Investigation of the dynamics of ephemeral gully erosion on arable land of the forest-steppe and steppe zone of the East of the Russian Plain from remote sensing data

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Abstract. Spatio-temporal estimation of the erosion of arable soils is still an urgent task, in spite of the numerous methods of such assessments. Development of information technologies, the emergence of high and ultra-high resolution images allows reliable identification of linear forms of erosion to determine its dynamics on arable land. The study drew attention to the dynamics of the most active erosion unit – an ephemeral gully. The estimation of the dynamics was carried out on the basis of different space images for the maximum possible period (from 1986 to 2016). The cartographic method was used as the main research method. Identification of a belt of ephemeral gully erosion based on materials of multi-zone space surveys and GIS-technology of their processing was carried out. In the course of work with satellite imagery and subsequent verification of the received data on the ground, the main signs of deciphering the ephemeral gully network were determined. A methodology for geoinformation mapping of the dynamics of ephemeral gully erosion belt was developed and a system of indicators quantitatively characterizing its development on arable slopes was proposed. The evaluation of the current ephemeral gully network based on the interpretation of space images includes the definition of such indicators of ephemeral gully erosion as the density of the ephemeral gully net, the density of the ephemeral gullies, the area and linear dynamics of the ephemeral gully network. Preliminary results of the assessment of the dynamics of the belt erosion showed an increase in all quantitative indicators of ephemeral gully erosion for the observed period.

1. Introduction
Erosion is the leading process of soil cover degradation on agricultural lands. The intensively plowed territories are most susceptible to soil erosion and lead to a decrease in the fertility of the soil cover, the formation of gullies in contrast to the territory occupied by natural vegetation.

To identify qualitative changes in the structure of basin erosion, it is possible to use the so-called "erosion belts" on the slopes of the catchments. In the structure of basin erosion 6 erosion zones are distinguished reflecting patterns of surface runoff formation and transformation of the flushing mechanism: 1) raindrop destructing; 2) sheet and rill; 3) ephemeral gullies 4) gully; 5) the prevailing accumulation; 6) areas of no erosion. At the same time, up to 80-90% of the entire surface of the plowed slopes falls on the belt of sheet and ephemeral gully erosion. In this work, a belt of ephemeral gully erosion was chosen for the study, here there is a maximum washout of the soil and it is morphologically well expressed in space images, due to the linear pattern created by the ephemeral gully network.
The choice of materials for space surveys as a tool for mapping the dynamics of erosion is determined by three factors: the ability to determine the dynamics over different time periods, the high quality of displaying linear forms of erosion in space images and the possibility of research in different regions. The use of images distributed free of charge in digital form and at different time intervals allows determining various parameters of ephemeral gully erosion: the density of the ephemeral gullies (km/km²), the density of the ephemeral gullies (unit/km²), the area and linear dynamics of the ephemeral gully network.

The basic method of investigation was the visual identification of ephemeral gully erosion by visual analysis of the screen image of high-resolution space images.

2. Material and methods

For the study, sites were chosen in the forest, forest-steppe and steppe zones of the east of the Russian Plain within the Republic of Tatarstan and the Orenburg region. For the convenience of mapping, the entire study area was divided into basins (along first-order watercourses). For each pool, the total length of the ephemeral gully network, the density of the ephemeral gully net and the density of the ephemeral gullies were calculated.

Sites for the study were selected according to several criteria: 1) the time of shooting for the observed periods should be approximately the same; 2) the plots should be fully plowed, without any projective covering by agrocenoses; 3) the quality of the images (no clouds, etc.) should be good; 4) pictures on the sites should be in the public domain and have a high and ultra-high resolution; 5) for deciphering, interfluvial plowed spaces with a morphologically well-defined net of ephemeral gullies should be selected. In the course of the work it is established that the identification of the linear erosion belt is most reliably carried out in late spring, autumn and early summer images. In other seasons, interpretation of linear forms of erosion in the fields is accompanied by large errors due to their leveling by cultural vegetation.

As the initial data for deciphering is the current ephemeral gully network, the images downloaded from the Google Earth program have a spatial resolution of 0.5-1.5 m. These are modern images for the period 2009-2015 which allow covering the territory within 10 km². Landsat images for the territory of the Samara river basin (the Orenburg region) and the Mesh river basin (the Republic of Tatarstan) were also taken for mapping. Landsat images have a resolution of 30 m which allows you to explore more extensive territory and study the dynamics of the ephemeral gully network during a longer time period from 1984 to 2015. Both types of images have sufficient resolution for deciphering the ephemeral gully network.

Ephemeral gullies in the images are decoded reliably according to the characteristic linear pattern of the image. Unlike gullies, they are depicted in the form of thin, more often, dark bands and lines along slopes with expansion in the central part. Ephemeral gullies are depicted by meandering lines with a large variability of the phototone (color) from almost white to almost black (figures 1, 2). All the linear forms visually determined in the picture were decoded. Area, linearly stretched contours at the tops of ephemeral gully erosion in the hydrosphere areas with a tree-like pattern did not belong to the ephemeral gully network since these sections are formed by plumes of ephemeral gully erosion spatially strongly changing their planned location due to a number of reasons (cultivation of arable land, etc.).

