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Population-Landscape Interactions in Development: A Water Perspective to Environmental Sustainability

This paper is an interdisciplinary attempt to address the relation between the population with its social interactions, and the resource base of the surrounding landscape. It tries to merge a sociological and anthropological approach in explaining population and demographic conditions with an ecohydrological approach in explaining fundamental environmental functions and phenomena in the landscape. It draws attention to the fact that Third World development often has to take place under genuine water scarcity. At the same time, livelihood demands and production activities necessitate manipulations of soil, vegetation and water, in spite of the environmental vulnerability typical of low latitudes. This calls for skillful balancing methods between intended benefits and unavoidable side effects to secure environmental sustainability, protection of land fertility being crucial.

INTRODUCTION

The Stockholm Initiative on Global Security and Governance (1) wants to generate a common responsibility for the future but limits its focus to the 1990s. After 2000 AD the Third World population will increase by another 2000 millions. How does the world prepare itself for such a challenge?

It is urgent that a conceptual framework be developed linking population including its sociocultural systems with the various functions of water in the landscape, elaborating the connection between environment, and development.

A growing population needs not only water but also biomass to provide food, fodder, fiber, fuelwood and timber. The photosynthesis process in dry climates consumes about 1000 m^3 of water per ton biomass produced (2).

The situation in the lowest-income countries indicates that the dry climate, the high evaporative demand of the atmosphere, and recurrent drought years are a key challenge (3). It is alarming to see that most, not all, of the lowest-income countries are located in the zone where the atmosphere is extremely thirsty (above 1500 mm per year in evaporative demand), and part of the year is dry (the arid, semiarid and sub-humid region) or interannual droughts cause particular problems. That the lack of water can be overcome, can be seen in the examples of Australia, S. Africa, Saudi arabia, provided there is access to the other crucial factors for development, i.e. knowledge, energy and money (4). Interactions between soil, water and vegetation remained a rather neglected issue until the time of the International Geosphere-Biosphere Programme (5).

Water belongs to several resource categories; it is both a naturally renewable flow resource; a location-specific state resource, and a biological resource. The resource dichotomy between land and water, practiced in environmental planning in the temperate zone, is difficult to accept in analyses of dry tropical issues. Where land productivity is water-limited the very large water consumption in plant production in comparison to the recharge of aquifers and rivers implies that both vertical and horizontal water flows have to be discussed in parallel (6).

There is moreover a water-related carrying capacity to pay attention to, since water is a finite resource (7).

But water enters into the issue of sustainable development because the water cycle constitutes the central clockwork in translating human land-use into environmental side-effects (8). Changes in one water-cycle component propagates onwards into a long chain-effect, producing biological end effects. Water is therefore extremely crucial in the causality chains that produce biodiversity disturbance.

WATER-RELATED FUNCTIONS IN THE LANDSCAPE

In order to discuss the possibility for man to satisfy the increasing resource demands of a rapidly growing population, the life-support systems and land manipulation required to obtain more biomass and more water need to be analyzed (9). Because of the multiple roles played by water in the landscape, we will analyze the landscape as seen from a water perspective (Fig 1).

Basic Life-support Functions in the Landscape

A crucial component if a natural landscape is to be productive is that it receives moisture by the atmosphere. The input of water from the atmosphere via precipitation forms two main branches on contact with the land surface. Part of the water returns to the

Waterhole in dry riverbed. Tanzania. Photo: A. Rapp.

