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ATTEMPTS AT QUALITATIVE AND QUANTITATIVE ASSESSMENT OF HUMAN IMPACT ON THE LANDSCAPE

ABSTRACT: RÓZSA P., *Attempts at qualitative and quantitative assessment of human impact on the landscape.* (IT ISSN 1724-4757, 2007).

During the past 50 years several approaches to anthropogeomorphology have been developed. The geomorphological approach is to study magnitude and rate of anthropogeomorphological processes; the socio-economic approach examines the economic and social influences on the dynamics of human geomorphological activity and the historical approach traces changes of human impact on geomorphological processes over time. Despite of the more and more intensive research, however, there is no widely accepted anthropogeomorphological synthesis, although some seminal publications have appeared in this topic. This paper reviews and discusses the principal publications on the quantitative and qualitative evaluation of human impact on Earth's surface.

KEY WORDS: Human impact, Socio-economic factors, Anthropogeomorphology.

INTRODUCTION

Anthropogeomorphology (or anthropogenic geomorphology) is a relatively new subdiscipline although it has considerable precursors. On the one hand, it is true that the pioneer works by Marsh and Sherlock (Marsh, 1864; Sherlock, 1922, 1931) were published almost 150 and 70-80 years ago, resp.; on the other hand, however, geomorphological studies began to focus more on anthropogenic landforms and processes in the 1960's. Due to the ever more intensive research, huge knowledge has accumulated, and special aspects of this subdiscipline have been also formed during the past 50 years. Although some key publications have appeared in this topic, a widely accepted paradigm-like anthropogeomorphological synthesis has not been elaborated. This paper attempts to provide a short summary of the quantitative and qualitative evaluation of human impact on the Earth's surface by critically reviewing the principal publications.

QUANTIFICATION OF ANTHROPOGEOMORPHOLOGICAL PROCESSES

The importance of humans as geomorphological agents is indicated by the fact that at least one third of the Earth's continental surface of 149 million km^2 is a scene of direct or indirect anthropogeomorphological activity. At the turn of the millennium arable land and plantations covered 15 million km^2 area, grazing land 35 million km^2 and built-up areas 2 million km^2 (Loh & Wackernagel, 2004). In addition, a considerable portion of forests of 38 million km^2 also underwent intensive human impact. The areal extension of human activities, however, is not suitable for either quantitative or qualitative indication of anthropogeomorphological impact on the Earth's surface, because the influence of economic activities related to land-use types may extremely differ from one another. For example, built-up areas covering less than 2 per cent of the continents suffer the most intensive landscape modification.

The amount of earth moved during and by various anthropogeomorphological activities seems to be the most proper index value for describing human impact on the landscape. The determination of this value, however, is not easy. On the one hand, some human activities (forest clearing, ploughing, grazing, etc.) characteristically modify landforms in an indirect way, i.e. by altering «natural» erosion processes, on the other hand, there are no precise statistical data concerning the amount of the earth moved by direct anthropogeomorphological activities.

A summarised estimation of human geomorphological impact for the 1970's was published by Nir (1983). By a critical review of available data, he concluded that, on the basis of the anthropic erosion rate, agriculture could be regarded as the most significant landscape-modifying human activity (tab. 1). To demonstrate the large mass of 173 billion tonnes he mentioned that it is more than one hundred times higher than the amount of silt carried by the Huanghe (Yellow River), one of the world's muddiest rivers.

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TABLE 1 - Rates of anthropogeomorphological processes (based on data by Nir, 1983)

Human activity	Rate of erosion (10^9 t/yr)
Forest clearing	1
Grazing	50
Tilling the land	106
Mining	15
Roads, railways and urban construction	1
Total	*173*

TABLE 2 - Summary of the estimated rates of anthropic and natural geomorphological activities (after Hooke, 1994, 2000 and Haff, 2003)

Geomorphological agent	Earth moved (109 t/yr)
Man (intentional based on GNP)	30
Man (intentional based on energy consumption)	35
Man (unintentional)	99
Total anthropic	*129* or *134*
Rivers	53
Glaciers	4
Slope processes	1
Wave action	1
Wind	1
Mountain building	44
Deep ocean sedimentation rates	7
Total natural	*111*

