Effectiveness of Geotextile Ropes in Slope Erosion Protection

Giang Nguyen 1,2, Jan Broda 2, Joanna Grzybowska-Pietras 2
1 University of Žilina, Faculty of Civil Engineering, Univerzitná 8215/1, 010 26 Žilina, Slovakia
2 University of Bielsko-Biela, Willowa 2, 43-309 Bielsko-Biala, Poland

Abstract. Paper deals with application of geotextile ropes in erosion protection of slope of gravel pit in Nieboczowy, Poland. For protection of the slope the segments formed from thick ropes were applied. The ropes with the diameter of 120 mm were produced by the Kemafil technology. Ropes were made from strips of stitch-bonded nonwoven produced from a mixture of recycled natural and synthetic fibres and strips of wool needle-punched nonwoven. The protected slope had the length of 4 to 6 m, slope inclination from 1:1 to 1:1.8 and total area of approximately 150 m². Generally, slope surface in protected section is without rills and gullies. This case also shows that vegetation is very good anti-erosion measure. Thanks ropes installed on the slope, favourable conditions for vegetation growth are created and maintained. Effectiveness of the ropes in slope erosion protection will be shown by the actual mean annual soil erosion rate EA and potential mean annual soil erosion rate EP for two cases: slope with the ropes and slope without the ropes. Values of EA and EP were calculated applying Universal Soil Loss Equation (USLE). Values of parameters of the USLE were determined based on rainfall records of 17 years, soils properties, slope geometrical parameters, cropping and management practices as so as erosion control practice on the site. The obtained value EA = EP =0.71 (t ha⁻¹ year⁻¹) in slope part with ropes shows that there is no erosion in this part at present and also in future. The value of EA = 15.68 (t ha⁻¹ year⁻¹) in slope part without ropes shows that there is strong erosion in this part at present. The value of EP = 71.27 (t ha⁻¹ year⁻¹) in slope part without ropes also shows that there will be strong erosion in this part in future.

1. Introduction
In recent years’ natural disasters combined with intense rainfall as well as agricultural and industrial human activity strongly interfering with the natural environment are the causes of numerous problems associated with surface soil erosion. Soil erosion became a serious problem, which affects banks of rivers and lakes, coastal dunes and natural slopes as well as various artificial slopes and embankments. In many cases to reduce the negative effect of erosion intensive measures have to be taken.

To protect slopes from water erosion various techniques are utilized. One possible alternative is the application of geosynthetics. Geosynthetics effectively protect slopes against surface soil erosion and have positive effect on vegetation development. A wide assortment of geosynthetics includes flat mats or blankets and three-dimensional products such as Husker Fortrac 3D® geogrids [1-2] or Presto GEOWEB® geocells [3]. Two-dimensional products are installed in a very close contact with the ground surface to cover significant part of the slopes. The covers shield the soil surface from the impact of falling rain, reduce kinetic energy of falling drops and prevent loosening of soil particles.
Additionally, the covers provide rough surface that slows down the runoff velocity, promotes water infiltration into the soil and deposition of sediment. The second group of geosynthetics, spatial products, are designed to be filled with the soil and seeded. Installed on the slope, they retain seeds and soil, stimulate seed germination, favour seedling development and accelerate development of plant roots. The spatial products not only protect slopes against surface erosion, but also stabilize slopes and prevent slopes veneer soil slippages.

In addition to mentioned products few years ago new innovative geotextiles were invented. The geotextiles were built from meandrically arranged thick ropes connected into segments with additional linking chains. For the manufacturing of the ropes the Kemafil technology was applied [4]. It was revealed that for the manufacturing the geotextiles the pre-consumer or post-consumer textile wastes can be used. The production of geotextiles extends the life of the fibres and is an interesting alternative to troublesome methods of waste textiles disposal.

The geotextiles formed from meandrically arranged ropes were successfully used for stabilization of slopes in disused lignite mine, as well as for protection of road side and drainage ditches and terrace slope [4-9]. Recently the meandrically arranged ropes were applied for erosion protection of slope in abandoned gravel pit in Nieboczowy (Poland). In previous papers the installation of ropes and their behaviour during one and a half year were presented [9-10]. In this paper the effectiveness of the ropes in erosion protection is analysed.

