Geogr. Fis. Dinam. Quat.
30 (2007), 167-173, 8 figg., 1 tab.

Boris V. GEORGIEVSKIY (*) & Arcady V. TEVELEV (*)

DYNAMICALLY INDUCED PATTERNS OF DISTRIBUTION OF MINOR RESERVOIRS ON THE EAST URALIAN PLATEAU (RUSSIA)

Abstract: Georgievskiy B.V. & Tevelev A.V., *Dynamically induced patterns of distribution of minor reservoirs on the East Uralian Plateau (Russia).* (IT ISSN 1724-4757, 2007).

The small ponds and pools located along minor stream valleys crossing the East Uralian Plateau were investigated as traces of increased human impact on the landscape. A complex analysis of ponds and pools spatial and temporal features was conducted using remote sensing data and digital elevation models integrated into a comprehensive GIS project. The data obtained allow us to reveal some regularity in the spatial distribution of reservoirs with various hydrological parameters. Based on long-term remote sensing observations we demonstrate a zonal distribution type of small ponds linked to the landscape dynamics of the reservoir area. In spite of the artificial nature of reservoirs we suggest a strong correlation between their spatial distribution and the modern (e.g. Alpine) structure of the South Urals. We show that zoning of increased human impact areas along the East Uralian Plateau can be derived from regional neo-tectonic regime expressed in topography.

Key Words: Human impact, Small ponds, Neotectonics, Remote sensing, East Uralian Plateau, Russia.

INTRODUCTION

The eastern slopes of the South Urals orogenic belt are a region of numerous minor ponds and pools, which are constructed mainly for the purpose of agriculture and drinking water supply. The study area is the Russian part of the East Uralian Plateau bounded by the Ural River on the west, the Uy River on the north and the national boundary on the east (fig. 1). The watershed between the Arctic and Caspian drainage systems runs along longitude 60°E. The steppe and forest-steppe landscape is dissected by numerous minor streams integrated into the drainage systems of headwaters of principal rivers.

The main channels draining the region are the tributaries of the Ural (Gumbeika, Zingeika, Bolshaya and Malaya Karaganka, Utyaganka, Suunduk and others) and Tobol rivers (Sanarka, Kurasan, branches of Toguzak river and Ayat river, Sintashta, Bersaut and others). In spite of low population density, human impact on the landscape is of large scale. It is explained by several factors. Firstly, a significant part of the territory is agricultural land with intensive soil erosion. Secondly, the water resources of the region are limited. Numerous dams on the shallow rivers sharply reduce discharge and essentially transform hydrological processes (Tevelev & *alii*, 2005).

The main purpose of the present study is to estimate the intensity of impact on the landscape by storage ponds and pools through the examination of the regularity of location of ponds and on the investigation of dynamics of a reservoir surface area changing over the observation period. In particular the water storage of pond is very important for an estimation of anthropogenic influence on the landscape. We suggest the ratio of area of water reservoir to local wetness index as an essential estimated parameter (Georgievskiy & *alii*, 2006). The significant information is provided by revealing the spatial zones in which capacity of reservoirs increase or decrease collectively over time. Understanding the spatially-structured character of anthropogenic impact of small ponds and pools on the landscape is very important for selecting ecologically favourable sites for future ponds and water reservoirs.

THE FACTS

Long-term field observation within the East Uralian Plateau, remote sensing data and a digital elevation model provided a basis for the present study. As a result of complex field geological mapping, data on geological and tectonic structure have been obtained; Quaternary sedimentological and geomorphological maps have been prepared. Vast amounts of information were collected on the neotectonics of South Urals, describing a wealth of exogenous processes, in order to reveal most recent geodynamics. Re-

(*) *Department of Dynamic Geology, Faculty of Geology, Moscow State University, Leninskiye Gory, Moscow 119899, Russia*
e-mail: bvgeo@mail.ru

FIG. 1 - Location map. Rectangle shows the study area (from the University of Texas Libraries, The University of Texas at Austin, web source: http://www.lib.utexas.edu/maps/commonwealth/kazakhstan_rel94.jpg)

mote sensing data (fig. 2 and tab. 1) represent satellite images of several systems (Landsat TM, Landsat ETM, Landsat ETM+, MK-4, KFA-1000) and of different date of acquisition. The spatial resolution of the digital elevation model (DEM) used is 3''. The DEM was created on the basis of SRTM (Shuttle Radar Topographic Mission) data.
METHODS

