Chapter 2
Human Impact in a Systems Approach

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Abstract All the material and energy flows evolved independently from and having existed prior to human presence are considered to be natural in origin. The cycles which are the least influenced by humankind and, therefore, in a 'quasi-natural' state are also in a dynamic equilibrium. The general model of material and energy flows is a result of a generalisation to the greatest extent and reflects the most relevant features of the so-called global geochemical cycles. Geographical factors relevant in geomorphologic processes can be recognised and interpreted in this model. Human society, over its history of approximately 10,000 years, has been intervening into natural processes more and more actively and effectively. Society can influence any of the exogenic geomorphic processes and human impacts can be present at any stage of such processes. There is not a single element of the natural system that would not be influenced by human intervention sooner or later. The degree of changes depends on the intensity of human intervention as well as on the susceptibility of the physical system. Anthropogenic activities without a direct impact on geomorphologic processes can also have consequences on the surface. In their investigation, a system-approach analysis can be of help.

Keywords System approach · Physical system · Geomorphic cycles · Anthropogenic activities

2.1 Some Characteristics of Physical Systems

The physical environment consists of an uncountable number of 'elementary units'. It is a matter of approach as to what is considered to be an elementary unit of a morphological object: an atom, a living being or a rock or soil type, etc.

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Interrelationships between objects (elements) can be of various intensities, direct or indirect. The elements with more direct interrelationships in a given space constitute natural units, *systems*. For scientific research purposes, system elements are detached from other elements of the surrounding world, so that their features can be studied in detail.

As research cannot extend to all subjects, substances and processes, for scientific or practical analysis purposes, a part of reality is isolated from its environment – in most cases only in theory. *Within the system* isolated, *there are functional and structural relationships among system elements*. It has natural boundaries which are to be observed in theoretical considerations. While studying these systems, their relations to their environments have to be analysed.

- *Isolated systems* are material systems with no material and energy input and output. Such systems can only be created in the laboratory – although it is not easy.
- *Closed systems* show energy input and output, but no material exchange with their environment. (The exchange of energy is, though, possible.) Such systems are rare on Earth.
- Between *open systems* and their environments both energy and material exchanges take place. Energy flow is mainly bound to material flow, i.e. materials drifting among systems carry a certain amount of energy. This can be, e.g., adsorbed heat energy or potential chemical energy. Open systems largely maintain their structures despite the material and energy flows through them.

All natural systems are classified as open systems. The maintenance of their basic structure does not mean system permanence; changes are significant and characteristic. Theoretically, changes within the system can be described accurately in case their initial and final stages are identified. In practice, however, information on the course of changes, in other words, the description of the series of intermediary stages by which the process of change is revealed, may often be relevant.

The persistence of system structure is a result of perpetual material and energy flows. Take a water regime as an example: it sustains all its essential features over the long term, while the water itself exhibits constant motion and is characterised by periodic water input (precipitation) and constant water output (estuary discharge + evaporation). This material flow is also pertained to energy flow. Water of high heat capacity absorbs heat from and emits it to the environment and, at the same time, represents a significant amount of kinetic energy which causes surface erosion, provides the energy coverage of bedload transport and also facilitates the operation of hydroelectric plants. Material and energy flows cause alterations in the system (river bed formation, soil erosion, changes in slope inclination), all essential features of the water regime (the shape of the catchment area, the number of major watercourses, mean estuary discharge, flood return intervals, the rate of evaporation), however, remain stable. This state of the system, though not static, can be regarded as equilibrium. A feature of natural systems is that they mostly tend towards a *dynamic equilibrium* through their functioning.

Natural systems are also connected to each other. Systems closely interrelated comprise a complex system; moreover, such complex systems can further build higher-level systems. These complex and multiple complex systems make up Earth's physical environment.

