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GEOGRAPHIC INFORMATION SYSTEMS (GIS) AS A TOOL FOR INTERPRETATION OF NEOTECTONICS IN THE PODHALE AREA, POLAND

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Abstract: A combination of approaches to the study of neotectonics is discussed. As an example, an analysis is presented for part of the Podhale region, where changes in the hydrogeological regime were observed. Comments are made on the manifestation of geological processes and principles in investigations of neotectonics, due to the results of precise digital terrain modelling (DTM) and geodetic surveys. The results obtained lead the authors to the conclusion that a reliable study on the geological activity of an area evaluated from considerations of river-channel morphology requires attention to changes in spatial development as a factor controlling the intensity of the hydrological regime. In such cases, a database of complex geodata information is required. A geodetic approach is presented, based on GNSS observations that become a new standard in geomorphologic studies. The results of GNSS observations provide quantitative estimates of displacements in the study area and allow assessment of their kinematics.

The Liesek1 and Nowy Targ GNSS stations reveal a significant variation in the annual rate of uplift changing from 0.8 to 0.2 mm/yr, respectively. The difference in displacement azimuths (30° at Liesek1 and 300° in Nowy Targ) indicates rotation of the Podhale area. The GNSS-derived dissimilar displacement vectors imply the impact of neotectonic movements on the channel geometry of the Czarny Dunajec River. However, according to the analysis presented, this geometry is strongly influenced by land use and climate, resulting in the incision of river channels in Quaternary sediments. The annual rate of channel indentation reached a mean value of 1.4 cm, and a maximum value 5.5 cm during the studied period from 1965 to 1975. This outcome corresponds to a cumulative effect of neotectonic uplift combined with the results of human activity and climatic changes. Consequently, our study shows that a particular attention must be exercised in drawing conclusions on neotectonic displacements based solely on geomorphological observations.

Key words: Neotectonics, GIS, photogrammetric, GNSS observations.

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INTRODUCTION

The authors present an approach to the application of geodetic tools in the analysis of Recent tectonic movements that is based on photogrammetric techniques and GIS studies. The study area is located in the Podhale region, southern Poland, regarded in many previous studies as tectonically mobile. It is located mostly in the drainage basin of the Czarny Dunajec River. Earlier published studies on movements in the Podhale region and the Polish Carpathians deal with the results of geological, geomorphological or geodetic surveys, carried out to determine both the mobility of the areas and the rates of the movements investigated (Niemirowski, 1974; Baumgart-Kotarba, 1978; Wyrzykowski, 1985; Ząbek *et al.*, 1993; Czarnecki *et al.*, 2004; Zuchiewicz, 2010). Geological studies generally utilise geomorphological methods (mostly the analysis of river channels), geological methods (structural analysis) or geophysical techniques (Niemirowski, 1974; Zuchiewicz, 1984; Starkel and Łajczak, 2008; Wyżga and Zawiejska, 2010; Zuchiewicz, 2010; Wyżga *et al.*, 2012). Geodetic studies often present results (displacement vectors) that disregard the geological observations or the geodetic results are not justified by the geological data (e.g., Łój *et al.*, 2009). Nevertheless, there are some studies (e.g., Zuchiewcz, 2010), that take a modelling approach to the investigation of neotecto-