TABLE 1 - List of the satellite image scenes used for the investigation

Index	*Acquisition Date*
p163r23_5t19860713	July 13, 1986
p163r24_5t19860713	July 13, 1986
p162r24_4t19890722	July 22, 1989
p162r23_4t19890722	July 22, 1989
p163r022_5t19870714	July 14, 1987
p163r023_7t20000524	May 24, 2000
p163r024_7t20000727	July 27, 2000
p162r023_7t20000602	June 02, 2000
p162r024_7t20000602	June 02, 2000
N-40-50-1990 Landsat ETM+ (Mosaic)	Components: From May 29, 1986 To June 27, 1995
N-40-50-2000 Landsat ETM+ (Mosaic)	Components: From June 30, 1999 To July 13, 2002

The research had two stages. In the first stage the comparative value ADC was defined (ADC is Area of pond Divided to Compound topographic index) and a variability map for the ADC parameter was compiled. The second stage included the recognition of small ponds and comparison the results obtained with satellite images of different acquisition date. ADC parameter equals the division of the pond area to compound topographic index (or local wetness index). Compound topographic index (CTI or wetness index) is the combination of local values of drainage area and topographic slope, i.e. CTI = ln (A / tan (α)), where A is the upslope contributing area, α – is the landscape slope (Beven & Kirkby, 1979). CTI is quantification of position of a site in the local landscape, which can be computed from a DEM. It is commonly used in hydrologic analysis to characterize the potential for different areas in a catchment to develop saturated conditions. It is used in a relief modelling (Florinsky, 1998) and in earth system sciences (e.g. Sørensen & *alii*, 2005). Taking into consideration the following two factors:

1) water storage basins have a very strong influence on the landscape (cf. Gorshkov, 1998; Lokot, 1989) and transform a natural hydrological system and processes (cf. Malin & *alii*, 1989) and

