International Cartographic Association
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The GIS-based approach for the permafrost active layer depth mapping

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Abstract: The depth of the active layer is highly valuable parameter of the biochemical processes and ecosystem dynamics in changing climate. Site area of our investigation was situated in the Evenkiysky District of Krasnoyarsk Krai, Russia near Tura settlement. We used field measurements of seasonal thawing layer depth (active layer depth) to estimate its spatial variability and its dependency of topography-based variables (elevation, slope and aspect). The spatial analysis of field sample plots location and after-forest-fire period length helped us to build the reference table and then extrapolate this data in a form of map for the site area. The produced map of active layer depth and applied data processing scheme are now using for the complex analysis and modelling of hydrochemical processes in terrain- and water-ecosystems.

Keywords: GIS, Thematic maps, Permafrost active layer depth, DEM

1. Introduction

The active layer is a surface part of the permafrost, that freezes and thaws each year. Therefore, the ddepth of the active layer is highly valuable parameter of the biochemical processes and ecosystem dynamics in changing climate.

We planned to use the active layer depth map for the analysis of biomass and carbon transformation processes in terrain- and water-ecosystems (Prokuskin et al., 2006, 2011) as a part of ongoing projects (see Acknowledgements). One of the corresponding subtask was to estimate the dependence of carbon stock value of the organic layer per test watersheds and seasonal thawing layer depth.

We used the local GIS-based data bank, including topographic site layers, digital elevation model (DEM), field sites forest inventory database, remote sensing (RS) satellite data, and input/resulting thematic maps of vegetation parameters (Korets et al., 2016).

Classification and inventory of the current diversity of forest communities and their environments (i.e. site conditions) were developed for Northern Siberia test site (area ~360 000 ha), situated in the Evenkiysky District of Krasnoyarsk Krai, Russia near Tura settlement (N64°17’, E100°13’). This classification considers characteristics of forest regeneration dynamics, such as trends and rates of forest regeneration succession in a range of site conditions; therefore, we used this conception as a basis for terrestrial ecosystem mapping. An algorithm of forest regeneration dynamics mapping based on a spatial analysis of multi-band satellite data, a digital elevation model, and ground truth data combined with expert estimates of the resulting land cover classes was applied (Korets et al., 2016). According this approach we used the automated classification of RS-based (spectral reflectance) and DEM-based (elevation, slope and modified exposition) to map forest regeneration series and site conditions for the Tura test site area. Based on this algorithm, Landsat TM/ETM/OLI satellite imagery, ASTER GDEM, and field data were processed for the test site area.

The field measurements data (Prokuskin et al., 2006) and above maps, available for the Tura site, incorporated in the GIS database allowed us to extrapolate and map the biomass and carbon pools values (kgC/m^2), using combined (spatially intersected) layers of vegetation growing condition and landcover.

The above thematic layers, including DEM (elevation above sea level, aspect angle, and slope angle), RS-based maps (burned areas after forest fire), carbon pools values, and streams watersheds polygons provided the basis for the further data processing.

2. Data processing and mapping

We used field sample measurements (2006 - 2015) of seasonal thawing layer depth (active layer depth) to estimate its spatial variability and dependency to local condition parameters. The spatial analysis of local site condition attributes (elevation, slope and aspect) and after-fire period length helped us to build the reference table (Table 1, Prokushkin et al., 2011) and extrapolate its data for the Tura local site area (Figure 1).

To extrapolate the table data we used intersection of GIS layers: raster digital elevation model and fire disturbance map (Figure 2). The first one based on combination of vector topography layers (1: 100 000 scale) and ASTER GDEM with pixel resolution of 20x20 m.

Proceedings of the International Cartographic Association, 2, 2019.
29th International Cartographic Conference (ICC 2019), 15–20 July 2019, Tokyo, Japan. This contribution underwent single-blind peer review based on submitted abstracts. https://doi.org/10.5194/ica-proc-2-65-2019 |

The map of burned forest areas was built by satellite imagery (Landsat MSS/TM/OLI, 1980 - 2013) processing together with Global Forest Change Map (Hansen et al., 2013) and retrospective state forest inventory data of 1960.

