environmental damage) remains below the ecological threshold limit in a region through policy-induced changes.

The EKC results are also useful in deriving irrigation demand in an economy. Past studies have mostly adopted fixed requirement type of criteria for estimating irrigation demand, and with one-to-one mapping for 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 shows a curvilinear relationship (inverted U-shaped) between irrigation and income level. This means 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 and structural factors. This means, if projection of the irrigation land (or demand for water uses) takes into account the nonlinear income effects and other substitution processes, it would improve the accuracy and overall performance of irrigation-forecasting models.

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

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

Annex A— Selected Literature on EKC for Water Resources

Past studies provide statistically significant and strong support for the existence of an EKC type relationship for air quality, water quality, river quality and deforestation (for details, see Panayotou 1997, 2000; Grossman and Kruger 1995; Bhattarai and Hammig 2001; Yandle, et al. 2002). Annex table 2 summarizes the selected past studies on the EKC for water-sector issues, along with their major findings. Most of the past water-sector EKC studies are on water quality related subject areas such as, dissolved oxygen (DSO) in river water, fecal coliform count in river water, Chemical Oxygen Demand (COD), and nitrate in river water (see Shafik and Bhandhopadhaya 1992; Grossman and Kruger 1995; Torras and Boyce 1998; Hettige et al. 2000; Yandle, et al. 2002). In relation to irrigation, Rock (1998) and Goklany (2002), the only two empirical studies, illustrate the possibility of an EKC relationship for water withdrawals in agriculture. The former uses statistical analysis and the latter adopts a mostly qualitative trend analysis.

Rock (1998) shows an inverted U-shaped relationship between annual water withdrawal (both total and per capita withdrawal) and per capita income level in the case of the USA and across countries (mostly developed countries). This study uses a single period data point for the analysis, which does not capture the dynamics of overtime changes on the relationship between the level of water withdrawal and income involved in the EKC analysis.

Using a graphical trend analysis at the global scale from 1900 to 1995, Goklany (2002) reported a rising trend in per capita irrigation water uses in agriculture and per capita cropland area in the earlier stage of development (until 1960) in substitutions of land acreage; and then a reduction in both of these factors in the later stage (from 1960 to 1995). He shows that this was the case both in USA and in globally (see annex figure 1). Goklany argues that increased agricultural productivity since 1960 onward and increased income and timely changes in other institutions and policies are the reasons for the emergence of such an EKC pattern for water withdrawals in agriculture. He also claims that water productivity worldwide has so far been not improved in comparison to land productivity, mainly due to less-defined property right structures in water resources than in agricultural land. Annex figure 1, adapted from Goklany (2002), depicts a possible emergence of the EKC relationship for water withdrawals in agriculture in a given economy.

In terms of the EKC relationship for natural resources, this relationship (EKC) has been empirically very well-established in the case of deforestation and change of forestland by past studies, as noted earlier (see Bhattarai and Hammig 2001). Showing a historical perspective, Mather et al. 1999 reported a graphical trend of 400 years of forest-cover change in selected countries of Western Europe (see annex figure 2), which very clearly illustrates a historical reality of EKC for forestland in these countries. The same relationship, in principle, would also apply for societal decisions on use of water-resources, since use of water resources is conceptually the same as the use of forest resources as both belong to the same renewable natural resources category.

ANNEX TABLE 1.

Countries selected for the regression analysis and their real income in 1990 (in PPP adjusted GDP per capita in 1985 constant US$).

Latin America	Income 1990	Africa	Income 1990	Asia	Income 1990
Argentina	4,706	Angola	678	Bangladesh	1,390
Bolivia	1,658	Benin	920	Bhutan	882
Brazil	4,042	Botswana	2,285	China	1,324
Chile	4,338	Burkina Faso	511	India	1,264
Colombia	3,300	Cameron	1,226	Indonesia	1,974
Costa Rica	3,599	Central Af. Rep.	579	Korea, Rep.	6,673
Dominican Rep.	2,166	Chad	399	Malaysia	5,124
Ecuador	2,755	Congo, Dem. Rep.	384	Myanmar	611
El Salvador	1,824	Congo, Rep.	2,211	Nepal	1,036
Guatemala	2,127	Côte d'Ivoire	1,213	Pakistan	1,394
Honduras	1,377	Ethiopia	324	Philippines	1,763
Jamaica	2,545	Gabon	3,958	Sri Lanka	2,096
Mexico	5,827	Gambia	790	Thailand	3,580
Nicaragua	1,294	Ghana	902		
Panama	2,888	Guinea	767		
Paraguay	2,128	Kenya	911		
Peru	2,188	Liberia	853		
Trinidad & Tob.	7,764	Madagascar	675		
Uruguay	4,602	Malawi	519		
Venezuela	6,055	Mali	531		
		Mauritania	791		
		Mozambique	760		
		Niger	484		
		Nigeria	995		
		Rwanda	756		
		Sierra Leone	901		
		Somalia	775		
		Sudan	757		
		Tanzania	550		
		Togo	641		
		Uganda	554		
		Zambia	689		
		Zimbabwe	1,182		
Sample average regional income	3,360		925	2,240	

