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PATTERNS IN THE DEVELOPMENT OF HORIZONTAL RIVER CHANNEL TRANSFORMATIONS IN THE REPUBLIC OF UDMURTIYA, RUSSIAN FEDERATION

Abstract: The paper presents a summary of a five year study into lateral migration of 55 channel reaches representing rivers of various sizes and running through various landscapes in the Republic of Udmurtiya in European Russia. Morphodynamic channel types were identified using large scale topographic maps. Principal factors influencing horizontal transformations of river channels were identified and relationships were determined between the river bank retreat rates and certain morphometric indicators.

Key words: geoecological monitoring, fluvial processes, morphodynamic river channel types, horizontal river channel transformations.

1. Introduction

The flatland territory of the Republic of Udmurtiya is dissected by a dense network of river valleys with a combined length of 30 000 kilometres. These are mostly broad riverbed valleys (flood flow channel) characterised by active meandering. This process involves a constant change of the channel shape, cutbank development and retreat and the build up of various bank reaches. This makes lateral erosion one of the most active exogenic geomorphological processes producing landforms displaying various rates of change and impacting on settlement patterns and infrastructure development along rivers.

2. Methodology and rivers studied

Fluvial processes have to be studied carefully if one is to avoid negative results. The most wide-spread method of observing fluvial processes and forecasting their development under the influence of natural and human factors is using geoecological monitoring systems.

Such a system first commenced in the Republic of Udmurtiya in 1999 at the instigation of the Republic's Natural Resources Committee. The new observation network is intended to cover as great a variety of landscapes as possible and to survey rates of lateral erosion on the most active river channel reaches that posed a threat to the economy and living conditions. Altogether 55 study reaches were identified on rivers of various sizes (according to Scheidegger) in various geographical conditions.

The fieldwork carried out during following summer seasons was intended to determine the rate of lateral movement of the river channel and the basic morphometrics of the selected reaches. To this end 250 water markers were installed in the channels featuring cutbanks (typically a high terrace escarpment). Additionally, 29 reaches were surveyed with a tachymeter on an annual basis.

The selection of the study reaches was based on a morphometric and morphological review of the Udmurtiyan river network, carried out at the early pre-fieldwork stage. After analysing topographic maps at a scale of 1:50000 and 1:100000, rivers of the 3-4th and higher orders were selected, particularly from the Cheptza, Siva, Kilmeza, Vala and Ilzsha drainage basins.

The selected rivers were then divided into reaches representing various channel types in accordance with a morphodynamic river classification (Chalov et al. 1998). In the overall classification of the regions of European Russia by fluvial processes, Udmurtiya is classified as an area with broadbed rivers.

The sinuosity index (K) was applied to identify broadbed rivers. The river channel reaches were broken down into seven types based on the pattern of their meanders, from the relatively straight-line ($K < 1.1$) to highly sinuous ($K > 2.0$).

3. Morphodynamic channel types, their location and hydrological and geomorphological characteristics

Two basic channel types have been defined using river morphology and the rates of horizontal channel deformation, i.e. relatively straight-line and meandering. Meanders go through several development stages differing in the intensity and direction of meander outline transformation, current kinetics and hydraulic characteristics. Each of these stages has a corresponding value of the current transport capacity and direction of channel deformation. Five types of meandering channel were identified in Udmurtiya (Table 1): 1) low-sinuous ($1.15 < l/L > 1.40$); 2) developed ($1.40 < 1/L > 1.00$); 3) sinuous ($1.70 < 1/L > 2.00$); 4) tortuous ($1/L > 2.00$); 5) broken (cut-off) ($1/L = 1.50\text{-}2.00$), where 1/L is the ratio of meander length to its wave length (Chalov et al. 2004).

In Udmurtiya the upper and lower river courses are typified by relatively straight--line non-braided channels, which account for between 16% of the total channel length in the River Siva drainage network and 28% in that of the River Izsh (Table 1). Meandering is the most typical of local fluvial processes and meanders are the most common channel form. Freely meandering rivers account for 77% of the overall river length in Udmurtiya (Petukhova 2003, Rysin, Petukhova 2004).

The most widespread meanders are those moving along the stream, accounting on average for 62% of the total (between 51% in the drainage network of the River Vala

Table 1. Reaches by morphodynamic channel type as a proportion of total river length (% channel length) in the Republic of Udmurtiya

Morphodynamic channel type	Cheptza	Vala	Kilmez	Siva	Izsh	Toyma and left-bank tributaries of the Viatka	Right-bank tributaries of the Kama	Udmurtiya average
1. Relatively straight-line non-branched	17	20	22	16	28	28	28	23
2. freely meandering	83	80	78	84	72	72	72	77
a) low-sinuosity	28	30	23	40	33	37	42	33
b) developed	18	21	20	15	17	19	22	19
c) sinuous	10	10	12	9	7	12	8	10
d) tortuous and cut-through	27	19	23	20	15	4	-	15

and 82% on the right-bank tributaries of the River Kama). Many of them represent various stages of meander development and indirect evidence of an active development of the sinuous channels. All three stages of meander development, low-sinuous to sinuous, can be found on individual rivers. The most common are the low-sinuous channels, at 33%, followed by the developed and sinuous types.

