Historical reconstruction and forecast of soil cover degradation based on erosion modeling and field soil survey data

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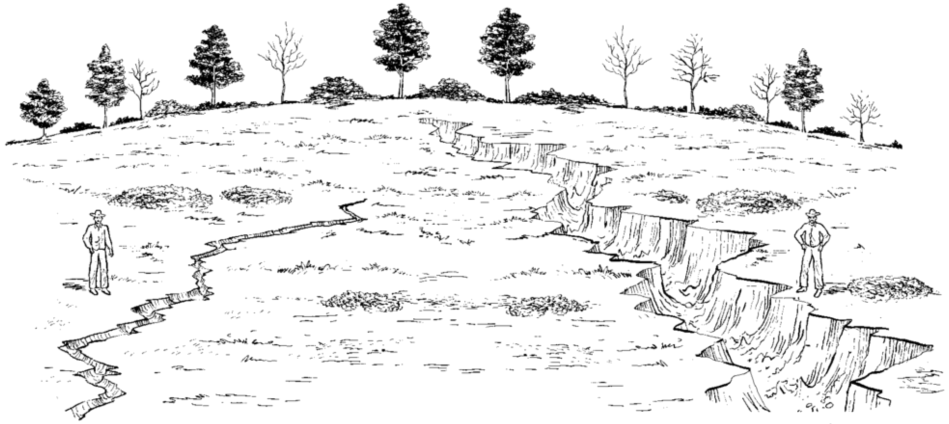
Megapolis
3 December 2022

Lecture plan

- Erosion and soil cover degradation
- General issues of soil erosion modeling
- Input parameters and assumptions of WaTEM/SEDEM
- Verification
- Historical reconstruction of soil erosion rates
- Digital mapping of erosion soil cover patterns

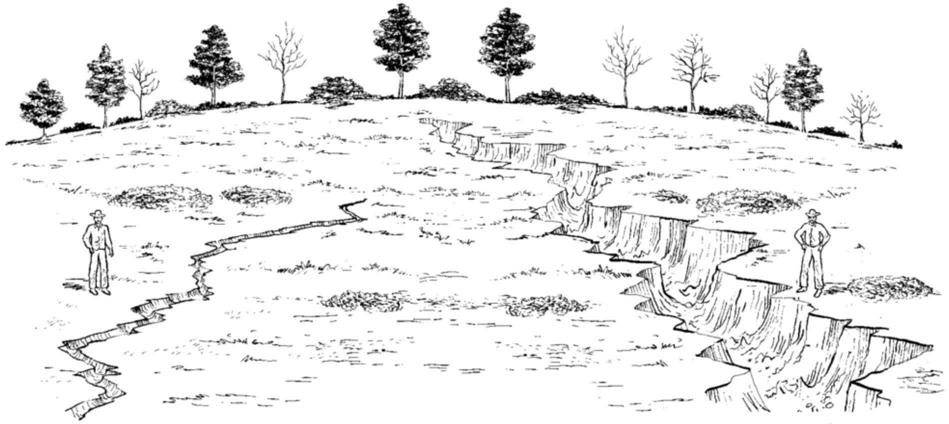
Erosion and soil cover degradation



Negative effects from soil erosion

Soil degradation and loss of soil fertility

Silting & pollution of rivers and other water bodies



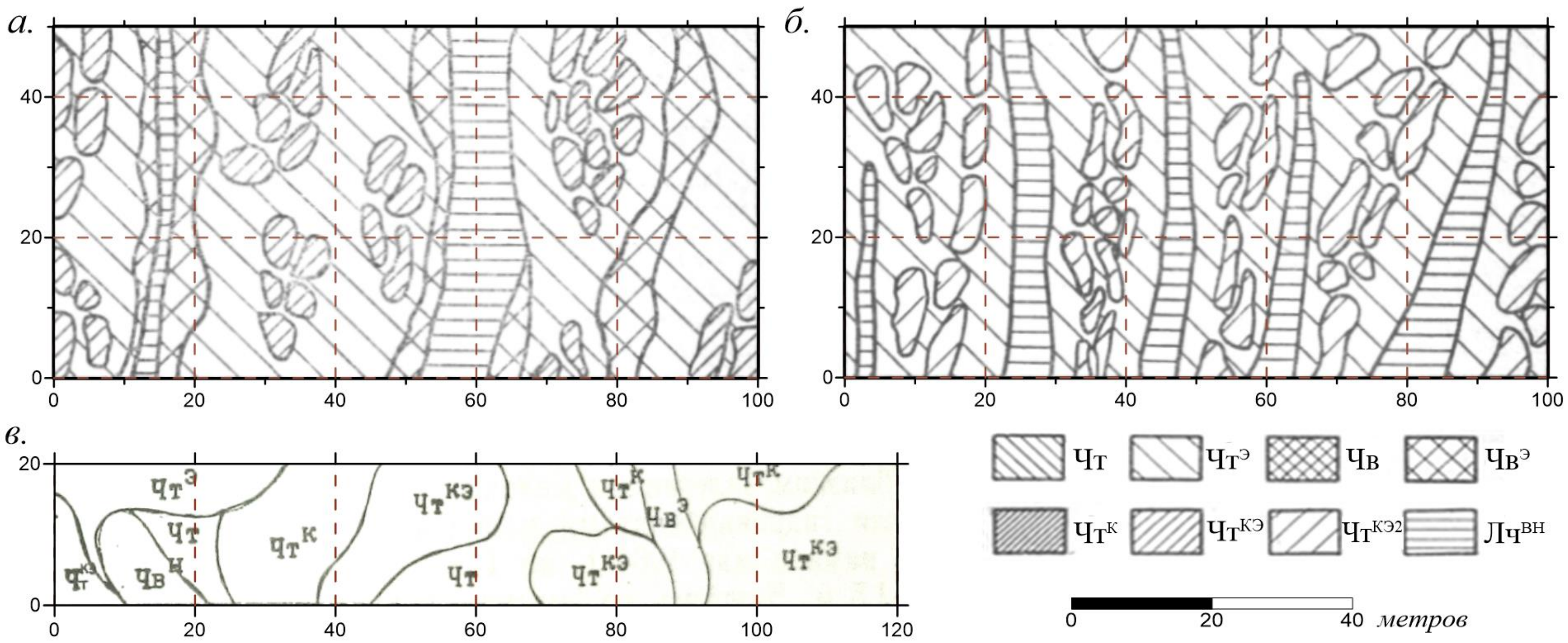
Negative effects from soil erosion

Soil degradation and loss of soil fertility

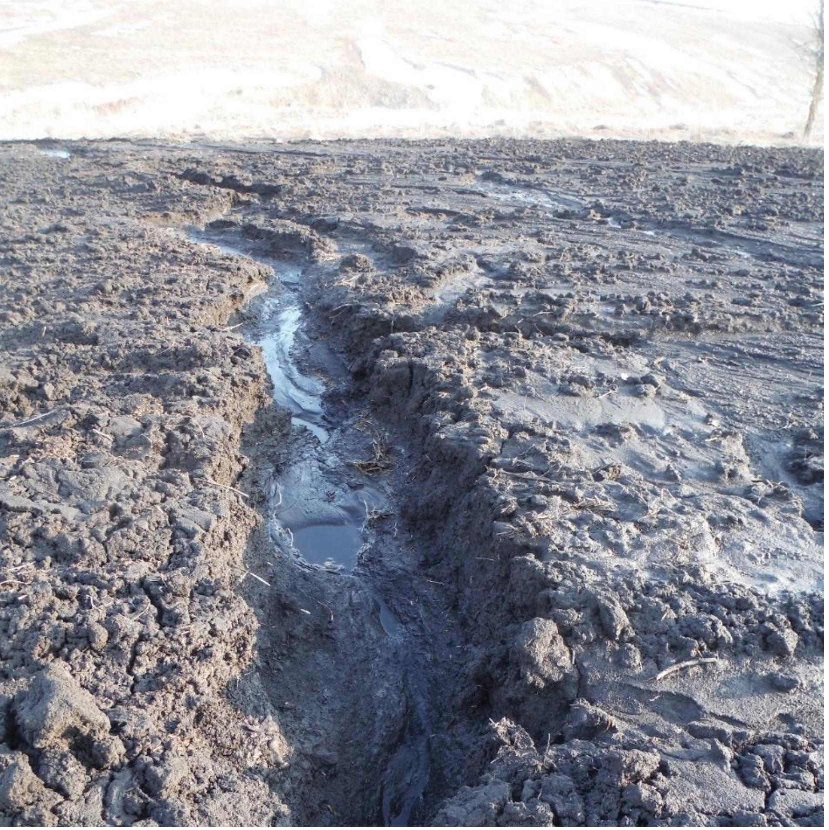
Today's lecture

Silting & pollution of rivers and other water bodies

Participation of different soil patterns

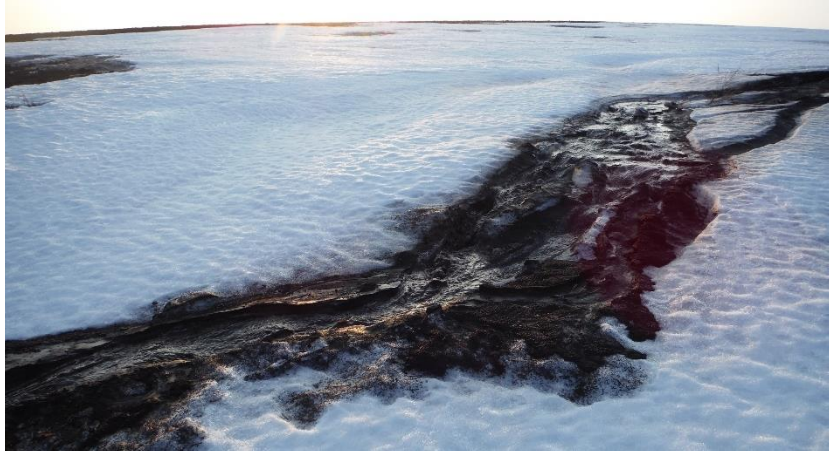


The process of soil degradation
is discrete in space




Snowmelt erosion

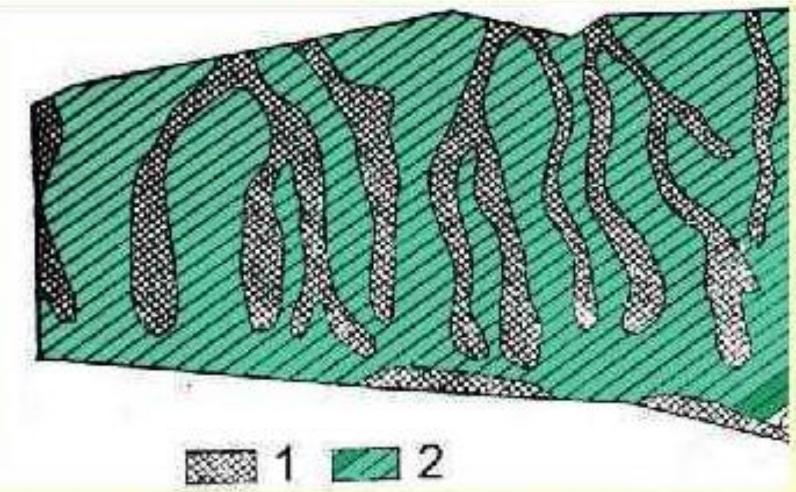
forms very discrete soil erosion cover patterns



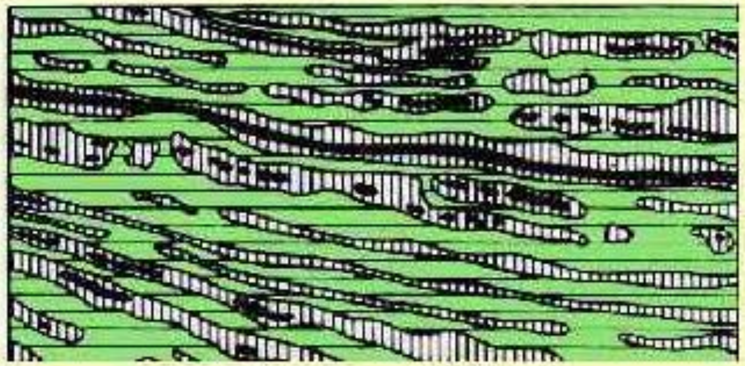
Rainfall erosion

Heavy rain erosion events form wide areas of eroded soils, usually clearly confined to the relief.

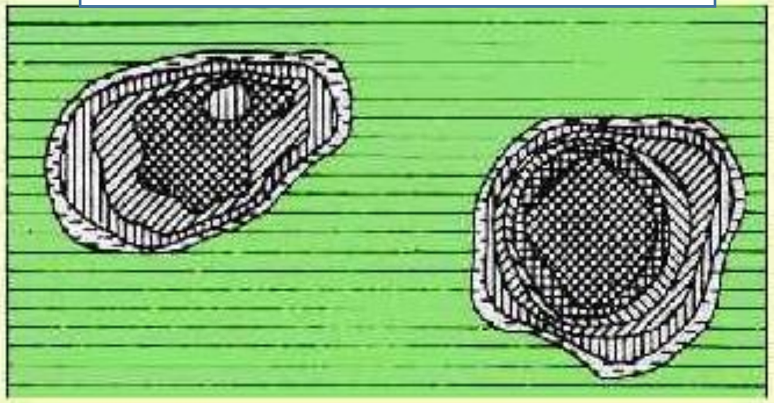
Shape of soil cover patterns



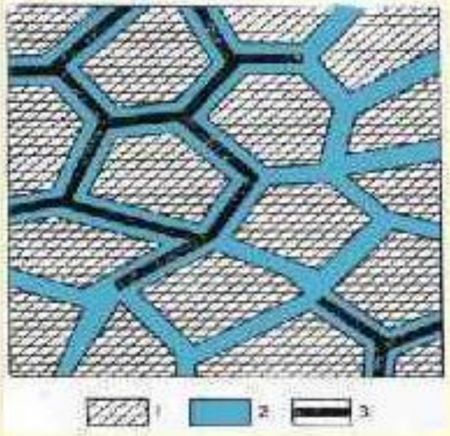
Dendritic



Rilly

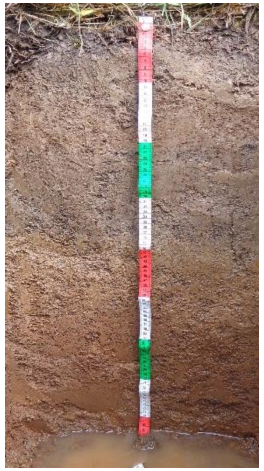


Roundish and ringed

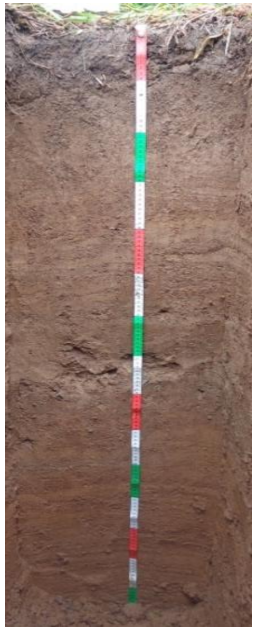


Polygonal

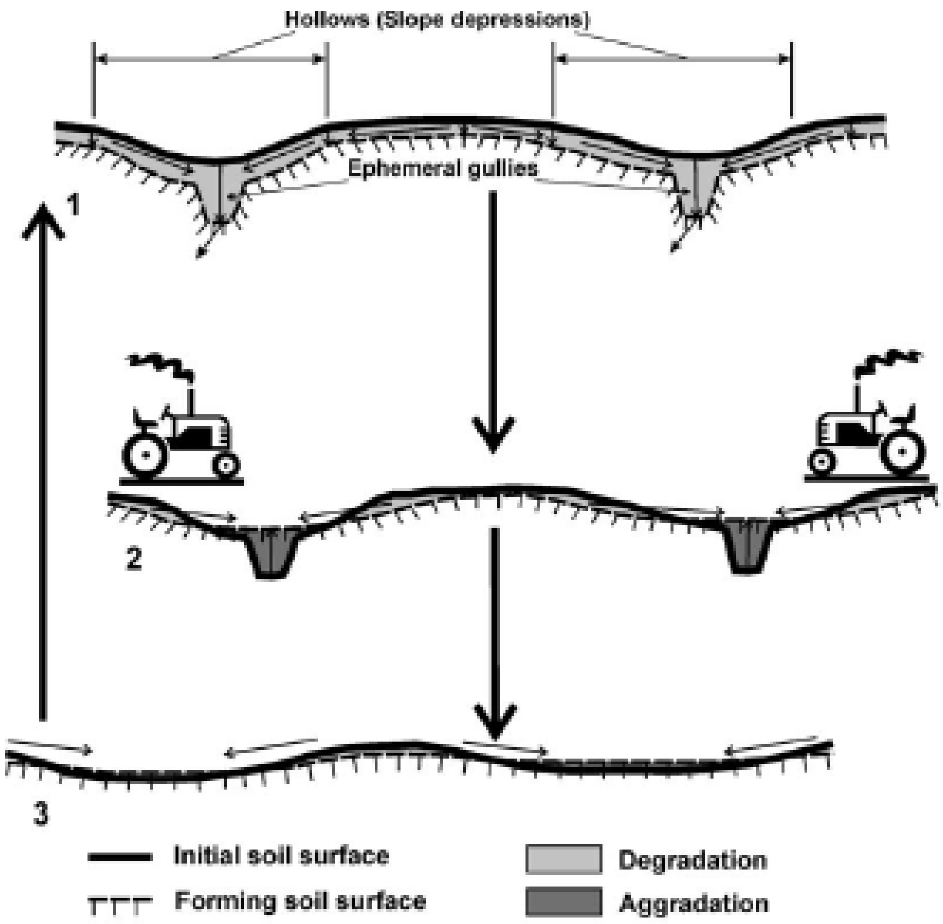
Sediment deposition (reclaimed soils)





