Working Paper

Challenges for Studying Population-Environment Interactions in the Arab Region

Wolfgang Lutz

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Contents

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Abstract

Since the Arab region largely belongs to the arid climate zone, concerns of fresh water availability in the context of population changes have a long tradition and are well entrenched in the Arab culture. In the future, however, this region is likely to face unprecedented challenges which result from a combination of continued very rapid population growth, combined with the prospect of significant climate warming. This paper presents alternative population scenarios to 2100 which are based on different fertility, mortality and migration assumptions and show that the population of the Arab region is still likely to increase by a factor of more than four. A more extreme scenario combining slow fertility declines with rapid mortality improvements may even result in an eightfold increase by the end of the next century. On the climate side, different General Circulation Models (GCMs) anticipate for the region increases in average temperature of between 3.0 and 4.5 degrees C under doubled CO_2 conditions (likely to be reached during the second half of the next century). The combination of these two trends makes population-environment issues in the region a vital challenge.

Because appropriate action requires appropriate scientific analysis which in the field of population-environment interactions is almost entirely lacking, the second part of the paper presents the outline of a possible research strategy. The PDE (Population-Development-Environment) approach that has already been applied to several case studies is proposed as a comprehensive strategy to encourage an interdisciplinary discussion and a science-policy dialogue around the building of a computer-based simulation model of these interactions, which has proven to be a useful facilitating tool.

Challenges for Studying Population-Environment Interactions in the Arab Region

Wolfgang Lutz

1. Introduction

The availability of fresh water has always been a basic prerequisite for human life and civilization all around the world. But in no other world region has water availability played such a dominating role in determining the settlement, growth and movement of human populations as it did in the Arab region. The efficient use of the scarce water resource has become a central ingredient of the Arab culture and of the structure of Arab societies and economies. It may be a new and still unusual issue to explicitly speak about general population-environment interactions in this region--as it is in all other regions--but to talk about water as a determinant of population trends and of population growth as impacting on water availability is certainly nothing new in the Arab region. Hence, the water issue will be a recurrent theme in this paper, although it will be embedded in a broader framework of population-development-environment analysis.

We will first look at different degrees of aridity and how they affect human settlement patterns, with empirical observed in the 19 Arab countries. Next, we will summarize our present understanding about likely future trends in population growth and climatic change in the Arab region. Finally, we will propose a strategy of how to study the complex population environment interactions in a more comprehensive and systematic way.

2. Population and Water in the Arab Region

In geophysical terms the Arab countries can all be classified as essentially being arid. Definitions of aridity vary greatly over time and space and a desert may mean something different in different parts of the world. To produce a more objective system of classifications, the Man and Biosphere (MAB) Programme of UNESCO (1977) defined three types of arid zones: hyper-arid, arid and semi-arid (see Table 1).

According to UNEP (1992) hyper-arid zones cover 7.5 per cent of the earth's land surface and receive only limited and highly variable rainfall, averaging less than 100 mm per year. They consist essentially of the Saharan, Arabian and Gobi deserts. Arid zones cover 12.1 per cent of the total world surface and have up to 300 mm of rainfall (200 mm in winter rainfall areas) with an interannual variability of 50-100 per cent. Arid zones are also mostly concentrated in Northern Africa and Western Asia. Semi-arid zones cover 17.7 per cent of the world's land surface and are defined by less than 800 mm of mean annual rainfall (500 mm in winter rainfall areas).

Table 1. The arid zones. Source: Clarke and Noin 1996, Table 1.

Zone	**Climate**	**Vegetation**
Hyper-arid (extreme desert)	Extreme drought, very great rainfall irregularity	Extremely sparse
Arid (desert)	Severe drought and rainfall variability	Thin
Semi-arid (semi-desert)	Weaker drought and rainfall variability	Grassy steppe, xerophytic bush or dry savanna

Human settlement patterns are greatly influenced by the degree of aridity. The bulk of the population in the partly arid countries is concentrated in the less arid areas. For example, the total population of Jordan occupies only one-tenth of its territory. The spatial distribution is extremely uneven due to the degree of aridity. This extreme unevenness of population distribution may even be taken as a characteristic of arid countries (Clarke and Noin 1996) and this skewness is presently intensifying by the process of urbanization. As we will see in the following analysis, many Arab countries show extremely high degrees of urbanization. Also in the most arid countries that largely depend on external sources for their renewable water supply populations tend to be very localized upon small land areas along rivers originating in humid areas.