As the sinuous stage develops further, the channels either straighten up by cutting off the meanders to form oxbow lakes, or alternatively the channels transform into the tortuous type that travels both downstream and sideways. These two types of channels account for 15% of the overall river length, with a greater proportion in medium-sized rivers (23-27%) and a smaller proportion in minor rivers (4% or less).

A meander that passes from one stage of development to another changes its quantitative parameters, i.e. length, width, radius, wave length and height. There is, therefore, a close relationship between meander parameters and the characteristic river discharge rates.

It is a traditionally established method to study meandering channels by determining the empirical relationships between the meander parameters and the quantitative indicators of the channel formation conditions. Factors influencing fluvial processes include characteristic discharge rates (such as the channel forming discharge, average discharge, bankfull discharge and maximum flood discharge); drainage area, valley and river surface gradients (Makkaveyev 1955, 1971, Kondrat'ev et al. 1959, Makkaveyev, Chalov 1986). The river length is also taken into account in certain situations as it depends on the drainage basin size. These parameters determine the average discharge (Chalov et al. 2004). A study by Pakhomowa (2002), involving numerous Russian rivers, shows that there is a relationship between channel rank and the characteristic parameters of free meanders.

A number of relatively uniform (average discharge) river reaches were identified, their boundaries marked by confluences of large tributaries. In each of these reaches characteristic parameters were determined, such as: the meander wave length (L), radius (R), height (h), length (l); as well as complex parameters (l/L) and (R/h) characterising the meander development, shape and hydrological indicators. The determination of empirical relationships had

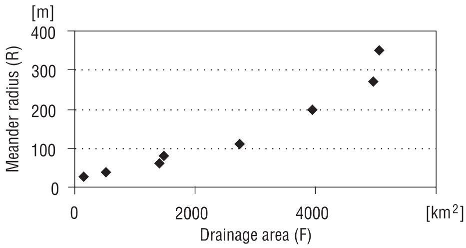

Figure 1. Meander radius (R) and drainage area (F) of the River Kilmez

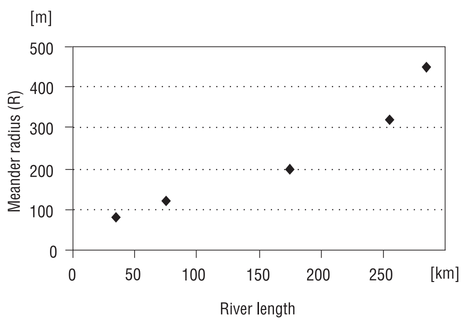

Figure 2. Meander radius (R) along the River Cheptza

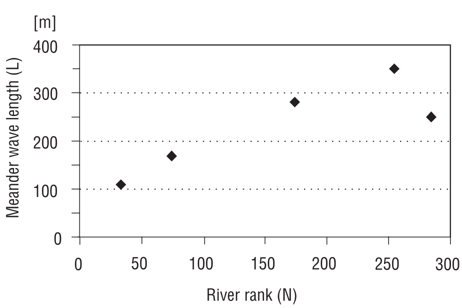

Figure 3. Meander wave length (L) along the River Cheptza

to rely on the river length, drainage area and the river rank due to the lack of sufficient hydrological data (there were just nine water gauging posts on the rivers studied).

The drainage area (F) reflects the regional channel forming conditions. That is why the r = f(F) ratio must be used for each river separately rather than for all rivers in general. The ratio, which can be identified precisely on each river (Figure 1), has a high correlation coefficient and has the form of a power.

There is also a strict relationship between the river length and meander radius, i.e. the longer the river, the longer the meander radius (Figure 2). The correlation is high for all rivers at ca. 0.95.

The meander wave length (L) also displays a strict positive correlation with the drainage area and the river length. The relationships are more complicated where those parameters dependent mainly on the shape of the meanders (l and h) are concerned, i.e. with the growth of the river size they first increase and then decrease in each of the characteristic meander shapes (Figure 3).

Rzhanitsyn (1985) proposed to utilise a relationship between the meander's hydrological and morphological parameters and the river ranks, the latter depending mainly on the river network structure. There are a number of schemes to determine river rank: according to Horton, Strahler-Filosofov, Rzhanitsyn, Scheidegger and others. In this study the Scheidegger scheme was employed: $N = \log_2(P)+l$, where: P is the number of first ranking tributaries (defined as a watercourse at least 10 kilometres long).