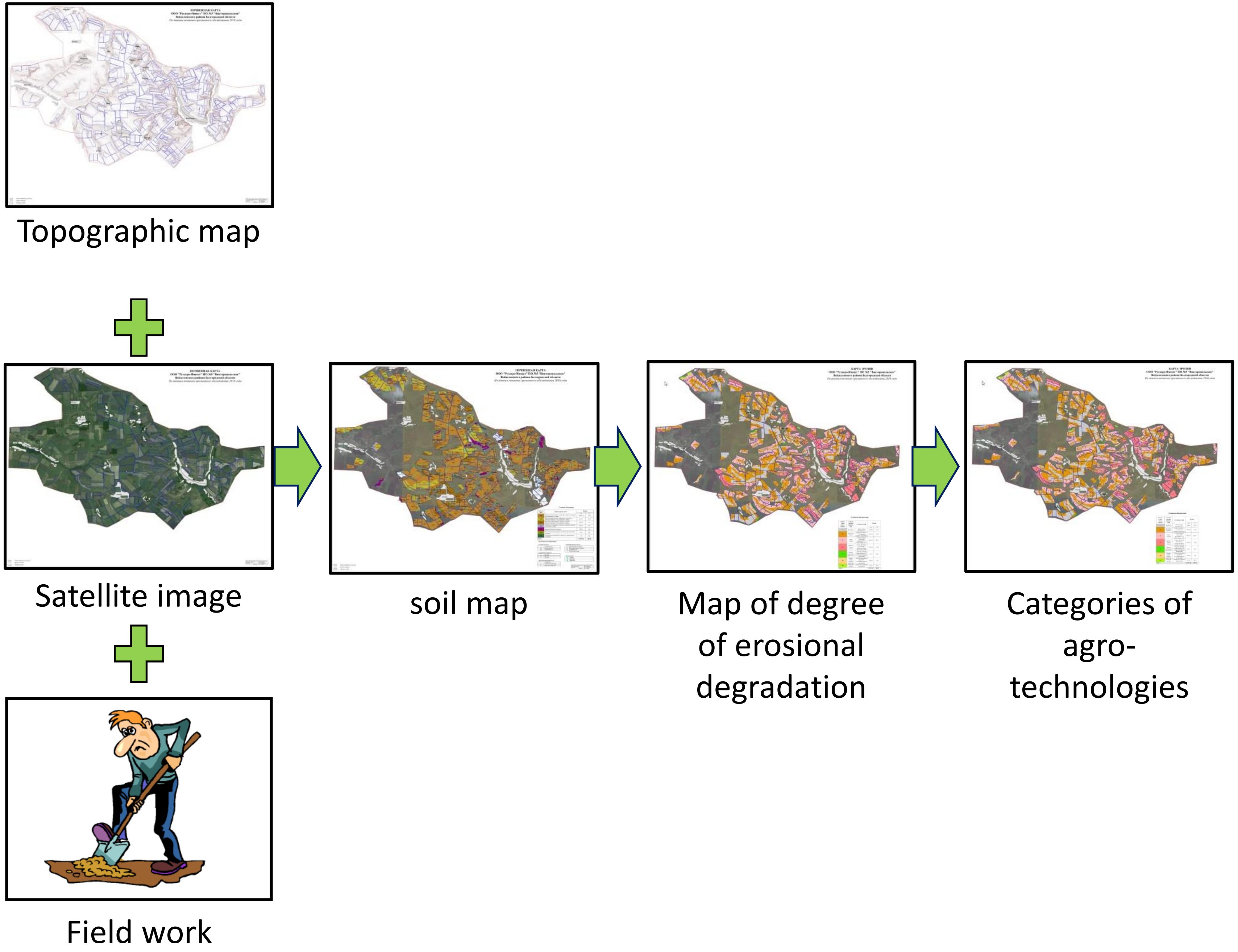

Tillage erosion



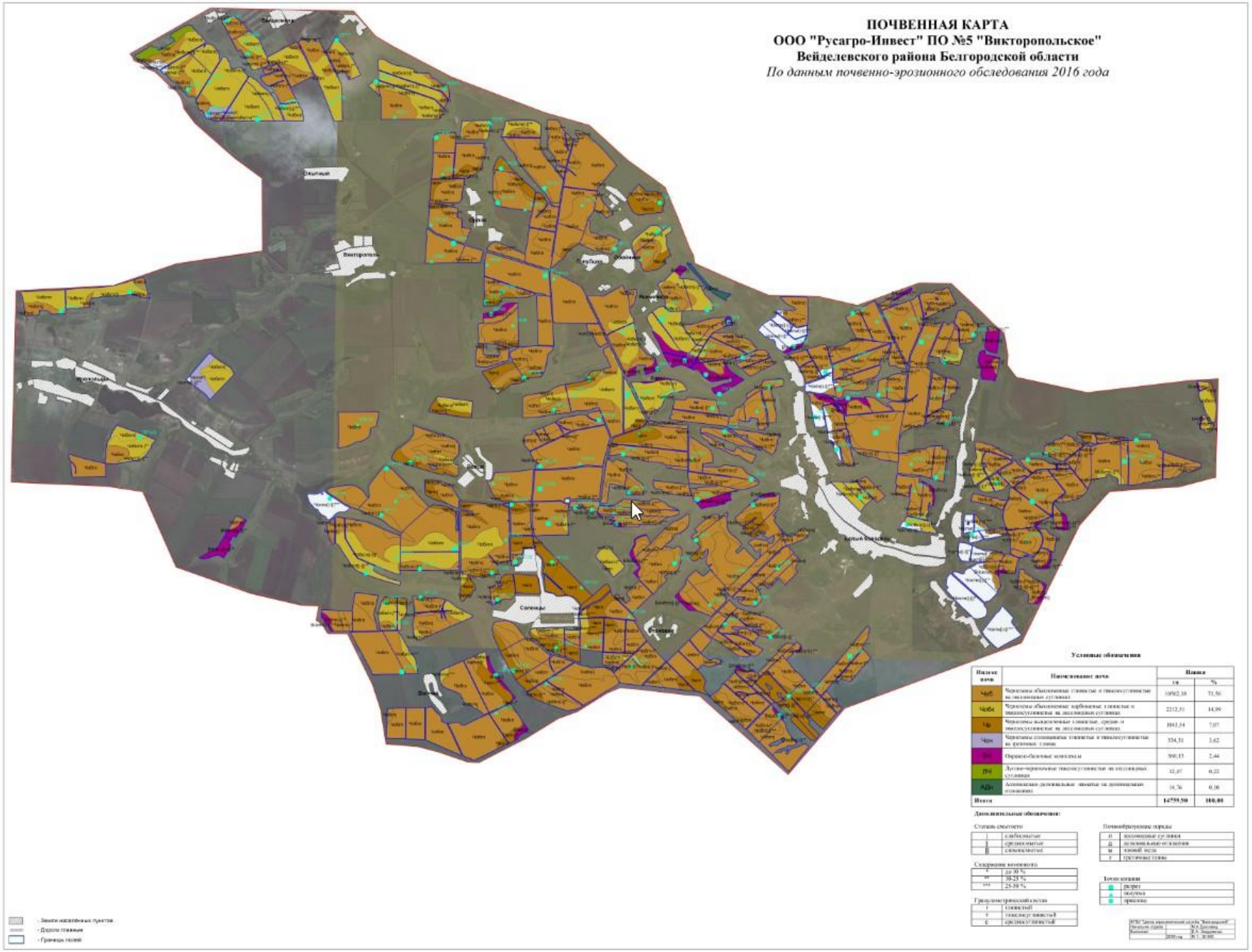
Belyaev et. al., 2005

The established practice of mapping of eroded soils in Russia

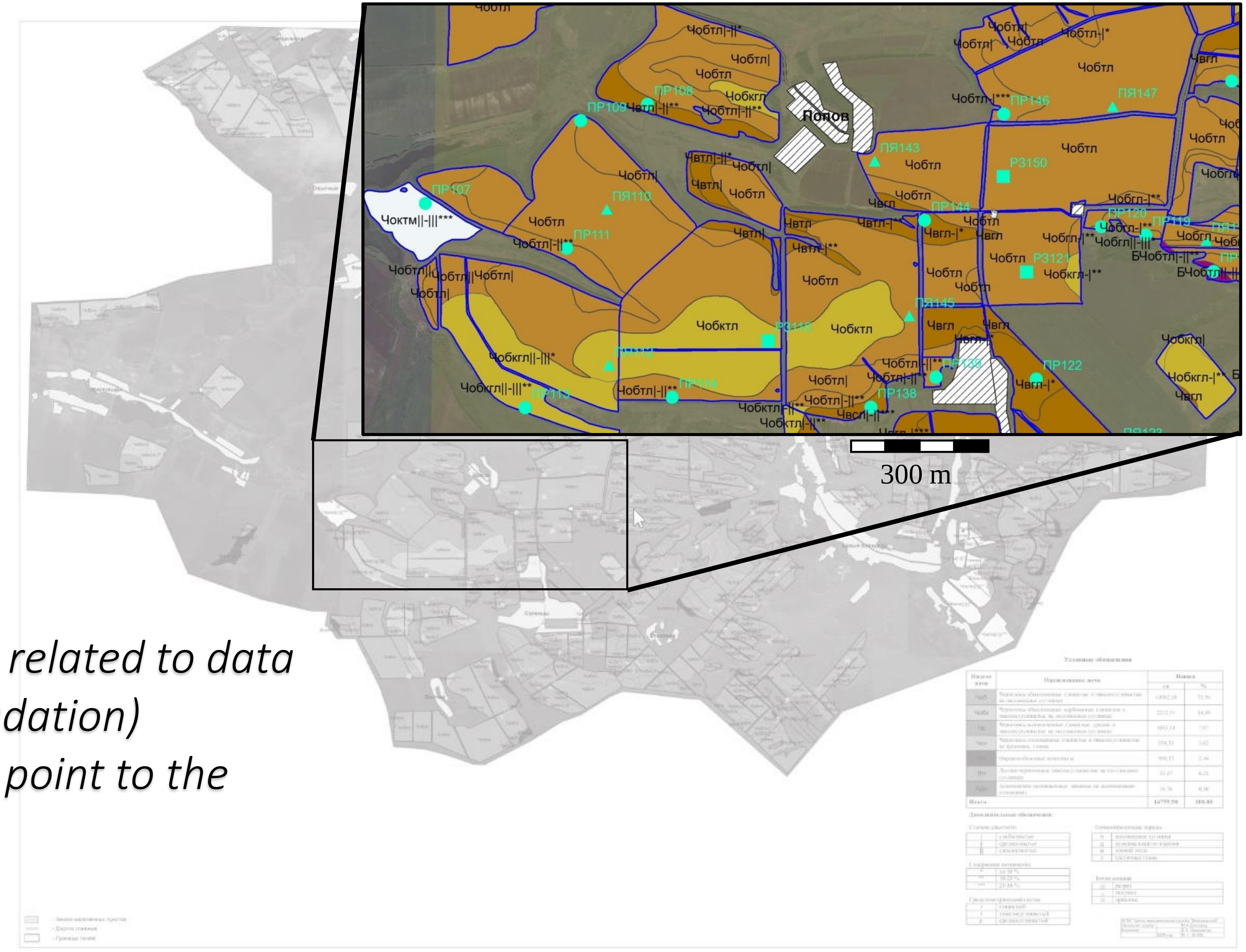
The established practice of mapping of eroded soils in Russia


Topographic map
Satellite image
Field work
soil map
Map of degree of erosional degradation
Categories of agro-technologies

Soil map


ПОЧВЕННАЯ КАРТА
ООО "Русагро-Инвест" ПО №5 "Викторопольское"
Вейделевского района Белгородской области
По данным почвенно-эрозионного обследования 2016 года

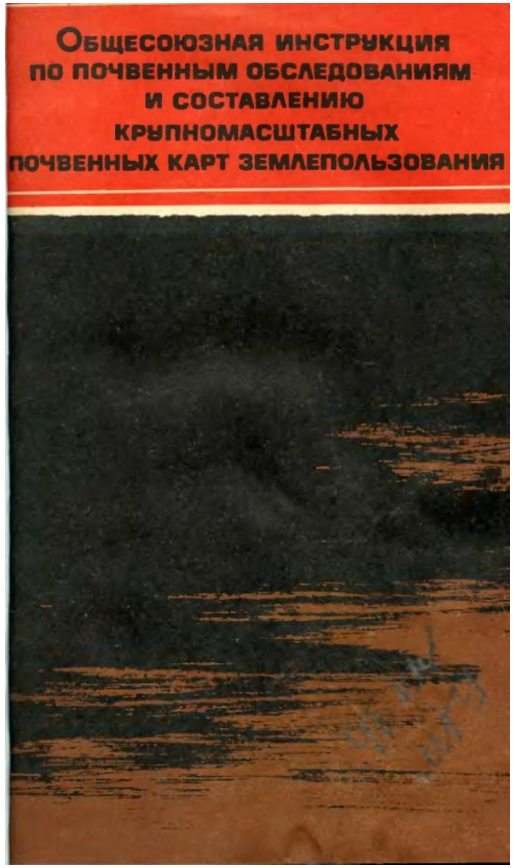
Soil map



The main problem is related to data (degree of soil degradation) interpolation from a point to the surrounding area.

State methodology

Result



Factors:

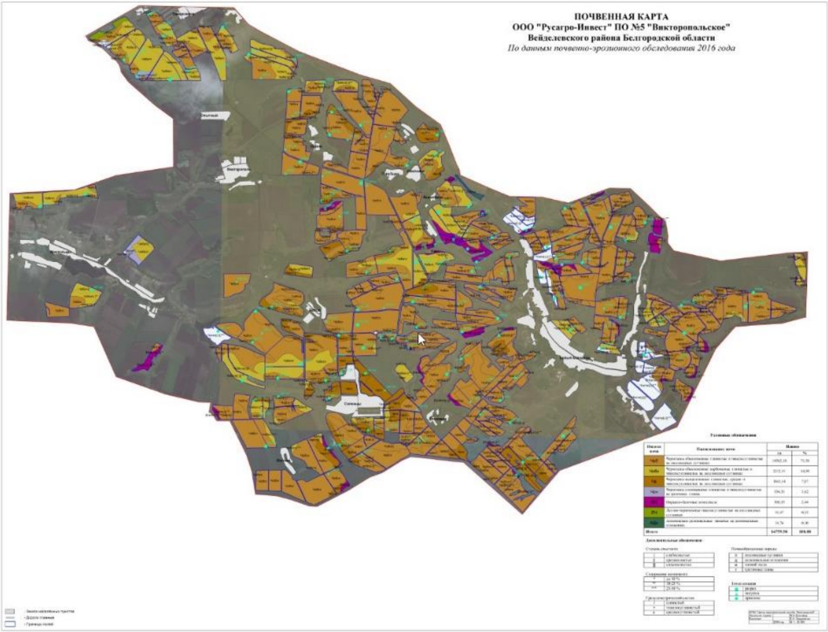
Relief
Exposure
etc.

Properties:

degree of soil degradation

~~**Soil erosion process**~~

Expert opinion



Soil cover mapping is carried out on the basis of expert opinion without taking into account the process of soil erosion.

Author's development

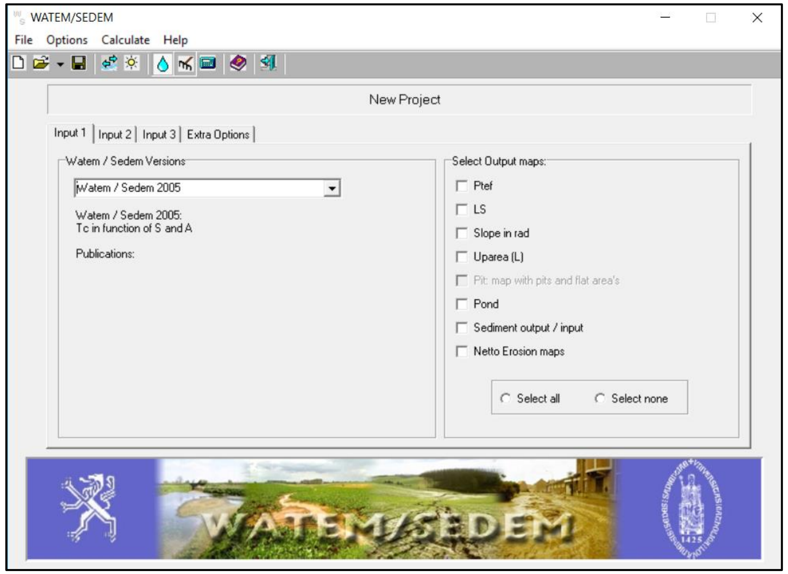
Result

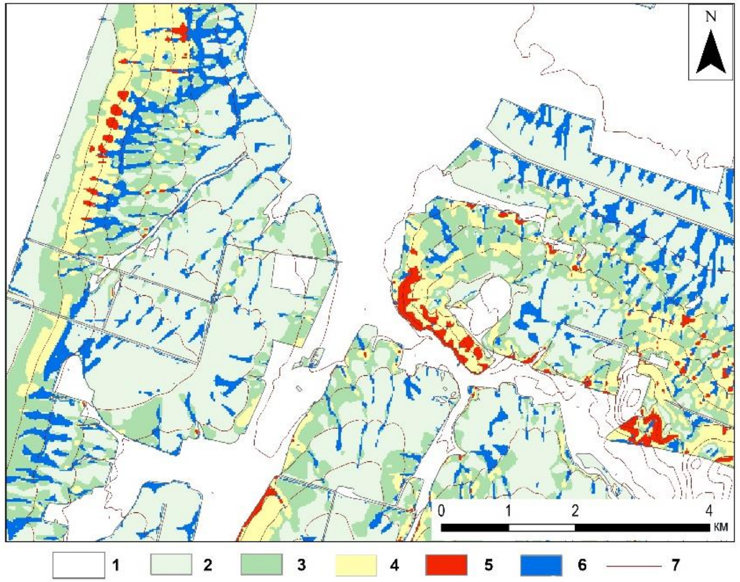
Factors:
Relief
Exposure
etc.

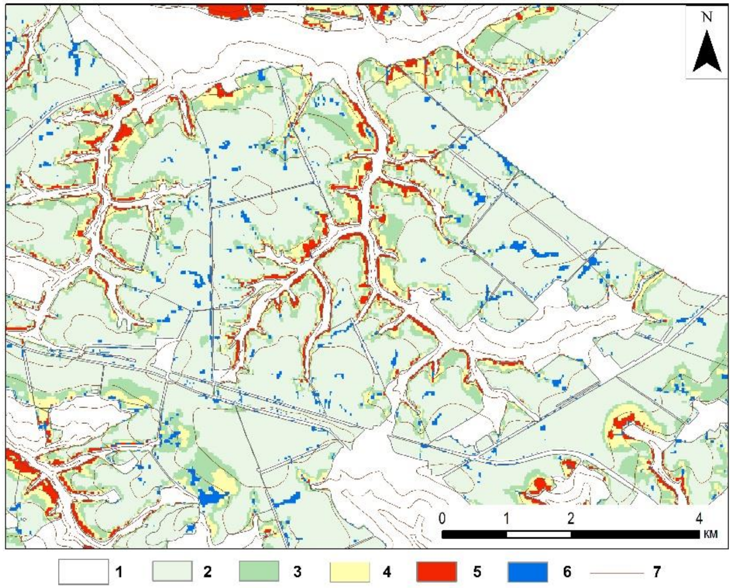
Soil erosion process

Properties:
degree of soil degradation

Modelling







General issues of soil erosion modeling

Early stages of erosion modeling

- **A.D. Ivanovskii, Ya. F. Kornev (1937)**

$W = A * I^{0.75} * L^{0.5} * X^{1.5}$

- **A.W. Zingg (1940)**

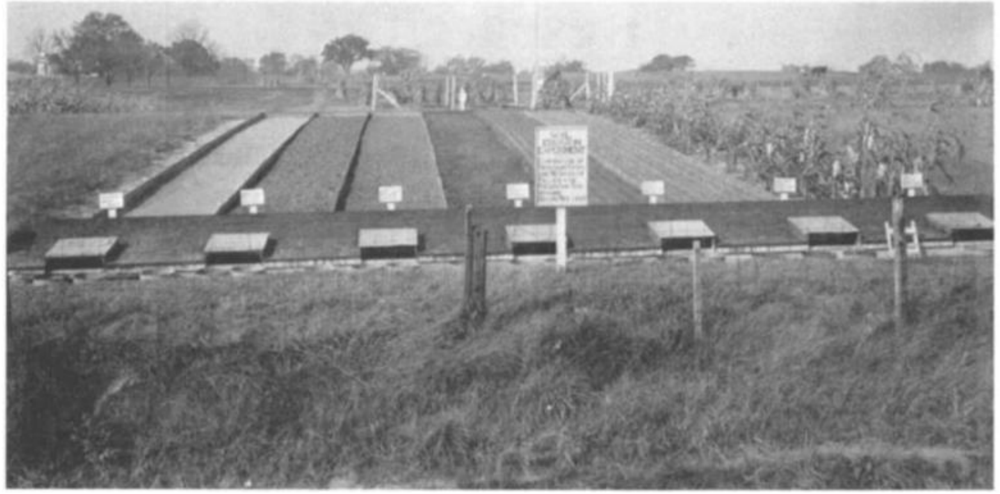
$W = A * I^{0.75} * L^{0.6}$

Wischmeier, Smith (1965, 1978) Universal soil loss equation (USLE)

