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The book is intended for geomorphologists, hydrologists, specialists on soil erosion, gully erosion and in-channel processes.

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The outcropping lithologies are mainly represented by clays ("Argille Varicolori") and/or alternated clays and sandstones (Flysch and "Terravecchia" Formation), with a few rare evaporites and limestones. The area is affected by spread accelerated erosion processes and mass movements.

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ON THE RESULTS OF THE GULLY EROSION MONITORING IN THE TERRITORY OF THE UDMURTIYA REPUBLIC

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1. INTRODUCTION

In order to study the gully formation mechanism and recieve some quantative characteristics of their seasonal and annual growth, monitoring of the growth of more than 160 gullies at 28 key sites located in different landscape conditions is being carried out starting from 1978. The territory of the Udmurtiya Republic is located in the east of the Russian Plain, in the southern part of the Vyatka-Kama water divide area. It is characterized by the dominance of the southern taiga (boreal forest) landscapes and, further to the south, zone of mixed coniferous and broad-leaved deciduous forests, transformed greatly by the anthropogenic activity. Total area of the Republic is 42.1 thousand km^2. The determination of the gully growth rate is carried out by means of the monitoring of their headcut advance be repeated measurements of distance from the headcut to the fixed datum mark. The observations are conducted once per year (usually in July) at the majority of key sites (93 gullies). At the 10 key sites (46 gullies) they are held twice (in May-June after the snowmelt, and in October-November after summer–autumn rainfall season. Since 1993, at 10 gullies located near the Izhevsk City (local capital) some additional observations have been held in summer after the heavy rainfalls. Measurements at the remaining 29 gullies were arranged episodically once per 2-3 years until 1996. Since 1996 the gullies mentioned above have also been surveyed annually.

Various types of gullies are under observation, among which primary gullies dominate (58.9%). A little more than half is represented by the so-called slope gullies, that cut through the main valley side upper break and their headcuts grow into the interfluve areas. Among the secondary gullies, the headwater gullies (62.3%) prevail over the valley bottom ones. To define the annual average gully growth during the monitoring period, airborne photographs with the scale of 1:10000–30000 taken in different years (1934–1991) were used. The choice of the key sections was also based on the analyses of 1957–1959 airborne photographs, on which actively developing gullies were selected. By the commencement of regular observations they had already been at different stages of development but continued to grow. In addition, some newly formed gullies appeared over the monitoring period, which also were involved into observation. As a result of that the total number of gullies studied have increased.

2. RESULTS OF THE INVESTIGATIONS

Examination of the data obtained testifies the wide range of the mean gully growth velocities for the last 4 decades. There are significant differences both in the primary and in the secondary gullies. The greatest differences are noticed for the primary gullies. The minimum rate of their headcut retreat for several years period varies within a range of 0.2–0.4 m/year. Maximum average growth rates are observed near the Mushak Settlement of the Kiyasovo District (7.3 m/year) and at the Staryc Bygi Village of the Sharkhan District (4.6 m/year). The mean growth rate for all the primary gullies over the period analyzed appears to be not very high – 1.2 m/year. Such sharp difference was not observed in the mean rates of the secondary gullies growth. Maximum mean values were observed for the 5 bottom gully key sites near the Varzy-Yatchy Settlement (3.9 m/year). For the headwater gullies this value decreases essentially (2.2 m/year). Intensive gully growth was also noticed at the Bolshoe Volkovo Village of the Vavozh District (2.8 m/year). Mean growth rate of the secondary gully type is a little higher than that of the primary gullies (1.4 m/year). Any spatial differentiation of the mean gully growth rate was not observed. Usually gullies characterized by comparatively low growth rate are located are close to those with considerable ones. Such a situation is typical for many districts in the Udmurtiya. In general the negative tendency in gully erosion activity is clearly observed, that is closely connected with the fall of agricultural production in the early 1990s.

Numerous investigations testify that gully growth intensity is largely defined by hydrometeorological conditions. The survey shows that in the eastern part of the Russian Plain 70–80% of annual gully increase occurs in spring. The leading role of such meteorological factors as snowmelt intensity and snow water storage are obvious [Dedkov, 1990]. The examination of 32 years-long monitoring data for the territory of the Udmurtiya Republic confirms these relations, but some regional specifics have also been revealed. Hydrometeorological conditions for the study area have been obtained from the hydrometeorological stations (HMS) located nearest to the key gully sections. Data cover the period of 1978–2008.

Monitoring data on the development of 13 gullies located near the Izhevsk City, 5 gullies of the key sections at the Selty Settlement, 5 gullies of the key section at the Vavozh Settlement and of 2 gullies of the key sections near the Sarapul City have been examined. All these gullies have been monitored over 32 years. The following indexes of spring hydrometeorological conditions are included into the analyses: a) maximum total snow water storage by the snowmelt commencement; b) snowmelt duration; c) snowmelt intensity; d) maximum soil freezing depth; e) surface runoff intensity as a ratio of maximum spring flood discharge to the average annual discharge of the nearest stream or river.

