Environ Dev Sustain
DOI 10.1007/s10668-007-9123-2

Measuring environmental degradation by using principal component analysis

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Received: 4 April 2007 / Accepted: 21 September 2007

Abstract The objective of the paper is to measure environmental degradation on the basis of some selected indicators by the application of a simple multivariate technique known as Principal Component Analysis. For this purpose the study considered six variables, namely, GDP per capita, fuel consumption, total fertility rate, water supply, sanitation, and electricity. However, because of unavailability of data, the variables such as technology relating to environment, waste disposal, air pollution, women/gender issues relating to environment, corruption, democracy etc. could not be considered. The results show that principal components explain about 62% of the variations in the level of environmental degradation. The variables like GDP per capita, fuel consumption, water supply and electricity played a major role in classifying the countries in terms of environmental degradation compared to the variables, sanitation and total fertility rate. The findings show that countries which have high GDP per capita, low fuel consumption, higher percentage of people having access to water supply and sanitation as well as electricity ranked higher in terms of environmental quality despite high fertility rate as shown by the spectacular example of Saudi Arabia. By contrast, those countries which have low percentage of population having access to safe water and sanitation as well as electricity, high fuel consumption and high fertility were ranked lower in terms of environmental quality despite high per capita income, as shown by the example of Angola which is placed in lowest position among the 51 selected countries. The results also show that correlation between poverty and environmental degradation is particularly acute in African countries where high population growth is acting as an exacerbating factor. The study concluded that high fertility has much impact on environmental degradation in case of poorer countries than in case of rich countries.

Keywords Poverty · Environmental degradation · Principal component analysis · GDP per capita · Total fertility rate · Sanitation · Water supply · Electricity · Fuel consumption

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1 Introduction

Perhaps the most striking phenomena in developing countries are the increased visibility of deepening poverty and environmental degradation since the end of Second World War. Although some countries have made significant progress in this respect, and some individual groups and social classes have escaped poverty, millions still suffer from chronic deprivation (Mabogunje 2002).

Despite the constraints globalization places on economic growth and the insecurity that arises from regional armed conflicts, advances in health sciences—especially in epidemiology—have led to a human population explosion. Between 1960 and 2000, the world's population grew from less than 3 billion to some 6 billion. World population reached 6.1 billion in mid-2000 and is currently growing at an annual rate of 1.2% (about 77 million people). The United Nations estimates that by 2050, world population will reach between 7.9 and 10.9 billion people (Mabogunje 2002).

The growth of world's population and the rapid growth of economic activity in the past have caused and are still causing severe environmental damage. The protection of world's natural environment will without doubt be one of the most challenging questions in the coming decades. As the world population and production per capita on a global level will continue to grow in the future, further environmental deterioration is to be expected. The demand for a better living standard in the Third World and the seemingly unlimited desire for higher incomes in industrialized countries will increase the use of natural resources such as raw materials and energy and will result in increasing emissions of polluting and toxic substances. Therefore environmental problems will play a more important role in political decision-making and there is a need to take environmental aspects into account when making decisions on the allocation of production factors and distribution of income (Van Ierland 1993).

The protection of the environment and of natural resources is therefore an essential part of development: without adequate environmental capital, development is undermined and this in turn may reduce the resources available for investing in maintaining and enhancing the environmental base. The poor are both victims and agents of environmental damage and hence alleviating poverty is not only moral imperative but also a prerequisite for environmental sustainability and sustainable development. Poverty and environmental degradation have the same or related root cause and poverty reduction is a pre-requisite for sustainable development (UNEP 1995).

In any case, environmental degradation has serious impact on man especially the poorest of the poor. Poor people are forced to overuse environmental resources to survive and this impoverishing of the environment again threatens their survival. For example, forests cover 22% of the world's total land, but the rate of deforestation is increasing rapidly, and particularly in poorer countries. In poorer countries, agriculture, forestry, and energy production, generate half of the GNP. The export of natural resources constitutes a substantial component of their exports. Therefore, economic activities which prevail in poor countries contributes directly to resource depletion and environmental degradation in most LDCs[1]

The environment is the source of what everyone needs to survive (air, water and food) as well as the source of the materials we require to take our lives from pure survival to subsistence and beyond (shelter, clothing, tolls and the infrastructure of collective human settlement). The absence or denial of these basic necessities constitutes absolute poverty (Masahauri and Omari 1997).

[1] http://www.ossrea.net/occasional/no5-01.htm

Although general indicators of development, such as GNP per capita, life expectancy at birth, infant mortality and calories per capita have steadily improved as a result of technological innovations, poverty is growing and the environment is being stressed on larger scales than ever before. (Gallipon et al. 1989; cited in UNEP 1995).

According to Kahn (1995), the effective social policy requires the development of a separate indicator of environment that is compatible to the measures for guiding other areas of social policy.

Thus the indicators can be an important tool for designing and evaluating poverty reduction strategies, projects and outcomes. They are useful for monitoring changes and trends over time, they provide a means for comparing progress across different countries and are needed for evaluating the results of projects. Without indicators, well-developed strategies and programs can be rendered meaningless. Indicators are tools for monitoring change. In order to assess poverty related improvements, it will be important to have a comparable core set of global indicators. However, the ultimate utility of any set of indicators will depend on the needs of local as well as global stakeholders. Thus any global efforts to monitor the poverty impacts of environmental change is likely to be most effective if it complements local initiatives and tries to meet local demands (Shyamsundar 2000).

The purpose of the present study is to develop an alternative measure of environmental degradation based on some selected indicators for some selected Asian and African countries by the application of a simple multivariate technique known as Principal Component Analysis (PCA). PCA is used here as a tool for measuring different dimensions in the data. Thus the factors used for the present study are measuring different dimensions of environmental degradation. However, the indices so derived are also ordered so that Z_1 (the first component) displays the largest amount of variation, Z_2 (the second component) displays the second largest amount of variation and so on. When doing a Principal Component Analysis, there is always the hope that the variances of most of the indices will be so low as to be negligible. In that case, the variation in the data set can be adequately described by the few observed variables (in this case six variables) with variances that are not negligible (Manly 1986, p. 60). Thus PCA is best suited for deriving a small set of linear combinations of the original variables that account for most of the total variance (Dillon and Goldstein 1984, p. 54).

