The main relief-forming factors of asymmetry of river valleys within the central part of East European Plain

A A Kourjanova and E V Petrova

Institute of Environmental Sciences, Kazan Federal University, 18, Kremlyovskaya Street, Kazan, 420008, Russia

E-mail: akurjan@mail.ru, helengeo@mail.ru

Abstract. The article examines the spatial distributions of asymmetry types in the slopes of the river valleys in the central part of the East European Plain. Five types of asymmetry are found in the studied region: planetary, climatic, hydrodynamical, structural (tectonic) and topographic.

Keywords: asymmetry, valleys, relief, East European Plain.

1. Introduction
Since the 1950s, both Soviet and foreign researchers have proposed a whole number of methods for quantifying the degree of asymmetry on the slopes of river valleys. The first quantitative indicator was proposed by A. Gloriad, J. Tricart [1]. Significant studies in the development of a quantitative determination of the asymmetry of river valleys slopes were carried out by V.N. Sementovskii [2], H. Karrasch [3], G.P. Butakov [4]. Later on studies were continued by H. French [5], C.B. Crampton [6], T. Czudek [7], H.Y. Akerman [8].

The asymmetry of the river valley in the center of the East European Plain was considered earlier except the territory of the Central Russian Upland [9, 10, 11, 12].

This paper shows the results of studying the asymmetry of the slopes of the river valleys in the central part of the East European Plain.

The considered territory extends in meridional direction from the Volga river head in the North to the Donetskaya ridge in the South. The Eastern border of this region is the Don valley, the Western border – the left tributaries of the Dnepr river. The landscape of the territory is flat, heightened to the West and lowered to the East.

2. Materials and methods
The degree of manifestation of the asymmetry of river valleys slopes was determined by the methods proposed by H. Karrasch [3] and G.P. Butakov [4].

For field researches the formula of H. Karrasch was used:

\[ A'' = 1 - \frac{\text{Agentle}}{\text{Asteep}} \] (1)

where Agentle, Asteep are the angles of inclination of the gentle and steep slopes in degrees.

At cameral works there was used the following formula:

\[ A = 1 - \frac{\text{Lsteep}}{\text{Lgentle}} \] (2)
where L steep / L gentle are the lengths of the horizontal location of the steep and gentle slopes. In this case, the asymmetry coefficient will vary from 0 in symmetrical valleys to values close to 1.0 in sharply asymmetric ones. The coefficient is limited on both sides. In the course of the work full study of large-scale topographic maps was conducted. The results of cameral work were monitored by field observations in selected key areas.

3. Results
The asymmetry appeared in all valleys of studied region. The average coefficient of the asymmetry for the whole region is equal to 0.45. From the North to the South the following regularity occurred: in the North region on the Valdai Hills the coefficient of asymmetry A consists of 0.46, in the South in the basin of the Moskva river it increases to 0.57, the maximal values (0.50-0.72) belong to the cold points and the minimal values (0.29-0.50) - to the warm ones. Moving from the North to the South the coefficient A decreases to 0.40 for the basin of the Oka river and to 0.47 for the basins of the Desna and Don rivers. In the Southern part of the region the coefficient of the asymmetry again increases to 0.50 in the basins of the Seim river and to 0.54 in basins of the Severskii Donets river. Here the maximal values of the coefficient of the asymmetry (0.47-0.87) belong to the warm points, but the minimal (0.19-0.40) - to the cold ones.

Five types of asymmetry are found in the studied region: planetary, climatic, hydrodynamical, structural (tectonic) and topographic.

The planetary type occurred in the valleys of all large rivers (Moskva, Protva, Ugra, Upa, Desna, Jizdra, Oka, Zusha, Seim, Severskii Donets, Oskol) excluding the basin of the upper Volga within Valdai Hills. The coefficient of the planetary type for the territory changes from 0.33 to 0.60 and the average is 0.49 (table 1, 2).

The minimal coefficient of the planetary asymmetry in the basin of the Jizdra river consists of 0.33. This region gives the most part of the symmetric sections (33%) and the lowest percent of the sharply asymmetric valleys (11%).

Table 1. The distribution of the planetary type of asymmetry

| №  | River valley | Average coefficient A | Symmetric valleys, % | Asymmetric valleys, % | Maximal expense of river, m/s |
|----|--------------|-----------------------|----------------------|-----------------------|-----------------------------|
| 1  | Upper Volga  | 0.64                  | 11.6                 | 53.5                  | 1124                        |
| 2  | Moskva river | 0.57                  | 20.8                 | 40.7                  | 1095                        |
| 3  | Oka river    | 0.40                  | 31.4                 | 16.1                  | 845                         |
| 4  | Protva river | 0.59                  | -                    | 82.2                  | 1150                        |
| 5  | Ugra river   | 0.45                  | 5.3                  | 52.6                  | 748                         |
| 6  | Upa river    | 0.42                  | 7.7                  | 38.5                  | 705                         |
| 7  | Desna river  | 0.56                  | -                    | 75.0                  | 1110                        |
| 8  | Jizdra river | 0.33                  | 33.3                 | 11.1                  | 810                         |
| 9  | Zusha river  | 0.53                  | -                    | 60.0                  | 1040                        |
| 10 | Seim river   | 0.52                  | -                    | 55.5                  | 1185                        |
| 11 | Sosna river  | 0.55                  | 4.8                  | 61.8                  | 1160                        |
| 12 | Oskol river  | 0.74                  | 3.3                  | 93.4                  | 1200                        |
| 13 | Don river    | 0.69                  | 3.7                  | 80.5                  | 1175                        |
Table 2. The average coefficients of the different types of the asymmetry

