Universal Soil Loss Equation – Using Grids

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Abstract

Soil erosion estimation is an important part of a land consolidation process. Universal soil loss equation (USLE) was presented by Wischmeier and Smith. USLE computation uses several factors, R – Rainfall factor, K – Soil erodability, L – Slope length factor, S – Slope gradient factor, C – Cropping management factor and P – Erosion control management factor. L and S factors are usually combined to one LS factor – Topographic factor. The single factors are determined from several sources, such as DTM (Digital Terrain Model), BPEJ – soil type map, aerial and satellite images, etc. Conventional approach to USLE computation, which is widely used in the Czech Republic, is based on selection of characteristic profiles for which all above-mentioned factors must be determined. The result (G – Annual soil loss) of such computation is then applied for a whole area (slope) of interest. Another approach to USLE computation uses grids as main data-structure. A prerequisite for a grid-based USLE computation is that each of the above-mentioned factors exists as a separate grid layer. Crucial step in this computation is to select an appropriate grid resolution (grid cell size). Too big cell size can cause undesirable precision degradation. Too small cell size can noticeably slow down the whole computation. Provided that cell size is derived from source's precision, appropriate cell size for the Czech Republic varies from 30m to 50m. In some cases, especially when new surveying was done, grid computations can be performed with higher accuracy, i.e. with smaller grid cell size. In such case, we have proposed a new method using two-step computation. First step computation uses bigger cell size and is designed to identify higher erosion spots. Second step then uses smaller cell size but it computes only within the area, which was identified in the previous step. This decomposition allows quick computation while the precision degradation is smaller then in the one-step computation. The above-described two-step method is suitable mainly for a combination of larger areas (several cadastral areas) and high precision sources at the same time. It is evident that in present such combination is rather unique, which means that in most cases the one-step computation with 30m–50m cell sizes is adequate. It is expected that in the future all sources used for determination of the factors will have higher accuracy and, therefore, the two-step computation will be needed.

Abstrakt

Výpočet erozní ohroženosti půdy je nedílnou součástí pozemkových úprav. K výpočtu se používá Wischmeier-Smithova univerzální rovnice ztráty půdy (USLE – Universal Soil Loss Equation). Rovnice obsahuje několik faktorů, které vyjadřují vliv deště - R, náchylnost půdy k erozi - K, délku svahu - L a sklonu svahu - S (dohromady topografický faktor - LS), ochranný vliv vegetace - C (pěstované plodiny) a ochranný vliv protierozních opatření - P. Nejdůležitějšími podklady pro určení jednotlivých faktorů jsou údaje o topografii území (digitální model terénu), údaje o půdě (BPEJ), letecké snímky a osevní postupy. V zájmovém

území se zvolí několik charakteristických profilů, pro které se určí hodnoty všech faktorů. Výsledkem výpočtu z erozních profilů jsou hodnoty odnosu půdy G pro jednotlivé plodiny nebo pro zvolený osevní postup, které se použijí pro celý pozemek (svah) a porovnávají se s přípustnou ztrátou půdy v závislosti na hloubce půdy. Z porovnání získáme území, které je ohroženo vodní erozí a kde je zapotřebí vybudovat protierozní opatření, v rámci pozemkových úprav se bude jednat o část plánu společných zařízení.

Grid jako datová struktura GIS umožňuje, v rámci jednoho výpočtu, získat hodnoty ztráty půdy G plošně pro celý pozemek. Předpokladem je existence gridů jednotlivých faktorů vstupujících do výpočtu univerzální rovnice ztráty půdy. Vlastní výpočet není složitý, jedná se vlastně o součiny jednotlivých hodnot z dílčích gridů. Důležitou otázkou je volba vhodného rozlišení gridů (velikosti gridové buňky). Velké gridové buňky mohou nepříznivě ovlivnit přesnost výsledku, malé gridové buňky s sebou nesou velký objem dat a mohou prodlužovat dobu výpočtu. Při volbě vhodné velikosti gridové buňky se vychází z přesnosti podkladů. Některé podklady mají svoji přesnost předem danou, a jejich zpřesnění je možné dosáhnout jen za cenu náročných a nákladných terénních prací (např. rebonitace). V takové situaci při výpočtu s malými gridovými buňkami je možné postupovat dvoustupňově, kdy se pomocí gridu s velkými buňkami vytipují místa erozně ohrožená a potom se výpočet zopakuje pouze v těchto územích již s malým rozměrem gridových buněk. Při aplikaci této metody při pozemkových úpravách je však možné použít již pro první výpočet velké rozlišení gridu, protože vzhledem k velikosti území (zpravidla jedno katastrální území) a objemu dat nenastane žádné zdržení vlivem časové náročnosti výpočtu a nedojde ani ke ztrátě přesnosti. V budoucnu, při očekávaném zpřesnění vstupních podkladů se předpokládá širší uplatnění dvoustupňového výpočtu.

Preface

Erosion is a phenomenon we encounter very often. Erosion with low intensity does not cause big damages. High intensity erosion causes topsoil loses, ditches clogging, crop damages, road damages, etc.

Determination of erosion intensity is very important in order to timely moderate its intensity and reduce the damages caused by erosion. Erosion can be reduced by several anti-erosion procedures of technical, bio-technical, agro-technical and organizational categories. Determination of erosion intensity and erosion location is very important for designing effective anti-erosion or support practice precaution. Various empirical and mathematical models exist for erosion intensity computation. One of the mostly used is so called USLE – Universal Soil Loss Equation.