2. Site characterisation
Investigations were performed in abandoned gravel pit Nieboczowy located near Raciborz in southern Poland. The area is located close to the Czech-Polish border in Silesia in the north part of Moravian Gate, the depression between the Carpathian Mountains in the east and the Sudetes in the west. The site belongs to the floodplain of the Oder river, the second largest river in Poland. The valley is rich in sand and gravel deposits. The abundant deposits are located shallowly under the soil and a thin layer of sand or clay and possess big thickness exceeding locally 15 m. Due to high demand for mineral aggregates the rich gravel deposits are intensively exploited.

In gravel pit Nieboczowy, after several years of exploitation, the deposits were exhausted and the extraction of gravel was interrupted. As a result of mining deep extraction pit with a depth of approximately 10 m was formed. The pit was naturally filled with water to form small pond (figure 1).

On the banks of the pit steep unstable slopes prone to local sliding and slipping were generated. In the north-facing bank of the excavation on the surface of native ground the artificial embankment with a high ca. 4 m was formed. The embankment erected from overburden material mined during mine operation coupled with the steep slope cut in native ground was especially unstable and endangered by local sliding (figure 1).

![Figure 1. The disused excavation of the gravel pit Nieboczowy.](left: a pond with slide; right: a plane translational slip of north-facing bank.)
3. Anti-erosion measures

For protection of the slope the geotextile segments formed from thick ropes were applied. The ropes with the diameter of 120 mm were produced by the Kemafil technology [11]. The ropes were manufactured from strips of wool needle-punched nonwoven and strips of stitch-bonded nonwoven made from a mixture of recycled natural and synthetic fibres obtained by the shredding and carding of post-consumer textile wastes. The part of the ropes made from recycled fibres was manufactured with addition of perennial ryegrass (*Lolium perenne*) seeds.

The ropes were meandrically arranged to form segments with the width of 1.8 m and the length of 6 m. In order to stabilize the segments, the subsequent turns of the ropes were connected with additional links made from thick polypropylene twine. Geotextiles ropes were used to secure a total area of approximately 150 m² in the most threatened part of the slope. The protected slope had the length of 4 to 6 m and the slope inclination from 1:1 to 1:1.8. The ropes were anchored in the crown of the slope and fastened at the surface with steel pins. The long “U-shaped” pins made from ribbed bars of diameters $\phi = 8$ mm were used. To protect bigger section of the slope the subsequent segments of ropes were spread alongside one another. Slope with installed ropes can be seen in the figure 2 (left). Effectiveness of installed ropes can be seen in figure 2 (right). As we can see in figure 2(right), there are many vegetation and no signs of erosion exist in the protected slope part.

![Figure 2. Effectiveness of geotextile ropes as anti-erosion measure.](left: slope state on 09.02.2016; right: slope state on 23.06.2016)

4. Quantitative soil erosion evaluation

4.1. Universal Soil Loss Equation (USLE) and erosion classification

To quantitatively evaluate erosion rate on slope, Universal Soil Loss Equation (USLE) [12] was applied. Mean annual soil erosion rate (actual erosion rate) $E_A$ ($t \text{ ha}^{-1} \text{ y}^{-1}$) was calculated using formula (1) [13]:

$$E_A = RKLSCP$$  \hspace{1cm} (1)

where $E_A$ is the mean annual soil erosion rate (actual erosion rate) ($t \text{ ha}^{-1} \text{ y}^{-1}$), $R$ is the rainfall erosivity factor (MJ $\text{mm ha}^{-1} \text{ h}^{-1} \text{ y}^{-1}$), $K$ is the soil erodibility factor ($t \text{ h MJ}^{-1} \text{ mm}^{-1}$), $LS$ is the topographic factor (dimensionless), $C$ is the cover management factor (dimensionless), $P$ is the erosion control practice factor (dimensionless).

The formula can be used for the estimation of the potential erosion rate, i.e. the erosion rate from the black fallow without any erosion control practices ($C=1$ and $P=1$). In such a case the formula abbreviates to:

$$E_P = RKLS$$  \hspace{1cm} (2)
where EP is the mean annual soil erosion rate (potential erosion rate) (t ha\(^{-1}\) y\(^{-1}\)).

