Factors of gully erosion on agricultural lands of the Republic of Tatarstan

Regina Azatovna Gaifutdinova*, Oleg Petrovich Yermolaev
Kazan Federal University, Institute of Environmental Sciences, Kremlevskaya st., 18, Kazan, 420008, Russia

ABSTRACT

This article discusses the factors of gully erosion and their spatial and temporal variation. According to the intensity of spatial and temporal variability of action all factors are divided into the groups of conservative and dynamic factors. The conservative group combines geological and geomorphological factors. The dynamic group is represented by anthropogenic and hydroclimatic factors. In order to explore the current dynamics of gully erosion on the territory of the Republic of Tatarstan the remote sensing of Earth data were used. Six basic pools, located in different geomorphological landscape areas, were selected as the objects of study concerning modern gully erosion. Using multi-temporal satellite images within the studied basins a linear and an area increment of gully systems were revealed. The major factors of gully erosion on the territory of the Republic of Tatarstan are determined on the basis of the studied elementary basins.

Keywords: gullies, gully erosion factors, space images

INTRODUCTION

Gully erosion is one of the most active geomorphological processes which determine the current division of relief, creating a threat of land and economic facilities destruction that make an impact on the state of hydrographic network upper parts [1]. The formation and the subsequent development of the gully forms are determined by a set of factors contributing to the gully appearance and determining the dynamics of its further development. One may determine two main trends in the study of gully erosion: 1) a comprehensive approach based on N.I. Makkaveeva's concept concerning the unity of erosion-accumulative processes in the water collection area; 2) the regional approach in the study of natural and anthropogenic

factors specificity. The assessment of various factors impact and their variability in time and space is important for each of these approaches.

According to N.I. Makkaveev's concept each link of the erosion network has different order flows and one need to assess separately the impact of each factor on the erosion activity of each flow network link [2]. The following is referred to the zonal erosion factors: climatic factors of runoff development, soil and vegetation cover. The azonal elements are the following ones: geomorphological structure and the nature of the territory cover rocks, modern tectonic movements and the vibrations erosion basis marks.

A great influence of surface runoff from the slopes occurring during heavy rains and snow melting is made on the development of erosion in gully network. The relative contribution of snow and rain floods varies depending on the catchment area. According to N.I. Makkaveev, the catchment area makes about 10-20 km^2 in forest zone, 100 km^2 in forest-steppe zone and up to 1000 km^2 in steppe zone. Snow flooding is greater than rain flooding at the excess of this area.

An integrated approach is used during the study of gully erosion in the overall system of exogenous processes occurring on the plains of the temperate zone [2; 3; 4] and in the mountains of southern Siberia [5]. The authors specify that the formation of gully network is facilitated by the development of suffusion, due to the formation of voids in the soil, and recurring natural fires, disturbing the natural vegetation, which leads in its turn to the increase of surface water runoff by several times.

The intensity of the collapse-scree processes developing on the sides of gullies, depends largely on the combination of meteorological conditions and the chemical and physical characteristics of the ground, forming the specific slope, and the periodic occurrence of floods which could take off the material accumulating at the foot slope. Anthropogenic factors include the following ones: plowing, overgrazing on pastures, the construction of settlements and transport communications and other violations of the vegetation cover, which protects soil from erosion [2; 3; 6].

Regional studies are divided by study territory and its area. N.N. Nazarov's article "On the issue of gully development factors in Perm Cis-Ural region" [7]

presented the results of the study concerning major factor determination concerning the development of various types of gullies. The evaluation of factor impact, their variability over time is determined by statistical analysis of gully formation indicators (mathematical modeling was applied, which includes up to 36 parameters of gully formation).

Foreign literature divides gully erosion factors into two groups: natural and anthropogenic ones. Anthropogenic factors include: a) unreasonable land use, b) overgrazing, c) mining, d) road construction, e) vehicle ruts. Four factors make up the group of natural gully formation factors: 1) relief, 2) precipitation, 3) lithology and soils, 4) vegetation. There is lot of information about the reaction of gully systems the on climate change. [8] For example, the annual amount of precipitation in Western Australia significantly decreased over the past decade, but rainfall intensity decrease is not observed [9]. There is also a greater impact of changes in land use on the development of gully erosion than as compared with climate change [10]. Over the past 25 years a significant reduction is observed in the rate of river system sediment redistribution within the agricultural zone of the Russian Plain. It was influenced by two main factors. The first of these is associated with a significant reduction in surface runoff during snow melt, resulting in gross soil loss decrease. The second factor is the most important in the Middle Volga region, it is associated with a large reduction of arable land area [11]. All studies were performed on the project Russian Science Foundation (RSF) «Spatial-temporal patterns of contemporary processes dynamics of natural and human-induced erosion on agricultural lands of Russia».