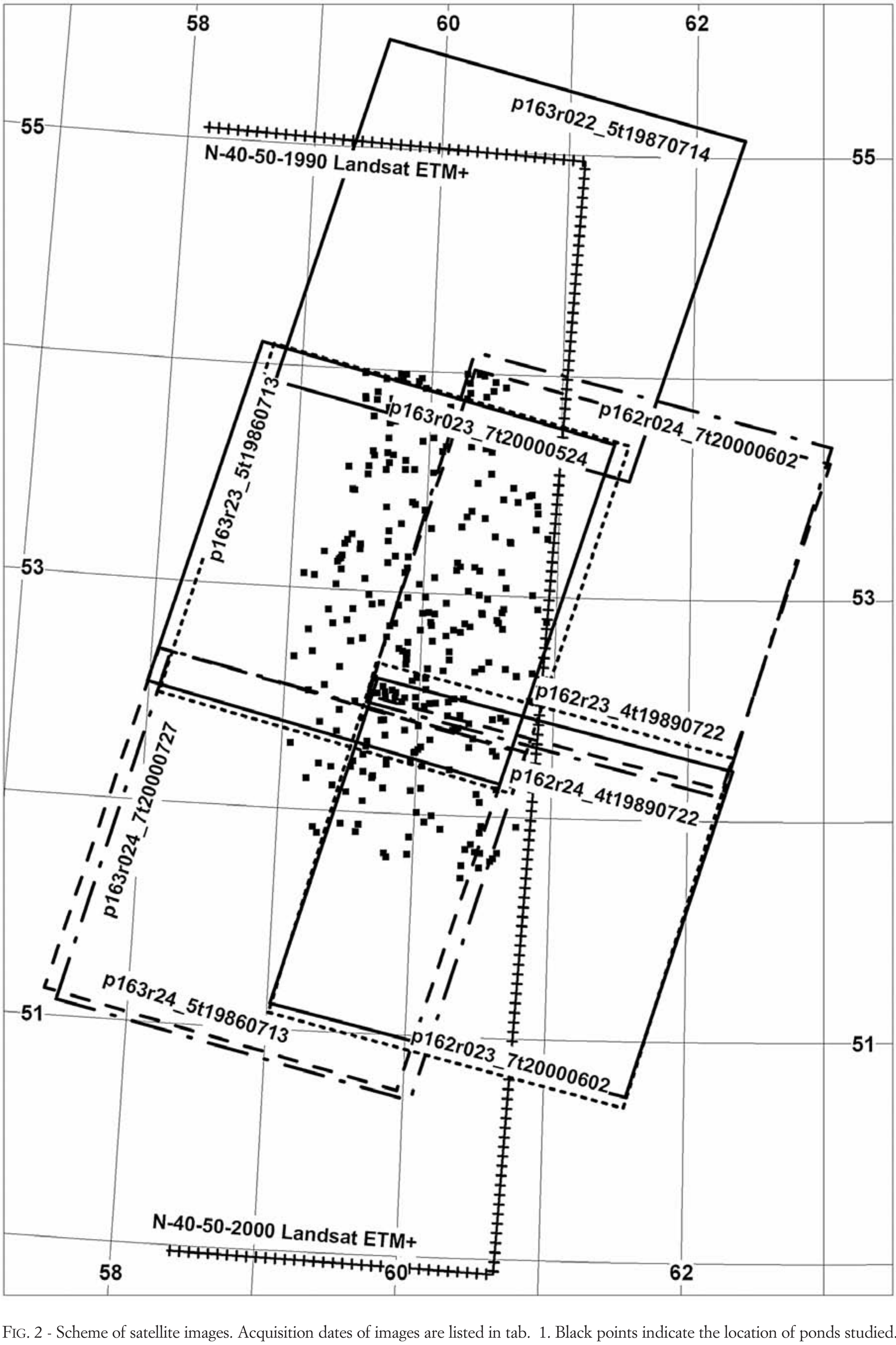

FIG. 2 - Scheme of satellite images. Acquisition dates of images are listed in tab. 1. Black points indicate the location of ponds studied.

2) wetness index (CTI) is the ratio of correlated values of flow accumulation and local slope, i.e. CTI is irrespective to their absolute values and reflect the local morphology.

We suppose that the value of ponds area normalized to CTI (i.e. the value of ADC) is a measure of the relative impact of ponds on the landscape (Georgievskiy & Tevelev, 2006).

To delimit drainage patterns we used the remote sensing georeferenced data (see section The Facts). Following the supervised classification of remote sensing data based on ponds and pools sampling, the verification of images obtained by smoothed classification followed and the results were integrated into a larger GIS project. Then different geometric parameters for water patterns were calculated. Moreover we used a digital elevation model (DEM) for the study area. In the frame of the GIS-project we calculated the compound topographic (or wetness) index CTI for each pattern. However, as the grid cell size of digital terrain model (DEM-grid and CTI-grid) is much below that of water patterns obtained by classification, there are many CTI grid cells with different values within each pattern. Thus, to compile the result map the recognized ponds were replaced with point objects (each point on the map is set in the middle of the corresponding pond) for which ADC values were calculated from ponds area and maximum value one of a CTI-grid cell covering the ponds. In the first stage the scheme of points distribution was composed. The attribute of them are ADC values. Then spatial interpolation with spline-methods was made and spatial variability of ADC was achieved (fig. 3).

In the second stage remote sensing data were interpreted. Satellite images of various dates were used with a range of 10-15 years (see tab. 1). More then 280 storage ponds and pools were analyzed. In process of recognition of water storage basins we found the different patterns of water reservoirs. The difference between the patterns consists in changes of water surface area (reservoir capacity) during the time. To achieve this goal for each small pond the change of water surface area was estimated, increase or decrease or no change was recorded. The changes of reservoir surface area were considerably larger than the spatial resolution of remote sensing data.

As a result the allocation of ponds with different tendencies of reservoir capacity changes were mapped (fig. 5).

