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To cite this article: O P Yermolaev and R A Medvedeva 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **817** 012114

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Geoinformation mapping of modern gully erosion in the steppe region of the Russian Plain

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Abstract. Considering the linear erosion processes in the river basins slopes it can be noticed that the gully erosion is most intensively changing the relief, leading to the complete soil cover destruction, and is making the land not suitable for agricultural use. The latest maps of the gullies' development in Russia were compiled more than 50 years ago and can be seen as very outdated. Since that time no comprehensive gullies network mapping has been carried out. Due to the gullies' network shape and their large size, the satellite images allow noticing their representation. The study of the modern gully network was carried out in the steppe east of the Russian Plain on an area of more than 38000 km². The gullies were mapped using high-resolution satellite images (1.65–0.4 m). It allowed compiling an electronic map of the modern gullies' density in river basins. The areal and linear dynamics of morphologically active gullies for the period 2003–2014 were determined using satellite images. The data obtained indicate a very weak territory dissection by the gullies. It can be asserted that for the majority of the gullies their peak of activity has already passed, and currently they are either in a state of dynamic equilibrium or are being transformed into balkas. These results correlate with the data obtained during the earlier study of the forest and forest-steppe zones in the same Russian region.

1. Introduction

Gully erosion is a leading factor impacting the relief and soil cover in the spectrum of slope fluvial processes. Gully forms are morphologically well expressed in the relief and form landscape units overtime. In this part of linear erosion, the maximum soil loss is observed and the loads (soils and grounds) are being transmitted to the rivers' terraces and floodplains from the upper parts of the slopes. The mechanism of gully formation is well understood. At the same time, core factors leading to the gullies' development in different regions worldwide as well as their morphology vary significantly. This leads to a lack of clear classification features, which complicates gully mapping. Since the gullies' formation can be attributed to the exogenic natural hazards class, it is required to understand the level of their development in a particular territory.

During the former Soviet Union, gully density maps were published for many regions in the former USSR, including the Middle Volga region [1–3]. However, these maps were based on information collected from topographic maps of different scales (1:100 000, 1:50 000 and 1:25 000) [1, 4–8]. Considering the large size of the USSR territory, not a complete mapping was conducted even for some of the regions. Mapping was carried out in key areas only based on the preliminary conducted expert zoning.



The application of such medium-scale topographic maps resulted in relatively inaccurate and crude gully network mapping, while more detailed large-scale topographical maps were only used for gully mapping in some key areas. Comparisons of such gully maps with field observations and interpretation of large-scale aerial photographs have shown that topographic maps do not fully reflect the spatial pattern of gully development. This is, of course, due to the generalization of topography in the cartographic preparation of topographic maps. As shown by comparative measurements of the gully network lengths derived from aerial images and large-scale topographical maps (1:25 000 scale), estimated gully network densities based on maps can strongly deviate (50–300%) from those based on aerial photograph interpretation [1, 8].

As a rule, such inaccuracies happen when ephemeral gullies and balkas, formed under sparse vegetation conditions, are incorrectly assigned to gullies. Ultra-high resolution (1.65–0.4 m) satellite images became available for public access in the 2000s which expanded gully erosion mapping and monitoring perspectives. These materials can be used to map gullies and are as detailed as aerial photographs. The combined use of space images and GIS technologies allows conducting a reliable mapping and assessment of the spatio-temporal development of gully erosion.

Currently, there are no major gully erosion development generalizations observed during the post-Soviet period in the steppe region of the European part of Russia. At the same time, this period was accompanied by a radical change in the economic paradigm and significant dynamics in land use. Moreover, there are very few generalizations found on the dynamics of gully erosion in various landscape zones of the European part of Russia, considering serious climatic changes. During the period from 1980 to 2012 in the steppe zone of European Russia, there was a significant reduction in the areas of arable and cultivated lands- by 6.3 and 27.6% respectively [9, 10]. This determines the relevance of the research on quantitative assessment of the modern gully erosion.

Hence, the objectives of this study are: to analyze the current spatial distribution and dynamics of gully network densities in the steppe region of the Russian Plain's eastern part (based on the Orenburg region study).