Topography attributes			After-fire period length, years							
Altitude, m	Aspect (angle, °)	Slope angle, °	1	5	10	20	30	50	70	>70
130 - 800	South (135-225)	2-5	90	100	110	120	110	90	70	60
130 - 800	South (135-225)	6-25	100	110	130	130	120	110	100	90
130 - 800	South (135-225)	>25	110	120	130	130	125	120	110	100
130 - 800	West (225-315)	2-5	70	80	90	100	90	70	60	50
130 - 800	West (225-315)	6-25	90	100	120	130	120	90	80	80
130 - 800	West (225-315)	>25	100	110	130	140	130	110	90	90
130 - 800	North (0-45, 315-360)	2-5	40	60	75	80	70	50	40	30
130 - 800	North (0-45, 315-360)	6-25	60	70	80	90	80	60	50	50
130 - 800	North (0-45, 315-360)	>25	80	90	100	100	90	80	70	60
130 - 800	East (45-135)	2-5	60	70	80	90	80	60	50	50
130 - 800	East (45-135)	6-25	80	90	100	100	90	80	70	70
130 - 800	East (45-135)	>25	90	100	100	100	90	80	80	80
130 - 300	Flat area	0-2	20	40	60	70	60	40	20	10
300 - 600	Flat area	0-2	70	80	90	100	95	80	70	60
601 - 800	Flat area	0-2	60	70	80	80	75	60	55	50

Table 1. The seasonal thawing layer depth (cm, bold numbers)

Then we classified DEM-based raster layers (altitude, aspect and slope angle) according the reference-table intervals (Table 1) and converted the resulting layers to vector polygons labeled by reference interval names. The layer of burned areas polygons was labeled by after-fire period length.

Finally, we overlaid and spatially intersected four polygonal layers to produce new polygons with all possible attributes combinations, provided by active layer depth values from reference-table. The resulting map of seasonal thawing layer depth for the Tura local site area is shown on Figure 3.

3. Conclusions

This paper demonstrate the application of typical GIS-based approach for spatial analysis, data interpolation and mapping. Using the GIS-based procedures of spatial intersection for the input layers: relief altitude, slope and aspect intervals, after-fire age intervals (for burned forest areas) and field reference data, we built the output map of seasonal thawing layer depth.

The produced map and applied data processing scheme are now using for complex analysis and modelling of hydrochemical processes in terrain- and water-ecosystems as a part of ongoing projects (2018 – 2020 see Acknowledgements).

As an example, we assessed the variation of the integrated values of ecosystem carbon stock (per layer) and seasonal thawing layer depth. We applied the zonal statistical analysis with the produced map and test watershed areas (Table 2). The correlation of shown parameters is shown on Figure 4.

4. Acknowledgements

This study was started in the framework of the grant by Ministry of Education and Science of Russian Federation №14.B25.31.0031 and involved to the projects of Russian Foundation for Basic Research № 18-05-60203, № 18-05-00235, and 18-05-00781).

