ISSN: 0975-766X
CODEN: IJPTFI
Available Online through
Research Article
www.ijptonline.com

ASSESSMENT OF THE INTENSITY OF SLOPE EROSION USING TERRESTRIAL LASER SCANNING

Artur Maratovich Gafurov*, Oleg Petrovich Yermolaev, Bulat Mansurovich Usmanov
Kazan Federal University, Institute of Environmental Sciences.
Email: arturgafurov@outlook.com

Received on 15-07-2016 *Accepted on 10-08-2016*

Abstract

Assesment of the intensity of soil erosion is a crucial challenge of modern geomorphology. Despite the fact that there are a number of methods of studying exogenous processes, such as assessment of intensity by rill wash, pins method, radioactive tracer method, the problem of quantitative assessment of erosion intensity in various sections of a temporary hydrographic net remains still unsettled. Terrestrial laser scanning (TLS) allows overcoming the difficulties associated with low productivity and accuracy of traditional methods. Operations on erosion intensity assessment were carried out on two key sites within the city of Kazan in 2013-2015, and on two sites in Vysokogorsky district of Kazan in 2015. The results of the measurements show the predominance of erosion (-37.69 m^3/ha on the first and -86.53 m^3/ha on the second key site) on the slope in Kazan and the predominance of accumulation (53.45 m^3/ha on the first and 71.66 m^3/ha on the second key area) in Vysokogorsky district of Kazan. The results obtained suggest the possibility of applying the TLS for a quantitative and qualitative assesment of the intensity of denudation, and determination of the process flow patterns. The method allows evaluating integrally the cumulative effect of the entire complex of exogenous processes, flowing on the slopes.

Keywords: Soil erosion, laser scanning, environmental impact assessment.

Introduction

Despite the fact that the erosion processes have been studied since the XVIII cent. [1], the problem of quantitative assessment of soil erosion intensity in various sections of a temporary hydrographic network still unsettled. Existing methods are either generalizing (erosion measurement by rill wash [2], radioactive tracer method [3]) [4], or too difficult to reproduce (soil-morphological method, method of microleveling) [5]. We should also mention the methods using the multispectral space images as data sources [6]. Despite the obvious advantages (increase in the efficiency of studying erosion processes) [7], the method has significant drawbacks [8]. These include the inability to assess erosion losses in the rill network, the lack of high-resolution materials of some areas [9]. Moreover, none of the existing methods of erosion recording provides a comprehensive information on the erosion and accumulation balance in different parts of the slope. This is primarily due to very low rates of soil wash processes, the morphological vagueness of the erosion forms and the complexity of the organization of repeated observations on cultivated lands [10]. Nevertheless, the assessment of the intensity of rill and sheet erosion is a fundamentally important task, since these types of erosion accounts for more than 2/3 of the slope surface and almost all area of cultivated lands [11].

Terrestrial laser scanning has a number of advantages of field survey, starting with the precision, reaching tenths of a millimeter [12], and ending with the TLS performance with exceptional level of detail of the obtained model [13]. In addition, based on the principle of remote information, it ensures safety at work in confined spaces [14].

However, despite all the benefits of the TLS, the technology has some limitations. For example, the meteorological sensitivity [15]. In addition, it is necessary to take into account the nature of the surface under study, as its reflecting characteristics may be the cause of so-called “shadows", i.e. the data-free areas [16].

Methods

Development and testing of the method was carried out in the territory of the slope areas within the city of Kazan. The position of the studied slope is 55°48.163’ N, 49°9.102' E and the average slope angle - 31.5 degrees, with the exposure to the south-west; the average length of the slope is 18 m, and the relative altitude - 9 m. Site selection was due to the lack of a solid sod cover, the high slopes, and the rectilinear shape of the cross profile. In conjunction with the already visually formed network of rill erosion, all these factors had to promote the intensive denudation after each storm event.