2. Material and Methods

The main source of gully mapping is satellite imagery. Identification of active gully length on the basis of satellite image interpretation. Were based multispectral satellite images of high and very high spatial resolution (ranging between 0.5 and 1.0 m; GeoEye, QuickBird and IKONOS). Before the mapping began, it was necessary to select the most appropriate periods for satellite image acquisition. Based on the comparison of images for the different seasons and field verification, autumn and spring images were found to be the most informative for the study of gully erosion in the study area. The thalwegs of the gullies can be traced well using the winter images, but (due to snow cover) it is difficult to distinguish the edges of gullies, impeding the accurate assessment of gully development. However, summer pictures generally show denser vegetation cover, making it more difficult to identify the bottoms of active gullies but easier to distinguish the stage of development of slope and bank gullies. Images from spring and autumn provided an excellent trade-off over time) were used for georeferencing. Where possible, additional fixed points were used, in order to improve the accuracy. The identification and mapping of gully forms was carried out based on visual interpretation by trained scientists using several interpretation signs [1, 11,12]. The main interpretation signs of active gullies were the following: characteristic shapes with sharp, geometrically well-defined boundaries; linear and branched forms on the image; the clear edge and the line of the thalweg; contrast photograph tone on different sides of the gully, occurring typically with V-shaped gullies; the presence of local bright areas on the slopes of the gullies, corresponding to areas unprotected by vegetation and testifying the activity of the erosion form. Field verification of the results of image interpretation was undertaken for several locations within the different landscape zones in the study area. The field verifications allowed evaluating the correctness of determining the boundary between active gully sections and gully sections in transition to dry valleys stabilized by vegetation. It was found that the uncertainty in determining this boundary varied between 10 and 15%. In addition, this

field verification showed that very short bottom gullies (length < 5 m) were usually missed in the aerial mapping because they were covered by vegetation. However, their proportion in the total active gully length was estimated to be only 1 – 2% [1, 13,14].

The gullies digitized from the aerial satellite images were converted into gully density by dividing the sum of the total length of mapped gullies (in meters) by the total area of the corresponding catchment (in km²). This gave a gully density measurement of kilometers of gully length per square kilometer of area (km km⁻²) [1].

The study uses a basin approach for creating a map of gully network density. A selection of basins previously allocated for the European part of Russia was carried out[1].Constructing the basin boundaries in the automatic mode. The updated model of topography and the raster model of the hydrographic network were used in constructing the boundaries of the river basins for the entire study territory, and in generating a corresponding electronic vector map. The boundaries were delineated in the automatic mode using the algorithm implemented in the Whitebox GAT software product. A series of test calculations were carried out preliminarily within the areas with different topographic features. The basins were delineated planarly, that is, not only the basins of small rivers (at the scale used, they were first-order streams) but also their inter-basin spaces [15]. Based on the findings, it was established that in the selected test areas the mean difference between the indicators of the basin areas as identified automatically and in the expert manner made up 3.6%. For the areas with weakly dissected lowland topography this error does not exceed 5%, while in the areas with relatively dissected, elevated topography it makes up about 2%. Such a quality of the automatic construction of the basin boundaries for the cartographic model thus developed may be considered quite satisfactory [15, 16].A total of 499 basins were identified in the study area.A total of 499 basins were identified in the study area. Basins with an area of about 300 km² (316 basins) prevail.

The forms' dynamics is determined for gullies that have external signs of active development. In order to perform this exercise images were obtained from open access resources such as Google Earth, Yandex, Bing, ESRI for the period of 11 years (from 29/09/2003 to 17/05/2014). The gullies' dynamics has been assessed in several stages. Firstly, active gullies search was conducted based on the images for the period 2003-2014 using the Sas. Planet software. The gully's brow and its thalweg were vectorized in two time intervals. Then the overlay technology was used - the imposition of the edge and thalweg of the gully and the allocation of the area of areal and linear increments. After that, a layer obtained in the Sas.Planet has been moved into MapInfo software product. The following quantitative indicators of the dynamics were calculated: the object area in 2003, the length of the object in 2003, areal growth, linear growth, dynamics of areal growth, linear growth dynamics, the share of the total area increase, the share of the length increase. In total 38 gullies were explored.The gullies dynamics database has been compiled (table 1).