Hydrological river ranks calculated in this manner correlate with average morphological parameters of meanders within uniform river reaches. It was found that the basic parameters of free meanders, such as R, h, I, and L are quite strongly related to the river rank and to a lesser degree also between themselves. The significance of those relationships increases with the growth of the river rank (N) (Figure 4), i.e. with increase in discharge.

Patterns of changing river channel parameters depending on the river rank can be used as a criterion to differentiate between small and medium sized rivers (Pakhomova 2002). For the territory of Udmurtiya, it is proposed to classify as small (I) rivers ranked 1-5; as medium sized (II) those ranked 6-9; and as large (III) rivers ranked higher than 9. Other parameters of various ranking rivers, i.e. their length, width and gradient, also differ considerably (Table 2).

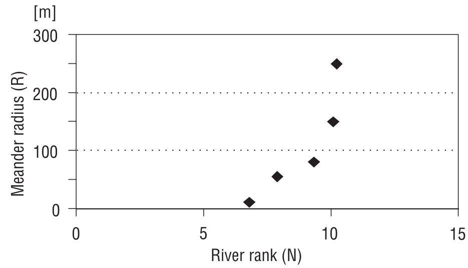

Figure 4. Meander radius (R) versus river rank (N). The example of the River Vala

Table 2. Characteristic features of various size rivers

Parameter	Group of rivers		
	I – small	II – medium	III – large
River rank	Up to 5	6-9	More than 9
Average discharge [$m^3 \cdot s^{-1}$]	< 2.0	2.0-20.0	> 20.0
Length [km]	< 25	25-100	> 100
Width [m]	5-10	25-100	> 100
Meander radius [km]	0.1-0.15	0.20-0.25	> 0.7
Gradient [$m \cdot km^{-1}$]	2-2.5	0.6-1.0	≤ 0.2

4. Bank dynamics

River ranking is also used to assess the intensity of fluvial system transformation. The Udmurtiyan rivers feature developed meanders since they cross plains, and this means that they will undergo bank transformation. The rate at which river channels move ranges widely from 0.1 to 10 metres per year or more. The average rate is ca. 0.5 metres per year (Table 3).

Table 3. Average annual retreat rate of river banks in Udmurtiya in 2000-2004

Reach No	River	Reach	Average annual bank retreat rate [m/year]				
			2000	2001	2002	2003	2004
1	Loza	Kush'ya	-	0.15	0.26	0.12	0.18
2	Niaz	Sundur	0.00	0.23	0.10	0.63	0.22
3	Loza	Loza	0.14	0.09	0.38	0.36	0.10
4	Ita	Zura	-	0.27	0.41	0.23	0.17
5	Cheptza	Debesy	0.48	0.44	0.44	0.52	0.15
7	Lyp	Sosnoviy Bor	0.43	0.19	0.24	0.24	0.19
8	Pyzep	Bani	-	0.86	0.32	0.68	0.18
9	Cheptza	Kamennoye	-	1.80	-	1.20	0.00

Table 3. Average annual retreat rate of river banks in Udmurtiya in 2000-2004 (continuation)

