STUDIA GEOMORPHOLOGICA CARPATHO-BALCANICA
VOL. XXXIX KRAKÓW 2005 PL ISSN 0081-6434
LANDFORM EVOLUTION IN MOUNTAIN AREAS

PAWEŁ PROKOP (KRAKÓW)

NATURAL HAZARDS AND ANTHROPOGENIC IMPACT ON ENVIRONMENT IN A TROPICAL MOUNTAIN CATCHMENT, MEGHALAYA HILLS, INDIA

Abstract. The studies have been carried on in the Umiew catchment of 493.7 km^2 in the area with highest rainfalls in the world reaching 12,000 mm annually. Reconstruction of heavy rains, landslides, earthquakes was based on various historical sources and collected rainfall data for the last 150 years. Satellite image interpretation and modelling soil erosion in a GIS environment supplemented the analysis. The Umiew catchment encompasses two typical landforms of the southern slope of Meghalaya Hills: forested deep canyon and degraded grass covered hilly plateau with small contribution of cultivable land. Natural hazards combined with human activity have accelerated the environmental degradation processes leading, in many places, to complete degradation of vegetation cover and soils. The relative importance of these processes is controlled by natural and anthropogenic factors. The regional continuous heavy rains with 20–25% of average annual precipitation in 3–4 days may cause landsliding on steep but forested canyon slopes. Earthquakes triggered rockfalls and landslides of which material fills river beds up to several meters height and cause changes in the river's regime. In both cases the absence or presence of forest cover becomes almost negligible. The effects of these extreme events are long lasting and give rise to high soil losses and the sediment delivery to the river network. On the contrary, degraded hilly plateau is very resistant on extreme events. Only locally, agricultural land with thicker regolith is susceptible to rainfall induced shallow landslides. The highest predicted annual soil erosion rates up to 145 t · ha^{-1} · yr^{-1} are limited to small fields under potato cultivation on short and steep slopes within hilly plateau. The analysis of maps and satellite images over a period 1910–1998 shows that the land use/cover in the study catchment is relatively stable and does not a straightforward response to the high demographic growth.

Key words: natural hazards, human impact, India

INTRODUCTION

The tropical mountains contain a variety of geosystems sensitive to climatic changes, natural disasters and socio-economic activity (Allan 1986; Messerli and Ives 1997). Although natural evolution with high frequency of extreme events can be an important element of environmental changes (Selby 1974; Starkel

1976, 2004), human impact is considered as the dominant driving force of degradation in tropical areas (Lambin 1997; Achard et al. 2002). The effects of human population pressure leading to deforestation, intensification of agricultural land use, soil erosion, mass wasting, flooding, reservoir sedimentation were observed all over the tropical regions in particular mountains (Ives and Messerli 1989; Van Lynden and Oldeman 1997; Gete and Hurni 2001; Vanacker et al. 2003).

The Meghalaya Hills represents an area where natural hazards (the highest rainfalls in the world, landslides, earthquakes) combined with human activity (deforestation, surface mining of limestone and coal, shifting cultivation) have accelerated the environmental degradation processes leading in many places to complete degradation of vegetation cover and soils (Chatterjee 1968; Starkel 1972; Ramakrishnan 1992; Starkel and Singh 2004). However scientific exploration of Meghalaya Hills began in the half of XIX c. (Oldham 1854), the knowledge of the complex interrelationships between mentioned factors is far from complete. Most of the studies concentrated on geology (Mazumdar 1978, 1986) and relief (Starkel 1972, 1989, 1996). During last decades ecologists undertook problems associated with impact of shifting cultivation on environment (Toky and Ramakrishnan 1983a, b; Ramakrishnan and Kushwaha 2001) and restoration of degraded ecosystems (Ram and Ramakrishnan 1988; Tripathi et al. 1995). On the contrary, only few attempts have been made to interpret hydrological and soil erosion processes limited to easy accessible areas (Mishra and Ramakrishnan 1983; Froehlich 2004a, b). The application of remote sensing for estimation of land use/cover changes did not increased the recognition of human impact on environment. The rates of deforestation differ considerably between authors due to different methodology (Forest Survey... 2001; Roy and Tomar 2001; Roy and Joshi 2002). From this review it appears to be a lack in the knowledge concerning interaction between natural and man-induced processes over long time scales.

The main objective of this study is to evaluate the role of natural hazards and human impact on environmental degradation of tropical catchment over last 150 years. More specifically, this study aims at assessing the impact of extreme rainfalls and earthquakes on mass movement as well as quantifying their effects together with land use/cover changes on water erosion.

MATERIALS AND METHODS

The annual and monthly rainfall records for the last 150 years and daily records for the 15 years 1986–2000 for Cherrapunji and Shillong have been collected from India Meteorological Department (IMD) in Pune and Regional Meteorological Office in Gauhati. Rainfall time series for Sylhet, Mawsynram and Mawphlang have been collected from different agencies for periods from 50 to 100 years. Only two stations Cherrapunji and Shillong conduct the continuous rainfall measurements. The rainfall intensities have been calculated during 15 minutes periods from hyetographs for both stations for two years 1999 and 2000.

Reconstruction of heavy rains, landslides, earthquakes was based on various historical sources; reports from British administration and field surveys mainly from XIX century. Present-day landslides distribution was estimated during fieldwork and through visual interpretation of False Color Composite (FCC) of Landsat MSS, TM and Indian Remote Sensing (IRS) satellite images for the period 1975–2000.

Land cover data were derived from the Survey of India topographic maps 1 : 63,360 from 1910, and Indian Remote Sensing (IRS–1D) satellite image with resolution 23 × 23 m from 1998. Maps were transferred into digital form and rectified together with satellite image to the Universal Transverse Mercator coordinate system in GIS (ILWIS) environment (International Institute... 1997) using the 1 : 50,000 topographic maps from 1966 as a target. Training areas for land use/cover map generation from satellite image were chosen during the 1998–2001 field work using a hand-held GPS. The maximum likelihood algorithm was applied for image classification. Four classes of land use/cover were delimited: forest, grasslands, paddy rice and potato cultivation.

A digital elevation model (DEM) of the study area was created from contours at intervals of 20 m, digitized from 1 : 50,000 topographic maps. The DEM was interpolated to raster with a resolution of 20 m. The proportion of forest in the 200-m classes of elevation were assessed from DEM and land use/cover data for 1910 and 1998.

The Revised Morgan-Morgan-Finney (RMMF) model was used in ILWIS to assess soil loss with the help of rainfall data, land use/cover map and calculated DEM (Morgan 2001). The RMMF model predicts detachment rates by rainfall and runoff. The detachment is compared with the transport capacity of the runoff. The lower of the two values is the annual rate of soil loss.

RESEARCH AREA

The Meghalaya Hills (the name Shillong Plateau is also used) is an active tectonic horst, rising up from Miocene time to an elevation of 2,000 m a.s.l., located between the Brahmaputra valley in the north and the Bangladesh plains in the south (Fig. 1). Although geologically plateau is a part of Gondwana land, often this area is included to the Indian Himalayan Region (IHR), because of the difference to surrounding lowlands environmental conditions and human activities (Rao 1994). Hills form the first orographic barrier for the humid southwest monsoon winds on their way from the Bengal Bay. The southern slope at its margin is dissected by steep canyons up to 1,000 m depth. There are situated Cherrapunji and Mawsynram, which record a mean annuall rainfall of 11,000–12,000 mm. Cherrapunji has the world record for high rainfalls over durations of between 31 days and two years since 1860–61 (World Meteorological... 1994).