USLE computations based on grids will be shown in this text. Main advantage of grid approach is that erosion computation is performed within the whole area of interest. Another advantage is that the output of such computation is a grid, which can be easily used for further analysis. In this text is shown grid computation of soil loss with respect to land adjustment process, which also priorities ownership consolidation, road accessibility, water and soil protection, ecologic stability with accent to nature and landscape equilibrium.

Universal Soil Loss Equation (USLE)

Soil loss is often determined with universal soil loss equation in practice. USLE computation is very simple and straightforward and was developed by Wischmeier and Smith. The equation contains few parameters - factors, separately describing the influence on erosion process. The result of such equation is an average long-term (often annual) soil loss, usually called as G [$\text{ton.hectare}^{-1}.\text{year}^{-1}$].

$$G = R.K.L.S.C.P$$

R factor - Rainfall and Runoff Factor

R is the rainfall and runoff factor. R factor describes erosion intensity of rain and is derived from a long-term weather station observation. Optimal term of observation is 50 years. In some cases 15-20 years is also tolerated. Value of R factor depends on frequency of occurrence, precipitation and intensity of rainstorm. This is rainfall with precipitation greater then 12,5mm and intensity greater then 24mm.hour^{-1}. An average value of R factor (R=20) is available for whole territory of Czech Republic. Detailed map of R factor is also produced from ČHMÚ observation. Values of R factor for several cities of Czech Republic and Slovakia are shown in appendix (Janeček,1992) and were taken into a software ERCN. ERCN software was used for a classic computation.

In example in this article was used an average value of R factor (R=20). Value of R factor can be changed in areas where a detailed map of R factor exists. In case of variable values of R factor is recommended to use an R factor grid, which can be created from a vector R factor layer. One can use constant value of R factor in case of typical size of areas for land adjustment. R factor value is then often computed as an average value of all available values.

K factor - Soil Erodability Factor

K factor describes erodability of soil. K factor value depends on granularity of soil. It also depends on content of organic particles, on composition of soil and its permeability. These soil characteristics influence infiltration abilities of soil and its resistance to an erosion caused by a falling raindrops and also erosion of surface drain. Once the soil characteristics are known a nomogram (Wischmeier-Smith, 1978) can be used. For an approximate determination of K factor from a BPEJ values can be taken a table introduced by (Janeček,2002). In cases of several values of K factor within one erosion profile, one weighted average value must be calculated, also by (Janeček,2002).

LS factor - Slope Length-Gradient Factor

L is a slope length factor and S is a slope steepness factor. These factors are often combined into one LS factor and referred to as the topographic factor. LS factor value depends on a slope and length of uninterrupted downhill. Various data sources are used for LS determination. Among the mostly used in practice are paper maps 1:5000 (SMO5) or 1:10 000 (ZM10) which contain contours. On these maps were often chosen several erosion profiles characterizing the main drain and runoff paths. Erosion profile with highest LS value was then selected as a cardinal erosion profile. In case of variable slope, one can use weighted average defined in (Janeček 2002).

C factor - Crop/Vegetation and Management Factor

C factor is the cover and management factor. This factor describes the influence of vegetation cover on erosion. Vegetation cover protects topsoil from raindrops, slows down the runoff and also improves a soil erosion characteristic. It is generally true that the denser and higher a vegetation cover is, the more effective is the protection against water erosion, especially from April to October when storm rainfall occurs. Corn, root crops, etc. do not protect as much as for example grain crops or even grass. Each crop has five variant values depending on state of farm and plant cover according to agricultural period. An average value of C factor for crop rotation in several years is computed from values of C factor for single crop.

P factor - Support Practice Factor

P factor is a support practice factor. Several anti-erosion precautions can be applied within the endangered areas, e.g. contour cultivation, terracing, etc. Values for such precautions are shown in (Janeček,2002). P factor value equal to one means no support practice is applied.

Grid

Grid is a finite collection of points. Grid type is often used for representing continuous spatial data. Grid data structure is very simple and often saves a disk space, because each grid cell stores only a value of a cell and not the coordinates of each grid cell. Coordinates are stored only at the header of the grid file. Both textual and numerical information can be stored in grid, e.g. digital terrain model or a land use. Using grids for spatial analysis is also advantageous especially in cases where spatial data covers whole areas. Among several superimposed grid layers mathematical operations or queries can be easily performed.

Grid is often created by spatial interpolation from measured spatial data. The process of grid creation is sometimes called gridding. Natural neighbor, triangular, inverse distance weighted or bilinear interpolations are usually used for grid creation from measured input data.

Irregularly spaced measured point data containing elevation value is a typical input data for grid creation. This data may come from geodetic measurement, map digitization, etc. It is very important to know the purpose of grid analysis, origin and precision of a spatial data, before starting any grid creation process. The least accurate input grid influences the precision of every multi-grid analysis. Another no less important thing is the analysis processing time. In case of large areas and small size grid cells, processing time can be unacceptably long. In order to shorten grid analysis processing time, spatial data must be reduced by some aggregation methods. Many GIS software have built-in spatial interpolation functions and data aggregation methods. For this example was used MapInfo and Vertical Mapper software.

Source data for grid computation

As source data for grid creation can be used almost any type and format of spatial or even tabular data. Optimal source data cover whole area of interest. Layers of each factor so far do not exist for the area of Czech Republic. These layers have to be created, either by reprocessing of any previous layers or by creating the layers from original or measured data.

BPEJ

One of the source data, which cover whole area of Czech Republic, is BPEJ. BPEJ data describe a soil valuation and soil quality. BPEJ was created by a complex surveying and probing of entire agricultural areas. BPEJ also contains characteristics of clime, slope steepness and topsoil parameters.

BPEJ data is administered by VÚMOP (Výzkumný ústav meliorací a ochrany půdy). BPEJ is also stored in digital cadastral maps.