For the 5 key sections located near the Izhevsk City, record of the HMS at the Pervomaysky Settlement and of gauging station on the Pozym River were used. The analyzed data show that annual mean growth of 13 gullies changes considerably for the period of 32 years. The comparison of active gully growth rate with meteorological characteristics reveals close relation of the former with the flood discharge. Correlation analysis also confirms it (r =

0.825). In 1979 maximum gully growth (2.8 m/year) was recorded, caused by the combination of extreme meteorological conditions and the state of the soil cover. A very severe snowy winter of 1978-79 promoted deep freezing of the water-saturated soils, while warm spring caused intensive snowmelt. The infiltration of snowmelt water into the frozen ground was negligible, which led to powerful surface runoff and high flood in streams and rivers. Periods characterized by low gully activity coincide with the low intensity of surface runoff. However, at the same time the index of snowmelt intensity in some years could be significant. High snow water storage and snowmelt intensity did not always produce high surface runoff, which depends on many factors. That explains why the relation between the gully growth and snowmelt intensity (r = -0.158) and also water storage in snow (r = -0.002) were insignificant. Relationships between the snowmelt duration (r = 0.172) and the depth of the soil freezing (r = 0.348) with the gully formation activity are a little higher but also insignificant.

The data of the Selty Settlement HMS and of the gauging station on the Nilga River is used for the key section number 3. It is characterized by lower range of variation of the annual mean gully growth rates than at previous sections. This can be explained by the fact that the majority of gullies there have already reached the last stages of their development and only one still develops actively. It is necessary to note that in the year 2000 all the gullies observed were filled up with ground when a motor road had been built there and therefore their growth stopped completely. General temporal pattern of the gully formation activity is analogous to the previous sections. More frequent oscillations of the intensity indexes of the surface runoff attract attention. The possible explanation is relatively great forest cover area of the Nilga River basin. The relation between the annual gully increase and snowmelt water runoff intensity is also clearly seen there (r = 0.774). Temporal variation of the maximum water storage in snow is different. It was highest in 1989-1991 and also in 1998-1999, producing high surface runoff and active gully formation. The snowmelt intensity was maximum in 1979 and the depth of the soil freezing that year reached almost 1.5 m. The relation between the gully growth rate and snowmelt intensity is not strong (r = 0.479), it is a little weaker for the maximum water storage in snow (r = 0.374). For the snowmelt duration (r= -0.072) and the depth of soil freezing (r = -0.085) no relationship is observed.

All the gullies of the key section at the Bolshoe Volkovo Settlement belong to the active growth stage. For their study the data of the Vavozh HMS and the gauging station located on the Vala River are used. During the years of the intensive surface runoff the mean rate of the gully growth at this key site reached 2.8–6.6 m/year. When the surface runoff was low and often coincided with negligible snowcover the activity dropped sharply (0.7–1.1 m/year). In spite of the fact that the maximum water storage in snow reached 250 mm last years, the surface runoff intensity and the depth of the soil freezing was low. As a result, no gully increase was observed. The relation between the gully growth rate and the intensity of the surface runoff was clearly noticed (r = 0.883). The connection with the other indexes was insignificant.

The gullies of the key sites of Devyatovo and Mazunino are located in the Sarapul District. They erode solid bedrocks and belong to the second or third stage of gully development in most cases. Their growth is comparatively slow. For the analyses of their dynamics the data of the Sarapul HMS and of the gauging station on the Bolshaya Sarapulka River (the Porkatchevo Village) are used. The maximum activity of the gully growth also occurs there in 1979. However the second maximum does not refer to 1991, as at the previous key sites, but shifts a year later. In 1992 more water accumulated in snow, the period of snowmelt was also shorter and so the intensity of snowmelt and of the surface runoff turned out more significant causing more active development of gully erosion than in 1991. Because of relatively shallow soil freezing (0.5 m) some of the surface runoff turned into the underground one, negatively influencing the gully growth [Rysin, 1998]. In 2001 despite the great snow water storage (216 mm – maximum for 32 years of observation) and considerable snowmelt activity, gully growth velocity accounted only to

0.2 m/year. It can be explained by the fact that the accumulated water storage was to large extent absorbed by the soil, and some portion evaporated. That is why the surface runoff turned out to be so weak. As a result the dependence of the gully growth velocity and the snow water storage ($r = 0.359$) and the snowmelt intensity ($r = -0.08$) was found unimportant. This dependence of annual average gully increase only from the surface runoff intensity is fairly clear ($r = 0.670$). Low coefficient of correlation if compared with the mentioned above sections is associated with the lack of statistics for the absence of information for the last 14 years from the gauging stations on the Bolshaya Sarapulka River as it was closed. The link between the snowmelt duration and the gully increase intensity turned out rather weak ($r = 0.363$). Relationship between the gully growth rate and depth of the soil freezing is practically absent ($r = -0007$).

The influence of summer meteorological conditions on the annual average gully growth was studied for the key sections located at the Izhevsk City and Selty Settlement where seasonal monitoring was arranged. The following factors were included into the examination: daily precipitation layer; exceeding of the maximum normal decadal sum of precipitation; total sum of precipitation during the warm period.