| Region               | A         | Types of the asymmetry |          |          |          |          |          |
|----------------------|-----------|------------------------|----------|----------|----------|----------|----------|
|                      | common    | Planetary              | Hydrodynamical | Structural | Topographic | Climatic |          |
| Valdai Hills         | 0.46      | –                      | 0.49      | –         | 0.47      | 0.51     |          |
| The Moskva river     | 0.57      | 0.61                   | 0.57      | –         | 0.40      | 0.49     |          |
| The Dniepr river     | 0.50      | 0.52                   | 0.40      | 0.43      | –         | 0.44     |          |
| The Oka river        | 0.40      | 0.49                   | 0.41      | 0.41      | –         | 0.39     |          |
| The Don river        | 0.47      | 0.69                   | 0.51      | 0.54      | –         | 0.44     |          |
| The Severskii Donets river | 0.54 | 0.59                   | 0.53      | 0.44      | –         | 0.52     |          |
| Average              | 0.45      | 0.56                   | 0.49      | 0.45      | 0.43      | 0.43     |          |

The possible explanation is the following:
1. The river flows in the latitudinal direction and its left bank has the southern exposition. Here passes the superposition of two types of the asymmetry: planetary and climatic. The climatic factor sufficiently decreases the difference between two slopes.
2. The strong twistiness of the river. It promotes the left bank to be usually steep (hydrodynamical asymmetry).

The maximal coefficients of the asymmetry of the planetary type are found in the Don valley (0.69) and in the low Oskol (0.82) e.g. in the largest rivers of the given region. For this valleys the most part of the sharply asymmetric sections of valleys and the minor part of the symmetric ones are accordingly observed (table 1).

The high correlation of the values of the coefficient of asymmetry and the average maximal expenses are calculated (table 1). The part of the whole length of the valleys due to the planetary type of the asymmetry consists of 10.9% (table 3).

Table 3. The part (%) of the types of asymmetry on the whole quantity of the asymmetric sections.

| Region             | Types of asymmetry |          |          |          |          |          |
|--------------------|--------------------|----------|----------|----------|----------|----------|
|                    | Planetary          | Structural | Hydrodynamical | Topographic | Climatic |          |
| Valdai Hills       | –                  | –        | 2.2      | 1.1      | 96.7     |          |
| The Moskva river   | 20.2               | –        | 15.7     | 9.6      | 54.5     |          |
| The Dniepr river   | 15.1               | 0.8      | 3.1      | –        | 81.0     |          |
| The Oka river      | 10.3               | 3.5      | 4.3      | –        | 81.9     |          |
| The Don river      | 8.4                | 5.1      | 8.1      | –        | 78.4     |          |
| Average            | 10.9               | 1.8      | 6.6      | 2.1      | 78.6     |          |

The hydrodynamical type of the asymmetry is well developed in the river valley of the given region. For example: rivers Ugra, Upa, Jizdra, Sosna, Nepriada tributary of the Oskol river and others. Passing as the planetary type the river valleys on the sections of the left meander have the steep left bank often directed to the South-East, the South and South-West. In addition the “right” asymmetry alternates by the "left" one (for the main rivers) in the confluences of the large right tributaries: the Oka and the Cherepue, the Upa and the Vatitsa, the Ugra and the Dolinka, the Don and the Devitsa, the Potudue and the Sosna, the Krasivaya Mecha and the Vyazoevka, etc. In 5-7 km downstream of the tributary mouth the normal asymmetry is reconstructed. A lot of occasions of the hydrodynamical asymmetry are found in the sections of the Volga valley, Tsna, Bol. and Mal. Koshy, Osuga rivers. The average coefficient of the hydrodynamical type for the region consists of 0.49 (table 2).

The part of the asymmetry of such type consists of 6.6% of the whole length of all valleys (table 3).

The hydrodynamical type is observed on the whole territory and the regularity of its distribution is not found.
The structural and tectonic types of the asymmetry are connected with the peculiarities of the formation of mountain rocks and with the manifestations of the tectonic structures in the landscape. On the territory of the investigated region a lot of structures effecting the formation of the river valley are revealed. Unfortunately, the connection between the construction of the land surface and the bed of the river valley was revealed only for several sections due to the absence of the detailed structural maps and to the fact that structures II and EI are not well revealed.