Hooke (1994, 2000) applied another method for estimating the efficacy of anthropogeomorphology. He grouped building, road and railway construction as well as mining as «intentional» anthropogeomorphological activities, while regarded agriculture as an «unintentional» anthropogeomorphological intervention. Therefore, the «intentional» and «unintentional» terms refer to the fact that human landscape modification is direct and deliberate in the first case, and it is basically (but not exclusively) indirect and unintended in the second one. To determine the quantity of the earth moved by intentional activities he used statistical data concerning the United States; according to his calculations amount of the annually moved earth is 0.8 billion (10^9) tons for building, 3.8 billion tons for mining, and 3 billion tons for road and railway constructions. Hooke used two parameters to determine the amount of annually moved earth for the world on the basis of data concerning the USA. He supposed that intentional human geomorphological activity in a given country might show linear connection with the Gross National Product (GNP) or with the energy consumption. Since GNP of the world in 1991 was four times higher than that of the USA, the total amount of earth moved by intentional human geomorphological impact can be estimated to be about 30 billion tons for that year. In the same year the USA shared 21.7 per cent of total energy consumption of the world; considering this proportion a total value of 35 billion tons can be calculated (Hooke, 1994). Concerning agriculture, Hooke's starting point is that today the per capita cultivated and grazing land is 0.3 and 0.6 hectares, resp. (Hooke, 2000). World population being above 6 billion people, the loss of material due to cultivation and grazing is 63 and 36 billion tons per year, resp. Consequently, total amount of earth moved annually by different human activities can be estimated to be about 130 billion tons. This amount is not merely comparable to natural geomorphological agents but presents anthropic processes as the dominant surface modifying factors (tab. 2).

Although the estimations by Nir and Hooke are of similar order, there is a remarkable difference regarding both the total amount and the contributions by the different human activities. The variation can be explained by several factors. First, it has to be considered that Nir's estimation refers to the erosion rate caused by human action, whereas Hooke's calculation represents the amount of the earth moved by human activities. Moreover, Nir principally used United Nations statistics for the whole world, while Hooke tried to calculate the extent of human impact for the world by extrapolating statistical data for the USA. It should be also taken into consideration that an estimation of geomorphological influence of unintentional human activities is quite difficult because of our insufficient knowledge on the «natural background». For instance, estimations by different authors on erosion rate due to grazing range from 10 to 25000 kg/ha/year (Nir, 1983). Undoubtedly, however, the rural activities still seem to be the most significant anthropogeomorphological factors. Finally, it also has to be noted that Nir's data refer to the mid-1970's, while Hooke's estimation concerns the early 1990's. The more than double value of the intentional geomorphological activities for the early 1990's can be partly reasoned by the increasing volume of these activities over the past fifteen years.

SOCIOECONOMIC FACTORS

Human modification of the Earth's landscape is as old as humankind itself; it might be said that human history is also the history of anthropogeomorphology. Potential human impact on the environment (and on the surface at the same time) is basically determined by two factors: technical progress and population growth.

Technical progress

Until the early Holocene (12,000 years BP) man used wood, bones and chipped flint implements and basically followed a hunting-gathering course in life. However, he also began to grow cereals, peas and lentils as well as to domesticate some wild animals. This era is called the first agricultural revolution. The first agricultural civilizations formed more or less simultaneously but independently from one another in the area of the so-called «Fertile Crescent» of the Middle East as well as in Eastern Asia, Mexico and Peru. 5000 years ago widespread irrigation resulted in a quantitative change in agriculture since it allowed several harvests in a year in the hot arid and semi-arid areas. Two fundamental technical inventions, the plough and the wheel, also happened at this time. The smelting of ores and processing of metals started a new chapter in human impact on the environment. Copper was produced for the first time ca 7-8000 years BP, and bronze was some thousand years later. In the Middle East iron was known as early as 5000 years BP, however, iron smelting became generally practiced as late as 1200-1000 BC.