Notes: 1. Per capita income in 1990 reported here is real GDP per capita (PPP adjusted at 1985 constant US dollars).
2. Total of 66 countries—20 from the Latin America region, 33 from the Africa region (sub-Saharan) and 13 from Asia—are selected in this study for the cross-country analysis.

Source: Summers and Heston. 1991, and updated by World Bank Growth Researchers Team, available at http://www.worldbank.org/research/growth/index.htm.

ANNEX TABLE 2.

Some of the selected econometric studies on environmental Kuznetian type of studies on water-sector-related issues.

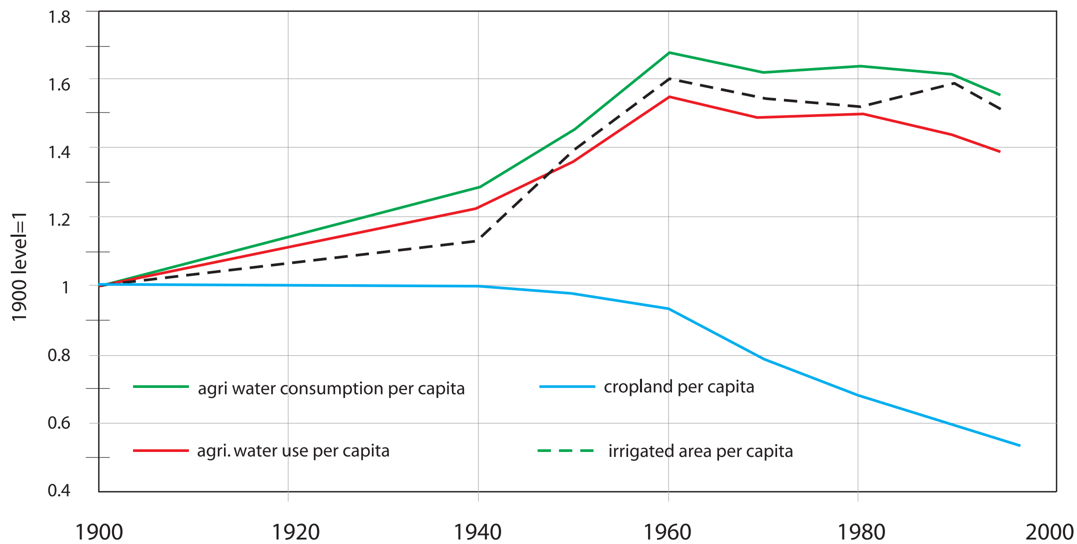
Name of study	Type of analysis	Dependent variables	Key independent variables	Major findings of the study
Shafik and Bandhopadhya 1992.	Panel regression for 65 countries (OLS), from 1966 to 1985.	1. D. Oxygen in river 2. Lack of safe water 3. Fecal col. in river.	Per capita GDP, time, and institutions, and - macro-economic variables.	1 Income is significant and negative, and EKC has a monotonously decreasing shape. 2 Income significant, and cubic shaped EKC after TPI of US$11,000 3 Income term is significant, with an inverted shape EKC
Grossman and Krugger 1995.	Panel regression for 42 countries from 1979 to to 1990 with alternate modeling. Also used cubic form EKC	1. D. O_2 in river 2. BOD in river 3. COD in river 4. Nitrate in river 5. Fecal col. in river 6. H. Metals in river	Per capita GDP city characteristics population density time trend	1. Lagged income significant in all cases of water-sector environmental indicators 2. Cubic term income is modeled which is positive, 3. U shaped EK-curved is found in the case of D. Oxygen (1), and inverted U-shaped curve in all other cases in column 3. 4. TPI differs by the type of environment indicators, which is $3,000 for D O in river, $7,500 for BOD in river, $8,000 for COD in river, $8,000 for Fecal coli form in river, and $5,000 for heavy metal in river.
Torras and Boyce1998.	Cross-country analysis of water-quality indicators for countries.	1. D. Oxygen in river 2. Fecal col. in river 3. Access to safe water	P C. income,cubic term, schooling, income inequality, political rights, institutional variables.	1. Inverted U-shaped EKC for D. Oxygen when income inequality is added. 2. Both squared and cubic income terms are significant and negative. 3. Inverted U-shaped for access to safe water with peak of $11,250 and trough of $20,215 (again rising curve after this income level).