We have only some examples where such connections are well observed: the Tuskar and the Rat rivers (basin of the Seim river) placed in the zone of the Kursk raising (II category) are distributed to the North-West. The vault is more raised in the Northern-Eastern part and it is lowered to the South-West. It characterizes the common asymmetry of the Kursk raising which can be called monoclinal. The asymmetry of the raising is the main reason of the stable right asymmetry of this rivers. The riverhead of Krasivaya Mecha river rounds from the South of the Ptanskoe raising, consequently the river valley has the curve and its right bank becomes steep directed to the North and North-West. Such picture is observed in the Sosna river where the river rounds Kozminskoe raising; here the steep right bank directs to the North-West. In this case the enlargement of the planetary type of the asymmetry occurs. At whole region the average coefficient of the asymmetry consists of 0.45 (table 2). The part of the structural type is 1.8% (table 3). In the Southern part of the region this type of the asymmetry is not revealed.

The level of climatic asymmetry development within the considered territory is showed in the table 4. The analysis of the spatial distribution of the coefficients of the climatic asymmetry suggests the regularity of the changes in the territory. The analysis of the levels of the expression for the asymmetry takes into account different mountain rocks in various regions. Using the correction coefficients to lithology for the level of river valleys slopes asymmetry in one case decreases the value A (the upper Seim river from 0.47 to 0.42) in other case increases it (basins of rivers Don, Oskol etc.) (table 4).

| №  | Region                   | A    | A correct | Steep slope, % |
|----|--------------------------|------|-----------|----------------|
| 1  | Valdai Hills             | 0.45 | 0.51      | 44.0           | 54.0           |
| 2  | The Moskva river         | 0.49 | 0.49      | 38.1           | 60.0           |
| 3  | The Dnepr river          | 0.41 | 0.44      | 56.2           | 49.0           |
| 4  | The Seim river           | 0.47 | 0.42      | 72.6           | 56.0           |
| 5  | The Oka river            | 0.40 | 0.39      | 68.2           | 49.0           |
| 6  | The Don river            | 0.39 | 0.44      | 69.6           | 43.0           |
| 7  | The Oskol river          | 0.48 | 0.51      | 82.5           | 62.0           |
| 8  | The Severskii Donets river | 0.49 | 0.52      | 72.5           | 54.0           |
|    | Whole                    | 0.44 | 0.43      | 64.8           | 53.0           |

The slowly decreasing A is observed from 0.51 in the North within Valdai Hills to 0.35-0.44 in the center (in the basins of Oka river, upper Don river, middle section of Dnepr river). In the South the value A increases again to 0.5 and more in the basins of the Oskol and Severskii Donets rivers. The maximal values of the coefficients A 0.5-0.54 are revealed in the basins of the Severskii Donets river and Aidar in the South and also in the basins of the Shlyny and Tsna rivers in the North of the studied region.

The minimal coefficients A regard for the basin the upper Oka river. The average coefficient of the climatic asymmetry in this region is equal to 0.43. The part of the sharply asymmetric valleys in this basin consist of 16.1%. This is the lowest part of the sharply asymmetric valleys. The weak asymmetry and the small percent of the sharp asymmetric valleys are possibly explained by the picture of the hydrological net, the small development of the river valleys, the superposition of the several types of the asymmetry and, as a consequence, the effect of the climatic factors decreases. One of the reasons of
the weak expression of asymmetry [2] is the presence of the pediments in this territory which are formed in the slopes of the warm points, they are smoothed and as a result the asymmetry of the slopes decreases.

For the Northern regions (the Valdai Hills and the basin of the Moskva river) the steep slopes dominate (directed to the cold points, N, NE, NW) (Table 4). In the upper Volga river only 38% of cases for steep slopes are directed to the warm points (SE, S, SW, W), but in the basin of the Moskva river accordingly – 19-40% and to the cold points – 62-70%. It shows the development of the northern type of the climatic asymmetry here. The border between the Northern and Southern types passes along the watershed of the Volga and Dnepr rivers, Moskva and Protva rivers, Moskva and Oka rivers.

In the upper Dnepr and the basin of the Protva river the part of the steep slopes directed to the warm points increases to 53-69% but in the basin of the Oskol river this part increases to 82%. The regular change of the part for the steep slopes directed to the warm points repeats the variation of the values for the coefficient A.

The connection of the steep slope with right or left slopes is not revealed. For several basins the part of the steep slope varies within 43%-60%, on the average consists of approximately 50% (table 4), that shows the independence of climatic asymmetry of the river valleys slopes in the direction of the river stream.

In nature, the asymmetry of the slopes of river valleys, only one type is observed rarely, as a rule we observe the superposition of two and more types. In any cases this superposition strengthens or decreases the level of the asymmetry.

4. Conclusions
The planetary type of asymmetry occurs in the valleys of all major rivers. The planetary type of asymmetry coefficient for the territory varies from 0.33 to 0.60. The hydrodynamic type is observed throughout the territory and the regularity of its distribution is not found. The average coefficient of asymmetry of hydrodynamic type for the region is 0.49. The structural and tectonic types are the main cause of stable right asymmetry in the rivers of the studied area. The climatic type of asymmetry, along with the planetary one is the main type in the studied region. It is typical for the most of small and medium rivers. The coefficient of this type of asymmetry can reach more than 95%.

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