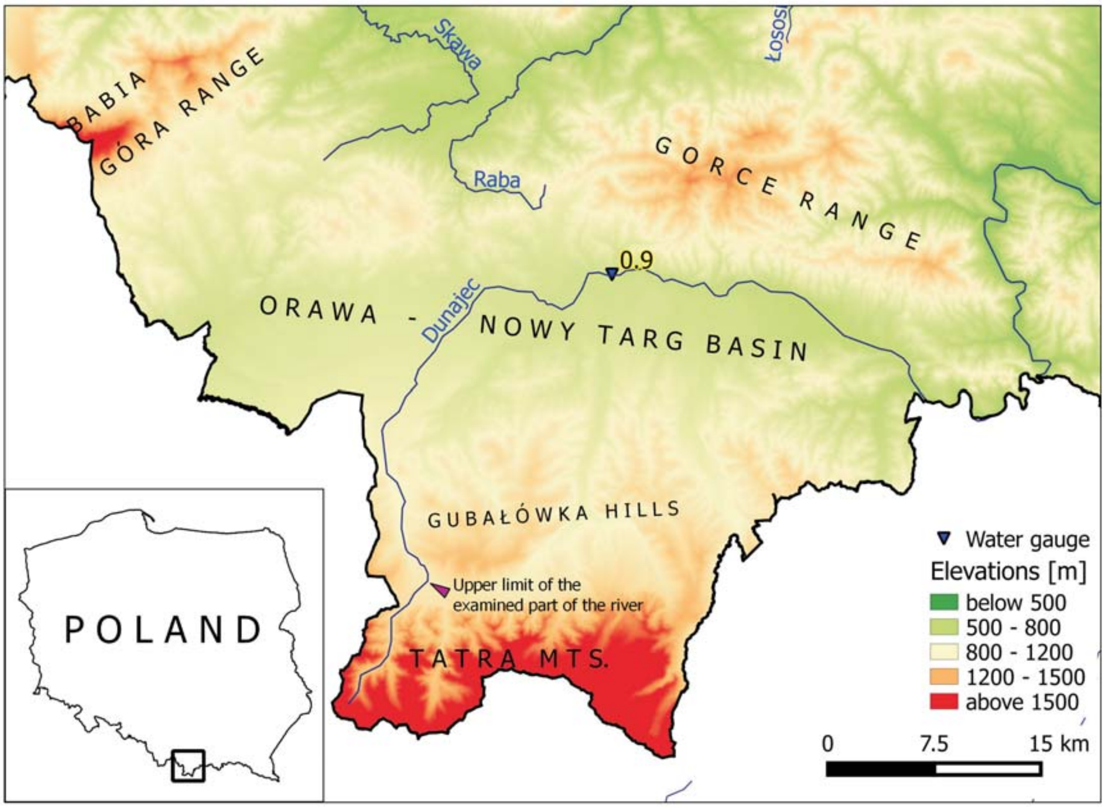

Fig. 1. Location of the study area.

nics with the utilization of all of the methods mentioned above. Over the past decade, major advances have been made in geodetic techniques, including GIS and photogrammetric tools, for example, applied with high accuracy to high-resolution data on the surface of a terrain as a numerical model of the terrain surface by Light Detection and Ranging (LIDAR) scanning. The high-accuracy orthophotomaps, prepared on the basis of archival maps for geomorphological studies to estimate the effects of erosion or tectonic movements over a period of time, can be considered as well. The results obtained from a permanent network of Global Positioning System/Global Navigation Satellite System (GPS/GNSS) reference stations provide reliable information on movement of the terrain surface. A collection of these new data for western Podhale is considered in the present account as well. The authors regard the paper as a continuation of the long-term scientific research by W. Zuchiewicz and they hope that it extends the current state of knowledge by giving new conclusions that differ from some existing views on the mobility of the Podhale area. The identification and quantification of the geodetic data in the field of neotectonics is often difficult and problematic because of the low rates, at which tectonic processes are manifested (Kowalczyk and Rapinski, 2013). A new perspective on neotectonics studies comes from continuous observations from GNSS. The present-day density of GNSS permanent stations in Poland is sufficient for the reliable determination of a national model for vertical movements of the Earth's crust with a resolution similar to that of the levelling network (Kontny and Bogusz, 2012), but still insufficient for studies of the activity of small tectonic units.

GEOLOGICAL SETTING

The study area is located in the Orava–Nowy Targ Basin, part of Orava–Podhale Depression. (Fig. 1). It was formed in the Miocene Epoch, as an effect of local subsidence related to overthrusting of structural complexes between the mountain chains and foothills of the Outer and Inner Carpathians, namely the Palaeogene Inner Carpathians basin, the Pieniny Klippen Belt and the Magura Nappe. The basin formed in this way became a lake, which was filled up over time with gravel and clay deposits; their thickness amounts to as much as 300 m in the west. Also in the Quaternary during successive glacial periods, alluvial fans were formed, together with glacial and river sediments. Hydrogeographically, the area can be divided into:

– the Orava Basin, the western part, drained by the Orava River and located in the drainage basin of the Black Sea;

– the Nowy Targ Basin, the eastern part, drained by the Dunajec River and draining into the Baltic Sea.

In the territory of Poland, there is a boundary line between the two passing through the region although it is not clearly observable in the field. It is the Main European Watershed, which separates the basins of the Black Sea and the Baltic Sea. The boundary passes Koniówka village on the western side of the Czarny Dunajec River and runs northwards to Piekielnik village. The western part of the Nowy Targ basin is the area of interest, where the Black Dunajec, a mountain river, flows into the area of Nowy Targ to merge with the Biały Dunajec and form the Dunajec River.

TECTONIC MOVEMENTS IN THE CONTEXT OF GEOLOGICAL AND GEOMORPHOLOGICAL EVIDENCE

Many authors considered only the geometry of the profiles of rivers in Polish Carpathians in their tectonic studies (Niemirowski, 1974; Baumgart-Kotarba, 1978; Zuchiewicz, 1984; Starkel and Łajczak, 2008). One of the analytical tools was a polynomial approximation of the profiles of the river channels. Differences in elevation between the theoretical and real profiles with the former below the latter is taken as evidence of young tectonic movements. The results of the studies carried out by Zuchiewcz and other authors demonstrate uplift movements in the Pieniny Klippen Belt with their intensity increasing westwards, uplifts of the eastern part of the Gubałówka Piedmont and subsidence of the Orava–Nowy Targ Basin (Zuchiewicz, 2010). This technique was often criticized because it did not take into account hydrological factors or conditions related to the shaping of a river channel.