Table 2 presents some demographic and environmental indicators for the 19 Arab countries (classification and data from UNDP 1995). The table first gives the estimated total population for the year 2000. Since this is only three years from now, it gives a more accurate picture of the current condition and conditions in the near future than census information which is usually quite dated, thereby giving much lower population sizes. With almost 70 million in the year 2000, Egypt is clearly the most populous Arab country. This is followed by a group of three countries, Algeria, Morocco and Sudan, that have roughly 30 million inhabitants. Next comes a group of four countries, Iraq, Saudi Arabia, Syria and Yemen, which will have in the order of 20 million people. Somalia and Tunisia have around 10 million; Jordan and Libya around 6 million. The estimated growth rate between 1992 and 2000 is highest in Jordan, Oman and Yemen with around 4 per cent per year. This high growth rate implies a doubling of the population in only 17 years and a quadrupling in 35 years. It is interesting to note that the ranking of countries according to the growth rate does not fully correspond to that of the total fertility rate (TFR) in 1992, where Yemen has the highest with 7.6 children per woman, followed by Oman with 7.2, and Libya and Saudi Arabia with 6.4. In five other countries the TFR is above 5.5. On average, fertility is lower in the North African countries than in Western Asia. But still the Arab region rivals only with Sub-Saharan Africa in having the world's highest fertility levels.

Table 2. Selected demographic and environmental indicators for the Arab countries.

STATE	**POP** (millions) 2000	**Annual population growth rate** (%) 1992-2000	**TFR** 1992	**Population density** (km^2)	**Urban population** (as % of total) 2000	**Food imports** (as % of merchandise imports) 1992	**Arable land** (as % of land area) 1992	**Irrigated land** (as % of arable land area) 1992	**Internal renewable water resources per capita** (1,000 m^3 per year) 1992	**Annual fresh water withdrawals: as % of water resources** 1980-89	**Annual fresh water withdrawals: Per capita** (m^3) 1980-89
Algeria	31.2	2.2	3.9	13	60	26	3.3	5.5	0.7	16	160
Bahrain	0.6	2.5	3.8	600	92	...	2.9	...	...	...	735
Djibouti	0.6	2.1	5.8	26	84	...	...	...	0.6	2	29
Egypt	69.1	2.0	3.9	69	46	29	2.6	101.7	0.1	97	1,213
Iraq	23.8	2.8	5.7	54	77	...	12.5	46.8	1.8	43	4,575
Jordan	6.4	4.0	5.6	72	74	21	4.6	16	0.2	41	173
Kuwait	1.8	-0.8	3.1	100	98	...	0.3	40	...	...	11
Lebanon	3.3	2.5	3.1	330	89	...	29.9	28.1	1.7	16	271
Libyan Arab Jamahiriya	6.4	3.4	6.4	36	88	...	1.2	11.5	0.1	374	692
Morocco	29.6	1.9	3.8	66	51	14	22.1	13	1.1	37	499
Oman	2.6	4.1	7.2	12	16	19	0.3	92.1	1.2	22	561
Qatar	0.6	2.0	4.3	55	93	...	0.6	114.3	...	174	234
Saudi Arabia	21.3	3.0	6.4	99	82	16	1.7	25.6	0.1	106	321
Somalia	10.8	2.5	7.0	17	28	20	1.7	11.6	1.3	7	119
Sudan	32.1	2.7	5.7	14	27	19	5.5	14.8	1.1	14	1,092
Syrian Arab Rep.	17.3	3.4	5.9	94	55	17	32.2	15.3	0.6	9	434
Tunisia	9.7	1.8	3.2	63	60	8	31.4	4.8	0.5	53	317
United Arab Emirates	2.1	2.2	4.2	25	86	17	0.5	12.8	0.2	140	414
Yemen	17.1	3.9	7.6	32	38	...	2.8	24.3	0.2	...	...

With respect to population density, the Arab region is extremely heterogeneous, which is a consequence of big differences in the size of national territories and the presence of large deserts. Densities range from 600 persons/km^2 in Bahrain and 330 in Lebanon, to only 14 in Sudan and 13 in Algeria. The degree of urbanization is highest in Kuwait (98 per cent), Qatar (93 per cent), Bahrain (92 per cent) and lowest in Sudan (27 per cent), Somalia (28 per cent) and Oman (16 per cent). This very strong heterogeneity in density and human settlement patterns makes it very difficult to find any consistent associations with the given set of environmental indicators.