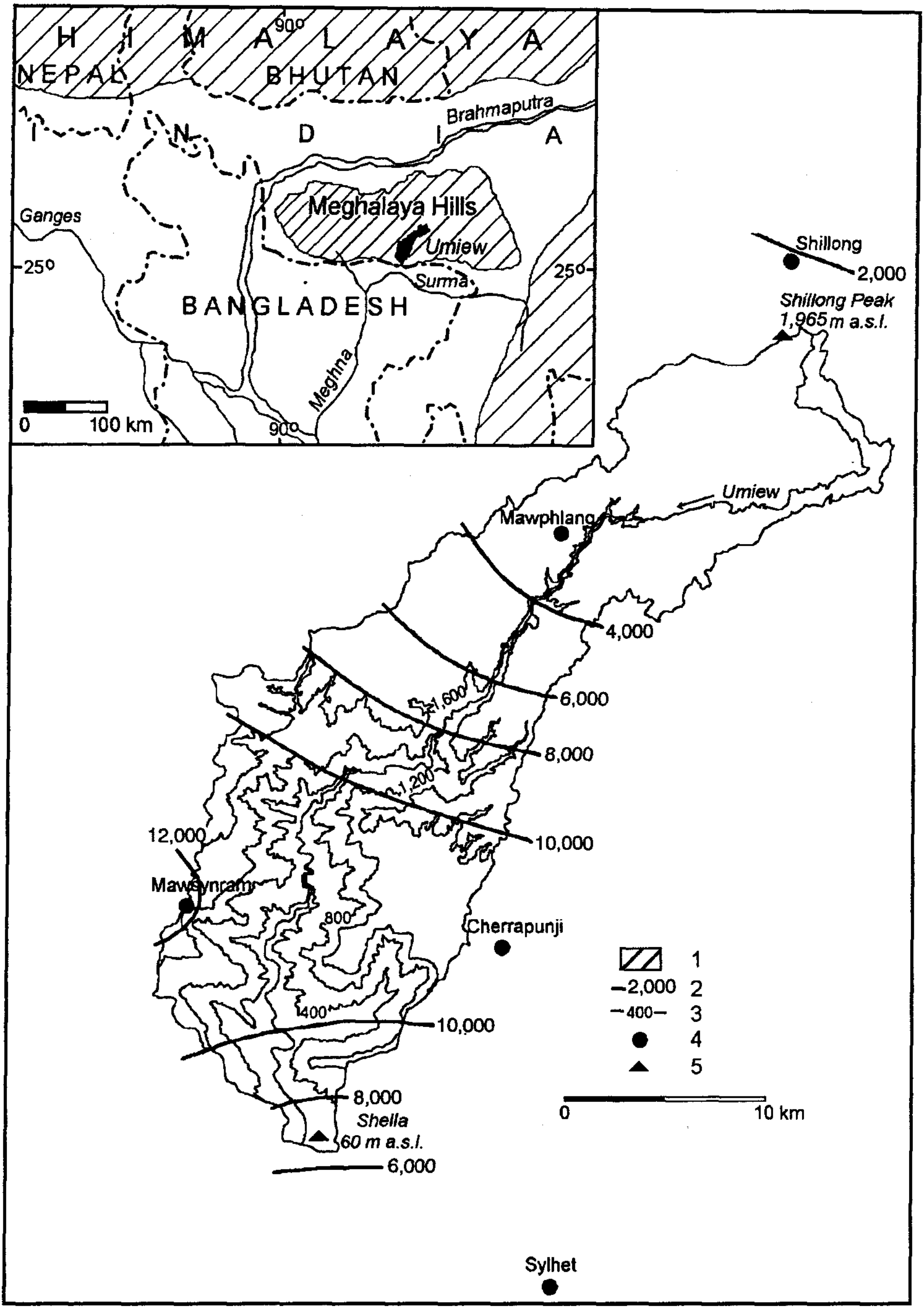

Fig. 1. Location of Meghalaya Hills and Umiew catchment. 1 — mountains and uplands, 2 — isohyetes with average annual rainfall [mm] for the period 1901–2000, 3 — contours every 400 m, 4 — rainfall stations, 5 — elevations (m a.s.l.)

Detailed studies have been carried on in the Umiew catchment of 493.7 km^2, encompassing two typical landforms of the southern slope of Meghalaya Hills: deep canyon and hilly plateau. The catchment is drained by the Umiew river 80 km long which is the right-bank tributary of the Surma flowing to the Meghna in Bangladesh. The river is characterised by strong altitudinal gradients, varying between 60 m a.s.l. and 1,965 m a.s.l. which results in a large variation in meteorological, hydrological and ecological conditions over short distances.

The upper part of the Umiew catchment is built up of Archaean gneisses and quartzites intruded by large granite batholiths (Mazumdar 1986). This part has a mature, structure-controlled landscape with relief energy 50–150 m. The relief which is dissected by the wide valley floors with meandering rivers is the product of long planation and weathering (Bandyopadhay 1972). Metamorphic and igneous rocks are covered near Cherrapunji and Mawsynram by horizontally bedded sandstones and limestones of the late Cretaceous-Palaeogene transgression, several hundreds meters thick. Southern margin of the catchment is truncated by the Dauki fault and form very steep slope with scarps have 800–1000 m high. Escarpments are interrupted by a system of deep canyons with amphitheaters of valley heads cut into the basement of igneous or metamorphic rocks. The upper part of their sides is steep, often vertical, and is bordered by complexes of resistant sandstones and limestones.

The climate is monsoonal with dry and cool season spanning from November to May and warm rainy season from June to October. The mean annual air temperature (1903–2000) is closely related to elevation and varies between 24°C in Sylhet (35 m a.s.l.) and 16.6°C in Shillong (1,500 m a.s.l.). In the most elevated parts of the plateau, temperatures fall below 0°C in winters though snowfall is rare. The mean annual precipitation (1901–2000) is strongly modified by relief and increases from 4,202 mm in Sylhet to 11,000–12,000 mm in of Cherrapunji (1,313 m a.s.l.) and Mawsynram (1,420 m a.s.l). Than precipitation decreases with the distance from the edge of plateau to 3,507 mm in Mawphlang (1,840 m a.s.l.) and 2,199 mm in Shillong.

Major soils in the area are Ultisols, Alfisols and Inceptisols (Soil Survey... 1975). The upper part of catchment is covered by old weathered deposits being stable for a long time and have given rise to soils up to 2 m deep. The young sedimentary complex around Cherrapunji and Mawsynram has comparatively less weathered soil material. Soils are generally shallow with dominant depth ranging from 30 to 50 cm. The soils are mixed with coarser rock fragments and the presence of large boulders on the surface indicates the scale of soil erosion (Prokop 2004). Forest is mostly confined to steep slopes of canyon and consists of climax subtropical evergreen forest mixed in the lower altitudes with tropical semi-evergeen forest and small orange and areca-nut plantations (Haridasan and Rao 1985). Subtropical pine forest is the secondary formation growing above 1,400 m a.s.l. It is generally fragmented and scattered between degraded grasslands. Temperate forest (broad-leaved hill forest) which assume covered grassland areas in the past (Bor 1942) are found only in small blocks on hilly plateau above 1,200 m a.s.l. Agricultural land is limited to the higher parts of the catchment, whereby the most important crops are paddy rice and potatoes.

NATURAL HAZARDS

RAINFALLS

The most distinctive feature of the Umiew catchment is the large amount of rain that annually falls in this area. The knowledge of rainfall parameters is fundamental for understanding thresholds of slope stability and the start of overland flow following soil erosion. For characteristics two stations — Cherrapunji with the highest and Shillong with the lowest rainfall were chosen.