Furthermore, in many studies (Niemirowski, 1974; Baumgart-Kotarba, 1978; Zuchiewicz, 1984; Starkel and Łajczak, 2008) there is the assumption that the rates of cutting into bedrock are the effects of tectonic movements and they can provide approximate values for the rates of tectonic uplift. On the basis of this assumption, W. Zuchiewicz carried out an analysis and a division of the river deposits in the Outer Carpathians into series (Zuchiewicz, 2010). As a result, he recognized a number of "geotectonic phases". Accordingly, a scheme was created by W. Zuchiewicz that links tectonic movements with the differences in the levels of bedrock on Quaternary terraces of selected valleys in the Polish Carpathians.

The characteristics of erosional downcuts in the rocky slopes by the rivers analysed are often a record of the tectonic history of the basement. The detailed geomorphological studies of river terraces carried out by various authors (Niemirowski, 1974; Baumgart-Kotarba, 1978; Zuchiewicz, 1984; Starkel and Łajczak, 2008; Zuchiewicz, 2010) demonstrated the mobility of particular tectonic units. Although the rates of vertical movement were subject to change, the tendency for uplift or subsidence to occur at particular locations is well documented. The highest value for the rate of uplift in the Polish Carpathians was established on the basis of the morphological structure of the Tatra Mountains. This process caused subsidence of the adjacent area, the Orava–Nowy Targ Basin (Zuchiewicz, 1984). The rate of uplift was estimated as from 0.1–0.4 mm/yr and the rate of subsidence from 0.05–0.12 mm/yr (Zuchiewicz, 2010). Some authors pointed out the Early Pleistocene uplift of the Gubałówka Piedmont with respect to the Pieniny Klippen Belt with a magnitude of 80–100 m (Zuchiewicz, 2010).

Estimation of the rate of movement was the subject of many papers, discussed in detail by Zuchiewicz (2010); not only the scale is controversial, but so too is even the sign (direction) of vertical movements. According to Zuchiewicz (2010), the divergence of opinions and discrepancy between data sets is an effect of the so-called age paradox: long-term rates (for example for the Quaternary) are always an order of magnitude less than those estimated for particular stages and for Recent times. Furthermore, it can be presumed that the estimated rates are the result of the limitation of the research methods and tools. An example of such a limitation is the length of a survey period, when some episodes or tectonic events can be detected, leading to the unjustified projection into the past, attributing tectonic activity to other stages.

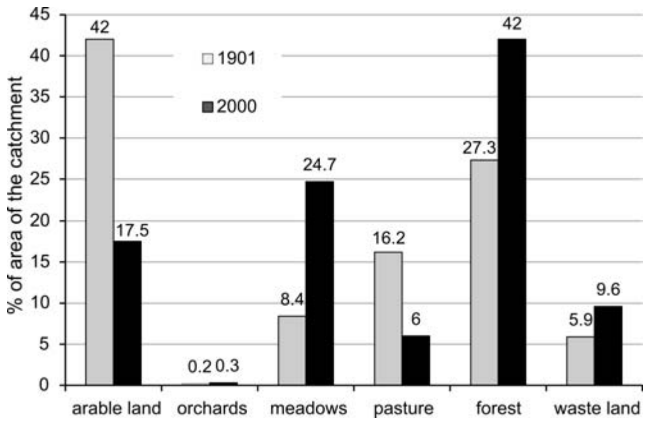

Fig. 2. Twentieth-century land-use changes in the upper part of the Dunajec (including Czarny Dunajec) River catchment (according to Wyżga *et al.*, 2012, modified).

HYDROLOGICAL SETTING

The contemporary geomorphological characteristics of the Czarny Dunajec River are strongly conditioned by human activity, especially by changes in land use and the hydrotechnical remodelling of the river channel, as is the case with other rivers in the Polish Carpathians. Before the end of nineteenth century, human impact was connected with deforestation and in particular the expansion of the area of arable land. This led to the creation of a dense network of dirt roads (Starkel and Łajczak, 2008). These factors combined with the climatological conditions (referable to the cool and wet period of 1550–1850, known also as "the Little Ice Age"), led to the formation of multi-brook river channels. Especially a considerable increase in slope erosion and as a consequence, growth of the amount of accumulated debris, was connected with the spread of potato cultivation in this area in the nineteenth century (Klimek, 1987). Since the beginning of twentieth century a reverse process is noticeable, namely channel incision and a reduction in the number of brooks associated with a river channel. This was caused by a reduction in the arable land area and an increase in the forested area of the catchment. These changes reduced the intensity of surface erosion (flushing), which caused a reduction in the amount of accumulated debris on the riverbed and an increase in the intensity of vertical erosion. Changes in land use during the twentieth century in the Czarny Dunajec catchment area (including the high–mountain part of the catchment) are illustrated in Figure 2.