The percentage of the total land area that is classified as arable land seems to be very dependent on climatic conditions and to some degree on the topographic structure. While roughly 30 per cent of the national territory of Lebanon, Syria and Tunisia is considered arable, it is only 0.5 per cent in the United Arab Emirates and 0.3 per cent in Oman and Kuwait. Also the proportion of the arable land that is irrigated does not directly correlate to any of the other variables. It seems to be mostly a consequence of the degree of aridity and the economic potential to pay for extended irrigation. In Qatar and Egypt more than 100 per cent of the land area considered arable is irrigated. In Tunisia and Algeria, on the other hand, only around 5 per cent of all arable land is irrigated.

For the internal renewable water resources per capita, all Arab states show a consistent pattern, namely that of extremely low water availability per person. Lebanon still has the highest, with 1,700 m^3 per year per person. Egypt, Libya and Saudi Arabia have the lowest, with only 100 m^3 per year per person. This is very low water availability by any standard. The problem is that as population is expected to further increase by a factor of four or even more, the total amount of internal renewable water resources will not increase or may even decrease as a consequence of climatic change. Hence, per capita availability will decline as a direct function of population growth. As Table 2 shows, in 1980-89 many countries withdrew large proportions of their theoretically available water. Only the oil-rich countries (and Libya with its fossil water) managed to exceed this ‘natural limit’ of renewable water resources. This ‘excess consumption’ of water based on non-renewable resources (fossil water or oil as a matter of fact) cannot be a sustainable strategy in the longer run; it is unlikely to be affordable for the large majority of the Arab population in the near to middle term future.

3. Prospects for the Future

While some environmental problems and constraints are already being felt, the real challenges are assumed to lie in the future. With the population of the Arab region expected to approximately quadruple over the coming century and the scarce fresh water resources staying constant or even declining due to possible climatic change, some major economic, social and even political problems arising from the conflict over the increasingly scarce resource might be anticipated.

In this section an attempt will be made to summarize the best scientific understanding we have today about possible future population growth in the region, and the state of the art with respect to modeling possible climatic change in this part of the world.

Tables 3 and 4 give the results and the underlying assumptions of alternative population projections for the two relevant world regions (North Africa and the Middle East which roughly correspond to the Arab countries) as defined in the IIASA book, *The Future Population of the World. What can we assume today?* (Lutz 1996). This book consists of a large set of substantive background chapters describing and analyzing past trends in the different world regions and discussing alternative fertility, mortality and migration assumptions to be made for the future. In the last two chapters these alternative assumptions are translated into alternative scenarios till 2100 and even a set of fully probabilistic population projections (see also Yousif et al. 1996 for North Africa). Contrary to the UN or World Bank projections, these IIASA projections also explicitly consider possible alternative paths in mortality and migration, and not only fertility as is done by most national projections. The results show that alternative mortality and migration assumptions do indeed make a very significant difference.

In Tables 3 and 4 the results of selected scenarios combining low and high fertility and mortality assumptions are presented. For lack of space here only the central migration assumptions are considered, which assume constant annual net migration losses in the order of 240,000 for North Africa and 30,000 for the Middle East.

A combination of the central fertility and mortality assumptions, which are also considered the most likely ones, will bring up the population of North Africa from the present 162 million to 439 million in 2050 and even 607 million in 2100. This is an increase by almost a factor of four. In the least likely case of high fertility combined with low mortality it would even result in 593 million in 2050 and an incredible 1.3 billion in 2100 in the six countries of North Africa. This would be roughly eight times the population of today. The lowest case is given by the very unlikely combination of low fertility and high mortality. Even in this lowest case the population would also double by the middle of the next century, but then decline to only 227 million by 2100. The figures clearly illustrate that alternative mortality assumptions do make a significant difference, e.g. the combination of low fertility with low mortality results in 357 million by the end of the century, which is 57 per cent higher than the 227 million under the high fertility assumption. The table also indicates that under all scenarios, the mean age of the population will increase. It is likely to increase from its present 25 years to between 33 and 50 over the next century, depending on the scenario.

For the Middle East region the projections show a similar pattern, the only difference being that the projected population growth is even more rapid. Even under the central scenario the population will increase by almost a factor of five to 738 in 2100. A first doubling will already have occurred by 2020. Even under the lowest scenario considered, the population of the Middle East will increase to 2.5 times its present size by the middle of the next century. Under the high fertility and low mortality scenario it would grow to an incredible 1.5 billion by 2100, which is a factor of ten. And as one can see from the set of assumptions, even this scenario assumed a gradual decline of fertility over time. A constant fertility scenario would yield even higher population numbers.