Reach No	River	Reach	Average annual bank retreat rate [m/year]				
			2000	2001	2002	2003	2004
10	Cheptza	Kozhylo	-	1.33	1.25	0.31	0.21
11	Varyzh	Keldykovo	-	0.42	0.32	0.29	0.10
13	Sepych	Glazov			0.49		0.12
14	Ubyt	Chura	-	0.34	0.13	0.00	0.00
15	Ubyt	Palagay	-	0.23	0.21	0.16	0.10
16	Cheptza	Yar	-	0.43	0.44	1.44	0.26
17	Cheptza	Diz'mino	-	1.27	1.65	1.05	0.25
19	Lekma	Nizshniu Ukan	-	0.16	0.07	0.0	0.14
20	Sada	Yur	-	0.17	0.10	0.05	0.06
21	Lema	Shamardan	-	0.10	0.05	0.08	0.10
22	Lekma	Pochinki	-	0.28	0.10	0.14	0.11
23	Kilmez	Goloviznin Yazok	-	2.24	1.43	0.56	0.20
24	Arlet	Chibir-Ziun'ya		0.29	0.23	0.13	0.11
26	Uva	Uva-Tiukla	-	0.45	0.51	0.37	0.17
27	Nylga	Nylga	-	0.57	0.63	0.45	0.14
28	Val a	Makarovo	0.52	0.98	0.52	0.38	0.21
29	Bilibka	Shoner	0.10	0.34	0.10	0.16	0.33
30	Sharkan	Titovo	0.51	0.12	0.56	0.15	0.15
31	Siva	Gavrilovka	0.27	0.60	0.85	0.23	0.20
35	Golyank	Golyany	0.38	0.20	0.25	0.3	0.32
36	Pozim	Kabanicha	0.44	0.05	0.12	0.28	0.10
37	Pozim	Pozim'	-	0.10	0.10	0.27	0.14
38	Izsh	Bolshaya Ven'ya	0.45	0.27	0.28	0.24	0.16
39	Ludzinsk	Yus'ki	0.33	0.46	0.27	0.13	0.10
41	Agrhyzka	Bagrash-Bigra	-	-	0.92	3.15	0.00
42	Postolk	Postolskiy	-	-	0.45	0.18	0.13
43	Bobinka	Abdes-Urdes	-	-	0.09	0.61	0.10
44	Piz'	Novokreshchenka	-	0.48	0.04	-	-
45	Kobylka	Klestovo	0.35	0.22	0.23	0.13	0.11
46	Khyrykm	Tavziamal		0.55	0.18	0.72	0.10
47	Izsh	Russkaya	0.22	0.12	0.14	0.46	0.10
48	Varzink	Yumyashur	-	0.15	0.11	0.20	0.27
49	Alnashk	Alnashy	-	0.19	0.21	0.15	0.17
50	Adamka	Grakhovo	0.20	0.25	0.40	0.15	0.19
51	Umiak	Russkiy Kuyuk	0.52	0.45	0.18	0.15	0.10
52	Umiak	Bazhenicha	-	0.15	0.13	0.13	0.12
53	Viatka	Krimskaya	3.25	3.97	4.53	3.0	1.23
54	Lumpun	Kharlamovskaya	-	-	-	0.16	0.10
55	Kilmez	Maliye Siumsi	-	-	-	0.65	0.00
		Average	0.48	0.54	0.50	0.47	0.17

Table 4. Bank retreat rate in rivers of various size

River size group	Average annual bank retreat rate [m/year]	Maximum bank retreat rate [m/year]	Relative bank retreat rate [%]
Small (I)	< 0.30	0.20-0.80	3.00-10.0
Medium (II)	0.31-0.60	0.40-1.50	1.50-3.00
Large (III)	> 0.61	> 1.50	1.00-1.50

The annual average (C_{mean}) and maximum (C_{max}) river bank retreat rates increase with increasing river rank (N) (Table 4, Figures 5, 6) with the respective correlation coefficients of 0.614 and 0.610. The relationship C = (f)N is expressed in exponential formulae: C_{mean} = 0.019exp0.35N; and C_{max} = = 0.022exp0.42N. The maximum river bank retreat rate differs greatly between small rivers, where it is a high value, and large rivers, where it is negligible. To eliminate an impact of river size on the river retreat rate an additional measure, the relative retreat rate (U) was introduced.

The relative retreat rate (U) expresses the ratio of the annual distance of bank retreat (B1) [m] and the average width of the water surface during the lowest water period (B2) [m] in a river reach: U = B1/B2 [%]. The relative rate (U) also displays a close relationship with the river rank (N), i.e. as the river rank increases the relative rate U diminishes (Table 4, Figure 7), which is expressed in the formula: U = 7.34exp(-0.154)N, with a correlation coefficient of 0.73.

The hydrological ranking is primarily driven by the average river discharge, which in turn influences the intensity of horizontal channel transformations. In the absence of channel forming discharge data the analysis of the bank retreat rates was carried out on the basis of the known average discharge (Q). As Q increased so did the average