As can be seen from the figure, in the twentieth century there were considerable changes in the area: a nearly 15% increase in forestation, combined with a decrease in arable

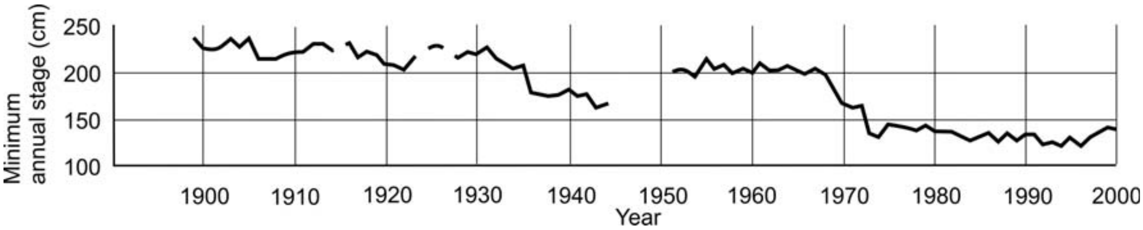

Fig. 3. Changes in minimum annual water stage at Nowy Targ gauging station in twentieth century (according to Wyżga and Zawiejska, 2010; modified).

land by 24.5%, a 6% increase in grassland and a 4% increase in wasteland, can be observed. These changes took place mainly in the high–mountain part of the catchment, after the Tatra National Park had been established in 1954. In the area of the Park, forestation increased markedly, as a result of the reduction in tree-felling as well as the cessation of grazing. Consequently, there was a considerable reduction in the quantity of eroded debris in the beds of rivers. The other land use changes, arable land turned into meadows and pasture, took place in the lower part of the catchment and further reduced the amount of debris supply. Additional anthropogenic factors intensifying the process of channel incision are river-channel regulation and hydrotechnical construction, i.e. measures that straighten the course of a river channel and thus increase its actual inclination and reduce the accumulation of debris. Moreover, the mining of river-bottom gravels for building purposes modifies channel structure and decreases the flow velocity (Wyżga *et al.,* 2012).

Regulation of the Czarny Dunajec above the water gauge in Nowy Targ (location and value of indentation as indicated in Fig 1.) was conducted in stages from the 1920s to the 1990s. The severity of bottom-gravel mining could be observed from the 1950s (Dudziak, 1965). Figure 3 illustrates the process of indentation of the river channel at this time. The data presented (minimum annual stages) come from a water gauge in Nowy Targ, and indicate a continuous, though irregular indentation of the river bed, with value of 0.9 m in the twentieth century. The strongest intensification of the process can be observed in the period 1965–1975.

This process can be clearly seen in the morphometric changes of the river channel, which can be deduced on the basis of archival cartographic materials from the years 1878, 1901, 1938, 1952, 1960 and 1979, as well as archival data IMGW and aerial photographs from the years 1956, 1964, 1977, 1983, 1994, 2002 and 2009 (Wyżga and Zawiejska, 2010). The river-channel zone underwent significant narrowing. There were decreases in tributary ratio, the number of streams for sections observed at regular intervals of 250 m; as well as decreases in the surface of the riverbed zone as a result of river regulation, and growth of resistance to erosion offered by vegetation (riparian and alder forests).

GEODETIC SURVEYS OF TECTONIC MOVEMENTS

Geological surveys on Recent Carpathian neotectonics widely discussed by W. Zuchiewicz (2010) provide questionable results for the area of Podhale in terms of movement rates and the number of interpretations of the geological facts. Furthermore, the activity of the area was usually envisaged for the Quaternary and the results were extrapolated to the present day. This sometimes involved verification of the rates on the basis of geodetic surveys. It should be noted that there is no reason to believe that the movements are a steady and linear process. Linear extrapolation of the evaluated movement rates is unjustified in many cases. This is an intuitive presumption rather than a scientifically sound method.

Geodetic surveys in the Podhale area can be classified as those carried out by means of classical methods and others, using satellite techniques. GPS/GNSS surveys provided very informative data on the movements of control points/reference stations. Aerial photography data was applied to detailed cartographic interpretations such as high-resolution digital terrain models (DTM), which are important for geomorphological studies. The new improved quality of such interpretations in many cases can re-evaluate opinions or ideas about the evolution of reliefs in areas studied.

Classical surveys

Geodetic surveys in the Podhale area for the purpose of estimation of tectonic movements were started in the 1960s and 1970s, when the Pieniny geodynamic polygon was established. It was the first in Poland and the next was the Tatra polygon. Geodynamic research in the Tatra Mountains Geodynamic Test Area was initiated in the mid-1980s and it is still carried out in the Polish and Slovakian parts of the Tatra massif. In both polygons, classical methods were applied although taking measurements in environmental conditions of a mountainous area were difficult. The results of these surveys and the technical problems related to the measurements were comprehensively discussed in papers by Makowska (2003) and Czarnecki *et al.* (2004).

