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VERIFICATION OF THE MUSLE TO DETERMINE THE AMOUNT OF SUSPENDED SEDIMENT

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Abstract: This paper evaluates the possibility of determining the transport of suspended sediment removed from two catchments with different physiographic conditions and varying hydrological regime, as well as with different catchment's land use. Two rivers, one mountain and one lowland, were selected for the experiment. The sediment transport was determined by USLE, with sediment delivery ratio (SDR). Mean annual transport of suspended sediment, calculated based on hydrometric measurements, including mean daily flows and the corresponding concentrations of suspended sediment, were compared with the values of the mean annual sediment transport calculated using USLE method with SDR and MUSLE method. Having flow hydrographs and the specified mean annual mass of eroded soil in the catchment, the total sediment transport was calculated based on the MUSLE equation. The results of calculations according to the MUSLE in its original form given by Williams & Berndt and in the modification of Banasik & Madeyski proved to be significantly higher than those obtained based on measurements – respectively over 16 and 4 times higher in the mountain river Wisłoka and over 4 and 0.8 times higher in the lowland river Dłubnia. With hydrological data for those rivers, the MUSLE equation was calibrated and α and β coefficients of the MUSLE were determined, amounting respectively to 0.0006 and 0.9065 for the mountain river Wisłoka and 0.0029 and 0.9262 for the lowland river Dłubnia. The calculated coefficients α and β of the MUSLE, both for the mountain river Wisłoka and the lowland river Dłubnia, differ considerably from the ones proposed by Williams and Brendt, as well as by Banasik and Madeyski. Due to the heterogeneous nature of the erosion and transport processes, their modeling by the MUSLE in its original form is highly uncertain and difficult in the case of any catchment.

Keywords: erosion, sediment delivery ratio, sediment yield, MUSLE

1. INTRODUCTION

Determination of the amount of sediment transported by a watercourse in a river cross-section is significant when designing hydraulic structures, river engineering systems and regulatory works. Sediment transport in irrigation canals is an important issue in the design and operation of irrigation systems (Depeweg & Mendez, 2002; Paudel et al., 2014). Correct operation of those systems needs a limitation of suspended sediment inflow and sedimentation. The limitation of sediments to irrigation systems not always is possible, but it is possible to project them in such way to limit sedimentation. To this end can be used to model an irrigation channel carrying suspended particles without sedimentation (Boogerd et al., 2001).

The river sediment transport can be determined directly, i.e. based on the sediment measurements or other physical characteristics that describe its concentration and indirectly, i.e. using computational methods based on empirical, semi-empirical and theoretical equations (Michalec, 2009). In small catchments, representing an area of 200-250 km^2, hydrological observations, including daily measurements of suspended sediment concentration and aimed to determine the average daily flow, are usually not conducted. Hence, the transport of suspended sediment is determined by indirect methods. Those methods are based on identifying hydraulic parameters describing water and sediment flow in the riverbed or on determining a number of factors contributing to erosion in the catchment and the amount of material entering the riverbed. These are most frequently empirical methods developed as a result of examinations of catchment erosion processes, which include methods based on the classification of the denudation intensity, runoff denudation ratios, as well as methods based on the Universal Soil Loss Equation (USLE), developed by Wischmeier & Smith (1965). Determination of the mean annual sediment yield based on the catchment erosion (E) calculated using the USLE equation requires the designation of the sediment delivery ratio (SDR). Average sediment yield (Y) can be expressed as:

$$Y = SDR\ E \qquad (1)$$

The sediment delivery ratio, is the fraction of gross erosion (interill, rill, gully and stream erosion) that is expected to be delivered to the outlet of the drainage area considered. Banasik et al., (2005) obtained satisfactory results by adapting this method in Poland to assess the mass of sediment flow using the product of SDR and soil loss by USLE. Banasik specified the SDR value as described by Roehl (1962). The SDR equation according to Roehl (1962) has the following form:

$$\log SDR = 1.91349 - 0.33853 \log_{10} F \qquad (2)$$

where F is catchment area in mi^2. This method of determining the mass of load transport is presented, among others, in the papers by Farnham et al., (1966), Van Vliet et al., (1978), Bogardi et al., (1983). The Roehl formula (3) is the most common in Poland in the calculations of mean annual sediment runoff from uncontrolled catchments, based on DR-USLE method (e.g. Banasik & Górski, 1992; Bednarczyk et al., 2000; Górski et al., 2011). According to Roehl (1962) the SDR coefficient, developed based on research conducted in catchments of the south-eastern United States, can be evaluated formula of parameters such as catchment area (F, (mi^2)), relief ratio (R_R, (mi)), catchment length (L, (mi)) and bifurcation ratio of the catchment BR (-).

As a result of uncertainty in the delivery ratio, Williams & Berndt (1977) proposed MUSLE with the replacement of the rainfall factor with a runoff factor. This method was developed based on the analysis of 778 freshets in streams located in 26 Texas catchments, ranging from 0.7 to 513 km^2. The MUSLE equation has the following form:

$$Y = \alpha\ (Q\ q_p)^{\beta}\ K\ LS\ C\ P \qquad (3)$$

where Y – mass of sediment transport (t), Q – runoff volume for the storm event (m^3), q_p – peak flow rate ($m^3\ s^{-1}$) and K, C, LS and P are the standard USLE factors for soil erodibility, crop management (cover), slope length-gradient, and erosion control practice. Coefficients α and β, specified by Williams are 11.8 and 0.56, respectively.

