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ROLE OF CLIMATIC AND ANTHROPOGENIC FACTORS ACCELERATING SOIL EROSION AND FLUVIAL ACTIVITY IN CENTRAL EUROPE

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Abstract

Comparison of climatically controlled phases of higher rainfall and flood frequency with the anthropogenic phases of effective soil erosion documents various overlappings and superpositions. The wetter phase with high frequency of extreme events leads to the transformation of relief, well expressed in the ecotonal zones and in the high mountains. Increased human activity controls an accelerated soil erosion, overbank deposition and tendency to breading. The most distinct changes, leading to the passing of thresholds and transformation of slopes and valley floors are connected with the coincidence of wetter climate and high anthropogenic pressure. Those phases were recognized in Central Europe during the middle Neolithic period, the early phase of the Roman period, the 10^{th}–11^{th} century and the Little Ice Age.

Key words: climatic factor, anthropogenic factor, soil erosion, fluvial activity, the Holocene.

INTRODUCTION

The intensity of soil erosion and fluvial activity is determined by two groups of factors: climatic and anthropogenic. Most of the erosion and deposition follows during the extreme events. Changes in their frequency and type depend on climatic fluctuations.

The deforestation and exploitation of natural resources caused by soil cultivation, overgrazing and other practices accelerate the intensity of runoff, soil erosion and deposition, as well as decrease the thresholds of appearance of various processes like landsliding, debris flowing or lateral migration of river channels.

There existed various opinions about the role of both groups of factors. Depending on spatial and time scales of available records and on regional differentiation, some researchers even took up a deterministic position stressing the prevailing role of one factor. Most distinct and rapid are the changes, proceeding in the ecotonal zones where every anomaly may cause a chain of changes, leading to a shift of ecotone or to a substantial transformation of the existing geoecosystem. The opinion that climatic changes play a leading role in these transitional ecosystems is rather common (cf. Dalfez *et al.* 1997, Issar 2003). Alternatively, in the relatively stable environments of the temperate zone, deforestation and agriculture is identified as the causative factor of more pronounced changes (Mensching 1957, Roberts 1989). These changes may have a gradual impact combined with feedback (cf. Frenzel 2000) or step-like distribution caused both by climatic fluctuations as well as economic and social changes (Starkel 1992, Berglund 2003).

The monitoring of the present-day events and examination of various detailed hydrological records covering the last two centuries deliver many examples of coincidence of both groups of factors (Mensching 1987, Lang *et al.* 2000, Oldfield & Dearing 2003, Starkel 1998a, b, 2002). The intensity of slope wash and sediment load is by 2–4 orders of magnitude higher on cultivated fields and in small catchments (Starkel 1987, Gil 1999) than in the natural forest ecosystems. In regions where deforestation and cultivation expanded in the 19-th century, this change is registered by a rapid rise in the rate of deposition at the feet of slopes and over floodplains and an accelerated shift in the shape of river channels (cf. Davis 1976, Knox 1977, Wasson *et al.* 1998). On the other hand, observations of the impact of low frequency heavy rainfalls and floods show the staggering effects of the transformation the cultivated areas (Selby 1974, Starkel 1976). The clustering of several extreme events leads to the total degradation of soil profile and the transformation of slope and channel forms (Starkel & Sarkar 2002).

CLIMATIC PHASES OF THE HOLOCENE

The Holocene period, especially in the temperate zone, is characterised by cooler and wetter phases alternating with drier and warmer ones. These phases mainly coincide with fluctuations in the solar activity and corresponding inverse variations in radiocarbon production (cf. Magny 1998, Chambers *et al.* 1999, Starkel 1999). The varying frequency of volcanic eruptions is an additional factor (Bryson 1989). Higher frequency of extreme events is a common feature of the wetter phases. This relates not only to the rainfall totals