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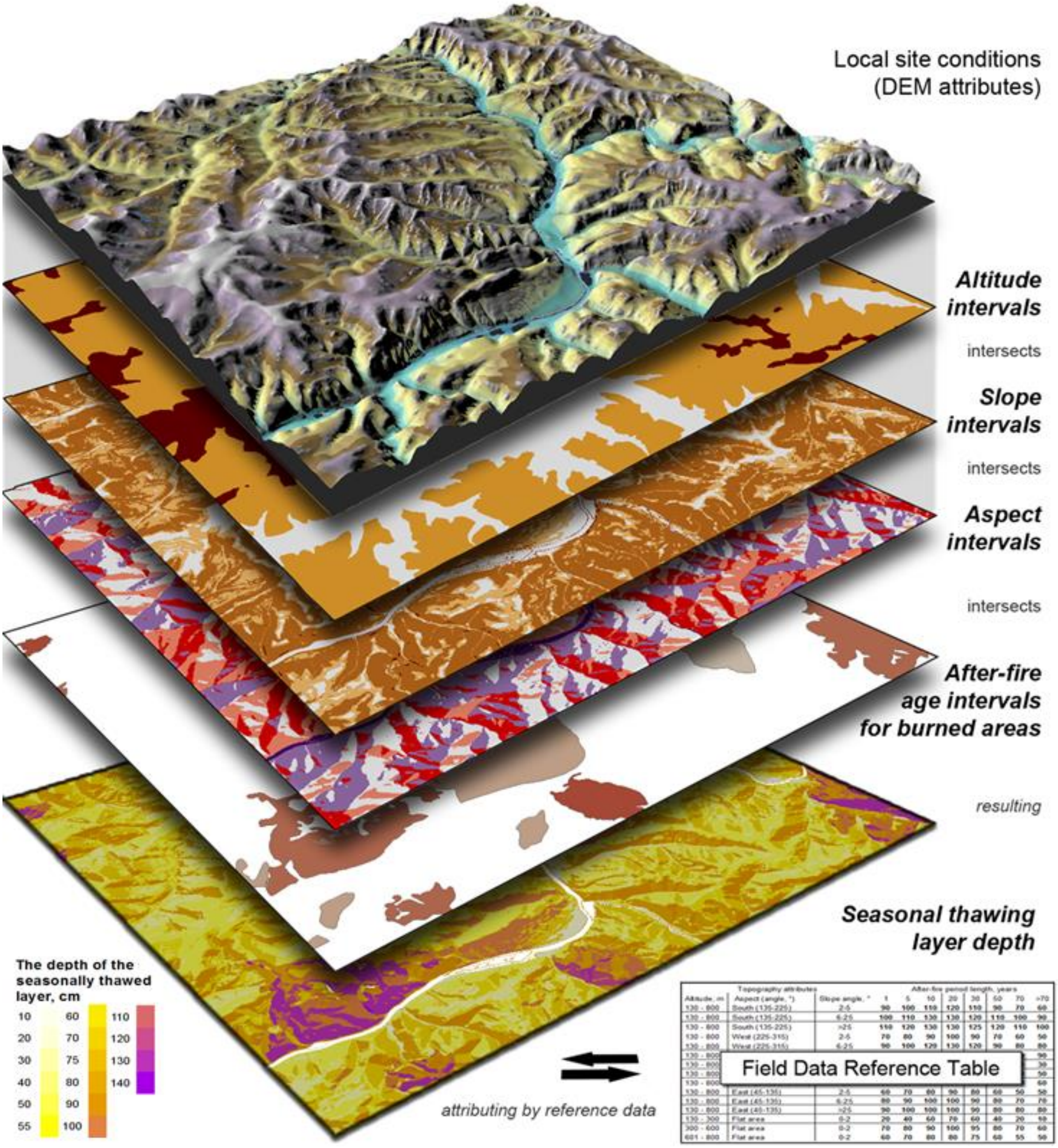

Figure 1. Seasonal thawing layer depth-mapping scheme.