The original aim of BPEJ was planning of agricultural production. Nowadays BPEJ is used mainly for tax purposes, determination of official price, land protection and also as a source for soil erosion computation. Important question arises when BPEJ is used as a source for grid creation. It is the determination of grid cell size. BPEJ contours were originally drawn onto the 1:5000 maps and later on digitized. This process influences the accuracy of BPEJ contours (from 5m to 10m). Another fact that has even bigger impact on resulting accuracy is scarcity of probes, which were organized in networks. Three types of probes were used for determination of soil characteristic. Average distance between basic probes was 260m-420m. Average distance between primary probes was 835m-1340m. Smallest delimited BPEJ areas were of 3-hectare size. In case of contrast areas size was 0.5-hectare. Resulting accuracy of BPEJ contours is 20m-30m, in extreme cases up to 50m. In case of better accuracy requirement, new probing must be performed. New probing is very expensive and is done only in large-scale land adjustment process. We cannot expect that new probing will be done within the whole area of Czech Republic in near future.

In our case BPEJ data was used for determination of K factor (from second and third digit of BPEJ code).

Digital Terrain Model (DTM)

Another very important source for erosion computation is digital terrain model. Ideally can be get directly DTM in some standardized storing format. DTM is the source for LS grid creation. DTM is often created from aerial photogrammetry, surveying or combination of both methods. Accuracy of the DTM layer depends on selected method, but generally spoken it will be always better than BPEJ layer accuracy. It is very important to select proper interpolation method when DTM is created from e.g. digitized elevation contours. Unsuitable interpolation method can cause some unwanted effects, e.g. “stair effect”.

Aerial Orthophotomaps

Orthophotomaps can be used also as a source for land use determination and support practices determination. Orthophotomaps together with spectral processing can be used also for C factor grid creation. Orthophotomap is an important source for having a real and up-to-date view on current situation and configuration of road network, built areas, etc.

Figure 1: arable soil blocks (B1-B20) and erosion profiles (1-20) used for classic erosion computation

In this text is shown erosion computation of Northwest of Kutná Hora area. The size of area was 25 km2. The arable soil blocks are of the 10,5 km2 size. Below is showed firstly classic erosion computation and then a grid computation.

Classic Computation

As a comparison for a grid computation, there is performed also a classic erosion computation using predefined erosion profiles. Erosion computation was done for every predefined erosion profile. Factor R was equal to 20 for every area. Factor K was determined from BPEJ data. Factor P was set to 1, which means no support practices are applied. Several scenarios with different settings of C factor were performed, see table 1.

Crop	Potato	Oilseed rape	Cereal	Pasture
Factor C	0,50	0,30	0,16	0,02

Table.1: Average year values of C factor for selected crop

Factor L was determined from length of each erosion profile. Factor S was computed from weighted average from several partial values of slope steepness within each erosion profile. VUMOP's ERCN software was used for computation. Computed soil loss values are shown in table 2. The results of such computation are then applied on whole soil blocks. These results are then compared with permissible soil loss, which is determined from BPEJ. In case of permissible soil loss overrun, support practice must be applied. Resulting accuracy of soil loss determination can vary from 10 – 30% (Švehla, 1995). Therefore it is important to present result soil loss value with respect to its accuracy and compare computed values with real situation in terrain.

G [$t.ha^{-1}.rok^{-1}$]									
Soil Block	Erosion Profile	C = 0,5		C = 0,3		C = 0,16		C = 0,02	
		Classic comp.	Grid comp.	Classic comp.	Grid comp.	Classic comp.	Grid comp.	Classic comp.	Grid comp.
B1	18	6,2	9,9	3,7	5,9	2,0	3,2	0,2	0,4
B1	19	2,9	9,9	1,7	5,9	0,9	3,2	0,1	0,4
B2	1	8,3	7,5	5,0	4,5	2,7	2,4	0,3	0,3
B2	2	10,4	7,5	6,2	4,5	3,3	2,4	0,4	0,3
B3	3	11,7	14,3	7,0	8,6	3,7	4,6	0,5	0,6
B3	4	10,0	14,3	6,0	8,6	3,2	4,6	0,4	0,6
B4	21	5,3	16,4	3,2	9,9	1,7	5,3	0,2	0,7
B5	5	12,7	13,0	7,6	7,8	4,1	4,2	0,5	0,5
B5	6	11,7	13,0	7,0	7,8	3,7	4,2	0,5	0,5
B6	7	7,6	11,3	4,6	6,8	2,4	3,6	0,3	0,5
B6	8	13,3	11,3	8,0	6,8	4,3	3,6	0,5	0,5
B6	9	18,1	11,3	10,9	6,8	5,8	3,6	0,7	0,5
B7	10	6,8	9,9	4,1	5,9	2,2	3,2	0,3	0,4
B7	11	10,3	9,9	6,2	5,9	3,3	3,2	0,4	0,4
B8	12	16,7	15,5	10,0	9,3	5,4	5,0	0,7	0,6
B8	13	9,4	15,5	5,6	9,3	3,0	5,0	0,4	0,6
B9	14	7,3	10,3	4,4	6,2	2,3	3,3	0,3	0,4
B10	15	12,2	9,5	7,3	5,7	3,9	3,0	0,5	0,4
B11	22	2,0	3,0	1,2	1,8	0,6	1,0	0,1	0,1
B12	16	2,9	6,3	1,7	3,8	0,9	2,0	0,1	0,3
B13	17	10,7	14,2	6,4	8,5	3,4	4,6	0,4	0,6
B14	20	11,0	8,2	6,6	4,9	3,5	2,6	0,4	0,3
B15	23	5,3	5,0	3,2	3,0	1,7	1,6	0,2	0,2