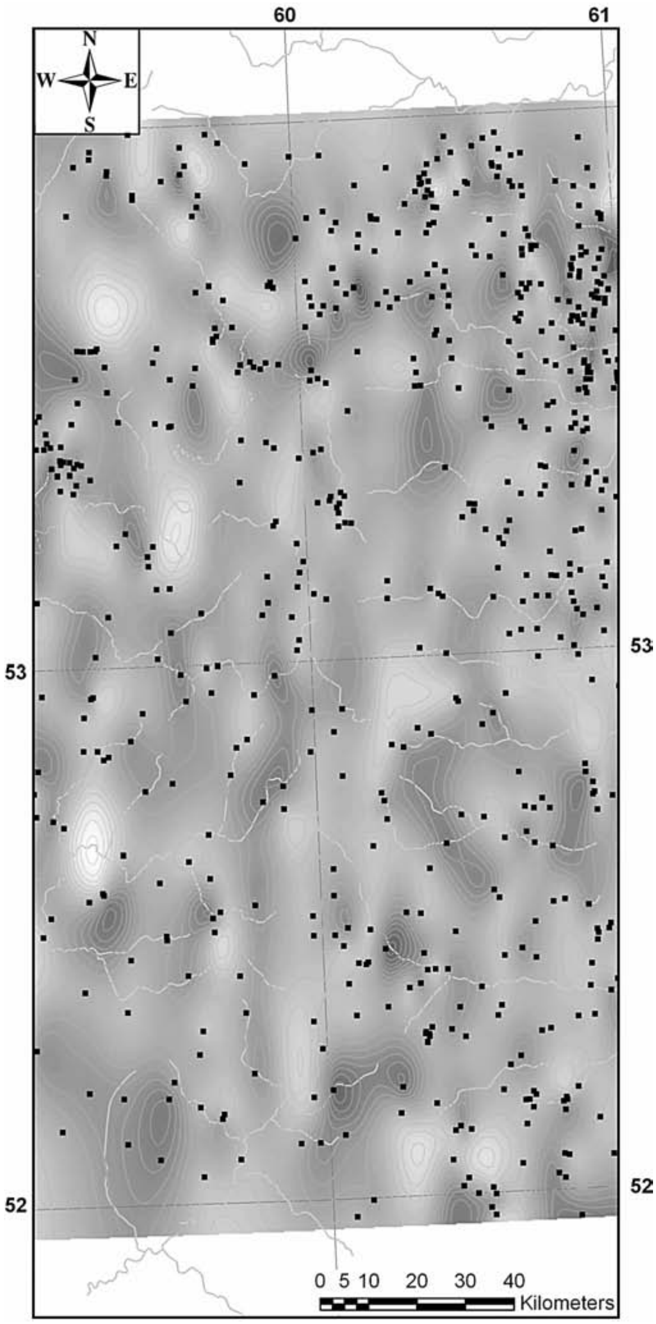

FIG. 3 - Map of variability of ADC parameter. ADC values are relative. The darker is colour, the higher is the ADC value. Black points indicate water basins within the study area. See text for further explanation.

STUDY AREA

In the studied area there are igneous, sedimentary and metamorphic rocks of different geodynamic environment (Legend…, 1999). Paleozoic formations are covered with thin Mesozoic and Cenozoic continental rocks in fragmentary distribution. The main geological feature is zonation, the zones from west to east are Vostochnomagnitogorskaya, Uysko-Novoorenburgskaya, Suhtelinskaya, Kochkaro-Adamovskaya, Kopeiskaya and Nizhnesanarsko-Tekeldytauskaya. The borders of Paleozoic zones are tectonic. In general the study area is characterized by thrust-folded structure, individual suture zones are steeply dipping and flatten with depth (Tevelev & *alii*, 2002).

Terrestrial Quaternary formations are thin, but they cover the ancient deposits of the East Uralian Plateau practically continuously. In accordance with the hydrographical structure there are three zones of Quaternary deposits: Miass-Uyskaya, Uralo-Gumbeiskaya and Tobol-Ayatskaya (Bekker, 1999).

The topography of the East Uralian Plateau is hilly and flat in the eastern part. Maximum relative relief is ca 240 m. The main geomorphological feature is the watershed between Ural and Tobol rivers (between the Arctic and Caspian drainage systems). Others features are: 1) regional geomorphological levels over the whole area; 2) sudden changes along boundaries of pre-Quaternary formations; 3) relation between the geomorphology and the geology.

The Neotectonic (Alpine) regime of the East Uralian Plateau is determined by global dynamic regime of South Urals. The geomorphological zones and neotectonics of the South Urals are connected with the renewal of ancient faults (Tevelev & *alii,* 2005). As it was mentioned by many scientists, the uplift of South Urals started at the beginning of the Quaternary (Lider, 1976) and continues to the present day. Thus, during the Quaternary uplift the inclination of eastern slopes increased and the drainage pattern changed.