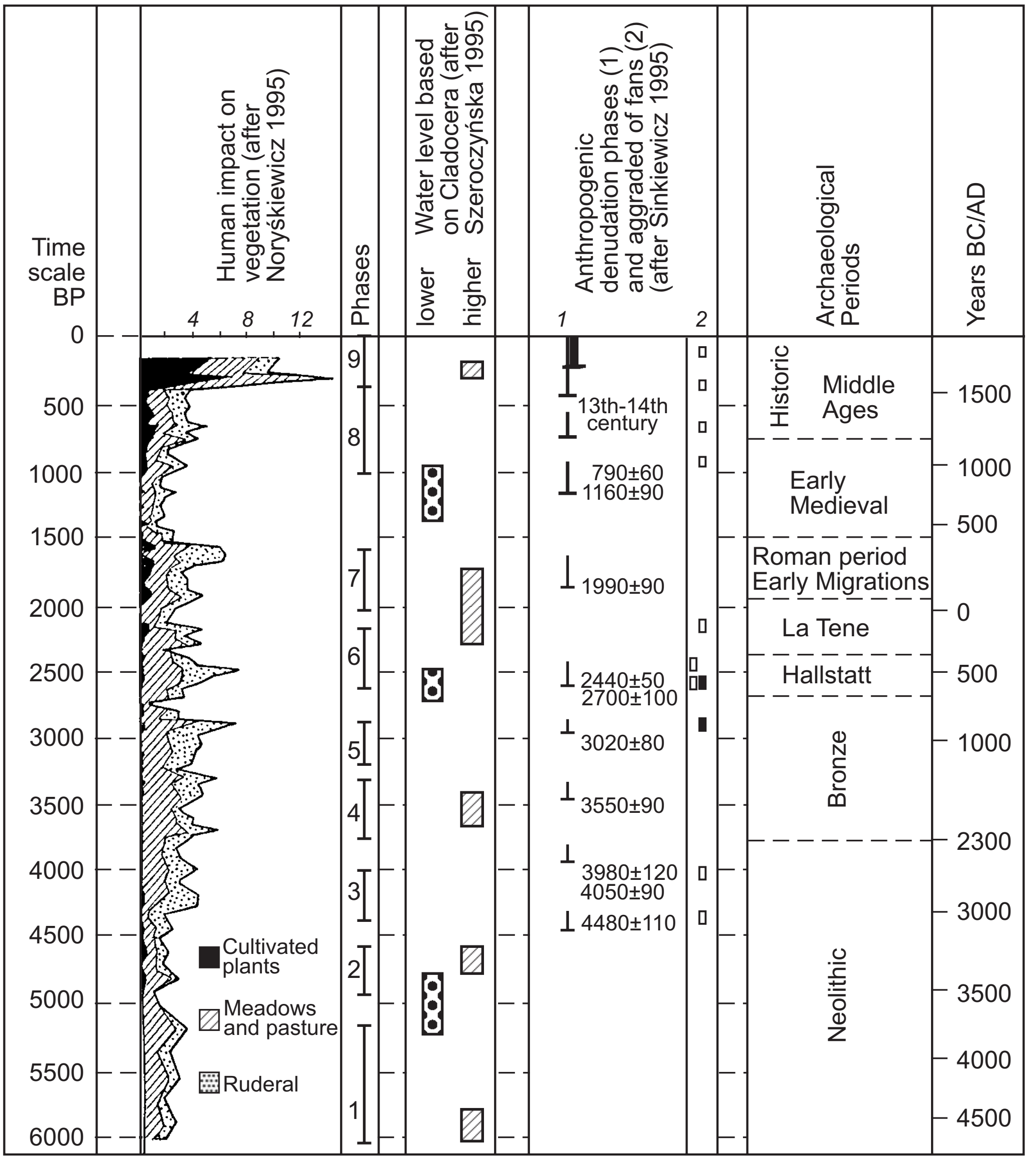

Fig. 1. Phases of environmental changes and human activity in the surroundings of Biskupin Lake, Polish Lowland (based on Niewiarowski *et al.* 1995).

but also to their duration and intensity (Starkel 1998, 2002). In the actual forms and deposits we find the confirmation of heavy downpours which are registered in slope wash, proluvial fans and debris flows, while continuous rains are evidenced in landslides, braided channels or channel avulsions. The best proof of their distinct climatic origin and relative absence of anthropogenically accelerated processes comes either from the phases older than the first Neolithic clearance or from the areas not transformed by man, like the high mountain belt. Therefore the information on the coincidence of glacial advances, lowering of the upper tree line and solifluction vertical zone, water level rises of large lakes, rapid rise of speleothems, *etc*. is very valuable (Haas *et al.* 1998, Magny 1998, Pazdur *et al.* 1999, Starkel 2003).

Besides the correlation of various events in one region we are faced with the question of long-distance correlation. The triggering factors include global fluctuation in solar radiation, in atmospheric circulation and oceanic water circulation. In the last two decades there has been a great deal of interest on continental or global correlations of various regional quasi-cyclic fluctuations and to combine them with fluctuations of ^{14}C and with continuous records preserved mainly in ice cores of polar regions. In most approaches the authors attempt to find a niche with undisturbed continuous sequence of continental deposits like Lake Gościąż in Poland (Ralska-Jasiewiczowa *et al.* 1998). But at the same time such a locality may not be able to register the most dramatic episodes of environmental evolution forming the characteristic regional features.

The correlation of warmer and cooler, wetter and drier phases is made possible by radiocarbon dating and other methods. In reality the boundaries of these phases differ up to two and more centuries in time. These differences are visible on various correlative tables included in many papers published in the last decades (cf. Magny 1993, Starkel *et al.* 1996, Haas *et al.* 1998, Issar 2003, Starkel 2003).