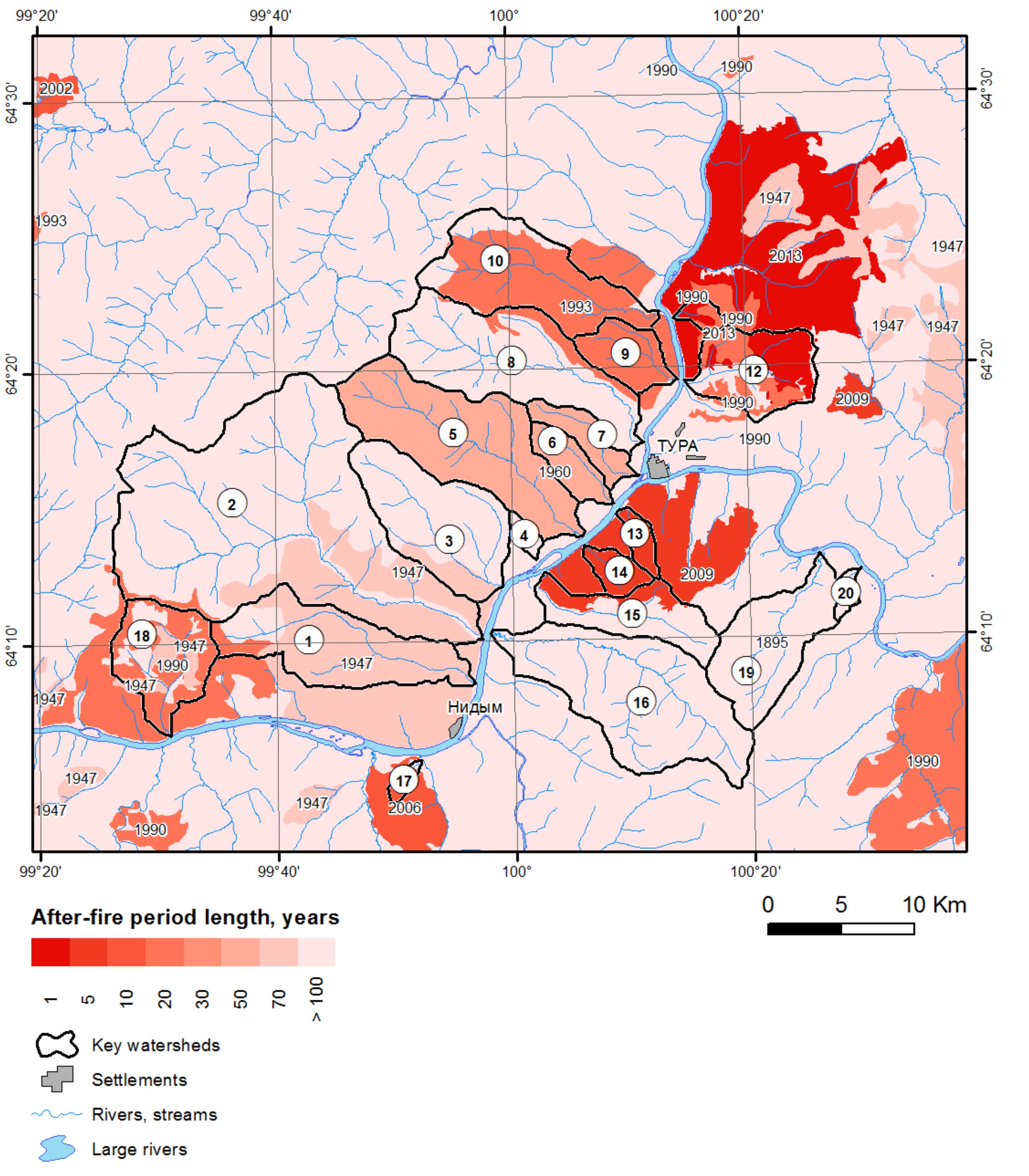

Figure. 2. Burned areas of different ages (Tura local site), mapped by Landsat MSS/TM/OLI imagery (1980 – 2013), Global Forest Change Map (Hansen et al., 2013) and old forest inventory data (1960).