B16	24	5,6	10,6	3,4	6,4	1,8	3,4	0,2	0,4
B17	25	19,5	11,4	11,7	5,9	6,3	2,7	0,8	0,5
B17	26	19,7	11,4	11,8	6,9	6,3	3,7	0,8	0,5
B18	27	8,4	10,1	5,0	6,1	2,7	3,2	0,3	0,4
B19	28	2,8	7,1	1,7	4,3	0,9	2,3	0,1	0,3
B20	29	7,6	14,5	4,6	8,7	2,4	4,6	0,3	0,6

Table 2: Soil loss G for classic computation (erosion profiles) and for grid computation

Grid Computation

Grid must be created for every factor with variable values. Before proceeding with soil loss computation, grid cell size must be set. Grid cell size is derived from grid with lower accuracy, usually K factor grid. In our case the cell size was set to 5m, because of size of entire area. Factor R was set to 20 for whole area, which means that instead of R factor grid creation only constant value was used. For areas where R factor has variable values grid must be created.

As mentioned above K factor grid was created from BPEJ information. To be more precise, vector polygons were transformed into grid.

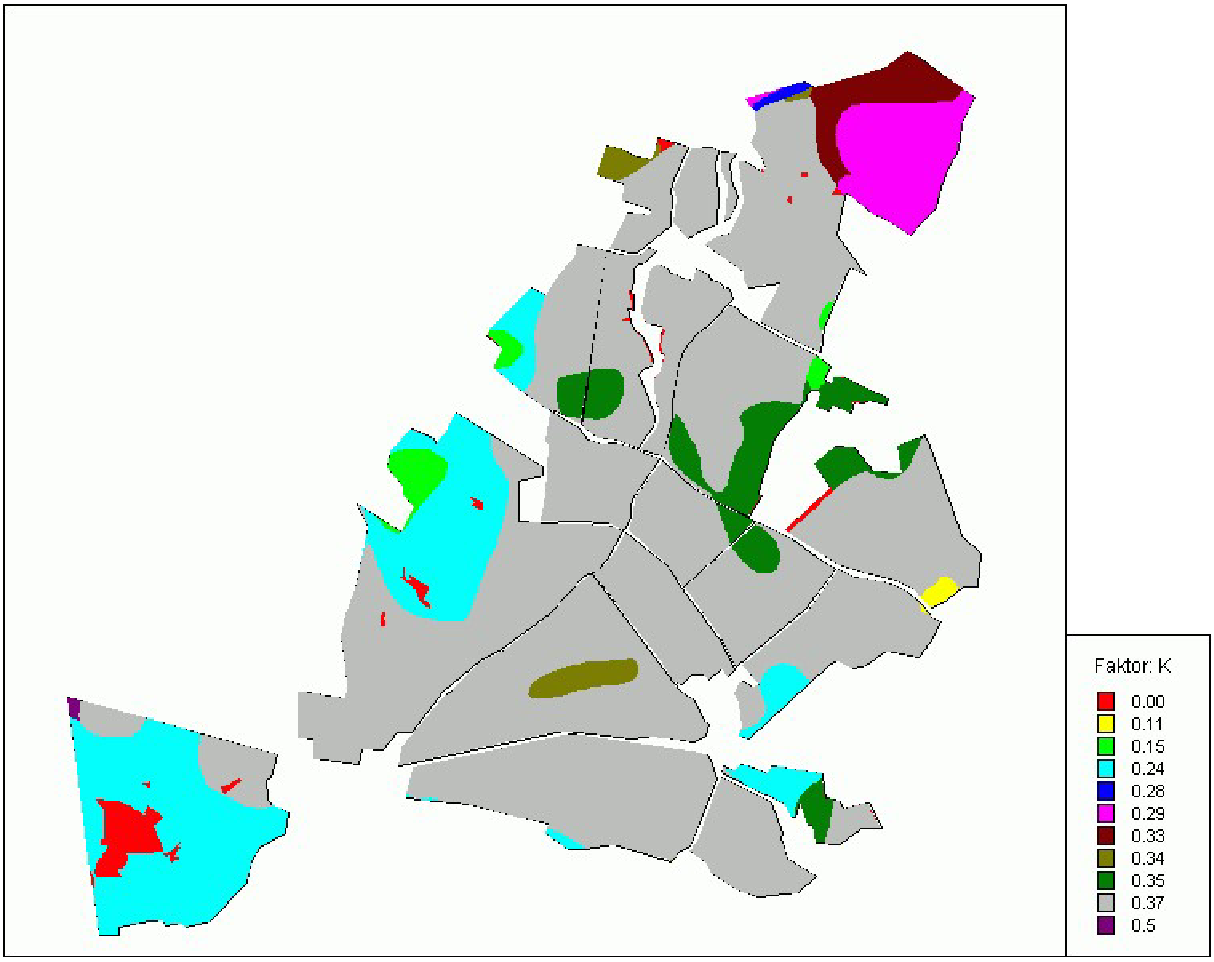

Figure 2: K factor grid was created from BPEJ information

LS grid creation

LS grid creation is the crucial part of entire soil loss computation (Mitasova, 1998). DTM grid is the input for LS grid creation (Hickey, 2001). Several methods exist for LS grid creation from DTM layer. In our case we used digitized elevation contours from 1:10 000 map. We used natural neighbor interpolation method for creating the DTM grid from elevation contours. LS grid was then derived based on created DTM grid.