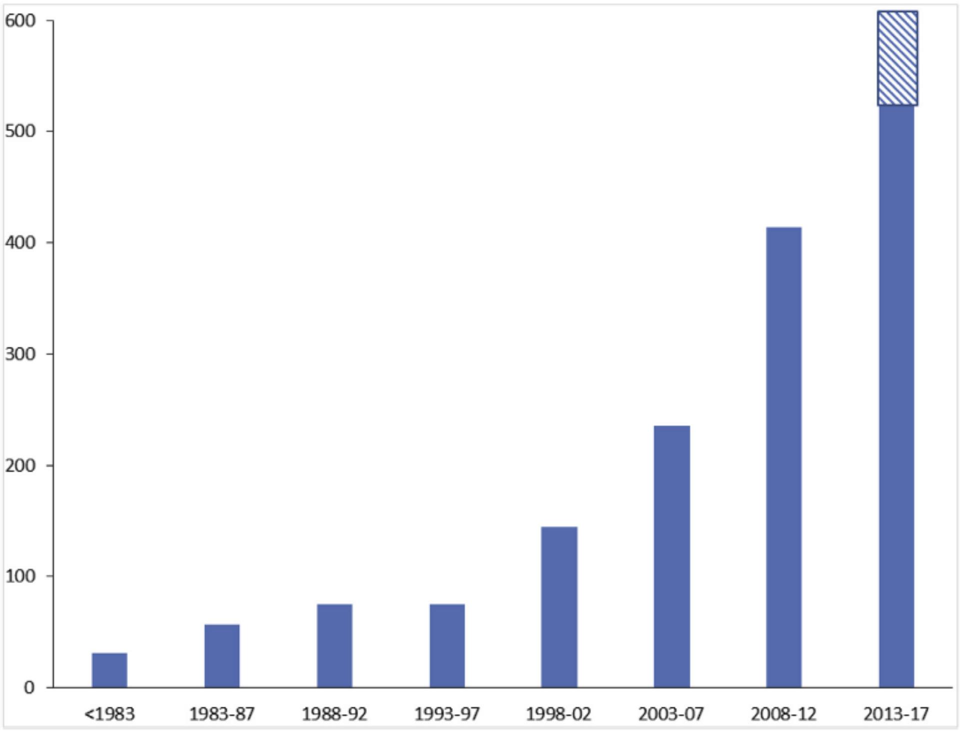
*A = R * K * LS * C * P*

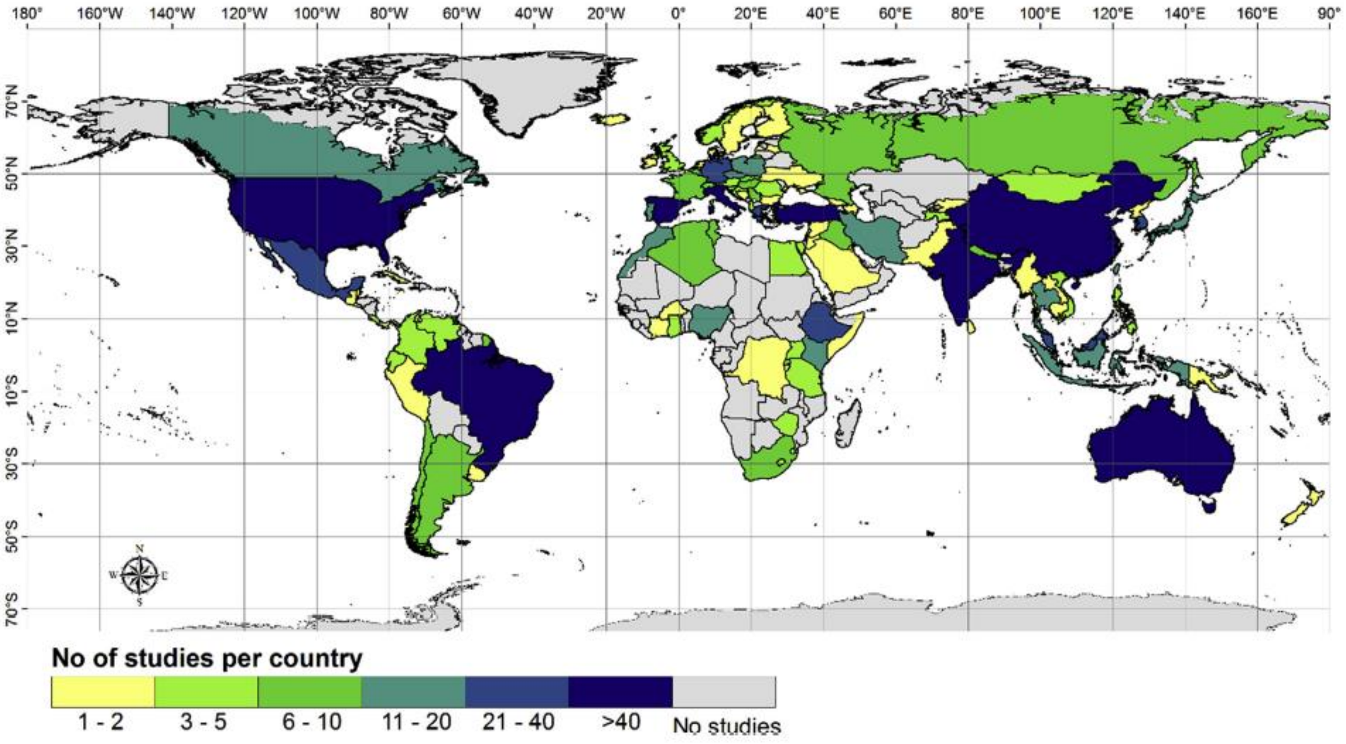
- A: average amount of soil loss caused by gully erosion (tons / ha year)
- R: rain erosivity factor (MJ.mm / ha.year)
- K: soil erodibility factor (tons h / MJ.mm)
- LS: topographical slope and length factor
- C: crop erosivity factor
- P: erosion control factor

Stock stations



Number of publications on mathematical modeling of soil erosion

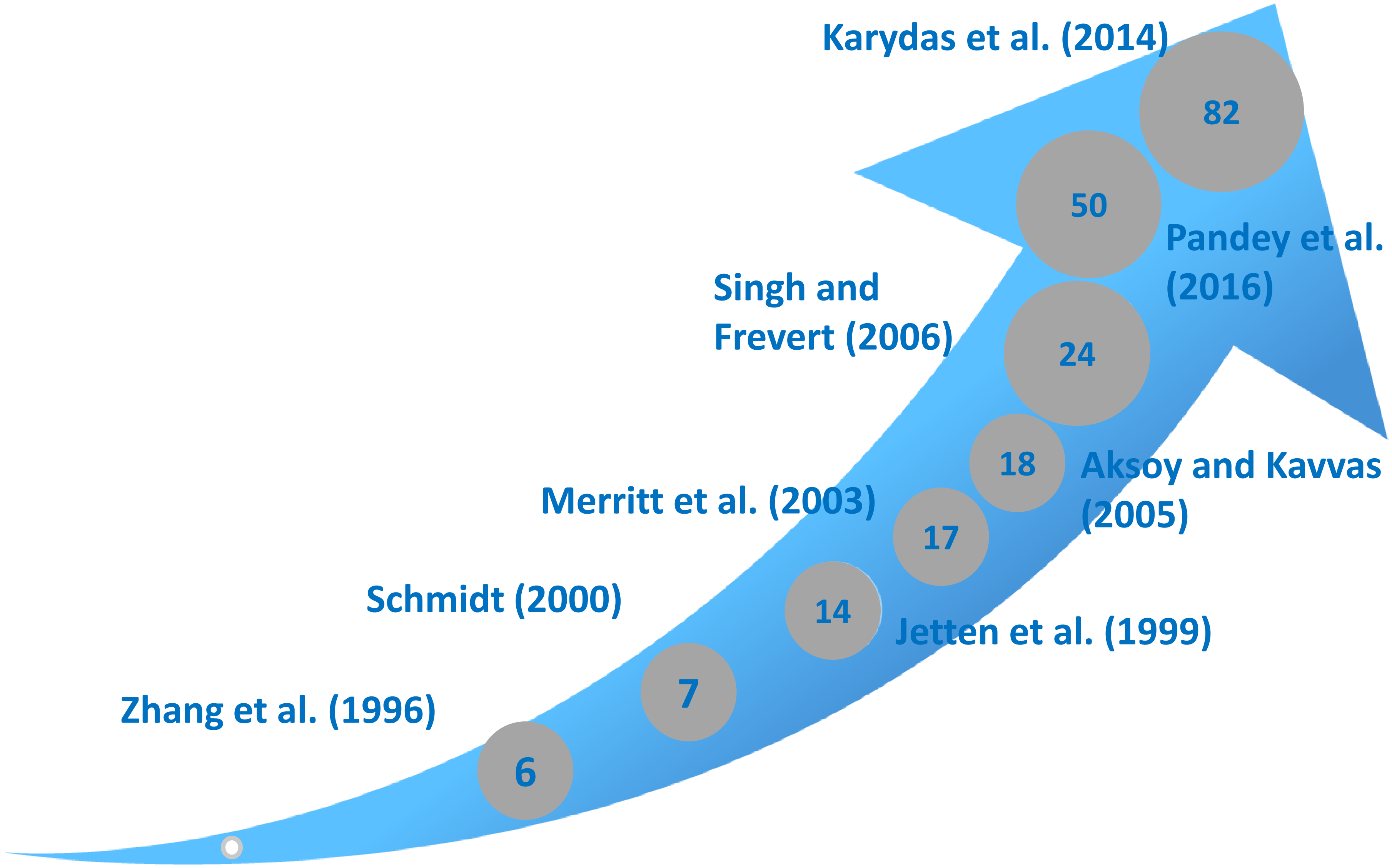




(Alewell et al., 2019)

https://doi.org/10.1016/j.iswcr.2019.05.004

Reviews of Soil Water Erosion Models



Regional models of water erosion of soils in the USSR and the Russian Federation

- G.I. Schwebs (1974, 1979, 1981)
- Ts.E. Mirtskhulava (1970)
- Model of the State Hydrological Institute (1979)
- G.P. Surmach (1979)

- G.A. Larionov (1993) modification of USLE & GHI model
- A.A. Svetlichny (2004, 2010, etc.) modification of the model of G.I. Schwebs
- Yu.P. Sukhanovsky (2008, 2010, 2013, etc.) modification of Ts.E. Mirtskhulava model

Model selection

- **Model algorithm**
- **Time window**
- **Study scale**
- **Integration into computer programs and online services**

Model algorithm

Rainfall water runoff

Snowmelt water runoff

Model algorithm

Empirical Models		Physically based models
	Ease of use	
	Input parameters	
	Scale	
	Forecast	
	Accuracy	

Time window

Average perennial	Event	Any period
AnnAGNPS, ANSWERS-continuous, APEX, CREAMS, GAMES, GLEAMS, HYPE, HSPF, OPUS, PESERA, WATEM/SEDEM, SPUR, SWIM и другие	ACTMO, ANSWERS, AGNPS, DWSM, EGEM, EUROSEM, GUEST, IDEAL, KINEROS, LISEM, MEDALUS, MEFIDIS, MULTSED, PALMS, PEPP-HILLFLOW, PERFECT, RHEM, RillGrow, RUNOFF, SEDIMOT, SHETRAN, SMODERP, TOPOG, WESP и другие	CASC2D, EPIC, GSSHA, IQQM, LASCAM, MIKE 11, PRMS, SHESED, SWAT, SWRRB, TOPMODEL, WEPP и другие

(Pandey et al., 2016)

Object size

Small catchments (<10 sq. km)	Catchments of medium and large rivers
ACTMO, APEX, CREAMS, EGEM, EPIC, EUROSEM, GLEAMS, GUEST, PALMS, PEPP-HILLFLOW, PERFECT, RHEM, RillGrow, SMODERP, SPUR и другие	AGNPS, AnnAGNPS, ANSWERS, ANSWERS-continuous, CASC2D, DWSM, EROSION-2D/3D, GAMES, GSSHA, HSPF, HYPE, IDEAL, KINEROS, LASCAM, LISEM, MEFIDIS, MIKE 11, PESERA, PRMS, RUNOFF, SEDEM, SHESED, SHETRAN, SWAT, SWIM, SWRRB, TOPMODEL, TOPOG, WESP и другие

WEPP

WATEM / SEDEM

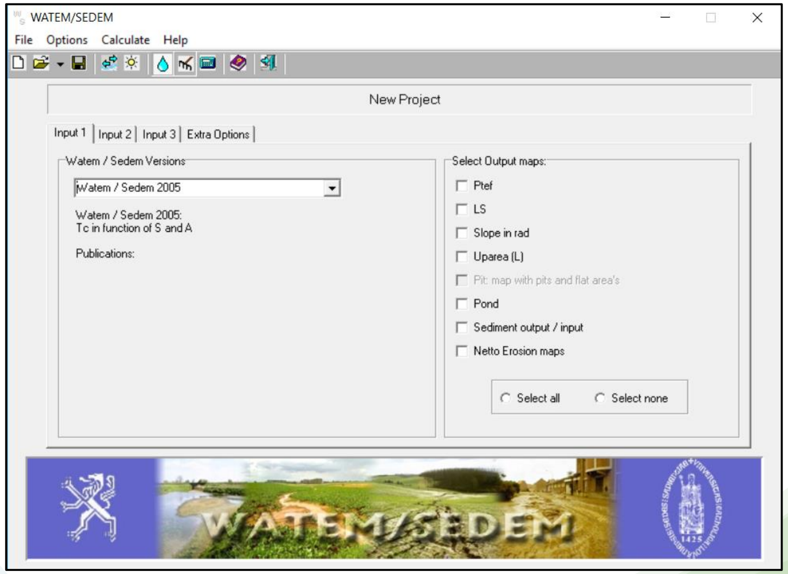
(Pandey et al., 2016)

Integration into computer programs and online services

Name	Last modified	Size
Parent Directory		-
Big Hole Area - Part of Beaverhead County, Montana.gdb	21-Jan-2016 21:58	855K
Big Horn County Area, Montana.gdb	21-Jan-2016 21:56	2.0M
Bitterroot Valley Area, Montana.gdb	31-Jan-2015 00:45	1.8M
Blaine County and Part of Phillips County Area, Montana.gdb	21-Jan-2016 21:56	767K
Broadwater County Area, Montana.gdb	21-Jan-2016 21:57	1.1M
Carbon County Area, Montana.gdb	30-Jan-2015 22:39	711K
Carter County, Montana.gdb	21-Jan-2016 21:35	1.0M
Cascade County Area, Montana.gdb	21-Jan-2016 21:59	1.0M
Choteau-Conrad Area; Parts of Teton and Pondera Counties, Montana.gdb	22-Jan-2016 00:00	1.2M
Chouteau County Area, Montana.gdb	21-Jan-2016 22:01	1.2M
Custer County Area, Montana.gdb	21-Jan-2016 21:42	1.6M
Dawson County, Montana.gdb	21-Jan-2016 21:43	551K
Deer Lodge County Area, Montana.gdb	21-Jan-2016 22:02	2.5M
Dillon Area - Part of Beaverhead County, Montana.gdb	21-Jan-2016 21:55	1.0M
Fallon County, Montana.gdb	21-Jan-2016 21:44	874K
Fergus County, Montana.gdb	21-Jan-2016 21:44	1.6M
Flathead County Area and Part of Lincoln County, Montana.gdb	21-Jan-2016 22:03	737K
Gallatin County Area, Montana.gdb	21-Jan-2016 22:04	2.3M
Garfield County, Montana.gdb	21-Jan-2016 21:45	1.2M
Glacier County Area and Part of Pondera County, Montana.gdb	21-Jan-2016 21:54	943K
Golden Valley County Area, Montana.gdb	22-Jan-2016 00:16	1.2M
Granite County Area, Montana.gdb	21-Jan-2016 22:03	2.0M
Hill County, Montana.gdb	21-Jan-2016 21:46	671K
Horse Prairie-South Valley Area - Part of Beaverhead County, Montana.gdb	21-Jan-2016 21:59	4.0M
Jefferson County Area and Part of Silver Bow County, Montana.gdb	21-Jan-2016 22:06	4.4M
Judith Basin Area, Montana.gdb	30-Jan-2015 22:02	947K
Lake County Area, Montana.gdb	21-Jan-2016 22:06	890K
Lewis and Clark County Area, Montana.gdb	21-Jan-2016 22:07	1.3M
Liberty County, Montana.gdb	21-Jan-2016 21:46	645K
MT Soils Updated 01252016.zip	25-Jan-2016 18:06	3.2M
Madison County Area, Montana.gdb	21-Jan-2016 22:08	1.9M
McCone County, Montana.gdb	21-Jan-2016 21:47	880K
Meagher County Area.gdb	21-Jan-2016 22:09	2.6M
Missoula County Area, Montana.gdb	31-Jan-2015 00:21	1.1M

Input parameters and assumptions of WaTEM/SEDEM

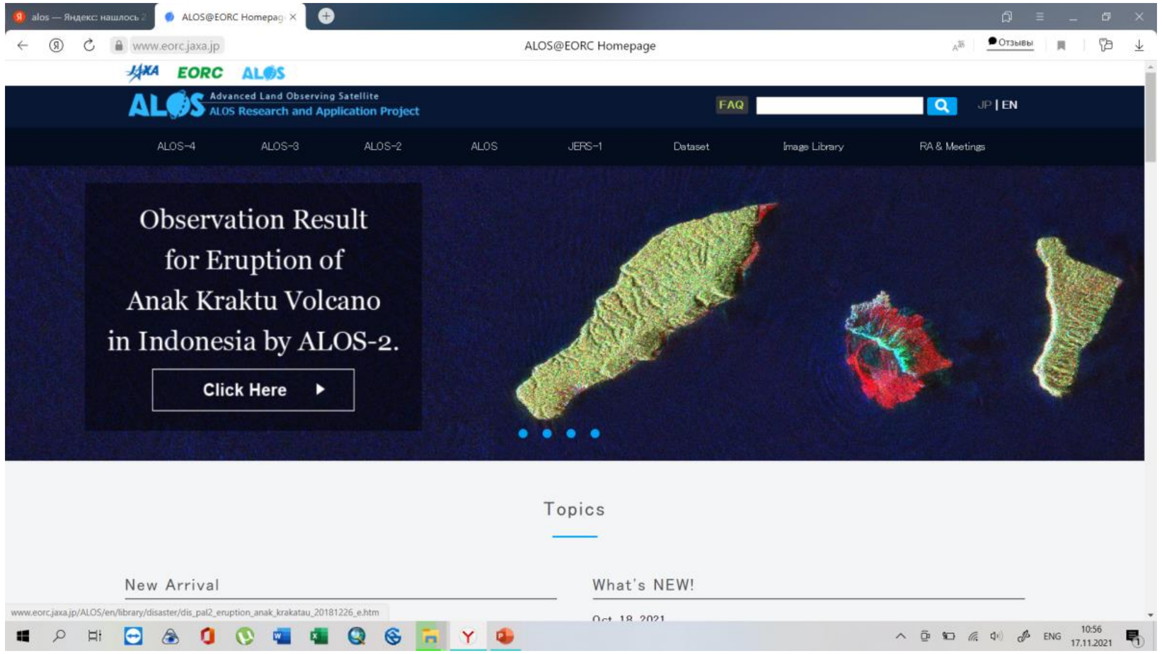
WaTEM/SEDEM

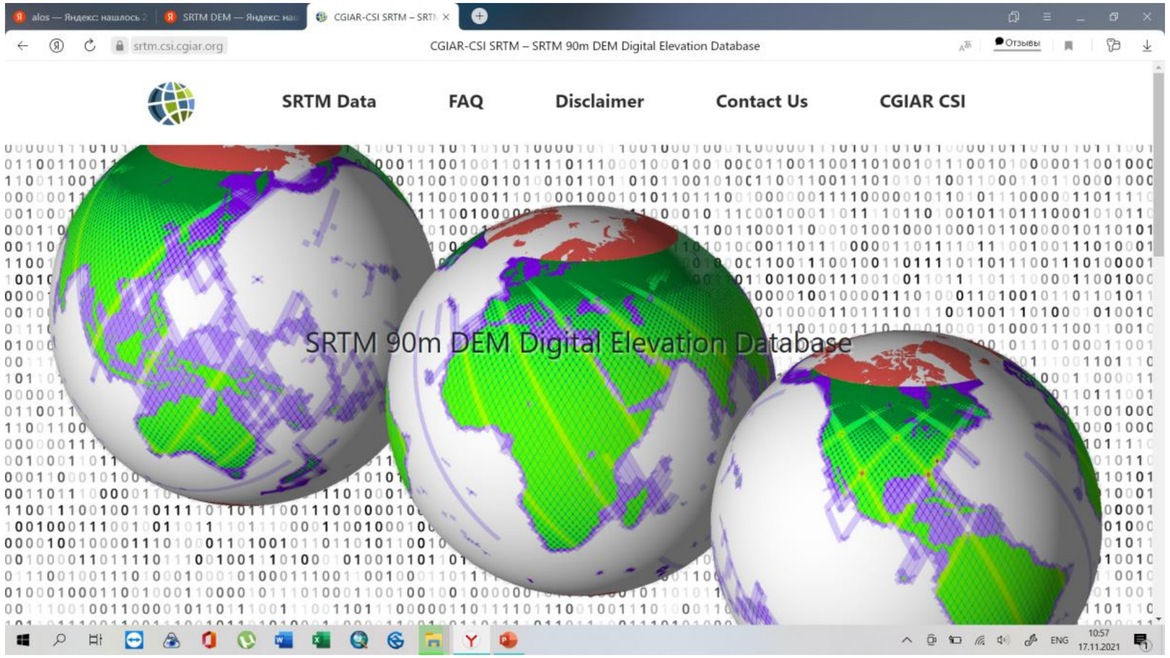


$$A = R * K * LS * C * P$$

- A: average amount of soil loss caused by gully erosion (tons / ha year)
- R – rain erosivity factor (MJ.mm / ha year)
- K: soil erodibility factor (tons h / MJ mm)
- LS: topographical slope and length factor
- C: crop erosivity factor
- P: erosion control factor