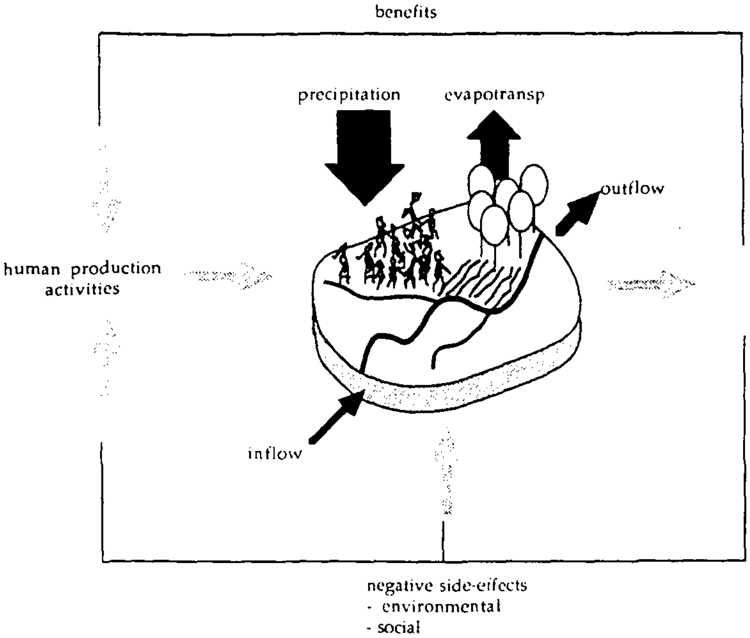


Figure 1. Whereas societal demands for livelihood determine human production activities in the landscape, the wettening of that landscape determines both its production capacity, the environmental vulnerability, and negative side-effects produced by the human landscape manipulations, needed to "harvest" biomass and water.

atmosphere, either as direct evaporation from wet surfaces or as part of the biomass production (transpiration). Water that percolates to the groundwater aquifers and later feeds the rivers, is a universal solvent with a unique dissolving capacity. It is chemically active and reacts with the surroundings through which it passes. These reactions are responsible for the water quality genesis (10).

The flowing water carries solutes along its pathways, such as nitrates leached from agricultural fields. The dissolving capacity of the moving water is triggered by the addition of acids from atmospheric pollutants. In the root zone the acid perturbates soil chemistry and causes damage to vegetation.

Water passing through the underground landscape divides it into different provinces with very different growing conditions. Hilltops and upper slopes are *recharge areas*: the water infiltrates the ground and moves downward through the soil layers. Local hollows, lower slopes and valley bottoms are discharge or *seepage areas*: the groundwater is returning to the land surface to evaporate or join the river. From a chemical point of view the root zones in these different provinces are fed with completely different water: in the recharge areas the water is low in salt content, in the discharge areas it is rich in solutes. The result is completely different vegetation in the different provinces. Mollisson (11) has produced a guide for land-use zoning in a semiarid region.

Distinction Between Endogenous and Exogenous Water

Agricultural production depends on the presence in the root zone of *endogenous* (locally produced) water. This is principally limited to the rainy season and expressed by the length of the growing season. Three months (90 d) is generally seen as the lower limit, below which only pastures are possible (12).

Since early human history, man has made skilful use of *exogenous* water (distantly produced water) from rivers, thereby expanding the growing season.

In semiarid areas with no exogenous water, yields are increased through rainwater harvesting, runoff collection and catchment management. Irrigation is limited to critical periods during the growing season (13). In climatically equivalent areas with access to exogenous water, irrigated crop growth may be possible for as many seasons as the water flow can support. In humid endogenous-fed landscapes, on the other hand, water management is centered around drainage and eutrophication, generated by leaching of excess fertilizers. Exogenous-fed landscapes, like the Netherlands, suffer from the additional problem of transboundary water pollution.

Hydroclimate Distinctions and Environmental Vulnerability

Four different modes of environmental vulnerabilities can be distinguished (14).

- Vulnerability to water scarcity due to dominance of the return flow to the atmosphere, leaving only very limited amounts to recharge the terrestrial water systems.
- Vulnerability to recurrent drought years due to large interannual fluctuations in rainfall.
- Vulnerability to erosion where the infiltration capacity of the land surface has been reduced by human action (overgrazing, compacting, exposure to radiation after deforestation) or where erodible soils are being exposed to heavy rains (e.g. deforestation on productive hillsides).
- Vulnerability to feedback from vegetation changes, manifested as changes in the return flow to the atmosphere with consequences for the flow of water in terrestrial systems.