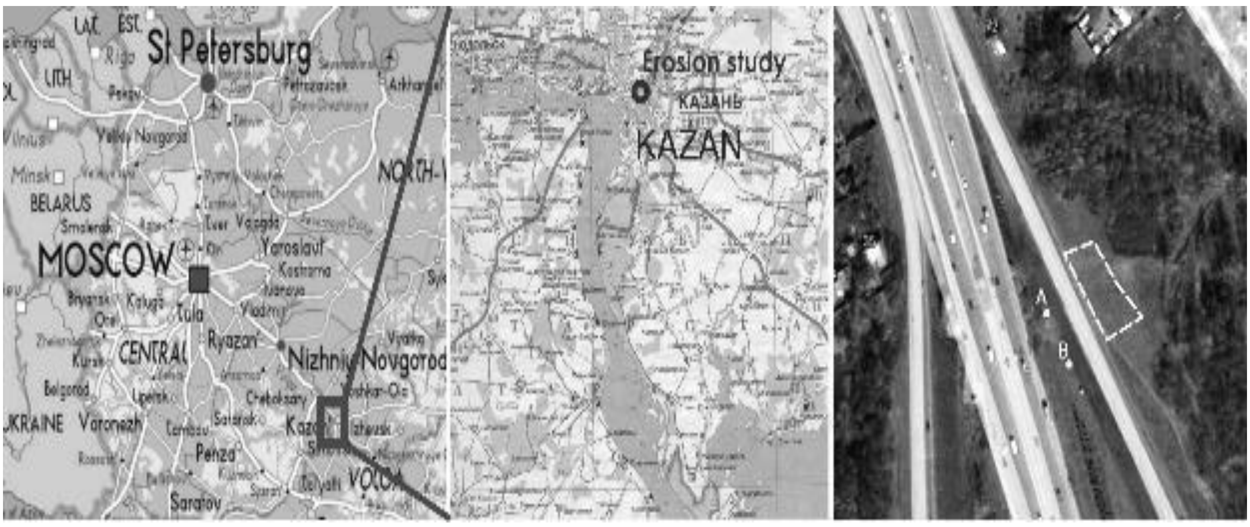

Figure 1. Slope fragments selected for TLS (observation platforms) on the left slope of the river Kazanka.

To monitor the soil erosion directly on arable lands during the storm-water runoff, a field sown with alfalfa was chosen on the north-eastern outskirts of the city of Kazan in the Kinderka river basin (Figure 2). The slope angle in this area is 5.52 deg., with the slope exposure to the north-west. Since the previous observations on the experimental sites showed that the contribution of the so-called sheet erosion as compared with the rill one is quite low, even in the steep areas of the slopes and has a value on the threshold of measurement accuracy [10], it was decided to monitor the erosion intensity and dynamics by its linear morphological forms. For scanning, 2 sites were selected with clear washouts of up to 30 cm wide.

Figure 2. The selected sites in the Kinderka river basin.

In 2014, the measurements were conducted with the use of a 3D terrestrial laser scanner Trimble GX. In 2015, we used an Trimble VX Spatial Station with laser scanning function. In addition, in 2015 we used a modern scanner Trimble TX8.

April 12, 2014, the first survey was conducted using the Trimble GX. During the investigation of the erosion slope, the scanner was installed at a distance of 30 m from the object, the survey was conducted in fast (color) mode, at 15 mm resolution at a distance of 25 meters, with 4 shots per point.

In 2015, the work was carried out at two sites with the exposed surface. Conditionally, they were classified as the “left” (A) and the “right” (B) platform according to the upward extension of the slope of the river Kazanka. According to the slope downfall, each of them was divided into three experimental plots such as the upper, middle and lower part of the slope.

For reliable scan leveling, a bench mark network was established. Standard deviation (σ) of error of referencing of all scans was 1 mm. The first survey in 2015 was conducted on May 26, and the next - on June 5, 2015. Total 4 surveys with the use of an Trimble VX Spatial Station were conducted on this site in 2015, and 2 surveys during the autumn time with the use of Trimble TX8, which allowed us to assess the effects of the hurricane that happened in Kazan on September 7.

The Trimble VX survey was conducted with the following settings: horizontal resolution 15 mm on 6 m, vertical resolution of 10 mm on 6 m.