LS-factor (topographical slope and length)





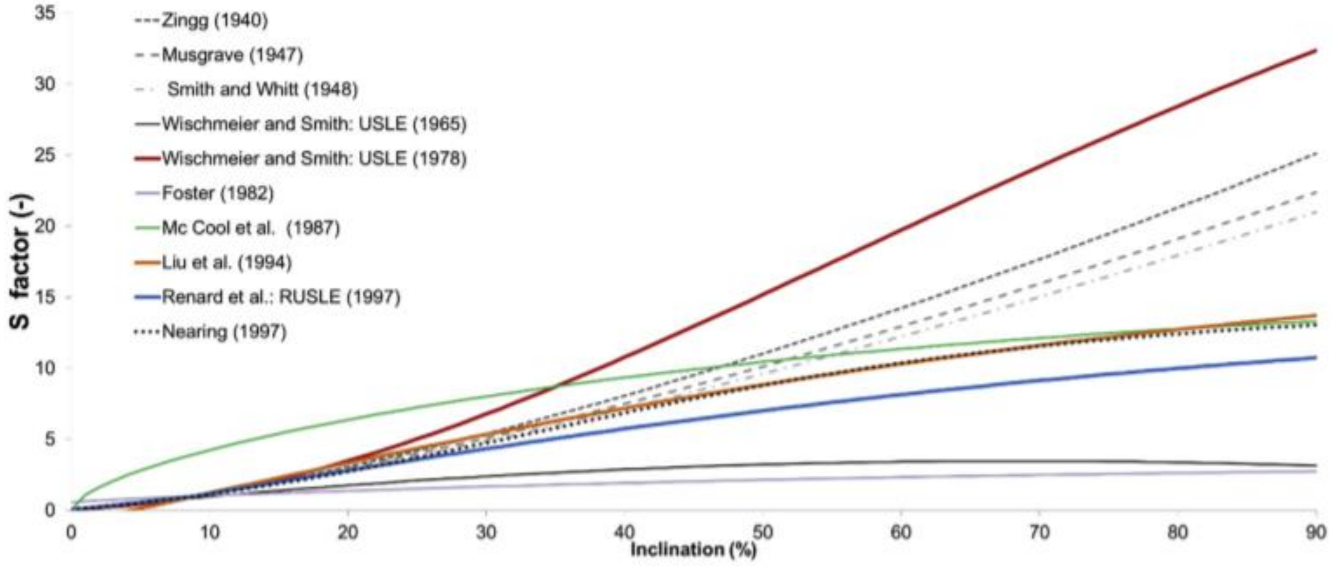


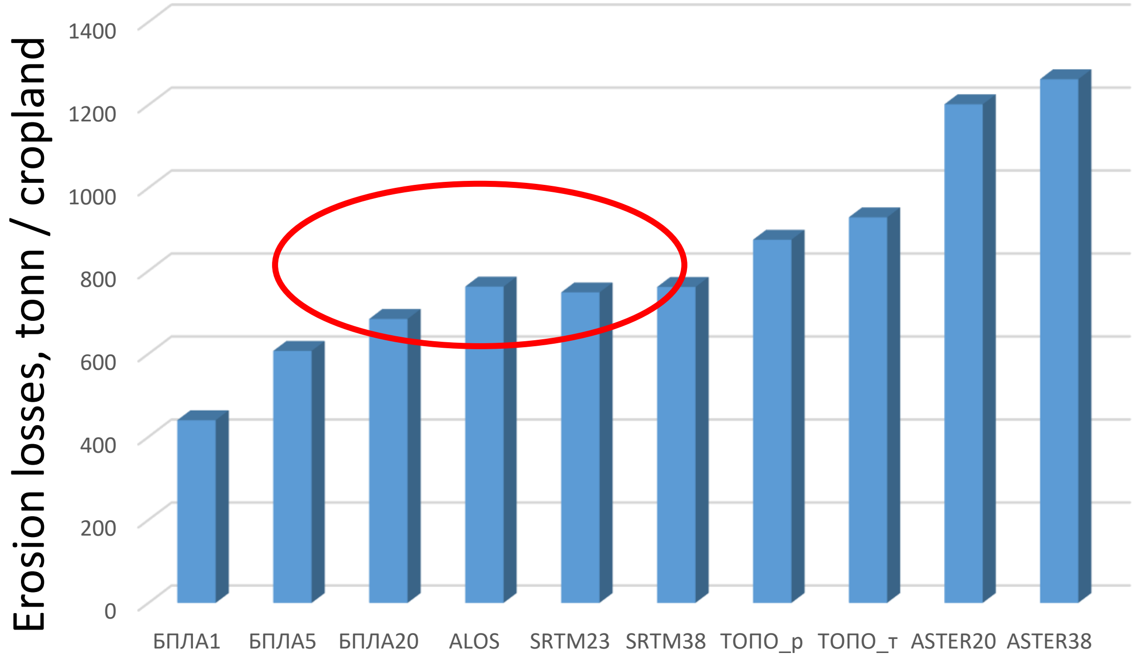
Fig. 4. Dependency of the S factor on inclination (slope steepness) for different parametrizations.

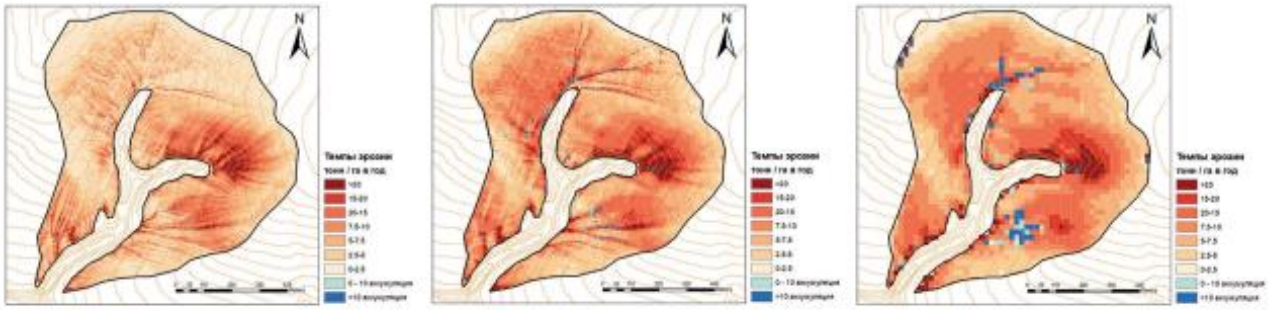
(Alewell et al., 2019)

https://doi.org/10.1016/j.iswcr.2019.05.004

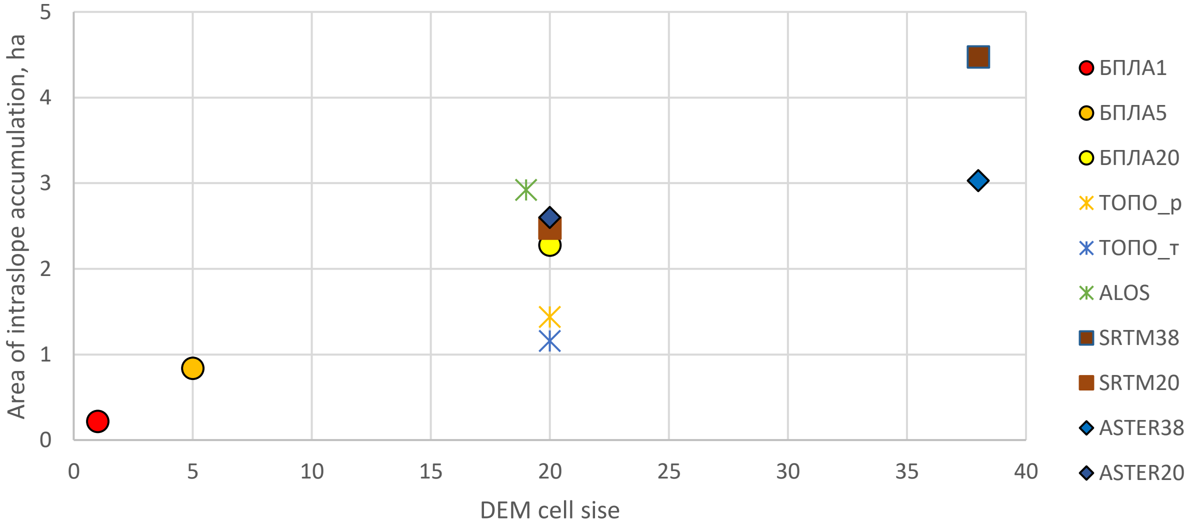
Resolution of digital elevation models (DEM)

№	Источник	Исходный размер пикселя ЦМР	Размер пикселя ЦМР для расчёта, м	Сокращённое название
1	Съёмка БПЛА	0,1 м	1	БПЛА1
2	Съёмка БПЛА		5	БПЛА5
3	Съёмка БПЛА		20	БПЛА20
4	Топографическая карта (интерполяция «Топо в растр»)	–	20	ТОПО_р
5	Топографическая карта (интерполяция триангуляцией)			ТОПО_т
6	ALOS (AW3D30)	1 угл. с	19	ALOS
7	SRTMGL1N v003		23	SRTM23
8	SRTM plus v3	38 м	38	SRTM38
9	ASTERGTM v003	1 угл. с	23	ASTER23
10	ASTER GDEM v2	38 м	38	ASTER38





UAV 1 м UAV 5 м UAV 20 м



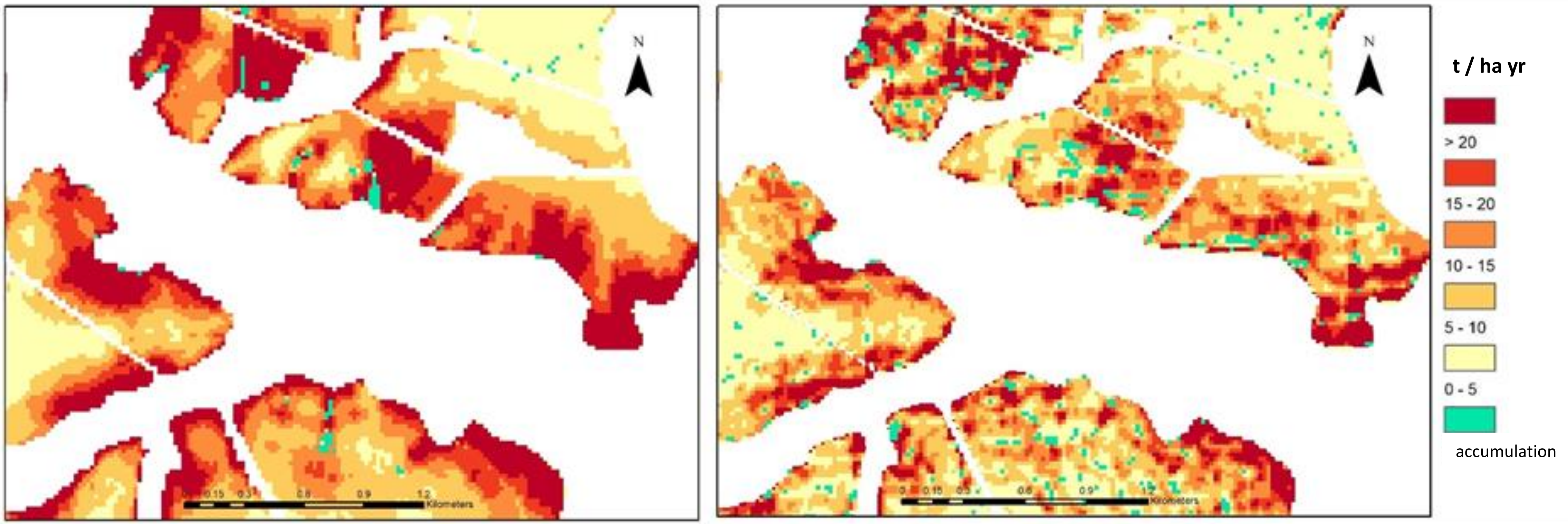
Zhidkin et. al., 2021

DOI: 10.21046/2070-7401-2021-18-5-133-144 (in Russian)

Spatial structure of erosion-accumulative processes using different DEMs.

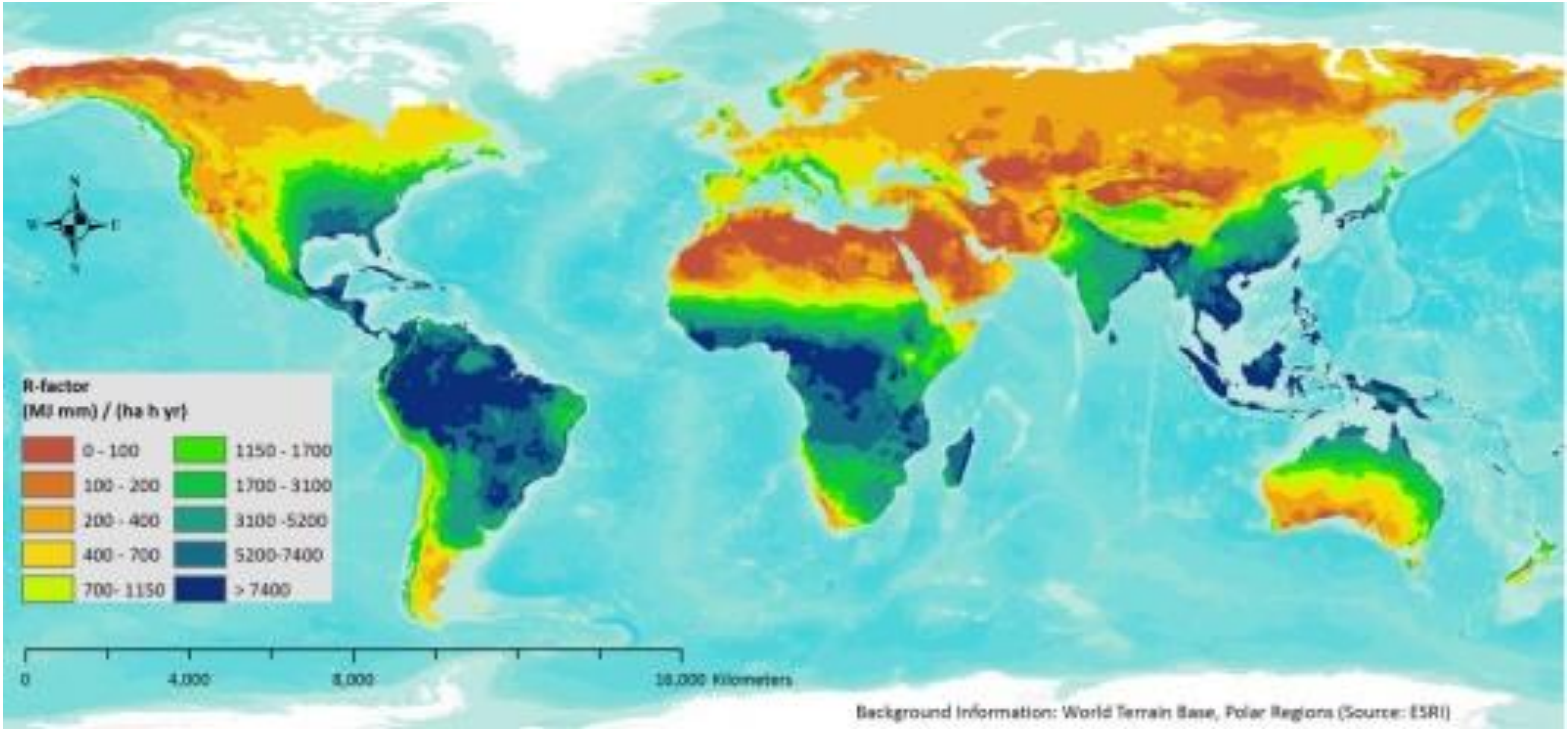
DEM based on topo maps

SRTM



R – rain erosivity factor

(Panagos et. al., 2017 https://doi.org/10.1038/s41598-017-04282-8)