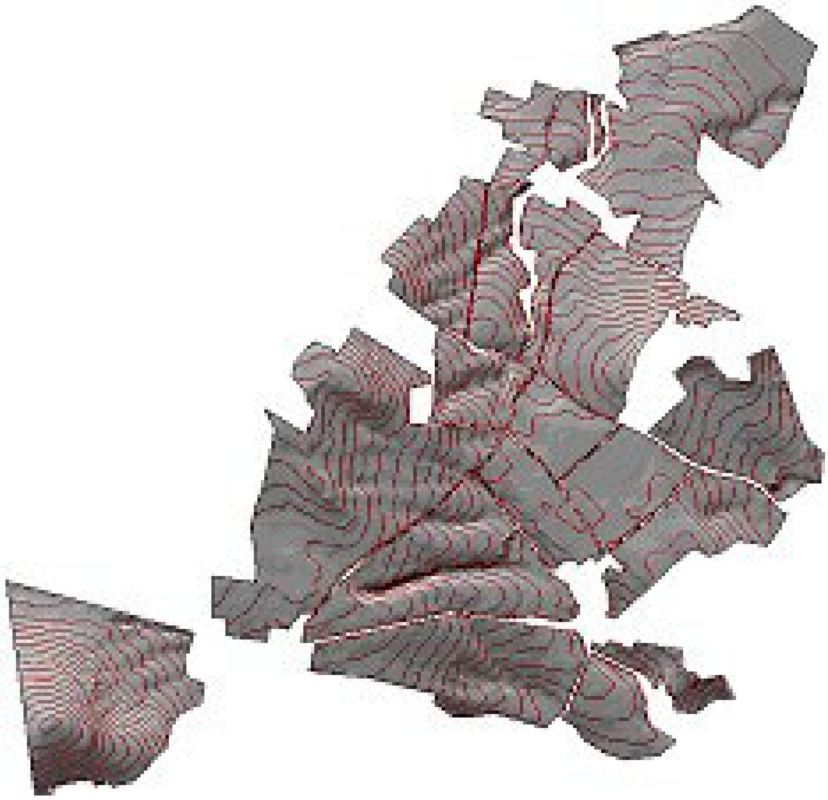

Figure 3: DTM grid with elevation contours

Figure 4: Topographic LS factor grid

As for the C factor, the same scenarios for different crops was applied, see table 1.

Source data needed for P factor grid creation were not available, therefore P factor was set to one. This means P and R factors act as constants in our computations. In case of variable P factor grid must be created. Real supporting practice precautions should be verifying by field reconnaissance.

Following figures 5,6,7,8 show soil loss within the soil blocks for different crops scenarios.