The uniformity of this system with extremely complex structure and function is explained by material and energy flows creating functional relationships by percolating into sub-systems. For the *material and energy flows which occur in the geospheres, certain cyclicity* is typical and it primarily involves the transport of chemical compounds and elements during which chemical and/or chemico-physical transformations take place. Such cycles are called *geochemical cycles*.

2.2 General Model of Material and Energy Cycles and Its Relevance for Geomorphology

Most of the material and energy flows had operated on Earth well before human presence. For instance, water reached the atmosphere through evaporation, solid particles and various gases as a result of volcanic activity, and later deposited on the soil or bare rock surfaces or in water or adsorbed on soil particles. From here, due to the dissolving effect of precipitation, they could have been carried to the groundwater and surface waters, as well as to seas and oceans through water systems. Plants and animals also contributed to the operation of material and energy cycles (photosynthesis, respiration). All the material and energy flows evolved independently from and having existed prior to human presence are considered to be natural in origin.

All geochemical cycles can be demonstrated by a model for the movement of chemical compounds or elements. The model shows the directions and courses of this movement as well as environmental objects where the given element or compound remained for a longer period of time (*reservoirs*), and all quantitative data available for them.

The number of natural storages (reservoirs) depends on the detail of modelling, i.e. on its resolution. An important feature of the cycle is *flux*, defining the amount of material transported along a given course within a defined period of time (usually a year). When the concentration of an element/compound remains constant in the reservoir, it indicates a balance between the input and output elements/compounds. This refers to a dynamic equilibrium. The cycles which are least influenced by humankind and, therefore, in 'quasi-natural' state are also in a dynamic equilibrium.

Having recognised the system is in such a state, the *residence time* of given elements in given reservoirs are defined as follows:

$$\text{residence time} = \frac{\text{the amount of the given element in the reservoir}}{\text{the input (or output) rate of the element (quantity per annum)}} \qquad (2.1)$$

In case the mass of *sodium* dissolved in the ocean is 15×10^{18} kg and it receives an additional annual amount of 10^{11} kg, the residence time is 150 million years.

As seen from this data, the time periods involved are rather long on the human scale. In the ocean, the residence time of the vast majority of elements is on the scale of million years. There are, however, geochemical cycles with shorter period as e.g. the terrestrial water cycle relevant from the point of view of geomorphology (precipitation reaching the surface, runoff, evaporation, residence in the atmosphere). Here residence times can be measured in the order of days and months.

The general model of material and energy flows is represented in Fig. 2.1. (O'Neill 1985). This model is a result of a generalisation to the greatest extent and reflects the most relevant features of the so-called *global geochemical cycles*. The upper cycle of the figure represents processes taking place on the surface of the lithosphere and in the two resilient geospheres (atmosphere, hydrosphere) whereas the lower one runs in the lithosphere. Water plays the most important role in material transport (precipitation, surface and subsurface waters on land as well as seawater).

Geographical factors relevant in geomorphologic processes can be recognised and interpreted in the figure. Sediment accumulation in the oceans eventually results in the formation of sedimentary rocks, which are transformed, metamorphosed and, in a modified form, take part in the folding of mountains in the course of plate tectonic movements. Eventually, plate tectonic cycles control macro-scale geomorphologic elements such as the orogenic structures, tectonic trenches, depressions and others.

Soil formation is a result of physical and chemical weathering processes among which biogenic weathering has a predominant role. Sheet wash caused by atmospheric precipitation, then stream erosion contributes to the evolution of a range