Trend analysis for annual and seasonal rainfall series shows these to be stable in Cherrapunji and Shillong over at least the last 150 years (Prokop and Walanus 2003). But the rainfalls are variable from year to year. The annual rainfalls in Cherrapunji fluctuate between 6,800 mm and 22,760 mm and in Shillong between 1,300 mm and 3,800 mm. The deviations are higher in Cherrapunji compared with Shillong and can exceed 100% annual average. There is a distinct seasonal distribution of rains. The thunderstorms connected with cyclones formed over Bay of Bengal produce large amount of rain between last decade of March and May. During monsoon season from June to September 70% of precipitation falls. At that time the rain falls almost every day in Cherrapunji and monthly totals fluctuate between 1,500 mm and 6,670 mm. The highest monthly total during monsoon season is only 1,267 mm in Shillong Station has 170 rainy days annually that is 12 days less compared with Cherrapunji.

The continuous heavy rains and heavy downpours are two types of rains distinguished over northeast India (Starkel and Basu 2000; Dhar and Nandargi 2003). They differ in their totals, intensity, duration, distribution in space and effects in environmental transformation. This typology can be also applied to rainfall characteristics in the Umiew catchment.

The continuous heavy rains are caused when the eastern end of the monsoon trough shifts northwards to the Brahmaputra valley or during the periods when "Break" monsoon situations set in over the India with a northward shift of the monsoon trough to the foot of the Himalayas (Dhar and Nandargi 2003). These two meteorological situations are responsible for causing continuous heavy rainfall on about 65% of occasions (Dhar and Nandargi 2000). The continuous rains lasting usually 3–4 days (there have been occasions when rain spells of 6–7 days). They have various intensities and totals exceeding 2,000 mm in Cherrapunji and 500 mm in Shillong, which is 20–25% of annual rain (Fig. 2). These continuous heavy rains cover larger areas from hundreds to thousands square kilometers on the southern slope of Meghalaya Hills.

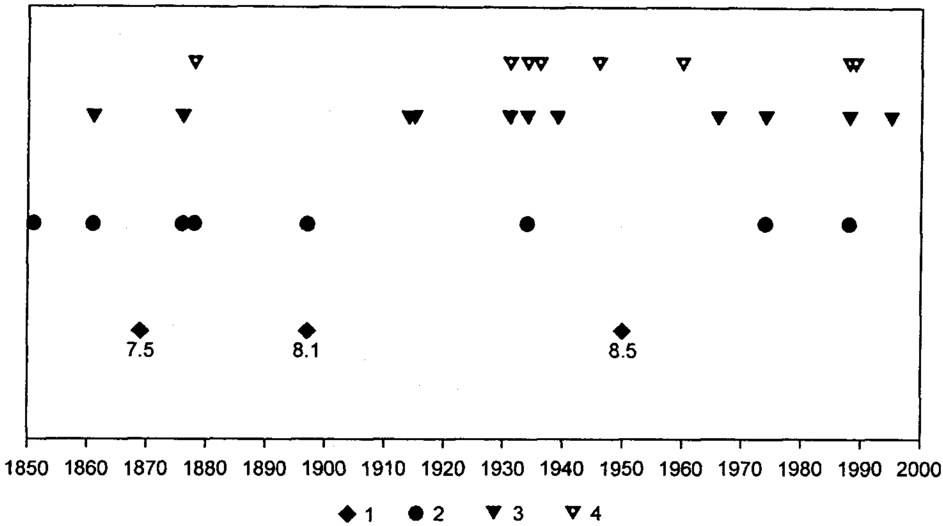

Fig. 2. Extreme events registered in the Umiew catchment during the last 150 years. 1 — earthquakes, 2 — landslides, 3 — heavy continuous rainfalls in Cherrapunji, 4 — heavy continuous rainfalls in Shillong

Orography beside cyclone activity is the additional cause of the enormous heavy downpours in Cherrapunji and Mawsynram (Starkel 1972; O'Hare 1997; Soja and Singh 2004). The highest 24 hours rainfall reached 1,563 mm in Cherrapunji in 1995. The highest rainfall in Shillong was only 415 mm in 1934. But one day rainfall of 381 mm recorded in 1878 was sufficient to cause the flood in Shillong (Sherer 1879). These heavy downpours of duration up to several hours are restricted to areas of dozens of square kilometers. They have especially high intensity during spring between end of March and May when the cyclone activity is highest.

The knowledge on the intensity of rainfalls is insufficient. In the Indian meteorological data publications, the rainfall intensity is calculated at a scale of 24 hours. Hyetograph analysis for period 1999–2000 shows that the highest rainfall during 15 minutes reached 53 mm (e.g. 3.5 mm · min^{-1}) in Cherrapunji and 19.5 mm (e.g. 1.3 mm · min^{-1}) in Shillong. R. Soja and S. Singh (2004) using pluviometers with 0.1 second time resolution obtained intensities closed to 2.0 mm · min^{-1} during several minutes intervals for the years 1999–2002 in Cherrapunji. Daily rainfalls above 500 mm with intensities of 40–70 mm · h^{-1} appear every year in this region.

RAINFALL-INDUCED MASS MOVEMENTS

The Umiew catchment is prone on mass movements due to extreme rainfalls and large contribution (more than 50% of area) of steep slopes above 15°. Landslides are not recorded systematically because a large part of the canyon is not accessible during rainy season and its central part is uninhabited. Although it is clear from historical sources that landslides were prominent feature.

T. Oldham (1854) mentions the oldest information about flood (in fact large hyperconcentrated mud and debris flow) in the Umiew catchment. This occurred on the 14 June 1851 and destroyed large portion of Shella village in the catchment outlet. Rainfall triggered landslides blocked the water flow in the rivers. That caused water level rise locally up to 15 meters (it was measured by the author that the water level rises to a maximum half of this height a during monsoon season) and undercut base of the steep slopes. The forested slopes were scored with gullies and deep ravines, extending from the level of the water up to the summit of the steep slopes. From one of these deep cuts on small stream at least 5 thousand tones of matter was removed. On the basis of T. Oldham's (1854) description it is possible to calculate that torrent wave started above Mawphlang and passed along 45 km during 2–3 hours to Shella. That was first noticed catastrophic event since the hills have passed under British rule in the 1835. Various sources mentioned landslides occurred in 1861, 1876, 1898 but they never had such effects.

Similar conditions appeared when heavy rainfalls and floods occurred in northeast India and Bangladesh in 1988. The annual rainfall in Cherrapunji reached 17,925 mm and exceeded the long term average for 63%. The Shillong station recorded 3,807 mm, the highest annual total for the period 1867–2000. Two series of heavy continuous rainfalls occurred between 4–7.07. with amounts 2,019 mm in Cherrapunji and 522 mm in Shillong as well as between 24–27.08. with amounts 1,989 mm in Cherrapunji and 441 mm in Shillong. The analysis of rainfalls together with Landsat satellite images from 1988 allow to find that the water level rise and connected with it landslides are the result of continuous heavy rains of 20–25% of annual average during 3–4 days. It was clearly visible that the Umiew river bed in the deep canyon was filled in sediment carried out from landslides developed on forested steep slopes. Hence the landslides and not cultivated land is the main source of sediment delivery to the river network. This type of extreme events are rare and occur once on tens years (Fig. 2).