By [13], based on the quantitative evaluation of soil erosion resulting from USLE modelling, the qualitative assessment of erosion risk can be carried out. According to the forecast soil loss, location can be assigned to one of the six erosion risk classes, with an assumption that the soil degradation level in each particular erosion class should correspond to grades of erosion intensity in Poland introduced by [14], see table 1.

**Table 1. Erosion classes and soil degradation (by [14] and [15]).**

| Erosion class | Erosion class description | Soil degradation |
|---------------|--------------------------|------------------|
| 1             | No erosion               | Does not occur   |
| 2             | Weak erosion             | Small surface soil loss |
| 3             | Moderate erosion         | Visible wash-off of humus horizon and deterioration of soil properties; full regeneration of soil not always possible through conventional tillage |
| 4             | Average erosion          | May lead to a total reduction of humus horizon and the development of soils with typologically unformed profiles; terrain dismemberment starts; considerable debris flow into surface waters |
| 5             | Strong erosion           | Can cause total destruction of the soil profile, including parent rock; large fragmentation of terrain and deformation of hydrology |
| 6             | Very strong erosion      | Effects similar to the ones for strong erosion, but more intensive; a permanent degradation of the ecosystem |

According to various literatures, authors in [13] introduce border values of soil loss for each class (table 2, table 3). Rendzina soils were given different criteria than other soils. It was justified by the profile, which in the case of rendzina is rather limited with rocky and stony fragments situated near the surface. The same level of erosion intensity results in bigger soil degradation.

**Table 2. Classification of actual erosion [13].**

| Erosion class | Erosion class Description | Erosion rate [t ha\(^{-1}\) year\(^{-1}\)] for rendzina soil |
|---------------|--------------------------|----------------------------------------------------------|
| 1             | No erosion               | 0-1                                                      |
| 2             | Weak erosion             | 1-5                                                      |
| 3             | Moderate erosion         | 5-10                                                     |
| 4             | Average erosion          | 10-15                                                    |
| 5             | Strong erosion           | 15-30                                                    |
| 6             | Very strong erosion      | >30                                                      |

Based on values of mean annual soil erosion rate (actual erosion rate) EA and mean annual soil erosion rate (potential erosion rate) EP calculated from equation (1) and (2) for the part of the slope, where the ropes are applied and for the part of slope, where no ropes applied, effectiveness of anti-erosion method using ropes will be shown.
Table 3. Classification of potential erosion [13]

| Erosion class | Erosion class Description | Erosion rate [t ha⁻¹ year⁻¹] for rendzina soil |
|---------------|---------------------------|---------------------------------------------|
| 1             | No erosion                | 0-2                                         |
| 2             | Weak erosion              | 2-10                                        |
| 3             | Moderate erosion          | 10-30                                       |
| 4             | Average erosion           | 30-50                                       |
| 5             | Strong erosion            | 50-100                                      |
| 6             | Very strong erosion       | >100                                        |

4.2 Rainfall erosivity factor (R) determination

By [13], rainfall erosivity for a single rainfall occurrence is calculated as a sum of the rain kinetic energy and its maximum 30 min intensity. The annual sum of these figures forms the $R_r$ factor. For modelling purposes its value equals the mean value in recent years. It is necessary to gather detailed meteorological (pluviographic) data to assess the value of the $R_r$ factor. Unfortunately, in Poland only ten measurement stations have gathered such data in recent years. A very similar situation occurs in various parts of the world and it became the main reason to look for alternative methods of estimating $R_r$ factor values. Such method should be based on data gathered regularly in measurement stations or on correlation with other easily accessible data. Author in [17] recommends the following formula for calculation of an annual erosivity rainfall factor in $(MJ*cm)/(ha.h.year)$, caused by rainfall only:

$$R_f = 0.226 F^{1.2876}$$

where $F$ is modified Fournier index by Arnoldus [18] and was calculated using formula:

$$F = \sum_{i=1}^{12} \frac{p_i^2}{p}$$

where $p_i$ is the monthly precipitation total in i-th month (mm), $P$ is the annual precipitation total (mm).

