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Characteristics of the slope and river runoff transformation and its influence on the activation of erosion and fluvial processes – a case study of small river basins in the Southern Urals and the Cis-Urals

Abstract: The paper presents an analysis of characteristics of changes in the slope runoff and the maximum water discharge during spring floods in small and medium river basins located in the Ural region. It has been shown that the ongoing degradation of natural catchment systems is manifested not only in the form of a reduced number of species in plant communities and their productivity, but also by transformations in the slope runoff and an increase in the maximum values of slope runoff during spring floods in river basins of different categories. This is evidenced by our long-term observations conducted at nature research stations and during long-term research expeditions. The growing human impact is accompanied by a large number of negative economic and ecological processes occurring in river basins and they should be addressed immediately. These processes are manifested in the form of erosion, riverbed deformations, as well as flooding and destruction of various objects, etc.

Keywords: river basin, natural complex, degradation, slope runoff, river runoff, economy, environmental impact, floods, destruction

1. Introduction

In recent decades, worldwide research has focused on the development of erosion processes. In Russia, the main emphasis in this area is put on the intensity of the development of gully systems as well as their classification in terms of the nature of their formation and development. This research has been particularly effective in the Moscow State University, the Kazan State University and the Udmurtia State University (Makkaveev and Chalov, 1984; Ryskin, 1998; Litvin et al., 2012; Veretennikova et al., 2016).

Apart from the above-mentioned works, particular attention should be paid to the results of research conducted at the Bashkir State University in terms of in-depth analysis of influencing factors, including slope and river runoff transformations (Gareev and Khabibullin, 2010; Gareev, 2015). The main feature that distinguishes this research is the fact that the intensification of the development of erosion processes is studied on the genetic landscape-hydrological level, which has some definite advantages. The main methodological approaches engaged in the course of the research conducted as well as their results are provided below.

The growing impact of human activities on natural complexes is accompanied by the formation of a large number of negative processes. They include processes associated with the transformation of slope runoff and flooding, which are of great importance due to their major economic and environmental impact. They can manifest themselves in the form of intensified erosion and transformation of fluvial processes. These processes are accompanied by the formation of both primary and secondary processes and phenomena, the mechanisms of which require comprehensive research and analysis (Kuchmen, 1960; Zorina, 2006; Gareev and Khabibullin, 2010).

It is known that due to the influence of exogenous processes occurring in the current climate conditions, the following distinctive elements of the relief has been formed: gully systems, valleys, terraces, floodplains and riverbeds of different categories that have characteristic features related to their origin within specific natural areas. At the same time, according to the information provided in numerous studies published in recent decades, there have been important changes reflecting a significant increase in the morphological processes and the rate of their manifestation and development. This is, for example, typical of New Zealand, Australia, Africa, North and South America, as well as large areas of the Eurasian continent. The main causes of negative processes are growing pasture digression, the violation of agricultural cultivation methods, the expansion of urbanized areas and others (Ryazantsev, 1999).

2. Methods and the study area

In order to study these processes in the conditions of varying anthropogenic impact on the catchment, we conducted long-term and large-scale comprehensive research on the degradation of natural catchment systems, especially in relation to the formation and variability of the slope runoff. We also studied the development of erosion, fluvial processes and formation of floods (catastrophic ones in particular). The research was carried out in 1995–2014 in the