The most common mass movements are the shallow landslides and mudflows. These occur each year but most remain unrecorded. Also they cannot be delineated on satellite images with typical resolution 20–30 m^2 like Landsat or IRS. They usually cover small areas of tens square meters on steep canyon slopes or on the cultivable hilly areas in the northern part of the Umiew catchment. Shallow landslides and mudflows were observed in the November 2002 during two days of continuous rain reaching 270 mm (200 mm fell during 24 hours) in Cherrapunji with the highest intensity of 20 mm $\cdot$ h^{-1}. They were restricted to very steep slopes above 35° on natural forested areas. In these cases denuded material very rarely reaches the rivers. Shallow landslides appeared also near Mawphlang on steep slopes above 15° on the cultivated land, especially where roads undercut the slopes. Therefore the rainfall of 250–300 mm during 1–2 days we can treat as the lower threshold inducing shallow landslides in the Umiew catchment. These conditions are met several times during each year, even the years with abnormally low rainfall of 7,000 mm in Cherrapunji.

The effects of extreme rainfalls except for rapid water level rise in small creeks and boulders sliding on slopes of deforested gullies (Starkel 1972, 1989) are not visible on grassland hilly plateau near Cherrapunji and Mawsynram. The degraded area is well protected by a stone pavement. Only removal of the upper layer of waste cover due to surface limestone, coal and rock mining can give the impulse to local mass movements.

EARTHQUAKES EFFECTS

Earthquake-induced landslides are an additional complicating factor when trying to distinguish natural processes from human impact. The seismicity of the Meghalaya Hills is connected with the process of subduction of the Indian plate beneath the Himalaya and tectonics of the Himalayan and Burmese Arcs (Kayal 1998). Three severe earthquakes occurred around the Umiew catchment over the last 150 years in 1869, 1897 and 1950 (Fig. 2). The 1869 Cachar earthquake (M = 7.5) is the oldest noted seismic event (Godwin-Austin 1868–1869). It is known only that it caused the liquefactions and relief changes in the south-eastern part of Meghalaya Hills. The estimated intensity was 6.0 in Cherrapunji and 6.5 in Shillong on the MSK scale (Ambraseys and Douglas 2004).

The earthquake of 12 June 1897 in the Shillong Plateau is the largest (M = 8.1) intraplate event in the last two centuries occurred in the Indian subcontinent. Much of what is known about the intensity distribution and effects of the event comes from R. D. Oldham's (1899) detailed report and his subsequent estimates of three months of heavy rains and aftershock activity following the earthquake. The earthquake almost totally destroyed settlements and small towns on the western part of the Plateau, and caused heavy damage in surrounding areas, chiefly due to the extensive liquefaction, and landslides. Most of these landslides occurred on the southern edge of Shillong Plateau, particularly around Cherrapunji in the Umiew catchment. Geology and relief favour the formation of landslides on steep canyon slopes. The upper part of hills around canyon is built up mainly from weathered sandstones and has a much lower cohesive strength than the underlying crystalline rocks. The vertical sandstone scarps are more easily broken into rockfalls and landslides. On the basis of R. D. Oldham's (1899) old sketch it was possible to estimate that at least 40% of vegetation cover from slopes of deep valleys was removed from crest to base at many places. The dislodgment of large mass of weathered rocks and exposure of slopes previously protected by forest caused of supply enormous volumes of sand to into the river network. The rivers were overloaded and they channels converted from deep and rocky to shallow filled by sand. The blocking of tributaries caused the water level rise. The highest barriers built up with rocks, mud and tress exceeded 60 m high. Accumulated water created great lakes upstream of barriers, which were burst after several days or even months. That caused the additional landslides on slopes cutting along river by flowing water.

Although, deeper into the hills where crystalline rocks dominate and they are not so deeply weathered as sandstones the landslides were rare and river beds retain their previous character unchanged. Natural effects of great earthquake on the degraded hilly plateau beside enormous building damages in Shillong were less remarkable and limited to thrown upward into the air stones on hillslopes and smaller landslides induced along the roads.

The impact of landsliding caused by large magnitude earthquakes on sediment budget and denudation over various durations is poorly investigated. According to C. F. Pain and J. M. Bowler (1973) most of the fine grained sediment supplied to river being flushed out within 0.5–2.0 years. A. J. Pearce et al. (1985) found that at least 50–75% debris retained in the fourth order catchment 50 years after the earthquake in New Zealand. In case of the Umiew catchment large part of fine and medium coarse sediment left in the valleys at least during few monsoon seasons. Today it is not visible in the main river, but rounded sandstone boulders of 1–2 meter size are still found in the crystalline stream beds of four orders.

The secondary effects of great earthquake were the destruction of villages, orange and areca-nut groves near the outlet of the Umiew river. The overloaded, shallow river lost capabilities of limestone transport from local quarries. These

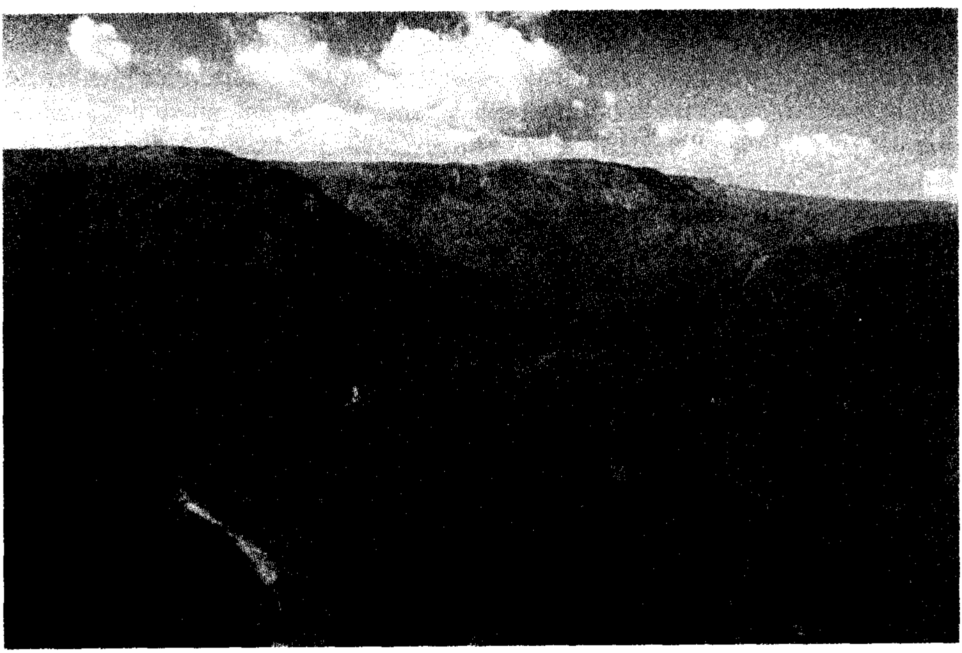

Photo 1. Lower part of the Umiew catchment with developed dense forest cover on the devastated slopes 100 years after earthquake from 1897

gave the impulse to the migration of people from foothills to higher elevations and location of new villages there.

Several villages never recovered after the devastation of the earthquake. Decreased population pressure created more "natural" conditions for the regeneration of forest cover. The maps from 1910 show vegetation cover developed on former landslides and today they are usually covered by dense forest (Photo 1). This is the evidence that the relaxation time in the Umiew catchment is similar to other humid tropical regions (Garwood et al. 1979; Froehlich and Starkel 1987; Guariguata 1990).

Latest registered severe seismic event (M = 8.5) in the XX century was the earthquake in 1950 with the epicenter on the Indo-China border. Due to remoteness to the Umiew catchment it was not so remarkable.

