

The main characteristics of slope and river runoff transformations under the conditions of degradation of natural complexes on the catchment

*Aufar Gareev**, and *Mansur Gainanshin*

Bashkir State University, 32 Z. Validi St., 450076, Ufa, Russia

Abstract. The article shows that conducting hydrological calculations in the basins of very small and small rivers and their catchments is associated with significant errors, which is accounted for not only by the drastic limitations of the observational materials, but is also due to significant slope and river runoff transformations depending on the impact of natural complexes degradation (plant communities, soil cover, etc.). In the meantime, it should be noted that the emergence of a number of adverse processes, such as the propagation of erosion and channel processes, floods, environmental and economic damage inflicted on natural and economic systems, etc. is largely associated with the slope and river runoff transformations. This predetermines the necessity of investigating the processes in question. Given the above-mentioned, the article serves to reflect the results of research conducted within the mountain forest area of the Southern Urals and the Cis-Urals by the academic staff of the Department of hydrometeorology and geoecology of the Bashkir state university from 1955 to 2012. The main factors contributing to the increased maximum water discharge during the spring flood are confined to an increase in the modules of runoff coefficients as the scale of anthropogenic load on natural complexes increases, and, consequently, to a decrease in the natural water-regulating capacity of the catchments. The above-mentioned processes have resulted in the increasing maximum values of slope and river runoff and account for the adverse effects observed in the natural, economic and ecological systems.

1 Introduction

One of the currently observed characteristic features reflecting the formation and development of processes in natural complexes and natural-economic systems consists in the fact that vast land areas display a rather high degree of transformation and degradation. The occurrence of such phenomena as erosion and channel processes, landslides, mudflows, etc. entails adverse economic and environmental consequences. This necessitates studying the regular patterns that reflect the mechanism, the structure and the

* Corresponding author: mansur5701@mail.ru

trends of ongoing changes with a view to minimize the damage from the negative impact of anthropogenic factors.

Based on the above-mentioned, large-scale and long-run research has been conducted within the Southern Urals and Cis-Urals to assess the impact of pasture land degradation towards the slope and river runoff transformations and, consequently, in respect of the development of sheet and linear erosion.

2 Research data and methods

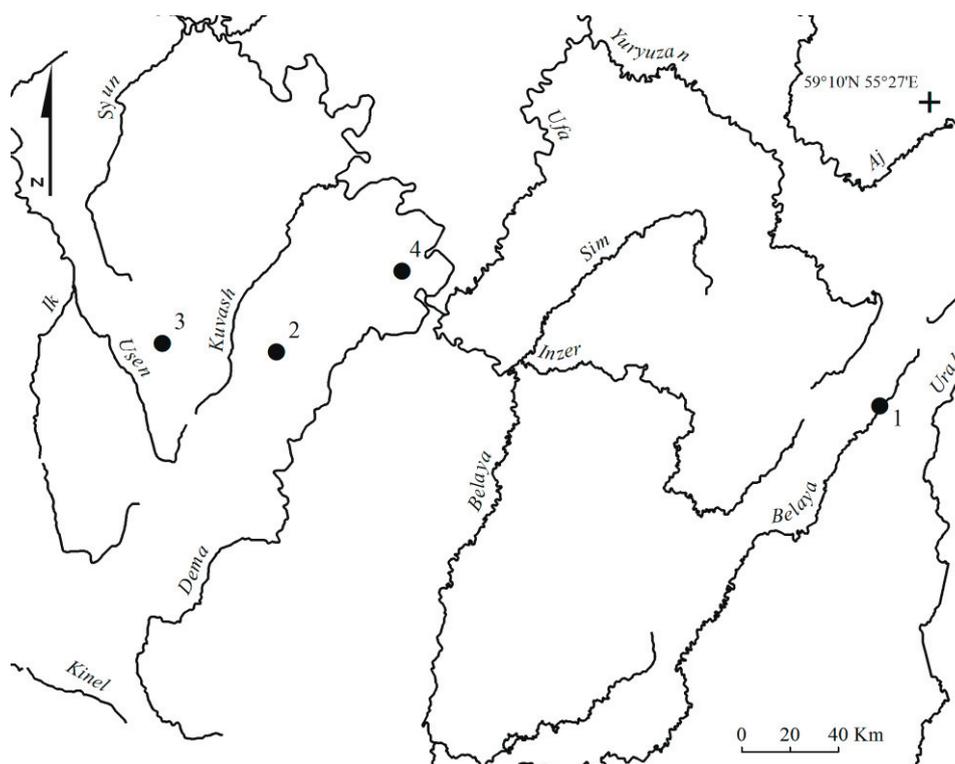


Fig. Locations of natural stations within the Republic of Bashkortostan: 1 – Makhmutovsky station; 2 – Udryakbashevsky station; 3 – Urmekeevsky station; 4 – the water-balance station "Dmitrievsky".