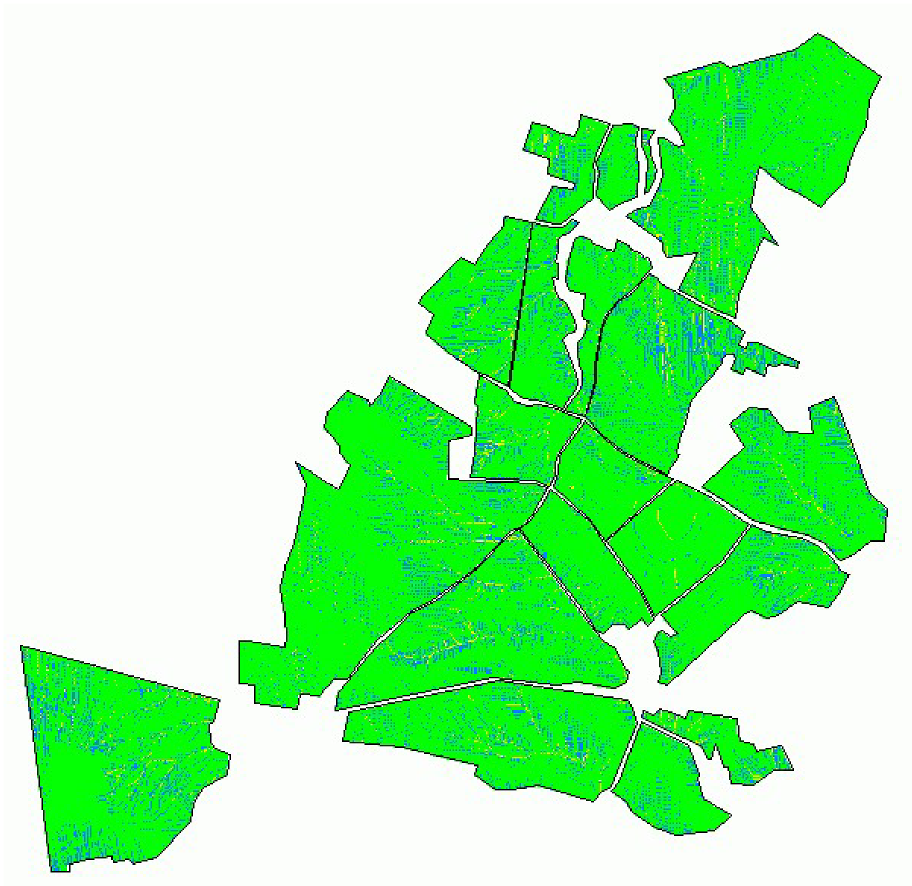
Figure 5: Grid G soil loss for C = 0,02

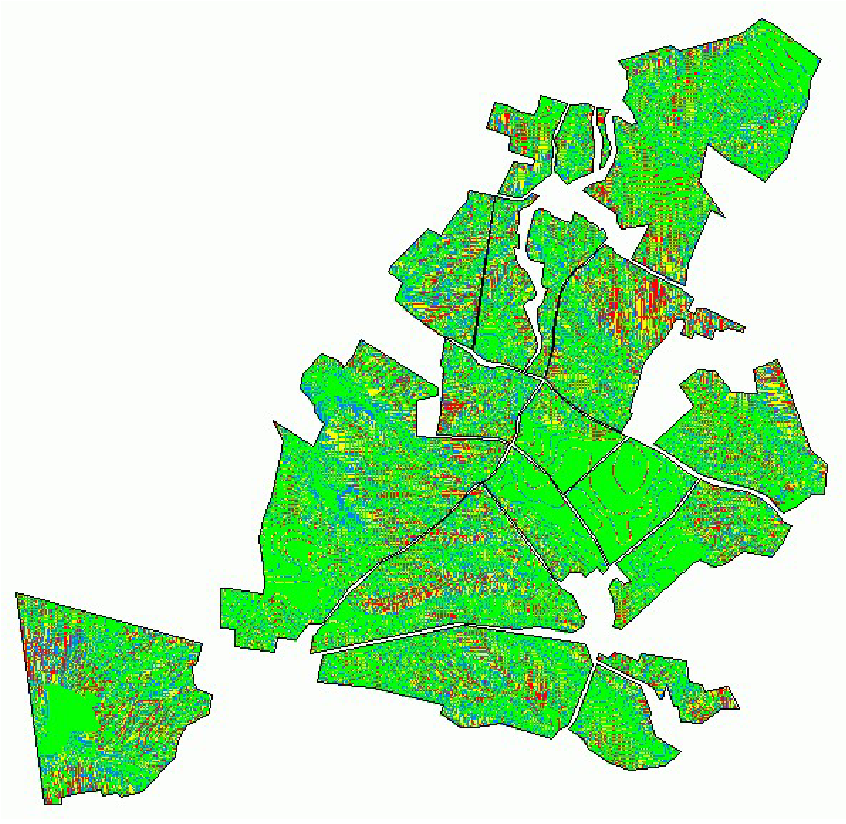
Figure 6: Grid G soil loss for C = 0,16

Figure 7: Grid G soil loss for C = 0,3

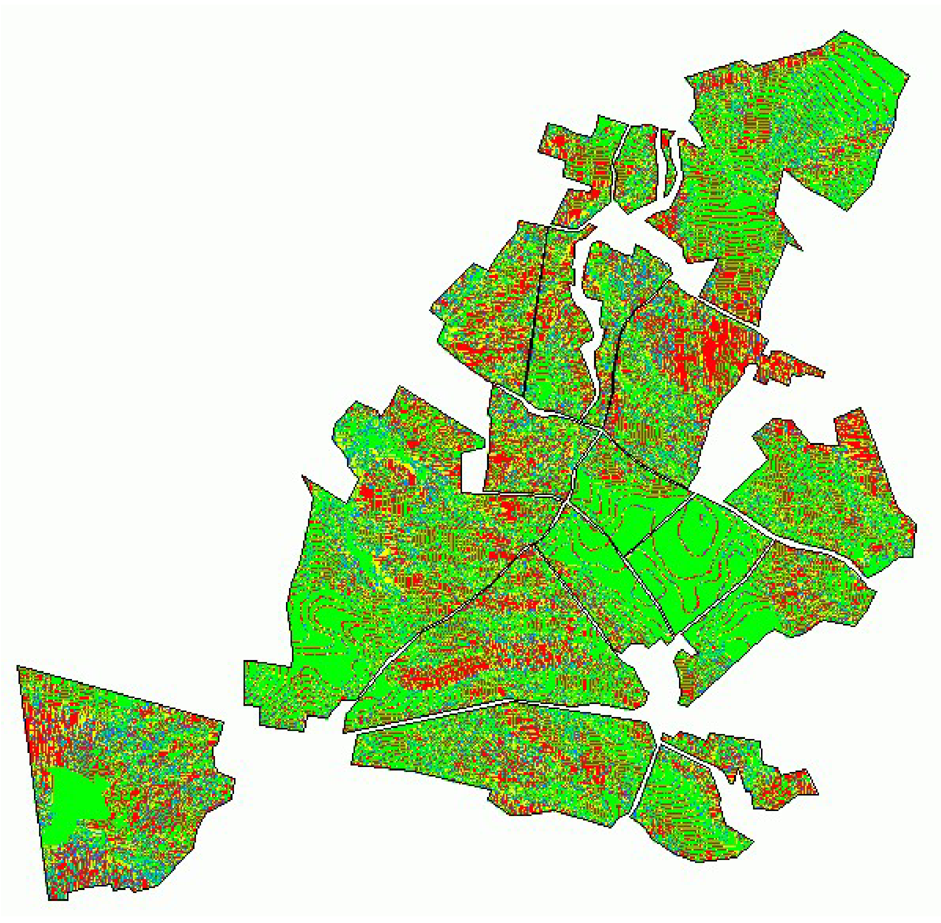

Figure 8: Grid G soil loss for C = 0,5

Comparison of both methods

In example was made comparisons of both classic soil loss computation and grid computation, see table 1. From the results shown in table 1 is concluded that both methods are comparable. Majority of classic and grid computation results vary within the interval of presumed accuracy. Differences between the two computations can be caused by lower accuracy in our DTM. Using more accurate DTM data, e.g. DTM created from aerial photogrammetry, can eliminate these inaccuracies.

Major advantage of grid computation is that the resulting grid displays entire area of interest. In case of classic erosion computation the result is computed only within the erosion profiles.