At the same time we may observe a tendency to introduce in terrestrial stratigraphy the concept of "milestones" *e.g.* Heinrich's events, or Bond's events to calibrate better the sequence of changes in the past (Bond *et al.* 2001). Very promising is the search for direct time markers like rapid global cooling about 2750 cal yr BP (van Geel *et al.* 1998) or other cooling about 8200 cal yrs BP (Alley *et al.* 1997, Magny *et al.* 2003). I also tried to identify a global phase of higher frequency of extreme events between 8.5–8.0 ^{14}C ka BP with a distinct cluster of volcanic eruptions and the fist cooling during the Holocene (Starkel 1999).

Concerning hydrological changes in the whole Europe the summary presented by S. Harrison *et al.* (1993) has many gaps in the central part of Europe. A good correlation of all phases has been documented in a relatively narrow 43–50°N latitudinal belt (Magny *et al.* 2003). Depending on cyclonic tracks controlled by the position of jet-stream, correlation of this part of western-central Europe (including the Alps), during particular periods is better with the Mediterranean region, whereas during other periods with the higher latitudes. Even comparing the sequence of lake level fluctuations in northern Poland and southern Sweden we observe distinct differences (Digerfeldt 1988, Ralska-Jasiewiczowa *et al.* 1998).

Farther to the east the phases with higher frequency of extreme rainfalls, reflected in the lowering of the vertical climatic – vegetation belts and the floods, (discussed by Magny *et al.* 2003), show a very good coincidence between the Alps with their northern foreland and the Carpathian with their foreland (Starkel *et al.* 1996, Starkel 2003).

In Southern Poland and the adjacent countries it was possible to identify the following phases of increased fluvial activity, mainly coinciding with coolings in the Alpine region (in ^{14}C ka BP): 8.5–8.0, 7.5–7.2, 6.5–6.0, 5.5–4.9, 4.5–4.1, 3.4–3.1, 2.8–2.7, 2.2–1.8, 1.6–1.5, 1.1–0.9 ka (Starkel 1983, Kalicki 1991, Starkel *et al*. 1996).

In the case of dendrochronological standards elaborated for various parts of Germany and Poland, as well depositional phases of subfossil oak trunks the correlation in W–E direction is also better than in the longitudinal transect (Krąpiec 1998, Kalicki & Krąpiec in: Starkel *et al.* 1996). A similar pattern in this latitudinal belt (45–55°N) may be recognised further east in Russia and Ukraine. For instance the wetter and cooler phase about 4.5–4.2 ^{14}C ka BP is reflected in the expansion of boreal species (*Picea*) from the north, in the shift of forest-steppe ecotone towards south and in the rise of the water level of the Caspian Sea (Kremenetsky 1997, Gerasimenko 1997, Meyev & Chepalyga 2002).

ANTHROPOGENIC PHASES OF ACCELERATED EROSION

The geomorphic effects of anthropogenic activity are connected with regionally differentiated socio-economic development. The introduction of new cultivated plants or new technology of tillage, metal smelling and irrigation practices did not take place at the same time. All these events were controlled among others by migration, trade connections, natural disasters, wars and later also by political boundaries. Therefore the correlation of phases of human activity between neighbouring regions and superimposed climatic fluctuations (also differentiated in space) should be examined more carefully (cf. Starkel 1992).

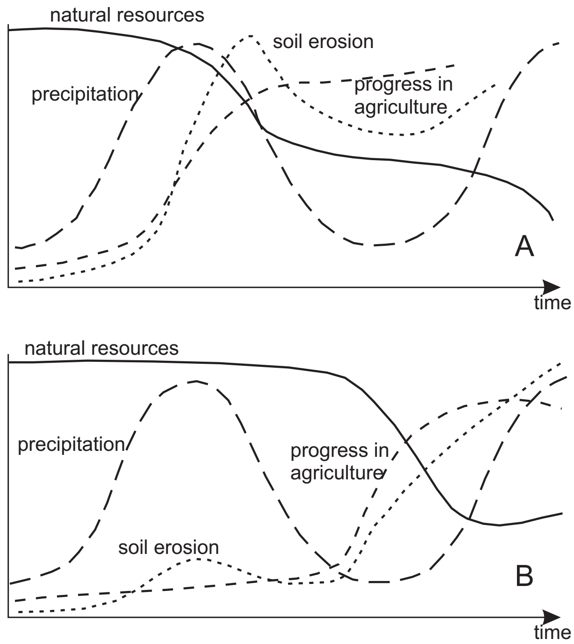

Fig. 2. Fluctuations in precipitation, phases of increased human activity and rate of soil erosion. Forest clearance is understood as regress of natural resources. Economic progress may start either during more humid phase (A) or during drier phase (B) (after Starkel 1992).