Based on the obtained digital elevation models (DEM), quantitative characteristics of the erosion and accumulation processes for all sites were calculated. For this purpose, we used Golden Software Surfer. Then, a layer of erosion and accumulation was determined in mm, as well as a predominant process, and the volume of erosion and accumulation [11].

Results

Acknowledging obvious the fact that the erosion processes depend on rainfall, our subsequent surveys were confined to them, and we focused on recording of changes resulting from storm-water runoff. The results of measurements made in 2014 are shown in Tables 1 and 2.

Table 1: The results of surveys on the site A on the left slope of the river Kazanka in 2014.

Dates	Section A							
	S (m^2)	V_+ (m^3)	V_- (m^3)	ΔV (m^3)	E (m^3/ha)	i_+ (mm)	i_- (mm)	Δi (mm)
20.06.14	98.30	0.36	-1.13	-0.77	-78.33	3.66	-11.50	-7.83
08.07.14	98.45	0.36	-0.37	-0.01	-1.02	3.66	-3.76	-0.10
21.07.14	170.05	0.83	-0.81	0.02	1.18	4.88	-4.76	0.12
30.08.14	164.38	0.87	-1.18	-0.31	-18.86	5.29	-7.18	-1.89
30.10.14	168.28	1.66	-0.44	1.22	72.50	9.86	-2.61	7.25

Table 2: The results of surveys on the site B on the left slope of the river Kazanka in 2014.

Dates	Section B							
	S (m^2)	V_+ (m^3)	V_- (m^3)	ΔV (m^3)	E (m^3/ha)	i_+ (mm)	i_- (mm)	Δi (mm)
20.06.14	96.04	0.45	-0.50	-0.05	-5.21	4.69	-5.21	-0.52
08.07.14	98.41	0.56	-0.28	0.28	28.45	5.69	-2.85	2.85
21.07.14	123.56	0.37	-0.49	-0.12	-9.71	2.99	-3.97	-0.97
30.08.14	121.55	0.43	-0.83	-0.40	-32.91	3.54	-6.83	-3.29
30.10.14	121.28	1.11	-0.19	0.92	75.86	9.15	-1.57	7.59

Started in 2014, the monitoring of the intensity and dynamics of slope erosion by terrestrial laser scanning continued in 2015 on the same key sites of the left slope of the river Kazanka. All work conducted in 2015 can be divided into two periods: the summer (Table 3) and autumn (Table 4) periods. On the site in the northeast of the city of Kazan in the Kinderka river basin two surveys were conducted. The first survey was conducted on July 30, 2015, the next survey was conducted on September 8 after several prolonged rains with total precipitation amount of 200 mm. The results of measurements are shown in Table 5.

Table 3: The results of surveys on the site B on the left slope of the river Kazanka for summer 2015.

Dates	S (m^2)	V_- (m^3)	V_+ (m^3)	ΔV (m^3)	E (m^3/ha)	i_- (mm)	i_+ (mm)	Δi (mm)
Total for section								
26.05-05.06 (a)	11.09	-0.09	0.06	-0.03	-28.80	-8.19	5.31	-2.88
05.06-20.06 (b)	11.09	-0.14	0.02	-0.12	-107.69	-12.23	1.46	-10.77
20.06-09.07 (c)	11.09	-0.05	0.06	0.02	13.65	-4.27	5.63	1.36
Upper section								
26.05-05.06 (a)	3.70	-0.05	0.003	-0.04	-117.00	-12.56	0.86	-11.70
05.06-20.06 (b)	3.70	-0.03	0.01	-0.02	-44.63	-7.82	3.36	-4.46
20.06-09.07 (c)	3.70	-0.02	0.01	-0.01	-29.07	-6.04	3.13	-2.91
Middle section								
26.05-05.06 (a)	3.69	-0.03	0.004	-0.02	-58.02	-6.88	1.08	-5.80
05.06-20.06 (b)	3.69	-0.03	0.002	-0.02	-65.62	-7.06	0.50	-6.56
20.06-09.07 (c)	3.69	-0.01	0.01	0.003	8.18	-2.20	3.02	0.82
Lower section								
26.05-05.06 (a)	3.71	-0.02	0.05	0.03	88.11	-5.14	13.95	8.81
05.06-20.06 (b)	3.71	-0.08	0.002	-0.08	-212.30	-21.76	0.53	-21.23
20.06-09.07 (c)	3.71	-0.02	0.04	0.02	61.66	-4.56	10.72	6.17

Table 4: The results of surveys on the site B on the left slope of the river Kazanka for autumn 2015.