Table 1. The gullies dynamics database fields.

Object number	Object area, m ²	Object length, m	Area growth, m ²	Length growth, m	Dynamics of the area growth, m ² /year	Dynamics of the length growth, m/year	Percentage of increase to total area, %	Percentage of increase to total length, %
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2.1 Description of the study area

This study is considering the Orenburg region in Russia (figure 1). It is bordered by the Republic of Tatarstan to the north, by the Bashkortostan Republic to the east, by the Samara region to the west. The total area of the territory is 38720 km². The only northern part of the region belongs to the southern forest-steppe zone. The rest of the territory is covered by the steppe zone.

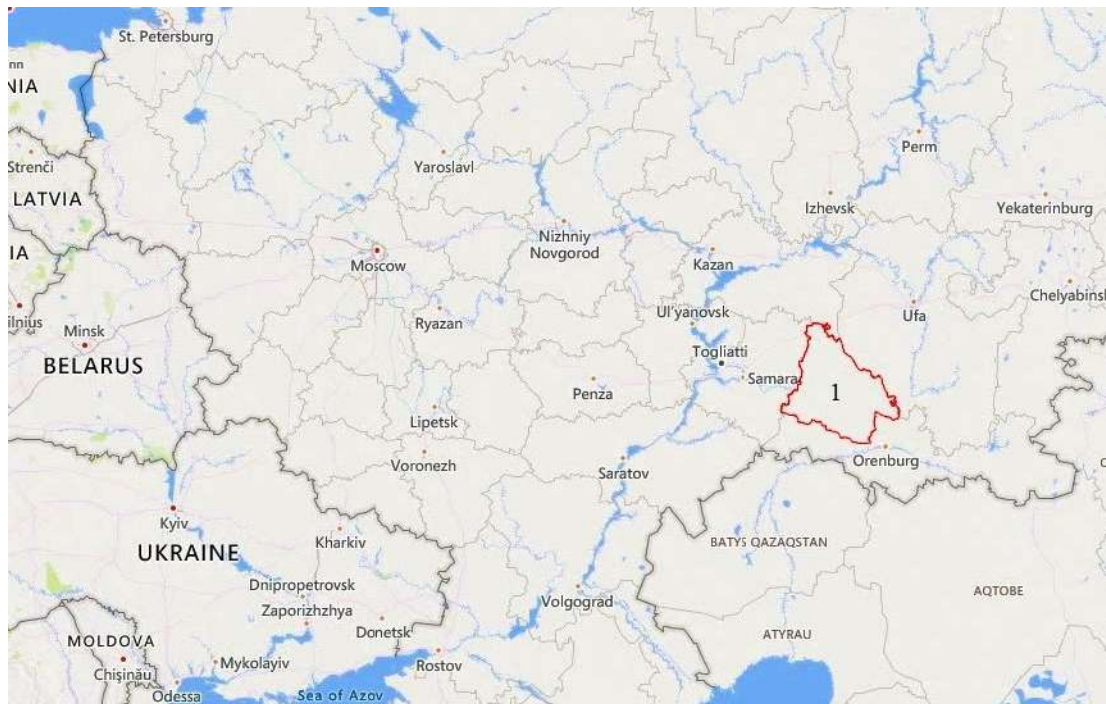


Figure 1. Location of the study area (1).

The northern border of the steppe runs along the valleys of the Maly and Bolshoi Kinel rivers and goes to the lower reaches of the Ik River. The territory is in the interfluvium of the Samara and Ika river basins. The relief is characterized by the predominance of low-lying plains, as well as by an elevated plain in the north and east part. Average heights are generally ranging between 150 to 350 m. The range of dissection is 100–200 m. The average slopes of the basins are small and amounting to 1.9° . The steeper basins are located in the north and the central part, there the slopes lie between $2-5^{\circ}$. Topographic factor (LS-factor) varies from 1 to 3 and is increasing to 3-5 in the north. Soil-forming rocks (soil-ground) are clay and loamy. The right slope of the Samara river basin in the Buzuluk region is covered by sandy rocks. The average annual temperature is increasing from north to south from $+4$ to $+6^{\circ}\text{C}$, and the sum of active temperatures - from 2000 to 3000°C . The average annual precipitation is 391 mm. Precipitation during the warm period is amounting up to 70%. The annual runoff layer regularly decreases from north to south from 150-100 mm to 50 mm. The soil cover is represented by Luvic and Haplic Chernozems. The forest cover is less than 5%. Forest tracts are well preserved on the steep slopes of the basins in the northern part of the region, where forests can be covering 20 to 40% of the territory. The maximum forest cover is typical for the basins in the vicinity of Buzuluk, where it can be more than 60%. Steppe landscapes are characterized by a high proportion of meadows located in the lower parts of the basin slopes. On average, meadows are covering around 40% of the area. The average share of the arable land is 40%[16].