Name of study	Type of analysis	Dependent variables	Key independent variables	Major findings of the study
Vincent 1997.	EKC analysis of river -water quality for a single country, Malaysia.	1. BOD in river 2. COD in river 3. Ammonia nitrogen in river	Population density, population. density* GDP, income per capita.	1. Lack of a significant relationship with income, so that EKC was not observed for most of the cases, rather there is a rising trend with income for most of the cases. 2. Unlike the cross-country analysis, water pollution and income have a weak relationship in a single country case. 3. Income not much significant but population density is significant in all cases and it is positive.
Rock M. 1998.	EKC analysis for water-sector-related factors for a single country (USA), but only a cross-state analysis for one point time change.	1. Annual water withdrawal in the US. 2. Annual per capita water withdrawal in the US. 3. Relative water scarcity, cross-country. 4. water intensity of GDP	Per capita GNP, population level, irrigation intensity of GDP, trade policy, socialism (governing institutions), etc.	1. Inverted U-shaped for annual water withdrawal, with TPI of $14,300. 2. Inverted U-shaped for annual per capita water withdrawal 3. Inverted U-shaped for relative water scarcity with TPI of $18,750 4. The findings provided strong evidence that water use varies in a systematic way as socioeconomic development proceeds. 5. The results provided strong evidence that water uses first rise, reach a peak, and then decline as income per capita that water use varies in a systematic way as increases. Thus, there is strong evidence for the EKC hypothesis.

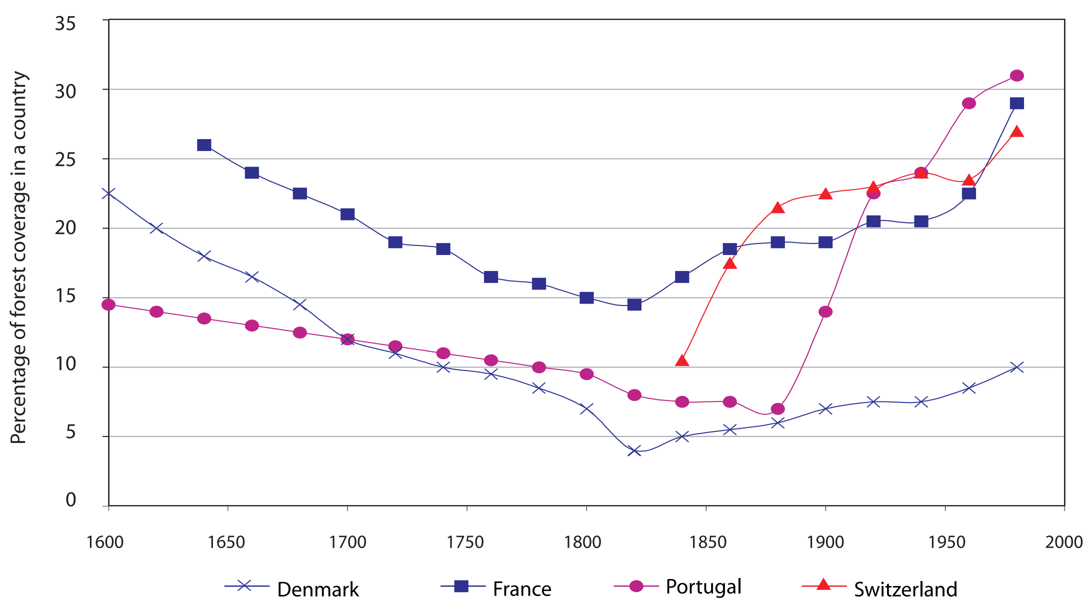
Name of study	Type of analysis	Dependent variables	Key independent variables	Major findings of the study
Hettige et al. 2000.	EKC hypothesis testing for industrial pollution using plant-level environment. Emission data from 13 countries. Different modeling tested from 1974 to 1994.	1. Share of manufacturing goods in total economy 2. Sectoral composition of manufacturing. 3. The intensity (per unit output) of industrial pollution at "end of pipe."	Per capita incomeIncome squareIncome* time, wage, regulation, electricity prices, interest rate, ndustry type, time trend	1. Industry share of national output follows a Kuznetian trajectory, not others. 2. When all the variables are combined, the results suggest rejection of the environmental Kuznetian trajectory for industrial water pollution, which increases and remains at that level for the higher-income level. 3. Sectoral composition gets "cleaner" through middle -income status and then stabilizes. 4. At the "end of pipe" analysis, the pollution intensity declines strongly with income, partly due to stronger regulation as income increases, partly due to pollution labor complementarity in production. 5. Income elasticity of both pollution and labor-intensity are approximately –1.
Goklany I. 2002	Trend analysis of aggregate and per capita water and land use by agricultural use in the US, and the world in the twentieth century.	1. Cropped land use per capita in US. 2. Per capita irrigation water uses in US 3. Global cropland and agri-cultural water uses.	1. Unlike other studies, this paper has only a trend analysis for single variable, and there is no multivariate analysis with the ncome factor.	1. There is a decreasing trend of US aggregate and per capita cropland over the years; on the other hand, increasing trend of agricultural water uses, both at the national and per capita level water uses. 2. Global trend of agricultural land and water use (1900–1997) shows stabilization of both per capita agricultural water use and agricultural water consumption. 3. Cropland per capita has significantly reduced after 1960.