The observations covered the period 1955-1999, where after in 1999-2012 field experiments, testing and observations were carried out in the forest-steppe zone of the Urals on the basis of the Udryakbashevsky and Urmekeevsky stations to clarify and verify the obtained patterns.

Variations of the slope runoff coefficient (α) and the runoff modulus (μ) are accepted as the main indicators allowing the explicit identification of spatial differentiations and transformations of the slope runoff and ablation, as well as the increases in their absolute values and in the indicators of the damaging capacity of the flows in the conditions of increasing anthropogenic loads on the natural complexes. According to the data provided in Table 1, the slope surface runoff modules ($l/s \cdot km^2$) tend to vary widely depending on the influence of the degree of degradation of natural complexes at the water catchment.

Depending on the peculiarities of formation as well as the spatial and temporal variability of the influence caused by the factors in total, the following 3 items should be

distinguished: 1) slope runoff, 2) runoff of small rivers of the 1st category and 3) runoff of the n-th order rivers.

With respect to assessing the degree of increase in the slope runoff values (Δy) and the augmentation of erosion processes under the conditions of degradation of natural complexes, the most indicative (significant) are the slopes of the southern, southeast, and southwest expositions [1]. Depending on the scale of anthropogenic loads, the runoff modulus values may increase by 0-10 l/s·km² with the weak one, by 15-250 l/s·km² with the medium one, and by 340-350 l/s·km² with the strong one respectively. In this case, a sharp increase in the water flow intensity, soil and subsoil erosion, and the development of processes of sheet and linear erosion is observed.

Table 1. Slope runoff values formed subject to the impact exerted by various levels of degradation of the natural complexes at the catchment (at the Makhmutovsky station).

Degree of degradation	Characteristics	Runoff modulus, μ , l/s·km ²	Runoff coefficient, α
Not present	Typical characteristics of natural complexes are retained.	0	0
Weak	Minor changes in the vegetation species composition, occasional soil compaction in the area of pasture degradation.	50–150	0,15–0,25
Medium	Substantial scarcity and declining in the species composition of the tree and grassland vegetation, the formation of trodden paths, the appearance of neophytes characteristic of degraded landscapes; clear-cut soil ablation.	180–250	0,30-0,45
Strong	Radical changes in the vegetation species composition, clear-cut manifestations of exacerbated sheet erosion, the formation of gills and ravines.	277–450	0,5-0,65

While clarifying and substantiating the results obtained for the mountainous areas of Bashkortostan, on the basis of similar studies for the basins of small and medium rivers of the South Cis-Urals in 1999-2012 (see Fig.), the peculiarities of changes in the maximum runoff were investigated for the long term, taking into account the presence of genetic associations both between the principal runoff-generating factors and the combined value of the influencing factors as well as water discharges of the studied line gauge.

The dynamics of temporal variations of the principal (natural) runoff-generating factors was studied for each of the stations and agrometeorological observation points, arranged at the basins selected in terms of the lowest values of artificial runoff regulation.

Taking into account the analysis of calculation and estimation data, including graphical associations, it was revealed that the river runoff trends peculiar to the rivers in the mountainous areas of Bashkortostan are also characteristic of the Cis-Urals. At the same time, the relative increase in maximum runoff for the period 1970-2000 is varied to a significant degree (5-16%), which, except for the spatial differentiation of the scale of anthropogenic load, plough-disturbance of the catchment area, etc., depends on the cavernous porosity indicators of the river basins.

The slope runoff transformation values, depending on the degree of degradation of natural complexes, are characterized by the same indicators as the mountainous area of

Bashkortostan. A distinctive feature is the fact that the formation and a substantial increase in slope runoff are observed here on the slopes of the northern exposure with a great incline. This is facilitated by the abundant subtraction of the material washed down from the superposed eroded sections, as well as by the colmatage and reduction of their water absorption capacity. This is quite frequently observed on the slopes of different orientations within uplands in the Tuymazinsky district in the B. Nugush river basin, in the proximity of the Urmekeevo village. It should be noted that this section is one of the conventional research objects where various conditions, rates of transformation in the slope runoff, and, consequently, propagation of erosion processes of various types as well as landslides are easily observed.

The modulus values of the maximum instantaneous slope runoff at a natural station located in the Blagovarsky district, despite the propagation of karst formations in the basins of temporary watercourses, amounted to 762 l/s·km², also contributing to the intensive development of sheet and linear erosion.

Thus, relying on the generalization of the vast long-term research data obtained both from the basins of the mountainous areas of Bashkortostan and the Cis-Urals, we can infer with great confidence that the degradation of natural complexes is accompanied by a substantial growth of the slope runoff and the maximum water discharge of small rivers. This is reflected in changes of the landscape-forming, environmental and economic characteristics of the territories, it should be taken into account not only in making adjustments to the river runoff indicators, but also in the water management and water protection activities at the river basins of various categories.