The results of classical methods (mostly levelling) provided data with values within the range of the average error of measurements. Values of the Tatra uplift in the range 0.5–1.6 mm/yr, obtained by these methods, are unreliable. For the Pieniny Klippen Belt the rates of vertical displacement (positive) were reported between 0.5–1 mm/yr (Wyrzykowski, 1985; Ząbek *et al.,* 1993; Czarnecki *et al.*, 2004). Another problem related to the measurements is the low number of measurement campaigns, a problem with far reference points and the low number of benchmarks. Levelling observations were carried out along the Nowy Targ–Czarny Dunajec–Chochołów road, where vertical displacements detected were negative with a value of –0.17 mm/yr, which is much below the value of the measurement error. Authors referring to a geological evaluation agreed that there was no tectonic cause for the changes to drainage (Czarnecki *et al.*, 2004).

The classical geodetic surveys provided no significant (in the sense of their accuracy) records of displacements that would suggest tectonic activity of the area. The only exception was the area of Czorsztyn, where small displacements were related probably to the reservoir that had been created nearby, although tectonic movements were considered as well as the additional effect of loading of the structure (Czarnecki *et al.*, 2003). At the end of 1990s, GPS observations were initiated and in the twenty-first century geodetic surveys are carried out mostly by this technique (GPS/GNSS).

Observations by means of aerial and satellite surveys

GPS/GNSS observations have increasing significance in the determination of tectonic movements, both vertical and horizontal. Such observations were carried out in the study area so that a geodetic network of well stabilized control points was applied in several GPS/GNSS observation campaigns and also in gravity measurements. Such a campaign was carried out in the CERGOP-2/Environment project as one of its local applications in the Tatra Mountains and adjacent areas. The control points of the geodynamic network established for the surveys were in the Polish and Slovakian parts of the Tatra Mountains. The results of the surveys were discussed by Mojzeš *et al.* (2004) and Mojzeš *et al.* (2012). The first paper dealt with the GPS survey results, obtained from 1998–2003, the second paper analyzed the results obtained over a longer period, from 1998–2010, and the results were related to observations at reference stations located at greater distances, such as stations BOR, GRAZ, JOZE, etc.

Depending on the adjustment method, a variety of results were provided: annual rates of vertical displacements from 1 mm/yr with an error of about 2 mm, up to 5 mm/yr with an error of about 2 mm (Mojzeš *et al.*, 2004; Mojzeš *et al.*, 2006). But smaller rates for one station involved higher rates than for the others, depending on the adjustment method applied. The continuation of the investigations in later years enabled more reliable conclusions because of the longer period analyzed (Mojzeš *et al.*, 2012). The authors suggested that the role of vertical displacements was not significant to the tectonic activity of the area. Instead, horizontal displacements were more influential, but even they demonstrate a large variability. The initial results demonstrated a dominant direction of the displacements to the NE or NW, depending on the method of calculation. In the longer time period, the displacement direction was S or SE. Only two points out of a dozen control points in the network are placed in the vicinity of the Czarny Dunajec River (i.e., no further away than 10 km). These are the points Liesek (Orava Basin) and Rolow Wierch (the Gubałówka Piedmont). The river channel is located approximately in the middle part of the oriented parallel segment line, the ends of which are these points. The point locations are important for the determination of movements of the channel of the river, caused by tectonics.