The analyzed facts testify a very weak connection between summer meteorological factors and the intensity of gully growth that is confirmed by the correlation analyses data. As the results of several years seasonal observation show, contribution of the summer period into total annual gully increase at the taken sections often ranges only from 5% to 30%. Besides, as it was mentioned above, nearby the Izhevsk City regular observations of the gully growth after heavy rainstorms have been conducted since 1993. Extreme gully increase at summer period of 1984 caused by an especially heavy rain of extreme intensity were also included into the examination. As at the Izhevsk HMS heavy rainfall is not registered by the pluviograph, its intensity was approximated by the 12 hours precipitation layer. Analyses of the results obtained show a very close dependence ($r = 0.845$) between the increase of gullies in length and the sum of 12 hours heavy rainfall. According to the table an average gully increase varies mostly within a limited range of values, very close to zero. However, when 12 hours precipitation layer exceeds 55 mm, the connection examined acquires practically functional dependence. This relation is much closer ($r = 0.893$) if one examines not medium but maximum indexes of the gully increase at the key stations. The last dependence is more objective as the rainfall intensity differs greatly even within relatively small territories.

The results obtained prove that the value of 12 hours precipitation layer close to 55 mm can be considered as a critical threshold for the intensive growth of the gullies. If this value is exceeded catastrophycally fast gully growth is likely to be observed. For example, after a heavy shower on August 5, 1984, when about 1.5 of monthly norm of precipitation occured during 24 hours, the maximum gully increase detected for a single event was 23.5 m. The main erosion process took place between 12:40 and 15:05 when the highest rainfall intensity was observed.

Summer gully growth is considerably defined by the antecedent spring runoff conditions and especially by the dates, durations and intensities of heavy rainstorms. Sometimes in summer significant retreat of a gully headcut occurs because of the collapse of the niche formed in the headcut bluff during the spring snowmelt. Niche collapse may take place even when there is no runoff, for instance under the heavy load of agricultural vehicles during the cultivation or when cargo transport passes along the field road turning round the gully head. Such a case was observed in summer 1996 at the Fertiky Village of the Votkinck District where the gully headcut retreated up to 1.5 m as a result of its upper wall collapse without any runoff.

3. CONCLUSIONS

In general, considerably small volume of the rainfall runoff compared with the spring snowmelt one, short duration of its influence, irregular character, high soil infiltration capacity and resistance to erosion all determine insignificant gully growth in summer period.

The leading role of the spring snowmelt runoff in the gully development is associated with large masses of snowmelt waters reaching the gully heads, as well as their long influence – up to 10–15 and more days. The intensity of the snowmelt water runoff depends greatly on the water storage in snow, temperature range during the snowmelt, the depth of the soil freezing, decreasing its infiltration capacity and a number of other factors.

GULLY DISTRIBUTION AND DEVELOPMENT IN THE SOUTHERN EAST SIBERIA (RUSSIA)

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1. STUDY AREA

The study area lies between 49–58^0 N and 88–122^0 E and includes the zones of the middle and southern taiga, forest-steppe and steppe, numerous mountain ranges, and intermontane depressions, where latitudinal zonality and altitudinal zonality are clearly pronounced. Orographically it is a large mountainous territory with heights more than 1000 m. Plains and plateaus occupy a subordinate place and are concentrated in the western and northeastern parts of the study area. The southern part of East Siberia is home to the main agricultural lands, where the major areas of erosion loss and scouring of soils were recorded (Litvin, 2001; Bazhenova et al., 1997; Ryzhov, 2003). The territory under consideration lies at the heart of Eurasia and is characterized by varied types of landscapes, and by a high contrast of the conditions.

2. MATERIALS AND METHODS

The map of the occurrence frequency and density of contemporaneous gullies was compiled by using topographic maps and aerial photographs at scales of 18000–100000, and field measurements made in the Angara region, Baikal region and Western Transbaikalia. The growth rates of the gullies were inferred from field survey data spanning the time interval 1985–2009, different-time topographic maps, aerial photographs and from high-resolution space images. The sediments of the gully fans were studied by lithologo-stratigraphic, isotopic (radiocarbon and cesium) and dendrochronological methods.

3. DEVELOPMENT STAGES OF GULLY EROSION

Within the current cycle of gullying over the last 250–300 years four intensification stages of linear erosion have been identified for the South of East Siberia, which are associated with periods of abrupt changes in nature management. They, with the exception of the first one, were all initiated through development of extensive areas into crop lands and were accompanied by a sharp enhancement of the rate of erosion loss, breaking-in and deflation of soil. The first period was in 17th–19th centuries, the second stage (1875–1930), the third stage includes the 1930s – first half of the 1950s. The subsequent (fourth) stage of linear erosion development spans the second half of the 20th century.

4. DISTRIBUTION OF GULLIES

Most gullies in the Southern East Siberia were formed during the last 100 years on arable lands, in cutover areas, pastures, populated localities and along the ruts and ditches at the sides of dirt roads under favorable geologic-geomorphologic conditions (dense network of ephemeral streams, wide occurrence of readily erodible loose