

# Mapping and spatial-temporal assessment of gully density in the Middle Volga region, Russia

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## Abstract

© 2018 John Wiley & Sons, Ltd. A large-scale mapping of gully density was carried out for the Middle Volga region of the Russian Plain (188 000 km<sup>2</sup>) based on the interpretation of aerial photographs (scale 1:17 000; surveys undertaken during 1956–1970). In addition, spatial-temporal dynamic of gully density were assessed for some parts of the study area (the Udmurt Republic and the Mesha and Ulema River basins of Tatarstan), based on the interpretation of aerial photographs (survey 1986–1991) and high resolution satellite images (2012–2015). Information on factors potentially controlling gully formation and development were collected and a geographic information system (GIS) analysis was conducted. Results show the strong development of gullies in the study area over the 1956–1970 period with an average gully density of 0.21 km km<sup>-2</sup>. For the Udmurt region, we found that gully densities varied little in the period 1956–1986, during which the total active gully length reduced with only 2%. This period was characterized by low variable climatic conditions and a stable fraction of arable land with a relatively continuous crop rotation system. However, gully dynamics seems to have changed more strongly during recent decades. We found a strong (order of magnitude) reduction in active gully density for the period 2010–2015 as compared to 1986–1991. The main reason for this is likely the increasing winter air temperatures. This leads to a significant reduction in surface runoff during spring as a result of snowmelt. Nonetheless, in some regions (i.e. the Udmurt Republic in the taiga zone), the abandonment of arable land after 1991 likely plays a significant role. Likewise, a decline in the frequency of extreme rainfall events (> 50 mm) may have played a role. All of these factors contribute to a reduction of surface runoff to the gullies and their subsequent stabilization. © 2018 John Wiley & Sons, Ltd.

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## Keywords

gully density, gully mapping, Middle Volga region, satellite image interpretation, snowmelt, spatial-temporal dynamic

## References

- [1] Aver'yanova GA, Petrov GP. 1961. The density of the hydrographic network of the Middle Volga. Proceedings of the Kazan Branch of the USSR. Series Energy and Water Resources 2: 81–96 (in Russian).
- [2] Bocco G, Valenzuela CR. 1993. Integrating satellite remote sensing and geographic information systems technologies in gully erosion research. Remote Sensing Reviews 7: 233–240.