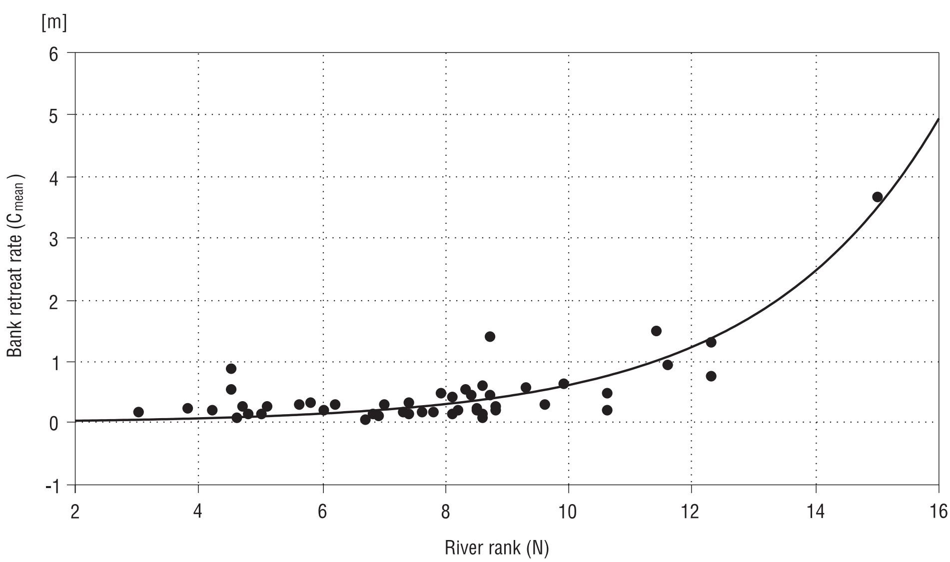

Figure 5. Annual average bank retreat rate (C_{mean}) versus river rank (N)

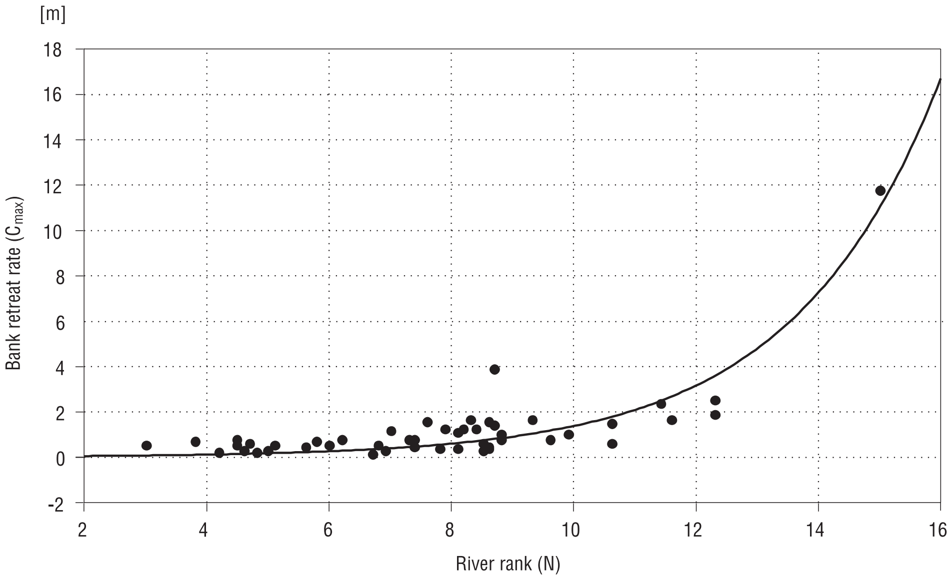

Figure 6. Maximum bank retreat rate (C_{max}) versus river rank (N)

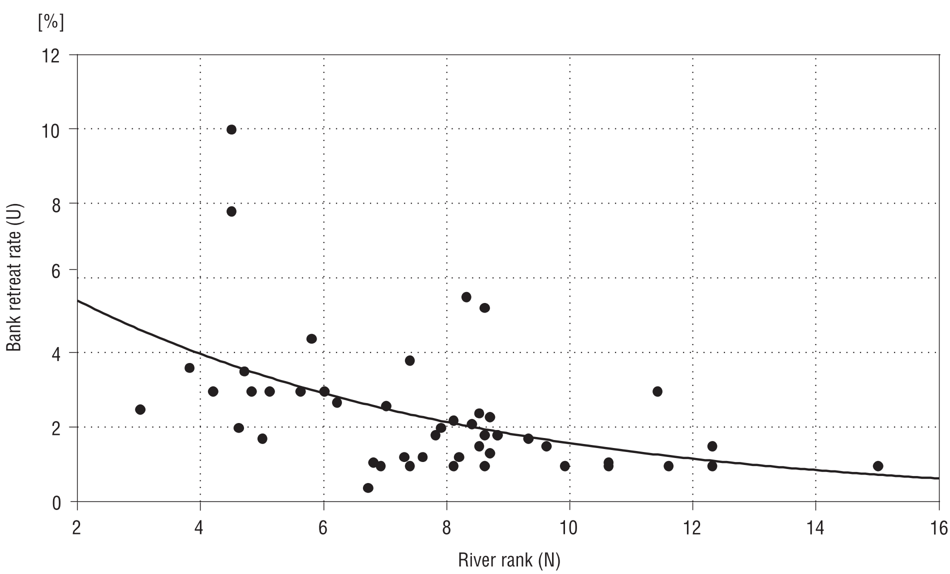

Figure 7. Relative bank retreat rate (U) versus river rank (N)