The ^{14}C dates of the palaeoliquefaction features indicate a recurrence period on the order of 500 yr for large earthquakes in the Shillong Plateau in addition to the seismic events presented on the Figure 2 (Sukhija et al. 1999). R. Bilham and P. England (2001) connect these events with moderate local earthquakes and large earthquakes in the Bhutan Himalaya. They assume that the Shillong Plateau is bounded by two reverse faults in the north and south and the recurrence interval for earthquakes resembling the 1897 event to be 3–8 kyr on each fault.

ANTHROPOGENIC IMPACT

LAND USE/COVER CHANGES

The southern slope of Meghalaya Hills has adequate precipitation, temperature and soil fertility to support vegetation growth (Tripathi et al. 1995). It is evident that the Umiew catchment was forested before first settling took place i.e. neolithic time (Bor 1942; Bareh 1997). Due to a long cultivation and mining history, with successive periods of land clearing and abandonment, over half of the primary tropical and subtropical forest has been degraded to grass formations (Ramakrishnan 1992).

Two land use/cover classes — forest and degraded areas covered by grasses occupied more than 95% area of the catchment in 1998 (Fig. 3). Time series analysis shows very stable proportions between them during last 100 years. Although population density grew up from 23 persons · km^{-2} in 1901 to 123 persons · km^{-2} in 1991 (Census of India 1991), forest area also increased from 44.6% in 1910 to 46.4% in 1998. Between 1910 and 1998 the rest of larger forest patches disappeared on easy accessible areas within hilly plateau. This was partly compensated by natural secondary forest regrowth on steeper uninhabited slopes of narrow canyon. Only few percent of the catchment area converted to agricultural land use (paddy rice and potatoes) is now cultivated. The paddy rice still covers the same flat valley bottoms occupied in 1910. It is not possible to compare in detail changes of potato cultivation on steep slopes. The fields are usually very small

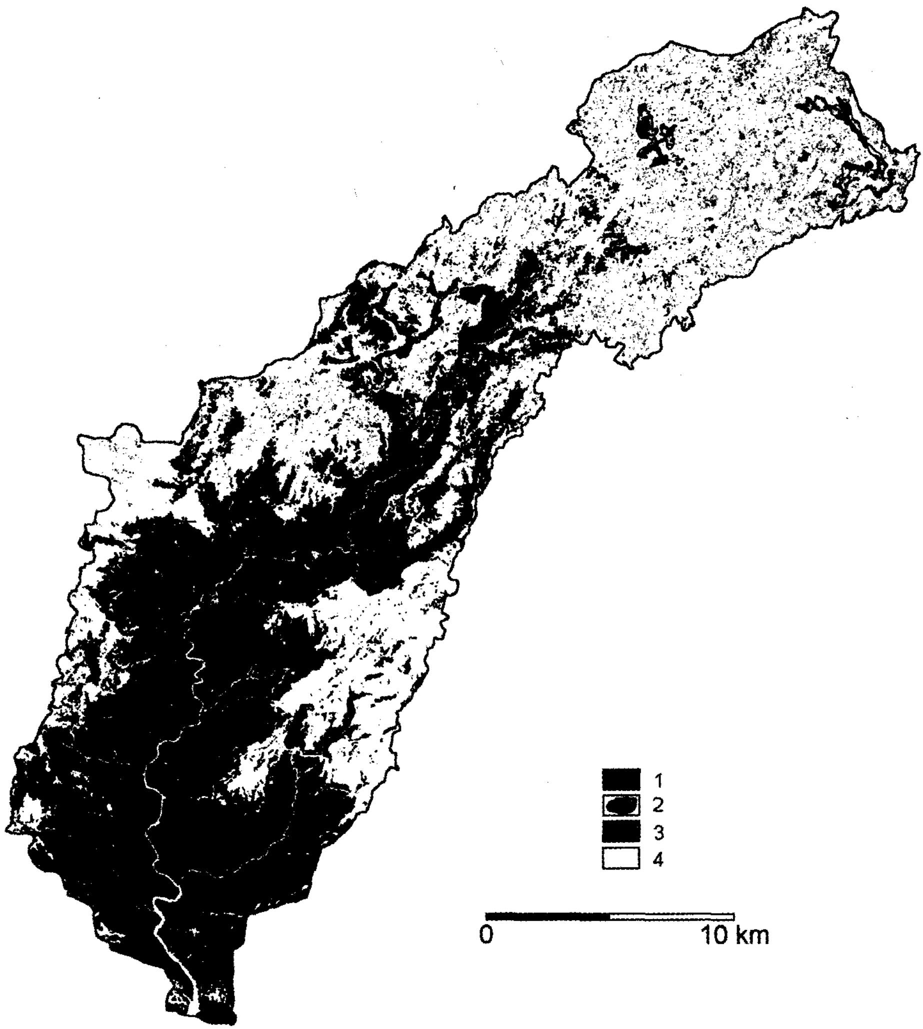

Fig. 3. Land use/cover map of the Umiew catchment compiled on the basis of satellite image IRS–1D from 1998. 1 — forest, 2 — paddy rice in larger valleys, 3 — potato cultivation on slopes, 4 — degraded grasslands/rock outcrops

and intermix with fallow land or degraded grasslands. Due to that they have not been delineated on the maps.

Forest distribution varies with elevation (Fig. 4). Generally, the proportion of forest fluctuates between 80–95% up to 1,200 m a.s.l. Above this altitude it constantly decreases to few percent at highest elevations. This distribution is closely related to relief and population density. The lower part of the catchment, below 400 m a.s.l., has been partly deforested due to intensive surface limestone mining from pre-colonial times or location orange and areca-nut plantations. The central part of

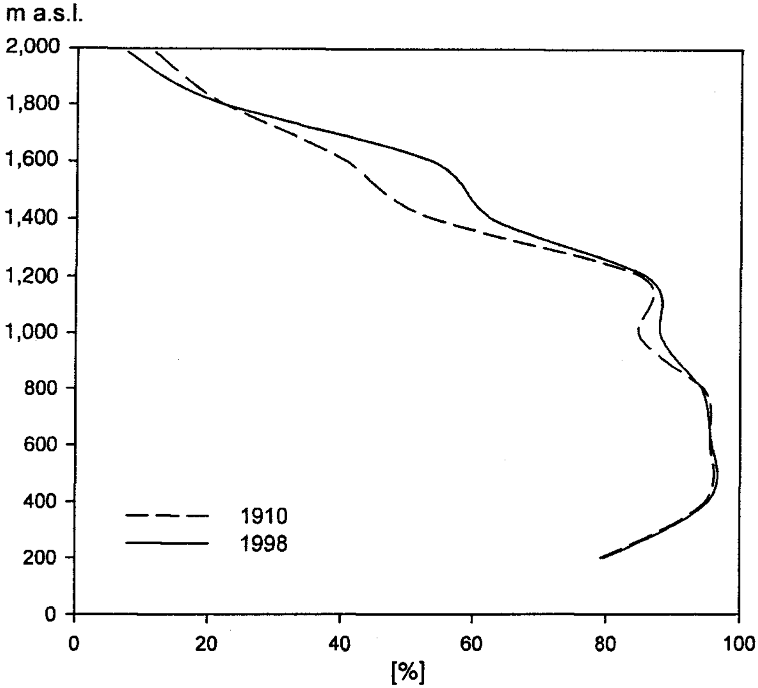

Fig. 4. Changes of the proportion of forest area with the elevation in 1910 and 1998 in the Umiew catchment

the canyon is severely dissected a dense drainage system about the density of above 10 km · km^{-2}. The forest proportion exceeds here 95% on steep slopes but disturbance has been increasing over the last decades as a selective logging and fuelwood extraction (Roy and Tomar 2001). Contribution of the flat areas increases above the 1,200 m a.s.l. They are usually severely degraded in the elevations of 1,200–1,600 m a.s.l. The upper part of the Umiew catchment has the highest population density, above 350 persons · km^{-2} and the lowest forest proportion of about 7%. The settled agriculture developed here to meet commercial needs of Shillong township. This is also area where are the largest changes of forest spatial distribution are found. The broad-leaved forests were converted to pure pine forests. The second one is converted to agricultural land use connected with slash and burn agriculture (Mishra and Ramakrishnan 1983) or it is utilised for commercial purposes. These processes result in forest fragmentation. Local authorities mainly due to land tenure system do not undertake the afforestation action. Most of the forests are in the private hands or village communities. Although fragmentation proceeds on flat areas the small patches of forest are still kept by farmers. In many cases young trees are left on fallow land for a growing. This is essential element of slash and burn agricultural system in higher elevations of the Umiew catchment (Tiwari 2003).