- [3] Bouaziz M, Wijaya A, Gloaguen R. 2009. Gully erosion mapping using ASTER data and drainage network analysis in the main Ethiopian rift. In Proceedings, IGARSS – Geoscience and Remote Sensing Symposium: Cape Town, South Africa; 113–116.
- [4] Brierley G, Stankoviansky M. 2002. Geomorphic responses to land use change: lessons from different landscape settings. *Earth Surface Processes and Landforms* 27: 339–341.
- [5] Burkard MB, Kostaschuk RA. 1997. Patterns and controls of gully growth along the shoreline of Lake Huron. *Earth Surface Process and Landforms* 22: 901–911.
- [6] Capra A, Porto P, Scicolone B. 2009. Relationships between rainfall characteristics and ephemeral gully erosion in a cultivated catchment in Sicily (Italy). *Soil Tillage Research* 105: 77–87.
- [7] Deser C, Phillips A, Bourdette V, Teng H. 2012. Uncertainty in climate change projections: the role of internal variability. *Climate Dynamics* 38: 527–547.
- [8] Desprats JF, Raclot D, Rousseau M, Cerdan O, Garcin M, Le Bissonnais Y, Ben Slimane A, Fouche J, Monfort-Climent D. 2013. Mapping linear erosion features using high and very high resolution satellite imagery. *Land Degradation & Development* 22: 24–32. <https://doi.org/10.1002/Ldr.1094>.
- [9] Gafurov AM, Rysin II, Golosov VN, Grigoryev II, Sharifullin AG. 2018. Estimation of the modern gully head retreat rate on the southern macroslope of the East European Plain using a set of instrumental methods. *Moscow State University Bulletin, seriya 5, Geography* 72–81 (in Russian).
- [10] Galang MA, Markewitz D, Morris LA, Bussell P. 2007. Land use change and gully erosion in the Piedmont region of South Carolina. *Soil and Water Conservation* 62(3): 122–129.
- [11] Gerasimov IP, Aseev AA. 1986. Geomorphological map of USSR, scale 1:2 500 000 (in Russian).
- [12] Golosov V. 2002. Soil erosion and small river aggradation in Russia. In Proceedings of 12th ISCO Conference, May 26–31, 2002. Tsinghua University Press: Beijing; 154–159.
- [13] Golosov VN. 2006. Erosion and Deposition Processes in the River Basins of Agricultural Plains. GEOS: Moscow (in Russian).
- [14] Gray DM, Toth B, Pomeroy JW, Zhao L, Granger RJ. 2001. Estimating areal snowmelt infiltration into frozen soils. *Hydrological Processes* 15: 3095–3111.
- [15] Grigor'ev II, Kovalev SN, Rysin II. 2016. The technogenic gullies. *Geomorphology RAS* 2: 27–33 (in Russian). <https://doi.org/10.15356/0435-4281-2016-2-27-33>.
- [16] Guerra AJT, Bezerra JFR, Fullen MA, Mendonça JKS, Sathler R, Lima FS, Mendes SP, Guerra TT. 2007. Urban gullies in Sao Luis city, Maranhao state, Brazil. In Proceedings of IV International Symposium on Gully Erosion, Progress in Gully Erosion Research, Casali J, Gimenez R (eds); 58–59.
- [17] Hayas A, Vanwalleghem T, Laguna A, Peña A, Giráldez JV. 2017. Reconstructing long-term gully dynamics in Mediterranean agricultural areas. *Hydrology and Earth System Sciences* 21: 235.
- [18] Hughes AO, Prosser IP, Stevenson J, Scott A, Lu H, Gallant J, Moran CJ. 2001. Gully Erosion Mapping for the National Land and Water Resources Audit, Technical Report 26/01: CSIRO Land and Water, Canberra.
- [19] Imwangana FM, Vandecasteele I, Trefois P, Ozer P, Moeyersons J. 2015. The origin and control of mega-gullies in Kinshasa (DR Congo). *Catena* 125: 38–49.
- [20] Ionita I, Niacsu L, Petrovici G, Blebea-Apostu AM. 2015. Gully development in eastern Romania: a case study from Falciu Hills. *Natural Hazards* 79(1): 113–138.
- [21] Johansen K. 2010. Object-based mapping of gullies from SPOT-5 imagery and ancillary data over catchment extents. In Proceedings, ISPRS XXXVIII-4/C7, Addink EA, Van Coillie FBM (eds): Ghent.
- [22] King C, Baghdadi N, Lecomte V, Cerdan O (eds). 2005. The application of remote-sensing data to monitoring and modelling of soil erosion. *Catena* 62(2–3): 79–93.
- [23] Kirkby MJ, Bracken LJ. 2009. Gully processes and gully dynamics. *Earth Surface Processes and Landforms* 34: 1841–1851.
- [24] Knizhnikov YF, Kravtsova VI, Tutubalina OV. 2004. *Aerospace Methods of Geographical Research*. Publishing center 'Academia': Moscow (in Russian).
- [25] Komarov VD, Makarova TT. 1973. Effect of the ice content, segmentation and freezing depth of the soil on meltwater infiltration in a basin. *Soviet Hydrology Selected Papers* 3: 243–249.
- [26] Koronkevich NI. 1990. Water balans of the Russian Plain and its anthropogenic changes. Nauka: Moscow (in Russian).
- [27] Kosov BF, Konstantinova GS. 1973. A comprehensive map of gully plain territory the USSR. *Geomorfologiya* 3: 3–9 (in Russian).
- [28] Labutina IA. 2004. *Interpretation of Satellite Images*. Aspekt Press: Moscow in Russian.
- [29] Langran KJ. 1983. Potential for monitoring soil erosion features and soil erosion modelling components from remotely sensed data. In Proceedings of IGARSS'83, San Francisco, CA, 1–4 February.
- [30] Larionov GA. 1993. Soil erosion and deflation. *Izd-vo MSU: Moscow* (in Russian).