Note: 1. Income means per capita GDP income with PPP adjusted 1985 constant US dollars, as explained earlier.
2. TPI = Turning point income associated with the EKC graph.
3. D. Oxygen = Dissolved Oxygen in river.
4. BOD = Biological Oxygen (O_2) Demand.
5. COD = Chemical Oxygen Demand.

ANNEX FIGURE 1.
Global agricultural per capita land and water use, 1900-1997 (adapted from Goklany 2002).



ANNEX FIGURE 2.
Long-term forest trends in selected European countries, 1600-1990 (adapted from Mather et al. 1999).



Annex B—Emergence of EKC in an Economy: Theoretical Issues[18]

Increased income growth leads to adjustments on economy-wide relative prices, which brings structural changes in the economy, including changes in environmental policies and institutions. But, the detailed processes of these changes and emergence of EKC relationship are not yet clearly understood or expressed in literature (see Yandle et al. 2002). There are two competing schools of thought on the relationship between income and environment.

The first states that maintaining a minimum level of environmental quality is a basic requirement for human beings, like food, clothing, shelter, health and so on. Therefore, a basic level of environmental quality is needed for human survival, and even for maintaining economic prosperity.

The second view holds that environmental quality is a luxury good, and its necessity is felt only after the fulfillment of a society's basic needs (see Ruttan 1971; Samuelson 1974; Antle and Heidebrink 1995; Torras and Boycee 1998; Yandle et al. 2002). According to this view, the demand for environmental protection is felt only when societal income reaches a certain critical level, which in turn, gives emergence to an EKC type relationship in the economy. Considering environment as a luxury good means that environmental demand proportionately increases more than the increases in income (income elasticity more than one). The implication of this theory for irrigation is that the societal concerns on environmental consequences of water diversion for agriculture (or irrigation) would emerge only when the society's basic needs are first met.

Institutions and emergence of EKC

Related to institutions and EKC, Yandle and Qin (1998) reported an EKC type of trajectory in the dissolved oxygen content (DOC) in selected river basins; and they suggest that strengthening of property rights institutions (water rights, etc.) ultimately helps in improving pollution reduction in a river. Because of the positive incentive structures created, the private-property-rights regime helps in managing the resources by properly internalizing the resource use externality at the level of the individual user (farmer). In fact, the same argument can also be extended to irrigation issues in relation to strengthening of water rights and water-pricing mechanisms for efficient and sustainable management of water use in agriculture. Here, Goklany (2002) argued that the lack of private-property-rights institutions on water (i.e., absence of water rights) as a major reason for low water productivity worldwide, more than land productivity.