In this method it is not necessary to determine the sediment delivery ratio SDR. The total runoff volume Q and pick flow rate q_p are determined from hydrographs. The MUSLE was used by different researchers, many of whom made some adjustments. Modifications developed by Das (1982), Banasik & Madeyski (1990), Nicks et al. (1994), Banasik & Walling (1996) or Sadeghi (2004) are among the most frequently cited ones. One of the MUSLE modifications was conducted by Banasik & Madeyski (1990), based on adaptive analysis of the equation for Carpathian rivers in Poland. Following those studies, coefficients α and β were established at 0.0278 and 0.80, respectively. Sadeghi (2004) established the β coefficient in the equation (3), amounting to 0.081 based on examinations of 15 freshets in the Amameh catchment with the area of 3712 ha. Sadeghi et al., (2007) based on eight storm in the Hinotani-ike watershed located in central Japan established coefficients α=60.62 and β=0.781. However, for the Chehelgazi waterhed in Iran, Sadeghi & Mizuyama (2007) established the α and β coefficient in the equation (3), amounting to 2.5 and 0.50, respectively.

Analysis of sediment transport in storm event was extensively described in the papers by e.g. Jackson et al., (1986), Banasik & Walling (1996), Benaman et al., (2005), Chutachindakate & Sumi (2008), Shamsudin et al., (2011), Hunink et al., (2012). The use of MUSLE as proposed by Williams and Berndt can give satisfactory results in calculations of the sediment transport in catchments with hydro-meteorological conditions different than those of the Texas catchments. Pandey et al., (2009) inferred that the MUSLE can be applied in the other parts of India watersheds. It was established based on the estimation of sediment yield using MUSLE for catchments, in which area of the watershed is approximately 28 km^2. The result obtained from the calculation can also affect method of determining the runoff volume and pick flow rate. The runoff is calculated based on the widely used Soil Conservation Service (SCS, now Natural Resources Conservation Service, NRCS) curve number method, and graphical peak discharge method is used to compute peak discharge (Zhang et al., 2009).

This paper presents the possibility of determining the suspended sediment transport removed from two catchments with different physiographic conditions, varying hydrological regime and different land use. Sediment transport (sediment yield) was determined using the USLE method with sediment delivery ratio (SDR) value designated by Roehl (1962) and the MUSLE method was used in the version given by Williams (1977), Banasik & Madeyski (1990), Sadeghi (2004), Sadeghi & Mizuyama (2007), Sadeghi et al., (2007). The calculation results were compared with the sediment transport rate calculated based on hydrometric measurements of mean daily flows and their corresponding concentrations of suspended sediment. This allowed to determine the applicability of soil loss equation as well as its modifications to determine the amount of suspended sediment in two catchments with different physiography and land development.

2. MATERIALS AND METHODS

Research was conducted in two selected catchments, i.e. a mountain river Wisłoka and a lowland river Dłubnia (Fig. 1). Both are the Vistula tributaries.

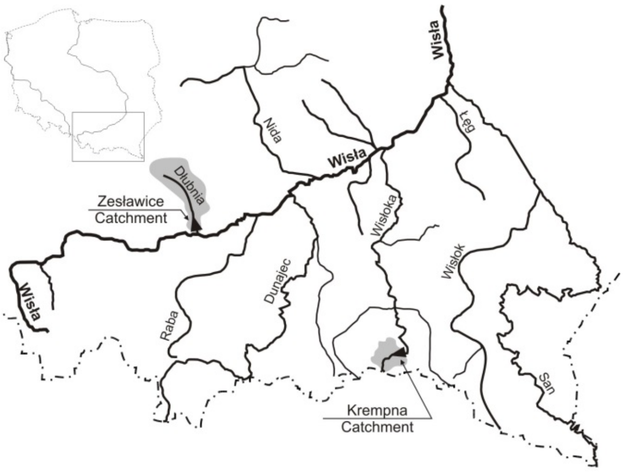

Figure 1. Location of the studied catchments

The Wisłoka catchment is located in the south of Poland. The spring of the river Wisłoka is located at a height of 575 m a.s.l. From the spring until the cross section of the river, where the water gauge Kotań is located, the Wisłoka has a length of 18.6 km. The catchment area to this section is 165 km^2. The water gauge profile is located in the 147.85 km of the river Wisłoka. Elevation of the staff gauge zero is 399 m a.s.l. The measurement cross-section in the river Wisłoka, marked as A-A, was adopted in a water gauge cross-section (Fig. 2a). Below the water gauge, in km 145.023 of the Wisłoka, there is a dam of a small water reservoir with a capacity of 112 thousand m^3. The surface formations are composed of residual and slope clay, formed by physical weathering of bedrock (Michalec, 2009). The catchment area, mostly due to its mountainous character, is largely (i.e. in 80%) covered with forests. The bottom part of the catchment and its flat slopes are small agricultural areas, whose only 4% are covered with arable land. Only about 2% of the catchment consists in road and building infrastructure, while grasslands occupy 14% of the area.