We obtained ample evidence of neotectonic activity (modern faults and folded debris) during fieldwork. Clastic dykes and folded structures in debris rocks are so important because they show the possibility of Quaternary seismic activity (Meyer & *alii*, 2006; Obermeiera & *alii*, 2005; Tuttle & *alii*, 1999). Unequal heights and different ages of alluvial fill terraces, originated since the second half of the Middle Neopleistocene, show the active dynamic (neotectonic) regime.

RESULTS AND DISCUSSION

The results are shown on two maps: the map of the spatial variability of the ADC value (fig. 3), the method of its compilation being described under «Methods», and the dynamics of water surface area of 288 small ponds (fig. 5). The first assumption made at drawing the first map, was that ponds and pools belong to the large river valley and ADC values are determined for the objects located near the main streams, hence ADC values only characterize valleys. The second assumption was that the spatial interpolation of ADC was based on the hypothesis that close segments of adjacent river valleys, having similar structural and geomorphological settings, develop under similar dynamic conditions. The regime of river valley evolution can change in discrete intervals, i.e. the river valley is characterized by segmental structure. Similar regime could be observed at the segment of adjacent valleys separated by a local watershed.

All this is evidence of a general dynamic evolution of drainage network within the study area. Thus the river network during its formation adapted to the geodynamics of the East Uralian Plateau. It is revealed in local alternations of intensive erosion and accumulation. The allocation of such sites or segments is conditioned by the general (regional) structural-geomorphological setting, in particular, by the location and structure of zones of weakness and active neotectonic structures.

During fieldwork we found evidence of this concept of river valley evolution. Thus in the valley of Bolshaya Karaganka (left tributary of Ural river) near the villages Mihailovka and Izmailovsky the river valley is controlled by structure and neotectonics (active uplift). As a result along the entire river valley segments of two different types alternate: predominantly erosional and predominantly accumulational (fig. 4a). In addition, even within homogeneous segments the hydrological processes are not uniform as illustrated by the deep-pool structure of the river valley (fig. 4b). The valleys in the Tobol basin show similar features. For instance, the whole river valley of Njiniy Toguzak has a deep-pool structure. Many valley segments are strongly rectilinear and the intensity of erosion or accumulation is a function of valleys direction.

The main feature revealed by the analysis of the interpolation map (fig. 3) is a diagonal spatial distribution (and joining) of zones with high and low ADC values. The elongated zones extend roughly from south to north and are traced usually across two or three valleys. It conforms to the segment-type structure and these zones mark the indi-

FIG. 4a - Segmented river valley (example of B. Karaganka near the villages Mihailovka and Izmailovsky). Arrows show the segments for which accumulation is the main factor. Dotted lines mark the benches of active neotectonic structure. See text for explanation.

FIG. 4b - Deep-pool structure of river valley segment (B. Karaganka river). See text for explanation.

vidual domains. Impacts of small ponds within these domains are similar and change abruptly beyond their boundaries. So the ADC values demonstrate the differences in the relative impacts of small ponds and pools on the landscape. Simultaneously, ADC variability may be used to reveal the structured character of the geological environment and indirectly the geodynamic setting controlling the allocation of small ponds and pools.

The map of fig. 5 is based on the visual interpretation of remote sensing data from various years. Small ponds and pools are divided into three categories: 1) ponds with increased water surface area (i.e. increased water capacity); 2) ponds with decreased water surface area (which became shallower or were destroyed) and 3) ponds without change. As streams in all channels are similar we suppose that the difference in water reservoir filling dynamics (reflected in water surface area changes) is related to structural and geodynamic effects. We consider that the active deformation of South Urals is revealed by the increase or decrease of stress conditions in the fractured zones that in turn influence the water content of aquifers. The whole study area belongs to Bolsheuralskiy groundwater basin.

The influence of active (neotectonic) movements on the hydrological regime and deposition of streams under human impact was mentioned by many scientists (e.g. Timar & *alii*, 2002). We obtained evidences on abrupt changes of erosion and accumulation in East Uralian Plateau such as local variation of base level. Such features are the (obviously Holocene) alluvial terraces of some decimetre thickness (fig. 6a), usually not in main large