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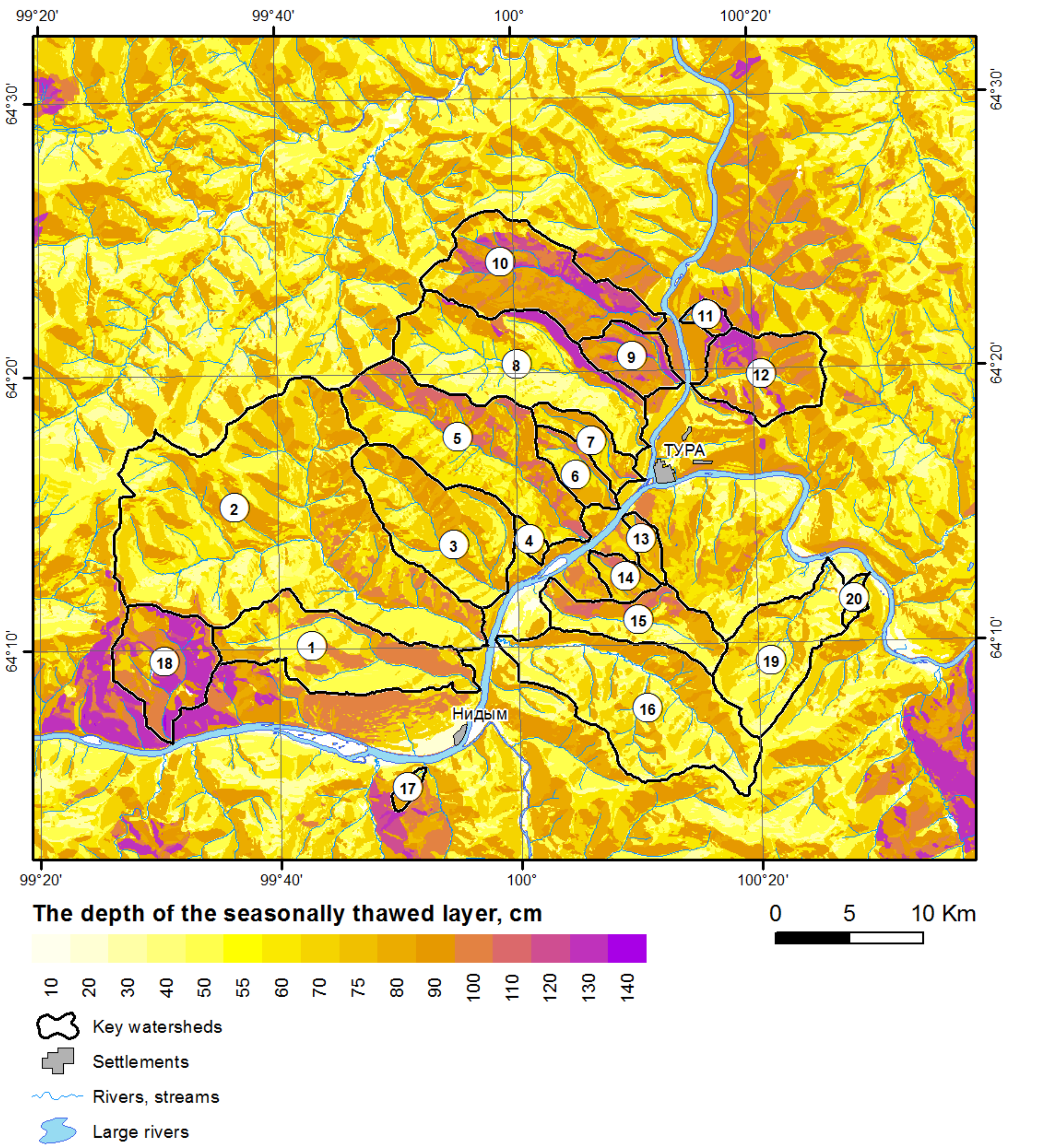

Figure. 3. Seasonal thawing layer depth map for the Tura local site.