The Dłubnia catchment is located north of Cracow. The catchment's area to the water gauge, located in cross-section of 8.4 km of the river, is 264 km^2. Length of the river Dłubnia, from its springs, located at an altitude of 417 m a.s.l, to the water gauge, equals 46.9 km. Elevation of the staff gauge zero is 210.0 m a.s.l. As there are two reservoirs located above the water gauge, whose dam is located in km 8.7 of the river Dłubnia, the B-B measurement cross-section was established in km 10+720 of the river Dłubnia, above the inlet to the reservoirs (Fig. 2b). Those are two small reservoirs with capacities of 220 thousand m^3 and 197 thousand m^3, in parallel arrangement and are supplied from the common water junction. The catchment area to the B-B measurement cross-section is 218 km^2. Soils formed on loess are the most common soil type in the Dłubnia catchment (Michalec, 2009). The catchment area is relatively sparsely forested, therefore forests have little effect on water balance within this catchment. The Dłubnia catchment is covered with coniferous habitats, habitats of thermophilic beech, as well as various upland oak-hornbeam forests. Forests cover relatively small area, i.e. only 7%, grasslands represent about 3%, while the arable land covers about 90% of the catchment area.

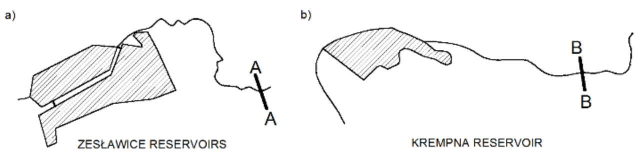

Figure 2. Location of the cross sections: a) A-A (the river Dłubnia), b) B-B (the river Wisłoka)

Calculations of suspended sediment transport were conducted in measurement cross-sections A-A and B-B for the river Wisłoka and Dłubnia, respectively. Transport of suspended sediment for each year was determined based on bathymetric measurements, while the mean annual transport was determined based on hydrometric data sequences from the operation periods of water reservoirs located below the measurement cross-sections in rivers Wisłoka and Dłubnia. The results of those calculations were adopted as reference in the evaluation of the applicability of the MUSLE method. Those calculations were conducted using hydrometric data sequences, including mean daily flows from the period of 1975-2003 for the river Wisłoka and 1966-1983, and 2005-2010 for the river

Dłubnia. Heterogeneity of hydrological data sequences, concerning water flow in gauge sections, was analyzed using a nonparametric rank sum Kruskal-Wallis test.

Suspended sediment transport were calculated on the basis of bathymetric measurements. The measurements of mean daily concentration of suspended sediment were conducted in the period 1996-2003 in the section A-A of the river Wisłoka and 2005-2010 in the section B-B of the rive Dłubnia. Daily, monthly and annual transport during the relevant observation period was calculated based on the obtained the values U (g s^{-1}), being the product of the flow and sediment concentration. The following seasons were separated having regard to the variability of erosion processes intensity during the year: spring thaw, summer heavy rains, autumn low water period and winter (Bednarczyk, 1994). Each of the separated seasons is characterized by a typical course of hydrological and meteorological phenomena, repetitive within the examined period. The plotted curves showing the relationship between the sediment concentration and the flow rate for each of the seasons were used to determine the amount of suspended sediment during the periods with no bathymetric observations. Those relationships enabled the completion of missing data for days not covered by the suspended sediment concentration measurements.

The calculations of the suspended sediment transport included the sediment concentration in the entire cross-section of the river. For this purpose, the correction factor "k" was determined as the ratio of the mean suspended sediment concentration in the river cross-section and the suspended sediment concentration at the constant sampling site. Suspended sediment concentration in the river cross-section was measured during the point bathymetric measurements. Mean annual suspended sediment transport, calculated based on hydrometric measurements, was compared with the values of mean annual sediment transport calculated using USLE method with SDR and MUSLE method.

3. RESULTS AND DISCUSSION

Hydrological data sequences, including mean daily flows in cross-sections A-A and B-B, were complemented by the values of mean daily concentration of suspended sediment. For this purpose, the developed relationships between sediment concentrations and flow rate were used for each of the separated hydrological-meteorological seasons. Figure 3 presents the exemplary curves formulated for the cross-section A-A.

Having the supplemented flow and sediment concentration data sequences, it was possible to calculate the values U (g s^{-1}), and then the daily, monthly and annual transport. Those calculations were based on point measurements of suspended sediment concentration. To take account of the concentration throughout the cross-section, the correction factors "k" were set as the quotient of the mean suspended sediment concentration in the transverse profile of the river and the concentration of suspended sediment at the constant sampling point.