In relation to institutional issues, the economy-wide structural changes brought on by income growth alter relative price structures, which would produce incentives for institutional change in the economy, including the emergence of EKC in the economy. Changes in relative prices and technology are the main factors responsible for institutional changes (see North 1990). As water becomes scarce, water needs for urban and industrial use gain higher priority than the farming sector due to the higher marginal value of water in industrial and urban sectors than in agriculture. This ultimately means reduced water uses for agriculture, and/or reduced irrigated land in the economy.

[18]There is no one unanimously accepted economic theory and conceptual view in explaining the emergence of EKC relationship in an economy (for details, see Panayotou 1997, 2000; Bhattarai 2000; Yandle et al. 2002)

Income growth also leads to changes in the political economy and public policy settings in a country, such as better availability of information, rising individual political power, more environmental awareness, and, in turn, increased demand for institutional changes for improved environment quality and demand for a pollution-free environment (see Samuelson 1974; Antle and Heidebrink 1995). Therefore, income growth strongly affects the environment via income-induced changes on institutions and governance structures. This has large implications for water allocation decisions and economy-wide water demand, and emergence of EKC for irrigation in an economy.

In relation to mechanisms of institutional change in the environment, we still do not know how all of these changes in institutions and societal preference actually translate back into societal resources use decisions (water allocation); and particularly, on what the detailed feedback mechanisms of institutional and regulatory policy changes for the emergence of an EKC relationship in an economy are. Past studies on the topic are still too scanty to conclude anything firmly (Yandle, et al. 2002). From studies so far, available on the topic, we can infer that the quality of institutions and governance factors are critical for emergence of the EKC in the economy (Yandle et al. 2002). To a large extent, these institutional changes are also dependent upon income growth.

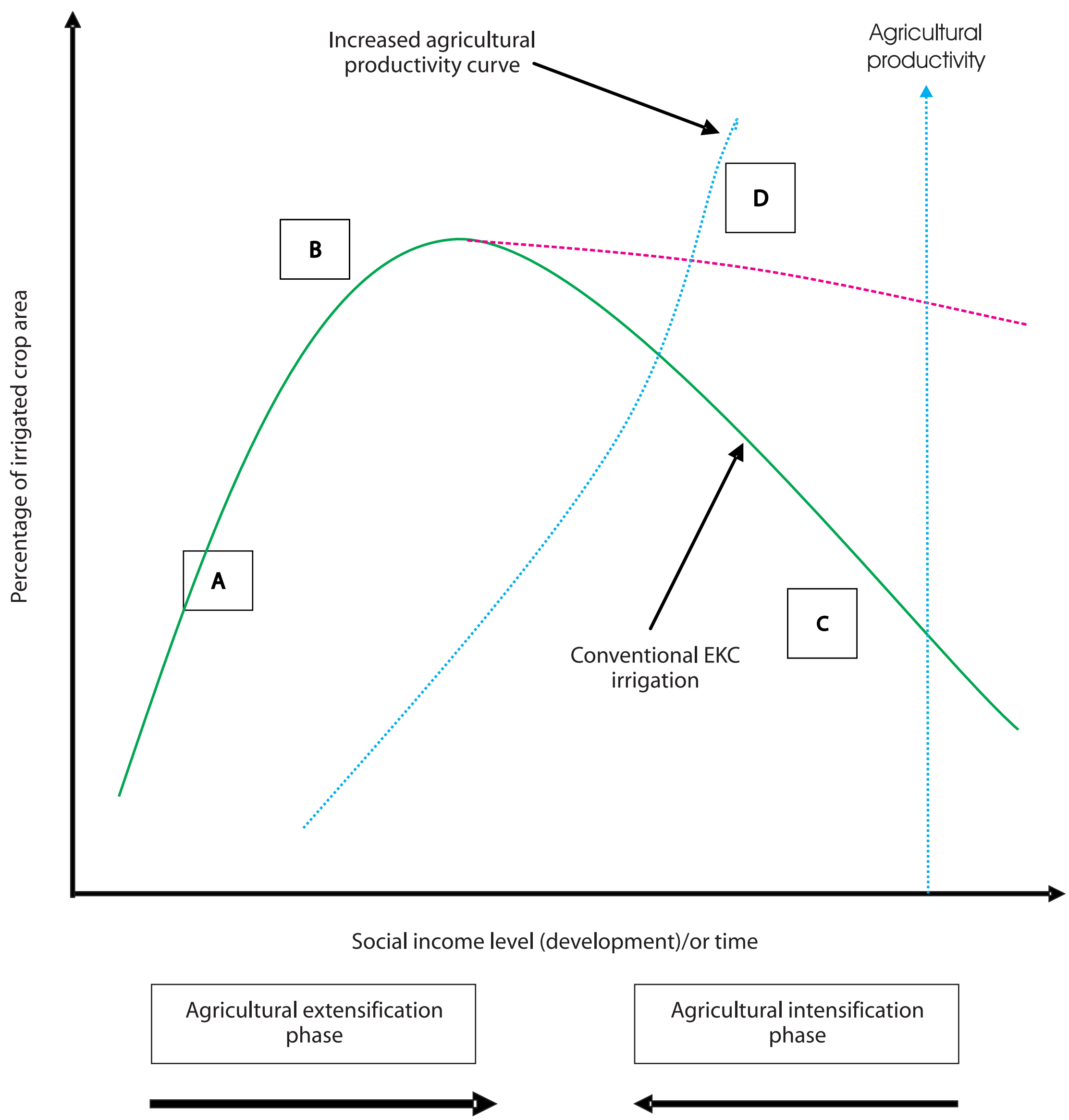
Agricultural productivity growth and the emergence of IKC in the economy