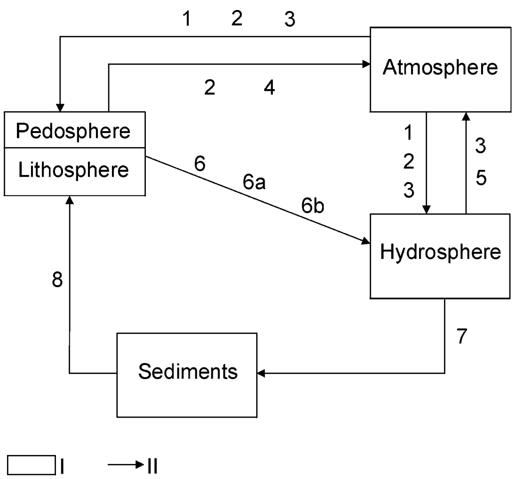

Fig. 2.1 The general model of material and energy cycles (geochemical cycles) Modified after O'Neill (1985) 1. precipitation, 2. dust, 3. vapourised water drops of the sea, 4. gas loss, 5. gas generation, 6. rivers (dissolved and suspended substance), 6a. glaciers, 6b. coastal erosion, 7. sedimentation and sediment deposition, 8. material exposure by folding and tectonism. I. reservoirs, II. material and energy flows

of geomorphological features. In a broader sense, sediment transport by water, and consequently, geomorphic action, that of glaciers as well as wave erosion along coasts and lake shores are also significant processes in the transformation of the surface. In addition to water, wind can also shape soil and rock surfaces (primarily unconsolidated and unvegetated sedimentary rock surfaces) – especially in arid and semi-arid regions.

All these processes are fundamental factors in geomorphic evolution. Some of them – mainly the impact of endogenic forces – cannot be altered by human activities; however, exogenic forces are influenced either directly or indirectly, deliberately or spontaneously by human action.

2.3 The Impact of Human Activities on Geomorphologic Processes

The figure illustrating the major geomorphologic cycles only reflects natural processes and only provides a general overview. Human society, over its history of approximately 10,000 years, has been intervening into natural processes more and more actively and effectively. The establishment of the first settlements built of rocks and/or clay also represented the first major anthropogenic geomorphologic impact, as rocks and clay had to be excavated resulting in the formation of depressions on the surface. During its history, humankind has been carrying out more and more production activities, which directly or indirectly altered the physical environment. In the flowchart below, the role of some anthropogenic environmental impacts regarded to be relevant in modifying geomorphologic processes are examined (Fig. 2.2).

Endogenic forces, responsible for the formation of major landforms, cause isostatic uplift and subsidence of the crust, vertical movements, folding and faulting, as well as by volcanism, producing hills and mountains of volcanic origin. These processes are accompanied by earthquakes. A common feature of these forces is the increase of differences in height measurable on the surface and the formation of slopes of various inclinations. Thus, gravitation has an active role in the displacements of crust material. In erosion, the inertial resistance of rocks also has a part to play (Fig. 2.2).

The impact of *exogenic forces* can be modified by a range of activities even for cases such as solar radiation. By the extinction of natural vegetation (whether it is carried out for agricultural or construction purposes), the amount of incoming solar radiation reaching the soil and/or rock surface changes significantly. This greatly increases the heating and cooling of rocks (temperature extremities of the 'bare' surface are also intensified by the increase in outward radiation) and accelerates physical weathering and, eventually, contributes to increased erosion rates.

Construction activities can also transform the heat input of the surface. Extensive built-up areas (e.g. cities), however, also exert an impact on precipitation. Sealed surfaces have an even stronger influence on surface runoff, a decisive factor of