C: crop erosivity factor

the most uncertain

Verification of soil erosion models

The importance of verification of erosion modelling

Erosion modelling results

=

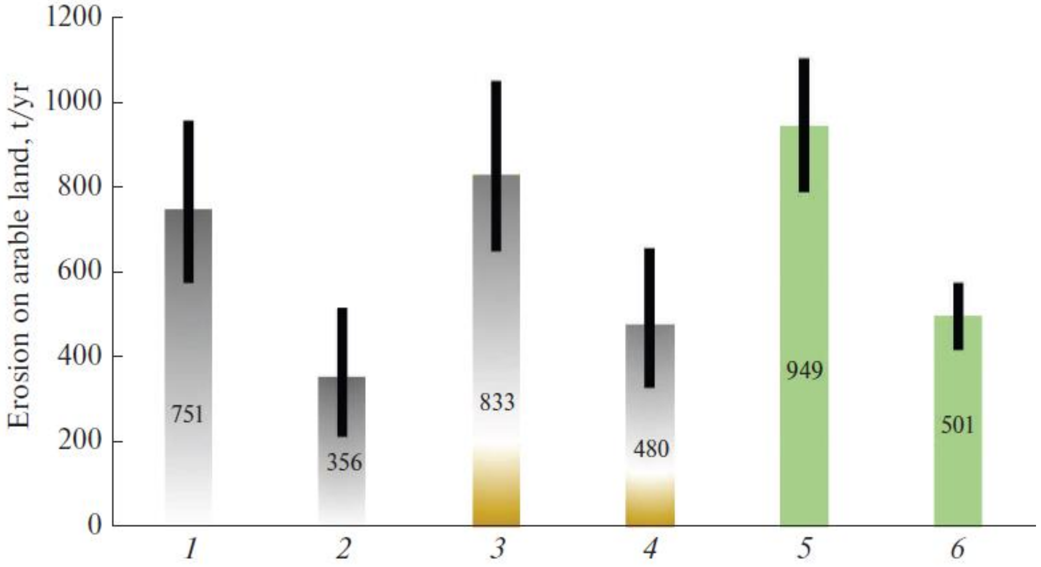
without verification

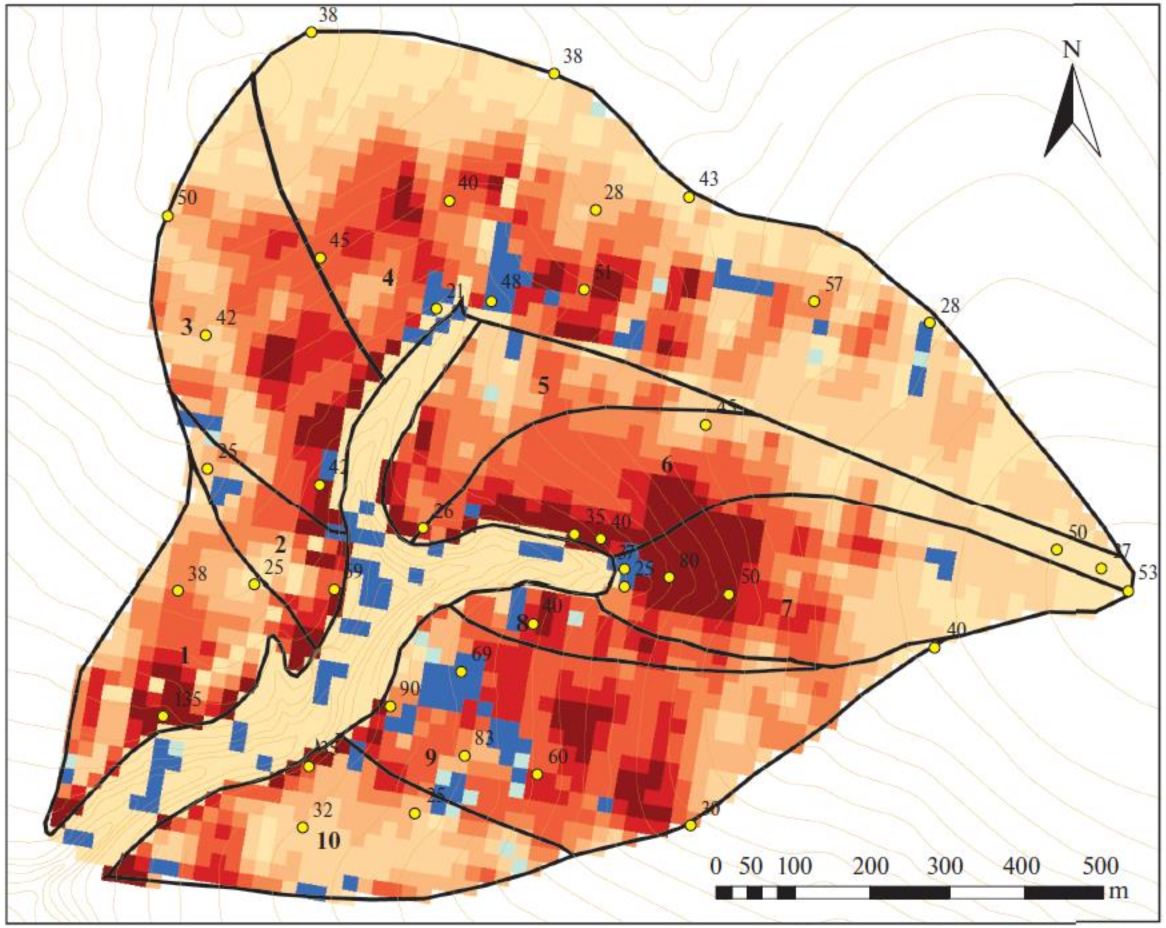
Expert opinion

WaTEM/SEDEM verification

Paper	Region	Model	Method
Quiñonero-rubio, et al. 2016	Spain	WaTEM/SEDEM	sediment measurement at the outlet
Boix-fayos et al. 2008	Spain	WaTEM/SEDEM	sediment measurement at the outlet
De Vente et all, 2008	Spain	WaTEM/SEDEM	sediment measurement at the outlet
Van Rompaey et all, 2001	Belgium	WaTEM/SEDEM	sediment measurement at the outlet (12 catchments)
Van Rompaey et all, 200	Italy	WaTEM/SEDEM	sediment measurement at the outlet (40 catchments)
Verstraeten et al, 2007	Australia	WaTEM/SEDEM	sediment measurement at the outlet (16 catchments)
Verstraeten 2006	France	WaTEM/SEDEM	sediment measurement at the outlet (20 catchments)
Ward et al, 2009	Europe.	WaTEM/SEDEM	sediment measurement at the outlet (26 catchments)
Lieskovský and Kenderessy, 2014	Slovakia	WaTEM/SEDEM	pin method
Alatorre et all, 2012	Spanish Pyrenees	WaTEM/SEDEM	Cs-137 (spatial estimates)
Feng et all, 2010	Chinese Loess Plateau	WaTEM/SEDEM	Cs-137 (spatial estimates)
L. Quijano et all, 2016	Spain	WaTEM/SEDEM	Cs-137 (spatial estimates)
Jakubínský et all, 2019	Czech Republic	WaTEM/SEDEM, USPED, InVEST and TerrSet	comparison of simulation results

An example of erosion model verification on a small watershed in the center of the Central Russian Upland



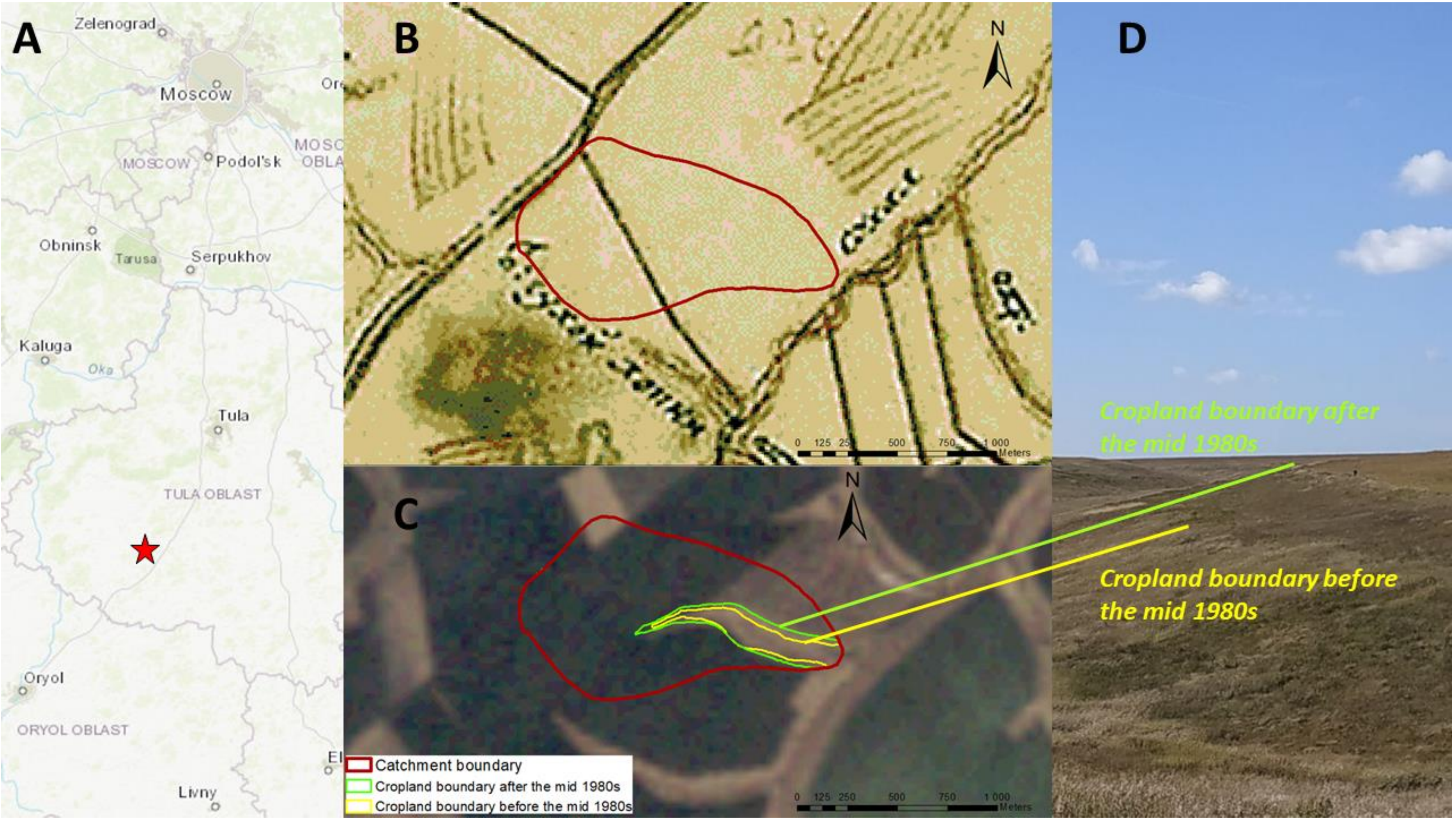


Golosov et. al., 2022

DOI: 10.1134/S1064229322100040

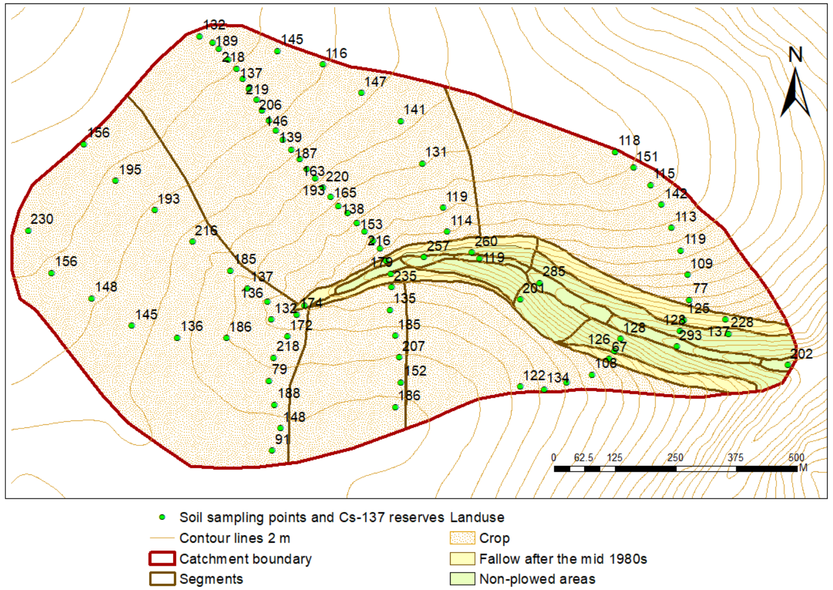
Historical reconstruction of soil erosion rates

An example of soil erosion models verification in a small catchment for different time windows with changing cropland boundary (Tula region, Russia)

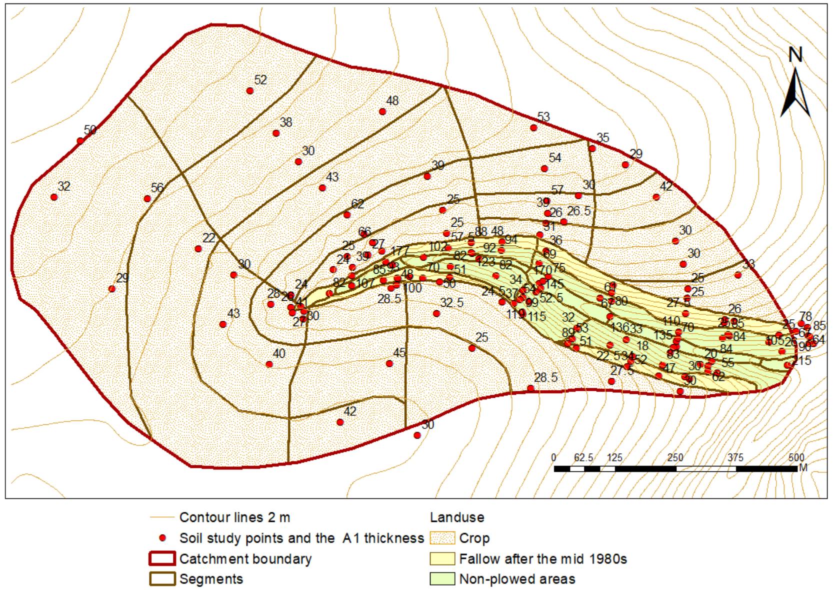


Long-term studies of soil erosion

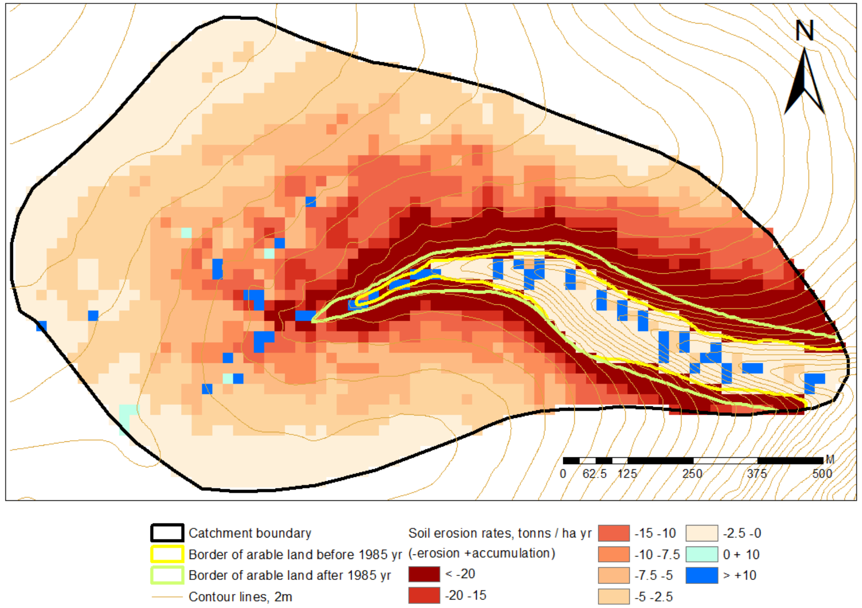
Radiocesium method



Soil profile truncation method

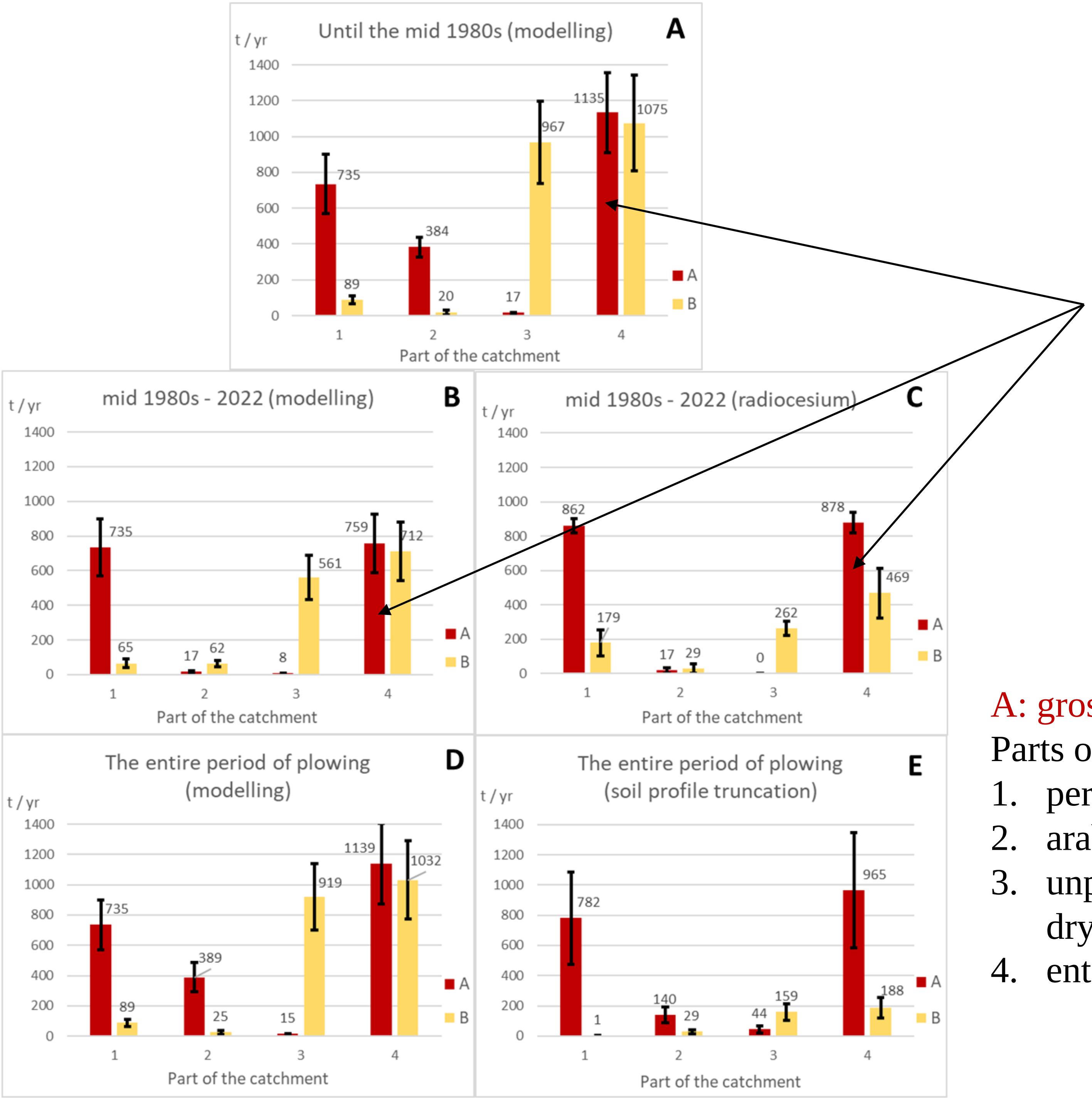


Erosion modelling



Zhidkin et. al., 2020
https://doi.org/10.1016/j.jenvrad.2020.106386

Koshovskii et. al., 2019
https://doi.org/10.1134/S1064229319050053



Soil loss was reduced by 30% due to the reduction of arable land by 5%.

A: gross erosion; B: sediment deposition.

Parts of the catchment:

1. permanently plowing part of the catchment, area 83.2 ha;
2. arable land abandoned after the mid-1980, area 4.3 ha;
3. unploughed parts of the catchment (sides and bottom of the dry valley), area 8.3 ha;
4. entire catchment area, area 95.9 ha.

*Manuscript is under review

International Soil and Water Conservation Research 10 (2022) 149–160

Contents lists available at ScienceDirect

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Original Research Article

A detailed reconstruction of changes in the factors and parameters of soil erosion over the past 250 years in the forest zone of European Russia (Moscow region)

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ARTICLE INFO

Article history:
Received 21 January 2021
Received in revised form
31 May 2021
Accepted 2 June 2021
Available online 5 June 2021

Keywords:
Anthropogenic soil erosion
Soil erosion history
Crop rotation
Magnetic tracer method
WaTEM/SEDEM