Authors in [12] state, that the early spring erosion by runoff from snowmelt, thaw or light rain on frozen soil may be include in the soil loss computation by adding a subfactor $R_s$ to the location’s erosion index $R_r$ to obtain total rainfall erosivity factor $R$ (it means $R = R_r + R_s$). Investigation of limited data indicate that an estimate of $R_s$ may be obtained by taking 1.5 times the local December through March precipitation, measured as inch of water. Licznar [16] state that when applying equation for USLE in SI units, it will be equal 1/10 amount of December through March precipitation.

To calculate total rainfall erosivity factor $R$, the monthly precipitation total in i-th month ($p_i$) and annual precipitation total ($P$) was obtained from rainfall station StaraKuźniawith station code 250180370) [19] (28.4 km from our location Nieboczowy) for period from January 2001 to March 2018. The value of total rainfall erosivity factor $R = 83.4((MJ*cm)/(ha.h.year))$ was calculated as a sum of average $R_r = 65.2((MJ*cm)/(ha.h.year))$ from equation (3) and average $R_s = 18.2((MJ*cm)/(ha.h.year))$ (as 1/10 amount of December through March precipitation) for mentioned period. This value was then applied in equations (1) and (2) to calculate $E_A$ and $E_P$.

4.3 Soil erodibility factor (K) determination

Soil erodibility factor (K) was calculated using formula posted in [12]:

$$100K = 2.1 \times M^{1.14} \times 10^{-4} \times (12 - a) + 3.25 \times (b - 2) + 2.5 \times (c - 3)$$

(5)
where:
M is a particle-size parameter which equals percentage of fraction 0.002-0.1mm times the quantity 100 minus clay percentage; “a” is an organic matter content (%), if organic matter content is larger than 4%, then a = 4; “b” is a soil structure code used in soil classification (very fine granular: 1, fine granular: 2, medium or coarse granular: 3 and very coarse granular: 4); “c” is a water permeability class (rapid: 1 (k_f ≥ 3.10^{-5} m/s); moderate to rapid: 2 (3.10^{-5} m/s ≥ k_f ≥ 1.5.10^{-5} m/s): 2, moderate: 3 (1.5.10^{-5} m/s ≥ k_f ≥ 4.8.10^{-5} m/s):, slow to moderate: 4 (4.8.10^{-5} m/s ≥ k_f ≥ 1.2.10^{-4} m/s), slow: 5 (1.2.10^{-4} m/s ≥ k_f ≥ 3.10^{-5} m/s) and very slow: 6 (3.10^{-5} m/s ≥ k_f ≥)), see [20]. Obtained values of K should be multiply by 1.313 to obtain K in unit (t.ha.h)/(ha.MJ.cm).

In our case, 3 soil specimens were taken from the slope with ropes. Determination of soil particles size distribution was carried out in accordance with the BS 1377: 1990. Part 2 (wet sieving method and sedimentation by the hydrometer method) [21]. Soil basic parameters such as water content (w), liquid limits (w_L) and plastic limits (w_P) were also determined in accordance with mentioned standard. Based on obtained values, soils classifications were carried out in accordance with the British Standard BS 5930:2015 [22]. After that, values of “M” and “b” were obtained from soils grain-size distribution. Values of “a” were obtained from tests carried out in accordance with [23]. Values of “c” were estimated based on soil classification. Input parameters and value of soil erodibility factor K can be seen in table 4.

**Tab 4.** Input parameters and value of soil erodibility factor $K(t*ha*h)/(ha*MJ*cm)$.

| Location/Specimen number | Nieboczowy |
|--------------------------|------------|
|                          | No. 1      | No. 2      | No. 3      |
| Soil classification by BS 5930:2015 [23] | CH         | CH         | CH         |
| Clayey fraction amount [%] | 28.7       | 32.1       | 30.7       |
| Silty fraction amount [%] | 63.3       | 61.3       | 56.7       |
| Fraction 0.002-0.1mm amount [%] | 65.05      | 62.73      | 59.16      |
| Sandy fraction amount [%] | 7.8        | 6.5        | 12.4       |
| Gravelly fraction amount [%] | 0.2        | 0.1        | 0.2        |
| Water content (w) [%] | 37.9       | 32.9       | 32.8       |
| Plastic limit w_P [%] | 26.2       | 24.4       | 20.6       |
| Liquid limit w_L [%] | 52.5       | 56.9       | 53.1       |
| Plasticity index I_P [%] | 26.3       | 32.5       | 32.5       |
| Consistency index I_c [-] | 0.55       | 0.73       | 0.62       |
| Particle-size parameter M [-] | 0.463937   | 0.425811   | 0.409979   |
| Organic matter content [%] | 2.52       | 1.06       | 1.38       |
| Soil structure code, b [-] | 1          | 1          | 1          |
| Water permeability class, c [-] | 6          | 6          | 6          |
| Soil erodibility factor K by formula (5) | 0.0558134  | 0.0558139  | 0.0558131  |