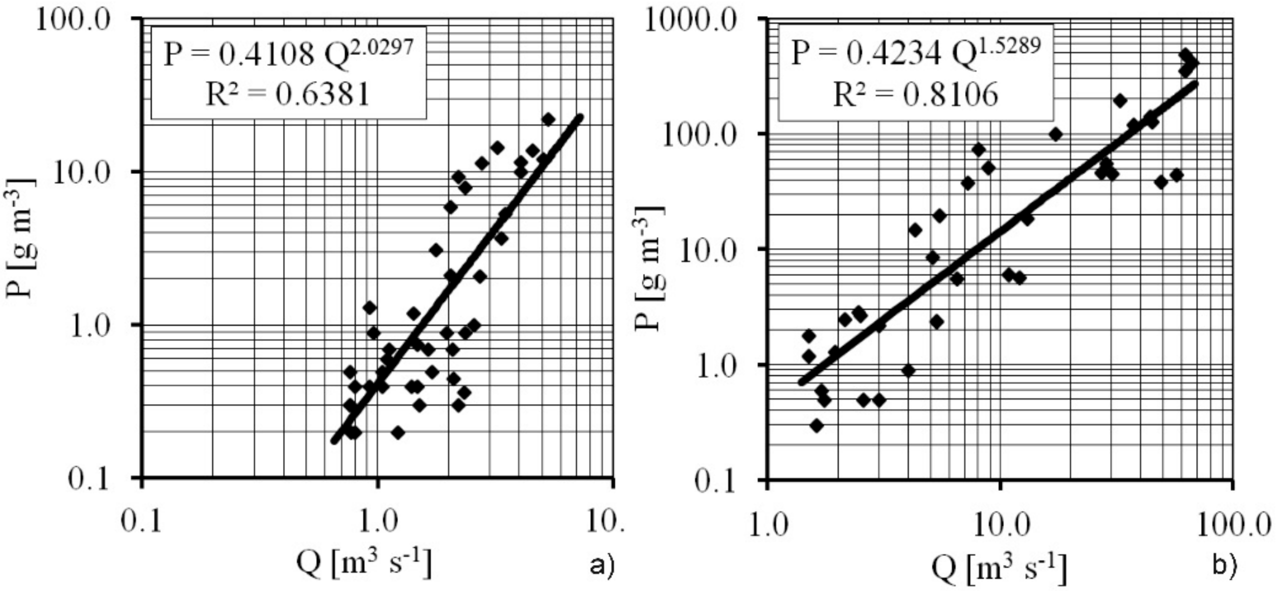

Figure 3. Functional relationships for mean daily flows and corresponding suspended sediment concentrations in separate hydrological and meteorological seasons – cross-section A-A on the Wisłoka river; a) season of autumn low discharges, b) season of spring melting of snow

The correction factors, calculated using Statistica for Windows, with a confidence interval of 95%, are as follows: 0.906 for the river Wisłoka and 1.065 for the river Dłubnia. The values of calculated mean annual mass of suspended sediment flowing into each of the reservoirs vary considerably. The reservoir at Krempna receives 6.27 thousand t year^{-1}, while the reservoir at Zesławice receives 19.98 thousand t year^{-1}.

With those values, the mean annual inflow of suspended sediment to the examined reservoirs was calculated using the USLE method with SDR. First, the parameters of USLE were determined (Table 1) and then the SDR parameter was estimated using the equation (3) and mean annual mass of sediment flowing (sediment yield) into the examined reservoirs was calculated (Table 1). In this table was also inserted the difference (Δ) of calculations results of mean annual mass of suspended sediment flowing into each of the reservoirs and sediment yield determined according to the USLE method with SDR.

Table 1. Parameters of USLE, sediment delivery ratio SDR and mean annual sediment runoff (sediment yield – Y) from studied catchments

Equation parameter	Wisłoka catchment	Dłubnia catchment
	Value of parameter	
The rainfall factor – R (J year^{-1})	103.9	86.994
The soil-erodibility factor – K (t ha^{-1} J^{-1})	0.820	0.539
The slope-length and slope-gradient factor – LS (-)	7.117	1.129
The cropping-management factor – C (-)	0.005	0.152
The erosion-control practice factor – P (-)	1.0	0.851
Annual average soil loss – E (t·year^{-1})	49145	149280
Sediment delivery ratio – SDR (-)	0.093	0.084
Sediment yield – Y (t year^{-1})	4554	12512
Difference of calculations results – Δ (%)	27	37

where: $\Delta_{Wisłoka}$ = [(6270–Y)/6270]100%, $\Delta_{Dłubnia}$ = [(19980–Y)/19980]100%,

Having flow hydrographs and the specific mean annual mass of eroded soil in the catchment, the total sediment transport was calculated using MUSLE (Table 2). The transport of suspended sediment in the cross-section A-A was calculated based on 184 storm events in the river Wisłoka, separated during 1996-2003, while the transport of suspended sediment in the cross-section B-B was calculated based on 63 storm events in the river Dłubnia, separated in the period 2005-2010. Table 2 presents the total mass of suspended sediment, calculated based on measurements of flow rate and suspended sediment concentration.

The results of calculations according to the formula (3) in its original form given by Williams and Brendt and modified by Banasik and Madeyski are higher than those obtained from the measurements – respectively over 16 and 4 times higher in the Wisłoka river (cross-section A-A) and over 4 and 0.8 times higher in the Dłubnia river (cross-section B-B). The results of calculations using MUSLE with the coefficient β established by Sadeghi (2004) and with coefficients α and β established by Sadeghi & Mizuyama (2007) and Sadeghi et al., (2007) indicate regionally closely matched coefficients in this formula, disqualifying the use of this modification of MUSLE in other catchments. Especially, the coefficients were determined for a few or only a dozen or so waves.

Table 2. Results of calculations of suspended sediment transport using the MUSLE method according to formulas by different authors

Method	Suspended sediment transport (t) in storm events in cross-section	
	A-A	B-B
measurements	135969	109863
Williams	2213701	465798
Banasik and Madeyski	594698	89864
Sadeghi (2004)	272	197
Sadeghi and Mizuyama (2007)	1923792900	239075282
Sadeghi et al. (2007)	858848	122793

With the amount of suspended sediment in the separated storm events, determined based on field measurements and the values of USLE parameters, established for the examined catchments (Table 1), regression relationships, shown in figure 3, were determined. Mass of suspended sediment in the separated storm events, marked as Y in figure 4, was determined based on flow measurements and the corresponding suspended sediment concentrations. Coefficients α and β of the MUSLE, amounting respectively to 0.0006 and 0.9065 for the cross-section A-A of the river Wisłoka (Fig. 4a) and amounting to 0.0029 and 0.9262 for the cross-section B-B of the river Dłubnia (Fig. 4b) were established based on regression relationships.