It is generally assumed that land use/cover changes have caused accelerated soil erosion and increased sediment yields in the rivers (Morgan 1986). Extreme rainfall and steep slopes in the Umiew catchment create potential conditions for efficient soil erosion. There are only two micro-scale erosion measurements close to the investigated area. Both experiments give an important information about the scale of erosion from two contrasting land use types on hillslope plateu: potato cultivation and degraded grasslands.

Soil loss was found to range between 34 and 56 $t \cdot ha^{-1} \cdot yr^{-1}$ for potato cultivation at 40° steep slopes near Shillong (Mishra and Ramakrishnan 1983). Significantly lower values were obtained for fallow land — only 7 $t \cdot ha^{-1} \cdot yr^{-1}$. It was also found that with increasing of fallow duration runoff and soil loss were further significantly reduced to 2 $t \cdot ha^{-1} \cdot yr^{-1}$.

^{137}Cs and $^{210}Pb_{ex}$ techniques were used for the study of soil loss in the grassland hillslopes near Cherrapunji (Froehlich 2004a, b). This study has shown that present rates of soil erosion are only 2.1 $t \cdot ha^{-1} \cdot yr^{-1}$ and most of the sediment from degraded grasslands is deposited at the foot of the slopes. Stream and recent flood plain sediments are derived primarily from gully and channel bank erosion.

Described environmental conditions near Cherrapunji are representative for a half of the Umiew catchment (Photo 2). The deforestation in the past caused excessive overland flow that removed fine sediment and produce armoring debris

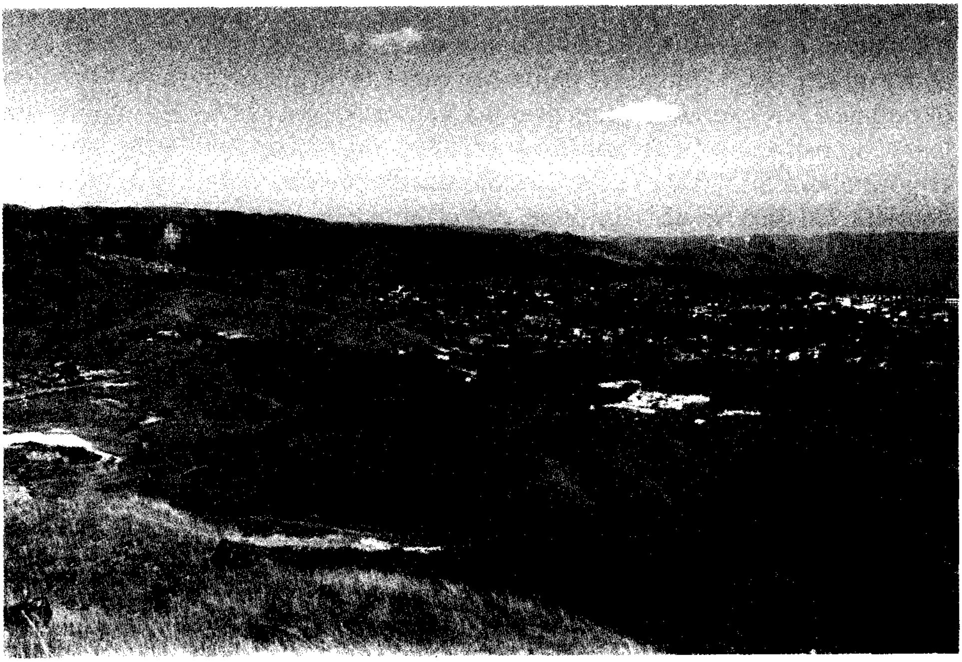

Photo 2. Deforested hilly plateau with degraded grasslands near Cherrapunji

with hard impermeable layer on soil surface which range up to 10–20 cm. Sands and gravels constitute more than 60% of the upper soil profile (Prokop 2004). The soils are heavily degraded and quite often devoid upper horizons and in many places they have a character of a waste cover only.

The application of the RMMF model complete soil erosion pattern in the entire catchment. Annual soil erosion predicted by model is moderate and range from 0–145 $t \cdot ha^{-1} \cdot yr^{-1}$. Two contrastive land use/cover types, natural dense forest and degraded due to human activity grasslands, give similar response to the soil erosion rates. The soil loss is the lowest in the valley bottoms under rice cultivation, dense forest and degraded grasslands — below 10 $t \cdot ha^{-1} \cdot yr^{-1}$ (Fig. 3). Those are within the tolerance limits of the mountain landscape (Morgan 1986). The highest erosion rates up to 145 $t \cdot ha^{-1} \cdot yr^{-1}$ (average 60 $t \cdot ha^{-1} \cdot yr^{-1}$) are under potato cultivation on short and steep slopes within hilly plateau in the northern part of the Umiew catchment.

The FCC satellite image analysis for the period 1975–2000 show that the Umiew river bed in the deep canyon is not filled in sediment during years with average rainfall. This is the evidence that most of the mobilized sediment from cultivated fields is being trapped on the flat and wide valley bottoms in the area with mature relief. Their favour to this terracing rice fields. Similarly, only little hillslope sediment is delivered to the streams in the area with degraded grasslands. The sediment delivery to the Umiew river bed dramatically increases during extreme events like heavy continuous rainfalls and severe earthquakes induce large landslides that give rise to high soil losses.

CONCLUSIONS

The area of the Umiew catchment is characterised by intense geomorphic processes including mass wasting, water erosion and fluvial activity. The relative importance of these processes is controlled by natural and anthropogenic factors. Natural extreme events are the dominant driving forces in environmental degradation of the Umiew catchment. The role of the human impact depends on the local environmental conditions and land use history.

The area of the canyon with steep slopes is most sensitive on mass movements (rockfalls, landslides and debris flows) triggered by extreme rainfalls and earthquakes. The regional continuous heavy rains with 20–25% of annual precipitation in 3–4 days may give to water level rise and cause landsliding on steep but forested slopes. Severe earthquakes may trigger rockfalls and landslides of which material fills river beds up to few meters high and changes river's channel regime. The absence or presence of forest cover in both cases becomes almost negligible. The majority of the sediment delivered to the river system is produced by mass wasting on forested land during these extreme events. The effects are long lasting and give rise to high soil losses for a number of years.