Further, since most of the indicators suffer from simultaneity and multi-co linearity, PCA is best suited for removing such difficulties because it maximizes the variance rather than minimizing the least square distance (Jha and Murthy 2001, p. 16) where any other technique (such as regression analysis) fails to do so. Since PCA is based on a linear transformation of the regressors such that they are orthogonal to each other by design, any information contained in the points in the event space is not lost. Second, the normality assumption is not essential, because in a real world situation, where there are wide differentials among countries and between individual effects of indicators, such assumption is dispensable. Third, with such a dispersed set of outcomes, PCA is ideally suited because it maximizes the variance rather than minimizing the least square distance. Therefore from the point of view of removing the limitations of regression analysis, PCA scores very well (Jha and Murthy 2001, p. 16)

As Das (1999) mentioned, the choice of the most appropriate method depends upon the type of the problem, the nature of the data and the objective of the analysis. In social sciences, variables are in general correlated and the researchers are not in a position to study the socio-economic dynamics with a set of independent variables. One needs to look for an alternative dimension reduction technique which will enable them to summarize the whole set of information into a manageable form without much loss of the information content of the original data. The theme of the multivariate analysis is simplification and "to summarize a large body of data by means of relatively few parameters" (Chartfield and Collins 1980; cited in Das 1999). Though the composite index can be built up using simple techniques like ranking and indexing methods, these techniques have many drawbacks one of which is the arbitrariness and allocation of equal weights. Furthermore, the technique like Human Development Index (HDI) as developed by UNDP in 1990 also suffers from serious limitations. One of the major drawbacks of this method is that it is an average of three indices: life expectancy index, income index and literacy index. Such an average value gives too much weight to the extreme values chosen and may be unduly affected by extreme values. As Streeten (1993) points out, such an average conceal great inequalities, and vast discrepancies between men and women, boys and girls, rich and poor, urban and rural residents, different ethnic or religious groups. It is also argued that in constructing HDI, equal weights were given to its three components without providing any justifications for doing so. Moreover, "it is not known how sensitive HDI is to changes in the weighting system employed. Hence the ranking of countries according to HDI can at best be considered as illustrative rather than evaluative" (Chowdhury 1991). According to Kelley (1991, p. 30), the specific weighting requires detailed justification about which HDI is substantially silent. Therefore, for the present purpose, PCA is best suited for constructing a composite index as the method of principal components provides an easy procedure of letting the data determine the optimal weights that capture the largest fraction of the variance (Ram 1982, p. 384).

Although various studies have been done on the issue of poverty-environment linkage, no detailed study has been undertaken on developing an index of environment so far which can act as a policy guide to formulate appropriate policies for environmental sustainability with targeted interventions in the lagging regions. The paper has been organized in the following way: the first section discusses about the method, section two deals with data and variables, section three presents results and discussion and section four ends with conclusion.

2 The method of principal component

The method used to derive the component scores using six economic and demographic variables for reflecting environmental degradation is Principal Component Analysis (PCA). PCA transforms the original set of variables into a smaller set of linear combinations that account for most of the variations of the original set. The principal component are extracted so that first principal component denoted by $PC_{(1)}$ accounts for the largest variation in the data.

Let us consider the variables $X_1, X_2, \ldots, X_p$. A principal component analysis of this set of variables can generate p new variables, known as the principal components, PC_1, PC_2, ..., PC_p. The principal components can be expressed as follows:

$$PC_1 = b_{11}X_1 + \ldots + b_{1p}X_p = Xb_1$$

$$\vdots$$

$$PC_p = b_{p1}X_1 + \ldots + b_{pp}X_p = Xb_p$$

or, in general,

$$PC = Xb$$

where b's are the coefficients for principal component and each column of b contains the coefficients for one principal component. Here, the coefficients for PC_1 is chosen such that it's variance is the largest, and PC_2 is chosen to have the second largest variance subject to the condition that PC_1 and PC_2 are uncorrelated, and so on. For any principal component, the coefficients of principal components are chosen such that $\sum_{i=1}^{p} b_{ij}^2 = b_j' b_j = 1$. Now, if we consider that the sample variance-covariance matrix of the original variables, X, is S_x then the coefficient vector, b_j, can be obtained by solving the following equations:

$$|S_x - \lambda I| b = 0$$

where λ is the vector of characteristic roots and b is a matrix comprising of the characteristic vectors corresponding to each characteristic root (Harris 2001). There may be p characteristic roots, some of which may be zero if there are linear dependence among the original variables, X. It may be noted here that PC_1 is computed by using the characteristic vector corresponding to the largest characteristic root, λ_1, similarly, PC_2 is computed by using characteristic vector corresponding to the second largest characteristic root, λ_2, and so on (Harris 2001).

It must be stressed that a principal component analysis does not always work in the sense that a large number of original variables are reduced to a small number of transformed variables. Indeed if the original variables are uncorrelated then the analysis does absolutely nothing. The best results are obtained when the variables are correlated, positively or negatively (Manly 1986, p. 60). One merit of PCA is that an increase in the number of variables that one may wish to include for deriving a composite index imposes very little cost on the analysis and one can include many related variables for deriving the principal components (Ram 1982, pp 227–247).

3 Data and variables

Data have been taken from Human Development Reports 2000 and 2002 and World Development Report 2003. The study first considered six variables like access to safe drinking water (2000), safe sanitation (2000), GDP per capita (2000), consumption of traditional fuel (1997), total fertility rate (1995–2000) and access to electricity 1997) to construct the index. Later it included variables like annual fresh water withdrawals (as % of water resources, 1987–97), annual renewable water resources (cubic meters per capita, 2000), commercial energy use (GDP output per kg, US$, 1997), carbon dioxide emissions (per capita metric tons, 1996) and writing and printing paper consumed (kg per capita, 1997) to see the extent of influence of these variables on environment in addition to the above six variables. The countries have been selected on the basis of those countries which have not yet achieved a replacement level of fertility (i.e. those countries whose total fertility rate is greater than 2.1) assuming that high population growth has an adverse effect on environment. This is because as the world population grows geometrically, great pressure is being placed on arable land, water energy and biological resources to provide an adequate supply of food while maintaining the integrity of our ecosystem. The continued production of an adequate food supply is directly dependent upon ample fertile land, fresh water, energy plus the maintenance of biodiversity. As the human population grows, the requirement for these resources also grows. Even if these resources are never depleted, on a per capita basis they will decline significantly, because they must be divided among more people (Pimentel et al. 1996).