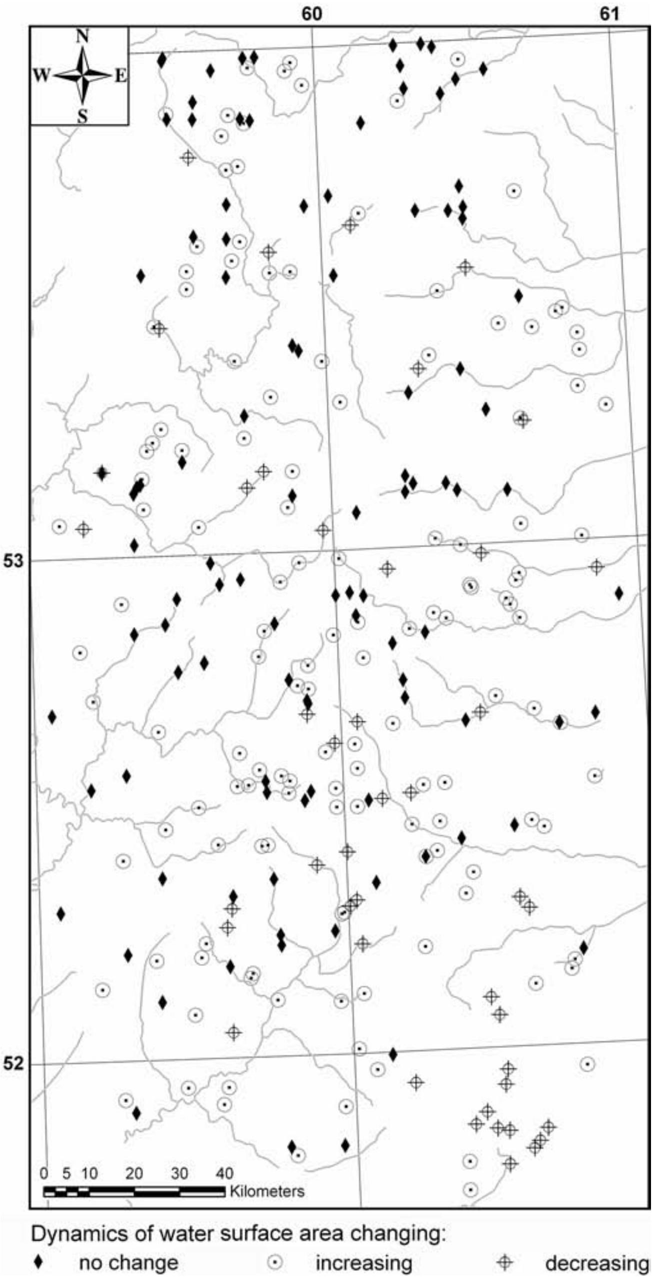

FIG. 5 - Map of dynamics of water surface changing of small ponds within East Uralian Plateau. There are three types of changes: increasing, decreasing and no change. The dynamic types are shown with different symbols.

FIG. 6a - Low Holocene alluvial terraces in Suunduk valley.

FIG. 6b - Low alluvial terraces in a small pond hollow (Suunduk river basin).

river valleys but in lake hollows and depressions, in the valleys of intermittent (or ephemeral) rivers.

The presence of faulted and folded structures within sequences of unconsolidated clastic materials proves paleoseismic events which took place when the local base level changed. It is important that along river valleys the heights of such terraces are not constant. In some cases the levels of low alluvial terraces drop and the stream is enclosed in older (Pleistocene) terraces. In other cases there are analogous Holocene terraces along the valley but with a slightly different thickness. This situation points to nonuniform variation of base level, in other words, evidences local variations and the specific character of hydrological processes during river valley evolution. It highlights the domain or segment structure of stream valleys.

There are identical low alluvial terraces in bench face of hollow of water storage basin (fig. 6b). It makes obvious the unstable and unsteady hydrological regime in such depressions. So the construction of dams and the creation of ponds transform natural landscapes, alter the local base level and have an influence on sedimentation processes. As a result the morphology of the river valley and stream discharge is modified.

Thus, small water basins (ponds and pools) are created by fast, practically catastrophic changes of valley structure and hydrodynamics. Here geodynamic factors and the structural geomorphological conditions can play a decisive role. It is manifested in the selective character of geomorphic processes. So we describe the true geological setting as a distinctly structured geological environment. This is in accordance with findings obtained on analysis of ADC variability map (see above). As it has been shown above the areas with increased or decreased ADC values (division of water surface area to local wetness index) does not dispose a chaotic (random) but a regular and systematic distribution of domains.