**Average soil erodibility factor K** 0.0558135

### 4.4 Topographic factor (LS) determination

By [12], the influence of the surface topography on erosion process is in the USLE modelling approach incorporated by the use of the topographic factor (LS). It combines two features - slope length (L) and slope steepness (S). The aim of the USLE equation was to estimate the soil loss in the erosion process for uniform slopes having the same steepness over their entire length. The slope length
is defined as the horizontal distance (not the distance parallel to the soil surface) from the origin of the overland flow to the point where either the slope gradient decreases enough that deposition begins, or runoff becomes concentrated in a defined channel [12]. When the slope length is measured in meters, the L-factor value is calculated as follows [12]:

$$L = \left(\frac{\lambda}{22.13}\right)^m$$  (6)

where $\lambda$ is the slope length, $m$ is the slope length exponent ($m = 0.5$ for steepness of 5 % or more; $m = 0.4$ for steepness of 3.5–5 %; $m = 0.3$ for steepness of 1–3.5 %; $m = 0.2$ for steepness <1 %).

The slope steepness factor (S) can be calculated as [11]:

$$S = 65.41 \sin^2(q) + 4.56 \sin(q) + 0.065$$  (7)

where $q$ is the slope steepness. Since slope in Nieboczowy had the length $\lambda = 4.0$ m, slope steepness $q = 45^\circ$ ($m = 0.5$) then L factor = 0.425, S factor = 35.994 and LS factor = L.S = 15.303.

4.5 Cover management factor (C)

By [13], the cover management factor (C) reflects the effect of cropping and management practices on erosion rates. It is calculated as the ratio of soil loss under actual conditions to losses experienced under the reference conditions (continuously fallow and tilled land) [24]. Determination of the C-factor value for agricultural crops requires detailed research of anti-erosion protection offered by a vegetation canopy at different growth stages and a reduction in erosion caused by surface cover and roughness. Previous cropping and management practices should be taken into account as well as the monthly changes of the rainfall erosivity factor. In some countries, C-factor values resulting from such research for the most often crop rotation practices are tabulated. For conditions in Poland, this kind of table describing the fully possible crop rotations has not yet been elaborated. In previous erosion research, the crop and management factor values were adopted from tables created in the USA or Bavaria [16]. Based on Bavarian research, C-factor values for the most typical Polish crops were proposed by [25]. The newest proposal of C-factor values for basic Polish crops can be found in [26] (not posted here for the reason of a large table). Taking into account application of ropes and also site visitations, we propose for all plots values $C = 0.01$ in slope part where ropes are applied (values of $C$ for “Green fallow” in [26]) and $C = 0.22$ in slope part where ropes are not applied (values of $C$ for “Other” in [25]).

4.6 Erosion control practice factor (P) determination

Erosion control practice factor (P) describes the ratio between soil loss on a field where erosion control practice is performed (contouring, strip cropping, terracing, subsurface drainage) to the loss on the same field with upslope and downslope tillage [24]. By the survey in [13], due to the large area that it covers and the source data used, the P-factor is only applied to plots with contouring. Values of the P-factor for parcels cultivated with contour tillage were defined according to the USLE methodology [12] as follows: $P = 1$ for slope steepness $\beta < 3 \%$, $P = 0.5$ (for $\beta$ from 3 to 8 %), $P = 0.6$ (for $\beta$ from 8 to 12 %), $P = 0.7$ (for $\beta$ from 12 to 16 %), $P = 0.8$ (for $\beta$ from 16 to 20 %), $P = 0.9$ (for $\beta$ from 20 to 25 %), $P = 1$ for $\beta > 25 \%$. On other land the P-factor value was assigned to 1. So in our case P had value 1.