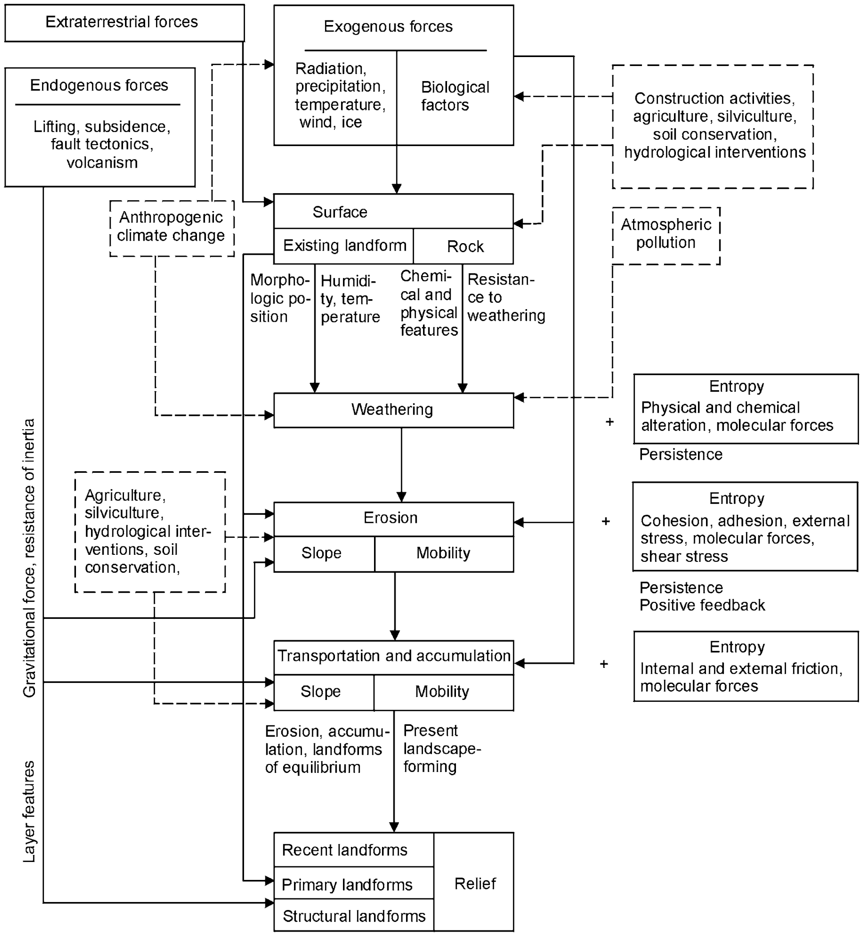

Fig. 2.2 Geomorphologic processes, influencing factors and the predominating entropy. After Bremer (1989), modified by including major anthropogenic impacts

water erosion. Linear structures (roads and motorways, railway lines and others) also significantly modify the geomorphic action of water.

Agricultural and forest management practices also greatly alter surface runoff: extensive clear-cuts may result in rapid erosion as the amount of precipitation retained by vegetation may drop abruptly.

Soil conservation measures (such as terracing), which aim at efficient rainwater retention, result in a decrease of the amount of surface runoff and, thus, have an adverse impact. Levelling and other activities may have direct geomorphological consequences.

Hydrological interventions (cut-offs, construction of dams, etc.) for flood control influence morphologic processes both directly and indirectly: they create new landforms as well as modify the process of channel erosion and even that of sediment accumulation.

The impact of *atmospheric pollution* on erosion is hard to estimate. However when considered that contaminants reaching the atmosphere in a considerable quantity (sulphur dioxide, nitrogen oxides, ammonia) undergo chemical transformations, and, as a result, acidic deposition takes place on the surface, it becomes clear that acidic substances intensify the process of chemical weathering and result in increasing erosion. This is accompanied by an increase in entropy.

Entropy is a thermodynamic parameter of a state indicating the amount of energy the can be transferred from one system to another in the form of work. When the system entropy is zero, its total energy can be applied for work. In case its energy transformable to mechanical work is zero, system entropy reaches its maximum. As seen in Fig. 2.2, geomorphic processes like chemical weathering, erosion, transportation and accumulation are accompanied by an increase in entropy. Here physical, chemical and combined chemico-physical processes operate.

Man-induced climate change impacts geomorphologic processes in a way basically modifying the operation of all exogenic forces. It is obvious that any change in the climate necessarily entails alterations in precipitation (amount, time distribution, intensity) and temperature. If the degree of cloudiness alters, solar radiation also undergoes changes. Obviously the overall air circulation should not remain constant either and thus, wind conditions and, as a consequence, the rate of deflation is also modified. Climate change also has an influence on glacial processes. It is well known that the transgression of glaciers in colder and more humid periods may result in increased ice motion velocities. Examples, however, can be found for the opposite too. Today, most of the glaciers are retreating and this is related to warming climate. It is also evident that human-induced climate change can also significantly alter the physical and chemical weathering of rocks.