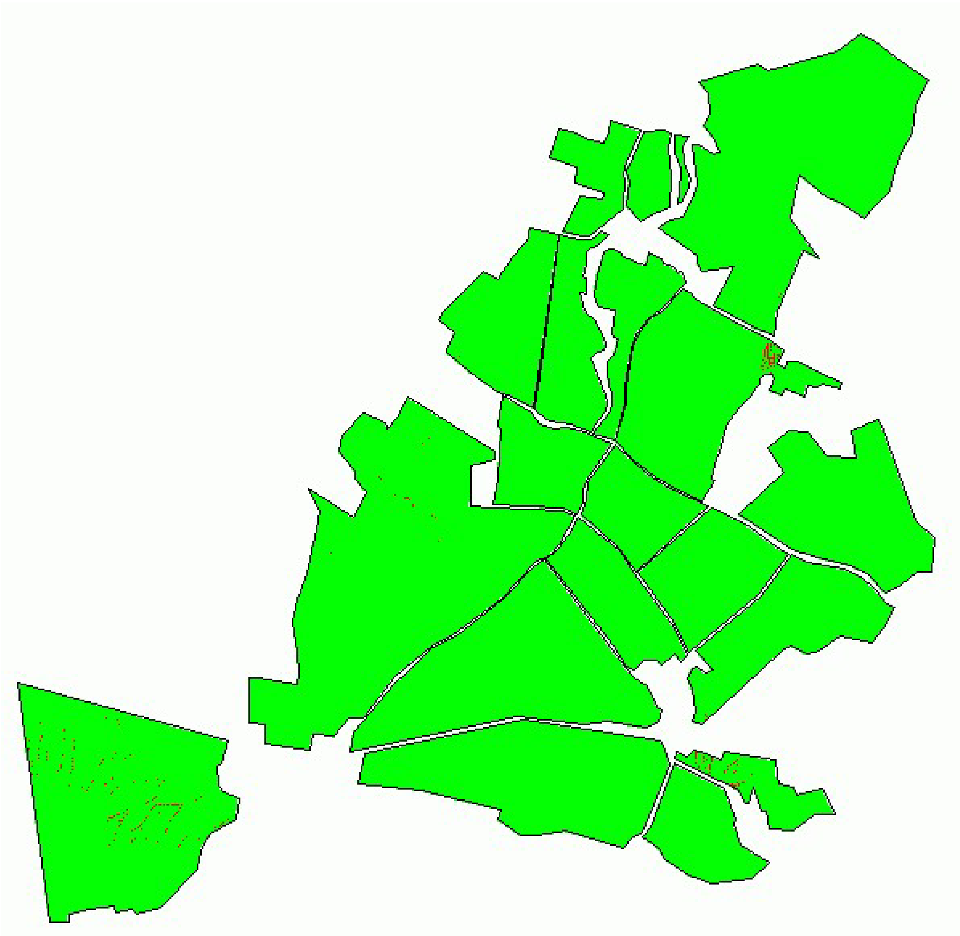

Figure 9: Grid of permissible soil loss overrun for C = 0,02

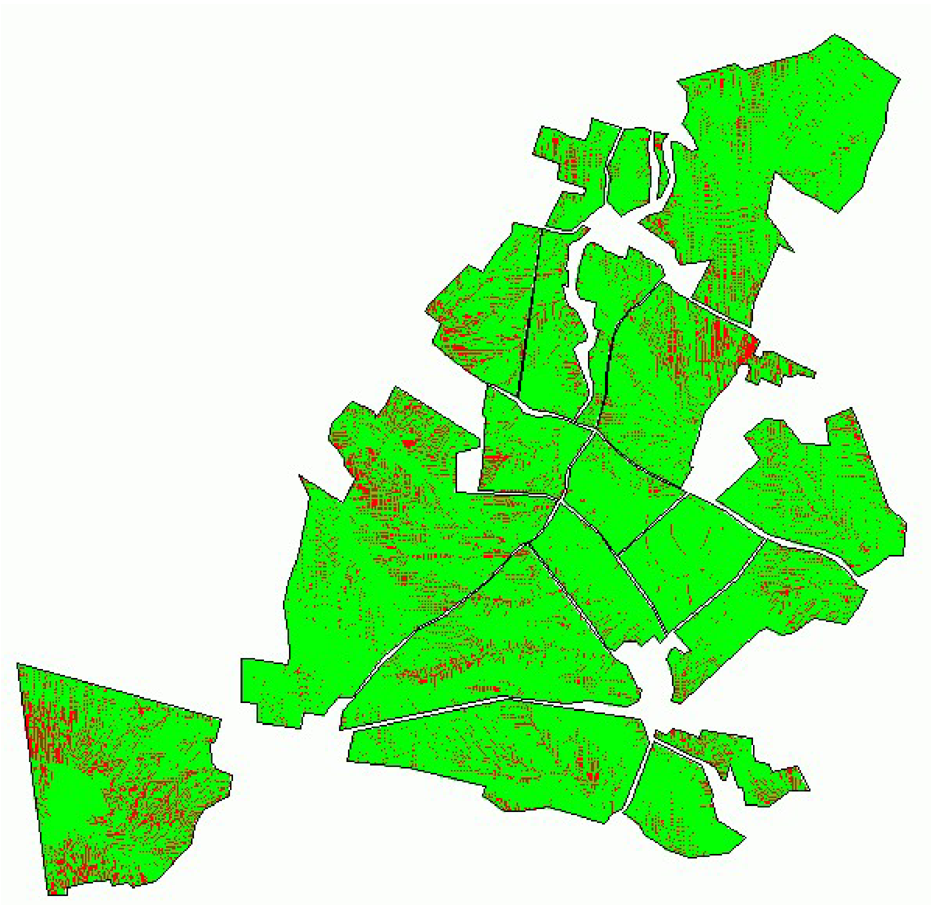

Figure 10: Grid of permissible soil loss overrun for C = 0,16

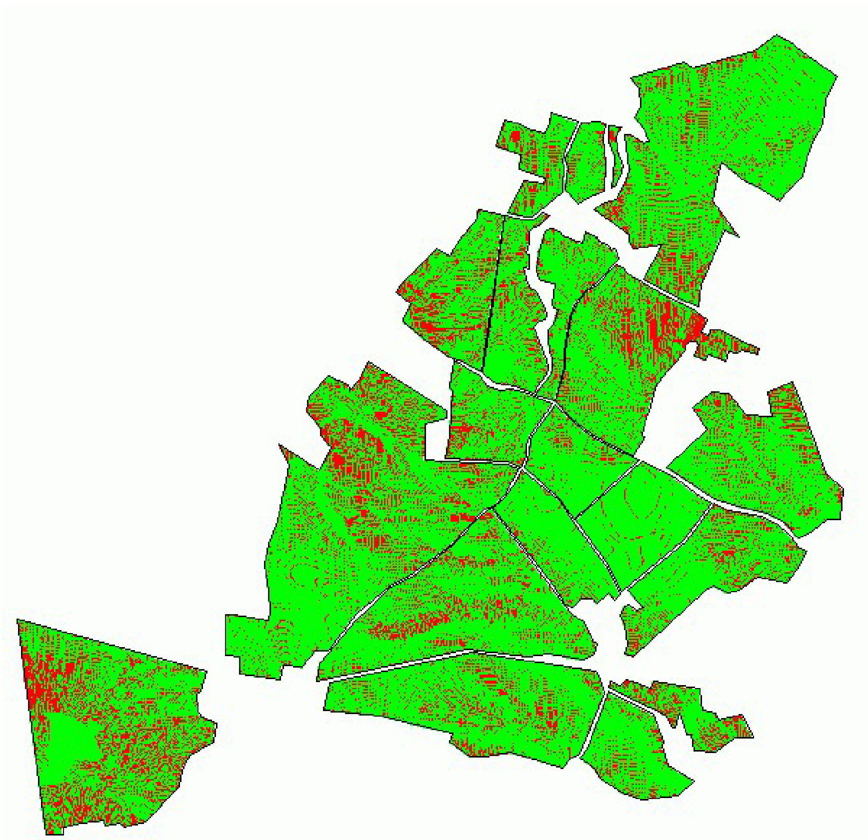

Figure 11: Grid of permissible soil loss overrun for C = 0,3

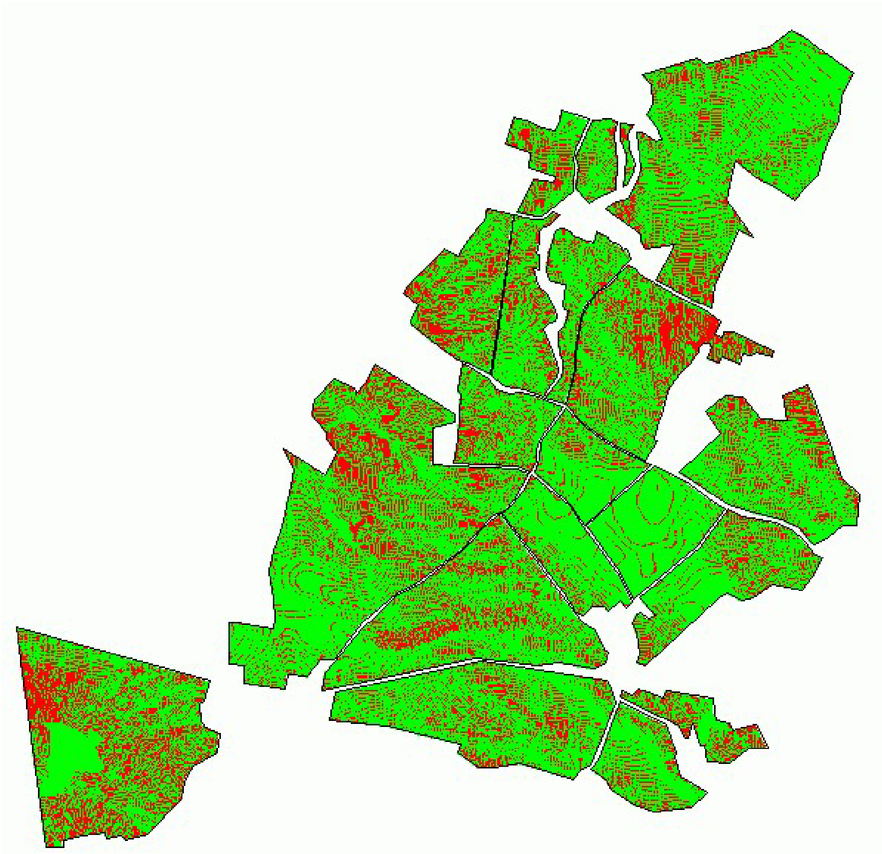

Figure 12: Grid of permissible soil loss overrun for C = 0,5

Red color in figures 9,10,11,12 shows places where computed soil loss exceeds permissible soil loss. It means that protection capability of selected crops at that places is overrun. From these figures we can see that pasture can be grown almost without any limitation. This result was expected; pasture scenario was computed mainly for comparison reasons. Other scenarios already have endangered spots, shown in red color. Computed results shown on figures 10 to 13 equals to already existing higher water erosion verified by terrain surveying. These endangered areas will be grassed over.

Conclusion

Soil loss grid computation is comparable to a classic computation using erosion profiles. Crucial part of grid computation process is the creation of grid layers for each factor. Many data sources created and used in land adjustment process is usable also for grid creation.

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