To understand better the human component of environmental changes, reconstruction of land use pattern through time is of supreme importance (Frenzel 1992, Berglund 1994, Fig. 1). In the early-Neolithic only small enclaves were under cultivation (Wasylikowa *et al.* 1985). In the mid-Neolithic phase of slash and burn cultivation (*ca.* 3000 BC) on the territory of Germany and Southern Poland no more than 10% of the area was under cultivation (Kruk 1993, Frenzel 2000). In many regions Bronze age cultures caused much more intensive land degradation (Niewiarowski *et al.* 1995 – Fig. 1, Berglund 2000).

During the Roman time, forest clearance and tillage became very intensive not only in the Mediterranean zone, but also in the vast northern areas of Imperium Romanum (Roberts 1989). It led to the formation of secondary plant communities, bare upland and also to extended aggradation (cf. Schirmer 1983, Jones *et al.* 1985, Cremaschi *et al.* 1994). The spread of agriculture and modern technologies during the Middle Ages was more pronounced. On the territory of Germany at 1300 AD about 30% of total area was under tillage, about 50% under grassland and only 20% remained forested (Lang *et al.* 2000). At that time in Poland between 40 and 70% of its total area was still under forest (Maruszczak 1988).

The socio-economic transformation and step-like progress in agriculture proceeded during periods with more humid or drier climate (Fig. 2). Therefore the effects of accelerated erosion and deposition should differ very much (Starkel 1992, Berglund 2003).

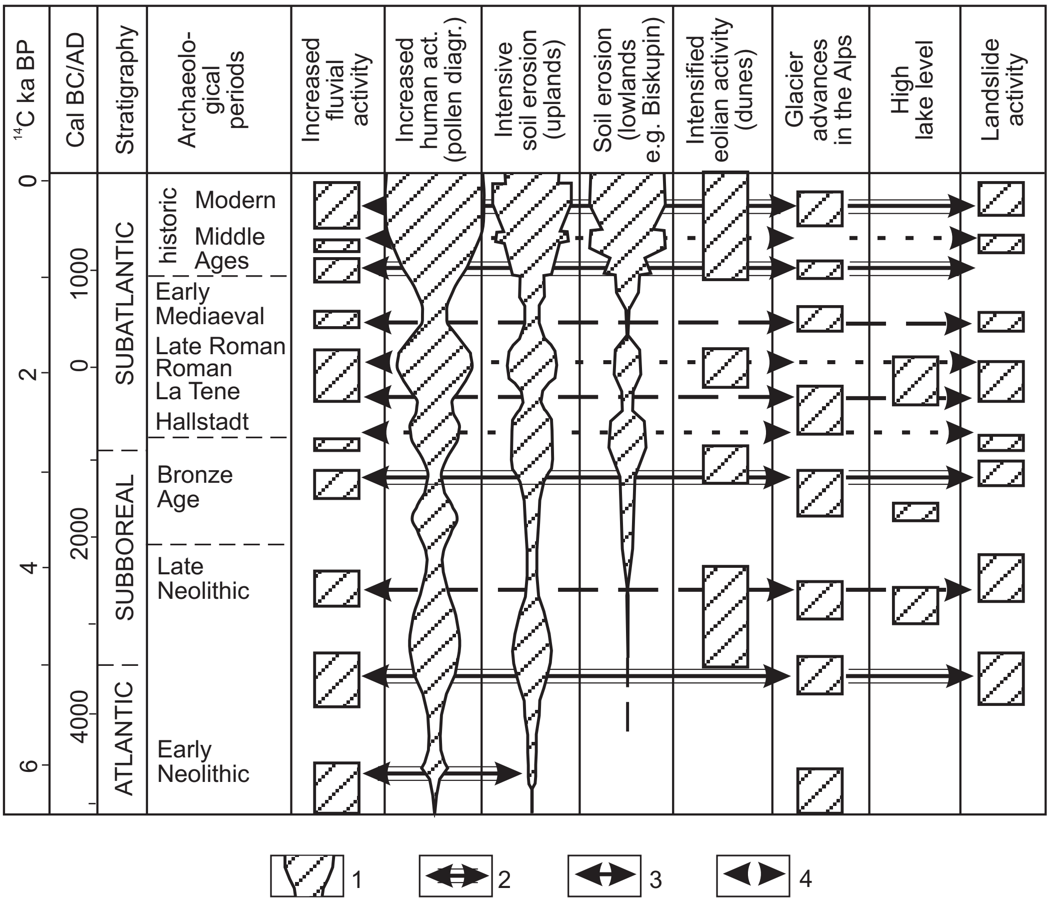

Fig. 3. Correlation of climatic phases and anthropogenically controlled phases of accelerated erosion on the territory of Poland (after various sources, Starkel in print). **1** – Intensity of human activity and soil erosion; **2** – Wetter phase correlate with anthropogenic phase of erosion; **3** – Wetter phase without anthropogenic component; **4** – Anthropogenic phase of erosion without coincidence with more humid phase.