SOCIETAL DEMANDS

The Livelihood Concept

Livelihood is defined here as: *securing a resource base or an occupational niche from which individuals can derive subsistence or subsistence plus levels of living on a reasonably regular basis*. Thus, livelihood is seen as being broader than what is commonly referred to in economics, i.e. employment and job creations.

Two Main Determinants of Livelihood Demands

While population size, relative to the resources, is often taken as a measure of the extent to which the life-support system can exist, per capita consumption also influences the ratio (15, 16). There are three essential questions: (a) What quantity of resources need to be secured? (b) What resources are pertinent for maintaining life? (c) How long can one maintain the condition one is living in? (16). These three questions can be seen as related to two determinants reflected in production activities (Fig. 2): (i) The consumption pattern as related to the concept of quality of life. (ii) Population growth (17).

Consumption Patterns and Quality of Life

The social interrelatedness of people is complex (18). As humans must live in social groups to survive, systems of norms and values are established to enable them both to cope with the interrelationships and to predict what behaviors others expect from them (19). It is evidently true that humans do not just fulfil their biological subsistence needs but, through the process of socialization, accept and strive to reach the level of living defined as desirable by the social environment (20).

From the functional evolutionary perspective (21) the evolution of a complex society is seen as a result of an inherent tendency among societies to increase adaptive capacity. This involves the ability to respond effectively to the surrounding environment. Therefore, social stratifications that evolve because of differences in the way *quality of life* is defined are unavoidable. While more contemporary societies have different adaptive mechanisms, i.e. different social institutional arrangements, they are not necessarily superior (22). Within a given context individuals will, to some extent, behave according to the principle of *enlightened interest*, cooperating with each other when it can further their interests, and struggling with each other when it seems appropriate. Some scientists (22) believe that technology will be able to increase the availability of resources. According to others, social mechanisms (23, 24) limit access even when the resources are made available.

It seems that the basic cause of intensification of stratification and differences in lifestyles is population pressure. In the evolution of the production process, when increasing scarcity of cultivable land occurs, some families begin to own more land than others. Intensification of this differentiation of access emerges in differences of lifestyles across social class and global regions.

While the the above is open to some criticism, there are obviously structural differences in lifestyles. This is to a certain extent related to the accessibility of resources across different societies. The landscape defines variations in food-consumption patterns, whereas societal value systems define the various symbols of quality of life desired (25).

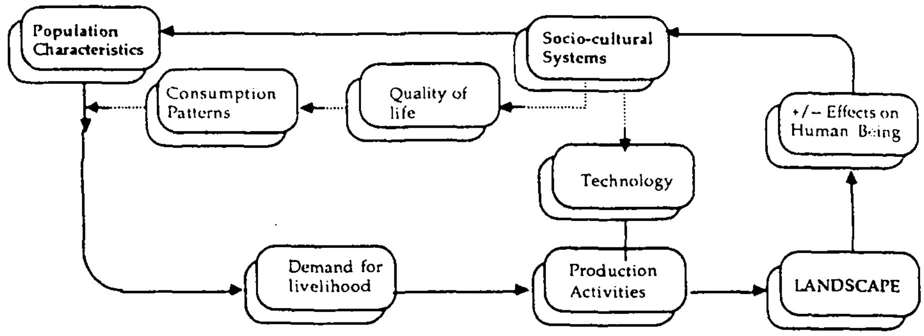


Figure 2. Details of the societal side of the society/landscape interactions. Production activities are driven by population characteristics, quality of life perceptions, and access to technology.

Production for Use and Production for Exchange

We can distinguish two broad types of production categories: *production for use*, and *production for exchange and investment* (26).

At present, it is evident that only small isolated societies practice the production for use modes. Examples can be found among the !Kung society in Africa, the Asmat, and the Dhani in West Irian, Indonesia. For such societies, the community sees the physical landscape as a *storage place*.

In societies in which *production for exchange* and investment is dominant, there is a tendency to try to optimize production in order to accumulate surpluses. In practical terms, however, production activities in a given landscape may be heterogenous. They should therefore be seen more in relative terms of more-or-less, rather than in the categorical sense of presence or absence.