MATERIALS AND METHODS

Six elementary basins located in different geomorphological landscape areas were selected as the objects of study on the territory of the Republic of Tatarstan. The choice of the territory was influenced by: a) the availability of sufficient amount of source material, b) the location of basins in three physical-geographic regions of the Republic of Tatarstan: Volga region, Western and Eastern Kama region - two basins in each area for comparative characteristics of gully formation process in similar physical-chemical geographical conditions. According to the geomorphological zoning of the Republic of Tatarstan territory (according to A.P. Dedkov, 1999), all selected basins represent a moderately dissected denudation plain of the lower plateau, which is the denudation surface with the heights of 140-160 of Meo Pleistocene age, formed in the periglacial climate [12]. There are also the similarities in the geological structure of the studied areas. Coating (overlapping) deposits constitute loams, slightly compacted forest sandy loams, sands, the capacity of which ranges from first meters up to 10-12 m are presented on the territories of all selected basins. The same value of the average density of gullies (0.4 km/km^2) is observed in the basins of Volga region and Eastern Kama region. In West Kama region this rate 2 was times less (0.2 km/km^2 on the average). The same area is characterized by minimum depths of erosion dissection, compared with Volga region and East Kama region.

The maximum average density of beams (0.8 km/km^2) among the studied areas of the Republic of Tatarstan at Western Kama region basins, the minimum one (0.3 km/km^2) is presented at Volga region basins. There is an inverse relationship gully density and beam density on the territory of the studied basins. Gully density indicator has significant differences. The highest values (0.8 of gully peak number per 1 km^2) belong to the basins located in Volga region. The mean value of gully density for Kama region territory is twice less than in Volga region and makes 0.4.

All elementary pools are located in the areas with a relatively high density of rural population (at least 5 men per 1 km^2), which provides the emergence of gully erosion on the territory of the Republic of Tatarstan. The low percentage of forest

coverage (no more than 35-40%) indicates favorable conditions for gully development.

Nowadays, there is a large number of methods for erosion intensity evaluation [13; 14]. In order to study the current dynamics of gully erosion on the territory of Volga region and Kama region of the Republic of Tatarstan, the data of the Earth remote sensing were used. Using multi-temporal satellite images within the studied basins a linear and an areal gain of gully systems were studied. In order to recognize the gully forms the interpretation of images is applied. Multi-temporal space images were taken from the program with public access Google Earth [15]. We used the multizone images of high and ultra-high resolution, distributed free of charge in digital form. The selection of images was carried according to the following parameters: 1) the quality of the picture is high and ultra-high; 2) flight period (the images of spring and autumn seasons have the highest priority); 3) The time period of images should provide the possibility to trace the dynamics of gully erosion. In accordance with the time period of selected images the period of study made 2009 - 2014.

RESULTS

In one year the largest linear increase of gullies is observed in Volga region basin (B.r. Ulema, Shonga r.) and it made 0.7%. An average growth of gullies in the basins of East Kama region made 0.35%. In West Kama region zero result means that along with the growing gullies there are those which stopped growing and significantly reduced its linear size. Thus, the increase and decrease of all gully linear dimensions with the basin at the calculation of the average value led to a zero result.

The analysis of areal growth of gullies showed similar results in the studied basins: a) the maximum areal growth was marked in Volga region basins (2% and 2.3%), b) the areal increase of gullies in Eastern Kama basins makes 3 times less than in Volga region basins c) the total areal increase of gullies in the basins of the Western Kama region showed zero results.

The most part of gullies on the territory of elementary river basins of East Kama region had no linear growth during the analyzed period. Approximately 1/5 of all

basin gullies had the linear growth of 1%. Area increase was observed among a greater number of gullies, as compared with the linear growth indicators.

Most part of gullies in the basins of Volga region has linear and areal increase during the study period, as compared to Eastern Kama basins. There is a significantly less number of gullies which ceased to grow. The basins of Volga region show the maximum values of gully density, as well as the values of linear and areal growth. This area of the Republic of Tatarstan is characterized by an active process of gully formation. The increase of gully formation in the basins of Western Kama region basins is marked locally. The gullies are determined which have up to 1% of linear increase and the area increase up to 3% during a year.

CONCLUSIONS

The factors have different effects of impact on the modern process of gully formation. The greater the intensity of the spatial and temporal changes of factor indicators, the greater its manifestation in the development of gully network. These dynamic factors should be represented by hydroclimatic and anthropogenic factors. Such conservative factors as geomorphological and geological ones are presented weakly in short time intervals. However, the division into dynamic and conservative factors is a conditional one, because factor indicators may change greatly during a decade or two and may change weakly or remain unchanged. The factor relationship plays a special role in this.