One possible explanation for the emergence of an IKC, other than the income growth and structural changes hypotheses discussed earlier, is based on agricultural productivity change (or technical change). Details are illustrated in annex figure 3. A faster growth in agricultural productivity, facilitated by irrigation development, means lesser requirement on further expansion of the cropland. Here, productivity enhancement complements the reduction in per capita availability of crop area, and allows to meet the food needs of rising population levels without need for expanding the cropland acreage. This means obviously a slower pace of irrigation development once productivity (and income) reaches a certain critical level (see, annex figure 3).

In annex figure 3, the increased land productivity and technical growth—shown by the rising dashed line and in the right-hand axis in annex figure 3—reduces pressure on expansion of the cropland. If agricultural productivity rises faster than the population growth in an economy, it will ultimately reduce the total demand for cropland in the future. This helps reduce the demand for irrigated cropland[19]; and ultimately leads to the emergence of an IKC in the economy.

[19]This is more relevant in the assumption of a closed economy, if there is no trade in the crops produced (food commodity). Globally, less than 10 percent of the total cereal production (food commodities) is traded (FAO 2000); therefore, this is not an unrealistic assumption. The introduction of trade in the above conceptual model in annex figure 3 may slightly alter the scenario but the basic conceptual relationship discussed here equally holds even allowing for trade on food commodities.

ANNEX FIGURE 3.
Agricultural growth based framework for the emergence of the Irrigation Kuznets Curve (EKC) in an economy.



Annex C—Econometric Issues and Estimation of the IKC Model

Econometric issues on estimating panel model

The panel form of the regression model is used in this study to analyze dynamic relationships between irrigation and income. Unlike a single point of time study or time series study for a unit, the panel model minimizes biases related to heterogeneity, multicollinearity, and missing or unobserved[20] variables in the model. Thereby it increases the efficiency of the parameter estimates (see Hsiao 1986; Green 1997). In this context, the panel model better separates the dynamics of marginal changes in irrigation caused by income growth, controlling the effect of other policy and structural factors. In reality, the panel model estimates the meta-relationship among the variables and it minimizes the multicollinearity and simultaneous biases among the explanatory variables. Multicollinearity is one of the major problems associated with this type of multivariate regression model, with several interrelated explanatory variables affecting the dependent variable at any point in time.

In this study, the fixed effects form of panel model is used, which allows varying historical and structural differences across countries by allowing each cross-section unit (country) to have a separate intercept term in the regression model; which is considered more appropriate for the analysis with such a large variation in structural and historical factors across countries as used in this study (see Hsiao 1986; and Green 1997).

Considering the large variation in size and scale across the countries selected, the fixed effects models are estimated by the weighted least square (WLS) technique, also called the Generalized Least Square (GLS) method. The weight for each observation is the reciprocal of the normalized standard deviation of the disturbance obtained from the initial Ordinary Least Squared (OLS) estimation. The generalized weighted least square regression (GLS) results are further iterated to minimize the error sum of squared, and the parameters from the converged models (also called iterated feasible GLS) are reported in the text. Thus, we have efficient parameter estimates, with least bias in the parameters estimated from the theoretically possible assumptions of error structures.