Riverine civilizations formed in the Nile Valley, in Mesopotamia and along the Huanghe and Indus rivers ca 4000 BC. The building and maintenance of irrigation canals required organization, division and central control of labour, which necessarily led to slavery. The first urban settlements and urban communities were formed in Mesopotamia ca 3-5000 BC. Urbanization (the «urban revolution») then spread over almost the whole Mediterranean. At the same time remarkable urban civilizations also took shape in India and China. Ancient urbanization culminated in the Roman Empire. The fall of the Empire, however, retarded European economy and urbanization for centuries. After a stagnation of 500 years, due to agricultural technical innovations as well as a more intensive utilization of water and wind power, an economic prosperity began in Europe as well, and, as a consequence, a new wave of urban development commenced. This progress was hindered by a disastrous plague in 1347; even 150 years was not enough to make up for the population loss (Livi-Bacci, 1992).

The socioeconomic circumstances as well as human geomorphological activity were dramatically changed by the industrial revolution, which began in England in the 18th century, and spread over Europe and North America by the end of the 19th century. Due to use of coal and steam power, the introduction of other technical innovations and the exploitation of new raw materials, a mechanized large-scale industry replaced the predominantly agricultural and handicraft-based economy, and resulted in a dramatic increase of productivity. This also involved a rapid progress in mining, transport and agriculture. The next stage of industrial development starting in 1870's is called as second industrial revolution. The use of alternating current and the spreading application of electricity transformed both economic and everyday life. The invention of the combustion engine made it possible to construct machines of higher efficiency, in turn, dramatically increasing the demand for petrol, radically transforming transportation and giving a new impetus to chemical industry. Since the mid-20th century the development of electronics and the utilization of nuclear power can be called the third industrial revolution (tab. 3).

Population growth

Before the Upper Paleolithic (35,000-30,000 BC) the number of human population can be estimated at some hundred thousands and the annual rate of growth did not reach 0.1 per mille, therefore, population doubled in 8 or 9 thousand years. At about 10,000 BC ca 6 million people lived on the Earth. During the next 10 thousand years the annual rate of growth reached 0.4 per mille, and the number of population 250 million. Except for periods of decline, growth became more rapid over the 17th and 18th centuries. World human population exceeded 750 million by the mid-18th century, i.e. by the beginning of the industrial revolution. Until the mid-20th century the rate of growth was almost ten times higher (it reached 6 per mille, a doubling time of 116 years), and number of population exceeded 2.5 billion. In the second half of the last century world population has doubled in forty years, and at the millennium more than 6 billion people lived on the Earth (Livi-Bacci, 1992). Over the last 250 years the concentration of population has dramatically changed. The spread of industrial revolution generated an urban explosion lasting to the present day. Because of the vast excess of rural labour, large-scale migration started to cities. At the end of the 18th century only 3 per cent of the world population were town-dwellers; one hundred years later this ratio increased to 13.6 per cent, in 1950 it reached 28.2 per cent, and now about half of the world population lives in urbanized regions.

TABLE 3 - The main social-economic eras (after Simmons, 1993 and Goudie & Viles, 2003)

	Age	**Time zone**	**Principal innovation**	**Energy source**	**Environmental impact**
	Hunting-gathering	to 10000 BC	beginning of tool production	human power	local and short-term
Agricultural	*early agriculture*	to 5000 BC	cultivation, domestication	human and animal power, wood, wind and water power	local, longer-term
	riverine civilizations	to 500 BC	irrigation, use of metals, spread of plough and wheel		
	agricultural empires	to the 1750's	terracing, road network, utilization of wind and water power		
Industrial	*first industrial revolution*	to the 1870's	spread of stem engines, industrialization	coal	regional, permanent
	second industrial revolution	to the 1950's	steel making, railway network, utilization of electricity, combustion engine	coal, petroleum	
	third industrial revolution	from the 1950's	plastics, electronics, utilization of nuclear power, computerization	petroleum, natural gas, nuclear fuels	global, permanent and perhaps irreversible

Three periods can be distinguished in the history of world population. The first lasted from the appearance of human race to the end of the Paleolithic, the second from the Neolithic to the industrial revolution, and the third began with the industrial revolution. The periods coincide with the three main technical-cultural eras (hunting-gathering, agricultural and industrial). The relationship between demography and economic development is obvious, it is, however, quite complex. On one hand, increasing population may act as an obstacle to economic development because population growth may set its own limits. On the other hand, demographic pressure may enforce more intensive production as well as inventions and the spread of new technologies. Technical progress may initiate economic development, which may allow a more rapid population growth and may create a demand for higher standard of living. This means that technical progress and population growth, mutually intensify their influence. Moreover, an increasing demand for ever higher standard of living may also generate further human intervention into natural geomorphic processes.