- [31] Latz K, Weismiller RA, Scoyoc GEV, Baumgardner MF. 1984. Characteristic variations in spectral reflectance of selected eroded alfisols. *Soil Science Society of America Journal* 48(5): 1130–1134.
- [32] Leopold LB, Wolman GM, Miller JP. 1964. *Fluvial processes in geomorphology*. W.H. Freeman and Company: San Francisco, CA.
- [33] Lyuri DI, Goryachkin SV, Karavaeva NA, Denisenko EA, Nefedova TG. 2010. Dynamics of Agricultural Lands in Russia in XX Century and Postagrogenic Restoration of Vegetation and Soils. Moscow: GEOS (in Russian).
- [34] Makkaveev NI. 1955. River Channel and Erosion in its Basin. *Izd-to AN SSSR: Moscow* (in Russian).
- [35] Millington AC, Townshend JRG. 1984. Remote sensing applications in African erosion and sedimentation studies. In *Challenges in African Hydrology and Water Resources*, Walling DE, Foster SSD, Wurzel P (eds), *Proceedings of the Harare Symposium*, IAHS Publication 144. IAHS Press: Wallingford; 373–384.
- [36] Mitchel CW. 1981. Soil degradation mapping from Landsat imagery in North Africa and Middle East. In *Geological and Terrain Studies by Remote Sensing*, Allan JA, Bradshaw M (eds). Remote Sensing Society: London; 49–68.
- [37] Nikol'skaya IA, Prokhorova MD. 2005. Cartographic method of gully erosion studies. *Geomorfologiya* 1: 44–52 (in Russian).
- [38] Park H, Sherstiukov AB, Fedorov AN, Polyakov IV, Walsh JE. 2014. An observation-based assessment of the influences of air temperature and snow depth on soil temperature in Russia. *Environmental Research Letters* 9: 1–7. <https://doi.org/10.1088/1748-9326/9/6/064026>.
- [39] Perevedencev JP, Shantalinskij KM, Vazhnova NA. 2014. Spatiotemporal variations of major parameters of temperature and humidity Regime in the Volga Federal District. *Meteorology and Hydrology* 10: 19–31 (in Russian).
- [40] Petelko AI, Golosov VN, Belyaev VR. 2007. Experience of design of system of counter-erosion measures. In *Proceedings of the 10th International Symposium on River Sedimentation, Vol. 1: Moscow*; 311–316.
- [41] Poesen J. 2011. Challenges in gully erosion research. *Landform Analysis* 17: 5–9.
- [42] Poesen J, Govers G. 1990. Gully erosion in the loam belt of Belgium: typology and control measures. In *Soil Erosion on Agricultural Land*, Boardman J, Foster IDL, Dearing JA (eds). Wiley: Chichester; 513–530.
- [43] Poesen J, Hooke JM. 1997. Erosion, flooding and channel management in Mediterranean environments of southern Europe. *Progress in Physical Geography* 21(2): 157–199.
- [44] Poesen J, Nachtergaele J, Verstraeten G, Valentin C. 2003. Gully erosion and environmental change: importance and research needs. *Catena* 50: 91–133.
- [45] Poesen J, Torri D, Vanwalleghem T. 2011. Gully erosion: procedures to adopt when modelling soil erosion in landscapes affected by gulying. In *Handbook of Erosion Modelling*, Morgan RPC, Nearing MA (eds). Blackwell-Wiley: Oxford; 360–386.
- [46] Polade SD, Pierce DW, Cayan DR, Gershunov A, Dettinger MD. 2014. The key role of dry days in changing regional climate and precipitation regimes. *Scientific Reports* 4: 4364.
- [47] Ries JB, Marzolf I. 2003. Monitoring of gully erosion in the Central Ebro Basin by large-scale aerial photography taken from a remotely controlled blimp. *Catena* 50: 309–328.
- [48] Rossi M, Torri D, Santi E. 2015. Bias in topographic thresholds for gully heads. *Natural Hazards* 79(1): 51–69.
- [49] Rysin II. 1998. Gully Erosion in Udmurtia. Udmurt State University: Izhevsk (in Russian).
- [50] Rysin II, Golosov VN, Grigoriev II, Zaitseva MY. 2017a. Influence of climate change on the rate of gully growth in the Vyatka- Kama watershed. *Geomorphology RAS* 1: 90–103 (in Russian).
- [51] Rysin II, Grigoriev II, Zaitseva MY, Golosov VN. 2017b. Dynamic of linear retreat of gully head within Vyatsko-Kamskoe interfluvium on turn of the centuries (result of long-term monitoring). *Vestnik Mosk-go Universiteta, seriya Geografiya* 1: 63–72 (in Russian).
- [52] Rysin II, Grigoriev II, Zaitseva MYu, Golosov VN, Sharifullin AG. 2017c. Long-term monitoring of gully erosion in Udmurt Republic, Russia, IAHS Proceedings 375. IAHS Press: Wallingford; 1–4. <https://doi.org/10.5194/piahs-375-1-2017>
- [53] Ryzhov YV. 2015. Formation of Gullies in the South of Eastern Siberia. "GEO": Novosibirsk (in Russian).
- [54] Sel'skoe khozyaystvo SSSR. 1988. *Statistichesky sbornik. Finanvy i Statistika: Moskva* (in Russian).
- [55] Sementovskiy AN. 1963. Regularities of Relief Morphology Platform (For Example, the Territory of Tatarstan). Kazan University Press: Kazan (in Russian).
- [56] Shruthi RBV, Kerle N, Jetten V. 2011. Object-based gully feature extraction using high resolution imagery. *Geomorphology* 134: 260–268.
- [57] Shruthi RBV, Kerle N, Jetten VG, Stein A. 2014. Object-based gully system prediction from medium resolution imagery using random forests. *Geomorphology* 216: 283–294.
- [58] Sidorchuk A, Litvin L, Golosov V, Chernysh A. 2006. European Russia and Byelorussia. In *Soil Erosion in Europe*, Boardman J, Poesen J (eds). Wiley: Chichester; 73–93.