In evolutionary analyses of changes in production patterns macro-sociologists and cultural-material anthropologists (27) have indicated that as agricultural modes of production took place *unequal distributions of life resources* increased as sharper social stratification took shape (28).

Dependence of Natural Resources in Other Regions

In societies where the main production relates to the *primary sectors*, the natural resources are seen as endogenous assets for economic growth (29). But the land may have little to offer for trade-exchange purposes (30). For societies where the main production processes relate to the *secondary sectors*, such as manufacturing and industries, technology and human resources are seen as endogenous assets for economic growth. In societies where the *tertiary* or *service sectors* predominate, technology and knowledge are the main assets. Such societies are highly dependent on durable and non-durable goods from other regions.

Population Growth During Different Stages of Demographic Transitions

The differences in population trends between less- and more-developed countries are closely related to three demographic facors: *fertility*, *mortality* and *migration*. Undoubtedly, as the size of population in a given region increases, pressure for subsistence needs increases. Table 1 indicates some characteristics in the main social systems of these demographic transition stages.

While most of the developing countries are currently at the same position in the *second demographic stages*, it is possible to find within these countries societies at the later stage of the *first demographic transition stage*. There, due to poor health conditions, high birth rates are balanced by high death rates (31).

The *second demographic transition stage*, characterized by low death rate as a direct function of improved health conditions, is problematic since the high birth rates remain, due to the positive social values of children. However, the main problems are basically twofold. (i) To what extent will these countries be able to accommodate future needs for employment as cultivable land gets scarce, should these countries' production modes remain agricultural in nature? (ii) Will the landscape be suitable to accommodate increased resource demands, should they move to different modes of production such as manufacturing when there are limitations in terms of both capital, skilled laborers, and the technological knowledge required? These countries will experience restraints not only in the modes of production but also in the water accessibility and water-operated biomass production.

Many developed countries are at present in *the third transition stage*, with low death rates and low birth rates. With the present value systems of the industrialized regions, even though population growth has slowed down in these regions, it is doubtful whether pressures for increased resources from the Third World will decrease.

LANDSCAPE MANIPULATIONS TO PROVIDE RESOURCES

The procedures by which water and biomass have been harvested involved landscape manipulations. Biomass productivity was increased by tilling, fertilizers, pesticides, and irrigation. Water was made easily accessible by digging wells and installing pipes and storage tanks. In the rivers, dams were built to make water accessible during the dry season.

Land Manipulations

Agriculture and forestry are equivalent to physical and/or chemical manipulations of soil and vegetation. In developing regions urbanization occurs in response to industrialization as an answer to demands for employment as the number of individuals in productive age increases and enters the labor force.

Urbanization involves major landscape manipulation, e.g., to soils, groundwater, and land-drainage patterns, adding strong components both in terms of reorganization of water flow, in order to support manufacturing processes, and disposal of chemicals and other waste products.

Water-system Manipulations

Different land-manipulation systems represent human responses to an increased need for croplands, higher yields, and alternative employment opportunities. In the case of water, the most simple response is the digging of wells to obtain groundwater.

Another conventional method of obtaining water when needed is by constructing water canals, conduits, qhanats and aqueducts to carry water from rivers and other sources to the user.

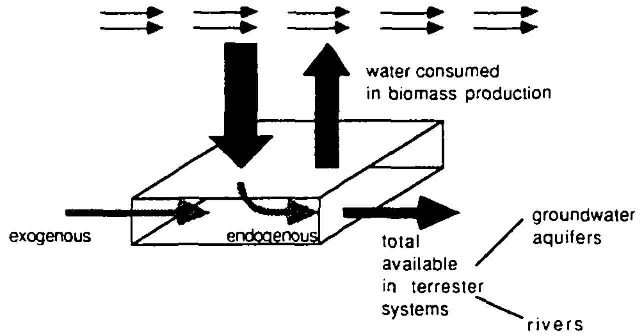
Where water availability is seasonal, dams and reservoirs are constructed to store flood-water for use during the dry season.