Despite all these apparently significant impacts of climate on geomorphic processes, some representatives of anthropogenic geomorphology do not consider human-induced climate change to be an impact of human origin. This is explained by the fact that during the Earth's history, a number of major natural climate changes took place with significant geomorphological consequences, and it is practically impossible to decide to what degree the anthropogenic character of climatic factors can be taken into account in recent geomorphologic processes, whether a landform developed under decisively climatic influence can be regarded anthropogenic in origin.

In addition to the process of natural erosion, the degree of accumulation is greatly modified by interventions of agriculture and forestry, soil conservation and water management measures (Fig. 2.2).

It can be seen that society can influence any of the exogenic geomorphic processes as well as that human impacts can be present at any stages of such processes. Whether landforms developed as an outcome of anthropogenic processes depends on the extent of human impact. This is, in certain cases, rather obvious and easy to define; however requires detailed analysis in others in order to classify given forms. The researchers' work is aggravated by the complicated, 'network-type' interrelationships of natural systems, i.e. an impact on any single physical element induces a number of indirect impacts on other factors. Section 2.4 is a review on some related principles.

2.4 Indirect Human Impacts on Physical Systems

Landforms can be regarded as elements of physical geographical systems. Before the emergence of humans, the factors of physical geographical systems were *topography* (landforms), *water* (surface and underground), *air/climate, rocks, soil and the biota*. In the literature on geography, regarding the nomenclature of these factors, major or minor differences are present according to the various sources (for details, see Kerényi 1995; Csorba 1997; Lóczy 2002). Among these, the most relevant difference is the indication of climate, instead of air, as a physical element. For air, water, organic world, soil and rocks, various substantial qualities are represented. The first two are decisive transporting agents in nature, thus playing a fundamental role in geomorphologic processes as well. Climate is, obviously, more than air and is also different in quality: a state of environment resultant from the interrelationship of the physical geographical factors, mainly described by the atmospheric parameters, e.g. air temperature at 2 m height, wind velocity (i.e. the horizontal component of air flow), relative air humidity and others. In the meantime, solar radiation is also a fundamental factor of climate, which drives the functioning of the whole organic terrestrial system.

For such reasons, using climate instead of air in the physical geographical system model makes the representation of the system more complete. (It should be noted here that renowned landscape researchers also analyse natural systems in the same approach; see Haase 1978; Leser 1991).

Let us investigate the interrelationships among the system elements within the physical geographical systems and alterations in the whole system caused by some characteristic impacts of human activities – with a special focus on topographic changes.

Various geometric forms indicate the decisive substantial quality of the system elements in Fig. 2.3 (Kerényi 2007). Rectangles represent the predominantly inorganic natural elements; a circle indicates the living world and a polygon marks soils, which are primarily interim between organic and inorganic. It is an inevitable fact that a rich biota exists in natural waters, but this is so marginal compared to the mass of the hydrosphere that the predominance of water as an inorganic agent should not be argued. From our point of view, the role of mechanical energy of the flowing water in geomorphic evolution is also taken into account and, in this respect, the amount of aquatic organisms is irrelevant.