- [59] Sidorchuk AY, Golosov VN. 2003. Erosion and sedimentation processes on the Russian Plain, II: the history of erosion and sedimentation during the period of intensive agriculture. *Hydrological Processes* 17: 3347-3358.
- [60] Sobolev SS. 1948. Development of Erosion in the European Part of the USSR and the Fight Against Them, Vol. 1. The USSR Academy of Sciences: Moskva (in Russian).
- [61] Stankoviansky M. 2003. Historical evolution of permanent gullies in the Myjava Hill land, Slovakia. Geomorphic responses to land use changes. *Catena* 51: 223-239.
- [62] Stokes A, Douglas GB, Fourcaud T, Giadrossich F, Gillies C, Hubble T, Mickovski SB. 2014. Ecological mitigation of hillslope instability: ten key issues facing researchers and practitioners. *Plant and Soil* 377: 1-2: 1-23.
- [63] Strahler AN. 1957. Quantitative analysis of watershed geomorphology. *Transactions of the American Geophysical Union* 38: 913-920.
- [64] Torri D, Poesen J. 2014. A review of topographic threshold conditions for gully head development in different environments. *Earth-Science Reviews* 130: 73-85.
- [65] Valentin C, Poesen J, Li Y. 2005. Gully erosion: impacts, factors and control. *Catena* 63: 132-153.
- [66] Vandaele K, Poesen J, Marques de Silva JR, Govers G, Desmet PJ. 1997. Assessment of factors controlling ephemeral gully erosion in southern Portugal and central Belgium using aerial photographs. *Zeitschrift für Geomorphologie* 41: 273-287.
- [67] Vanmaercke M, Poesen J, VanMele B, Demuzere M, Bruynseels A, Golosov V, Bezerra JFR, Bolysov S, Dvinskih A, Frankl A, Fuseina Y, Guerra AJT, Haregeweyn N, Ionita I, Makanzulmwangana F, Moeyersons J, Moshe I, NazariSamani A, Niacsu L, Nyssen J, Otsuki Y, Radoane M, Rysin I, Ryzhov YV, Yermolaev O. 2016. How fast do gully headcuts retreat? *Earth-Science Reviews* 154: 336-355.
- [68] Vannoppen W, Vanmaercke M, De Baets S, Poesen J. 2015. A review of the mechanical effects of plant roots on concentrated flow erosion rates. *Earth-Science Reviews* 150: 666-678.
- [69] Vanwalleghem T, Bork HR, Poesen J, Schmidtchen G, Dotterweich M, Bork H, Deckers J, Bruschi B, Bungeneers J, De Bie M. 2005. Rapid development and infilling of a historical gully under cropland, central Belgium. *Catena* 63: 221-243.
- [70] Vanwalleghem T, Van Den Eeckhaut M, Poesen J, Deckers J, Nachtergaele J, Van Oost K, Slenters C. 2003. Characteristics and controlling factors of old gullies under forest in a temperate humid climate: a case study from the Meerdaal Forest (central Belgium). *Geomorphology* 56(1): 15-29.
- [71] Vrieling A. 2006. Satellite remote sensing for water erosion assessment: a review. *Catena* 65: 2-18.
- [72] Vrieling A, Rodrigues SC, Bartholomeus H, Sterk G. 2007. Automatic identification of erosion gullies with ASTER imagery in the Brazilian Cerrados. *International Journal of Remote Sensing* 28(12): 2723-2738.
- [73] Wischmeier WH, Smith DD, Uhland RE. 1958. Evaluation of factors in the soil-loss equation. *Agricultural Engineering* 39: 458-462.
- [74] Yermolaev OP. 2002. Erosion in Basin Geosystems. Unipress: Kazan (in Russian).
- [75] Yermolaev OP. 2017. Geoinformation mapping of soil erosion in the Middle Volga region. *Eurasian Soil Science* (1): 130-144.
- [76] Zhao J, Vanmaercke M, Chen L, Govers G. 2016. Vegetation cover and topography rather than human disturbance control gully density and sediment production on the Chinese Loess Plateau. *Geomorphology* 274: 92-105.
- [77] Zinck JA, López J, Metternicht GI, Shrestha DP, Vázquez-Selem L. 2001. Mapping and modelling mass movements and gullies in mountainous areas using remote sensing and GIS techniques. *International Journal of Applied Earth Observation and Geoinformation* 3(1): 43-53.
- [78] Zorina EF. 2003. Gully Erosion: Patterns and Potential for Development. GEOS: Moscow (in Russian).