Intensity of Water-system Manipulations

How intensively the water system has to be manipulated in order to provide water needs, depends on the quantity relations between general water availability in the landscape and water demand. Natural water availability, i.e. the recharge of water systems (aquifers, rivers) provides a constraint to the demands that can be satisfied without additional water being added from the outside by measures such as desalination or interbasin transfer. It limits either the size of the population that can be supported or the per capita water demands that can be satisfied.

The total amount, here termed the *poten-*

Figure 3a. The overall freshwater availability in a country/region is principally finite when seen in a long-term perspective. It is basically composed of, on the one hand, the *endogenous* part, i.e. the surplus from regional rainfall (after subtracting the return flow to the atmosphere) that is recharging national aquifers and rivers; and on the other the *exogenous* part imported from upstream countries.



tial water availability, can be expressed as a certain finite number of flow units per year (Fig. 3a). The *accessible part* that can in fact be used for withdrawal-based purposes depends on seasonal variations and geographical distribution. This *mobilizable fraction* is however constrained by topography, conflicting water interests, evaporation losses and other unavoidable environmental side-effects.

In today's water-scarce and low-income Third World countries, population growth is therefore equivalent to increasing population pressure on a finite resource, as illustrated in Figure 3b. In a medium-term perspective of a few decades, the potential water availability puts a limit on the population that can be supplied at the minimum acceptable per capita level.

The water needed by the household is however only a small amount (32). The rural African household may have a demand of 5–25 L per day depending on the distance to the water source, the size of the family and the number of water drawers in the family (generally females). Around 75 L per day is considered adequate for good hygiene to protect against diseases. WHO has indicated 150 L per day as the water needed per household in Third World cities (33).

In a modern temperate-zone country, the industrial water demand varies strongly with the types of industry and technology and the degree of water conservation practiced. In Sweden, the 1990 industrial demand is estimated as 7 H (H=Household demand of 100 L per day), producing an overall water demand of 13 H (34). In a dry country, agriculture has often to be irrigated in order for yields to be drought-proofed. FAO states that 15–70 H is needed for self-sufficient agriculture based on irrigation (35).

Water Constraints to the Population-supporting Capacity

Consequently, the overall water demands are a function of the production activities in a given landscape. The possibility to satisfy these demands evidently depends on the size of the population in view of the fact that water availability is *finite*. The larger the population, the lower the ceiling in terms of maximum water demand that can be fulfilled. If we take 25 H as a fair estimate of the water demand in a Third World country with a dry climate and a fairly water-efficient irrigation system (36), countries which are already at 1100 persons per flow unit will *not* be able to provide the water needed. If Israel is taken as a model of how far water-saving irrigation can be carried (overall water demand 14 H), and if 100% mobilization level is assumed, then 2000 persons per flow unit could basically be sustained. Several Third World countries will however have passed this level by 2025 AD. In such countries, there is, in other words, not enough freshwater available to support the drought-proofed crop production needed for self-sufficiency in food production (37).

Population Pressure and Increased Demands for Livelihood Determines Landscape Manipulations

Socioeconomic development depends on unavoidable manipulation of the landscape for the purpose of gaining access to enough biomass on the one hand (food, fodder, fiber, fuelwood, timber), and enough water on the other. In Third World countries the production activities needed to fulfil increased demands may well be constrained due to the limited speed in technological advancement as well as societal constraints.

A realistic assessment of what the landscape may produce in the long run is crucial to national planning. Ecohydrological constraints that may limit that capacity include the hydroclimate but also the fact that precipitation input is being divided between the return flow to the atmosphere and the surplus recharging aquifers and rivers.

In dry-climate regions this partitioning is sensitive to vegetation changes. More biomass use involves an increase in the return flow to the atmosphere, which may in dry climates be of the order of 1000 m^3 per ton biomass produced (7). This sensitivity to changes in vegetation is well-known from industrialized countries with similar climate (39, 40). In the regions where most poverty-stricken Third World countries are found, there is consequently a need to balance water-consuming biomass production (natural as well as anthropogenous) against what is left to support the water needs of human society as well as other species.

Environmental and social consequences of landscape manipulation have in other words to be discussed from a *balancing perspective*. By applying sustainability criteria in terms of allowable consequences of landscape manipulation, the carrying capacity of different areas can be determined.