Poor people are forced to overuse environmental resources to survive, and this impoverishing of the environment again threatens their survival. Thus poverty contributes greatly to environmental stress leading to increasing levels of poverty trap. An important factor in the poverty trap is the rapid population growth in poor societies. Rapid population growth puts more pressure on the environment and especially the non-renewable resources, and reduces the environment's ability to dilute the wastes. In fact, rapid population growth in the Third World countries often has a double-edged negative effect, simultaneously increasing the number of job seekers, while destroying the resources needed to create job. The environment cannot be sustained with these increasing rates of population growth especially in LDCs. The present study therefore hypothesizes that high population growth has adverse effect on environment in case of poorer countries rather than in case of high income countries.

A variety of indicators can be used to monitor change in any particular situation. Given that resources for monitoring and evaluation are limited, choosing the right set of indicators is very important. The choice depends on the goal or purpose for which monitoring is required, the scale at which monitoring is required and on the quality of available indicators. However, the main components which relate to poverty and environment are the following:

(i) Women /Gender issues as they relate to poverty and environment
(ii) Technology level as it relates to environment
(iii) Fuel (wood, Charcoal, fossil)
(iv) Water supply
(v) Waste (collection, treatment and disposal)
(vi) Human settlement pattern and environmental degradation.

However, because of unavailability of data on many important indicators relating to poverty and environment, the choice of the variables used in the present study depend on the following criteria:

(i) and (ii): Water supply and sanitation: Water supply is an area where poverty plays a big role in the degradation of the environment. The poor have no easy access to water supply of good quality and at all times. Available global evidence suggests that two most important ways in which environmental quality has a negative impact on health of the poor is through water and indoor air pollution. Access to safe water and sanitation are commonly used indicators for assessing health outcomes such as diarrhea (Masahauri and Omari 1997).

Water supply quality in urban poor areas has very close relation to the sanitation levels in the areas. There is a connection between the poverty level of a given community and the level of sanitation attained by the same. Poverty of the said community will inevitably affect the quality of sanitation available and consequently the potability of the water supply. Competition for water resources among individuals regions and countries and associated human activities is already occurring with current world population growing. About 40% of the world's people live in region's that directly compete for shared water resources (Pimentel et al. 1996). Contaminated drinking water transmits diseases such as diarrhea, typhoid and cholera. In developing countries, diarrheal diseases are believed to have killed about 3 million children annually in the early years 1990s and 1 million adults and children older than 5 years annually in the mid-1980s.

The lack of solid waste management in squatter settlements is also visibly disturbing. These areas receive minimal garbage collection service or none at all. For example in 1993, in Dhaka, Bangladesh, 90% of the slum areas did not have regular garbage collection services. The problems resulting from such conditions are obvious—odors, disease vectors, pests that are attracted to garbage (including rats, mosquitoes and flies), and the overflowing drainage channels clogged with garbage. Leachate from decomposing and putrefying garbage contaminates water sources. Because the poorest areas of cities are generally those that receive the fewest sanitation services, the uncollected solid wastes usually include a significant proportion of fecal matter (Mabogunje 2002). As Nath et al. (2000) pointed out, the countries of Southern Black Sea region are also facing mounting and apparently intractable problems in managing their solid waste with increasingly serious implication for public health and quality of life. Since data on waste disposal/ management are not available, the study uses data on fresh water withdrawn annually as well as access to safe drinking water as indicators of environmental degradation. It is hypothesized that access to safe water and adequate sanitation have positive effect on environment.

(iii) Fuel: Fuel is a special item that relates to the environment. In his endeavor to develop man needs fuel for various works such as food preparation, water treatment, warming up houses etc. The type of fuel to be used depends on the income level of the society in question. The rich and affluent will most probably use "clean" fuel like electricity and gas while the poor will be confined to the use of firewood and charcoal, which are cheap and environmentally damaging (Masahauri and Omari 1997). Because fossil energy is a finite resource, its depletion accelerates as population needs for food and services increase. As supplies of fossil fuel dwindle, the cost of fuel increases everywhere. The impact of this is already a serious problem for developing countries where the high price of imported fossil fuel makes it difficult, if not impossible for poor farmers to power irrigation and provide for their other agricultural needs. Worldwide per capita supplies of fossil energy show a significant decline (Pimentel et al. 1996).

However, the dependence of the poor on biomass fuels for cooking and other domestic uses increases the concentration of suspended particulates, which often reach levels that exceed WHO standards in areas where the poor are concentrated. The need of the poor for cheap means of transport within urban areas has encouraged the proliferation of highly polluting transportation modes such as single-stroke engine motorcycles. Poorly maintained second hand vehicles heighten the level of air pollution in most cities of developing countries (Mabogunje 2002). However, air pollution through vehicles is a problem of both developing and even some high income countries also. Almost 4 billion children die each year of acute respiratory infection linked to indoor and outdoor air pollution. More than 100 million people in Europe and North America, even in some Asian countries are still exposed to unsafe air with some air pollutants proving more difficult to control than expected (Roberts 1998). But because of lack of information on air pollution we are constrained to use data on traditional fuel consumption and deforestation for the present purpose. It is hypothesized that the higher the fuel consumption, the higher the deforestation which will have negative effect on environment.

(iv) Electricity: Electricity is one of the major determinant of poverty as well environment. Poor has less access to electricity. In the absence of electricity poor will continuously depend on firewood and charcoal which are cheap and environmentally damaging. Therefore access to electriciy is also an indicator of environmental degradation. Thus it is hypothesized that electricity will have positive effect on environment.