Work with images is carried out in MapInfo. With the help of it the forms of linear erosion and the boundaries of arable lands were traced and translated into a vector format. Further, the area of arable land, the total length of the ephemeral gully network, the number of peaks of the ephemeral gully erosion, their density was calculated.
3. Results and discussion

On the basis of space images, the basin deciphering was carried out within the Republic of Tatarstan and the Orenburg region. In the course of studies to determine the dynamics of the ephemeral gully erosion belt a system of deciphering features (regional standards) for definition of ephemeral gully network has been developed, and field verification of the deciphering results has been carried out. A technique for geoinformation mapping of the dynamics of the ephemeral gully erosion belt has been developed, the main parameters quantitatively characterizing the dynamics of this belt have been obtained (tables 1, 2).
Table 1. Dynamics of a belt of ephemeral gully erosion on the example of a site near the village of Totskoye, Orenburg Region.

| Indicators                          | 25.09.2010 | 03.05.2013 |
|------------------------------------|------------|------------|
| Area of arable land (km²)          | 6.36       | 6.36       |
| Total length (km)                  | 64.18      | 94.78      |
| Number of vertices                 | 144        | 204        |
| Density of the ephemeral gullies   | 10.09      | 14.9       |
| Density of the ephemeral gullies   | 22.6       | 32.07      |

Table 2. Figures of the belt of ephemeral gully erosion from Landsat images for 8 sites in the Samara river basin of the Orenburg Region.

| Basin No. | Area of arable land, km² | Total length, km | Number of vertices | Density of the ephemeral gullies, km / km² | Density of the ephemeral gullies, unit / km² |
|-----------|--------------------------|------------------|-------------------|------------------------------------------|------------------------------------------|
|           | 1988 2015 1988 2015      |                  |                   |                                          |                                          |
| 1         | 15.3 15.3 60.6 62.1      | 70 79            | 3.96 4.06         | 4.57 5.16                                |                                          |
| 2         | 16.8 16.8 80.32 83.55    | 130 135          | 4.78 4.97         | 7.74 8.03                                |                                          |
| 3         | 25.67 25.67 101.7 122.05 | 140 151          | 3.96 4.75         | 5.45 5.88                                |                                          |
| 4         | 34.03 34.03 146.1 167.9  | 194 239          | 4.29 4.93         | 5.7 7.02                                 |                                          |
| 5         | 91.4 91.4 165.7 245.6    | 205 300          | 1.81 2.69         | 2.42 3.28                                |                                          |
| 6         | 57.6 57.6 113.8 167.8    | 96 189           | 1.98 2.91         | 1.66 3.28                                |                                          |
| 7         | 53.91 53.91 94.1 99.6    | 102 151          | 1.74 1.85         | 1.89 2.8                                 |                                          |
| 8         | 55.1 55.1 101.5 104.3    | 120 125          | 1.84 1.9          | 2.17 2.27                                |                                          |

In general, conducted studies on 35 field sites in the region showed that there was an increase in all quantitative characteristics of the belt erosion from 1988 to 2016. In the Republic of Tatarstan, a significant increase in the total length of the ephemeral gullies is observed in the basin of the Mesha River near the village of Sokury (4% from 17.05.2012 to 27.04.2016) and in the Volga river basin near the village of Burtasy (37% from 12.04.2009 to 28.04.2016). However, it should be noted that it is quite difficult to estimate the overall trend of the dynamics of the modern ephemeral gully network of Google Earth images for 2009-2016, as it is not always possible to find pictures of good quality for only one season in one territory.

According to the images of the Landsat of the Samara River Basin, Orenburg Region it was possible to trace the dynamics of the ephemeral gully network for a sufficiently long time interval for one season, we considered two images - April 19, 1988 and April 29, 2016. The obtained data showed that in this territory there is an increase in all parameters of the ephemeral gully network. On the average, the density of the ephemeral gully network increased by 6%. The maximum increase in the total length of the ephemeral gullies corresponds to basin No. 5 along the Samara River (47%).

4. Conclusions
The use of high-resolution and ultra-high-resolution images makes it possible to reliably identify the belt of ephemeral gully erosion expressed by ephemeral gully network on the slopes of river basins by a direct and indirect set of deciphering features characteristic of this belt. At key sites approaches have been developed for geoinformation mapping of these linear forms of erosion as well as dynamics using high resolution satellite imagery. A system of quantitative indicators characterizing its development on arable slopes has been proposed for the belt of ephemeral gully erosion. The obtained results on the dynamics of the belt of ephemeral gully erosion allow us to reveal the time trend of the increase in its development from 1988 to 2016.
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