Soil is a different case in many respects. This layer is sometimes only 20–30 cm deep and the ‘buffer layer’ of geomorphic processes is 1.5 m deep in general. While particles of the soil humus layer are eroded from the surface by wind or water, at the lower boundary of the soil section, the inorganic rocks undergo biogenic

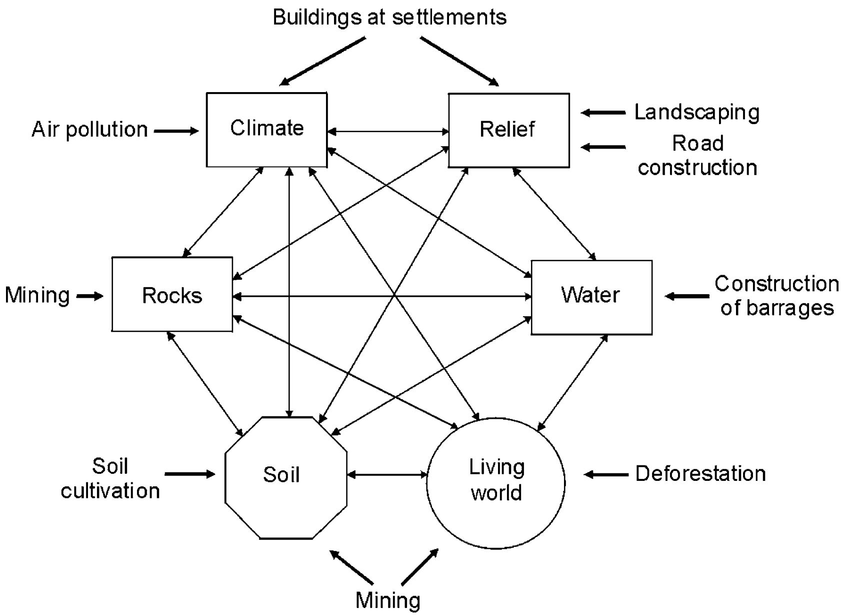

Fig. 2.3 Some typical impact points of the physical geographical system and anthropogenic activities (by Kerényi 2007)

weathering – i.e. soil formation takes place. When these two processes are balanced, the thickness of soil layer is constant, the surface of the given slope has a loss in substance and, depending on whether erosion is along particular lines or uniform over the surface, morphological changes follow.

Soil is transitional between organic and inorganic environmental elements in respect to the fundamental processes taking place within, i.e. humus formation, are determined by its extremely rich biota. Soils are also interwoven by the root system of superior vegetation; vegetation and soils are indispensable to each other: vegetation receives water and nutrients necessary to its sustenance, whereas the removal of vegetation results in soil loss (accelerated soil erosion).

This supports the representation of the interrelation between the *biota* and soils in our system model. It is claimed that this is one of the closest interrelationships in physical geographical systems (Fig. 2.3).

As mentioned above, the impact of the biota on *rocks* (biogenic weathering) is, in many cases, direct. Plants (so-called pioneer plants) able to settle on bare rocks by their root acids and micro-organisms living in symbiosis on their roots, trigger the process of soil formation. Meanwhile, the hardness and chemical composition of rocks defines what species are capable of living on them.

Water is a necessary living condition of the organic world; the vegetation on the surface, however, has a major influence on the water balance of a given geographical region, partly through transpiration and partly through hindering runoff. The presence of water also determines the processes of rock weathering and also plays a part in the water storage of rocks (depending on their structure) as well as defines the amount of runoff. The same interrelationship is observed for soils and water.

Climate, on the one hand, exerts a direct influence on the living conditions of organisms and, by this, on species composition. (Here we refer to stenotopic and eurytopic species.) Undoubtedly, climatic factors strongly influence inorganic environmental elements, e.g. greater variation in the temperature enhances physical weathering; warmer air of low humidity increases evaporation. Climate is also a decisive factor in the formation of *topography*, as falling precipitation and wind are both capable of carrying a significant amount of solid substance resulting in the constant modification of landforms.

The reaction of inorganic environmental elements on the climate can also be represented by recalling well-known phenomena. The colour of the rock surface determines the degree of reflected radiation, influencing the heating of air. Water, by its rather high heat capacity, contributes to balanced climatic conditions; the extension of water surface has an influence on the level of direct evaporation. Diverse topography, the inclination and exposure of slopes modify the value of irradiation at various locations and greatly influence local (micro- and/or meso-) climate.