4.7 Quantitative soil erosion evaluation

Based on obtained values of rainfall erosivity factor R, soil erodibility factor K, topographic factor LS, cover management factor C and erosion control practice factor P, introduced in previous chapters, the mean annual soil erosion rate (actual erosion rate) $E_A$ and mean annual soil erosion rate (potential
erosion rate) $E_P$ for slope parts with and without ropes were calculated, see table 5. (classes of actual erosion rate and potential erosion rate were determined in accordance with table 2 and table 3).

Table 5. Mean annual soil erosion rate of slope in Nieboczowy

| Location   | With ropes | Without ropes |
|------------|------------|---------------|
| R [MJ*cm]/(ha.h.year)]   | 83.4       | 83.4          |
| K [(t*ha*h)/(ha*MJ*cm)]   | 0.0558135  | 0.0558135     |
| LS [-]         | 15.303     | 15.303        |
| C [-]          | 0.01       | 0.22          |
| P [-]          | 1          | 1             |
| $E_A$[t ha⁻¹ year⁻¹] | $0.71$     | $15.68$       |
| Actual erosion class | (1) No erosion | (5) Strong erosion |
| $E_P$[t ha⁻¹ year⁻¹] | $0.71$     | $71.27$       |
| Potential erosion class | (1) No erosion | (5) Strong erosion |

As we can see in the table 5, erosion of slope in Nieboczowy is effectively restricted by the ropes. While the part of the slope, where the ropes are applied is stable with first actual erosion class (no erosion) and also first potential erosion class (no erosion); the part the slope, where no ropes are applied, suffers erosion with fifth actual erosion class (strong erosion) and expected potential erosion class is also fifth (strong erosion).

5. Conclusions
The slope created during gravel extraction in abandoned gravel pit in Nieboczowy is exposed to strong erosive action. On the basis of the quantitative evaluation of soil erosion from USLE modelling the slope is assigned to fifth actual erosion risk class and fifth potential erosion class. These classes correspond to strong erosion, which can cause total destruction of the soil profile and large fragmentation of terrain. The first signs of mentioned changes are visible on the slope.

The part of the slope protected with geotextiles formed from meandrically arranged ropes is classified in the first class, both of actual and potential erosion risk class. In accordance with classification, erosion does not occur at this place. The great change in the classification results from the essential change of the cover management factor C. The ropes installed on the slope accelerate its greening and formation of the dense green cover. In this way erosion is eliminated and soil movement are not observed.

Acknowledgment
The authors gratefully acknowledge the funding by ERANET-CORNET consortium under the international research project PROGEO 2 “Geotextiles from Sustainable Raw Materials and Textile Waste, New Mobile Production Technology and New Application Fields in Drainage and Hydraulic Engineering” DZP/CORNET/1/20/2017.
References