The sediment transport in 184 storm events in the cross-section A-A, calculated using the MUSLE model in the form: $Y = 0.0006\,(Q\,q_p)^{0.9065}$ K LS C P (Fig. 4a), is 109377 tones and the one calculated based on measurements of flows and the corresponding suspended sediment concentrations equals 135969 tones. The total sediment transport calculated using MUSLE is 20% lower than the one calculated based on measurements of flows and the corresponding suspended sediment concentrations. The total mass of transported sediment in 63 storm events in the cross-section B-B of the river Dłubnia, calculated using MUSLE model in the form: $Y = 0.0029\,(Q\,q_p)^{0.9262}$ K LS C P (Fig. 4b), equals 103878 tones. On the other hand, according to the calculations based on measurements of flows and the corresponding suspended sediment concentrations the total sediment transport equals 109863 tones and is 5% greater than the one calculated based on measurements.

Due to the diverse hydrological nature of the rivers of the examined catchments, the obtained different values of coefficients α and β as compared to the MUSLE (3) do not allow for the generalization of the MUSLE method, as shown in the Figure 5. This graph was prepared for the parameters of USLE, developed for the Wisłoka catchment and different values of the product of the total runoff volume (Q) and peak flow rate (q_p). For the same parameters of USLE and freshet parameters of e.g. 10^5 and 10^{10}, the Y values are respectively 5.8 and 7.2 times higher in the lowland river (Dłubnia) than in the mountain river (Wisłoka). Such significant differences in the results indicate the need to revise the MUSLE and to introduce the parameters characterizing the hydrological conditions of catchments, as suggested, among others by Williams (1977), Jackson et al., (1986) or Benaman et al., (2005).

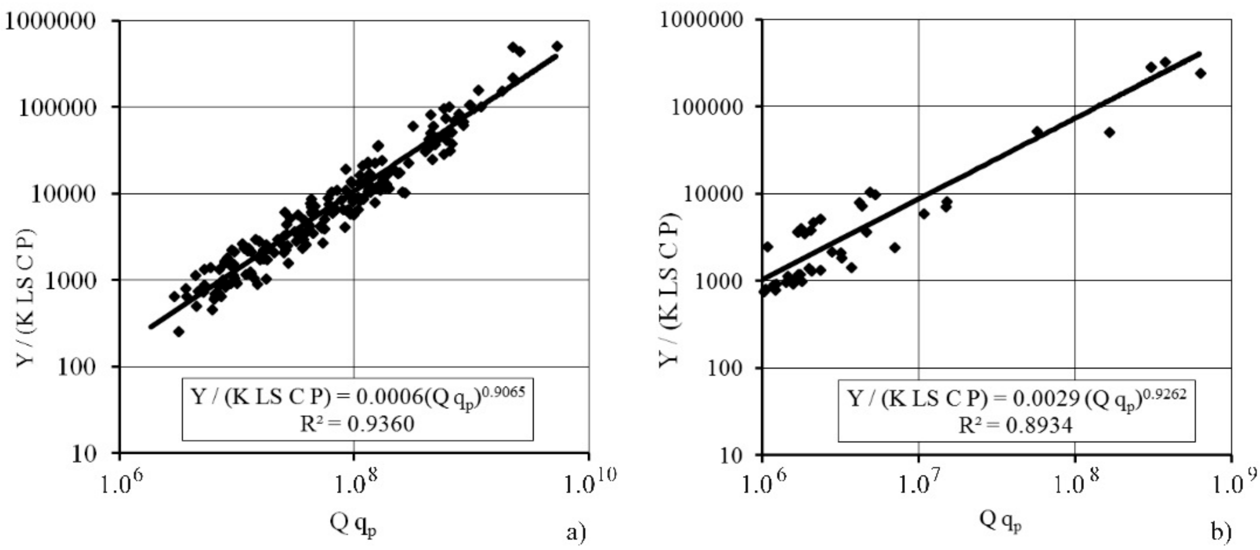

Figure 4. Regression relationship of freshet wave parameters and the parameter being the quotient of suspended sediment transport (Y) and the product of the parameters of the USLE (K LS C P); a) the river Wisłoka, b) the river Dłubnia

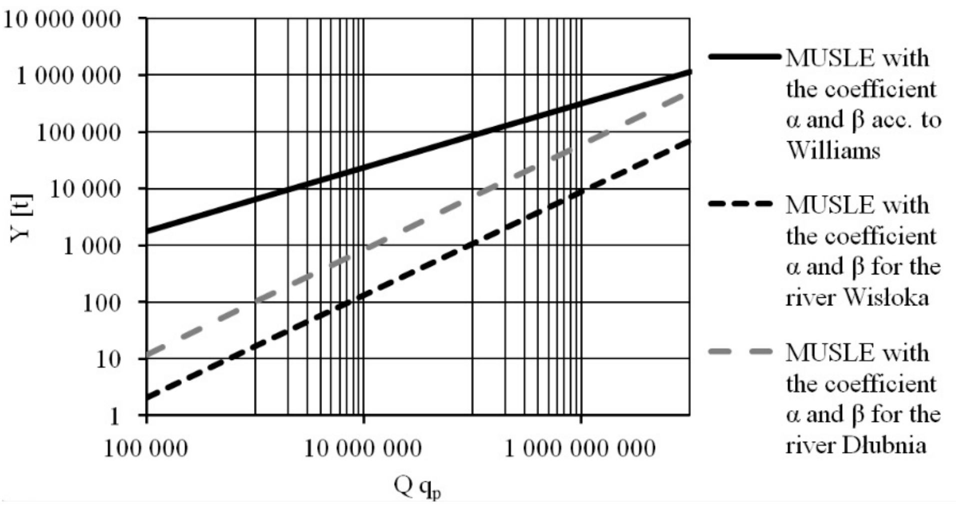

Figure 5. Comparison graph of the calculations of the transported sediment mass (Y)

