SOIL EROSION CALCULATION USING AERIAL IMAGES BASED DTM IN A CROSS BORDER VINERY REGION

Kemper, H.*[a]; Kemper, G.[a]; Klaumuenzner, T.[a]

[a] GGS GmbH Speyer/Germany – hannah.kemper@ggs-speyer.de

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ABSTRACT:

This paper shows the effect of different terrain models extracted out of nadir and oblique aerial surveyed data and the processing to DTM with respect to soil erosion risk evaluation. A cross border area between Germany and France, close to the city of Wissembourg, was affected by soil-erosion several times in the past. Vineyards aligned with the slope improve the risk for soil erosion. Applying the Universal Soil Loss Equation (USLE) in GIS-environment highlights areas of higher or lower risk in order to assist in strategies for a better the soil loss prevention. The lack of sufficient soil data limits the spatial resolution of the study and details given are mainly provided through the very dense terrain model. Nevertheless, terrain is one of the major factors defined in the slope angle and slope length.

INTRODUCTION

High rates of soil erosion in vineyards and soil fertility loss in vinery regions is acknowledged among scholars in earth sciences. Several agricultural practices used during vine cultivation have a major impact on the soil built-up and vulnerability to soil thickness loss (Novara et al. 2011) (Chevigny et al. 2014). Vinery is seen as the form of agriculture having the highest impact on soil fertility causing soil losses due to heavy machinery, wheel traffic and trampling (Cerdà et al. 2017).

Especially in vinery areas in the northern part of Europe, the orientation of the vineyard rows along the slope facing to the south for collecting sun are in many cases aligned with the falling line which enhances the soil erosion risk.

The research area is located in a cross border vinery region between Palatinate (Germany) and Alsace (France). In recent years observations of debris flows from the German towards the French side and strong erodibility of soil surface were discussed in public. After having high rainfall, the slopes of the vineyards favored the flows of soil material towards the city of Wissembourg (France). There is some federal data existing about this problem, nevertheless the dataset is quite generalized with a resolution of 25m per pixel[1] and not able to recreate the soil flows observed in the area. Considering the status of a cross border area there are some administrative issues in the cooperation between the two countries that should be recognized whilst considering the implementation of the results into measures for soil protection.

Figure 1. The research area north of Wissembourg done as a screenshot from Google earth. In the north is the village of Schweigen-Rechtenbach in Germany while in the south the city of Wissembourg is situated at the river Lauter in France. The border is marked in yellow.

2. EXTRACTING DTM FROM AERIAL IMAGES

Regarding the calculation of soil erosion a great enhancement can be done by using modern photogrammetric methods including aerial images and digital terrain models. Using an oblique imaging system from GGS (OIS-L) with one 150 MP Nadir and four 100 MP oblique cameras a GSD of 5cm was acquired. The use of the dataset enhanced the calculation of a 3D model of the area for a more detailed understanding of the terrain and land surface. A first research point was the comparison of the nadir with all images for the DSM creation.

* Contributing author
[1] https://lvermgeo.rlp.de/de/geodaten-geoshop/opendata/

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Figure 2. The screenshot shows the DSM of test-area 2 created from the nadir camera only as a take-off from the OIS-L, the screenshot below the DSM from the OIS-L.

Figure 3. This screenshot shows the DSM of test-area 2 created from the complete camera-setup using all five views of the OIS-L.

Two ways of DSM extraction were used in order to compare the accuracy and terrain representation. In a first test scenario only the nadir data was used to create a classic point cloud that is used on most terrain models. This is shown in Figure 2. In a second scenario the data of all five cameras was entered into the dense point matching, the same method as also used for the extraction of 3D city models.

The Figure 3 shows the more detailed DSM of the OIS-L. The DSM of the Nadir camera is more or less a 2.5D model that smooths the surface compared with the far better representation in the DSM from the OIS as a full 3D model. To generate a DTM out of the DSM, filtering takes more time but is far more precise.

In a first step the DSM was analyzed by slope and distance factors to generate a DTM. These are still more less standard procedures to find the right values for the chosen area. Applying this, mesh generation and hope filling result in DTMs of both areas out of both DSMs.

A first derivation is a slope map which is important to enter into the erosion calculation. Another terrain factor is the aspect and the length of an erosion path in the terrain.

Figure 4. 3D model of vineyards in research area with the retention basin

Having learned from the past, at least the water retention basin was constructed that was 50% by the heavy rain period in February 2022, the first time since three years. On the other side the maintenance of the smaller drainage trenches and tubes is visible which is also a political issue. The most vine farmers operate from the German side while the effect of the run off affects more the French area.