The hilly plateau is under strong influence of human activity. The relative role of human impact depends on the regolith thickness, the relief, and land use history of the area. The most degraded grasslands are very resistant on extreme events due to stone pavement on the soil surface. The highest soil erosion rates were in the past and present-day hillslope erosion is very low. The landslides are not observed. Only heavy storms can generate sediment through gully and stream bank erosion. On the contrary, cultivable land with thicker weathered cover is prone on rainfall induced landslides and that annual soil erosion rates are highest here.

Both contrasting landforms and connected with them land use/cover types — canyon with natural dense forest and degraded by human activity grasslands within hilly plateau give similar low soil erosion rates due to totally different reasons.

The analysis of maps and satellite image over a period (1910–1998) show that land use/cover in the study catchment is relatively stable and does not a straightforward response to the high demographic growth. The major land cover change processes observed are expansion of grasslands-croplands and reforestation with coniferous forest, leading to a more fragmented landscape structure in the upper part of the Umiew catchment. The deforestation in the uplands is compensated for by a regeneration of secondary forest on abandoned low-lying areas.

ACKNOWLEDGEMENTS

This paper was completed as part of an Indian National Science Academy (INSA) fellowship and cooperation with the Department of Geography North-Eastern Hill University (NEHU) in Shillong under the scientific exchange programme between Indian Department of Science and Technology (DST) and Polish Committee for Scientific Research (KBN).

Department of Geomorphology and Hydrology of Mountains and Uplands
Institute of Geography and Spatial Organization, Polish Academy of Sciences
ul. św. Jana 22
31-018 Kraków, Poland
e-mail: pawel@zg.pan.krakow.pl

REFERENCES

Achard F., Eva H. D., Stibig H. J., Mayaux P., Gallego J., Richards T., Malingreau J. P., 2002. *Determination of Deforestation Rates of the World's Humid Tropical Forests*. Science 297, 999–1002.

Allan N. J .R., 1986. *Accessibility and altitudinal zonation model of mountains*. Mountain Research and Development 6, 185–194.

Ambraseys N. N., Douglas J., 2004. *Magnitude calibration of north Indian earthquakes*. Geophysical Journal International 159, 165–206.

Bandyopadhay M. K., 1972. *Geomorphological Characteristics of the Southern Part of the Khasi Hills*. Geographical Review of India 34, 2, 184–189.

Bareh H., 1997. *The history and culture of the Khasi people*. Delhi, 512 pp.

Bilham R., England P., 2001. *Plateau 'pop-up' in the great 1897 Assam earthquake*. Nature 410, 806–809.

Bor N. L., 1942. *Relict vegetation of Shillong Plateau-Assam*. Indian Forest Records 3, 6, 152–195.

Census of India, 1991. New Delhi.

Chatterjee S. P., 1968. *La geographie regionale du Plateau de Meghalaya*, [in:] *India; Regional Studies*, ed. R. L. Singh, IGU, Calcutta, 218–244.

Dhar O. N., Nandargi S., 2000. *A Study of Floods in the Brahmaputra Basin in India*. International Journal of Climatology 20, 771–781.

Dhar O. N., Nandargi S., 2003. *Hydrometeorological Aspects of Floods in India*. Natural Hazards 28, 1–33.

Forest Survey of India, 2001. *The State of Forest Report*. Dehra Dun, 130 pp.

Froehlich W., 2004a. *Soil erosion in experimental catchment*, [in:] *Rainfall, runoff and soil erosion in the globally extreme humid area, Cherrapunji region, India*, eds L. Starkel, S. Singh, Prace Geograficzne 191, 81–89.

Froehlich W., 2004b. *Soil erosion, suspended sediment sources and deposition in the Maw-Ki-Syiem drainage basin, Cherrapunji, northeastern India*, [in:] *Sediment Transfer Through The Fluvial System*, eds V. Golosov, V. Belyaev, D. E. Walling, IAHS Publ. 288, 138–146.

Froehlich W., Starkel L., 1987. *Normal and extreme monsoon rains — their role in the shaping of the Darjeeling Himalaya.* Studia Geomorphologica Carpatho-Balcanica 21, 129–160.

Garwood N. C., Janos D. P., Brokaw N., 1979. *Earthquake-Caused Landslides: A Major Disturbance to Tropical Forests*. Science 205, 997–999.

Gete Z., Hurni H., 2001. *Implications of land use and land cover dynamics for mountain resource degradation in the Northwestern Ethiophian highlands*. Mountain Research and Development 21, 184–191.

Godwin-Austen, 1868–1869. *Earthquake in the Cachar Hills, Extracts from Letters from Captain Godwin-Austen*. Proceedings of the Royal Geographical Society of London 13, 5, 370–372.

Guariguata M. R., 1990. *Landslide disturbance and forest regeneration in the Upper Luquillo Mountains of Puerto Rico*. Journal of Ecology 78, 3, 814–832.

Haridasan K., Rao P. R., 1985. *Forest flora of Meghalaya*. Vol. I, II, Bishen Singh, Dehra Dun, 905 pp.

International Institute for Aerospace Survey and Earth Sciences, 1997. *ILWIS — The Integrated Land Water Information System. User's Guide*. Enschede, The Netherlands, 511 pp.

Ives J. D., Messerli B., 1989. *The Himalayan Dilemma: Reconciling Development and Conservation*. Routledge and UNU Press, London, New York, 296 pp.

Kayal J. R., 1998. *Seismicity of northeast India and surroundings — development over the past 100 years*. Journal of Geophysics 19, 9–34.

Lambin E. F., 1997. *Modelling and monitoring land cover change processes in tropical regions*. Progress in Physical Geography 21, 375–393.

Mazumdar S. K., 1978. *Morphogenetic Evolution of the Khasi Hills, Meghalaya*. Miscellaneous Publications 30, Geological Survey of India, 208–213.

Mazumdar S. K., 1986. *The Precambrian framework of part of the Khasi Hills, Meghalaya*. Records of the Geological Survey of India 117, 2, 1–59.

Messerli B., Ives J. D. (eds), 1997. *Mountains of the World: A Global Priority*. Parthenon Publishing, New York, London, 493 pp.

Mishra B. K., Ramakrishnan P. S., 1983. *Slash and burn agriculture at higher elevations in North-Eastern India. I. Sediment, water and nutrient losses*. Agriculture, Ecosystems and Environment 9, 69–82.

Morgan R. P. C., 1986. *Soil erosion and conservation*. Longman, 298 pp.

Morgan R. P. C., 2001. *A simple approach to soil loss prediction: a revised Morgan-Morgan-Finney model.* Catena 44, 305–322.

O'Hare G., 1997. *The Indian monsoon*, Part 2: *The rains*. Geography 82, 335–352.

Oldham R. D., 1899. *Report on the great earthquake of 12th June 1897*. Memoirs of the Geological Survey of India 30, Calcutta, 379 pp.

Oldham T., 1854. *On the geological structure of part of the Khasi Hills*. Bengal Memoirs of the Geological Survey of India 1, 2, 76 pp.

Pain C. F., Bowler J. M., 1973. *Denudation following the November 1970 earthquake at Madang, Papua New Guinea*. Zeitschrift fur Geomorphology, Supplement Band 18, 91–104.

Pearce A. J., O'Loughlin C. L., Watson A. J., 1985. *Medium-term effects of landsliding and related sedimentation evaluated fifty years after an M7.7 earthquake*. International Symposium: *Debris flows and disaster Prevention*, September 3–5, 1985, Tsukuba, Japan, 291–296.

Prokop P., 2004. *The Soils*, [in:] *Rainfall, runoff and soil erosion in the globally extreme humid area, Cherrapunji region, India*, eds L. Starkel, S. Singh, Prace Geograficzne 191, 42–43.