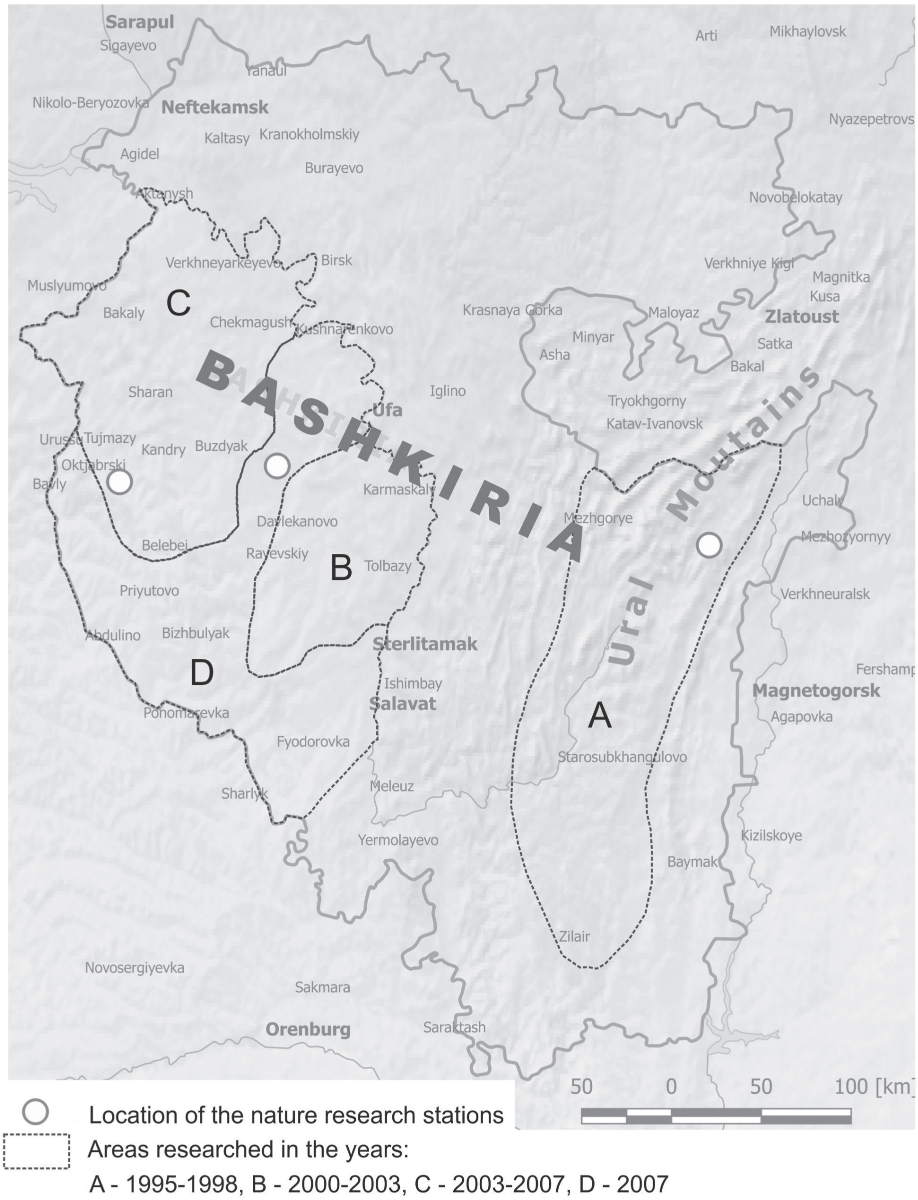

Figure 1. The study area: the Southern Urals and its direct western foreland - Cis-Urals

mountain-forest and forest-steppe zones of the Urals including the Southern Urals (Fig. 1) through a field survey and observations at nature research stations. The research on the conditions of formation and variability of the slope runoff, depending on the influence of human activity, was carried out at runoff sites, temporary streams and permanent watercourses (rivers) of the 1st and 2nd orders (the order of runoff formation in the catchment).

3. Results

According to the data presented in Table 1, values of slope runoff modules ($l \cdot s^{-1} \cdot km^{-2}$) vary significantly depending on the impact of degradation of natural systems in the catchment. Thus, the runoff was not observed at undisturbed experimental sites in all years with different rainfall, but there was a significant increase at sites with growing degradation, which consequently contributed to the intensification of erosion processes. Similar patterns are typical of small rivers, which can be used to assess values of the absolute and relative increase in the maximum discharge during spring floods and thus the increase in destructive capacity of water flows.

Table 1. Increase in the slope runoff depending on the extent of degradation of natural catchment systems

№	Degradation level	Characteristics	Runoff modules $l \cdot s^{-1} \cdot km^{-2}$
1	None	Typical characteristics of natural systems	0
2	Low	There are some changes in bioproductivity of plants and species composition; in some places, soil compaction has reached the level of pasture digression.	50-150
3	Medium	The areas are characterised by considerable scarcity of woody and herbaceous vegetation, trodden paths, reduction in vegetation species composition; neophytes typical of degraded areas can be found and soil washout is observed.	180-250
4	High	There has been a major change in vegetation species composition; species adapted to conditions of pasture digression have survived; the exposed areas with manifestation of sheet erosion as well as gullies and ravines have been formed.	277-450

In order to analyse the runoff changes in detail, we divided the study area into zones according to the range of human impact, including grazing, which allowed us to assess the changes in a varied manner.

Synthesis and analysis of materials collected during experimental and field observations allowed us to determine the magnitude of transitory (correcting) factors that should be taken into account in order to assess the maximum water discharges with respect to their increase up to a specific value depending on the extent of human impact. Values of the factors are presented in Table 2.

Table 2. Transitory factors (Ki) used to calculate the maximum water flows during spring floods on rivers with minor anthropogenic changes in the mountainous regions of Bashkortostan

Group of zones	Zone number – degree of anthropogenic load	Ki
I	1, 5, 9 – standard	1
II	3, 4, 8 – slight excess	1.25
III	2 – average excess	1.5
IV	7 – significant excess	2.0
V	6 – great excess	2.5

Thus taking the above into account, the calculation formula for the first order rivers in the study area is as follows:

$$Q_{pi}=F_i q_{pi} K_i, \quad (1.1)$$

where Q_{pi} is water discharge in % of availability;
F_i is the catchment area relative to the *i*th section (cross section of the monitored reservoir); q_{pi} is a runoff module [$l \cdot s^{-1} \cdot km^{-2}$]; K_i is a transitory factor.

At the confluence of several first order rivers (or elementary basins), resulting water discharges are determined by the formula:

$$Q_{pi}=\Sigma Q_{pi}= \Sigma F_i q_{pi} K_i \quad (1.2)$$

Explanation of the symbols as above.