3. THE EROSION EQUATION

In 1978 Wishmeyer and Smith published the book "predicting rainfall erosion losses – a guide to conservation planning. This was the beginning of the world wide soil erosion research. Even the results found by Wishmeyer and Smith are more an estimation than a real balance, more research took place and has been able to precise the erosion forecast. Nevertheless, still today the relatively easy to be applied equation is frequently used around the globe since the factors are quickly to determine and the equation is really simple. This USLE (universal soil loss equation) analyzes the factors that lead or predict soil erosion. The dUSLE (differential USLE) or revised USLE (RUSLE) takes the neighborhood relation into account and also calculates the run-out and run-in effects from parcel to parcel. This is an important innovation to determine the LS Factor. The USLE is limited to agricultural areas with a certain range of the named factors, other areas needed new researches and the adaptation was far more complex (Frankenberg et.al. 1990).

This paper proposes a workflow to calculate the soil erosion using the USLE and partly the RUSLE considering rainfall, soil erodibility, and slope and land management factors. The USLE or the differential USLE uses standardized methods that at least give an indication without warranty of absolute correctness.

To calculate the risk for soil erosion, the Universal Soil Loss Equation (USLE) was applied in a QuantumGIS Environment.

$$A = R * K * L * S * C * P \qquad (1)$$

A represents the potential long-term average annual soil loss

R is the rainfall and runoff factor by geographic location

K is the soil erodibility

L*S is the slope length-gradient factor.

C is the crop/vegetation and management factor.

P is the factor describes soil erosion prediction practices

Besides the terrain data that was extracted from the photogrammetric preprocessing all other information has been received from federal offices and do not exceed the resolution better than 25 m. The resolution is far lower than the DSM and the extracted DTM and the derived LS Dataset. The Processing steps will be shown in the next chapter.

4. STEPS OF PROCESSING

The digital surface models (as seen in figure 5) contain many elements, such as trees, houses, vine-rows, that disturb the analysis of erosion characteristics. They have to be eliminated for achieve a DTM that is important for the equation and the quality of the allover result. For the first step of the removal of disturbing elements, the function "DTM filter (slope-based)" ("saga:dtmfilterslopebased") provided by SAGA-GIS was used with the values Radius = 1, Slope = 2 and performed on a powerful computer.

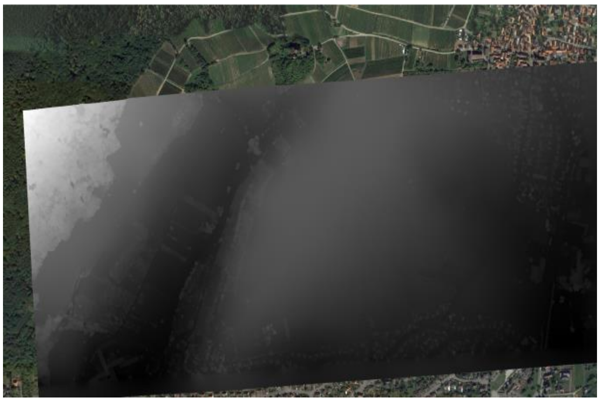

Figure 5. The DSM of the entire study area overlaid on the orthophoto.

The result cuts out correspondingly high slopes on small distances and is useful for the following steps. The procedure was used for relatively small areas to avoid removal of smaller but relevant morphological features. Working with these filters is sensitive and have to be slightly tuned for different areas with different surface structure. Applying this guided to the result below (can be seen in figure 6).

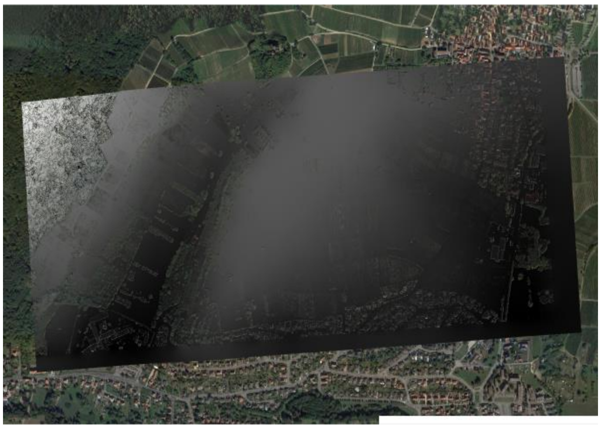

Figure 6. The DTM of the entire study with the cut off areas that represent buildings and higher vegetation. The grey values represent the DTM while all colored areas are from the orthophoto underlying this data set

For further processing, the result obtained from the DTM filter was smoothed and converted to vector geometries. The elevation information was preserved. This height information was used to cut out non-bare-ground-information. The integration of additional filter algorithms as size and curvature have been applied to generate a 3-angulated network which itself enabled the extraction of contour lines as shown in Figure 7.

Figure 7. The final received vector based DTM with objects shown that are placed on top of the surface in colors from the orthophoto or the colored point cloud.