Table 3. Summary results to 2100, North Africa (includes the following countries: Algeria, Egypt, Libya, Morocco, Sudan, and Tunisia). Source: Lutz 1996, p. 443.

Fertility **Mortality** **Migration**	**C** **C** **C**	**L** **H** **C**	**H** **H** **C**	**L** **L** **C**	**C** **L** **C**	**H** **L** **C**
Total population size (in millions)						
1995	162	162	162	162	162	162
2010	228	220	232	223	229	235
2020	277	256	288	266	282	299
2050	439	311	519	362	468	593
2100	607	227	912	357	716	1288
Mean age (in years)						
1995	24.6	24.6	24.6	24.6	24.6	24.6
2010	26.0	26.5	25.4	26.6	26.0	25.5
2020	27.4	28.4	26.2	28.8	27.6	26.5
2050	32.1	35.9	28.1	37.8	33.0	29.4
2100	39.5	43.5	33.7	49.8	42.2	36.9
Assumed total fertility rates						
1995-2000	4.24	4.14	4.35	4.14	4.24	4.35
2010-2015	3.70	3.18	4.22	3.18	3.70	4.22
2020-2025	3.35	2.59	4.11	2.59	3.35	4.11
2050-2055	2.62	1.82	3.42	1.82	2.62	3.42
2095-2100	2.04	1.54	2.54	1.54	2.04	2.54
Assumed life expectancies for both sexes combined (in years)						
1995-2000	64.8	64.4	64.4	65.2	65.2	65.2
2010-2015	67.9	64.9	64.9	71.0	71.0	71.0
2020-2025	70.2	65.4	65.4	75.0	75.0	75.0
2050-2055	74.1	65.9	65.9	82.5	82.5	82.5
2095-2100	76.8	65.9	65.9	87.7	87.7	87.7

C = Central
L = Low
H = High

Table 4. Summary results to 2100, Middle East (includes the following countries: Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen). Source: Lutz 1996, p. 449.

Fertility **Mortality** **Migration**	**C** **C** **C**	**L** **H** **C**	**H** **H** **C**	**L** **L** **C**	**C** **L** **C**	**H** **L** **C**
Total population size (in millions)						
1995	151	151	151	151	151	151
2010	234	226	238	229	235	241
2020	301	278	313	287	305	323
2050	517	375	610	426	546	685
2100	738	299	1088	453	859	1491
Mean age (in years)						
1995	23.1	23.1	23.1	23.1	23.1	23.1
2010	24.3	24.8	23.8	24.8	24.3	23.8
2020	25.7	26.8	24.7	27.0	25.9	24.9
2050	31.8	35.6	28.1	37.1	32.6	29.1
2100	41.0	45.1	35.1	51.6	43.9	38.3
Assumed total fertility rates						
1995-2000	5.34	5.20	5.47	5.20	5.34	5.47
2010-2015	4.35	3.80	4.91	3.80	4.35	4.91
2020-2025	3.68	2.90	4.45	2.90	3.68	4.45
2050-2055	2.58	1.78	3.38	1.78	2.58	3.38
2095-2100	1.95	1.45	2.45	1.45	1.95	2.45
Assumed life expectancies for both sexes combined (in years)						
1995-2000	67.7	67.2	67.2	68.1	68.1	68.1
2010-2015	70.7	67.7	67.7	73.8	73.8	73.8
2020-2025	72.9	68.2	68.2	77.7	77.7	77.7
2050-2055	77.0	68.7	68.7	85.3	85.3	85.3
2095-2100	79.6	68.7	68.7	90.5	90.5	90.5