Dates	S (m^2)	V_+ (m^3)	V_- (m^3)	ΔV (m^3)	E (m^3/ha)	i_+ (mm)	i_- (mm)	Δi (mm)
Section A								
07-08.09	30.43	0.02	-0.13	-0.11	-37.69	0.60	-4.37	-3.77
upper	9.82	0.01	-0.04	-0.04	-38.42	0.68	-4.53	-3.84
middle	15.22	0.01	-0.06	-0.06	-37.29	0.52	-4.25	-3.73
lower	5.38	0.00	-0.02	-0.02	-37.47	0.66	-4.41	-3.75

Section B								
07-08.09 (d)	23.42	0.01	-0.17	-0.17	-73.28	0.22	-7.55	-7.33
upper	7.07	0.00	-0.05	-0.05	-70.60	0.21	-7.27	-7.06
middle	8.55	0.00	-0.06	-0.06	-69.40	0.15	-7.09	-6.94
lower	7.80	0.00	-0.06	-0.06	-76.84	0.29	-7.98	-7.68
08.09-23.11 (e)	14.38	0.07	-0.19	-0.12	-86.53	4.57	-13.22	-8.65
upper	3.58	0.02	-0.05	-0.03	-86.35	4.64	-13.27	-8.63
middle	4.84	0.03	-0.06	-0.03	-69.98	5.72	-12.72	-7.00
lower	5.96	0.02	-0.08	-0.06	-100.10	3.60	-13.60	-10.01

Table 5: The results of survey of the arable lands in the Kazanka river valley.

Dates	S (m^2)	V_+ (m^3)	V_- (m^3)	ΔV (m^3)	E (m^3/ha)	i_+ (mm)	i_- (mm)	Δi (mm)
Section A								
30.06-08.09	4.49	0.002	0.026	0.024	53.45	5.79	0.45	5.35
Section B								
30.06-08.09	18.7	0.017	0.151	0.134	71.66	8.07	0.91	7.17

Discussion and summary

Increase in accumulation with the beginning of the autumn 2014 is due to the soil saturation with moisture coming from the increased precipitation, which led to soil swelling in the lower third of the slope. Generally, both sites had mainly erosion observed; on site A, the average eroded volume was -4.94 m^3/ha (Table 1), on site B, the same indicator amounted to -13.15 m^3/ha (Table 2).

In 2015, during the first period - the summer - the scanning of site B was conducted from May 26 to July 9 with an Trimble VX Spatial Station. Total 4 surveys were conducted. During this period, there were several heavy rains: April 20, 22.8 mm of precipitation, May 18-19 - 7.2 and 7.1 mm, June 16 - 8.9 mm, June 23 - 28.6 mm, July 10 - 24.2 mm, July 12-13 - 19.4 and 12.5 mm, and the last summer rainfall was on August 1 - 27.7 mm, respectively. The erosion values during 26.05-5.06 amounted to 2.8 mm (28.80 m^3/ha), and during 5.06-20.06 - 10.8 mm (107.7 m^3/ha). Such high values of erosion are due to high slope angle of the observed slopes. During the last observation summer period of 20.06-09.07, erosion prevailed at the top of the slope - 2.9 mm, and accumulation at the bottom - 6.2 mm, so, in general, there was a slight accumulation - 1.36 mm (13.65 m^3/ha) (Table 3).