This procedure is especially relevant in the area of grapevines. In addition to various information with unnatural height values, areas below a certain minimum size were also removed. The removal of minimum sizes also facilitates the removal of certain small-scale structures, such as the vines. Problems with the chosen methods often occur in the area of gardens, with hedges, or with flat roofs on slopes, which tend to be accounted for as one element (as shown in figure 8).

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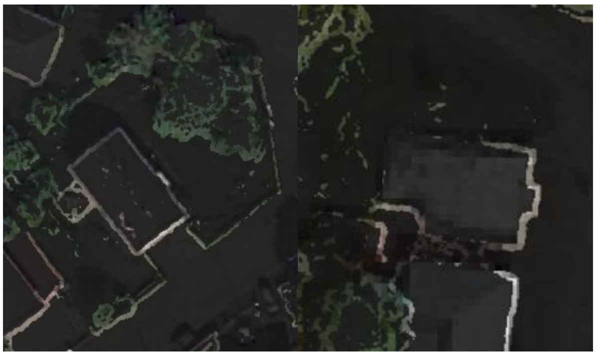

Figure 8. Errors resulting from incorrect division (left: hedges and lawn are not separated, right: slope and rooftop are not separated).

The vector layer, with the non-bare-ground information cut out, serves as a stamp for the original digital elevation model and is computed with it. The removed appearances in the vector layer are cut out and appear as NoData values in the result. To interpolate the resulting NoData values, the SAGA-GIS function "Close Gaps" ("saga:closegaps") was used, where approximate values are interpolated. It should be noted that this is only a computational approximation using the surrounding information and, especially in forest areas, a relatively large deviation from real values can occur if no ground elevation information is available and / or they are located at the edge of the study area, as shown on Figure 9 in the upper left. The result can be seen in figure 10.

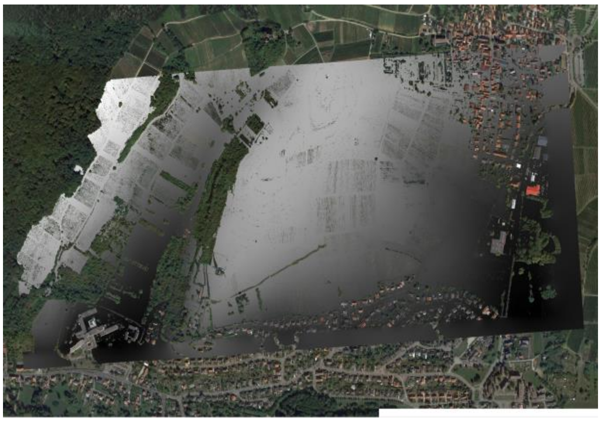

Figure 9. Additional applied filtering of the DTM for closing gaps with SAGA-GIS.

The L and the S factor were determined using the SAGA-GIS function "Ls-factor, field based" ("saga:lsfactorfieldbased"), which provides a common result for this, the LS factor. The obtained LS-factor is then multiplied with the factors for rainfall erosivity (R), soil erodibility (K) and the cropping management (C and P), using the SAGA-GIS function "Raster product". Care should be taken to ensure that data is available for the study area. NoData values should be replaced with the value "1" to reduce erroneous values. This can be done with the "native:fillnodata"-function of QGIS.

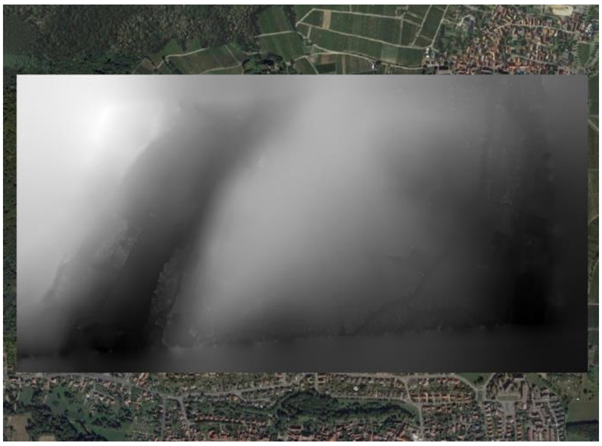

Figure 10. Processed DTM with closed gaps.

Figure 11. The very important calculation then was the extraction of the LS factor that represents the length of the erosion parcel and the slope.

The interesting result is the LS factor map (Figure 11). As red lines the still existing built not really maintenance collection holes for water are detected. They should collect water and eroded soil to hamper the down-flow of water with soil. The basins are meanwhile often filled with soil and the infiltration is blocked. They need urgently more care and maintenance. This is a known fact – so far the information from the municipality of Wissembourg – now visible in the LS map.

In QGIS the Raster calculator has been the basis for the Erosion calculation.