Knowing that the population of the Arab world is likely to more than quadruple over the next century and may possibly even increase by a factor of eight if fertility does not decline rapidly, one starts to think immediately how these huge numbers of people will be able to live given the constraints on some natural resources and most prominently fresh water. But the problem is worse than that because one cannot even count on a fixed amount of fresh water availability due to global climatic change, which will also affect the Arab region. The recent IPCC report (Houghton et al. 1996) has removed doubts that the world climate is indeed warming as a consequence of man-induced emissions of greenhouse gases and most prominently CO_2. Although global warming is now virtually certain, the degree of warming, the consequences on rainfall and especially the regional features of climate change are still very uncertain because of the intrinsic complexity of the global atmospheric system and the interactions between the oceans and the atmosphere.
Table 5 gives a summary of the projections of some of the most prominent General Circulation Models (GCMs). These models calculate the regional differentiations of changing climatic conditions. Some simulations now also include the effects of increasing concentrations of aerosols in the atmosphere, which has the effect of reducing the temperature increase in certain regions. The table gives information on the increase in mean temperature (in degrees centigrade (C)) and in the anticipated change in precipitation (in per cent as compared to the present average). The upper part gives the results for an equilibrium double CO_2 condition, for several GCMs. The lower part gives the expected change of time from present conditions to the 2070s. The data given are averages for the entire region ranging from the equator to 40 degrees North and from -10 West to 60 East. This section of the world's surface covers the entire Arab region. (It does, however, also include some humid areas in central Africa.)

Table 5. GCM climate change scenarios for the Middle East. Source: Cynthia Rosenzweig, personal communication.

Scenario	Temperature difference (C)	Precipitation change (%)
Equilibrium 2xCO_2		
GISS 4x5	4.33	-1.6
GFDL R30	3.35	+6.3
CCCM	3.59	-1.5
Transient		
UKMO 2030s	1.73	-2.8
UKMO 2050s	2.61	+3.9
MPIE 2030s	1.51	+1.3
MPIE 2050s	2.35	+0.8
GF01 2010s	1.13	-1.0
GF01 2040s	2.25	+4.1
GF01 2070s	3.78	+3.1

Annual averages from -10W to 60E, 0N to 40N.
Transient = ~1% increase in GHG concentrations per year
GCMs:
GISS Goddard Institute for Space Studies (4x5 resolution)
GFDL Geophysical Fluid Dynamics Laboratory R30
CCCM Canadian Climate Centre
UKMO United Kingdom Hadley Centre
MPIE Max Planck Institute ECHAM1-A
GF01 GFDL89 transient simulation

Table 5 immediately shows that the results for temperature change are much more consistent than those for rainfall. All major GCMs predict a significant increase in temperature in the region of between 3.0 and 4.5 degrees C under doubled CO_2. This very significant warming, expected for the Arab region, is substantially higher than the expected warming at the global level (Houghton et al. 1996) although the underlying scenarios are not strictly compatible. Since this increase is not evenly distributed over the year, there is also an increased likelihood of very extreme (i.e. very hot) temperature events.

With respect to rainfall the uncertainty is much higher. Some models predict an increase while others expect a decrease in precipitation. The picture is also highly complex because of strong regional differentiation and the seasonality of rainfall. One must also consider that increasing temperature increases evapotranspiration, thus leading to lower soil moisture. Soil moisture projections (Gordon and O'Farrell 1996) indicate that under doubled CO_2 conditions, declines in soil moisture may occur in the Arab region. Declines are projected to be greater in the Middle East than in North Africa, which is already very arid.

An additional problem which is a direct consequence of climate warming is the expected rise in sea level. After some early estimates that expected an increase of more than two meters in the not so distant future, recent projections resulting from more sophisticated models result in more moderate but still significant increases. Those models generally estimate an increase in the average global sea level of 40-50 cm by 2100. Over the next 400 years it may then further increase to about 150 cm (Houghton et al. 1996). Such increases may pose serious threats to low lying coastal areas not just because of possible flooding but also because of salt water intrusion which is already causing problems in areas such as the Nile delta (Strzepek et al. 1995).

These two mega-trends of the coming century, rapid population growth and climate warming, both work into the direction of aggravating already existing problems and reducing the margin of flexibility for efforts to overcome the problems. Of course there is optimism that rapid technological progress paired with rapid social and economic development may still create a way out of the dilemma of four times more people having to cope with deteriorating environmental conditions. But we also have to be aware of the fact that if such a technological option exists, it will only be feasible in a highly-educated society. Hence, education and especially the basic education of broad segments of the population is likely to be a key factor in any effort to cope with those serious challenges for the future (see e.g. Lutz 1994). A strong emphasis on general education also has the advantages of increasing public awareness about these issues, improving the skills to manage the system, and tending to reduce the rates of population growth through voluntarily lower fertility. This key importance of basic education in the context of population-development-environment interactions will not be further discussed here, because a separate session of this meeting explicitly deals with the issue of education.