(v) GDP per capita: The poorer the society the worse the environmental situation. It is therefore imperative to say that if the environment is to be improved or at least protected, the income of the poor must be enhanced to a certain level, which can be sustained by the given resources available in the environmental setup (Masahauri and Omari 1997). It is beyond doubt that economic activities presupposes a functioning environment. However, there is less consensus about the effects that economic growth has on environmental quality but income regularly has the most significant effects on the indicators of environmental quality. As GDP moves beyond Environmental Kuznets Curve (EKC) turning points, it is assumed that the transition to improving environmental quality takes place (Sigrid 1999). However it is hypothesized that increased GDP may have positive effect on environment.

(vi): Total fertility rate: To poor people, environment is an enormous capital asset. Rapid population growth directly contributes to environmental degradation. And population growth may break down social norms and resource management systems, further contributing to environmental degradation. Yet environmental degradation can also increase population growth. Dasgupta and Maler (1991, cited in Kahn 1997) hypothesize that children are "produced" not only for consumption purposes and for retirement and insurance purposes but also to increase the workforce. Therefore level of fertility may have an indirect impact on the level of poverty and therefore on environmental degradation.

3.1 Deforestation

Deforestation leads to impoverishment of people as well as of the environment because in addition to providing timber and fuel wood, forests are relied on by many local communities for food, medicine and many non-timber products that provide a means to generate income. Wood provides 17% of all energy consumption in developing countries and over 70% in the 40 poorest countries. Though wood fuel is in principle a renewable resource, the fact that in many parts of the world it is being depleted just as surely as if it were an irreplaceable fossil fuel. If present trends continue, the wood fuel supplies of many hundreds of millions of people will be exhausted long before the oil fields on which the industrialized world depends have run dry (UNEP 1995).

However, since the variable 'deforestation' representing environmental degradation overlaps with the variable 'fuel consumption', the present study considers only fuel consumption as a variable representing environmental degradation. The present study previously considered both fuel consumption and deforestation as variables representing environmental degradation and the results show the these combined variables along with other variables explains only 53% of the variation in the level of environmental degradation. Therefore the variable deforestation has been dropped from the analysis.

3.2 Corruption and democracy

Theoretical and empirical studies have shown that democracy and corruption influence environmental policies. The study by Pellegrine and Gerlagh (2006) shows that corruption stands out as a substantial and significant determinant of environmental policies while proxies for democracy have only insignificant impact. But because of unavailability of the data on corruption and democracy for some of the countries included in the study, it was not possible to include such important variables. It should also be mentioned in this

Table 1 Eigenvalues of the correlation matrix (six variables)

Components	Eigenvalue	Difference	Proportion	Cumulative
PRIN1	3.7268	2.9566	0.6211	0.6211
PRIN2	0.7702	0.1940	0.1283	0.7495
PRIN3	0.5761	0.1608	0.0960	0.8455
PRIN4	0.4152	0.0362	0.0692	0.9147
PRIN5	0.3790	0.2466	0.0632	0.9779
PRIN6	0.1324	.	0.0220	1.0000

Source: Calculated by the author

connection that data on corruption should be used with caution because of large margin of error and methodological problems.

4 Results and discussion

Table 1 shows the eigenvalues of the correlation matrix. It is found that first component explains 62% of the total variation in the data. However, since the eigenvalue of the first component (in case of six variables) is greater than one, in the present case only the first component is used to calculate component score for each country to determine the ranking of selected countries[2]. Table 2 shows the eigenvectors of the selected variables. From the Table we see that GDP per capita, fuel consumption, safe drinking water and electricity carried more weight than sanitation and total fertility rate in case of ranking of countries.

Table 3 shows the ranking of the selected countries based on Principal Component (PC) scores as well as ranking based on GNP per capita. From the above Table, we see that among the selected countries, Saudi Arabia topped the list in terms of environmental quality followed by Chile and Malaysia. Malaysia is the frontrunner among the selected Asian countries in terms of environmental quality although the rate of deforestation is quite high and printing and writing paper consumed (kg per capita) is one of the highest (but fuel consumption is pretty low compared to other low income countries, see Table 4). Among the Latin American and European countries, Chile and Turkey respectively, topped the list while among African countries South Africa fare well in terms of environmental quality mostly because fuel consumption is one of the lowest and annual rate of deforestation is also the lowest among the African countries.

Table 2 Component loadings (Eigenvectors, six variables)

Variables	Component 1	Component 2
Total fertility rate	–0.382	0.594
Sanitation	0.380	–0.149
Safe drinking water	0.409	–0.274
Fuel consumption	–0.414	0.083
GDP per capita	0.446	0.387
Electricity	0.412	0.626

Source: Calculated by the author

[2] Perhaps the most frequently used extraction approach is "root greater than one" criterion. Originally suggested by Kaiser (1958; cited in Dillon and Goldstein 1984), this criterion retains those components whose eigenvalues are greater than one. The rationale for this criterion is that any component should account for more "variance" than any single variable in the standardized test score space (see Dillon and Goldstein 1994, p. 48).