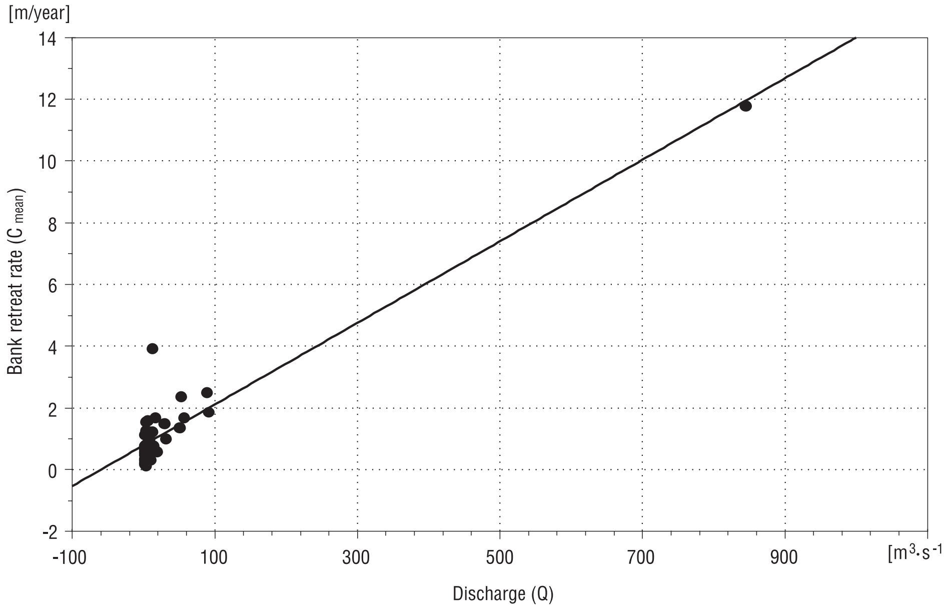

Figure 8. Annual average bank retreat rate (C_{mean}) versus average discharge (Q)

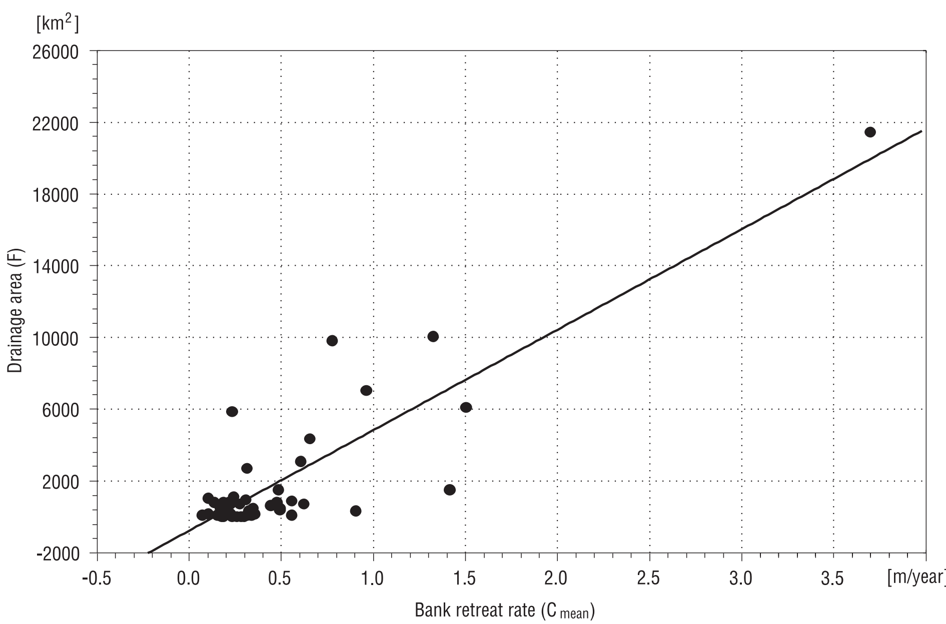

Figure 9. Annual average bank retreat rate (C_{mean}) versus drainage area (F)

and the maximum annual retreat rates (correlation coefficients respectively, 0.869 and 0.936). The relationship is of a linear type (Figure 8) and is expressed with the formula C = 0.795+0.013Q.

The average river discharge is a function of the drainage area. An analysis of the relationship between the bank retreat rate (C) and the drainage area (F) showed a strict relationship between them (Figure 9) with a correlation coefficient of 0.865 and the formula:C = 0.221+0.00013F.

The meander bank retreat rates differ along a river as a result of the changing discharge. For example on the river Cheptze, with its five study reaches (Table 5), the size of horizontal channel transformations generally increases downstream.