As shown previously, with the increase in the order of rivers in relation to the local reduction of the floodplain complexity and the water accumulation capacity (while maintaining other physico-geographical conditions), there is a certain decrease in the spring runoff modules, depending on the distribution of water in the floodplain complex.

Taking the above into consideration, the calculated value of the maximum discharge for rivers of the *n*th order can be defined by the following formula:

$$Q_{pi}= A\Sigma F_i q_{pi} K_i, \quad (1.3)$$

where A is the transformation ratio of the river flow measured by the correlation of actual and estimated data.

In river basins whose natural systems have undergone significant negative changes (effects of degradation processes), the corresponding increase in the estimated maximum of water discharge can be determined based on the value of $\Delta Q_{p\%}$, i.e. the absolute value of water discharge in respect of the natural complex degradation. Consequently, the absolute (estimated) value of the maximum water discharge, resulting from the degradation of natural systems in the catchment (without regulation of runoff by ponds and reservoirs) can be defined by the expression:

$$Q'_{p\%}= Q_{p\%} + \Delta Q_{p\%}, \quad (1.4)$$

where $Q_{p\%}$ is the calculated value of the maximum discharge p% probability with no effect of degradation of natural systems in the catchment.

Thus, the correlation between the values $Q'_{p\%}$ and $Q_{p\%}$ can be presented as the following ratio:

$$K = \frac{Q'p\%}{Qp\%}, \quad (1.5)$$

which can be used to determine the maximum meltwater discharges of a surveyed river.

On the basis of special calculations and estimates, we have determined the values of K in each of the studied river basins (Table 3).

As shown in Table 3, for most of the rivers in the Urals region, the value of the multiplying factor is in the range of 1.12–1.17. The

Table 3. Values of the factor (K) in the calculation of the maximum meltwater discharge in the river basins of the Ural region

№	River – monitored section	K	Notes
1	the Chermasan – New Yurmanovo	1.12	
2	the BolshoyIk – Taishevo	1.08	
3	the Buy – TatarUrada	1.27	TBS
4	the Bir–Malosukhoyazovo	1.14	
5	the Urshak– Lyahovo	1.17	
6	the Lemeza – Nizhnyaya. Lemeza	1.14	
7	the Miyaki – Miyaki-Tamak	1.14	

deviations occur in the basins of the BolshoyIk (Taishevo) and the Buy (Tatar Urada). In the former case, the reason are almost untouched forest complexes in the basin. In the latter case, it should be determined during further calculations and evaluations.

As shown earlier, degradation of natural (forest) complexes in the mountainous Bashkortostan as well as in the vast areas of the Urals region occurs as a result of overgrazing, as well as the imposition of other types of human activities (deforestation, household use, littering, etc.). This leads to the formation of a complex of factors contributing to the intensification of transformation, changes in the slope and river runoff and the growing impact of some negative ecological and economic processes, such as further development of erosion processes, changing trends in erosion-accumulation processes, siltation of a riverbed in lower reaches, siltation of ponds, reservoirs, floodplain complexes, etc.

The ability to predict values of the maximum water discharge, while taking into account the assessment of the effect of specific (existing) characteristics of factors determining the runoff is of great interest for practical purposes. For example, with the determined values of the factors for the before-flood period in winter and using specific calculation methods and assessments, we can determine the expected value of the maximum discharge in the percentage of availability. For this purpose, the following equation can be used:

$$Q_p=f(W_p,h_{cp,p,}R_{p,}\Delta_{t,p}), \quad (1.6)$$

where W_p is the autumn moisture reserves in soil, $h_{cp,p}$ is the water equivalent of snow before melting, R_p is the depth of frozen soil during the winter season, $\Delta_{t,p}$ is the growth rate of positive temperatures during a spring snowmelt.

In general, values of 1% of water availability are accepted in calculations, which is a combination of corresponding values of factors responsible for runoff. Spatial variability of selected characteristics are presented in the work by A.M. Gareev and I.L. Khabibullin (2010), which can be used in hydrological and water management calculations.

In conclusion, the obtained results show the increase in the maximum water discharge in small and medium rivers. It should be emphasised that the landscape-hydrological approach presented in this work should be considered when assessing such characteristics as: the increased runoff, the development of erosion processes, changes in water discharges forming a riverbed, riverbed erosion intensity, emergencies and environmental disasters related to the deformation of oil-product pipelines running through the river network, the stability of hydraulic structures, bridge crossings etc.

4. Conclusions

Long-term field experiments and observations have revealed that natural systems degrade along with the growing anthropogenic factors. The main effects of the negative human impact are as follows: the increase in the maximum water discharges as part of the slope and river runoff and the increase in the destructive capacity of water flows.

Analysis of the significance of factors affecting the formation of the maximum discharges during the spring flood shows that within the Southern Urals and the Urals region, these factors include: changes in the value of autumn moisture reserves and water reserves in the snow cover, changes in the depth of frozen soil and in the intensity of the air temperature rise during spring snowmelt.

The revealed regularities should be taken into account when addressing the practical problems.

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