Table 3 Ranking of Selected Asian and African Countries Based on Indicators of Environment (using 6 variables)

Countries	PC score	PC ranking	GNP per capita ($PPP)	GNP ranking	Fuel consumption
Saudi Arabia	1.75	1	11367	1	0.0
Chile	1.53	2	9417	2	11.3
Malaysia	1.46	3	9068	4	5.5
Uruguay	1.38	4	9035	5	21.0
South Africa	1.28	5	9408	3	43.4
Libya	1.25	6	7570	9	0.9
Lebanon	1.20	7	4308	20	2.5
Mexico	1.00	8	9023	6	4.5
Costa Rica	0.98	9	8650	7	54.2
Turkey	0.95	10	6974	10	3.1
Venezuela	0.91	11	5794	16	0.7
Iran	0.90	12	5884	15	0.7
Brazil	0.89	13	7625	8	28.7
Panama	0.88	14	6000	14	14.4
Uzbekistan	0.76	15	2441	32	0.0
Colombia	0.72	16	6248	11	17.7
Egypt	0.69	17	3635	24	3.2
Peru	0.65	18	4799	18	24.6
Kyrgyzstan	0.63	19	2711	29	0.0
Algeria	0.59	20	5308	17	1.5
Dominican Republic	0.38	21	6033	13	14.3
Syria	0.36	22	3556	25	0.0
Morocco	0.22	23	3546	26	4.0
Philippines	0.21	24	3971	22	26.9
El Salvador	0.09	25	4497	19	34.5
Paraguay	0.01	26	4426	21	49.6
Indonesia	– 0.06	27	3043	27	29.3
Zimbabwe	– 0.15	28	2635	30	25.2
Guatemala	– 0.16	29	3821	23	62.0
Honduras	– 0.21	30	2453	31	54.8
Ecuador	– 0.23	31	3203	28	17.5
Nicaragua	– 0.26	32	2366	33	42.2
Bangladesh	– 0.33	33	1602	40	46.0
Vietnam	– 0.44	34	1996	35	37.8
Pakistan	– 0.44	35	1928	37	29.5
Gabon	– 0.66	36	6237	12	32.9
Senegal	– 0.79	37	1510	41	56.2
Cameroon	– 0.80	38	1703	39	69.2
Myanmar	– 0.90	39	1027	44	60.5
Sudan	– 0.93	40	1797	38	75.1
Ghana	– 1.01	41	1964	36	78.1
Zambia	– 1.06	42	780	50	72.7
Yemen	– 1.09	43	893	48	72.7

Table 3 continued

Countries	PC score	PC ranking	GNP per capita ($PPP)	GNP ranking	Fuel consumption
Kenya	– 1.12	44	1022	45	80.3
Tanzania	– 1.27	45	523	51	91.4
Nepal	– 1.29	46	1327	43	89.6
Niger	– 1.33	47	896	47	80.6
Mozambique	– 1.71	48	854	49	91.2
Togo	– 1.74	49	1442	42	71.9
Benin	– 1.79	50	990	46	89.2
Angola	– 1.88	51	2187	34	69.7

Source: Calculated by the author

Among the Asian countries, Myanmar and Nepal have the highest rate of environmental degradation (Nepal has one of highest rate of fuel consumption and annual rate of deforestation is 1.1, Myanmar also has very high rate of fuel consumption) while among Latin American countries Nicaragua ranked the lowest in terms of environmental degradation (Nicaragua has one of the highest rate of deforestation and also high rate of fuel consumption). Results based on PC scores also shows that most of the African countries have high degree of environmental degradation, Angola being the lowest among 51 countries. This is mostly because of high fuel consumption in these countries. Available evidence shows that in 1980, fuel wood accounted for 58% of energy in consumption in Africa, 17% in Asia and 8% in Latin America. Among some individual countries, it is 68% in Kenya, and 98% in Mozambique (UNEP 1995, p. 39).

When we compare the ranking of the countries based on PC scores with that of ranking based on GNP per capita we find that there are wide differences in case of some selected countries. The highest differences are found in case of Lebanon, Kyrgyzstan, Uzbekistan, Gabon and Angola. Lebanon, Uzbekistan and Kyrgyzstan rank higher in terms of PC ranking but rank low in terms of GNP per capita alone. The main reasons for these countries to be placed in higher position is that in all these cases, access to sanitation and safe drinking water, access to electricity are much higher despite low per capita income. Further, total fertility rate in these countries is lower than the average while fuel consumption is almost nil or much lower than average fuel consumption in these countries. By contrast, in Gabon and Angola, access to sanitation is much lower while access to safe drinking water is only moderate. Further, total fertility rate as well as fuel consumption in both these countries are much higher which placed them in lower position despite their moderately higher per capita income.

From Table 3 it is evident that those countries which have higher per capita income as well as higher access to sanitation, safe drinking water, electricity, low fuel consumption ranked higher in terms of environment despite higher fertility rate. But that does not imply that fertility has no impact on environment, rather the link between population growth and environmental degradation is direct and positive. The important thing is that high fertility has more impact on environment in case of poorer countries than in case of rich countries because of less fuel consumption in these countries. Further, population in developed countries is expected to change little during the next 50 years and is even expected to decrease in some countries. However, in the developing world, population is expected to increase by 3.3 million between 2000 and 2050 (Mabogunje 2002).

Chart 1 Profile of environmental degradation

Region	Lowest (0.90–1.75)	Low (0.21–0.89)	Medium (–0.66–0.09)	High [–1.88–(0.79)]
Asia	Malaysia	Philippines	Bangladesh	Myanmar
			Vietnam	Nepal
			Pakistan	
			Indonesia	
Middle East	S. Arabia	Syrian Arab Republic		
	Iran			
	Libya			
	Lebanon			
Europe	Turkey	Uzbekistan		
		Kyrgyzstan		
Latin America	Chile	Dominican Republic	El Salvador	
	Venezuela		Paraguay	
	Costa Rica		Guatemala	
	Mexico		Honduras	
	Uruguay		Nicaragua	
Africa	South Africa	Algeria	Gabon	Senegal
		Egypt		Sudan
				Ghana
				Yemen
				Kenya
				Niger
				Mozambique
				Togo
				Benin
				Angola
				Tanzania
				Zambia

The analysis has been extended to include factors like energy consumption, renewable water resources, fresh water withdrawn annually, emission of carbon dioxide and writing and printing paper consumed (per capita) in addition to the above six variables to see the extent of influence of these factors on environmental degradation. The results show that addition of these variables explain only 41% of the total variance which is not satisfactory. By iteration, the variables like renewable water resources, carbon dioxide emissions and energy consumption were dropped and the index was calculated with the remaining eight variables which explain about 51% of the total variance (using only first component) and 64% of the variance (using first two components, see Table 5).