The second period - autumn: after extreme rainfall (25.1 mm), on September 7-8 a survey with 3D laser scanner Trimble TX8 was conducted on two sites, and on November 23 - with Trimble VX Spatial Station. Soils were heavily moistened. The amount of erosion in the upper and middle section of the right site was about 7 mm (70.6 m^3/ha) and a little more than 7.7 mm (76.84 m^3/ha) - in the lower section. The average volume of soil erosion on the entire site was 7.3 mm (73.3 m^3/ha). On the left site, due to the outcrop of the protective geogrid ensuring erosion and landslide protection, the erosion values after the rainfall were almost 2 times less than the on the right: 3.9, 3.7, 3.8 mm for the upper, middle and lower parts, respectively, and averaged 3.8 mm (37.69 m^3/ha) (Table 4).

Based on the results of laser scanning DEM, the positional structure of the rill erosion was analyzed. For site A, the density of the rill network was 8.24 m/m^2, and 6.48 m/m^2 for site B. As a result of extreme rainfall on September 7, the density of the rill network increased by 5% on site A and by 13% on site B.

If considering the qualitative changes, then the maps of terrain differences will be the most valuable for visualizing the changes occurred (Figure 3). The construction of longitudinal and transverse profile (Figure 4) and the study of the positional structure of rill erosion (Figure 5) is also informative.

All sections of the left slope of the river Kazanka have a tendency to the alignment of the rill channels, increase in their total number, and merging of rills into large streams (Figure 5). Furthermore, there is a general increase in their length, depth and width. The largest rills reach 15 cm in depth, while the average depth of rill network is 3 cm. However, it should be noted that the erosion occurs not only in the drainage lines. Moreover, there is a relationship between the amount of precipitation and the proportion of sheet wash: thus, during the periods with a high precipitation layer, the sheet wash was 50% of the total wash - 20.06-09.07 (43 mm precipitation) - 48.6%, 07-08.09 (25.1 mm precipitation) - 55.3%.

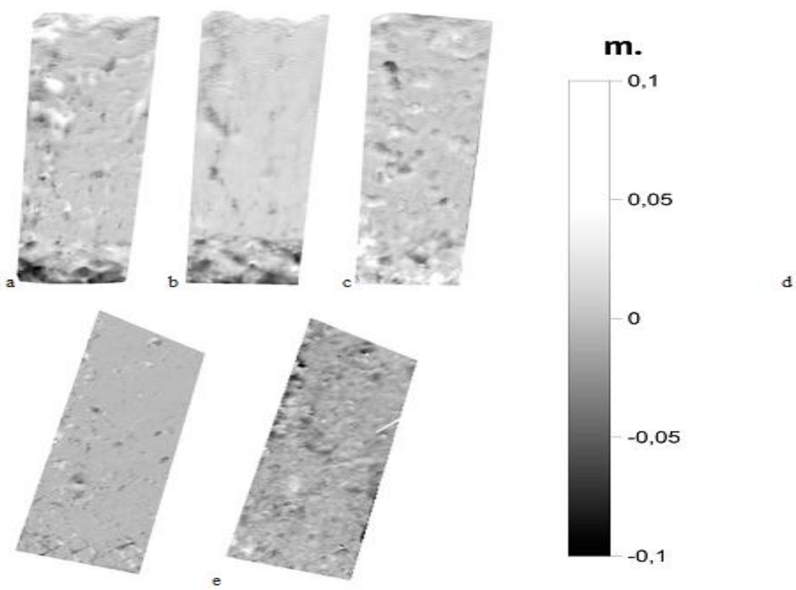

Figure 3. Maps of terrain differences for site B on the left slope of the river Kazanka in different periods of observation.