Table 5. Variation of average annual bank retreat rates along the River Cheptza

Reach	Distance from confluence [km]	Average annual bank retreat rate [m/year]
Debesy	52	0.5
Kamennoye Zadel'e	142	1.0
Kozhylo	168	1.2
Diz'mino	245	1.5
Yar	258	1.4

Flood flow and low-water level duration vary from year to year, just as does the average annual discharge. If over several years the frequency of floods and their related maximum discharge diminishes, then the channel transformations will also be reduced, and vice-versa. This type of relationship was found in all the hydrological posts on the Udmurtiyan rivers.

Other factors than discharge with an impact on the bank retreat rates include the river gradient, valley bed lithology, and the soil and vegetation cover, etc. To determine the role of these factors in driving lateral erosion, a correlation coefficient was calculated of the average annual bank retreat and the gradient of the studied reaches. Thus the correlation was established between the bank retreat rate and the meander radius. The results are shown in Table 6.

The river gradient has a considerable impact on the intensity of fluvial processes. The river erosion/transport capacity grows at steep gradients. This relationship is particularly evident for large rivers ($\eta = 0.758$), while group I and II rivers have lower correlation coefficients (respectively $\eta = 0.577$ and $\eta = 0.451$). A strong dependency of the bank retreat rate on the channel gradient is only observed in large rivers ($\eta = 0.835$), while in group I and II rivers there is no such impact.

Table 6. Correlation coefficient (η) between bank retreat and chosen river features

Group of rivers: (Number of rivers)	small I (14)	medium II (25)	large III (14)
River gradient	0.577	0.451	0.758
River reach gradient	0.250	0.211	0.835
Meander radius	0.687	0.381	0.812

Lateral erosion is also influenced by the meander radius. The longer the radius the faster the current at the top of the meander where turbulent flow develops and the bank retreat is the fastest. While in medium sized rivers this relationship remains small ($\eta = 0.381$), it grows in small rivers ($\eta = 0.687$), and peaks in larger rivers ($\eta = 0.812$).

The rate of retreat of the concave meander bank depends on the channel width during low water level. Most of the Udmurtiyan rivers, with the exception of the river Viatka, are small with channels up to 200 m wide and the retreat rate is not high. There is a strict relationship between river width and bank retreat rate with a correlation coefficient of 0.91.

Geology and geomorphology also play a considerable role in the formation of river channels. Details of a drainage basin geology largely determine the channel type and its deformation intensity. The annual average bank retreat rate is strictly related to the resistance of the material of the undercut banks. This is an inverted proportional relationship, i.e. the greater the bank material resistance, the slower the rate at which bank undercuts retreat. This is confirmed by calculated correlation coefficients. The relationship is particularly evident in group I and III rivers (small and large) and less so in the most numerous group II of medium-sized rivers, where the range of retreat rates and bank resistances is the greatest (Table 7).

Table 7. Coefficients (η) and (R) correlating the resistance of the banks to undercutting and their retreat rate

Group of rivers	R	η
I (small)	-0.766	0.62
II (medium)	-0.236	0.44
III (large)	-0.607	0.69

The rate of lateral erosion also depends on the degree of afforestation of the drainage basin (Table 8). Human activity has reduced Udmurtiya's forest cover causing changes to the local erosion/accumulation balance. The overall forest cover of the Republic stands at 48.3%, while forest cover in the drainage basins of the rivers studied ranged from 10-20% in the south to 70% or more in the north.

Table 8. Eroded river banks as a proportion of the total river length [%] in the Republic of Udmurtiya

Drainage basin	Group of rivers			Drainage basin average	Forest Cover [%]
	I (small)	II (medium)	III (large)		
Cheptza	6.4	10.3	33.3	15.7	60.0
Vala	3.6	7.7	35.1	12.6	61.8
Kilmez	0.1	8.0	35.2	13.0	71.3
Siva	6.9	12.1	71.0	16.6	48.2
Izsh	6.9	10.7	35.3	13.3	45.2
Left bank of Viatka and Toyma	9.2	28.9	14.5	19.7	45.5
Right bank of Kama	12.6	32.2	-	19.2	13.5
Left bank of Kama	2.4	10.9	42.8	10.4	75.6
Upper course of Viatka and Kama	0.0	4.3	-	3.1	85.9

5. Human impact on channel transformations

The contemporary status and development of rivers, despite the existence of natural factors, is defined by the degree of human intervention in the fluvial processes. Economic activity in river valleys is multifaceted, which is particularly evident in the valleys of large rivers. In Udmurtiya the predominance of small rivers means a lower human pressure, but small rivers respond more quickly to both natural and human changes in the drainage area.

The cutting of forests and intensive farming in the drainage basins has led to a growing concentration of the transported bedload in the rivers and its increased accumulation in the channels and on the floodplain. Often earth dams are erected in the summertime to conserve the water resources of small rivers. Many of them are destroyed during springtime floods causing the current to accelerate and activate erosion processes in the river channels. In 2003, the banks of the River Agryzka (River Izsh drainage basin) retreated by eight metres as a result of a dam break.