3. Results and Discussion

In total 931 gullies were mapped in the study area. An electronic map of the gullies' density in river basins has been compiled (figure 2). Six classes are highlighted on the map gully densities: catchments having no significant gullies (0 m km^{-2}), very low gully densities ($0-5 \text{ m km}^{-2}$), low gully densities ($5-20 \text{ m km}^{-2}$), moderate gully densities ($20-50 \text{ m km}^{-2}$), high gully densities ($50-100 \text{ m km}^{-2}$) and very high gully densities ($100-500 \text{ m km}^{-2}$). The total length of the gullies network is 121.06 km. The average length of the gullies is 242.5 m, the maximum length of the gully is 9555 m, and the density of the gullies' dissection is 3.2 m km^{-2} (table 2).

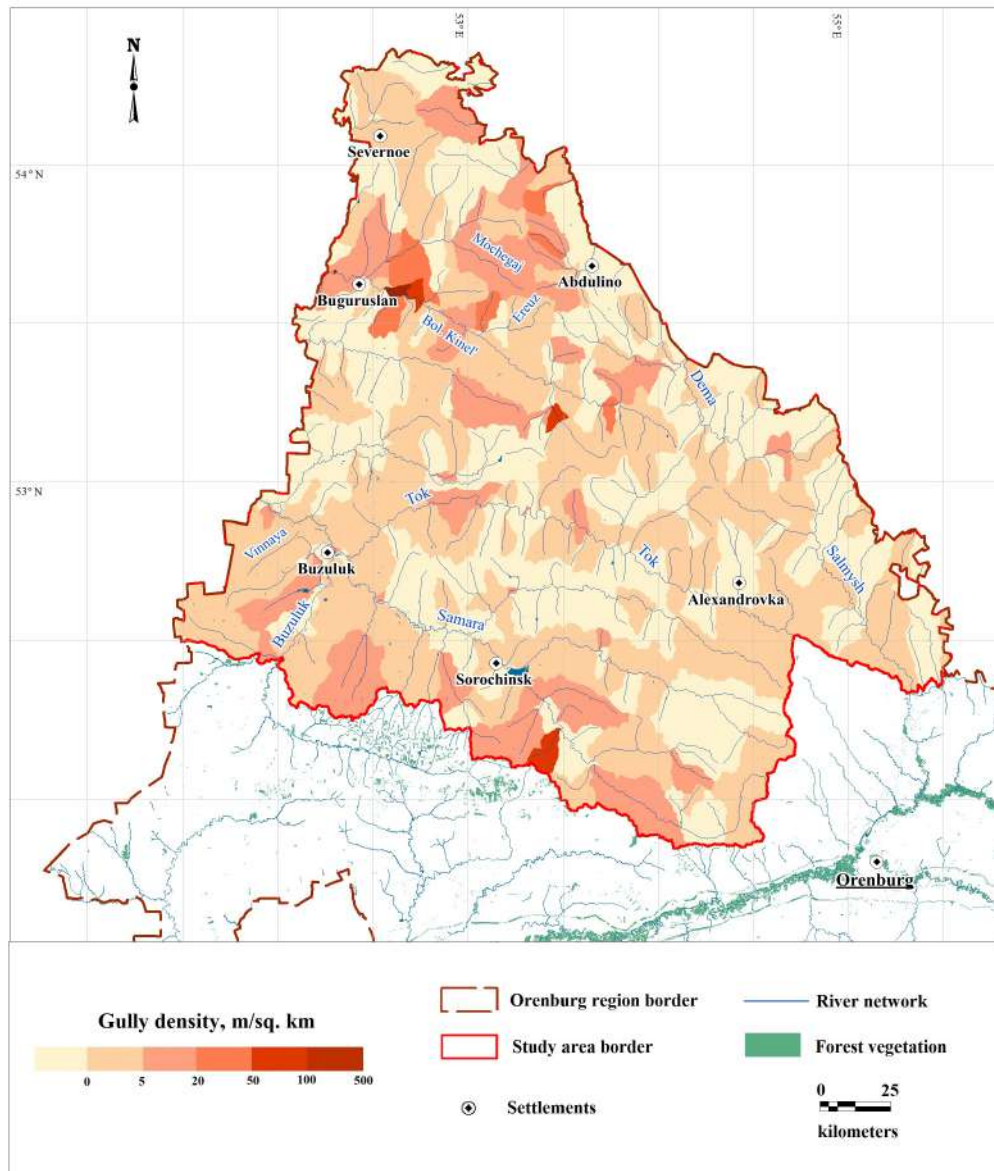


Figure 2. Gully densities of the study region

Table 2. Statistical gully indicators of the studied river basins.

Statistical indicators	Length, m	Gully density, m km ⁻²
Minimum	0	0
Maximum	9555	178
Average	242.5	3.2
Standard deviation	786.7	14.3
Median	0	0
Variance	618.9	0.2

Basins with low and moderate gully are located in the northern and southern parts of the region. It can be noticed that the data obtained on the gullies' dynamics vary significantly. Almost a third of externally active forms do not have a linear increase over a studied period of time. Moreover, in 20%

of cases, there are no changes in the gullies area meaning that a part of externally active gullies is in a state of dynamic equilibrium and, possibly, passes into the stage of balka development. Most often these are gullies that cut into bedrock. For other gullies, the average annual linear growth is 2.1 m/year, and the areal growth is 98 m² per year. The maximum annual linear growth is reaching 22 m. It is not the magnitude of the linear and areal growth absolute values but the relative values that are important for the gullies' development. Therefore, for example, with a gullies' linear growth by 6.2 m, the relative increase to their initial length is 190% to 404%, and with an increase of 22.6 m per year - about 20%. Several gullies (21%) are actively changing their planned shape. Over 11 years these changes are amounting from 11 to 190% of their initial shape. A small linear growth of