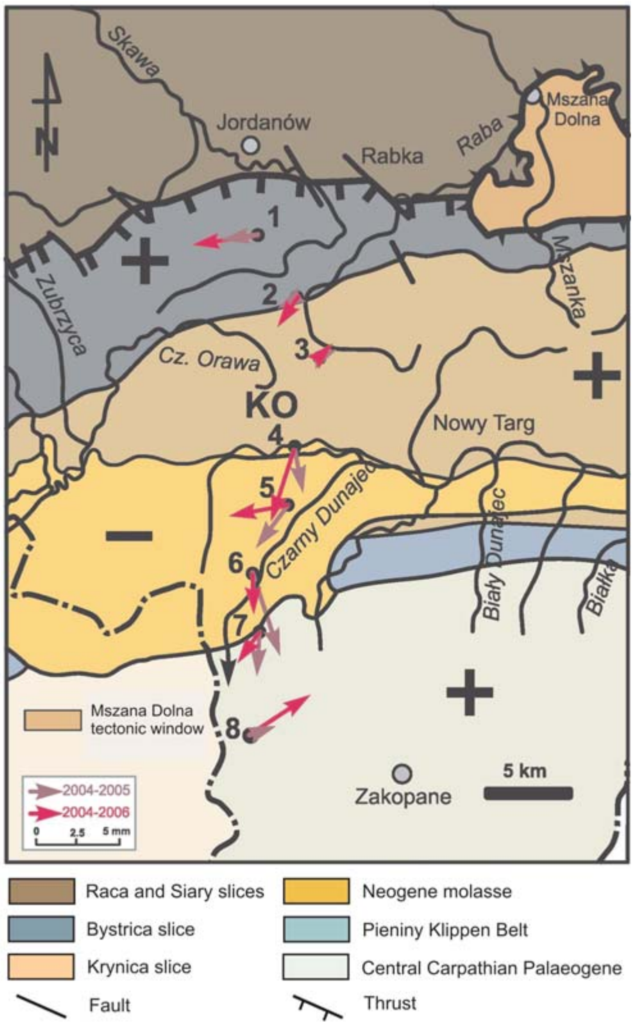

Fig. 4. Vectors of horizontal displacements at stations located on the Kotlina Orawska (KO) geodetic survey (after Łój *et al.*, 2009).

At the same time, in the 2004–2006, a geodynamic network was established in a research project carried out by UST-AGH Kraków along the Dunajec River, in the Podhale area. Some of the points evaluated in GPS observations in the years 2004, 2005 and 2006 were located in the profile of the Czarny Dunajec Valley, in the Orava Basin (the southern part the KO profile). The results of the research work were discussed by Łój *et al.* (2009). The errors assumed in adjustments were an average error in centring of the satellite antenna of ±0.3 mm and an error of height measurement of ±1.0 mm. The displacements of the points of the profile (points KO04 – KO07) demonstrated southward horizontal displacements (SSW or SSE). The other points in the KO profile were located on various tectonic units and demonstrated various directions of horizontal displacement (Fig. 4).

Of course, for investigations of the Recent tectonics of the Carpathians, a time period of a year is not sufficient for the estimation of tectonic movements and the surveys discussed should be regarded as preliminary. The future of the evaluation of tectonic movements by GPS/GNSS seems to apply permanent observations at reference stations. In 2008,

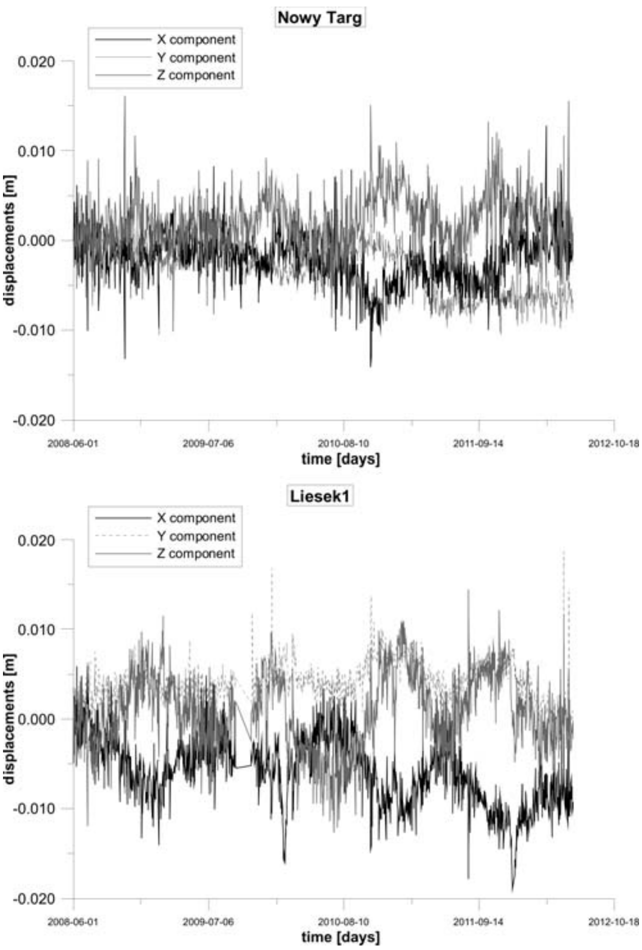

Fig. 5. Displacements of the Nowy Targ (A) and the Liesek 1 (B) stations, expressed in the European Terrestrial Reference Frame 2000 (ETRF 2000).