However, for the purpose of comparison, the present study calculated ranking of selected countries using both first and second component (since the eigenvalue of these two components is greater than one). The results show that addition of these two variables, namely, fresh water withdrawn annually and writing and printing paper consumed (kg per capita) explain about 13% of the total variance. The ranking of countries (Table 6) shows that Malaysia topped the list while Saudi Arabia ranked fourth in terms of environmental

Table 4 Indicators of environment for some selected countries

Countries	Deforestation 90–95 (%)	Fresh water withdrawals Per capita cubic meters (1987–1997)	Printing and writing paper consumed (kg per capita) 1997	Carbon dioxide emissions per capita 1996	Fuel consumption (as % of total energy use) 1997	Electricity consumed 1997 (per capita)
Malaysia	2.4	633	27.6	5.8	5.5	2474
Philippines	3.5	811	5.0	0.9	26.9	454
Thailand	2.6	596	13.5	3.5	24.6	1352
Sri Lanka	1.1	573	2.8	0.4	46.5	255
China	0.1	439	7.8	2.8	5.7	758
Indonesia	1.0	407	7.1	1.2	29.3	395
India	0.0	588	2.2	1.1	20.7	329
Pakistan	2.9	1269	1.4	0.7	29.5	321
Nepal	1.1	1397	0.1	0.1	89.6	47
Myanmar	0.3	454	2.3	1.0	63.9	96
Bangladesh	0.9	134	1.1	0.2	46.0	89
Saudi Arabia	0.8	1002	6.2	0.2	0.0	10690
South Africa	0.2	391	24.9	6.9	43.3	3776
Botswana	0.5	81	0.5	1.4	–	–
Gabon	0.6	70	0.4	3.3	32.9	700
Morocco	0.3	454	2.3	1.0	4.0	430
Ghana	1.3	35	0.6	0.2	78.1	204
Zimbabwe	0.6	136	1.9	1.6	25.2	894
PNG	0.4	28	0.8	0.3	62.5	–
Cameroon	0.6	38	0.8	0.3	69.2	184
Kenya	0.3	87	1.8	0.3	80.3	126
Congo	0.2	20	0.3	1.9	53.0	48
Lao PDR	0.8	260	0.3	0.1	88.7	–
Madagascar	0.8	1694	0.3	0.1	84.3	–
Sudan	0.8	669	0.1	0.1	75.1	46
Togo	1.4	28	0.2	0.2	71.9	–
Congo Democratic	0.7	8	0.1	–	91.7	90
Nicaragua	2.5	267	1.0	0.7	43.4	442

Source: Human Development Reports 2000 and 2001

quality. But a close analysis of the ranking of the countries shows that additions of these two variables had very little or no effect in case of low income countries but there are some variations in case of higher income countries. For example, Malaysia which ranked third using six variables now is placed in highest position while Saudi Arabia was placed in fourth position. Second, Mexico which was placed in 8th position using six variables now ranked 17th position which is worth mentioning. But since the value of the eigenvector of the variable, writing and printing paper consumed (kg per capita) in case of first component is very low (.056, see Table 7), it is difficult to ascertain the effect of this variable in case of ranking of the countries. Again, since the eigenvector of this variable is very high (.916, see Table 7) in case of second component, we also used the scores of second component to

Table 5 Eigenvalues of the correlation matrix (using eight variables)

Component	Eigenvalue	Difference	Proportion	Cumulative
1	4.0915	3.0179	0.5114	0.5114
2	1.0736	0.2103	0.1342	0.6465
3	0.8632	0.2384	0.1079	0.7536
4	0.6247	0.0462	0.0781	0.8317
5	0.5785	0.1954	0.0723	0.9040
6	0.3830	0.1392	0.0479	0.9519
7	0.2438	0.1026	0.0305	0.9823
8	0.1412	.	0.0177	1.0000

Source: Calculated by the author

rank the selected countries in respect of environmental degradation (Table 8). This shows that Malaysia ranked the highest in terms of environmental degradation while Brazil ranked the lowest which is not realistic. And all other ranking does not reflect the reality as the sign of the variables are not in expected direction. Writing and printing paper consumed has in fact a two way effect. So it is difficult to ascertain the effect of this variable in case of environment. Thus the variable has been dropped from the analysis.

Attempt was then made to calculate the index using seven variables (dropping the variable, writing and printing paper consumed) and the results show that these variables explain only 52% of the total variance (considering component 1) and 67% of the variance (using component 1 and component 2). An interesting thing is to note that the ranking of the selected countries as well as the scores based on seven variables are more or less the same as the ranking of countries based on six variables except a few variations. Therefore, the ranking based on six variables seems to be more accurate than seven or eight variables[3].

5 Conclusion

From the above discussion it is clear that PCA gives a better measure of well-being than GDP per capita alone. The main criticism of GDP per capita is that it does not take into account the case of environmental degradation.

Many economists argue that GDP and the National Income and Product account that underlie GDP, should be modified to take environment into account. In particular, Daly 1977, Peskin 1976 and Repetto 1989 (all cited in Kahn 1997) have argued that disastrous consequences can occur when macroeconomic policy is based on promoting the growth of GDP without taking the environment into account. They argue that not only does these emissions ignore other aspects of the quality of life, but GDP is seriously flawed as a measure of economic progress. Repetto (as cited in Kahn 1997) argues that the depreciation of natural capital should be factored into NDP in a fashion analogous to the depreciation of human made capital. To make good the deficiency in GDP however, there has now been proposals for what is called "Green GDP", which is an index of economic growth with the environmental consequences of that growth factored in. But critics argue that several problems bedevil Green GDP. One is that nature does not come prepackaged in units like cars, houses, bread etc. Even worse, Green GDP requires measurement of the

[3] Scores based on six and eight variables have been retained for the purpose of comparison. Scores based on seven variables are not shown as it makes a little or no difference in the case of ranking of countries.