The examined rivers are characterized by varied hydrological regime. Flow variability and dynamics may be characterized by a parameter showing the irregularity of mean monthly flows in the multi-year period, defined as the quotient of the highest mean monthly flow and the lowest mean monthly flow. The value of this parameter for the mountain river Wisłoka ranges from 8.33 to 24.30 (mean 14.47), while for the lowland river Dłubnia it ranges from 2.17 to 9.30 (mean 3.92). Consideration of the flow value variability, with significant impact on the amount of sediments removed from the catchment, may be one of the solutions in the calibration of the MUSLE. This however requires a suitable database.

Therefore, when using the MUSLE in the form proposed by Williams (1977) there is a possibility to obtain false calculation results. This equation is used, among others, in the SWAT model. The SWAT model calculates surface erosion caused by rainfall and runoff within each HRUs using the Modified Universal Soil Loss Equation (MUSLE) (equation 3). Tesfahunegn et al., (2013) concluded, that the SWAT model (Soil and Water Assessment Tool) is a very useful tool for planning alternative catchment management options to tackle soil degradation due to erosion.

However Pandey et al., (2009) give that the percent deviation of the annual estimated sediment yield from the observed values varied in the range of 5.2 to 29.6%. From the results obtained through performance evaluation of the application of the MUSLE in the Karso watershed, it could be inferred that the MUSLE can be applied in the other parts of India for watershed management.

4. CONCLUSIONS

The Universal Soil Loss Equation is one of the most common and most widely used tools for determining the erosion in catchments. This equation is used in conjunction with the latest GIS techniques and satellite data (e.g. Stefaneascu et al.. 2011; Castravet, 2012; Parveen & Kumar, 2012; Tirkey et al., 2013; Costea, 2015; Karaş & Oğuz, 2015). The determination of mean annual sediment runoff from the catchment using the USLE method requires the designation of sediment delivery ratio. Gumiere et al., (2011) reported that the limitation of SDR approach is that this do not integrate the effects of spatial distribution of land management practices with sediment removal from the entire catchment. No information about sediment sources is given by this approach. The results of sediments transport calculations got using USLE and appointed SDR are different about 27% and 37% from the value of transport given from measurements. They also show, that using a relationship worked by Roehl (1962) in different geographical regions is not given a satisfactory result. Elaboration of SDR relationship as a function of catchment area, or other parameters, requires results of erosion and sediment transport. The collection of studies carried out so far could contribute to development of Roehl historical method.

The calculated coefficients α and β of the MUSLE, both for the mountain river Wisłoka and the lowland river Dłubnia, differ considerably from the ones proposed by Williams & Brendt (1977), as well as by Banasik & Madeyski (1990). The MUSLE with the coefficients given by Williams & Brendt (1977), as well as by Banasik & Madeyski (1990) provide significantly overestimated calculation results. The amounts of sediment transported in the rivers calculated using the MUSLE in the form proposed by Williams may be subject to considerable error, as showed, among others by Banasik & Madeyski (1990), or Sadeghi (2004). It is therefore advisable to conduct further examinations and measurements, aiming to obtain more data, enabling the development of the MUSLE parameters not only for the currently analyzed part of Poland. The attempt to calibrate the MUSLE, undertaken by Sadeghi (2004), Sadeghi & Mizuyama (2007), provided only one variant, whose coefficients are suitable for the calculation of sediment transport only in catchments with hydrological and physiographic conditions, corresponding to Iranian ones. Sadeghi (2004) even emphasizes that the available sediment yield models, which were developed under specific geographical conditions, need to be calibrated before application in this area. Sadeghi et al., (2014) also made a review of use of the MUSLE method based on 49 publications. From among which only 13 of them contained modification of values of α and β coefficients. Sadeghi et al., (2014) established, that according to the results of its study, it can be concluded that the application of the MUSLE model may produce reasonable estimates when it is applied under appropriate conditions similar to those where the original model was developed or calibrated accordingly.

According to Easton et al., (2010) obviously, the erosion routines (USLE, RUSLE, MUSLE, sediment rating curves) in many of the large scale watershed models are crude, at best, and do not incorporate the appropriate mechanistic processes to reliably predict when and where erosion occurs, at least at the scale needed to manage complex landscapes. But these methods can be and are used for calculation of sediment transport. The SWAT model uses the MUSLE to estimate sediment yield

(Panagopoulos et al., 2007; Shen et al., 2012; Xu et al., 2013). Moreover Kinnel (2010) reports that, since the end of the 1970s empirical soil erosion models such as the USLE and its refined versions, the Revised USLE and the Modified USLE have been used worldwide to evaluate soil erosion magnitude under various conditions. For the sake of results got from sediment transportation calculation, in two rivers, with use MUSLE according to Williams (1977), and also according to modifications of other authors, there is a necessity of this equation verification. Findings of coefficients α and β of the MUSLE should be study taking the hydrological regime of the catchment into consideration. This was also suggested by Williams (1977), who stated that it may be necessary to recalibrate the runoff term in MUSLE to the site of interest. According to Jackson et al., (1986), the recalibration of MUSLE should include both climate and hydrological conditions of the catchment's watercourse. According to the authors of this paper, due to the heterogeneous nature of the erosion and transport processes, their modeling by the MUSLE in its original form is highly uncertain and difficult in the case of any catchment. A similar statement is included in the paper by Benaman et al., (2005).