Why a cross-country analysis is used for the EKC (IKC) study?

The basic notion of an EKC-based analysis is to capture the overall effects of income growth on environmental quality (measured by one indicator). To perceive such income induced changes on societal resources use decisions, a quite big jump in per capita income level is required which in turn takes a long period of time. This is rarely found in one country in the short span of time like the 20 years selected for this study, except the recent unprecedented cases of a few countries like Taiwan and Japan in Asia. Therefore, a cross-country analysis with countries from various levels of income is usually a preferred option to shortcut the process. In addition, even for a short span of time, a cross-country model provides a large variation of other broad-scale institutions and policy variables. This is also one of the reasons that most of the past studies on the EKC topic have used cross-country-level analysis; here, we have followed the same process.

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[20]In aggregate-level analyses, the missing data and data-gathering errors across the agencies, or countries, are some of the major factors leading to the biases in the results.

In addition, a cross-country analysis better captures the dynamics of the meta-relationship among the key variables—observed across countries and over the time that are free from the context-specific anecdote factors. This allows for validating a generic type of policy prescription (hypothesis) applicable to a wider region. Moreover, interpretation of the variable sign from the panel set of cross-country model also needs to be done with caution, as the panel model gives us a meta-relationship between two variables across the sample countries, which is different from the results obtained from the simple linear regression model for one country, usually seen in the applied policy-studies (for detailed discussions on these issues, see Hsiao 1986; Green 1997).

Annex D—Data and Their Sources

The data sets of percentages of irrigated cropped area across the countries, and other macro-policy related variables, such as per capita GDP (PPP adjusted) income growth, agricultural value added, manufacturing sector value added, annual inflation rate, and secondary school enrolment were taken from World Bank (2001). The other variables like cereal yield and net irrigated cropland area were taken from FAO statistics (FAO 2001). Earlier in table 1, descriptions of the irrigation and explanatory variables used, and the expected sign of explanatory variables with irrigation level are summarized.

Likewise, the institutions-related variable, governance (index 2 to 14), is created here by summing up political liberty and civil liberty indices. Here, higher index means more political freedom and more civil liberties. Each of the two variables (political and civil liberty) is on an index of 1 to 7, and each is created by the summing of 25 separate freedoms and governing-quality-related indicators of a nation at any point in time.[21] These cross-country data on political liberty and civil liberty factors are provided by freedom house, and they are also called the Freedom House Index. Detailed descriptions of these data are also found in Gastil 1987, and at http://www.freedomehouse.org.

Because of the need of Purchasing Power Parity adjusted GDP per capita across the countries (constant currency), and the limitation on availability of cross-country data sets on other institutional and macroeconomic policy variables, the analyses in the study covers only the 20-year period from 1972 to 1991 (annual data). This includes data from 66 tropical countries, i.e., 13 countries from Asia, 33 countries from Africa and 20 countries from Latin America, for which the continuous annual data series are available for the period selected here.

[21]The political and civil liberty related data for cross-country comparison are available only since 1972, which is why the time series analysis is restricted to the period since 1972.

ANNEX TABLE 3.
Structural changes in the Taiwan agrarian sector economy over the last five decades.