Though the internal system of relationships of our model has only been roughly represented, it still seems to be rather complicated. We did not aim at describing the interrelationships in detail as it would be the subject of a full course in physical geography. We mainly intended to draw attention to the fact that the elements of physical geographical systems are closely interrelated; thus any impact on one of its elements would never be restricted to the alteration of that very element.

Several *anthropogenic activities*, with either direct or indirect impact on the development of anthropogenic features are represented in Fig. 2.3. Some of them are tackled below and the consequences of the given anthropogenic intervention will be briefly analysed.

Prior to construction, terrain levelling is usually carried out. Depending on the topographical features, it is accompanied by a restrained or a more comprehensive geomorphological transformation, in certain cases even resulting in a direct damage to the natural environment as, for instance, in the Buda Hills within the territory of Budapest, where, as a consequence of urban development, a number of minor caves have been destroyed. Terrain correction inevitably results in the emergence of human-made landforms, among others, terraces or road cuts.

In addition to the direct transformation of the surface, construction works also have other consequences. As a result of building activities, surface runoff is modified locally by changing slope angle or by surface sealing. In the latter case, an extremely wide range of artificial materials of variable permeability are applied. The rate of erosion can be modified to some degree by the altered runoff water amount and its modified speed: it can either increase or cease when, e.g., the whole amount of rainwater runoff is canalised (see also Chapter 3).

Whichever of the above-mentioned interventions occurs, there will be a change in the rate of (evapo)transpiration as well as the reflected radiation depending on the surface cover, i.e. the microclimate is influenced.

The consequence of terrain correction is the destruction of the biota and most of the soil. Although, some kinds of landscape restoration are usually done after construction, this 'new biota' cannot be compared to natural or quasi-natural ecosystems in biodiversity and in their capability for adjustment. In artificial ecosystems, these fundamental features are lacking.

A case study is presented below, where the primary aim was not the modification of topography but the construction of a barrage and associated system channels and dam for the purpose of irrigation. During the construction of the Kisköre Barrage Scheme (on the Tisza River, in the Great Hungarian Plain), it became evident already in the first stage of works that such an investment could not be accomplished without alterations made to the terrain. Terrain correction impacted, in this case, a more significant area compared to an average construction in an urban area. In addition to the barrage, the establishment of flood-control dykes seemed to be necessary. Vast earthworks of the channel system included not only the establishment of linear channel bed forms but the accumulation of the excavated soil. Whereas the primary aim was water supply for irrigation, everything changed in the landscape: an enormous backwater surface increasing evaporation, moderating temperature extremes in the surroundings, raising groundwater levels and changing the living environment around. In the flooded area, terrestrial organisms either perished or migrated elsewhere, soil cover was destroyed whereas organisms living in lotic habitats are replaced by others typical of lacustrine environments. This increased inundation will exert a pressure on rocks, and their repeated subsidence will trigger minor earthquakes. (At areas of higher relief, terrain correction can cause landslides or rockfalls when the 'support' of soil or rock layers was disrupted.)

There is not a single element of the natural system that would not be influenced by human intervention sooner or later.

The conclusion drawn from the facts mentioned above is simple: any human activity represented in Fig. 2.3 necessarily has indirect impacts, altering all elements of the physical system to some extent. The degree of changes depends on the intensity of human intervention as well as on the susceptibility of the physical system. During the planning of activities resulting in direct topographic changes, such indirect impacts are important to be analysed, however, in the other way round: anthropogenic activities without a direct impact on geomorphic processes can also have consequences on the surface. In their exploration, a system-approach analysis is helpful. In the following chapters of this book, the direct and indirect geomorphologic impacts of all human activities mentioned above are studied. Here, it should be emphasised that in order to minimise environmental damage, production activities of the society must be adjusted to the susceptibility of physical systems.

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