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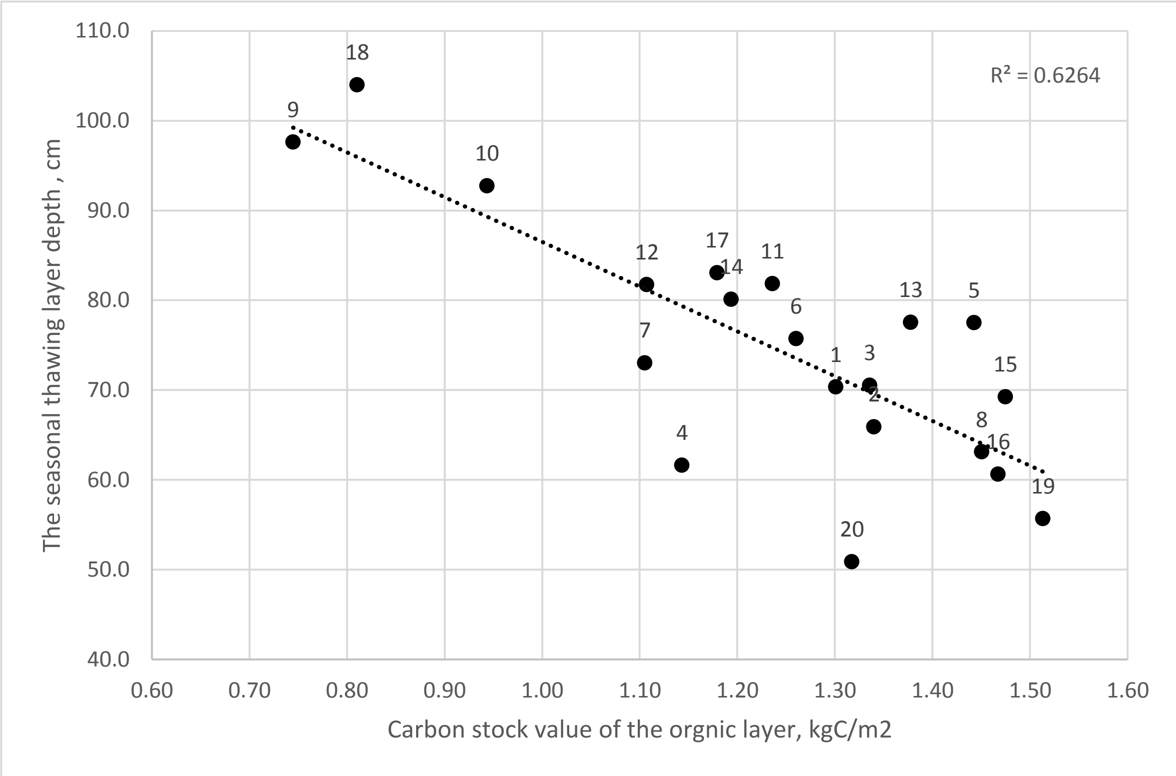

Figure. 4. Seasonal thawing layer depth vs carbon stock value of the organic layer per key watershed areas (points and labels).

Watershed №	Area , km^2	Min.	Max.	Mean	STD
1	68.7	10	130	70.4	20.7
2	254.3	10	130	65.9	18.1
3	67.6	10	100	70.5	15.8
4	3.7	50	90	61.6	11.7
5	91.7	30	110	77.5	19.8
6	15.4	40	120	75.7	16.5
7	15.6	10	110	73.1	14.8
8	89.1	10	130	63.1	26.4
9	20.8	10	130	97.6	17.0
10	70.5	10	140	92.8	20.1
11	4.9	20	130	81.9	16.1
12	41.0	10	130	81.8	20.9
13	6.9	10	100	77.6	13.2
14	9.6	60	120	80.1	13.3
15	36.0	10	110	69.3	25.2
16	102.8	10	90	60.6	19.8
17	3.2	10	120	83.1	15.4
18	43.2	10	140	104.0	21.2
19	52.2	10	90	55.7	16.9
20	3.8	10	90	50.9	17.8

Table 2. Seasonal thawing layer depth statistics for test watershed areas.

 https://doi.org/10.5194/ica-proc-2-65-2019 |