Year	Per capita GNP (at 1995 const. US$ value)	Net irrigated area (1,000 ha)	Total crop area (1,000 ha)	Total paddy field (1,000 ha of net land	Total planted rice area (1,000 ha)	Agricultural population (% of total population)	Total agricultural household population (million)	Agricultural share in GDP
1952	1,130		1,521	534	778	52	4.38	32
1955	1,160		1,508	533	750	51	4.60	29
1960	790		1,600	526	766	50	5.37	29
1965	1,050	490	1,680	537	773	45	5.74	24
1970	1,530	425	1,656	529	776	41	6.00	16
1971	1,670	431	1,620	526	753	40	5.96	13
1972	1,910	431	1,586	521	742	41	6.23	12
1973	2,380	431	1,567	516	724	39	6.11	12
1974	2,840	431	1,644	518	778	38	6.04	12
1975	2,010	432	1,659	516	790	36	5.79	13
1976	3,030	432	1,606	521	788	35	5.76	11
1977	3,270	429	1,566	521	779	34	5.73	11
1978	3,690	424	1,549	517	753	34	5.77	9
1979	4,030	420	1,494	515	722	33	5.74	9
1980	4,340	416	1,400	509	638	30	5.39	8
1981	4,400	412	1,398	503	669	28	5.10	7
1982	4,190	404	1,380	502	654	27	4.98	8
1983	4,320	404	1,334	501	646	23	4.32	7
1984	4,660	396	1,285	497	587	23	4.28	6
1985	4,680	394	1,257	495	564	24	4.69	6
1986	5,550	397	1,267	495	538	22	4.29	6
1987	7,100	394	1,261	488	502	21	4.07	5
1988	8,230	394	1,216	484	471	19	3.82	5
1989	9,380	390	1,184	480	477	18	3.67	5
1990	9,490	391	1,155	477	455	21	4.29	4
1991	10,060	403	1,127	473	429	21	4.21	4
1992	11,450	399	1,089	465	397	20	4.08	4
1993	11,500	385	1,077	464	391	19	3.99	4
1994	12,130	388	1,035	461	366	19	4.01	4
1995	12,650		1,036	459	363	19	3.93	4

Source: CEPD, 2000; and previous IWMI publications.

ANNEX TABLE 4.

Agricultural sector macro-level structural changes in some of the selected countries, 1960 to 1999.

Country	Year	Agricultural value added percentage of GDP	Labor force in the agriculture sector	GDP per capita (constant 1995 US$)
1. South Korea	1960	35	——	1,255
	1980	14.41	34	3,765
	1995	6.2	12.5	10,875
2. Japan	1960	13.12	——	8,213
	1980	3.70	10.4	27,673
	1995	1.94	5.7	40,955
3. Malaysia	1960	34.32	——	975
	1980	22.6	37.2	2,297
	1995	12.95	20	4,310
4. Chile	1965	8.75	——	2,092
	1980	7.25	16.3	2,665
	1995	9.24	15.7	4,589
5. Argentina	1965	12.9	——	6,048
	1980	6.35	12.9	7,794
	1995	5.7	1.3	7,430
6. Canada	1965	5.42	——	10,826
	1980	3.72	5.4	16,398
	1995	2.45	4.1	19,733

Source: The World Bank's World Development Indicators (CD rom data set) 2001.

ANNEX TABLE 5.

Detailed results from the partial IKC from the tropical-global model, 1972–1991.

Independent variables/ equation number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
GDP	0.05	0.04	0.09	0.075	0.06	0.033	0.06	0.09
	(3.45)**	(1.9)*	(5.4)***	(4.6)**	(3.03)***	(2.3)***	(4.4)***	(4.77)***
GDP squared	-0.009	-0.003	-0.012	-0.01	-0.0086	-0.008	-0.02	-0.007
	(-2.44)**	(1.01)	(3.33)***	(2.6)***	(2.31)**	(2.2)***	(1.7)*	(1.65)*
Time	0.004	0.008	0.009	0.01	0.007	0.002	0.009	0.008
	(13.22)**	(20.3)***	(24.0)***	(26.4)***	(18.3)***	(7.7)***	(25.9)***	(18.9)***
Electricity (-1)		0.0004						
		(7.5)***						
Inflation rate (-1)			-0.00005					
			(2.3)**					
GDP growth rate (-1)				-0.0006				
				(2.09)**				
Ag value added (-1)					0.0008			
					(2.17)**			
Cereal yield (-1)						0.00005		
						(4.8)***		
Ag. value-added growth (-1)							-0.0002	
							(0.8)	
Manuf. value add Gw (-1)								-0.0003
								(1.65)
Adjusted R^2 (Unweighted)	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Number of observations	1,210	892	1123	1130	1128	1210	1079	969
Number of countries	64	47	63	63	64	64	62	59

Notes: 1. F statistics significant at 1% level for all regression models. Values in parentheses are absolute t- statistics, * = significant at 10%, ** = significant at 5%, *** = significant at 1%.

2. Dependent variable: Percentage of crop area irrigated.

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Postal Address:
P O Box 2075
Colombo
Sri Lanka

Location
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Tel:
+94-11-2787404

Fax:
+94-11-2786854

E-mail:
iwmi@cgiar.org

Website:
http://www.iwmi.org

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