It is known that the maximum water discharge values are used as indicators for various water management and hydrological-ecological calculations (applied in constructing hydrotechnic facilities, substantiating anti-erosion measures, etc.). Meanwhile, as it is evident from the practice of calculations, the identification of the maximum discharge rates of spring floods using conventional methods in some cases leads to low accuracy. Thus, according to the research conducted by V.K. Ryazantseva [2], the inaccuracy in traditional calculations is quite high and often amounts up to 20-400%. Moreover, these studies are based on probabilistic approaches and tend to ignore the changes occurring in the catchment.

Proceeding from the above-mentioned, it should be noted that while determining the maximum water discharge for small and medium rivers in relation to water management calculations, it is necessary to make appropriate (multiplying) corrections depending on the degree of anthropogenic loads and the degree of degradation of natural complexes at the catchment. In the meantime, it should be borne in mind that: 1) the degradation of natural complexes is accompanied by a change in the correlation between runoff-generating factors in the direction of increasing the maximum discharge of both the slope and the river runoff; 2) applying the formulas recommended in reference books (construction codes and regulations) when designing water facilities for small unexplored rivers of the 1st and 2nd order (hydrotechnic constructions, anti-erosion measures), results in inaccuracy and affects the reliability of the calculations and estimates in relation to the water management design. In accordance with the above-mentioned, while calculating the maximum water discharge of spring floods, it is necessary to take into account the influence of anthropogenic load by introducing the corresponding correction factors [3].

3 Results

Based on the analysis of the data reflecting the changes in the indicators of the coefficients and runoff modules, identified using measurements within the mountainous areas of Bashkortostan, the averaged values of the transition coefficients have been determined,

taking into account the degree of anthropogenic loads on the catchment in the previously identified areas. Their values are to be found in Table 2.

Table 2. The values of transition coefficients (K_i) for the resultant anthropogenic load on natural complexes in calculating the maximum discharge of spring floods for small rivers of the mountainous areas of Bashkortostan.

District groups	District numbers – degree of anthropogenic load	K_i
I	1,5,9 – reference	1
II	3,4,8 – slight excess	1,25
III	2 – medium excess	1,5
IV	7 – significant excess	2,0
V	6 – large excess	2,5

Thus, taking into account the above-mentioned, the calculation formula for the 1st order rivers is as follows:

$$Q_{pi} = F_i q_{pi} K_i, \quad (1)$$

If several rivers of the 1st order (or elementary basins) merge, the resulting water discharge is determined by the formula:

$$Q_{pi} = \sum Q_{pi} = \sum F_i q_{pi} K_i \quad (2)$$

As it was shown earlier, while the river orders increase, depending on the presence of local recessions in flood-floodplain complexes and their accumulating capacity (with the other physical and geographical conditions retained), a certain decrease in the modulus values of spring runoff occurs. Given the above-mentioned situation, the estimated value of the maximum discharge for small rivers of the n-th order can be determined by the formula:

$$Q_{pi} = A \sum F_i q_{pi} K_i \quad (3)$$

where A is the river runoff transformation coefficient determined by the correlation of the actual and calculated data.

Having made predictive calculations of the maximum water discharge, taking into account a combination of climatic factors and the degree of anthropogenic load, as well as having constructed cross sections for each river station, using the $Q = f(H)$ graphs and detailed topographic maps, the flood zone area can be identified, the economic and environmental damage from the floods may be estimated.

In respect to river basins, within which natural complexes underwent significant adverse modifications (degradation processes), the corresponding increase in the estimated maximum water discharge can be determined on the basis of recording the increase in water discharge by $\Delta Q_{p\%}$.

Consequently, the absolute (calculated) value of the maximum water discharge formed as a result of the degradation of natural complexes at the catchment (in the absence of regulated runoff at ponds and reservoirs) can be determined by the formula:

$$Q'_{p\%} = Q_{p\%} + \Delta Q_{p\%}, \quad (4)$$

where $Q_{p\%}$ is the calculated value of the maximum water discharge of $p\%$ availability in the absence of the influence of natural complexes' degradation on the catchment. Thus, the ratios between the $Q'_{p\%}$ and $Q_{p\%}$ indicators form a multiplying coefficient

$$K = Q'_{p\%} / Q_{p\%} , \quad (5)$$

Using the above coefficient it is possible to determine the value of the maximum melt-water discharge at the main-stream station of the analyzed river. It should be noted that the identified patterns are in line with the results of studies conducted earlier by N.I. Koronkevich [4], G.V. Nazarov [5], V.E. Vodogretsky [6]. Thus, they have revealed in sufficient detail the characteristics of the reducing slope runoff under the afforestation of territories occupied by agricultural land, changes in the water absorption capacity of various types of soils, which makes their application possible even when anti-erosion measures are taken, with consideration to the scale of the anthropogenic load impact on components of natural complexes and natural and economic systems. This reflects the importance of landscape-hydrological research.

The results of the given research can be successfully employed in substantiating anti-erosion measures, to prevent (minimize the scale) of adverse effects of floods, etc., taking into account the anticipating character (forecasts) of hydrological calculations and estimates.

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