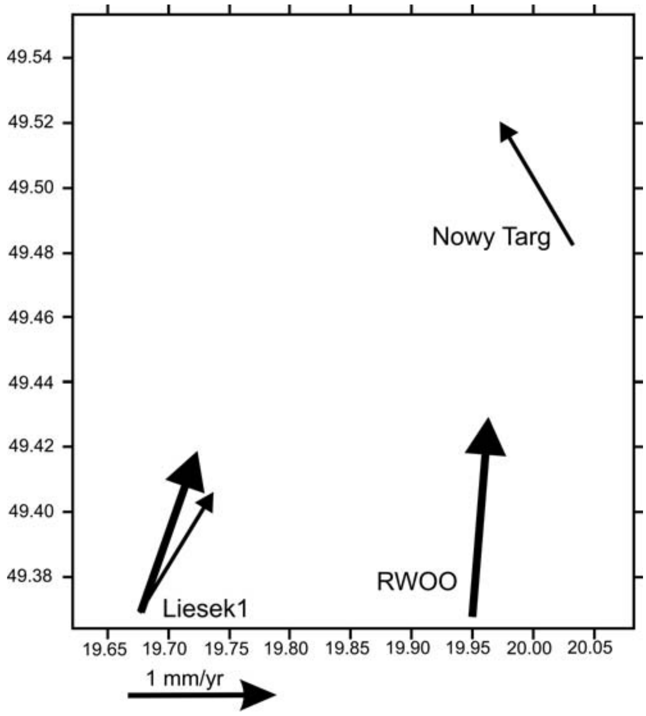

Fig. 6. Vectors of horizontal displacement rates of reference stations of ASG EUPOS network (thin lines) and network points of subproject of CERGOP-2/Environment (thick lines). Vectors in local coordinate system.

Aktywna Sieć Geodezyjna – European Position Determination System (ASG-EUPOS), a Polish network of GNSS reference stations, started to operate, in cooperation with Slovakia.

There are stations in the Podhale region and two of them are located in the study area, namely the Liesek1 and Nowy Targ stations. The results of permanent observations provide the most reliable evidence of displacements. It should be noted that displacements might not be representative for the area, where a station is located. Figure 5 presents records of the positions of the Nowy Targ and the Liesek1 stations, expressed in the European Terrestrial Reference Frame 2000 (ETRF2000) frame. The trends of changes for a particular component provide the velocity vector or displacement vector that should be expressed in topocentric coordinates.

The next figure (Fig. 6) presents vectors of horizontal displacements of these stations with reference to the local topocentric frame. They agreed approximately with the results evaluated in the Central European Research on Geodynamics OP-2 (CERGOP-2)/Environment Project, presented by Mojzeš *et al.* (2012). They are oriented approximately northwards, but there are some differences, indicating the effect of the tectonic setting.

MONITORING OF GEOMORPHOLOGICAL PROCESSES USING PHOTOGRAMMETRIC TECHNIQUES

The monitoring of geomorphological processes and the dynamics of indentation and erosion in river basins provide information about climate change, changes in vegetation cover and soil, and neotectonic movements, in particular vertical ones. Currently, the cartographic and photogrammetric materials are available for the assessment of the nature of geomorphological processes over the past 200 years. Thus, the evaluation of the impact of modern tectonic movements on the formation of river channels is possible and consequently the intensity of these movements can be assessed. The Czarny Dunajec section was examined from the connection with the Kirowa Woda and Chochołów creeks (indicated with purple arrow in Fig. 1) to the water gauge in Nowy Targ.

Another modern geodetic tool in geomorphological investigations is high-resolution terrain models derived from air photographs, which could be applied to numerical analysis and completing photo maps. Such high-resolution photos were adopted in the analysis of the area discussed, improving the detailed analysis of the course of the Czarny Dunajec (Fig. 7). A preliminary analysis was carried out for the Kiry–Witów section of the Czarny Dunajec channel. The high-resolution DTM, derived from an air photo of that area depicts the course of the river channel and its changes in asymmetry and slope that might be partly related to a landslide (Fig. 7).

The research materials were aerial photographs from the years 1964, 1977, 1983, 1994 and 2009, rectified into orthophotos. Part of the study area is also visible on aerial photographs from the years 1954 and 1956. However, these photographs do not show continuity of the river and thus have been omitted in the study. All of aerial photos used were made, using similar methods and materials (frame size 23 × 23 cm, focal length 152 ±0.5 mm), but the scale of the photos varies from 1:12000 (1964) to 1:30000 (1994). The lower parameters of accuracy of the photos from 1994 are compared by means of better determined parameters of camera distortion for this material. The process of producing an orthophotomap consisted of the calculation of internal and external orientation parameters, and orthorectification. Additionally, radiometric correction was needed, particularly for the aerial photos from 1964 and 1977. Photos from 2009 were received from state archives as ready orthophotos with the reference system European Petroleum Survey Group 2180 (EPSG 2180)/Państwowy Układ Współrzędnych Geodezejnych 1992 (PUWG 1992) and a pixel size of 25 cm. The resulting orthophotos were used to digitize particular elements of the riverbed zone: the channel, mid channel gravel bars, vegetated islands, lateral gravel bars and backwaters. A summary of the surface of these elements in the test section of the river is shown in Figure 8.

A large difference in the degree of variability of the river channel was demonstrated. It corresponds with various layers of rock in outcrops and with changes caused by the superimposed effects of anthropopression. The strongest (approximately 0.5 m in 10 years) indentation of the channel was observed in the years 1965–1975. It was a period of intensified anthropogenic impact, mainly in the form of gravel mining in the riverbed and significant regulation of the channel. These facts confirm the mechanism of vertical erosion augmented by unloading the water from the dragged debris.