Let us consider the example of Southern Poland and adjacent regions (Starkel 1987, 2005). The first distinct phase of accelerated erosion was connected with the middle Neolithic Funnel Beaker culture, which started during the second part of the wetter phase (4000–3600 BC) and continued during relatively warmer and drier period (Fig. 3). It was a time of intensive slope wash, gullying and the start of deposition of alluvial loams in tributary valleys, dissecting the loess plateau (Śnieszko1995, Kruk *et al.* 1996).

The next increase in the humidity and lake level rise about 2900–2400 BC was accompanied by the retreat of tillage, extension of pastures and by strewing on the treeless interfluves of burial mounts of the Corded Ware culture. During late phase of the Bronze period (Lusatian culture – from about 1200 to 700 years BC) before the climate started to become more wet, thick colluvial deposits are recorded from various parts of Poland (Sinkiewicz 1998, Śnieszko 1995, Twardy 2002) as well from laminated sediments in the Holzmaar Lake (Zolitschka & Negendank 1998).

The Roman time in its earlier phase (2500–2200 BP) is distinct by high lake levels and cooling (Ralska-Jasiewiczowa *et al.* 1998, Klimenko 2004), but not much in the aggradation. Accelerated deposition is more characteristic for the 1st – 3rd century AD, when the upper Vistula valley saw in expansion of agriculture as well as iron smelting and pottery industry (Kalicki 1991, 2000). For the first time the bottoms of river channels rose up and the upbuilding of floodplain was recorded up to the lowest course of the Vistula river valley (Starkel ed. 1990).

The following cooler and wetter phase of the 5th–6th century AD does not coincide with accelerated soil erosion (Fig. 3). During that migration period the tendency to abandon cultivated areas and reforestation prevailed. Nevertheless frequent floods are registered by the high number of subfossil oak trunks, connected with lateral shifting of river channels (Krąpiec 1998, Starkel *et al.* 1996). A new phase of intensive erosion and aggradation is connected with the subsequent extension of cultivated land and denser population in the 10th and 11th century and is combined also with higher flood frequency (cf. Starkel 1995, in print) and with glacial advance in the Alps (Magny 1993). Also during that phase the settlements of the 9th century Great Moravian State were buried by flood deposits (Havlicek 1977). Farther to the east in still forested Berezyna river valley of Byelorussia this flood phase is also recorded being only controlled by climatic factor (Kalicki 1996).

An even more pronounced acceleration of soil erosion as in 14th–16th century. The process was regionally differentiated depending on the time of forest clearance and foundation of new villages (Starkel 1995, 2005). This phase overlapped with the beginning of the Little Ice Age, when throughout Europe frequent floods were recorded (Brazdil *et* *al.* 1999, Starkel 2001) and the middle sections of numerous river channels changed their pattern from the meandering to the braided (Szumański 1977).

CONCLUSIONS

Comparison of climatic phase of higher rainfall and flood frequency with anthropogenic phases of effective soil erosion in Central Europe document their possible overlappings and superpositions (Figs 1, 2, 3). The wetter phases with higher frequency of extreme events lead to transformation of relief, especially well expressed in montane areas and mountain foreland. Accelerated soil erosion and overbank deposition are mainly controlled by increased human activity, which may start either during wetter or drier phase (Fig. 2). Macklin and Lewin (2003) in their study of soil erosion in the British Isles express the opinion that land use plays a key role especially in small basins by moderating or amplifying the climate signal. Oldfield and Dearing (2003) underline the role of rapid change in land use. But the most dramatic changes, leading to the passing of stability thresholds and to transformation of slopes and valley floors (including the type of river channels) seem happen, when wetter phases and high anthropogenic pressure coincide. In central Europe these were the middle Neolithic phase, the earlier part of the Roman period, 10^{th} –11^{th} centuries and the Little Ice Age.

REFERENCES

Alley R.P., Mayewski P.A., Sowers T., Stuiver M., Taylor K.G., Clark, P.V. 1997. Holocene climate instability: a prominent widespread event 8200 years ago. *Geology* 25, 483–486.

Berglund B.E. 1994. Methods for quantifying prehistoric deforestation *Paläoklimaforschung* 12, 5–11.

Berglund B. 2000. The Ystad Project – a case study for multidisciplinary research on long-term human impact. *PAGES News* 8, 3, 6–7.

Berglund B. 2003. Human impact and climate changes – synchronous events. And a causal link? *Quaternary International* 105, 7–12.