HISTORICAL APPROACH

Recently, Hooke (2000) presented a quantitative estimation of the history of human impact on the landscape. The factual information behind his calculation is naturally debatable since he had to rely on assumptions and premises. However, his estimation is in accordance with the general pattern, i.e. the three main technical-cultural eras of humankind figured by the socioeconomic factors. As a starting point, on the basis of archeological and historical data, Hooke estimated the mass of material moved by humans in the cases of certain relatively advanced societies in the past, and calculated the trend line determined by them. To obtain a worldwide average he scaled the curve by multiplying each point by the ratio of a per capita estimate for the world (6 tons/year) to that for the USA (31 tons/year). In his opinion, the curve obtained by this re-estimation may show the pattern of the intentional human impact over the past 4500 years (fig. 1).

To estimate the geomorphological impact of agriculture in terms of food supply in the past, Hooke assumed

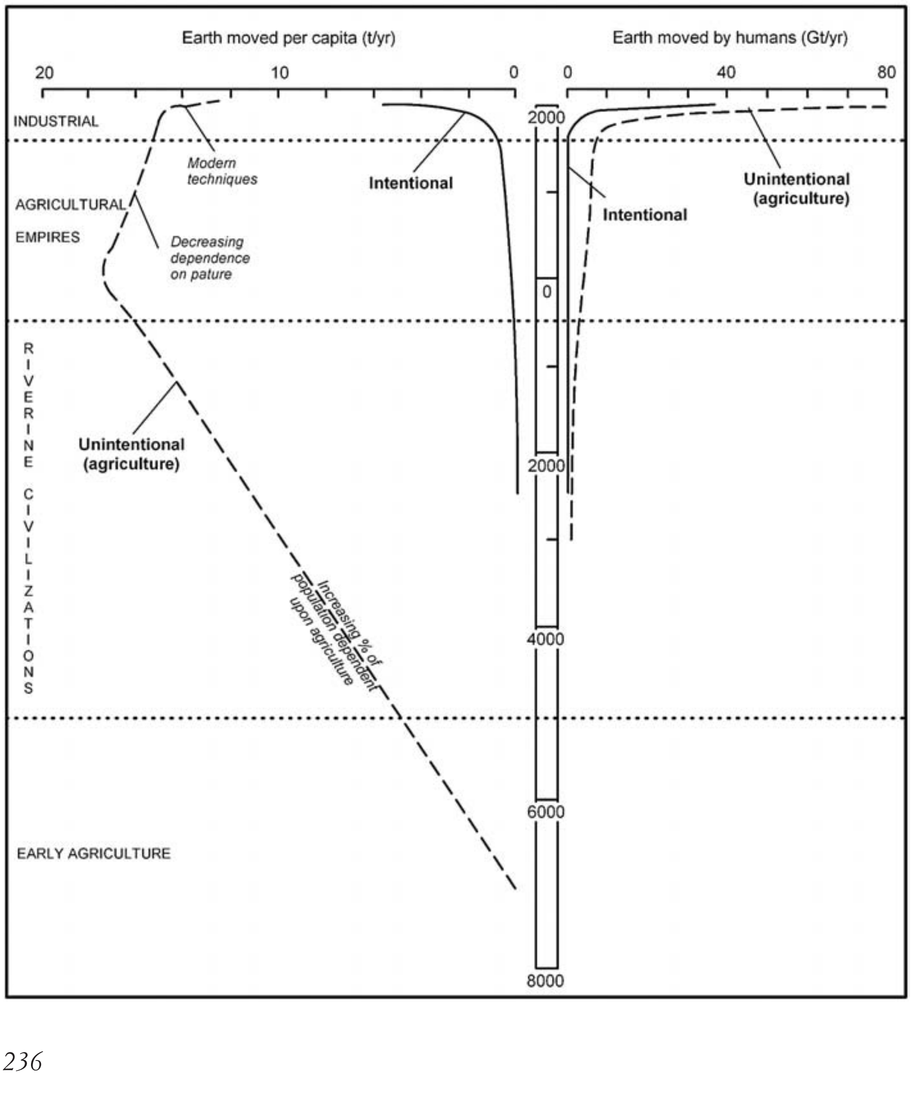

FIG. 1 - Amount of earth moved annually per capita by human intervention from 7000 BC to the present (on the left) and total amount of earth moved annually by human geomorphological activities during the past 5000 years (on the right) (compiled after Hooke, 2000).