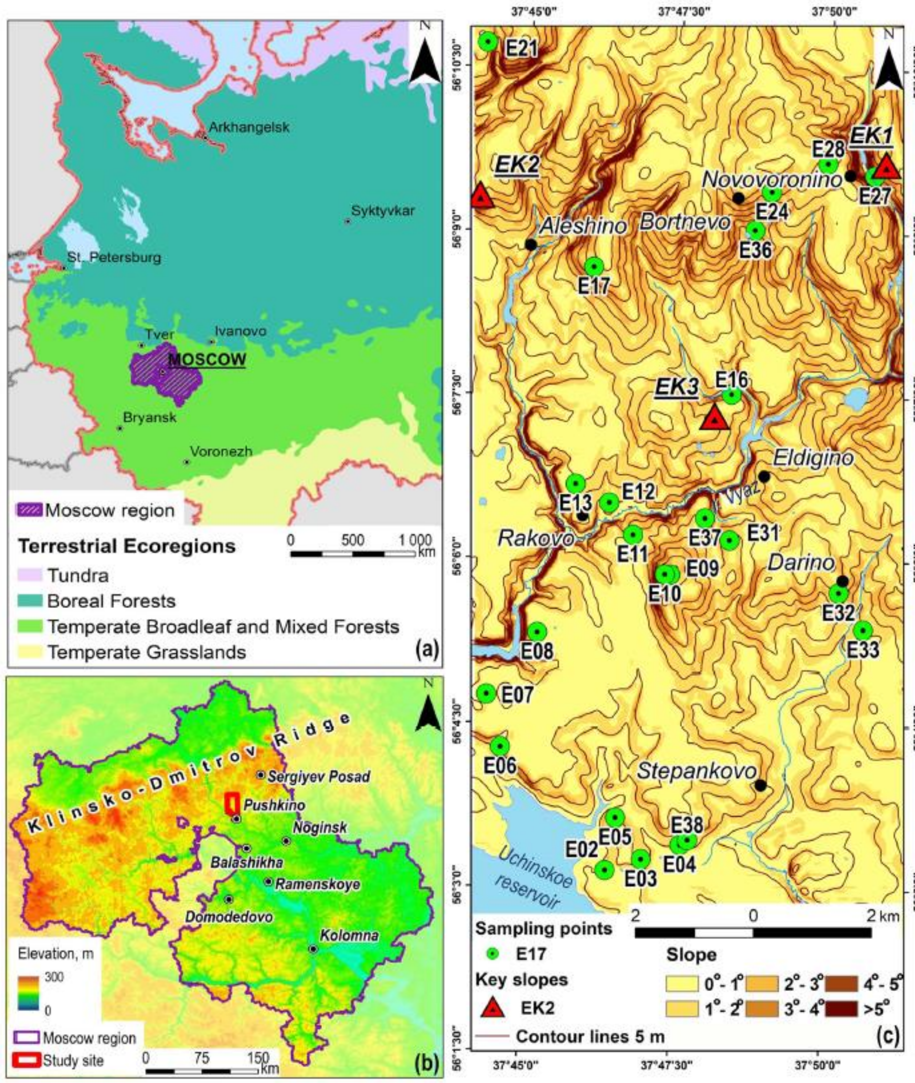
ABSTRACT

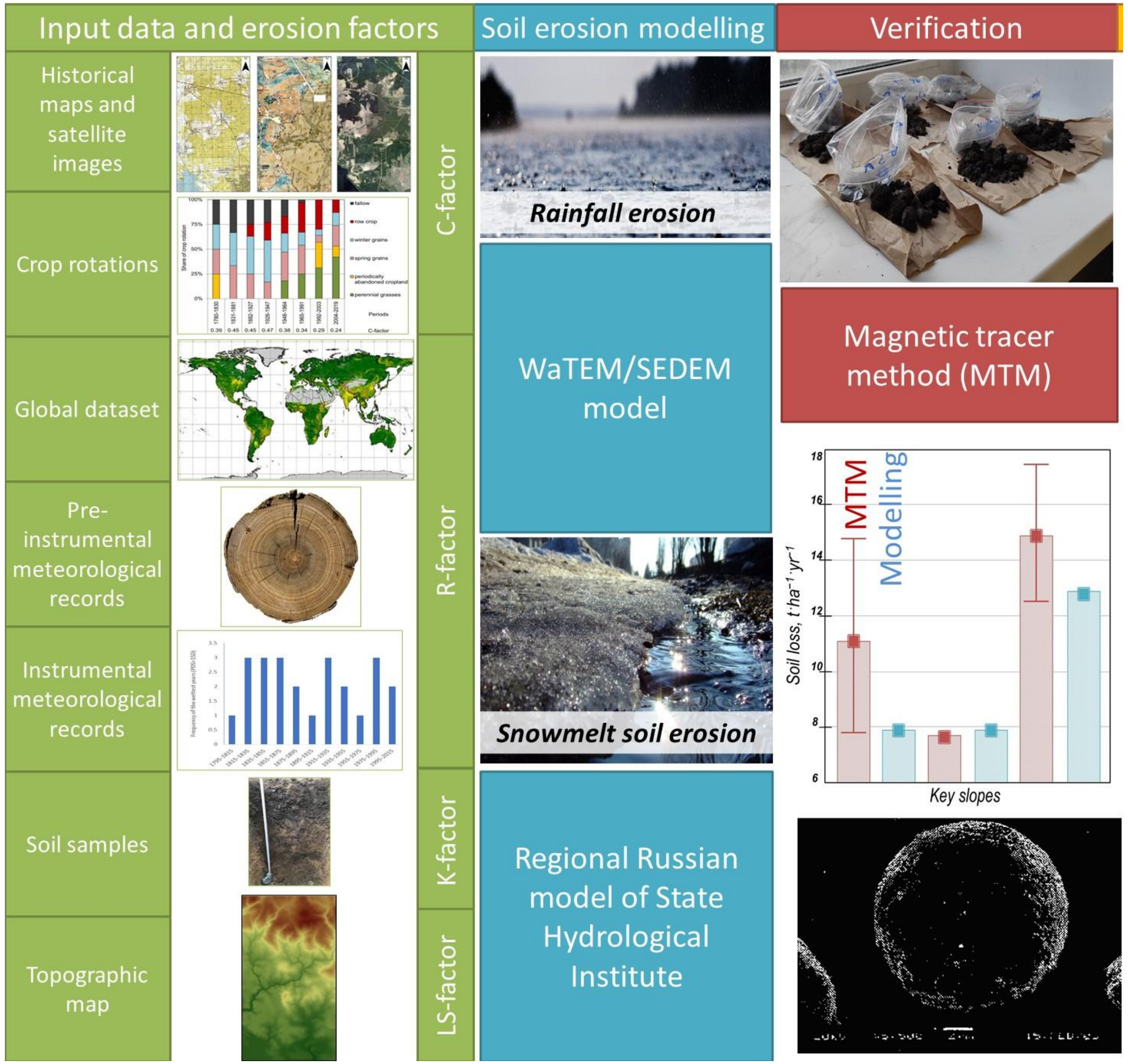
Accelerated soil erosion is a major threat to soil, and there are great variations in the rate of soil erosion over time due to natural and human-induced factors. The temperate forest zone of Russia is characterized by complex stages of land-use history (i.e. active urbanization, agricultural development, land abandonment, etc.). We have for the first time estimated the rates of soil erosion by the WaTEM/SEDEM model (rainfall erosion) and by a regional model (snowmelt erosion) over the past 250 years (from 1780 to 2019) for a 100-km^2 study site in the Moscow region of Russia. The calculations were made on the basis of a detailed historical reconstruction of the following factors: the location of the arable land, crop rotation, the rain erosivity factor, and the maximum snow water equivalent. The area of arable land has decreased more than 3.5-fold over the past 250 years. At the end of the 20th century, the rates of gross erosion had declined more than 5.5-fold (from 28×10^3 to 5×10^3 t·ha^{-1}·yr^{-1}) in comparison with the end of the 18th century. Changes in the boundaries of arable land and also the relief features had led to a significant intra-slope accumulation of sediments. As a result of sediment redeposition within the arable land, the variation in net soil erosion was significantly lower than the variation in gross soil erosion. The changes in arable land area and in crop composition are the factors that have to the greatest extent determined the changes in soil erosion in this territory.

1. Introduction

on this topic were published in 2014 (Li & Fang, 2016). A much smaller number of studies analyzed the impact of changes in land-

Reconstruction of changes in the factors and parameters of soil erosion over the past 250 years





Zhidkin et. al., 2022
https://doi.org/10.1016/j.iswcr.2021.06.003

Reconstruction of changes in the factors and parameters of soil erosion over the past 250 years

1797 yr

1861 yr

1871 yr

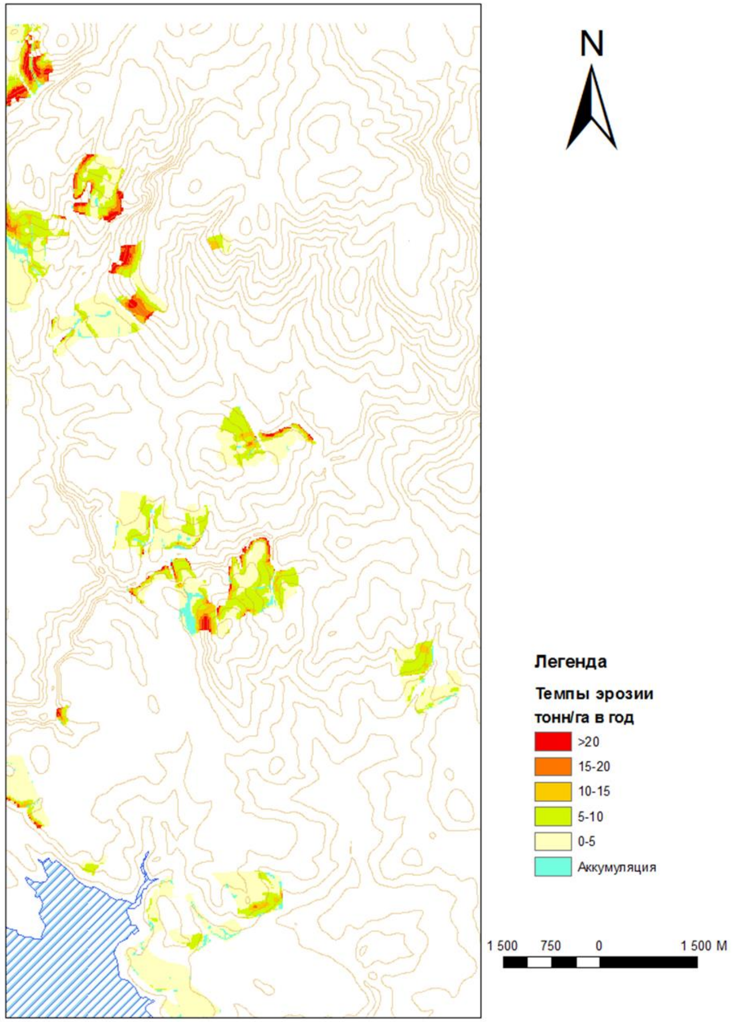
1917 yr

1954 yr

1985 yr

2000 yr

2018 yr



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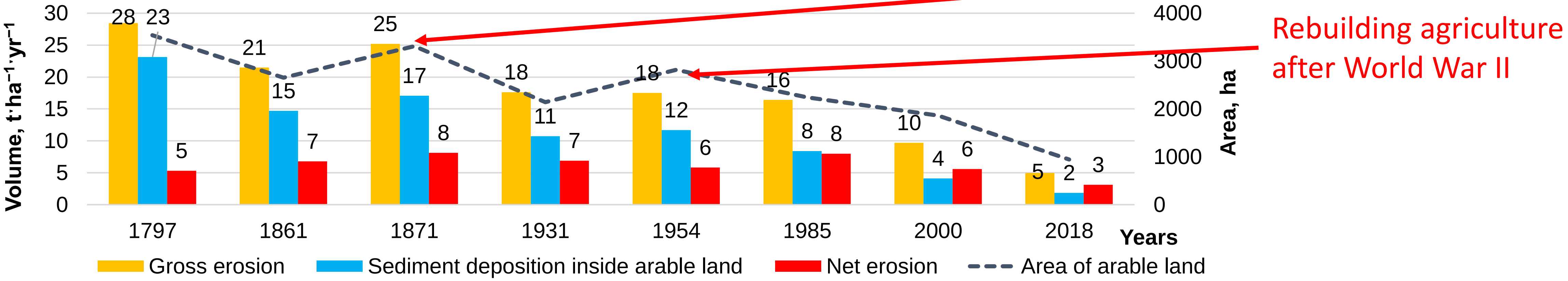
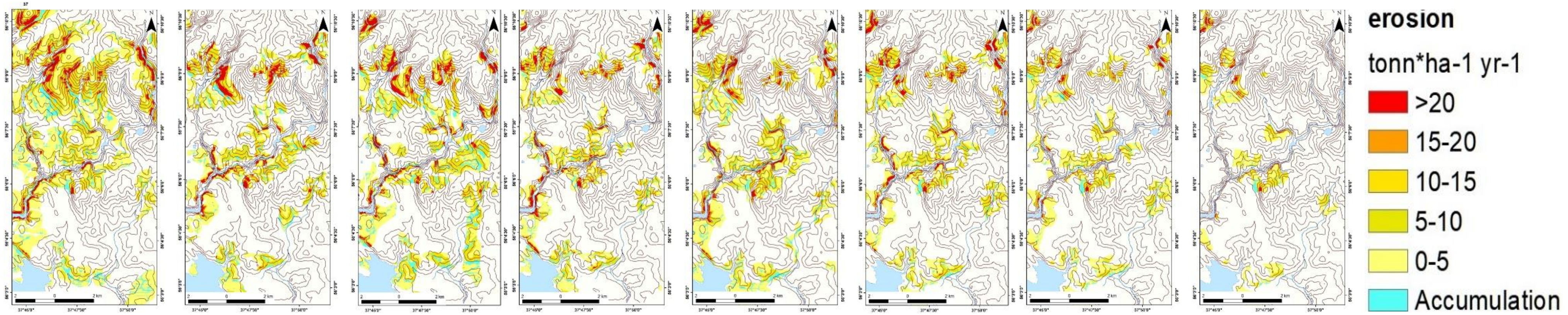
Reconstruction of changes in the factors and parameters of soil erosion over the past 250 years





1797 1861 1871 1931 1954 1985 2000 2018

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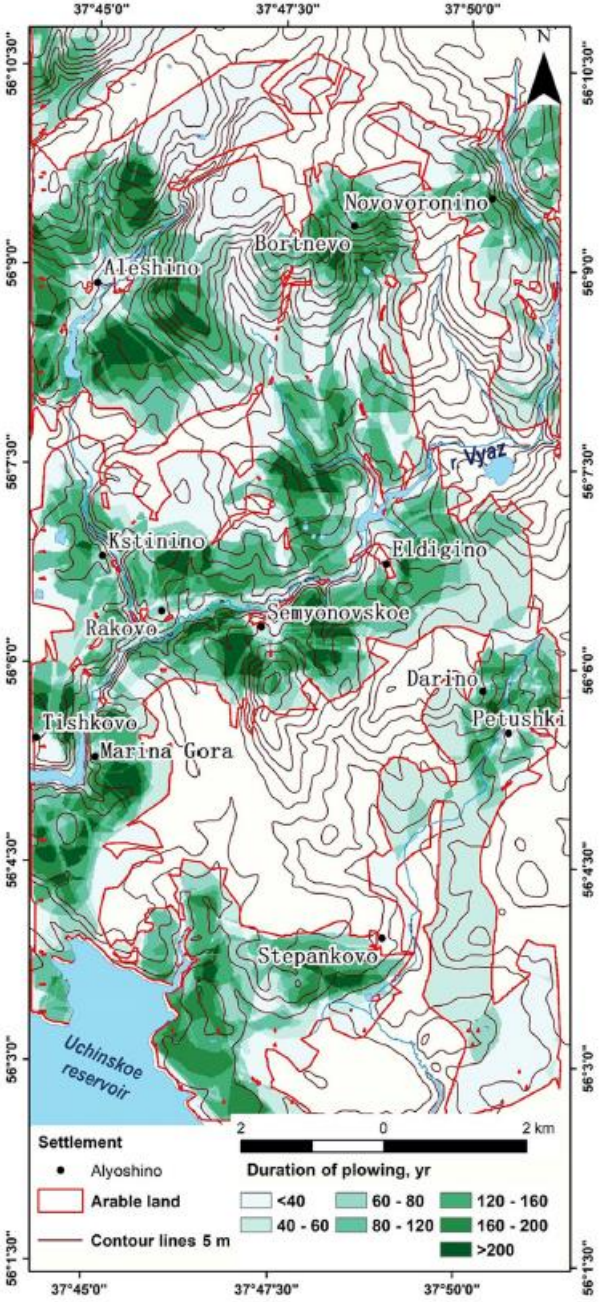
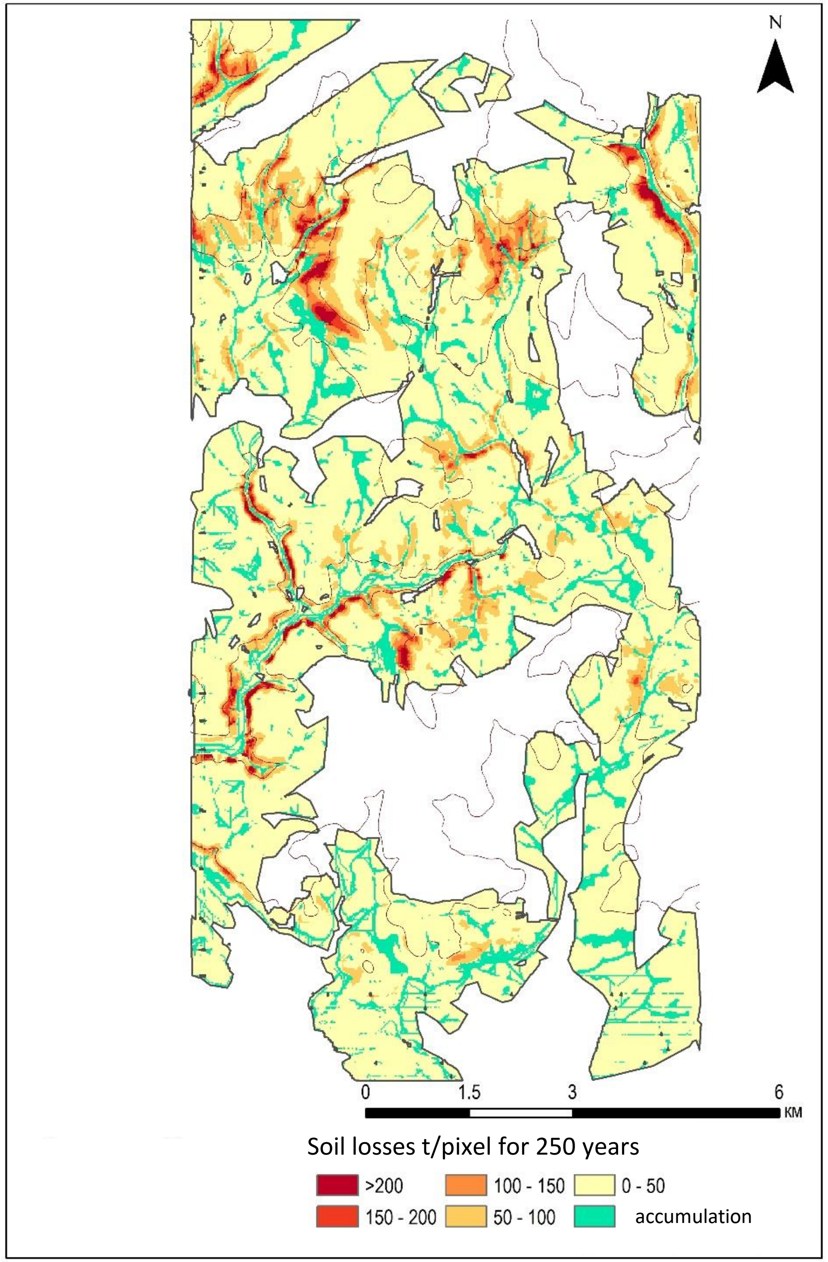
Duration of plowing



Soil erosion losses



Digital mapping of erosion soil cover patterns

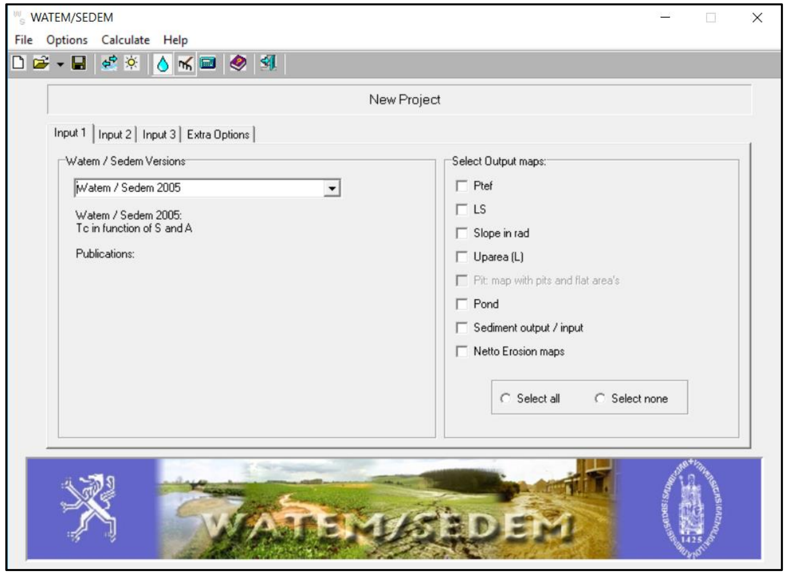
Author's development

Factors:
Relief
Exposure
etc.