Prokop P., Walanus A., 2003. *Trend and periodicity in the longest instrumental rainfall series for the area of most extreme rainfall in the world, northeast India*. Geographia Polonica 76, 2, 25–35.

Ram S. C., Ramakrishnan P. S., 1988. *Hydrology and soil fertility of degraded grasslands at Cherrapunji in North-Eastern India*. Environmental Conservation 15, 28–35.

Ramakrishnan P. S., 1992. *Shifting Agriculture and Sustainable Develompent: An Interdisciplinary Study from North-Eastern India*. UNESCO-MAB Series, Parthenon Publications, Paris, 422 pp.

Ramakrishnan P. S., Kushwaha S. P. S., 2001. *Secondary forests of the Himalaya with emphasis on the north-eastern hill region of India*. Journal of Tropical Forest Science 13, 4, 727–747.

Rao K. S., 1997. *Natural Resource Management and Development in Himalaya. A Recourse to Issues and Strategies*. ENVIS Monograph 1, GB Pant Institute of Himalayan Environment and Development, Almora, India, 56 pp.

Roy P. S., Joshi P. K., 2002. *Forest cover assessment in north-east India — the potential of temporal wide swath satellite sensor data (IRS–1C WiFS)*. International Journal of Remote Sensing 23, 2, 4881–4896.

Roy P. S., Tomar S., 2001. *Landscape cover dynamics pattern in Meghalaya*. International Journal of Remote Sensing 22, 18, 3813–3825.

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

Sherer J. F., 1879. *Report on the administration of the Khasi and Jaintia Hills for the year 1878–79*. Calcutta, 14 pp.

Soil Survey Staff, 1998. *Keys to Soil Taxonomy*. United States Department of Agriculture, Washington D.C., 332 pp.

Soja R., Singh S., 2004. *The rainfall characteristics*, [in:] *Rainfall, runoff and soil erosion in the globally extreme humid area, Cherrapunji region, India*, eds L. Starkel, S. Singh, Prace Geograficzne 191, 59–71.

Starkel L., 1972. *The modelling of monsoon areas of India as related to catastrophic rainfalls*. Geographia Polonica 23, 151–173.

Starkel L., 1976. *The role of extreme (catastrophic) meteorological events in contemporary evolution of slopes*, [in:] *Geomorphology and climate*, ed. E. Derbyshire, J.Wiley, Chichester, 203–246.

Starkel L., 1989. *Valley floor evolution in the marginal areas of the Himalaya mountains and the Khasi-Jaintia Plateau*. Zeitschrift fur Geomorphology, Supplement Band 76, 1–8.

Starkel L., 1996. *Present-day Formation of the Southern Part of Meghalaya Plateau*. Hill Geographer 12, 1–2, 13–19.

Starkel L., 2004. *Temporal Clustering of Extreme Rainfall Events in Relief Transformation*. Journal Geological Society of India 64, 4, 517–523.

Starkel L., Basu S. (eds.), 2000. *Rains, Landslides and Floods in the Darjeeling Himalaya*. Indian National Science Academy, New Delhi, 168 pp.

Starkel L., Singh S. (eds.), 2004. *Rainfall, runoff and soil erosion in the globally extreme humid area, Cherrapunji region, India*. Prace Geograficzne 191, 110 pp.

Sukhija B. S., Rao M. N., Reddy D. V., Nagabhushanam P., Hussain S., Chadha R. K., Gupta H. K., 1999. *Timing and return period of major paleoseismic events in the Shillong Plateau, India.* Tectonophysics 308, 53–65.

Tiwari B. K., 2003. *Innovations in Shifting Cultivation and Land Use and Cover Change in Higher Elevations of Meghalaya, India,* [in:] *Methodological issues in mountain research. A socio-ecological system approach observations*, eds P. S. Ramakrishnan, K. G. Saxena, S. Patnaik, S. Singh, UNESCO, MAB, ICIMOD, NEHU, New Delhi, Oxford and IBH Publishing Co. Pvt. Ltd., 163–175.

Toky O. P., Ramakrishnan P. S., 1983a. *Secondary succession following slash and burn agriculture in North-Eastern India. 1. Biomass, litterfall and productivity.* Journal of Ecology 71, 735–745.

Toky O. P., Ramakrishnan P. S., 1983b. *Secondary succession following slash and burn agriculture in North-Eastern India. 2. Nutrient Cycling.* Journal of Ecology 71, 747–757

Tripathi R. S, Shankar U., Pandey H. N., 1995. *Present Status and Strategies for Ecorestoration of Degraded Ecosystem at Cherrapunji,* [in:] *Ecorestoration of Degraded Hills*, eds B. K. Tiwari, S. Singh, Kaushal Publ., Shillong, 23–59.

Vanacker V., Govers G., Barros S., Poesen J., Deckers J., 2003. *The effects of short-term socio-economic and demographic change on landuse dynamics and its corresponding geomorphic response with relation to water erosion in a tropical mountainous catchment, Equador.* Landscape Ecology 18, 1–15.

Van Lynden G. W. J., Oldeman R. L., 1997. *The Assessment of the Status of Human-Induced Soil Degradation in South and Southeast Asia.* International Soil Reference and Information Centre, Wageningen, 41 pp.

World Meteorological Organisation, 1994. *Guide to Hydrological Practices.* 5th edn., 168, Geneva, Switzerland, 735 pp.

STRESZCZENIE

P. Prokop

NATURALNE ZAGROŻENIA I WPŁYW CZŁOWIEKA NA ŚRODOWISKO W GÓRSKIEJ ZLEWNI TROPIKALNEJ, WYŻYNA MEGHALAYA, INDIE

Badania prowadzono w latach 1999–2002 w zlewni Umiew o powierzchni 493,7 km^2, obszarze o najwyższych na świecie opadach, sięgających średnio 12 000 mm rocznie. Zlewnia obejmuje dwa charakterystyczne dla południowego skłonu Wyżyny Meghalaya typy rzeźby: kanion porośnięty tropikalnym i subtropikalnym lasem oraz pagórkowate plateau porośnięte zdegradowanymi formacjami traw z niewielkim udziałem terenów użytkowanych rolniczo. Naturalne zdarzenia ekstremalne są dominującą siłą prowadzącą do zmian w środowisku badanej zlewni. Wpływ człowieka ma znaczenie drugorzędne i zależy od warunków lokalnych oraz historycznych uwarunkowań. Stwierdzono, że rozlewne opady sięgające 20–25% średniej sumy rocznej oraz trzęsienia ziemi powyżej 7 stopni w skali Richtera przyczyniają się w największym stopniu do powstania ruchów masowych i degradacji szaty roślinnej. Osuwiska rozwinięte na zalesionych stokach są głównym źródłem dostawy materiału do sieci rzecznej. Pagórkowate plateau, gdzie faza największej erozji wystąpiła w przeszłości, jest bardzo odporne na zdarzenia ekstremalne. Związane jest to z występowaniem na powierzchni silnie scementowanego, szkieletowego bruku ograniczającego procesy grawitacyjne i erozję. Jedynie północna część zlewni z grubszą warstwą zwietrzeliny jest narażona na płytkie osuwiska oraz występującą lokalnie wysoką erozję do 145 t · ha^{-1} · rok^{-1} z upraw okopowych. Ponad pięciokrotny wzrost gęstości zaludnienia w zlewni Umiew w XX wieku doprowadził wprawdzie do większej fragmentacji lasów na pagórkowatym plateau, równocześnie jednak wzrosła powierzchnia leśna w obrębie opuszczonych przez ludność stromych stoków kanionu.