As shown in fig. 5, small ponds and pools with different dynamics of water capacity change are not randomly distributed either but grouped in clusters. Commonly the allocation of similar areas (with similar dynamics) is not restricted by local watersheds, but these areas consolidate the segment of adjacent river valleys. Furthermore there is no correlation between the position of domains (neither in the case of ADC zones and pond zones of identical dynamics) and distance from river heads, regional slope, altitude or geological settings. In some cases (see fig. 5) the ponds with analogous dynamics form a group. They may be of two types: the first extends roughly from south to north and the second has an asymmetrical character. Considering the fact that in most cases the course of neotectonic structure is from south to north too we have another confirmation of neotectonic (Alpine tectonic regime) influences on the allocation and geodynamics of water storage reservoirs and small ponds.

It is most likely that the real mechanisms of deformation of the geological environment within East Uralian Plateau are very complicated and complex. The evolution of the region may be conceived as a mosaic of local changes of surface morphology which are accompanied by migration of regions with maximum vertical and horizontal gradients, and therefore by regular time relocation of zones with maximum intensity of exogenous processes.

CONCLUSIONS

From our investigation the following conclusion can be drawn. The formation and functioning of the numerous small ponds and pools within East Uralian Plateau are essential factors of human impact on the landscape. The major hydrological and hydrographical features are controlled by the structural geomorphological setting, made unstable, unsteady and flexible by the Holocene neotectonic activity of the South Ural orogenic belt. The nature of the human impact on the landscape may be revealed by means of two integral parameters: 1) the spatial variation of the value water surface area divided by the local wetness index and 2) the type of dynamics of water capacity for ponds. Both parameters relate to the structure type of the geological environment.

REFERENCES

BEVEN K.J. & KIRKBY M.J. (1979) - *A physically based, variable contributing area model of basin hydrology*. Hydrological Science Bulletin, 24, 43-69.

FLORINSKY I.V. (1998) - *Combined analysis of digital terrain models and remotely sensed data in landscape investigations.* Progress in Physical Geography 22, 1, 33-60.

GORSHKOV S.P. (1998) - *Conceptual basis of geoecology.* Smolensk, 445 pp. (in Russian).

LOKOT L.I., GORLACHEV V.P., GORLACHEVA E.P & ALII. (1985) - *Eutrophication of small reservoirs.* Nauka, Novosibirsk, 160 pp. (in Russian).

MEYER M.C., WIESMAYR G., BRAUNER M., HAUSLER H. & WANGDA D. (2006) - *Active tectonics in Eastern Lunana (NW Bhutan): Implications for the seismic and glacial hazard potential of the Bhutan Himalaya.* Tectonics, 25, TC3001, doi:10.1029/2005TC001858.

OBERMEIERA S.F., OLSONC S.M. & GREEND R.A. (2005) - *Field occurrences of liquefaction-induced features: a primer forengineering geologic analysis of paleoseismic shaking.* Engineering Geology, 76, 209-234.

SØRENSEN R., ZINKO U. & SEIBERT J. (2005) *On the calculation of the topographic wetness index: evaluation of different methods based on field observations.* Hydrology and Earth System Sciences, 2, 1807-1834.

TEVELEV ALEX. & KOSHELEVA I.A. (2002) - *Vostochno-Uralskoe podnyatie and Zaurale (Geological structure and evolution history of South Ural).* MSU, Moscow, 123 pp. (in Russian).

TEVELEV ALEX., KOSHELEVA I.A., TEVELEV ARC. & *alii* (2005) - *State Geological Map of Russian Federation in scale 1:200 000. The South Uralian Series. Quadrangle N-41-XXV.* Explanatory Notes, Saint Petersburg, 215 pp. (in print).

TIMÁR G. & RÁCZ T. (2002) - *The effects of neotectonic and hydrological processes on the flood hazard of the Tisza region (East Hungary).* European Geosciences Union, 267-275. (Stephan Mueller Special Publication Series, 3).

TUTTLE M.P. (1999) - *Towards a Paleoearthquake Chronology for the New Madrid Seismic Zone: Collaborative Research.* M. Tuttle & Associates and Central Region Geologic Hazards Team, USGS, USGS Award No: 1434-HQ-97-GR-03082.

URSEIS-95 Project (2001), *Deep-seated structure and geodynamics of the South Urals.* Tver, 286 pp.

(Ms. received 20 February 2007; accepted 30 November 2007)