that population dependent upon agriculture increased consistently from 9000 BP, and around 2000 BP it reached 100 per cent and has remained at that level. Consequently, annual sediment loss from tilling and pasturing increased linearly over that 7000 years period. It should be emphasized that the expression of «population dependent upon agriculture» does not refer to the population engaged in agriculture; it concerns the fact that food supply of humankind has been practically provided by crop cultivation and animal husbandry since that time, i.e. food supply depends on agricultural production. About 2000 BP (that is time of accomplishment of riverine civilizations and agricultural empires) the per capita amount of the earth moved by agricultural activities began to decrease gradually since grazing lost of its importance in feeding world population. Moreover, a unit land provided food for ever more people because of spreading technical innovations, such as iron ploughs, irrigation, etc. Due to the dramatic increase in agricultural productivity and the implementation of soil conservation practices, the relative impact on the landscape from agricultural activities has rapidly declined since the industrial revolution, particularly, over the last 50 years. The impact of the intentional anthropogeomorphological activities increased slowly until the industrial revolution, and their geomorphological importance was subordinate to that of agriculture. Then, however, this pattern dramatically changed: while the per capita amount of earth moved by agriculture has considerably decreased, intentional anthropogeomorphological activities are gaining more importance.

The total amount of earth moved intentionally and unintentionally can be simply estimated by multiplying the per capita values by the population in the past (fig. 1). Although the rate of population growth may seem to «overwrite» the pattern on this scale, it is obvious that human impact had increased slowly and gradually until the industrial revolution and this increase was predominantly due to increasing unintentional activities. The industrial revolution drastically transformed this pattern. The linear increase of the amount of earth moved by humans turned into exponential and intentional activities became more and more important. As a consequence, man is increasingly able not only to modify geomorphic processes but also to reshape the landscape.

QUANTIFICATION OF POTENTIAL HUMAN IMPACT

It seems obvious that the per capita amount of earth moved by the human activities should be regarded as a basic parameter for the quantification of human impact. As it was mentioned before, this parameter, however, is hardly useful in the lack of detailed statistical data as well as considerable variation between the different estimations. Human environmental impact is generally characterized by the equation of **I=P·A·T** (Erlich & Erlich, 1990), where I is environmental impact, P is population, A is per capita affluence, and T is a technology factor. Some authors (e.g. Haff, 2003) suggest that this equation should be applied to estimate the significance of the human factor in geomorphic processes. Although this assumption seems to be logical, the equation is hardly used for the quantification of human impact because there is no simple parameter for the technology factor, which might represent the general geomorphic capability of humans.

The most useful model proposed until now for the quantification of potential anthropogeomorphological impact was formulated by Nir (1983). His «index of potential anthropic geomorphology» is based on two parameters, namely «the degree of development» (*DD*) and «the degree of perception» (*DP*). The former one reflects the rate of human impact, while the latter concerns the perception of damage from anthropogeomorphological processes (*AGP*), i.e. the extent of combating the erosion caused by human intervention. In Nir's opinion, *DD* can be expressed by the percentage of urban population (*UP*), while *DP* (or degree of the lack of perception) can be expressed by the percentage of illiteracy (*DI*) since the level of illiteracy may indicate education, and education is a necessary condition for forming a public degree of perception. Therefore, he proposes to define the rate of the *AGP* as the average of the two variables. Constructing his model, Nir intended to consider natural conditions that have an influence on geomorphic processes induced by human activities. For this reason, he also included the influence of relief and climate, the two principal physical factors modifying geomorphological processes. As a result, his «index of potential anthropic geomorphology» (*I*) is formulated as