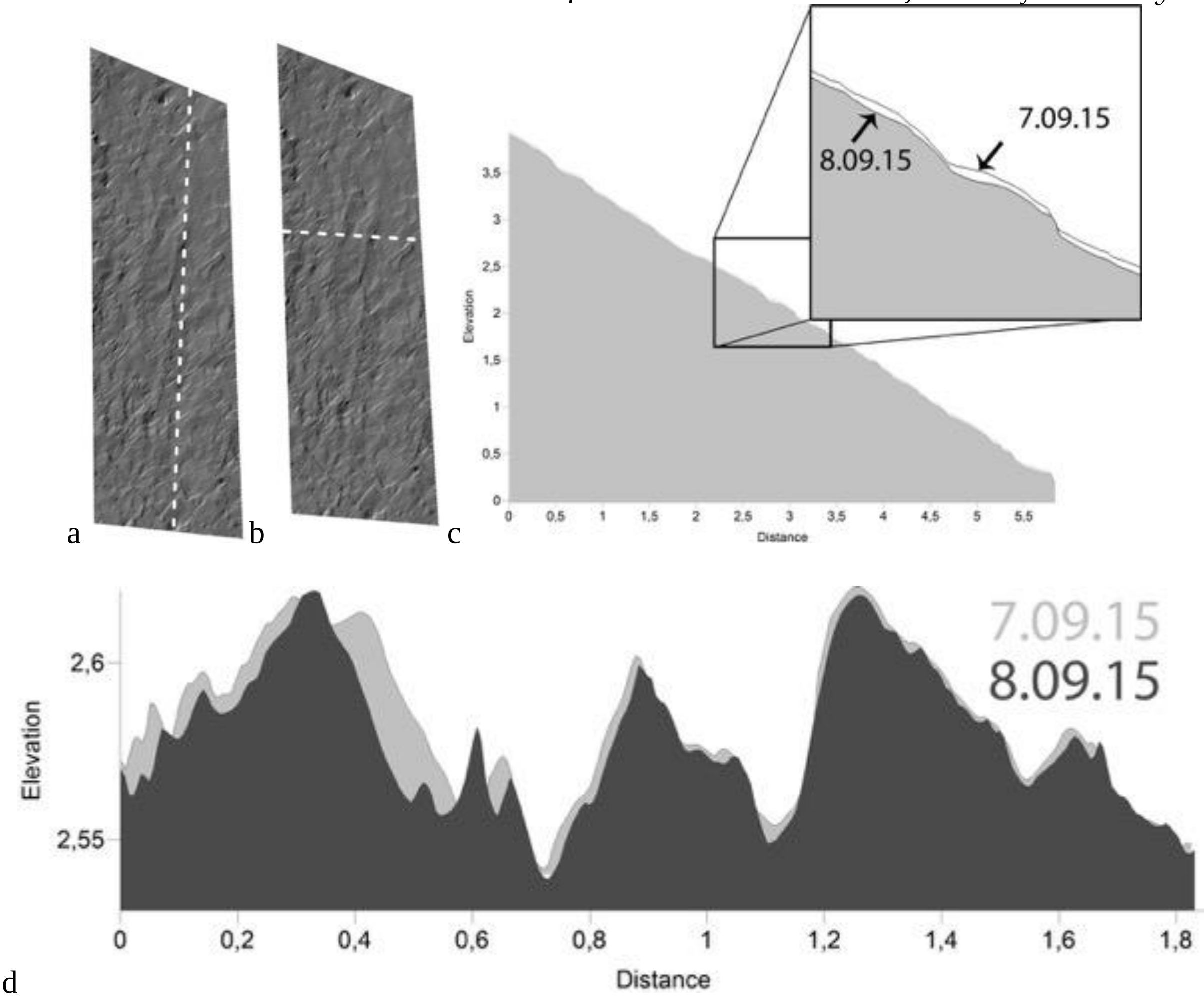

Figure 4. Longitudinal (a, c) and transverse (b, d) profiles of site B

on the left slope of the river Kazanka for autumn 2015

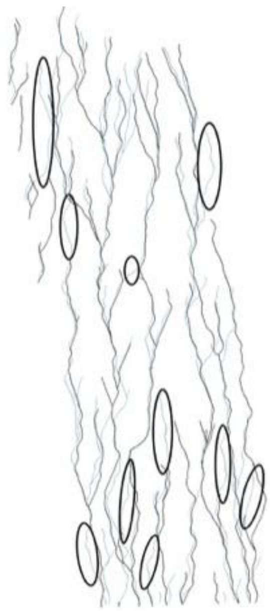

Figure 5. A map of changes in the positional structure of microrill erosion exemplified by the left slope of the river Kazanka for autumn 2015

If considering the longitudinal profile of washouts on the site in the Kinderka river basin (Figure 10), it is worth noting that the profile has a stepped pattern that is likely due to the uneven layer of precipitation throughout the year, as well as the age of erosion.