[1] http://www.huesker.com/, access: 05/2018
[2] http://www.huesker.com/fileadmin/Media/Reports/EN/JR_E_F_Embankments_Bridging_of_Sinkholes_Fortrac-A1-Polen.pdf, access: 05/2018
[3] http://www.prestgeo.com/, access: 05/2018
[4] J. Broda, A. Gawłowski, M. Rom, R. Laszczak, A. Mitka, S. Przybyło, J. Grzybowska-Pietras, “Innovative geotextiles for reinforcement of roadside ditch,” Tekstilec, vol. 59, pp. 115-120, 2016.
[5] M. Seeger, “Preventing erosion,” Knitting International, vol. 115, pp. 28-33, 2009.
[6] J. Broda, S. Przybyło, K. Kobiela-Mendrek, M. Rom, J. Grzybowska-Pietras, R. Laszczak, “Biodegradation of sheep wool geotextiles,” Int. Biodeterior. Biodegradation, vol. 115, pp. 31-38, 2016.
[7] J. Broda, A. Gawłowski, R. Laszczak, A. Mitka, S. Przybyło, J. Grzybowska-Pietras, M. Rom, “Application of innovative meandrically arranged geotextiles for the protection of drainage ditches in the clay ground,” Geotext Geomembranes, vol. 45, pp. 45-53, 2017.
[8] J. Broda, J. Grzybowska-Pietras, G. Nguyen, A. Gawłowski, R. Laszczak, S. Przybyło, “Application of recycled fibres and geotextiles for the stabilisation of steep slopes,” 17th World Textile Conference AUTEX 2017: Textiles - Shaping the Future, IOP Conf. Ser.: Mater. Sci. Eng. vol. 254, 2017.
[9] J. Broda, A. Gawłowski, J. Grzybowska-Pietras, M. Rom, S. Przybyło, R. Laszczak, “Application of geotextiles for the stabilization of steep slopes in gravel pits,” Inżynieria Ekologiczna = Ecological Engineering, vol. 18, pp. 71-77, 2017.
[10] J. Broda, S. Przybyło, A. Gawłowski, J. Grzybowska-Pietras, E. Sarna, M. Rom, R. Laszczak, “Utilisation of textile wastes for the production of geotextiles designed for erosion protection,” The Journal of the Textile Institute, published online 17.06.2018: https://www.tandfonline.com/doi/full/10.1080/00405000.2018.1486684?scroll=top&needAccess=true
[11] R. Arnold, A. M. Bartl, E. Hufnagl, “Production of cord and narrow fabric products with Kemafil technology,” Band- und Flechtindustrie, vol. 30, pp. 76-81, 1993.
[12] W. H. Wischmeier, D.D. Smith, “Predicting Rainfall Erosion Losses – A Guide to Conservation Planning,” USDA Handbook 537, Washington, D. C., 1978.
[13] W. Drzewiecki, P. Wężyk, M. Pierzchalski, B. Szafańska, “Quantitative and Qualitative Assessment of Soil Erosion Risk in Małopolska (Poland), Supported by an Object-Based Analysis of High-Resolution Satellite Images,” Pure Appl. Geophys., vol. 171, pp. 867–895, 2014.
[14] A. Józefaciuk, Cz. Józefaciuk, “Mechanism and methodical guidelines for the study of erosion processes,”(in Polish), Library of Environmental Monitoring, PIOŚ, Warszawa, 1996.
[15] R. Wawer, E. Nowocień, “Digital Map of Water Erosion Risk in Poland: A Qualitative, Vector-Based Approach,” Polish Journal of Environmental Studies, vol. 16, pp. 763–772, 2007.
[16] P. Licznar, “Modeling of soil water erosion,” (in Polish), Scientific Papers of the Wrocław University of Environmental and Life Sciences No. 456, Monograph XXXII, 2003.
[17] P. Licznar, “Forecasting erosive rainfall in Poland on the basis of monthly rainfall,”(in Polish), Archives of Environmental Protection, vol. 30, pp. 29–39, 2004.
[18] H.M.J. Arnoldus, “Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco,” Assessing Soil Degradation. FAO Soils Bulletin 34, Rome, 1977.
[19] https://dane.imgw.pl/data/dane_pomiarowo_obserwacyjne/dane_meteorologiczne/miesieczne/opad/, access: 05/2018
[20] National Soil Survey Handbook, “Part 618 Soil Properties and Qualities,” https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=41981.wba
[21] BS 1377 : 1990. Part 2 : “Methods of test for soils for civil engineering purposes. Part 2.
Classification tests,"London : British Standards Institution, 1990.

[22] BS 5930:2015 “Code of practice for ground investigations,” London : British Standards Institution, 2015.

[23] PN-88/B-04481: “Building soils. Laboratory tests, (in Polish language),” Polish Committee for Standardization, Warsaw, 1988.

[24] K. G. Renard, G. R. Foster, G. A. Weesies, D. K. McCool, D. C. Yoder, “Predicting soil erosion by water: A Guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE),” *Agriculture Handbook No. 703*, U.S. Department of Agriculture, 1997.

[25] K. Koreleski, “Attempts to assess the intensity of water erosion,” (in Polish), *Scientific Papers of the Agricultural University of Cracow, Scientific Session*, vol. 35, pp. 91–100, 1992.

[26] T. Stuczyński, P. Koza, A. Łopatka, I. Duer, J. Jadczyzsyn, “Report on analysis of indicators of product, result and impact set for axis 2 of RDP 2007-2013 and selected evaluation questions included in the Common Monitoring and Evaluation Framework Manual,” (in Polish), *Guidelines (CMEF) along with determination of the sources and data availability*. IUNG-PIB, Puławy, 2010.