On the political side these demographic and environmental factors may also lead to increasing tensions within the Arab world due to objectively differing interests. One already obvious problem is the controversy over transboundary fresh water supply (see Hillel 1994). The most important case is clearly the Nile river, where the life support system of 60 million Egyptians crucially depends on water entering the country from the Sudan. In the likely case of twice as many Egyptians and three times as many Sudanese in 2050, together with a possible decrease and higher irregularity of the Nile water flow, future conflicts over water seem to be almost pre-programmed. But also on the issue of climate change there are diametrically opposing views within the Arab world. In the discussions about the UN Framework Convention on Climate Change (FCCC) the oil-exporting Arab states are vigorously fighting against any agreement that would result in a limitation of global CO_2 emissions, while Egypt already understands that its delicate ecological balance may be seriously threatened through further increasing CO_2 emissions and the resulting climatic changes.

In conclusion to this section on future trends, there seems to be little doubt that resolving these difficult problems will become easier with slower population growth and a lower rate of global warming, and of course, with wise policies concerning socioeconomic efficiency and environmental management. These seem to be safe statements that can be made on the basis of the superficial analysis given above. Beyond that, however, we have to admit that we know very little about the real mechanisms in which population, socioeconomic development and the environment interact. But a better understanding of these complex interactions is a necessary prerequisite for designing the right policies already in the near future. Solid empirical information about these issues is also the basis for successful transboundary negotiations on the water conflicts discussed above.

For this reason I would like to issue a strong plea for comprehensive scientific analysis of population-environment interactions in the Arab countries. I consider this an absolute priority, which comes second only to the need to immediately increase basic education, especially for women. Since I will speak about the education priority elsewhere, I would like to use this opportunity to outline the kind of scientific analysis that I consider most urgent to appropriately address the serious future problems that we have identified above.

4. A Framework for Analyzing the Complex Interactions

A superficial look at the rapidly increasing number of scientific books and papers may lead to the wrong conclusion that enough is being done in this field. The number of studies on economic issues in the Arab region seems to be exponentially growing and so are the publications on certain environmental questions. The overwhelming majority of these studies, however, is very narrow in scope, and specific issues are singled out that often disregard the complex system of which they are a part. But what is needed to adequately address the population-environment issue in a way that can contribute to solving the serious future challenges is a very comprehensive and integrated assessment of all relevant factors ranging from the natural to the social sciences and even culture and with a strong policy component. Such a research effort needs to be developed in every country according to the specific conditions, but there are some general desirable features that will be briefly outlined below.

Over the past few years a team at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria, has designed such a research strategy in a series of case studies (Mauritius, Cape Verde, Yucatan). It has been labeled the PDE (Population-Development-Environment) approach. The basic idea of this approach is to assemble an interdisciplinary team of scientists to work towards a quantitative model of the most important factors and interactions of the country or region to be studied. It is important to emphasize that this quantitative model is not an end in itself (as it is in many modeling exercises) but that it is primarily intended as a facilitating tool for an interdisciplinary scientific dialogue and for a science-policy dialogue. This is based on the experience of many interdisciplinary discussions that have shown that unless there is a specific well-defined task to be done, such discussions will at best become interesting exchanges of opinion. But since different disciplines think in terms of different paradigms and speak different languages, the best one can hope for in the usual setting of scientific meetings is a multidisciplinary discussion in the sense that one phenomenon is studied independently from a multitude of angles but not a truly interdisciplinary study in the sense that these different angles become interconnected. It is our experience, however, that e.g. a demographer and a hydrologist can start working together in a productive interdisciplinary manner if they sit down together and discuss choices of variables, parameter values and functional relationships for a quantitative population-water model in a specific region. This way a true collaboration becomes possible on specific questions despite the different scientific paradigms, and experience shows that during the course of this work these paradigms may even be expanded in a way that makes them at least partially compatible.

Quantitative models may have a similar facilitating function in the science-policy dialogue because they can help to go beyond simply announcing your views and towards thinking jointly about documented empirical issues in the context of a clearly-defined framework. But this is still a harder thing to achieve than an interdisciplinary scientific discourse, because politicians often seem to have a different agenda, giving less priority to trying to understand what is actually going on. But if the scientific PDE analysis is to be useful for solving some of the future problems, the involvement of political decision makers at various stages of the study is crucial. Even if one does not succeed in convincing the politician to believe the findings of the work, one will at least better understand his concerns; this in turn may help in adjusting the model to directly address these concerns.