gullies alongside their high areal growth indicates an active change in their cross section, a decrease in the steepness of slopes, and a gradual transition of these forms into balkas. Thus, the gullies in the study area are at different stages of their development. Only 16% of the observed gullies are in the active stage. The rest of the gullies are either actively changing their transversal profile and transforming into balka, or are in the stage of dynamic equilibrium. The latter group of gullies, most likely, is also transforming into balkas. However, under extreme climatic (abnormally intense rainfall) and anthropogenic impact (improper plowing of slopes, roads, etc.), it can pass into the stage of active growth again with the creation of a morphologically more complex shape.

4. Conclusions

For the first time data on the modern gullies development was obtained for a large region of the European part of Russia, which is located at the junction of the southern forest-steppe and steppe landscape zones. The thalweg gullies were detected using high resolution remote sensing and gis technologies. An electronic map of the current gullies network density in river basins has been created for this region for the first time as well. The gullies density in the studied area is not high. There is a domination of the territories wherogullies are either completely absent, or their density is ranging between 5-10 m km⁻². The study determines active gullies dynamics for the period 2003-2014. The data obtained for the gullies dynamics varies significantly. Almost a third of externally active forms do not have a linear increase over a studied period of time, and in 20% of cases, there is no change in the gullies area at all. The average annual linear growth is 2.1 m/year, and the area is 98 m²/year. The maximum annual linear growth is reaching 22 m. Only 16% of the observed gullies can be considered being in the active stage. The rest of the gullies are transformed into balkas. The results indicate the decrease of gully erosion in the steppe zone of the eastern region in the European part of Russia.

Acknowledgements

The study was carried out with the support of the Russian Science Foundation (20-67-46017).

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