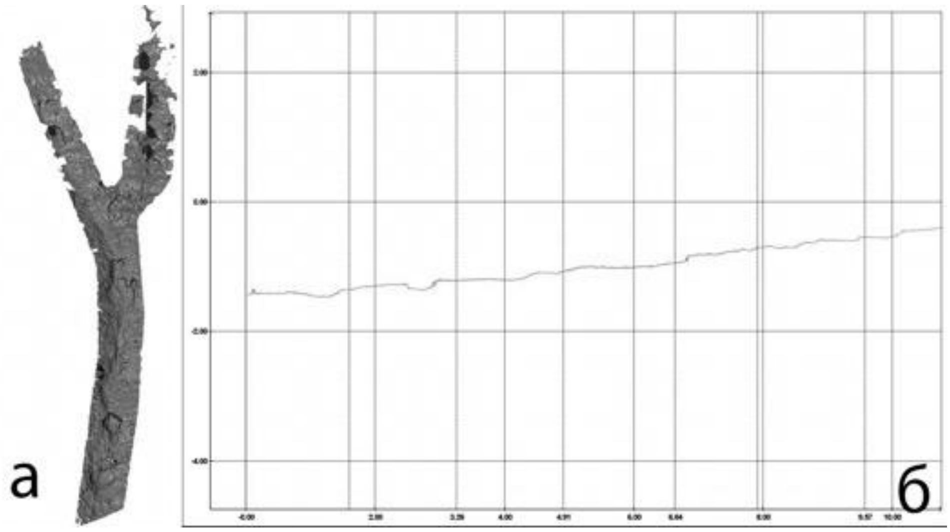

Figure 10. Longitudinal profile on a slope in the Kinderka river valley (section A). a - the selected longitudinal profile, b - a graph of the longitudinal profile

Based on data on the precipitation amount, a quantitative assessment of the relationship between the precipitation and erosion and accumulation was carried out (Table 5).

Table 5: The results of the analysis of the correlation ratios for the left slope of the river Kazanka.

Date	Precipitation mm	Section A		Section B	
		Erosion layer, mm	Accumulation layer, mm	Erosion layer, mm	Accumulation layer, mm
20.06.14	33.6	-11.50	3.66	-5.21	4.69
08.07.14	37.8	-3.76	3.66	-2.85	5.69
21.07.14	15.2	-4.76	4.88	-3.97	2.99
30.08.14	63.7	-7.18	5.29	-6.83	3.54
30.10.14	84.8	-2.61	9.86	-1.57	9.15
05.06.15	10.3	No measurements conducted in 2015		-8.19	5.31
20.06.15	16.5			-12.23	1.46
09.07.15	43.7			-4.27	5.63
07.09.15	25.1			-7.55	0.22
23.11.15	124.5			-13.22	4.57
η^2		**0.7**	**0.59**	**0.39**	**0.42**
η		**0.83**	**0.77**	**0.62**	**0.65**

Thus, on the left site of the slope of the river Kazanka, erosion caused by the amount of precipitation is 39%, while the correlation ratio is 0.62, which indicates the average correlation. The correlation of accumulation and precipitation amount is roughly similar - r=0.65, the accumulation caused by precipitation amount is 42%.

Conclusion

Accurate assessment of the intensity of slope erosion is important for the improvement of our understanding of the erosion dynamics. Conventional tools for evaluation and measurement provide very low resolution and are limited in use in the places where the surface of interest is difficult to access. The TLS overcomes these difficulties by collecting high-resolution data (2000 - 4000 points/m^2 for our study). It ensured quantitative and qualitative assessment of the intensity of erosion processes, and determination of the process flow pattern. This gives an opportunity to assess a denudation-accumulative balance on the slopes. The method allows evaluating integrally the cumulative effect of the entire complex of exogenous processes, flowing on the slopes. Meanwhile, as well as any other method, it has its own limitations: high accuracy scanning is possible only on fully exposed surfaces, difficulties during the repeated observations on arable lands (setting and maintenance of bench marks), consideration of the requirements for the survey conditions, and, oddly enough, too high scanning density.