How should this facilitating tool be structured? It is clearly unfeasible to do a model which describes in some detail all relevant aspects of human life and the environment. Every model has to make choices but these choices should only be made after having looked at the issue as broadly as possible. The basic idea of the PDE approach is to consider the human population as being embedded into the sphere of social and economic activities (development) which again is at every point inside the laws of nature and the natural environment. This very broad view, which is also reflected in the basic structure of Figure 1, is now made more specific on the basis of the following three principles:

1. The model should only include relevant aspects that could potentially make a difference in the case considered.
2. The model should be as simple and straightforward as possible, avoiding ‘magic’ black boxes.
3. Only unambiguous and direct relationships should be hard-wired in the model. All other aspects should be treated as part of the soft model structure, as expressed by scenario settings.

Figure 1. Basic structure of the general PDE model. Source: Lutz 1994, p. 215.

While there is little that is new about the first two principles, the third may need some explanation. The PDE approach is based on some of the lessons learned from global modeling of the 1970s and early 1980s. The system should not become an artificial world in itself which, due to many predefined feedback loops, develops its own life and takes off in directions that can hardly be followed by common sense and have little to do with reality. We wanted to avoid hard-wired unchangeable feedback loops that are based only on ambiguous theory and scattered empirical evidence.

An example of this is whether fertility and mortality levels should be made direct functions of any other demographic, economic, or environmental parameters in the model. Because the vast literature on socioeconomic fertility determinants does not suggest any clear and simple functional relationship between fertility and a set of non-demographic parameters, it was decided not to specify such a relationship in the hard-wired part of the model. Instead, the user can decide when and how in the course of running the model the fertility levels in the different population groups should be changed, based either on changing socioeconomic or environmental conditions or simply on assumptions about relevant cultural and behavioral changes. This possibility of user-defined feedback through scenario assumptions is called the soft model. With respect to fertility, there are also several hard-wired aspects which work through the changing educational composition of the population: if the user assumes different fertility levels for different educational groups, a change in the educational composition of the population--which is also influenced by economic and government policy parameters--has a direct impact on the average fertility level in the population. This is a simple consequence of changing weights. Similar distinctions between hard and soft parts of the model can be found for many different sectors.

Following these thoughts, Figure 1 gives the model proposed as a general guideline for the PDE approach. At the center one finds the population broken down--in the first instance--by age and sex. This gives the traditional age pyramid with men (on the left) and women (on the right), with the youngest age group at the bottom and the oldest at the top. Although some models deal primarily with total population size, we believe that age structure, in particular, is an essential feature of the population which has immediate effects on the economy and society. Furthermore, over time, disregarding the population age structure would make it impossible to capture the momentum of population growth which--especially in the Arab countries--is quantitatively an extremely significant phenomenon. The growth rate of the population can only be indirectly affected through fertility rates, with the population structure exerting momentum.

In addition to looking at population size by age and sex, the suggested PDE population module includes two other important variables which are population based. These also address certain aspects of social development, namely, education and labor-force participation. With regard to education, there is an enormous amount of demographic literature indicating that education is one of the most important, if not the single most important, covariate of demographic behavior. Education appears to play an equally important role with regard to the effects of population composition on economic and socioeconomic development in general. Again and again, studies show that the skills of the population--and of the labor force in particular--are a major determinant of progress in virtually every field. Education also seems to be one of the key variables in a broader understanding of development as a change from a rather fatalistic attitude toward life to more rational planning. Labor-force participation is the other population-based variable that is considered to be particularly economically relevant. There is little doubt that the labor force contributes to the creation of national wealth along with advancement in the development process.

This form of the population module (cross-classified in a multistate population model) seems to be relatively unambiguous, with respect to both substance and methodology. It is an attempt to summarize, in one compact unit, the essentials of population dynamics that can be handed over to the rest of the model for economic, environmental, and policy considerations. Parameters of change in the population module are fertility, mortality, and migration in each subgroup, as well as schooling and labor-force entry and exit.

In Figure 1 the population parameters are embedded at every point in the sphere of social and economic activities, including accumulated knowledge and infrastructure that may be summarized by the notion of development. This includes models of production and consumption by economic sectors as well as imports, exports, and domestic trade. Obviously savings, investments, and government expenditures also need to be considered. Finally government policies play a crucial role in all social, economic, and even environmental aspects.

Unlike most other modeling attempts at addressing these issues, the PDE model does not want to be primarily an economic model. Its emphasis is on the population--environment relationship. But because population factors hardly ever directly interact with environmental factors, the economic module is intended to serve as a linkage between the two. In designing the economic module, one is faced with a dilemma: on the one hand, the philosophy of the PDE approach asks for as simple a model as possible to serve the purpose of linking population to the environment, whereas, on the other hand, one is in competition with a large number of very sophisticated economic models that do not attempt to provide this linkage.