Soil erosion process

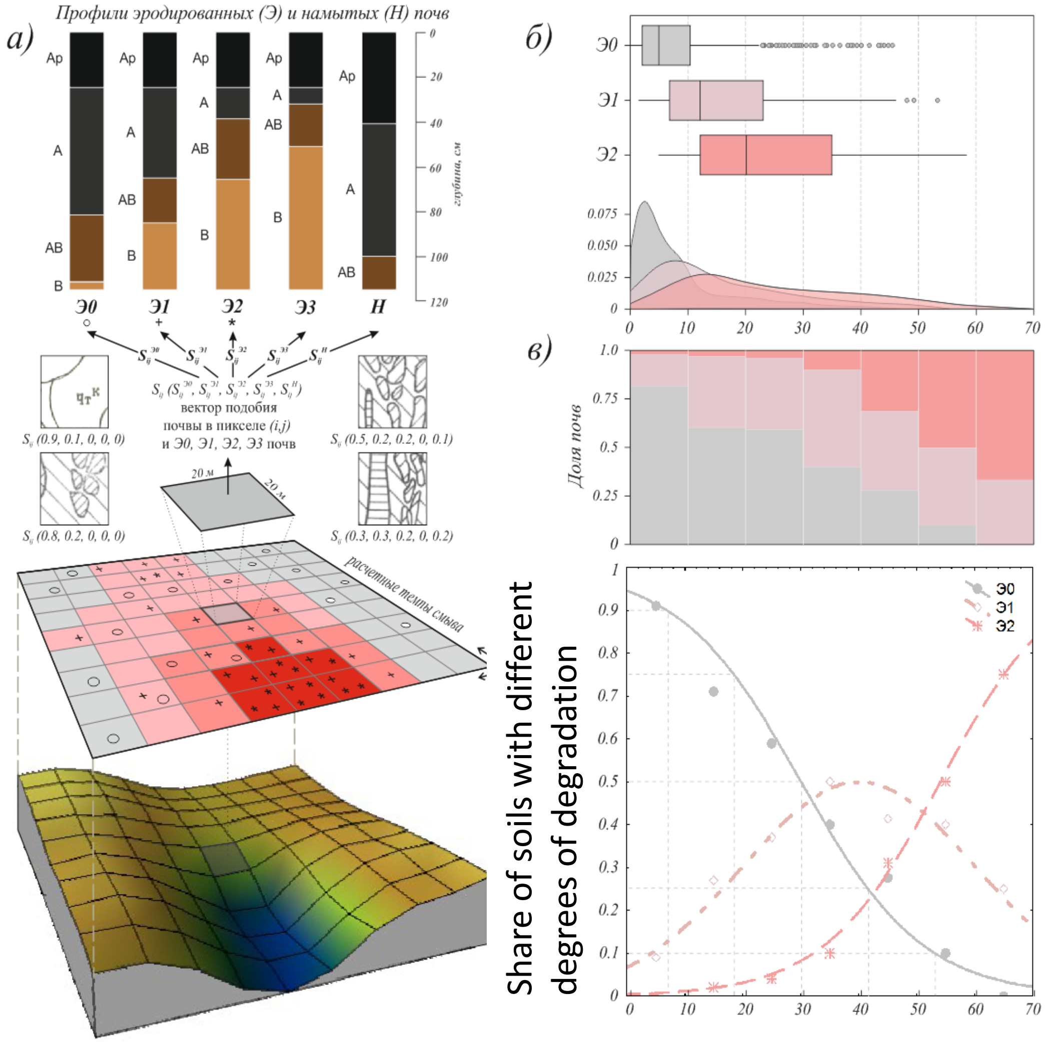
Properties:
degree of soil degradation

Modelling



Digital mapping of erosion soil cover patterns

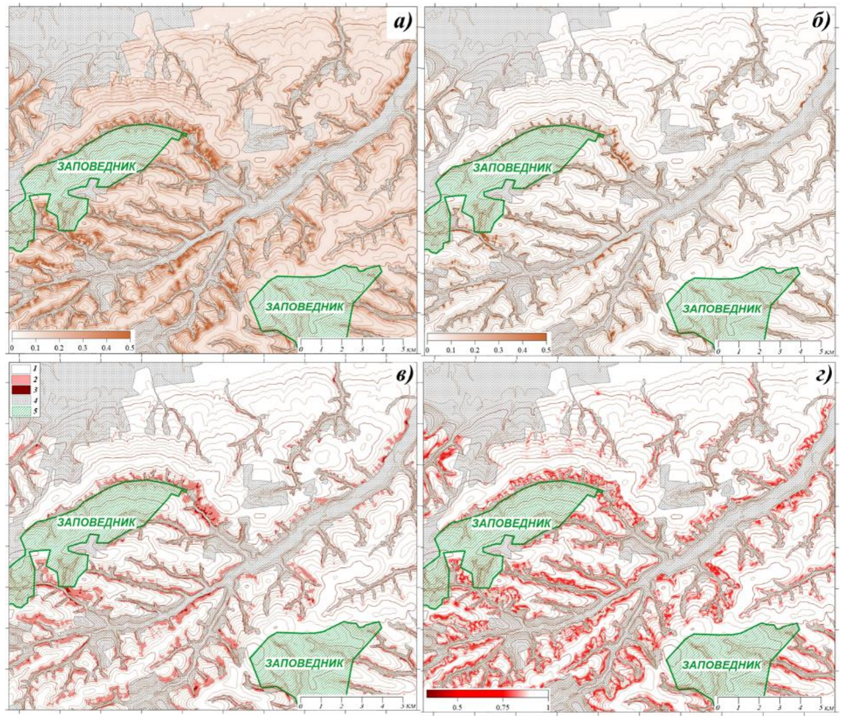
Generalized research scheme



Share of soils with different degrees of degradation

Rates of soil erosion, t/ha yr

Result

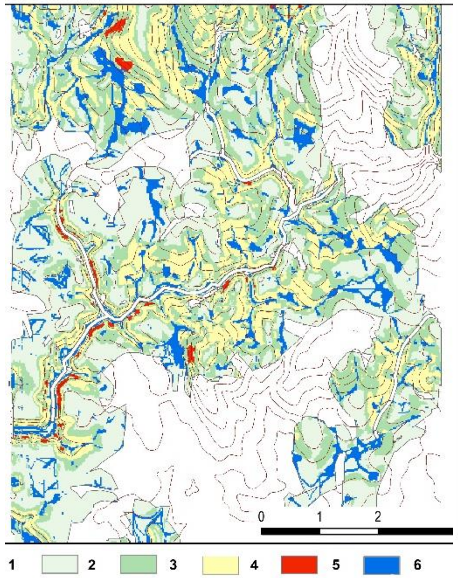


Component composition of erosive soil combinations of arable land: a) share of E1 soils, b) share of E2 soils; c) the category of soil erosion prevailing in the PC composition (1 - not washed away (E0), 2 - slightly washed out (E1), 3 - moderately washed out (E2)), d) a measure of the diversity of the composition of soil combinations (0.33 - polydominant, 1 - monodominant)

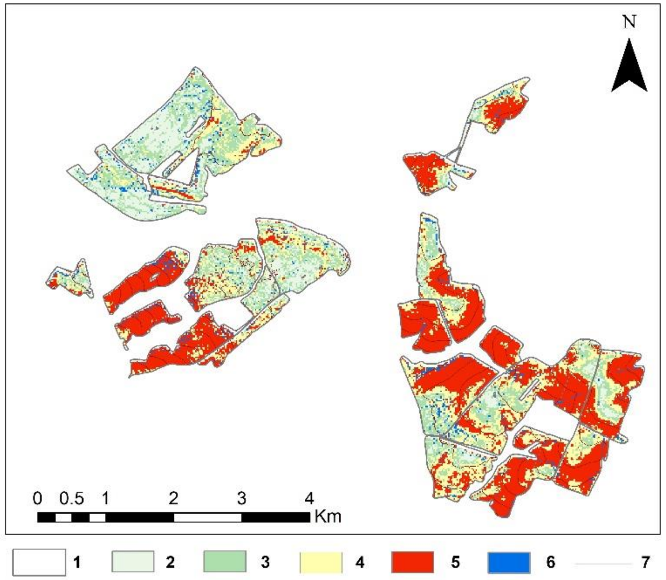
Kozlov et. al., 2022

DOI: 10.19047/0136-1694-2019-100-5-35 (in Russian)

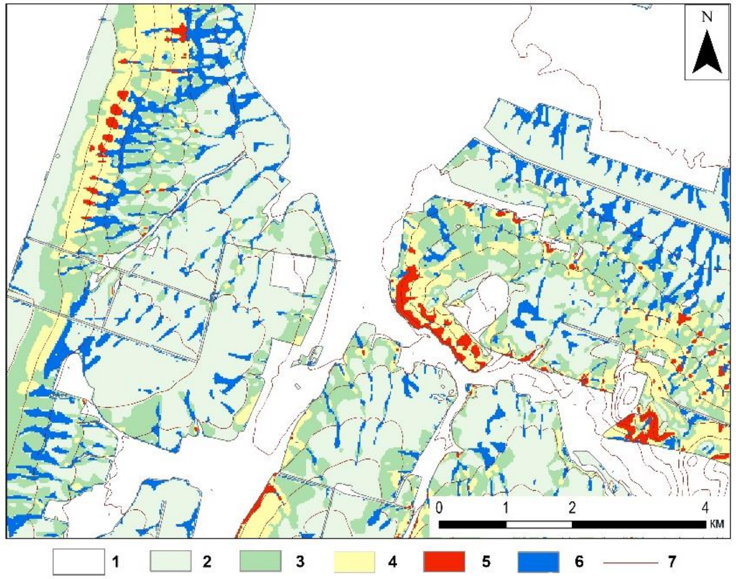
Moscow region



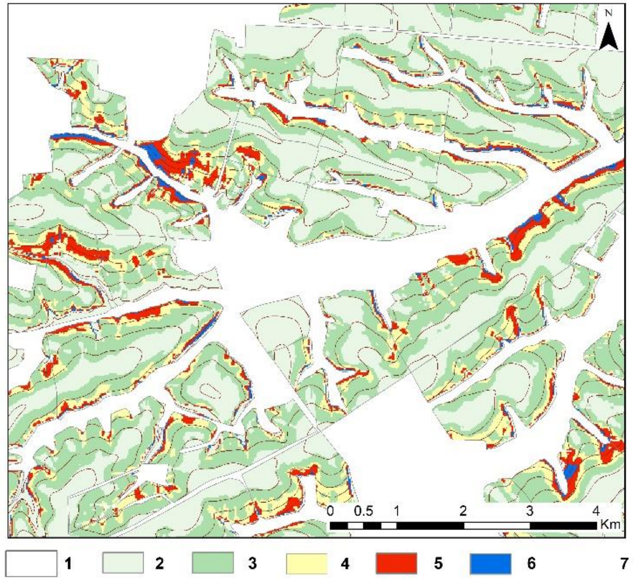
Orel region



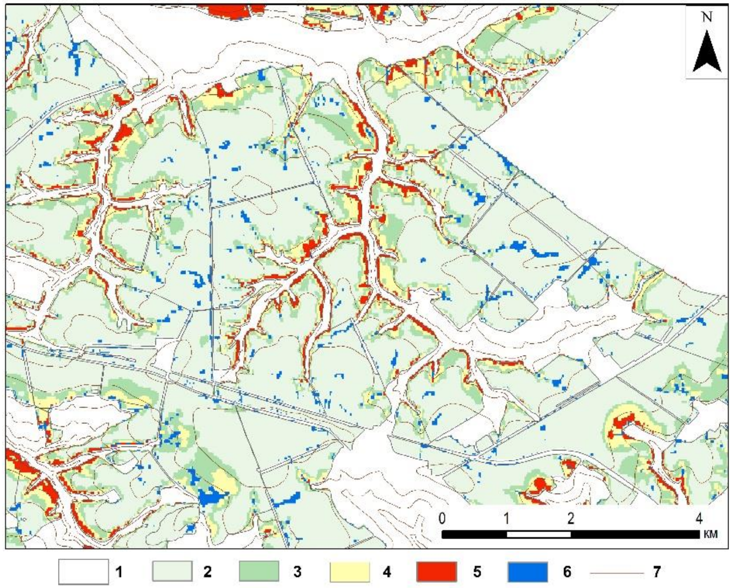
Bashkortostan region



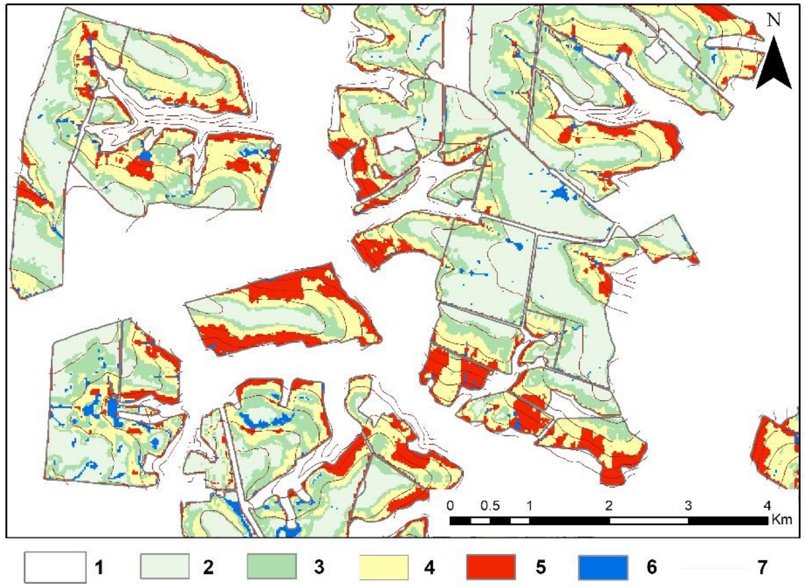
Kursk region



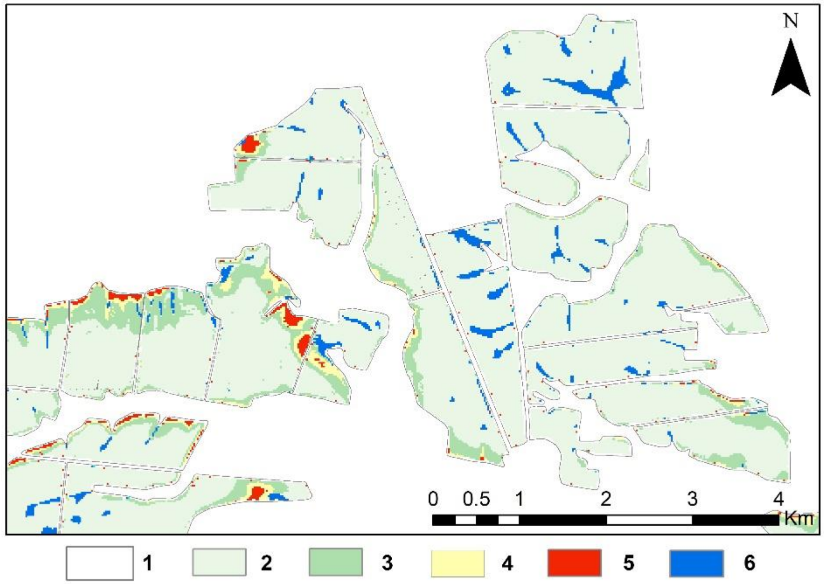
Belgorod region (Prohorovskii)



Belgorod region (Shebekino)



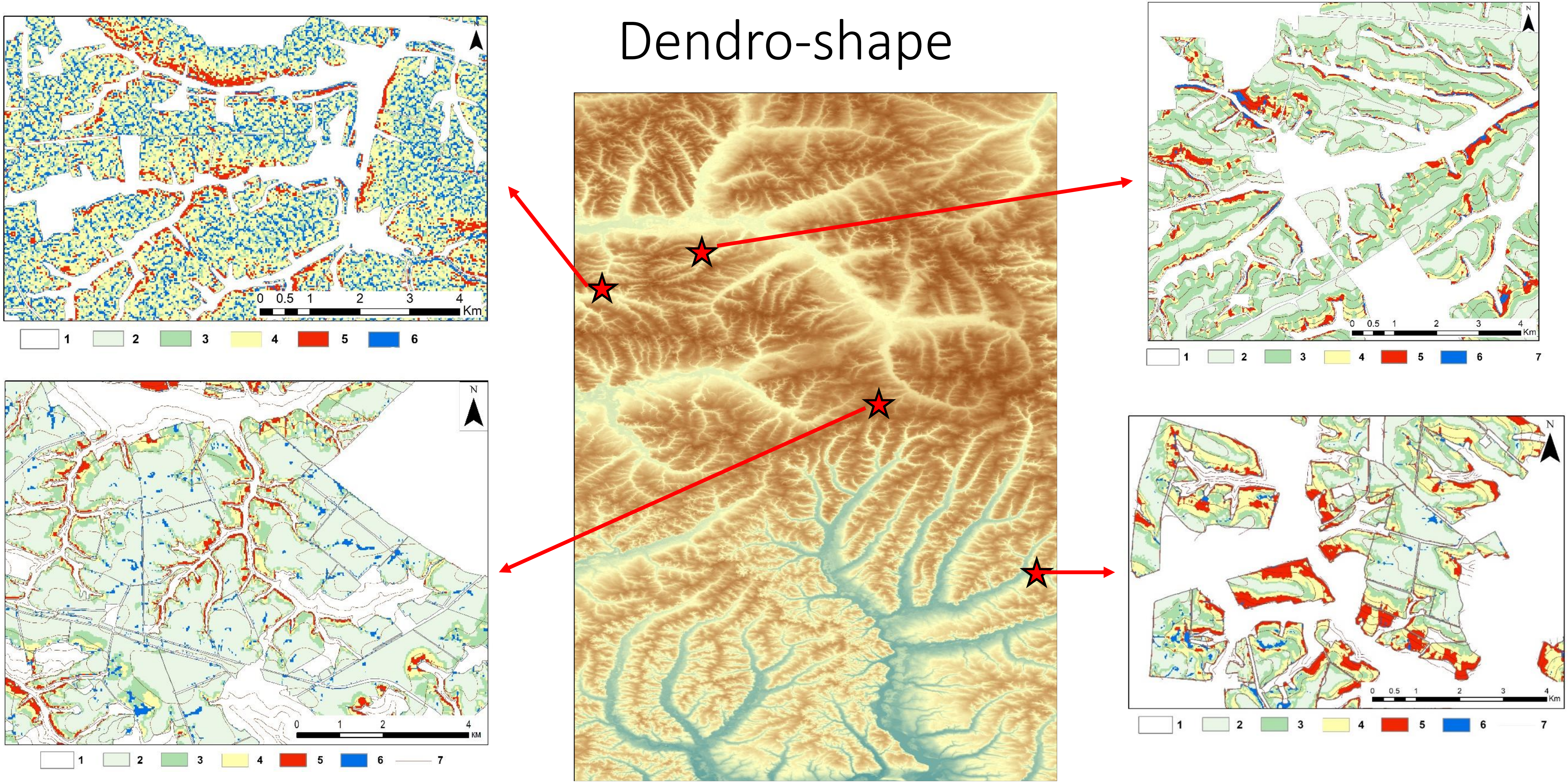
Tambov region



**Zhidkin et al., 2023 under review in "Маккавеевские чтения" (in Russian)*

What is the shape of erosion soil cover patterns?