SIDE EFFECTS OF POPULATION-LANDSCAPE INTERACTIONS

Environmental Side-effects

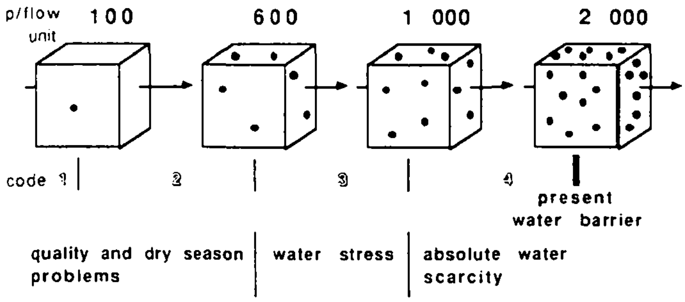
Even if the purposes of all different landscape manipulation are beneficial, the very fact that they involve changes of an intricately interacting soil-vegetation-water system means that secondary side-effects will be produced. Basically, a whole set of phenomena are being disturbed and the consequences of these disturbances are propagated by water-cycle continuity (41). When water pathways and flows through the ground are altered in order to gain access to water, or where soluble chemicals are introduced, consequences will follow in terms of altered solute flows. Soluble substances will leach out of soils, e.g., agricultural chemicals, etc.

Avoidable side-effects include pollution, overexploitation of groundwater, salinization and water logging of irrigated lands. With an improved resource literacy among planners, both landscape manipulations and land management would be better adapted to what sustainability criteria demand. On the other hand, other side-effects will remain *unavoidable*. This includes effects of vegetation changes following from water-cycle continuity, and effects of water-level increases as a reservoir is being filled.

Water: Large irrigation schemes are often tied to the building of a dam. The flow regime is typically based on the agricultural water needs, sometimes also hydropower production and the water needs of traditional social groups are easily neglected (42, 43). Attention should also be given to the *in situ* water needs of local populations when deciding the managed flow regime.

Another example relates to consequences of depletion in aquifer. The typical example is the Ogallalla aquifer running under eight US-states of the High Plain area. The richness of this aquifer has been extensively used for wasteful extraction of irrigation water (44). A frequent consequence is land subsidence which may often be irreversible

Figure 3b. Visualization of different levels of population pressure on water. Each cube indicates one flow unit of one million cubic meters of water per year, available in aquifers and rivers; each dot represents 100 individuals jointly depending on each flow unit.



because of physical changes taking place in the soil when the water in the pores is being pumped away (45).

Land: The degradation and soil fertility effects may remain hidden by increased fertilizer levels or other responses to reduction in yields (46).

There is also the interlinked consequences of exaggerated fertilizer use in agriculture. The assumption is that increased fertilizer use will increase yields. The rural population has no option but to use local groundwater even when nitrate levels become high as a result of fertilizers. Infant mortality may increase as the water becomes toxic. For many Third World countries a safe water supply will mean increased costs because there is no simple technology to reduce the nitrate levels.

Social Side-effects

Marginalization: In the absence of institutionalized societal mechanisms and reduction of population growth it seems that these societies, which have less capital assets, will have no choice but to raise their land productivity. As industries need capital, societies lacking this will have little choice but to remain agriculturally dependent (47, 48). Once on marginal land, the poor will become even poorer. They will also lose access to safe water because the urban fringe seldom has piped systems (49).

Increasing Expectations: As improved communication intensifies contact among societies, a process of increased expectations by individuals as well as societies may well take place based on psychological *demonstration effects.* Given the limitations of production capabilities and economic power of various social groups, the question is raised as to whether in the future unfulfilled expectations will not become a social *time bomb* (50). Unless adequate measurements are taken, unemployment problems may threaten social and political stability and may well have global repercussions (51).

Traditional Understanding of Landscape Limitations: In an evolutionary perspective the world is entering a different stage of population and environment interlinkages. In the past, human beings treated their land based on local knowledge developed over the centuries by trial-and-error (46). As production for use expanded to production for exchange, humans were able to invent technology and develop their knowledge to overcome the natural constraints.