A decrease of the surface backwaters, lateral gravel bars and mid channel gravel bars was recorded throughout the study period. The area of the vegetated islands revealed slight fluctuations without any clear trend. This proves constant intensity of changes in channel course, while the area of the channel increased in the years 1964–1983, and subsequently decreased and stabilized in the period 1994–2009. The average width of the riverbed zone in the section examined was: 76.5 (1964), 66.9 (1977), 56.75 (1983), 44.0 (1994), 40.2 m (2009). Referring these values to the intervals between the times of the air photography, an average speed of narrowing of the riverbed zone was obtained, with a mean value of 0.8 m/year. The most rapid narrowing was in the years 1977–1983 (1.7 m/year), and the slowest in the period 1994–2009 (0.26 m/year). The greatest acceleration of riverbed narrowing follows directly the period of intense channel indentation, found on the basis of water-gauge readings. Comparing these values with the previously cited graph (Fig. 3), it can be stated that the annual rate of channel indentation during the entire research period reached a mean value of 1.4 cm, and a maximum value 5.5 cm in the 10-year period from 1965 to 1975.

The changes analyzed on the ground adjacent to the riverbed of the Czarny Dunajec lead to the conclusion that

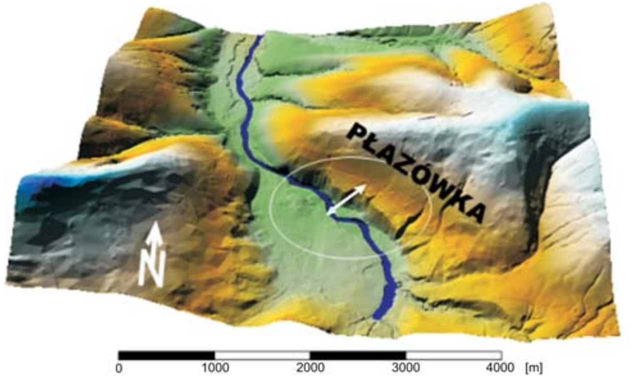

Fig. 7. The DTM of Czarny Dunajec River near Witów. Suggested landslide is marked as a probable reason for changes in course of the Czarny Dunajec.

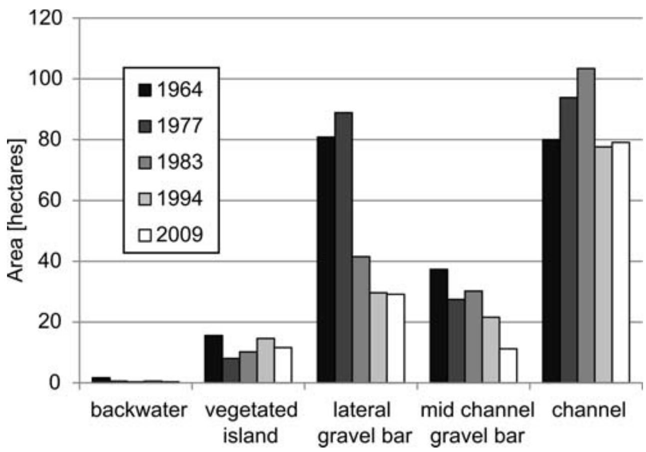

Fig. 8. Dynamics of riverbed changes of Czarny Dunajec in period 1964–2009.

the analysis of the effects of ground movement must be conducted in a wider context, also taking into account changes in land development. It is necessary to maintain a spatial database for this purpose, containing data on landforms and land-use conditions, obtained from archival cartographic and photogrammetric materials.

CONCLUSIONS

The observations of horizontal displacements in the Podhale area, carried out in the ASG EUPOS project, at Nowy Targ and Liesek1, show components of a displacement vector that are similar to those obtained in the framework of the CERGOP project until up to 2003 (Mojzeš *et al.* 2004). The differences in the displacement rates of the stations are consistently about 0.2 mm/yr. There are significant differences in the vertical displacements of the stations: both demonstrate uplift, but at Liesek1 the annual rate is clearly higher (0.8 mm/yr) than at Nowy Targ (0.2 mm/yr). The differences in displacement azimuths (azimuths of 30° at Liesek1 and 300° in Now Targ) indicate rotation of the Podhale area. Although the rates of deformation are small and probably not detectable in classical geodetic surveys, the effects should be expressed in the geomorphological profile and the process can affect the geometry of river's channels. However, according to the analysis presented, this geometry is strongly influenced by land use and climate, where river channels were incised in Quaternary sediments. Observations of the displacements of the ASG EUPOS stations mentioned and analysis of the GIS data with respect to the influence of geomorphological effects and particularly human activity are elements that are new to research on the tectonic activity of the Carpathians. The paper demonstrates the need to apply new tools in neotectonic studies that deal with a wide range of data types.

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