Bond G., Kromer B., Beer J., Munscheler R., Evans M.N., Sowers W., Hoffman S., Lotti-Bond R., Hajdas I. Bonani G. 2001. Persistent solar influence on North Atlantic climate during the Holocene. *Science* 294, 2130–36.

Brazdil R., Glaser R., Pfister Ch., Dobrovolny P., Antoine J.M., Barriendos M., Camuffo D., Deutsch M., Enzi S., Guidoboni E., Kozyta O., Rodrigo F.S. 1999. Flood events of selected European rivers in the sixteenth century. *Climatic Change* 43, 239–285.

Bryson R.A. 1989. Late Quaternary volcanic modulation of Milankovitch climate forcing. *Theoretical and Applied Climatology* 39, 115–125.

Chambers F.M., Ogle M.J., Blackford J.J. 1999. Palaeoenvironmental evidence for solar forcing of Holocene climate: linkages to solar science. *Progress in Physical Geography* 23, 181–204.

Cremaschi M., Marchetti M., Ravazzi C. 1994. Geomorphological evidence for land surfaces cleared from forest in the central Po plain (northern Italy) during the Roman period. *Paläoklimaforschung* 10, 119–132.

Dalfes H.N., Kukla G., Weiss H. (eds) 1997. Third millennium BC, climate change and old world collapse. *NATO ASI Series* 1–49, Springer Verlag.

Davis M.B. 1976. Erosion rates and land use history in Southern Michigan. *Environmental Conservation* 3, 139–148.

Digerfeldt G. 1988. Reconstruction and regional correlation of Holocene lake – level fluctuations in Lake Bysjon, South Sweden. *Boreas* 17, 165–182.

Frenzel B. (ed.) 1992. Evaluation of land surfaces cleared from forest by prehistoric man in early Neolithic times and the time of migrating Germanic tribes. *Paläoklimaforschung* 8.

Frenzel B. 2000. Datiert der klimawirksame Eingriff des Menschen in der Haushalt der Natur erst aus dem beginnenden Industriezeitalter? *Rundgespräche der Kommission für Ökologie* 18, Entwicklung der Umwelt seit der letzten Eiszeit, 33–46, München.

Gerasimenko N.P. 1997. Environmental and climatic changes between 3 and 5 ka BP in southern Ukraine. *NATO ASI series I* 49, Springer Verlag, 371–399.

Gil E. 1999. Water circulation and wash down on the flysch slopes used for farming purposes in 1980–1990 years (Original: Obieg wody i spłukiwanie na fliszowych stokach użytkowanych rolniczo w latach 1980–1990). *Zeszyty IG i PZ PAN* 6, Warszawa, 78 pp. (in Polish).

Harrison S., Prentice J.C., Wick L. 1993. Climatic controls on Holocene lake-level changes in Europe. *Climate Dynamics* 8, 189–200.

Haas J.N., Richez I., Tinner W., Wick L. 1998. Synchronous Holocene climatic oscillations recorded on the Swiss Plateau and at timberline in the Alps. *The Holocene 8*, 301–309.

Havlicek P. 1991. The Morava River Basin during the last 15 000 years. In L. Starkel, K.J. Gregory and V. Baker (eds) *Temperate Palaeohydrology*, J.Wiley, 319–341.

Issar A.S. 2003. Climate changes during the Holocene and their impact on Hydrological Systems. *International Hydrology Series* IHP – UNESCO, Cambridge Univ. Press, 127 pp.

Jones R., Benson–Evans K., Chambers F.M. 1985. Human influence upon sedimentation in Llagorse Lake-Wales. *Earth Surface Processes and Landforms* 10, 227–236.

Kalicki T. 1991. The evolution of the Vistula river valley between Cracow and Niepołomice in Late Vistulian and Holocene times. *Geographical Studies* Spec. Issue 6, Warszawa, 11–37.

Kalicki T. 2000. Grain size of the overbank deposits as carriers of palaeogeographical information. *Quaternary International* 72, 107–114.

Kalicki T. 1996. Climatic or anthropogenic alluviation in Central European valleys during the Holocene? In J. Branson, J. Bron, K.J. Gregory (eds) *Global Continental changes*: *The context of Palaeohydrology*, Geological Society Special Publication 115, 205–215.

Klimenko V.V. 2004. Sharp cooling of the Northern Hemisphere in the Early Subatlantic Age (650–280 BC). *PAGES News* 12, 13–15.

Knox J.C. 1977. Human impacts on Wisconsin stream channels. *Annals of the Association of American Geographers* 67, 323–342.

Krąpiec M. 1998. Oak dendrochronology of the Neoholocene in Poland. *Folia Quaternaria* 69, 5–134.