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REFERENCES

Banasik K., Barszcz M. & Brański J., 2005. *Major components of a sediment budget for river catchments in Poland*. Int. Sym. On Sediment Budgets held at the 7th Scientific Assembly of the International Association of Hydrological Sciences. Foz do Iguaco, Brazil. IAHS Publ. 292, 32-36.

Banasik K. & Górski D,, 1992. *The use of the Universal Soil Loss Equation USLE for assessment of quantity of floating rubble flowing from small catchments*. Water Management 3, 62-66 (in Polish).

Banasik K. & Madeyski M., 1990. *An attempt to use a modified universal soil loss equation for evaluating suspended sediment load in the surge waves in small Carpathian watersheds*. Annals of Agricultural Science. Series F 82 (3/4), 7-15.

Banasik K. & Walling D.E., 1996. *Predicting sediment graphs for a small agricultural catchment.* Nordic hydrology 27(4): 275-294.

Bednarczyk T., 1994. *Determination of suspended load in cross-section of small reservoir in Zesławice*. Scientific Fascicles 291(15). Agricultural University Cracow, 7-18 (in Polish).

Bednarczyk T., Madeyski M. & Michalec B., 2000. *Assessment of usefulness of DR-USLE method when suspended transport is calculated*. Scientific Fascicles 385(XI), Agricultural University Wrocław, 173-181 (in Polish).

Benaman J., Shoemaker C.A. & Haith D.A., 2005. *Calibration and validation of soil and water assessment tool on an agricultural watershed in upstate New York*. Journal of Hydrologic Engineering 10(5), 363-374.

Bogardi I., Fogel M., Duckstein L. & Bardossy A., 1983. *Estimation of sediment loading into agricultural reservoirs with scarce data*. Scientific Procedures Applied to the Planning, Design and Management of Water Resources Systems. IAHS Publ.. 147, 87-98.

Boogerd P., Scarlett B. & Brouver R., 2001. *Recent modelling of sedimentation of suspended particles: a survey*. Irrig. and Drain. 50, 109–128. DOI: 10.1002/ird.15.

Castravet T., 2012. *Estimating annual soil loss by water erosion in the middle Pruit Plain. Republic of Moldov*a, Geographia Napocensis VI (2), 110-115.

Chutachindakate Ch. & Sumi T., 2008. *Sediment yield and transportation analysis: case—study on Managawa river basin*. Annual Journal of Hydraulic Engineering, JSCE 52, 157-162.

Costea M., 2015. *Assessment of land susceptibility to hydric erosion in small river basin from central part of Romania using GIS applications*. Carpathian Journal of Earth and Environmental Sciences. Vol. 10, No. 2, 133-144.

Das G., 1982. *Runoff and sediment yield from upper Ramganga catchment*. Thesis (Ph.D.), G.B.Pant Univ. of Agr. And Tech., Pantnagar, India: 121.

Depeweg H. & Mendez N., 2002. *Sediment transport application in irrigation canals*. Irrig. and Drain. 51, 167–179.

Easton Z.M., Fuka D.R., White E.D., Collick A.S., Biruk Ashagre B., McCartney M., Awulachew S.B., Ahmed A.A. & Steenhuis T.S., 2010. *A multi basin SWAT model analysis of runoff and sedimentation in the Blue Nile, Ethiopia*. Hydrol. Earth Syst. Sci 14, 1827–1841. DOI:10.5194/hess-14-1827-2010.

Farnham C.W., Beer C.E. & Heinemann H.G., 1966. *Evaluation of factors affecting reservoirs sediment deposition*. IAHS Publ. 71, 741-758.

Górski D., Popek Z., Banasik K. & Hejduk L., 2011. *Impact on small reservoirs on reduction of solids transport*. In: Prediction and Reduction of Diffuse Pollution, Solid Emission and Extreme Flows from Rural Areas – case study of small agricultural catchment (ed. by Banasik K, Oygarden L & Hejduk L), 219–232 (in Polish).

Gumiere S.J., Le Bissonnaisa Y., Raclotb D. & Cheviron B., 2011. *Vegetated filter effects on sedimentological connectivity of agricultural*