Channel morphology is often affected by engineering structures, including roads and railways, erected next to or within the channel. Bridges were among the earliest engineering measures influencing the channels. A bridge hampers flood flows leading to the emergence of a headwater wave upstream of the bridge (especially in small rivers) and a tailwater wave downstream. This accelerates the bank undercutting in the vicinity, especially below the bridge. As illustrated on some of the channel reaches studied, there is a clear difference in the intensity of the channel transformations upstream and downstream of a bridge with much lower retreat rates above the bridge (Table 9).

Table 9. Bank retreat rate above and below bridges (data from 2003)

Reach	Average annual bank retreat rate above bridges [m/year]	Average annual bank retreat rate below bridges [m/year]
Ita n/Zhur	0.10-0.15	0.25-0.40
Lyp n/Sosnoviy Bor	0.01-0.10	0.50-0.90
Gol'yanka n/Gol'yana	0.10-0.20	0.30-0.50
Ludzhinka n/Yus'ki	0.05-0.10	0.30-0.40

In the study of anthropogenic factors it must not be forgotten that rivers also have the capacity to cause an impact on human living conditions through their retreating banks which can damage engineering structures, farm fields and forests.

6. Conclusions

Rivers have predominantly broad channel beds in the Republic of Udmurtiya. Their upper and lower sections have relatively straight and non-braiding channels. The most typical fluvial process is meandering resulting in various types of meanders which account for 77% of the overall river length.

A strong positive relationship between meander parameters (radius and wave length) and those indirectly indicating the river water capacity (river length, drainage area and river rank according to Scheidegger) has been proven.

Regular observations carried out since 1999 along 55 study reaches have shown that the rate of horizontal channel movements varies greatly, from 0.1 to 10-13 metres per year or more. It was determined that the average and maximum annual bank retreat rates increased exponentially with increasing hydrological ranking of a river. The relative bank retreat rate shows an inverse relationship here. As the hydrological ranking is linked to the river's average discharge there is a strict relationship between the average and maximum annual bank retreat rate and the river's average discharge (r = 0.869) and drainage area (r = 0.865).

Alongside the average discharge, the bank retreat rate also depends on the following factors: river gradient, resistance to erosion of the channel bed geology, meander radius and width and forest cover in the drainage basin. The impact of the factors on the channel horizontal travel varies depending on river magnitude.

The development of horizontal channel transformations largely depends on human activity. The greatest impact is that of engineering structures erected on the river banks and in the channels, which exacerbate environmental problems in the valley floors.

References

Chalov R.S., Alabyan A.M., Ivanov V.V., Lodina R.V., Panin A.V. (Чалов Р.С., Алабян А.М., Иванов В.В., Лодина Р.В., Панин А.В.), 1998, *Морфодинамика русел равнинных рек*, ГЕОС, Москва.

Chalov R.S., Zavadsky A.S., Panin A.V. (Чалов Р.С., Завадский А.С., Панин А.В.), 2004, *Речные излучины*, Изд. Моск. Унив., Москва.

Kondrat'ev N.E., Liapin A.M., Pin'kovsky S.I., Fyodorov N.N., Yakunin I.I. (Кондратьев Н.Е., Ляпин А.М., Попов И.В., Пиньковский С.И., Федоров Н.Н., Якунин И.И.), 1959, *Русловой процесс*, Гидрометеоиздат, Ленинград.

Makkaveyev N.I. (Маккавеев Н.И.), 1955, *Русло реки и эрозия в ее бассейне*, Изд. АН СССР, Москва.

Makkaveyev N.I. (Маккавеев Н.И.), 1971, *Сток и русловые процессы*, Изд. Моск. Унив., Москва.

Makkaveyev N.I., Chalov R.S. (Маккавеев Н.И., Чалов Р.С.), 1986, *Русловые процессы,* Изд. Моск. Унив., Москва.

Pakhomova O.M. (Пахомова О.М.), 2002, *Горизонтальные русловые деформации и их связь с порядковой структурой речной сети*, Геоморфология, 3.

Petukhova L.N. (Петухова Л.Н.), 2003, *Развитие русловых процессов в условиях различных ландшафтов Удмуртии*, Вестн. Удм. Унив., Сер. Науки о Земле.

Rysin I., Petukhova L., 2004, *Monitoring of channel processes on the interfluve between the Kama and the Vyatka rivers*, [in:] *Sediment Transfer through the Fluvial System*, Proceedings of the International Symposium, Moscow, August 2004, IAHS Publication, 288.

Rzhanitsyn N.A. (Ржаницын Н.А.), 1985, *Руслоформирующие процессы рек*, Гидрометеоиздат, Ленинград.

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