$$I = \frac{UP + DI}{2} \cdot \frac{1}{100} \cdot (K_c + K_r),$$

where K_c and K_r are constants reflecting climatic and relief conditions, resp. The values of these constants may range from 0.4 to 0.8, and from 0.2 to 0.8, resp. The multiplication by 1/100 converts $(UP + DI)/2$ to a range from 0 to 1. Nir proposed this index as a parameter to indicate how potential anthropogeomorphological processes are harmful in a given country. In his opinion, when $I<0.30$, human geomorphological activities represent limited hazard; when $0.30 \leq I \leq 0.49$, the hazard is not negligible and some erosion control is required; if $I \geq 0.50$, the hazard involves considerable damage and powerful measures are urgently required.

The advantage of Nir's index is that the required data can be obtained for most countries. Moreover, by using prediction for urban population and illiteracy in the future, potential *AGP* can be also predicted (fig. 2). On the other hand, however, some details of the concept are debatable. Larger countries may have extremely variable topography and climatic features, therefore, the characterization of climate and relief conditions by a single value can led to sweeping generalization in these cases. Moreover, regarding the constants K_c and K_r, Butzer (1984), referring to evidence from observations by Jansen and Painter (1974), argues that relief heavily outweighs the influence of precipitation seasonality and intensity.

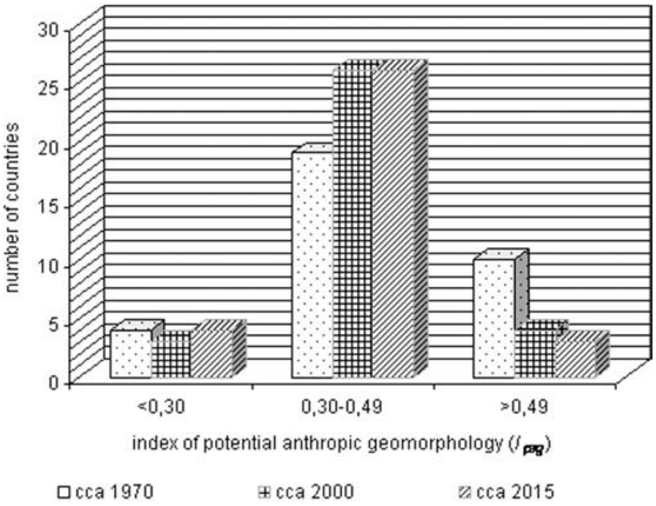

FIG. 2 - Distribution of the index of potential anthropic geomorphology (*I*) for 33 countries* in 1970, 2000 and 2015 (after Nir, 1983; and Rózsa, 2006).
*Algeria, Australia, Brazil, Botswana, Bulgaria, Canada, Chile, Greece, Hungary, India, Indonesia, Iran, Israel, Japan, Malawi, Malaysia, Mexico, Morocco, Nepal, New Zeeland, Panama, Philippines, Poland, South Korea, Switzerland, Syria, Tanzania, Thailand, Tunisia, Turkey, UK, USA, Zambia.

Another questionable point is the percentage of urban population as a parameter of *DD*. Undoubtedly, there are criteria of obtaining municipal rank (e.g. population, offices, services, spatial attraction, urban building methods, etc.) reflecting the *DD*; but they can hardly be expressed by numerical data. Moreover, these criteria are different from country to country and from time to time. Perhaps, it is not an overexaggeration to claim that those settlements are included which are declared urban officially. The percentage of urban population is an administrative-statistical category, consequently, its application as a parameter indicating socioeconomic development may be misleading.

CONCLUSION

Despite remarkable progress in anthropogeomorphology over the last few decades there has been no widely accepted method for the quantification and qualification of human impact on the landscape. According to different estimations, however, human activity has been identified as the predominant geomorphic agent, even if evaluation methods vary. Calculations also show that rate of intentional human impact has become ever higher compared to that of agriculture since the industrial revolution. Rural activities, however, remain to be the most significant in anthropogeomorphology. Nir's model attempts to quantify socioeconomic and physical factors related to human impacts on geomorphic processes by formulating the index of potential anthropic geomorphology (*I*). With the undoubted advantages of this index (such as simplicity, data availability and usability for forecasting), some limitations of his concept are pointed out.

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