Acknowledgements

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. The study was supported by Russian Foundation for Basic Research (project №14-05-00503).

References

1. Tolchelnikov Iu.S. Soil erosion and deflation. Appropriate controlling methods // M.: Agropromizdat, 1990. P. 158.
2. Sobolev S.S., Ponomarev S.I. The study of erosion resistance of soil // Soil science No. 9-10, Pp. 495-496.
3. Litvin L.F. Geography of soil erosion of agricultural land of Russia. M.: Akademkniga ICC, 2002. P. 255.
4. Zaslavsky M.N. Erosion studies. M.: Vysshaia shkola, 1983. P. 320.
5. Larionov G.A. Soil erosion and deflation. M.: Publishing House of Moscow University, 1993. P. 200.
6. Ditts L.Iu., Katunkina E.V. The use of remote sensing data in the study of soil-erosion processes // Natural and Mathematical Science in the modern world. 2015. No.8 (32). Pp. 58-64.
7. Richards J. A., Richards J. A. Remote sensing digital image analysis. – Berlin et al.: Springer, 1999. – T. 3.
8. Knizhnikov Iu.F. Aerospace sensing. Methodology, principles, problems. - M.: Publ. house of Moscow University, 1997. P. 128.

9. Vanmaercke, M., Poesen, J., VanMele, B., Demuzere, M., Bruynseels, A., Golosov, V., Fernando, J., Bezerra, R., Bolysov, S., Dvinskih, A., Frankl, A., Fuseina, Y., Guerra, A., Haregeweyn, N., IonitaI., Imwangana, F., Moeyersons, J., Moshe, I., Samani, A., Niacsu, L., Nyssen, J., Otsuki, Y., Radoane, M., Rysin, I., Ryzhov, Y., Yermolaev, O. How fast do gully headcuts retreat? // Earth Science Reviews, 2016. 154, 336–355. http://dx.doi.org/10.1016/j.earscirev.2016.01.009
10. Usmanov, B., Yermolaev, O., & Gafurov, A. Estimates of slope erosion intensity utilizing terrestrial laser scanning. // Proc. IAHS, 2015, 367, 59–65, http://dx.doi.org/10.5194/piahs-367-59-2015.
11. Buckley S.J. et al. Terrestrial laser scanning in geology: data acquisition, processing and accuracy considerations // J. Geol. Soc. London. 2008. V. 165. № 3. Pp. 625–638.
12. Carrivick J.L., Smith M.W., Carrivick D.M. Terrestrial laser scanning to deliver high-resolution topography of the upper Tarfala valley, arctic Sweden // GFF. 2015. V. 137. № 4. Pp. 383–396.
13. Liapishev K.M., Pogorelov A.V., Shuliak D.Iu. The study of landslides using surface laser scanning technology. // Geodesy, cartography and mine survey: Russian scientific Internet conference with international participation: Proceedings of the Conference, 2014. Pp. 26-32
14. Prokop A., Schön P., Singer F., Pulfer G., Naaim M., Thibert E., Soruco A. Merging terrestrial laser scanning technology with photogrammetric and total station data for the determination of avalanche modeling parameters. // Cold Regions Science & Technology vol: 110, 2015. Pp. 223-230.
15. Prokop A. Assessing the applicability of terrestrial laser scanning for spatial snow depth measurements. // Cold Regions Science & Technology vol:54, 2008. Pp. 155–163.
16. Bechet, J., Duc, J., Jaboyedoff, M., Loye, A., and Mathys, N. Technical Note: Erosion processes in black-marls at the millimetre scale, the input of an analogical model, Hydrol. // Earth Syst. Sci. Discuss., 11, 2014. Pp. 2263-2275.
17. Yermolaev, O.P., Maltsev, K.A. and Ivanov, M.A. Automated Construction of the Boundaries of Basin Geosystems for the Volga Federal District // Geography and Natural Resources, 2014, Vol. 35, No. 3, Pp. 222-228. DOI: 10.1134/1875372814030044.

Corresponding Author:

Artur Maratovich Gafurov*,