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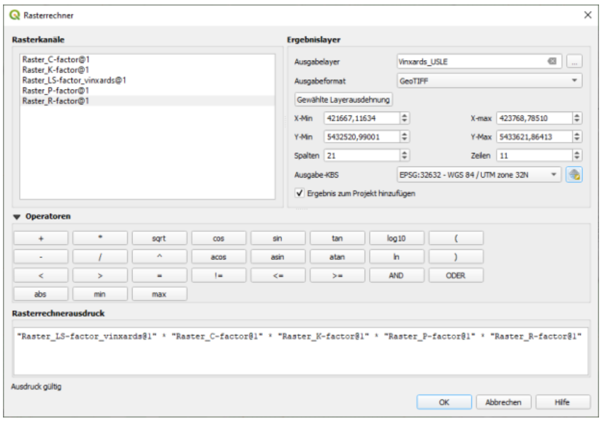

Figure 12. In QGIS applied raster value calculation for the USLE.

Accordingly, the result obtained is Universal Soil Loss Equation (USLE). If the areas of different factors have too strong deviations from each other, the corresponding results should be considered individually. At edges there are sometimes large value changes according to NoData-values that were changed to "1", otherwise there would be holes by multiplying with "NoData" respectively zero (as can be seen in figure 13).

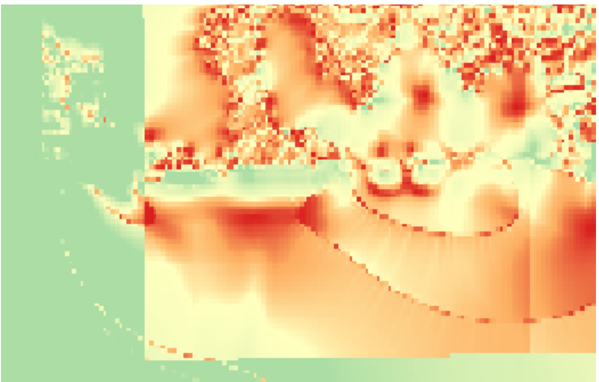

Figure 13. Example for Deviations by NoData.

There are some deviations at the frame of the study area that is the result of a bad agreement of the data. Such effects are smaller as bigger the area is. However, the lack of information of the other factors limits a better spatial resolution of the overall result.

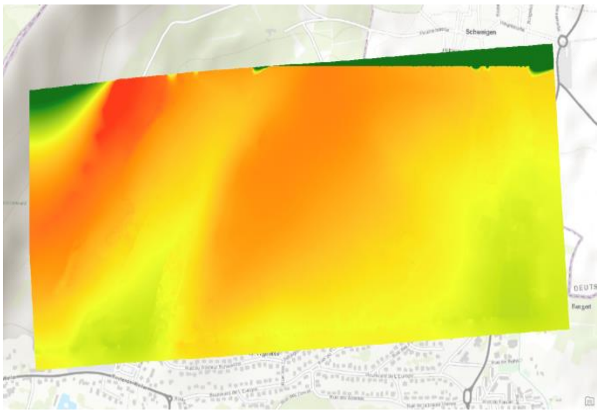

Figure 14. The final result of the soil erosion risk that mainly is related to the terrain factors.

The nicely discovered effect of the LS factor and the drainage trenches is not anymore visible in the final result. Maybe with additional filter algorithms this information can be more dominant to receive a result that helps to predict the soil erosion.

RESULTS

The results created with the proposed method show details that could not be created from common satellite imagery or the data provided by national surveying organizations. The accuracy and resolution of the 3d model is excellent and can be used for the erosion risk evaluation.

The use of oblique data did significantly improve the DSM and assisted in the derivation of the DTM due to more clear filtering operations. The photogrammetric dataset reveals in more details of the soil erodibility in the area and thus enhanced the understanding of dynamics on a smaller level. Concerning the European Revised Universal Soil Loss Equation (RUSLE) important data products got evaluated in this study, as well as the identification of modified runoffs and gullies in the research area. Nevertheless the very poor resolution of the soil data did not allow improving the overall result even the terrain data play a major role in this equation.

The proposed workflow is useful to evaluate cross border issues in sustainable land management and to evaluate existing datasets of federal institutions to take political decisions for a better cooperation between Germany and France. Further, this study proposes a workflow for the detection of soil erosion and soil thickness reduction using aerial oblique imagery and digital terrain models as basis. Finally further ideas of improvement and critique were discussed showing that the potential of further development is very high.

The study just started will continue for a wider area and with additional analytics. Next planned steps are to get more detailed data extracted from different databases especially to get a higher resolution of the K and C factors. Actually the resolution of the overall result is very poor due to the low resolution especially of the K C and P factors. Another factor needs to be adjusted; rainfall is due to climate change not anymore longer distributed as in the past, longer periods of dry weather and heavy rainfalls will increase. An additional point to improve is the result is to get deeper into the relation of the L and S factors as the RUSLE is doing.

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