According to linear and area growth during the study period, all the gullies on the agricultural lands of the Republic of Tatarstan can be divided into the following groups: 1) the gullies with a positive linear and areal growth; 2) the gullies either with a positive linear growth, or with an areal growth; 3) the gullies, which stopped growing and which are in the process of overgrowing.

The basins of Western Kama region demonstrate the process of gully system reduction during the period of 2004-2014, indicating the process of gully overgrowing and their gradual transformation into beams.

On the territory of all selected elementary basins one of the leading factors of gully erosion is an anthropogenic one (high density of rural population, large areas

are occupied by pastures and meadows, the presence of linear objects). The reasons of gully formation process local strengthening may be the greatest depth of soil freezing and an increasing amount of precipitation (climatic factor), as well as large areas occupied by meadows (overgrazing - anthropogenic factor), which is typical of the basins located in Volga region. The analysis of gully erosion development factors indicates their considerable variability in space and in time, that is, the factors which are relevant for erosion within the same elementary basin, become background ones, or change the direction of links on other sites.

ACKNOWLEDGEMENT

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. The work (methods, analysis and results) was funded by the Russian Science Foundation (project №15-17-20006).

REFERENCES

1. B.P. Lyubimov, Nikolskaya I.I., Prokhorova S.D. The intensity of the modern gully erosion in the European part of Russia // Soil erosion and channel processes. Issue 12.; Moscow Univ. publ. house 2000. 297 p.
2. Maccaveev N.I. The erosion-accumulative processes and the topography of a river bed. Selected works. M.: MSU publishing house, 1998. 285 p.
3. Ryzhov Yu. V. Gully erosion in the intermountain basins of South-West Baikal // Geomorphology. № 3. 1998. pp. 68-73.
4. Golosov V.N. Erosion and deposition processes in the river basins of cultivated plains. GEOSb Moscow, 2006, 296 p.
5. Ryzhov Y. V. The formation of gullies in the south of Eastern Siberia. Novosibirsk Academic Publishing House "Geo", 2015. 180 p.
6. Vanmaercke, M., Poesen, J., VanMele, B., Demuzere, M., Bruynseels, A., Golosov, V., Fernando, J., Bezerra, R., Bolysov, S., Dvinskih, A., Frankl, A., Fuseina, Y., Guerra, A., Haregeweyn, N., IonitaI., Imwangana, F., Moeyersons, J., Moshe, I., Samani, A., Niacsu, L., Nyssen, J., Otsuki, Y., Radoane, M., Rysin, I.,

Ryzhov, Y., Yermolaev, O. (2016). How fast do gully headcuts retreat? Earth ScienceReviews.154,336–355. http://dx.doi.org/10.1016/j.earscirev.2016.01.009.

7. Nazarov N.N. Concerning the issue about gully formation factors in Perm Cis-Ural region / The geodynamics of flat terrain. Kazan: Publishing House of Kazan University, 1992. pp.78-90.
8. Fatemeh Mousazadeh, Khairulmaini Osman Salleh/ Factors controlling gully erosion development in Toroud basin – Iran. Procedia – Social and Behavioral Sciences. 2014. pp. 506-512.
9. Valentin C, Poesen, J. - Li Yong: Gully erosion: impacts, factors and control (Gully erosion: a global issue), Catena, 63. 2005. pp. 132-153.
10. Li, Y., Poesen, J., Valentin, C., 2004. Gully Erosion Under Global Change. Sichuan Science Technology Press, Chengu, China. 354 pp.
11. Yermolaev, O. P., Golosov, V. N., Kumani, M. V., Litvin, L. F., Rysin, I. I., and Dvinskikh, A. P.: Recent changes in sediment redistribution in the upper parts of the fluvial system of European Russia: regional aspects, Proc. IAHS, 367, 333-339, http://dx.doi.org/10.5194/piahs-367-333-2015.
12. Dedkov A.P. Relief // Geological monuments of nature in the Republic of Tatarstan. Kazan: Watercolor Art, 2007.pp. 9-13.
13. Usmanov, B., Yermolaev, O., & Gafurov, A. (2015). Estimates of slope erosion intensity utilizing terrestrial laser scanning, Proc. IAHS, 367, 59–65, http://dx.doi.org/10.5194/piahs-367-59-2015.
14. Yermolaev O., Avvakumova A. Cartographic-geoinformational estimation of spatio-temporal erosion dynamics of arable soils in forest-steppe landscapes of the Russian Plain (2012) IAHS-AISH Publication, 356, pp. 332-337.
15. Google Planet Earth. URL: http://www.google.com/earth/ (date of appeal: 10.02.2016).