CONCLUSION

In the Third World, population growth will be reflected in a population-driven increase in the intensity of landscape manipulation. The intensity will be further accelerated by such external influences aiming at increased output of production. The results are differential impact for different social groups and a further marginalization of the already poor.

Tendencies and Future Prospects

The present tendencies, in terms of environmental degradation and the acceleration of poverty, are highly frustrating for the present world population. Behind the interlinked social and environmental landscape-related problems are the perceptions of the different actors involved; the people living in an area, the policy makers on the national level, and the foreign consultants and financing bodies influencing the activities and projects in that area.

Population growth to 6.2 billion in Third World countries by 2000 AD seems unavoidable. The role of water in the food production process, the hydroclimatic constraints, and the role of water as a solvent translating soluble waste and fertilizer surpluses into water pollution, all contribute to limiting sustainable productivity and sustainable life support.

Social expectations on economic growth are however continually strengthened. Expectations are raised by international promises of poverty extinction and global equity based on ideas of technology transfer, irrespective of fundamental hydroclimate differences, and transfer of the concept of "a good way of life", irrespective of sociocultural differences.

Call for a Holistic View

A conceptual framework has to be developed which takes into account the variability of the physical landscape as well as the sociocultural conditions within the landscape. In developing this more holistic and more realistic development concept it is necessary to critically analyze past patterns and trends and the fallacies of present explanatory models. Are they reliable enough for use in projections into a time period when land productivity and water-resource limits are being approached? Are mechanisms which were active in the past in unloading certain fundamental constraints likely to be repeated in a similar way in the future?

Differences in Quality of Life Perceptions

The quality of life concept represents a partly subjective, partly objective concept. The subjective dimension is psychosocially related in a way that has to be taken seriously. It relates to the perceptions of the individuals in a population and has crucial relevance for their reactions when expectations cannot be met. The objective dimension of the concept, is directly related to subsistence: to basic needs in terms of safe household water, food security, minimum purchasing power, family health, etc. It is important to be aware of the fact that quality of life may, therefore, differ between societies. A Swede, a Saudi and an Indonesian would evidently expect different mixes of livelihood components.

Adaptive Abilities

It will be fundamental to match rapidly enough the reduced per capita water availability and the increasing per capita demands. In order to keep even the present level of water demands, more water-resource structures are needed to make more water accessible for use.The financial aspects of water-resource development projects that are needed to supply the rapidly growing population in low-income countries, require serious attention.

Sustainability Criteria in Balancing Landscape Manipulations

What is urgently needed is the development of our capability to balance the skilful landscape manipulation needed against the disturbances caused, so that fundamental sustainability criteria are fulfilled:

– environmental sustainability (three basic principles, see below);

– economic sustainability: efficiency of production; absorption of labor force;

- social sustainability: sustaining the values and norms of society (dignity, human rights, equity/equal access).

Environmental sustainability may be seen as a necessary condition for the other two (53). Three different sets of principles may be distinguished.

- **First principle.** Variety of life has to be protected involving genetic variety, species variety, and ecosystem variety.

- **Second principle.** Air has to remain breathable, groundwater drinkable, soil productive, and fish and meat edible.

- **Third principle.** Renewable resources have to be harvested within their regeneration capacity.

Revisiting the Self-sufficiency Goal

There may be limited options of self-sufficiency in terms of basic needs even on a subsistence level, as indicated by the FAO-IIASA study the on population supporting capacity of different Third World regions (54). Water-related limitations in a dry-climate tropical region indicate that not even basic food needs could be locally satisfied for the unavoidably increasing population size (7, 38).

Thus, the present idea of thinking globally, acting locally, for environmental protection has to be complemented by *global actions to compensate* countries that will not be able to be self-sufficient.

Crucial Actions

Crucial measures for the future include female education and active development of livelihood security in rural areas. Equally urgent is that the next generation be supplied with both the knowledge and the consciousness needed to understand the various limitations in both natural and social conditions that will operate in their lives.

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