Table 6 Ranking of selected countries based on PCA using eight variables (using scores of component 1)

Countries	PC score	PC ranking	GNP per capita	GNP ranking
Malaysia	1.99	1	9068	4
S. Africa	1.77	2	9408	3
Chile	1.66	3	9417	2
S. Arabia	1.66	4	11367	1
Uruguay	1.45	5	9035	5
Libya	1.02	6	7570	9
Costa Rica	1.02	7	8650	7
Venezuela	0.94	8	5794	16
Brazil	0.89	9	7625	8
Panama	0.85	10	6000	14
Turkey	0.80	11	6974	10
Iran	0.77	12	5884	15
Colombia	0.74	13	6248	11
Egypt	0.61	14	3635	23
Peru	0.59	15	4799	18
Uzbekistan	0.57	16	2441	30
Mexico	0.53	17	9023	6
Algeria	0.50	18	5308	17
Kyrgyzstan	0.48	19	2711	27
Dominican Republic	0.40	20	6033	13
Syria	0.29	21	3556	24
Philippines	0.22	22	3971	21
El Salvador	0.17	23	4497	19
Morocco	0.08	24	3546	25
Indonesia	0.02	25	3043	26
Paraguay	0.01	26	4426	20
Guatemala	–0.19	27	3821	22
Honduras	–0.23	28	2453	29
Zimbabwe	–0.24	29	2635	28
Nicaragua	–0.27	30	2366	31
Bangladesh	–0.39	31	1602	38
Pakistan	–0.48	32	1928	35
Vietnam	–0.47	33	1996	33
Gabon	–0.70	34	6237	12
Cameroon	–0.80	35	1703	37
Senegal	–0.81	36	1510	39
Myanmar	–0.91	37	1027	41
Sudan	–0.94	38	1797	36
Ghana	–1.01	39	1964	34
Zambia	–1.05	40	780	47
Yemen	–1.09	41	893	45
Kenya	–1.11	42	1022	42
Tanzania	–1.23	43	523	48

Table 6 continued

Countries	PC score	PC ranking	GNP per capita	GNP ranking
Niger	–1.29	44	896	44
Mozambique	–1.64	45	854	46
Togo	–1.65	46	1442	40
Benin	–1.71	47	990	43
Angola	–1.79	48	2187	32

Source: Calculated by the author

Table 7 Components loadings (Eigenvectors, using eight variables)

Variables	Component 1	Component 2
Total fertility rate	–0.355	–0.137
Sanitation	0.351	0.072
Safe drinking water	0.389	0.036
GDP per capita	0.428	0.025
Electricity	0.396	–0.053
Annual fresh water Withdrawals	0.341	–0.360
Writing and printing paper consumed	0.056	0.916
Fuel consumption	–0.371	0.019

Source: Calculated by the author

benefits arising from public goods provided by nature for which there are no market indicators of value. So the issue of Green GDP is still debated and question arises as to what should be counted in Green GDP (Boyd 2007).

Since HDI does not include environment component, attempt has also been made to formulate HDPI (a framework of pollution sensitive human development indicator). This HDPI is based on the method of calculating HDI by incorporating into HDI of an environmental factor measured in terms of CO_2 emissions from industrial process per capita (Vega and Urrutia 2001). But as mentioned earlier, HDI has some limitations and the present study makes an attempt to explore the possible linkage between population growth, poverty and environment based on some selected indicators applying the method of PCA. The findings of the study shows that both population growth and poverty have much adverse consequences on environment in developing countries than in developed countries. Since the conditions of poverty in developed countries are different from those in undeveloped countries, the findings of the present study shows that those countries fare well in terms of environmental quality which has high GDP per capita, higher percentage of people having access to sanitation and safe drinking water and less consumption of fuels despite high fertility rate. Therefore, in both developed and undeveloped countries, poor and low-income people are disproportionately affected by environmental degradation and more likely to be exposed to toxic pollutants in their homes and workplace. Therefore poverty needs to be eradicated in developing countries before they can turn their attention to environmental protection.

However, the issue of environment-population growth and poverty is complicated by the fact that many of the critical variables depend on one another so that the impact of any one variable is difficult to isolate. Because the relationship between population growth, poverty

Table 8 Ranking of countries based on PCA using scores of component 2 (in case of eight variables)

Countries	PC Score	PC ranking	GNP per capita	GNP ranking
Brazil	5.61	1	7625	8
Paraguay	2.97	2	4426	20
Egypt	0.40	3	3635	23
Uzbekistan	0.25	4	2441	30
Turkey	0.09	5	6974	10
Morocco	0.09	6	3546	25
Kyrgyzstan	0.09	7	2711	27
Togo	0.09	8	1442	40
Vietnam	0.08	9	1996	33
Libya	0.06	10	7570	9
Peru	0.02	11	4799	18
Bangladesh	–0.00	12	1602	38
Myanmar	–0.01	13	1027	40
Iran	–0.01	14	5884	15
Kenya	–0.02	15	1022	42
Algeria	–0.03	16	5308	17
Sudan	–0.03	17	1797	36
Guatemala	–0.05	18	3821	22
Cameroon	–0.05	19	1703	37
Honduras	–0.06	20	2453	29
Syria	–0.06	21	3556	24
Ghana	–0.07	22	1964	34
Nicaragua	–0.08	23	2366	31
Tanzania	–0.08	24	523	48
Senegal	–0.10	25	1510	39
Zimbabwe	–0.10	26	2635	27
Panama	–0.12	27	6000	14
Philippines	–0.14	28	3971	21
Zambia	–0.17	29	780	47
Pakistan	–0.19	30	1928	35
Costa Rica	–0.19	31	8650	7
Colombia	–0.20	32	6248	11
Dominican Republic	–0.21	33	6033	13
Niger	–0.22	34	896	44
Indonesia	–0.26	35	3043	26
El Salvador	–0.27	36	4497	19
Mozambique	–0.27	37	854	46
Gabon	–0.29	38	6237	12
Benin	–0.33	39	990	43
Uruguay	–0.35	40	9035	5
Angola	–0.41	41	2187	32
S. Arabia	–0.42	42	11367	1
Venezuela	–0.44	43	5794	16

Table 8 continued

Countries	PC Score	PC ranking	GNP per capita	GNP ranking
Yemen	–0.45	44	893	45
Chile	–0.54	45	9417	2
Mexico	–0.59	46	9023	6
S. Africa	–1.38	47	9408	3
Malaysia	–1.46	48	9068	4

Source: Calculated by the author

and environment are so complex, continued effort and further research are needed to better understand the relative importance of population growth, the mechanism by which it causes environmental damage and its interactions with other factors like poverty. Since no detailed study has so far been made on developing an index of environment based on selected indicators relating to poverty and environment, the present study can at least give a partial picture of the poverty-environment linkage which can provide a basis for planners and programmers to begin the process of eliminating or reducing environmental degradation to some extent. However, the present index of environment could be improved to a great extent if adequate information on technology relating to environment, waste disposal, air pollution, democracy, corruption women/gender issues relating to environment etc. are available.