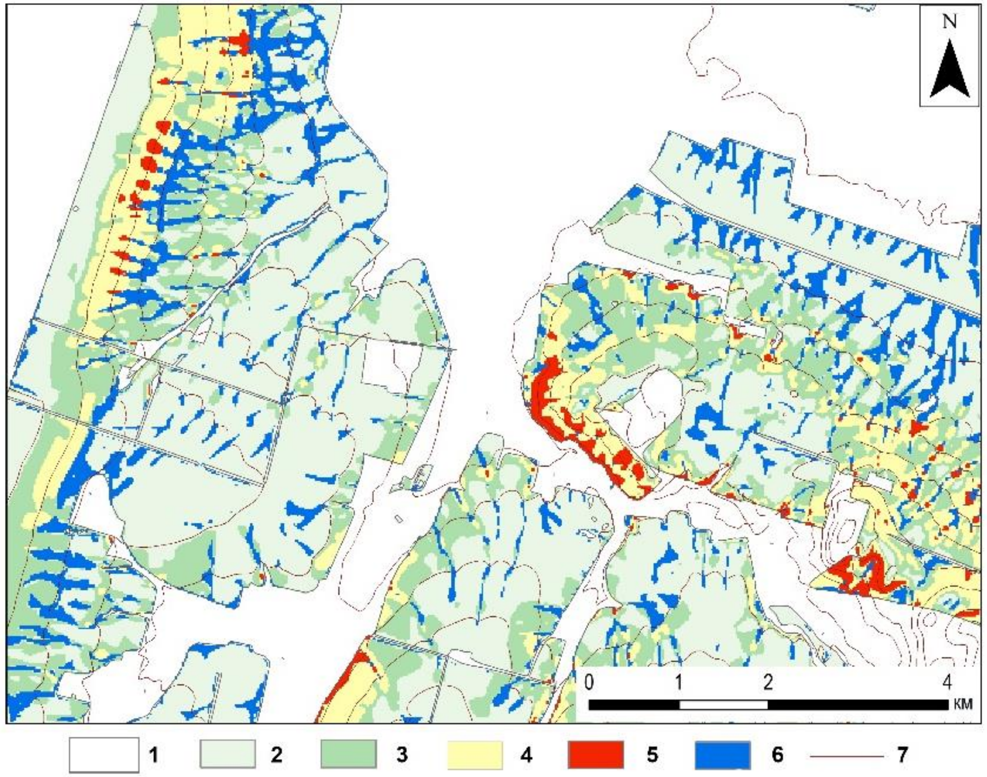
Dendro-shape



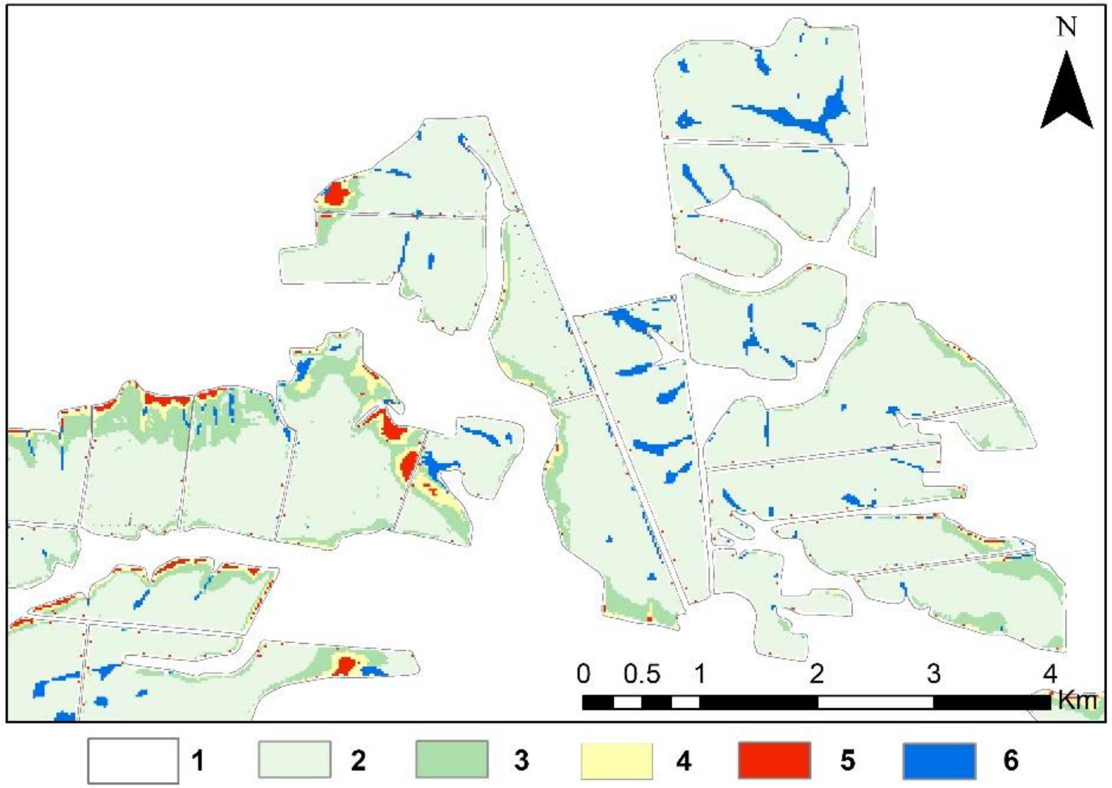
The size of the areas of eroded soils depends on the degree of dissection of the relief

Focal erosion

Bashkortostan region



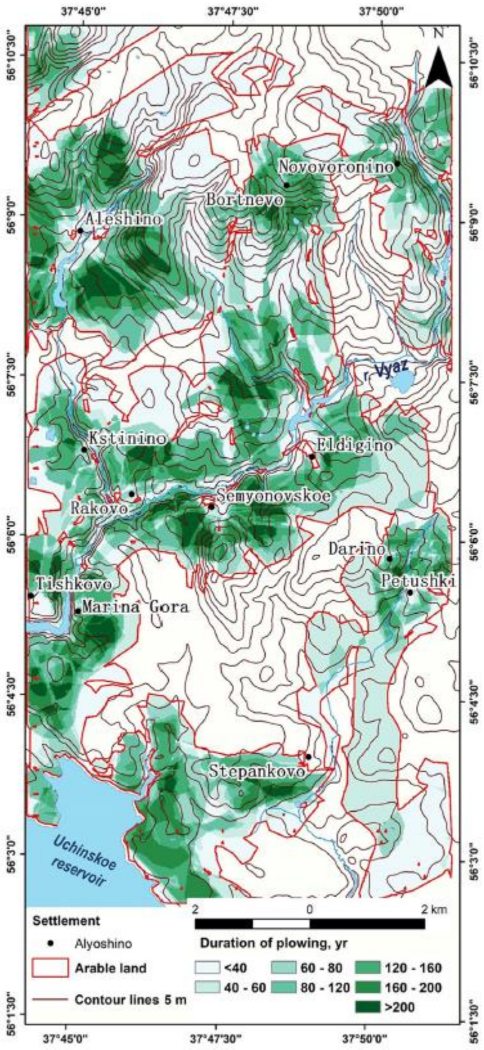
Tambov region



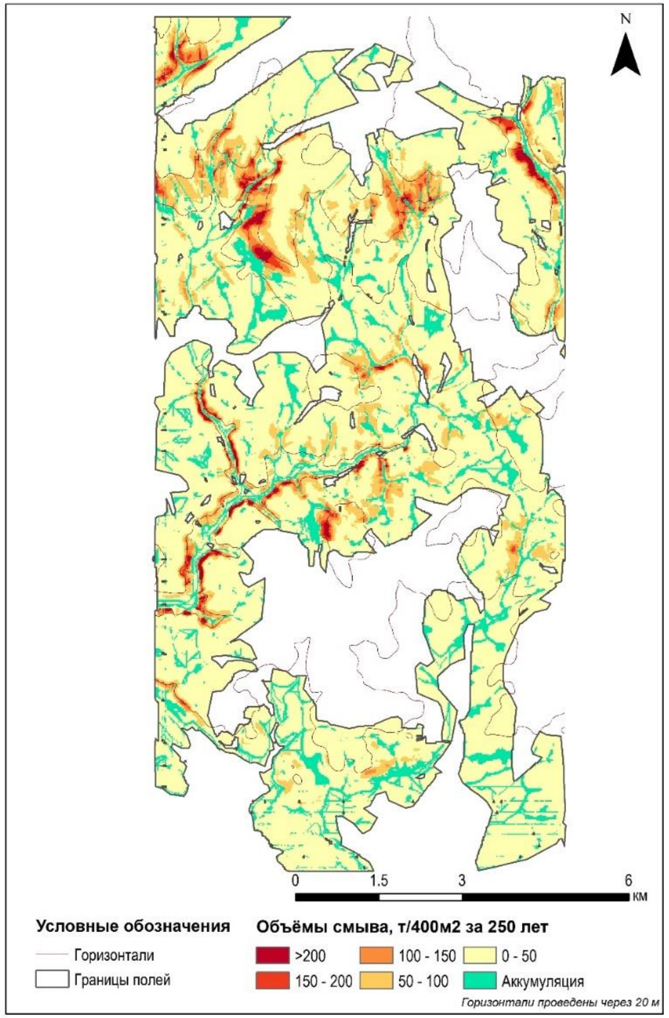
The shape of eroded soil cover patterns depends on the microrelief

Moscow region

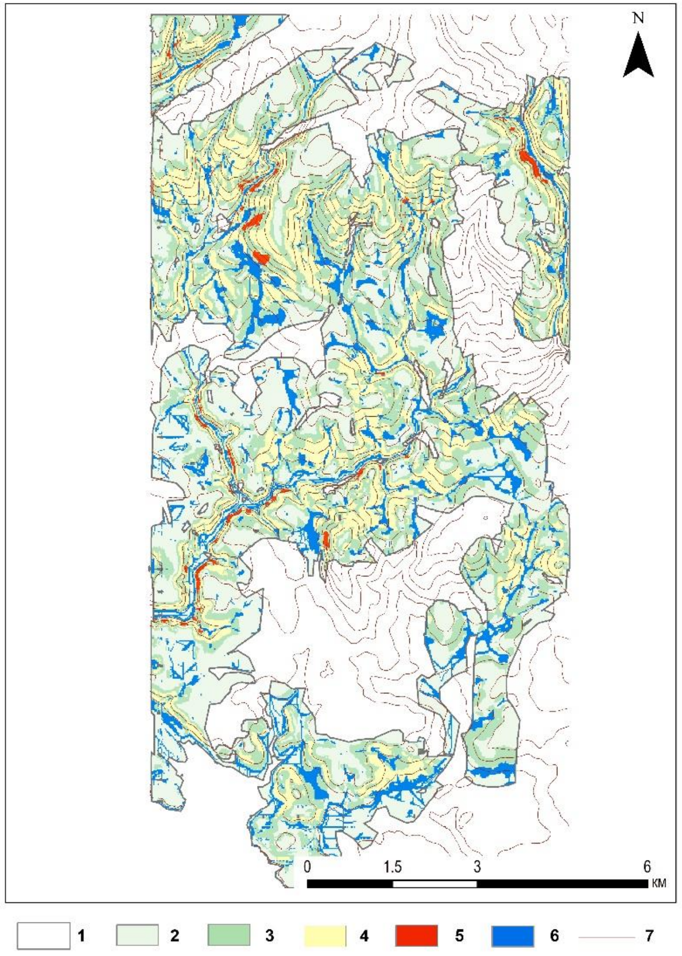
Duration of plowing



Soil erosion losses



Soil erosion soil cover patterns

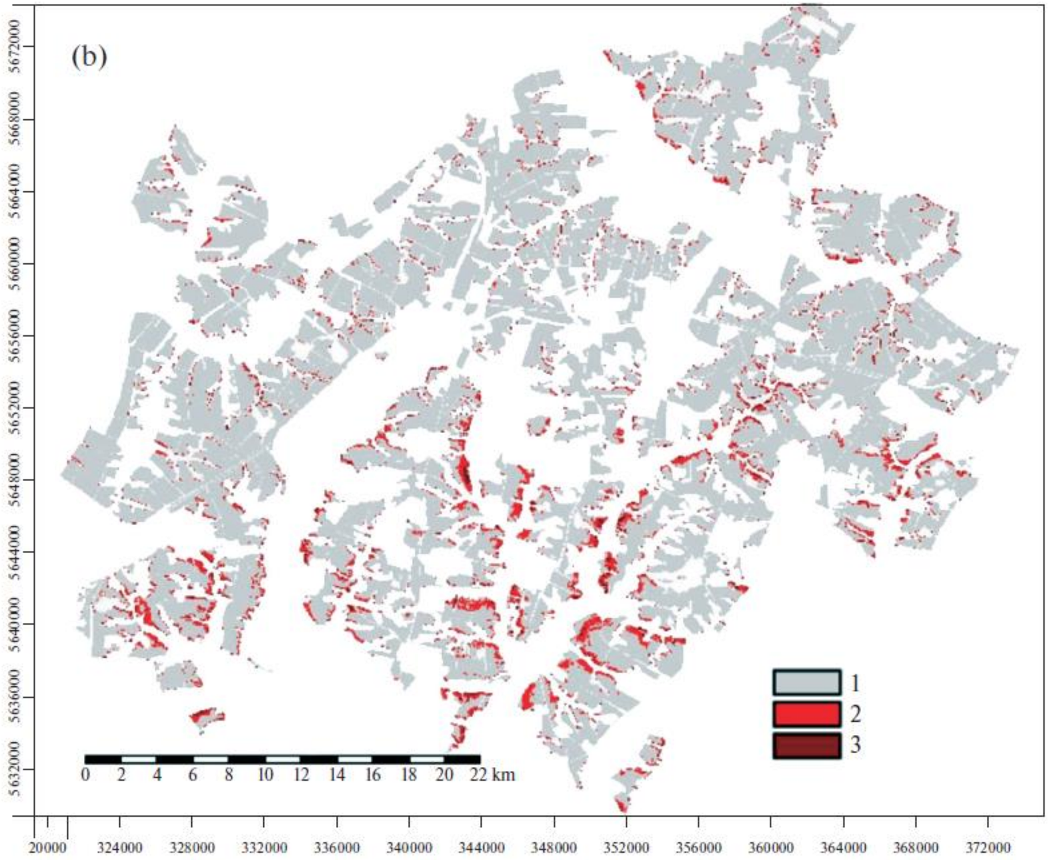


Zhidkin et. al., 2022
https://doi.org/10.1016/j.iswcr.2021.06.003

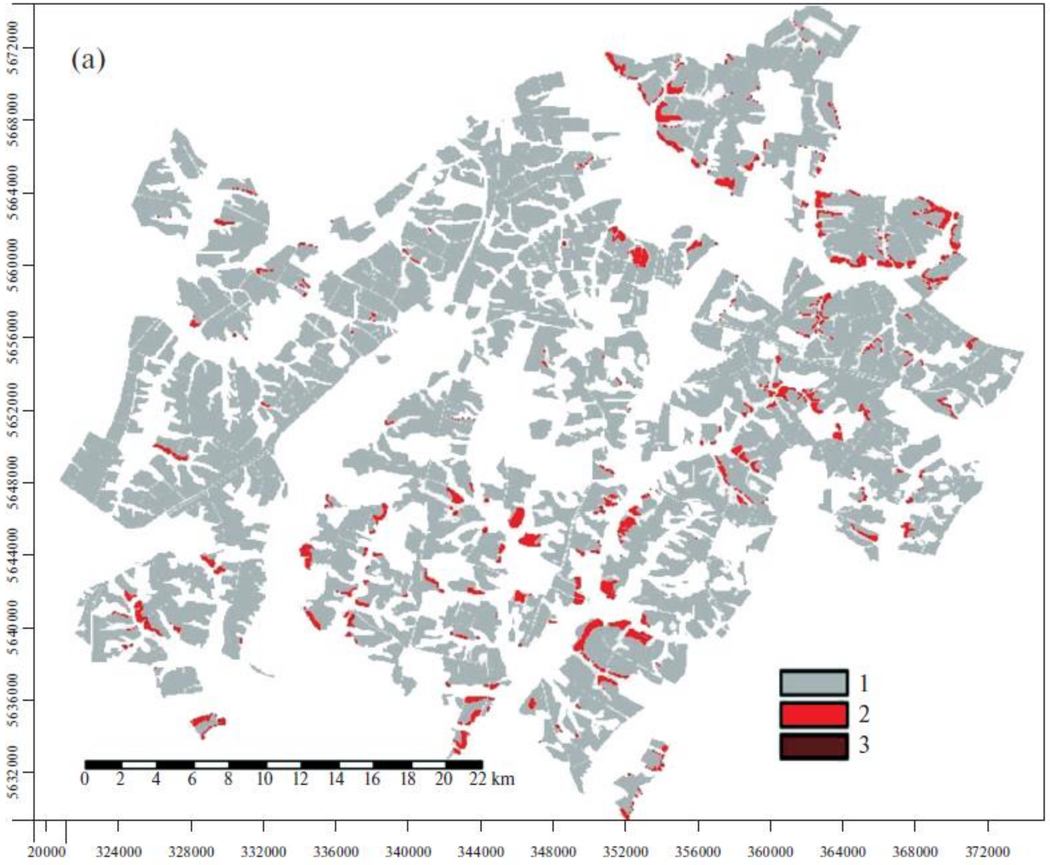
The shape of the soil-erosion cover patterns depends not so much on the relief as on the agricultural history.

Comparison of different methods for mapping eroded soils (Belgorod oblast)

Digital method



Traditional (visual-expert) method



1 - noneroded and slightly eroded, *2* - moderately eroded, *3* - strongly eroded soils

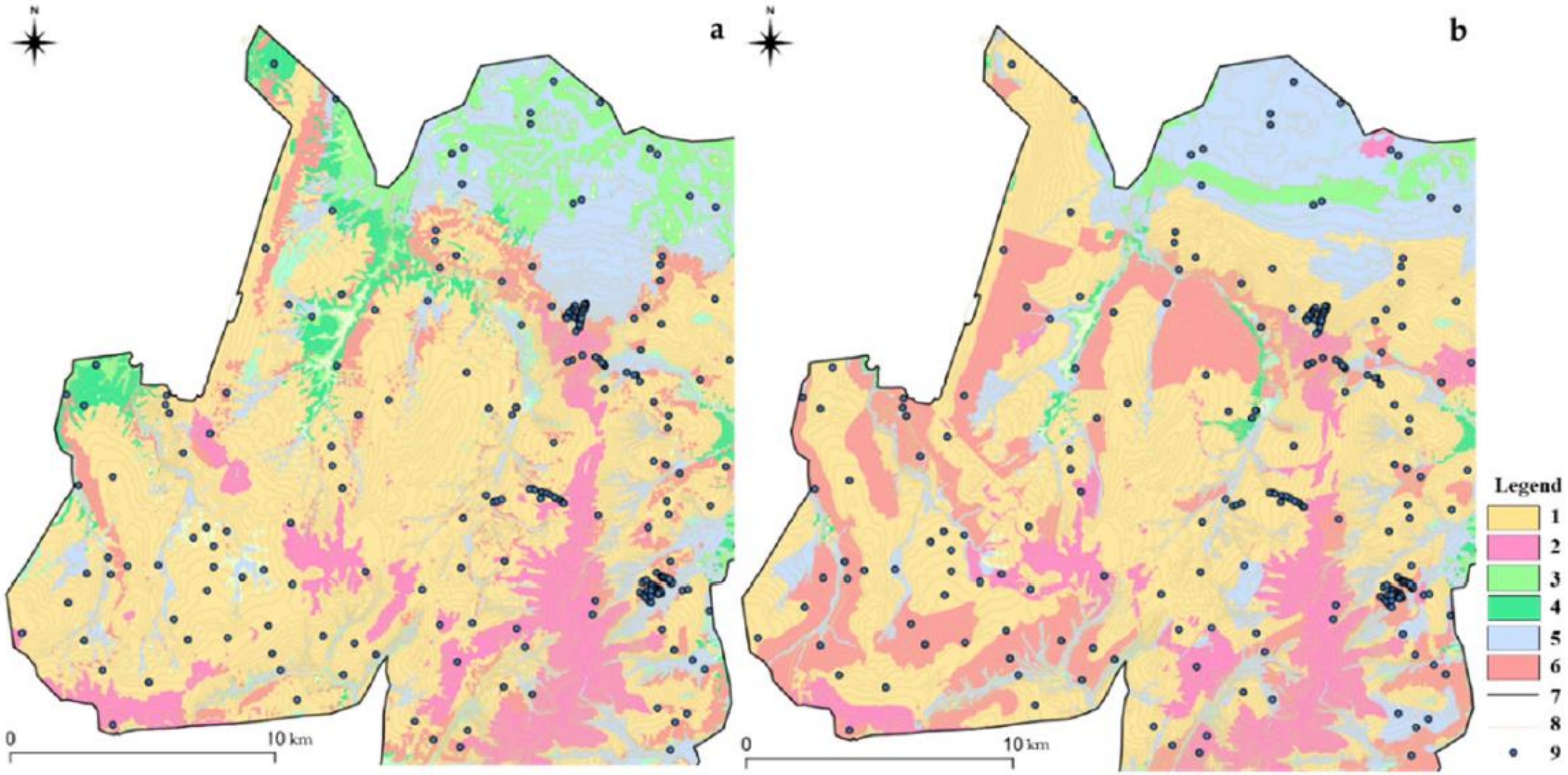
(Zhidkin et. al., 2021)

DOI: 10.1134/S1064229321010154

Comparison of different methods for mapping eroded soils (rep. of Bashkortostan)

Digital method

Traditional (visual-expert) method



Discrepancy in the area of eroded soils – 26%

(Lozbenev et. al, 2022)
https://doi.org/10.3390/soilsystems6010014


Thank you for attention!