Kremenetski C.V. 1997. The late Holocene environment and climate shift in Russia and surrounding lands. *NATO ASI Series I* 49, Springer Verlag, 351–370.

Kruk J. 1993. Socio-economic development and changes in the natural environment of loess uplands in the Neolithic 4800–1800 BC (Original: Rozwój społeczno-gospodarczy i zmiany środowiska przyrodniczego wyżyn lessowych w neolicie (488–1800 BC). *Sprawozdania Archeologiczne* 45, 7–17 (in Polish).

Kruk J., Millisauskas S., Alexandrowicz S.W., Śnieszko Z. 1996. Environmental changes and settlement on the loess uplands. *Instytut Archeologii i Etnologii PAN,* Kraków, 139 pp. (in Polish with English summary).

Lang A., Preston N., Dickau R., Bork H.J., Mackel R. 2000. LUCIFS – Examples from the Rhine catchment. *PAGES News* 8, 11–13.

Macklin M.G., Lewin J. 2003. River sediments, great floods and centennial – scale Holocene climate change. *Journal of Quaternary Science* 18, 101–105.

Magny M. 1993. Holocene fluctuations of lakes levels in the French Jura and Sub-alpine ranges and their implications for past general circulation pattern. *The Holocene* 3, 306–313.

Magny M. 1998. Reconstruction of Holocene lake-level changes in the French Jura: methods and results. *Paläoklimaforschung* 25, 67–86.

Magny M., Begeot C., Guiot J., Peyron O. 2003. Contrasting pattern of hydrological changes in Europe in response to Holocene climate cooling phases. *Quaternary Science Reviews* 22, 1589–1596.

Maruszczak H. 1988. Environmental changes of Polish territory in historical period (Original: Zmiany środowiska przyrodniczego kraju w czasach historycznych). In L. Starkel (ed.) *Przemiany środowiska geograficznego Polski*, Wszechnica PAN, Ossolineum, 109–135 (in Polish).

Mensching H. 1957. Soil erosion and formation of haugh-loam in Germany. *Extrait des C.R. et Rapports*, *Union Hydrologique* Toronto, 1, 174–180.

Mensching H. 1987. Anthropogenic sedimentological changes during the Holocene in Northern Africa. *Striae* 26, 35–40.

Meyev E.G., Chepalyga A.L. 2002. The Caspian Sea (original: Kaspijskoe Morie). In A.A. Velichko (ed.) *Dynamics of terrestrial landscape components and inner marine basins of northern Eurasia during the last 13 000 years*, Moscow, *GEOS*, 182–190 (in Russian).

Niewiarowski W., Noryśkiewicz B., Piotrowski W., Sinkiewicz M. 1995. An outline of natural and anthropogenic changes of geographical environment in the Biskupin area during the last 7000 years. *Quaternary Studies in Poland* 13, 77–88.

Oldfield F., Dearing J.A. 2003. The role of human activities in past environmental change: In K.D. Alverson, R.S. Bradley, T.F. Pedersen (eds) *Paleoclimate, global change and the future,* IGBP Series, Springer, 143–162.

Pazdur A., Goslar T., Gradziński M., Hercman H. 1999. The course of hydrological and climatic changes in carstic areas of Southern Poland based on isotopic records (Original: Zapis zmian hydrologicznych i klimatycznych w obszarach krasowych Polski południowej na podstawie badań izotopowych). In A. Pazdur, A. Bluszcz, W. Stankowski, L.Starkel (eds) *Geochronology of the Upper Quaternary in Poland*, Instytut Fizyki Politechniki Śląskiej, Gliwice, 157–177 (in Polish).

Ralska-Jasiewiczowa M., Goslar T., Madeyska T., Starkel L. (eds) 1998. *Lake – Gościąż, Central Poland a morphographic study*. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

Roberts N. 1989. *The Holocene, an environmental history*. Basil Blackwell, Oxford, 227 pp.

Schirmer W. 1983. Die Talentwicklung an Main und Regnitz seit dem Hochwürm. *Geologisches Jahrbuch*, A71, 11–43.

Selby M.J. 1974. Dominant geomorphic events in landform evolution. *Bulletin of the International Association of Engineering Geology* 9, 85–89.

Sinkiewicz M. 1998. Evolution of anthropogenic denudation in the middle part of northern Poland (Original: Rozwój denudacji antropogenicznej w środkowej części Polski północnej). Wydawnictwo UMK, Toruń, 99 pp. (in Polish).

Starkel L. 1976. The role of extreme (catastrophic) meteorological events in contemporary evolution of slopes. In E. Derbyshire (ed.) *Geomorphology and Climate* Wiley, Chichester, 203–237.

Starkel L. 1987a. Man as a cause of sedimentologic changes in the Holocene. *Striae* 26, 5–12.