catchments in erosion modelling: A review. Earth Surf. Process. Landforms 36, 3–19.
Hunink J.E., Droogers P., Kauffman S., Mwaniki B.M. & Bouma J., 2012. *Quantitative simulation tools to analyze up- and downstream interactions of soil and water conservation measures*. Supporting policy making in the Green Water Credits program of Kenya. 111, 187-194.
Jackson W.L., Gebhard K. & van Haveren B.P., 1986. *Use of the Modified Universal Soil Loss Equation for average annual sediment yield estimates on small rangeland drainage basins*. Published in Drainage Basin Sediment Delivery, IAHS Publ. 159, 413-422.
Karaş, E. & Oğuz, I., 2015. *A new approach to determine land use planning and soil conservation measures on soil erosion classification*. Carpathian Journal of Earth and Environmental Sciences. Vol. 10, No. 2, 145- 158.
Kinnell P.I.A., 2010. *Event soil loss, runoff and the Universal Soil Loss Equation family of models: A review*, J. Hydrol. 385: 384–397. DOI:10.1016/j.jhydrol.2010.01.024.
Michalec B., 2009. *Selected methods for suspended sediment transport determination. Infrastructure and ecology of rural areas*. Monograph. Polish Academy of Sciences. (8), 91, (in Polish).
Nicks A.D., Williams R.D., Williams J.R. & Gander G.A., 1994. *Estimating erosion with models having different technologies*. In: Proc. 25^{th} Annual Conf. Intl. Erosion Control Assoc., Reno, NV, February 15-18, 51-61.
Panagopoulos I., Mimikou M. & Kapetanaki M., 2007. *Estimation of Nitrogen and Phosphorus Losses to Surface Water and Groundwater Through the Implementation of the SWAT Model for Norwegian Soils*. J. Soils Sediments 7(4), 223–231.
Pandey A., Chowdary V.M. & Mal BC., 2009. *Sediment yield modelling of an agricultural watershed using MUSLE, remote sensing and GIS*. Paddy Water Environment 7, 105–113.
Parveen R. & Kumar U., 2012. *Integrated Approach of Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for Soil Loss Risk Assessment in Upper South Koel Basin, Jharkhand*. Journal of Geographic Information System 4, 588-596.
Paudel K.P., Schultz B. & Depeweg H., 2014. *Design of non-wide canals for sediment transport. Case study of Sunsari Morang irrigation scheme, Nepal*. Irrig. and Drain. 63, 584–589, DOI: 10.1002/ird.1862.
Roehl J., 1962. *Sediment source area, delivery rations and influencing morphological factors*. IAHS Publ. 59, 202-213.
Sadeghi S.H.R., 2004. *Applications of MULSE in prediction of sediment yield in Iranian conditions. 13th International Soil Conservation Organization Conference-Brisbane*. In: Conserving Soil and Water for Society, Sharing Solution, Paper No. 998, 1-4.
Sadeghi S.H.R. & Mizuyama T., 2007. *Applicability of the Modified Universal Soil Loss Equation for prediction of sediment yield in Khanmirza watershed, Iran*. Hydrological Sciences Journal–des Sciences Hydrologiques 52(5), 1068-1075.
Sadeghi S.H.R., Mizuyama T., Miyata S., Gomi T., Kosugi K., Mizugaki S. & Onda Y., 2007. *Is MUSLE apt to small steeply reforested watershed?* Journal Forest Research 12, 270–277.
Sadeghi S.H.R., Gholami L., Khaledi Darvishan A. & Saeidi P., 2014. *A review of the application of the MUSLE model worldwide*. Hydrological Sciences Journal, 59, (2), 1–11.
Shamsudin S., Rahman A.A. & Darom A.R.M., 2011. *Determination of detention pond sediment loads using Monte Carlo simulation, Malaysia*. Journal of Environmental Hydrology 19 (4), 1-9.
Shen Z.Y., Chen L. & Chen T., 2012. *Analysis of parameter uncertainty in hydrological and sediment modeling using GLUE method: a case study of SWAT model applied to Three Gorges Reservoir Region, China*. Hydrol. Earth Syst. Sci., 16, 121–132. DOI:10.5194/hess-16-121-2012.
Ştefănescu L., Constantin V., Surd V., Ozunu, Al. & Vlad, Ş.N., 2011. *Assessment of soil erosion potential by the USLE method in Roşia Montană mining area and associated Natech events*. Carpathian Journal of Earth and Environmental Sciences. Vol. 6, No. 1, 35-42.
Tesfahunegn G.B., Vlek P.L.G. & Tamene l., 2013. *Application of SWAT model to assess erosion hotspot for sub-catchment management at Mai-Negus catchment in northern Ethiopia*. East African Journal of Science and Technology 2(2), 97-123.
Tirkey A.S., Pandey A.C. & Nathawat M.S., 2013. *Use of Satellite Data, GIS and RUSLE for Estimation of Average Annual Soil Loss in Daltonganj Watershed of Jharkhand (India)*. Journal of Remote Sensing Technology 1(1), 20-30.
Van Vliet L.J.P., Wall G.J. & Dickinson W.T., 1978. *Erosional losses from agricultural land and sediment delivery ratios in small agricultural watersheds*. Project Report 16 and 17. Ontario Institute of Pedology and School of Engineering University of Guelph; 166.
Williams J.R., 1977. *Sediment delivery ratios determiner with sediment and runoff models*. Int. Assoc. Hydrol. Sci. 122, 168-179.
Williams J.R. & Berndt H.D., 1977. *Sediment yield prediction based on watershed hydrology*. Trans. Am. Soc. Agric. Eng. 20(6), 1100–1104.
Wischmeier H.W. & Smith D.D., 1965. *Predicting rainfall erosion losses-aquide from cropland east of the Rocky Mountains*. USDA, Agriculture Handbook, 282, 47.
Xu Y.D., Fu B.J. & He C.S., 2013. *Assessing the hydrological effect of the check dams in the Loess Plateau, China, by model simulations*. Hydrol. Earth Syst. Sci. 17, 2185–2193,

DOI:10.5194/hess-17-2185-2013.
Zhang Y., Degrootei J., Wolter C. & Sugumaran R., 2009. *Integration of Modified Universal Soil Loss Equation (MUSLE) into a GIS framework to asses soil erosion risk*. Land Degrad. Develop. 20, 84–91.

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