Acknowledgements I would like to express my deep gratitude to the Director, Centre for Policy Research (CPR), Universiti Sains Malaysia, for giving me the opportunity to join CPR as a Visiting Research Fellow and conduct my research activities here. I also deeply acknowledge the helpful comments of Dr. Chan Huan Chiang of CPR, Universiti Sains Malaysia, for his helpful comments in writing this paper.

Appendix

Appendix from Table 2 we have the following components loadings (eigenvectors) to calculate the component scores based on available data which are standardized

Variables	Component loadings (Eigenvectors)	Standardized values[a] for Country A	Standardized values for Country B
Total fertility rate	–0.382	X_{11}	X_{21}
Sanitation	0.380	X_{12}	X_{22}
Safe drinking water	0.409	X_{13}	X_{23}
Fuel consumption	–0.414	X_{14}	X_{24}
GDP per capita	0.446	X_{15}	X_{25}
Electricity	0.412	X_{16}	X_{26}

[a] Xs represent standardized scores [(Actual Value–Mean Value)/Standard Deviation] for the variables considered (See Dillon and Goldstein, 1984, p: 52)

Now using these component loadings (eigenvectors) and standardized scores of the variables, the component scores for any country can be calculated as follows:

Score for country A = $-0.382 \times X_{11} + 0.380 \times X_{12} + 0.409 \times X_{13} - 0.414 \times X_{14} + 0.446 \times X_{15} + 0.412 \times X_{16}$

Score for country B = $-0.382 \times X_{21} + 0.380 \times X_{22} + 0.409 \times X_{23} - 0.414 \times X_{24} + 0.446 \times X_{25} + 0.412 \times X_{26}$

The study uses statistical software package SAS to calculate the component scores based on available data.

References

Boyd, W. J. (2007). Nonmarket benefits of nature: What should be counted in green GDP? *Ecological Economics, 61*(4), 716–723.

Chowdhury, H. O. (1991). Human development index: A critique. *The Bangladesh Development Studies, XIX*(3), 125–126.

Das, A. (1999). Socio-economic development in India: A regional analysis. *Development and Society, 28*(2), 313–345.

Dillon, W. R., & Goldstein, M. (1984). *Multivariate analysis: Methods and applications*. New York: John Wiley and Sons.

Harris, J. R. (2001). *A primer of multivariate statistics (3rd edn)*. London: Lawrence Erlbaum Associates Publishers.

Poverty and environmental degradation. Available at: http://www.ossrea.net/occasional/no5–01.htm

Van Ierland C. E. (1993). *Macroeconomic analysis of environmental policy*. Netherland: Elsevier.

Jha, R., & Bhanu Murthy, K. V. (2001). *An inverse global environmental kuznets curve, trade and development, 2001/02*. Canberra, Australia: Economics RSPAS, Australian National University.

Kahn, R. J. (1995). *The economic approaches to environmental and natural resources*. New York: The Dryden Press.

Kahn, R. J. (1997). *The economic approaches to environmental and natural resources (2nd edn)*. New York: The Dryden Press.

Kelley C. A. (1991). The human development index: Handle with care. *Population Development Review, 17*(2), 315–324.

Mabogunje, L. A. (2002). Poverty and environmental degradation: Challenges within the global economy. *Environment*, Jan–Feb, 2002.

Manly, B. (1986). *Multivariate statistical methods: A primer*. London: Chapman and Hall.

Masahauri, D. A., & Omari, C. K. (1997). Poverty and environment. Available at: http://www.jet.co.t3/paper4.htm

Nath B., Pelovski Y., & Stoyanov, S. K. (Eds). (2000). *Sustainable solid waste management in Southern Black Sea region*. Dordrecht, Netherlands: Kluwer Academic Press.

Pellegrini, L. & Gerlagh, R. (2006). Corruption, democracy and environmental policy. *Journal of Environment and Development, 5*(3), 332–354.

Pimentel, D., et al. (1996). *Impact of population growth on food supplies and environment*. Baltimore, USA: AAAS Annual Meeting.

Ram, R. (1982). Composite indices of physical quality of life, basic needs fulfillment and income: A principal component representation. *Journal of Development Economics, 11*, 227–247.

Roberts, L. (1998). Focus: Environmental degradation is contributing to health threats worldwide. Our Planet 9.5, Available at: http://www.ourplanet.com/imgversn/9.5/roberts.html

Shyamsundar, P. (2000). Poverty—Environment Indicators. Environmental Economic Series Paper No. 84, World Bank Environment Department.

Sigrid, S. (1999). Delinking economic growth from environmental degradation?: A literature survey on the Environmental Kuznets Hypothesis. Working Paper Series No. 6, Institute for Volkswirtschaftstheorie und Politik, Wien, Wirtschafts University.

Streeten, P. (1993). Human development: Means and ends. *The Bangladesh Development Studies, XX1*(4), 65–76.

UNEP (1995). *Poverty and the environment: Reconciling short-term needs with long-term sustainability goals*. Nairobi: UNEP.

UNDP (2000). *Human Development Report 2000*. New York: Oxford University Press.

UNDP (2002). *Human Development Report 2002*. New York: Oxford University Press.

Vega De la M. C. L., & Urrutia A. M. (2001). HDPI: A framework of pollution sensitive human development indicator. *Environment, Development and Sustainability, 3*, 199–215.

World Bank (2003). *World Development Report 2003*. New York: Oxford University Press.