Starkel L. 1987b. Anthropogenic sedimentological changes in Central Europe. *Striae* 26, 21–29.

Starkel L. (ed.) 1990. Evolution of the Vistula river valley during the last 15 000 years, part.III. *Geographical Studies* Special Issue 5, IGiPZ PAN.

Starkel L. 1992. The feedback mechanisms between the environmental systems and the behaviour of prehistoric man. *Paläoklimaforschung* 8, 25–37.

Starkel L. 1995. Reflection of extreme floods of historic period in the fluvial and slope deposits in the upper Vistula catchment (Original: Odbicie ekstremalnych wezbrań okresu historycznego w osadach rzecznych i stokowych w dorzeczu górnej Wisły). *Acta Universitatis Nicolai Copernici* Geografia 27, Toruń 13–20 (in Polish).

Starkel L. 1998a. Frequency of extreme hydroclimatically – induced events as a key to understanding environmental changes in the Holocene. In A.S. Issar, N. Brown (eds) *Water, Environment and Society in Times of Climatic Change*, Kluwer Publishers, 273–288.

Starkel L. 1998b. Extreme events in the last 200 years in the upper Vistula basin; their palaeohydrological implications. In G. Benito, V.R. Baker, K.J. Gregory (eds) *Palaeohydrology and Environmental Change*, Wiley, 289–306.

Starkel L. 1999. 8500–8000 yrs BP humid-phase – global or regional? *Science Reports of Tohoku University* 7th Series, Geography, 49, 105–133.

Starkel L. 2001. Extreme rainfalls and river floods in Europe during the last millennium. *Geographia Polonica* 74, 69–79.

Starkel L. 2002. Change in the frequency events as the indicator of climatic change in the Holocene (in fluvial systems). *Quaternary International* 91, 25–32.

Starkel L. 2003. Short – term hydrological changes. In K.J. Gregory, G. Benito (eds) *Palaeohydrology, understanding global change* Wiley, 20, 337–356.

Starkel L. 2005. Anthropogenic soil erosion since the Neolithic time in Poland. *Zeitschrift für Geomorphologie* (suppl.) 139, 189–201.

Starkel L. (ed.) 1990. Evolution of the Vistula river valley during the last 15 000 years part.III. *Geographical Studies* Special Issue 5, IGiPZ PAN.

Starkel L., Kalicki T., Krąpiec M., Soja R., Gębica P., Czyżowska E. 1996. Hydrological changes of valley floors in upper Vistula basin during late Vistulian and Holocene. Evolution of the Vistula river valley during the last 15 000 years, (ed. by L. Starkel), *Geographical Studies* Spec. Issue 9, Wrocław, 7–128.

Starkel L., Sarkar S. 2002. Different frequency of threshold rainfalls transforming the margin of Sikkimese and Bhutanese Himalaya. *Studia Geomorphologica Carpatho-Balcanica* 36, 51–67.

Szumański A. 1977. Changes of river channel of lower San river in 19th and 20th century and their impact on the morphogenesis of floodplain (in Polish). *Studia Geomorphologica Carpatho-Balcanica* 11, 139–154.

Śnieszko Z. 1995. Evolution of loess areas of Polish Uplands during last 15000 years (Original: Ewolucja obszarów lessowych Wyżyn Polskich w ostatnich 15000 lat). *Prace Naukowe Uniwersytetu Śląskiego* 1496 Sosnowiec 122 pp. (in Polish)

Twardy J. 2002. Stages of the Holocene evolution of dry valleys in the Łódź Plateau, based on sediment analysis (Original: Etapy neoholoceńskiej ewolucji suchych dolin denudacyjnych na

Wyżynie Łódzkiej w świetle analizy osadów). *Acta Universitatis Nicolai Copernici* Geografia 32, Toruń, 127–137 (in Polish).

Van Geel B., Renssen H. 1998. Abrupt climate change around 2650 BP in North-West Europe: evidence for climatic teleconnections and a tentative explanation. In A.S. Issar, N. Brown (eds) *Water, Environment and Society in Times of Climatic Change* 21–41, Kluwer Academic Publishers.

Wasson R.J., Mazari R.K., Starr B., Clifton G. 1998. The recent history of erosion and sedimentation on the Southern tableland of southeastern Australia; sediment flux dominated by channel incision. *Geomorphology* 24, 291–308.

Wasylikowa K., Starkel L., Niedziałkowska E., Skiba S., Stworzewicz E. 1985. Environmental changes in the Vistula valley at Pleszów caused by Neolithic man. *Przegląd Archeologiczny* 33, 19–55.

Zolitschka B., Negendank J.F.W. 1988. A high resolution record of Holocene palaeohydrological changes from Lake Holzmaar, Germany. *Paläoklimaforschung* 25, 37–52.