But no matter which approach to economic modeling is chosen, certain features should be retained. With regard to the linkage of the economic module to the population module, all of the selected basic population characteristics--sex, age, education, and labor-force participation--must be reflected in the economic input parameters and must make a difference in the results. The educational composition of the population also has important independent effects on the economy. Firstly, higher education is assumed to increase economic productivity and, as a consequence, the competitiveness on the world market, and lead to faster technological progress. Secondly, consumption patterns are assumed to depend on age and education. Because the population module can only provide such information about individuals that cannot be directly translated into household distributions, consumption is also defined for individuals by age instead of the usual household definition.

Another general criterion for the economic module is that it should consider the main components of the economy separately, in order to allow the analysis of changes in the economic structure. But a model of the world market for relevant export goods is not being attempted. It would be a very complex task in itself. Instead external factors--such as export demand--are treated through scenario-defined input parameters. The economic module should also produce some basic indicators of material well-being, quantify government expenditures and investment in various important aspects of infrastructure, education, and social security, and provide unemployment figures. Finally, the economic module is expected to produce--as output variables--the input parameters for the various environmental modules. These parameters include water-demand figures, water pollution, solid waste, changes in land use, and possibly air pollution and impacts on biodiversity.

Figure 1 finds the environment broken down into four basic environmental sectors: air, water, land, and energy. The air module should be concerned with the chemical composition of the air, along with air temperatures and humidity, and the direction, speed, and seasonality of winds. The specific aspects and models selected to describe relevant aspects of atmospheric change depend, to a great degree, on the country or region chosen. In urban and industrial areas in particular, emphasis would be placed on air pollution which displays immediate implications on human health and on the health of the vegetation, especially forests. For more global considerations, attention would probably be directed to greenhouse gases along with those gases responsible for ozone depletion.

The water module is probably the most relevant of the environmental aspects, due to its direct link to human life-support systems. Problems with water supply can, in both the short and long term, lead directly to health problems such as those caused by lack of food production or by the consumption of contaminated water. Because most regions have different semi-independent water systems such as rivers, groundwater, lakes, and coastal waters, the water module should consist of several sub-modules that describe and model the dynamics of the systems relevant for life in the specific regions. For each subsystem, two important and different aspects of water need to be considered: the quantity and the quality. Both aspects are important, and problems with either one may cause problems for the system. However, quantity and quality are not independent. The quality of a given amount of polluted water can be improved by adding clean water. Hence, quantity can solve the quality problem.

Theoretically, the land-use model includes all aspects of surface structure, vegetation, and soil composition. In cases where soil degradation and erosion are serious problems, appropriate models which describe these phenomena in physical terms need to be chosen. In the case of Mauritius, the land module was mostly concerned with questions of land use and regional distribution, which are closely tied to economic changes and the values of different categories of land. This module distinguished between four major types of land use: urban use (including settlements and industries), sugar-cane fields, other agriculture, and beaches which, because of the tourist industry, have by far the highest value per land unit. The land-use module reconciles competition from different users, and puts constraints on the economic module and on environmental aspects. Its specific form will depend greatly on the region to be studied.

The influence on all nonhuman living things (other species) can certainly be very relevant for the human-environment interaction. This aspect includes considerations of biodiversity as well as the changing distribution of species. It is relevant not only for basic life-support systems but also for the disease environment that affects human mortality and partly also fertility.

Energy could be treated either as a separate module or as part of the economic module.

As was stressed initially this general PDE approach, which was outlined above, must be operationalized differently in different settings. Therefore PDE models are expected to take rather different forms in accordance with the specific environmental conditions or perceived priority issues. But irrespective of whether we call it the PDE approach or give it another name, important is the comprehensiveness of addressing quantitatively or qualitatively all relevant issues that we expect to make a difference, based on our best present knowledge.

Because of the obvious great mismatch between the enormous size of the problem of very rapid population growth and climate change in the Arab region on the one hand, and our very poor understanding of the complex interactions between population and the environment on the other hand, now is the time for scientists to take the responsibility to do their best to narrow this gap of knowledge and even leave the safe grounds of strictly disciplinary demography. Our demographic skills are now needed in a broader interdisciplinary context, and we should not shy away from it.

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