CZECH UNIVERSITY OF LIFE SCIENCES IN PRAGUE

Faculty of Environmental Sciences

BACHELOR THESIS

Jade Zierden

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WIND EROSION MODELLING USING GIS

Jade Zierden

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

BACHELOR THESIS ASSIGNMENT

Jade Zierden

Environmental Engineering

Thesis title

Wind Erosion Modelling Using GIS

Objectives of thesis

The proposed thesis will review several wind erosion models and suggest a procedure for modelling wind erosion using ArcGIS. The review will compare the inputs, accuracy of results, and difficulty of use of the models. The new ArcGIS procedure will aim to provide a tool that could be used over large areas anywhere in the world.

Methodology

The review of the wind erosion models will be conducted through research of source materials and personal experiences as a first-time user. The source materials will provide information about the required inputs of the models and the historical accuracy of the results. The author's experience with the models will supplement the research to add a more personal opinion about the models and how user-friendly they are for a first-time user.

The gathered research for the model review will help introduce a procedure to calculate soil lost by wind erosion in ArcGIS. The procedure will include the components of the reviewed wind erosion models and assign each input variable to GIS layers; these layers will represent input data to calculate an output layer to provide the wind erosion of a given area over a given time.

The proposed extent of the thesis

according to the Deans regulation No. 2/2020 Methodological guidelines for writing diploma thesis at the FES

Keywords

Wind erosion, erosion modelling, GIS, WEQ, RWEQ

Recommended information sources

Borrelli, P., Lugato, E., Montanarella, L., Panagos, P., 2017: A New Assessment of Soil Loss Due to Wind Erosion in European Agricultural Soils Using a Quantitative Spatially Distributed Modelling Approach. Land Degradation & Development Volume 28, Issue 1. 335-344.

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Jarrah, M., Mayel, S., Tatarko, J., Funk, R., Kuka, K., 2020: A review of wind erosion models: Data requirements, processes, and validity. Catena Volume 187. 1-16.

Woodruff, N., Siddoway, F., 1965: A Wind Erosion Equation. Soil Science Society of America Volume 29, Issue 5. 602-608.

Youssef, F., Visser, S., Karssenber, D., Bruggeman, A., Erpul, G., 2012: Calibration of RWEQ in a patchy landscape; a first step towards a regional scale wind erosion model. Aeolian Research Volume 3, Issue 4. 467-476.

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Author's statement:

I hereby declare that I have independently elaborated the bachelor/final thesis with the topic of: "Wind erosion modelling using GIS" and that I have cited all of the information sources that I used in the thesis as listed at the end of the thesis in the list of used information sources. I am aware that my bachelor/final thesis is subject to Act No. 121/2000 Coll., on copyright, on rights related to copyright and on amendments of certain acts, as amended by later regulations, particularly the provisions of Section 35(3) of the act on the use of the thesis. I am aware that by submitting the bachelor/final thesis I agree with its publication under Act No. 111/1998 Coll., on universities and on the change and amendments of certain acts, as amended, regardless of the result of its defence. With my own signature, I also declare that the electronic version is identical to the printed version and the data stated in the thesis has been processed in relation to the GDPR.
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Abstrakt

Větrná eroze způsobuje četné škody na zemědělské půdě, včetně snížení udržitelnosti, degradaci půdy a menší produkci plodin. Naštěstí existuje řada způsobů, jak větrnou erozi snížit, včetně větrolamů, upravených zemědělských postupů a typu vegetačního krytu. Cílem této práce je navrhnout postup modelování větrné eroze s využitím geografických informačních systémů, který by mohli používat lidé s jakýmkoliv stupněm vzdělání a zkušeností s aplikací. Navrhovaný model větrné eroze je testován pomocí dvou scénářů na stejném zemědělském poli u obce Znojmo v průběhu roku 2023. První scénář simuluje pole s kukuřicí osázenou a pěstovanou během přibližného vegetačního období a druhý scénář simuluje pole ponechané rok holé. Pěstování kukuřice přineslo maximální hodnoty transportní kapacity v rozmezí od 17 683 do 53 712,9 kg/m. Udržování holé půdy vedlo k vyšším hodnotám maximální transportní kapacity v rozmezí od 17 980,9 do 54 617,9 kg/m na ploše zemědělského pole. Celková ztráta půdy na poli během roku činila 51 384 969 kg s kukuřicí a 52 249 892 kg s holou půdou, respektive 406,29 a 413,13 tun/hektar/rok.

Abstract

Wind erosion causes numerous damages to agricultural land, including reduced sustainability, soil degradation, and less crop production. Fortunately, there are also a number of ways to reduce wind erosion, including wind barriers, modified agricultural practices, and type of vegetation cover. The aim of this work is to suggest a wind erosion model using geographic information systems which could be used by people with any level of education and experience with the application. The suggested wind erosion model is tested using two scenarios on the same agricultural field near the village Znojmo during the year 2023. The first scenario simulates the field with corn planted and grown during the approximate growing season, and the second simulates the field left bare for a year. Planting corn produced maximum transport capacity values in a range from 17,683 to 53,712.9 kg/m. Keeping the soil bare produced larger values of maximum transport capacity in a range from 17,980.9 to 54,617.9 kg/m in the area of the agricultural field. Total soil loss for the field during the year was 51,384,969 kg with corn, and 52,249,892 kg with bare soil, or 406.29 and 413.13 tons/hectare/year respectively.

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1. Introduction

Wind erosion causes soil loss all over the world, which can impact sustainability and productivity of agricultural land (Zhao et al., 2021). Arid and semi-arid regions are the most affected by wind erosion (Zhao et al., 2021), and in some arid regions, one strong wind storm could have the ability to strip more soil nutrients than an entire year of deposits could replace (Sterk et al., 1996). Commercial agriculture uses large fields, which provides an increase in saltation and suspension forms of erosion (Kheirabadi et al., 2018). Wind erosion causes soil degradation (Zhao et al., 2021), and soil degradation can increase wind erosion (Seager et al., 2008), which creates a dangerous cycle. Fortunately, measures can be taken to reduce wind erosion, and modelling wind erosion can describe which measures would be most effective for specific areas. One method for reducing wind erosion is to add wind barriers to a field (Tatarko et al., 2019). There is a large increase of wind erosion immediately after the plowing of agricultural fields, so another measure to reduce erosion is to reduce or even eliminate plowing (Tatarko et al., 2019). Keeping a cover crop greatly reduces wind erosion because vegetation cover has a high impact on wind erosion rates (Tatarko et al., 2019; Scheper, 2021).

Throughout the study of wind erosion and development of models, researchers found the same general factors which must be taken into account to predict soil loss: erodibility of the soil, climate statistics for the area, crop cover, and field geometry information. Depending on the specific model type, these factors are organized into different equations, charts, or tables. The models which will be the focus of this study are the Wind Erosion Equation, the Wind Erosion Prediction System, and the Revised Wind Erosion Equation. The Wind Erosion Equation was the first published model (Woodruff and Siddoway, 1965), and therefore has many flaws. The model makes incorrect assumptions (Woodruff and Siddoway, 1965; Fryrear, 2001b) and has low accuracy when compared to measured soil loss (Fryrear, 2001b). Although it has gone through many improvements over the years, the Wind Erosion Equation is not suitable for most prediction scenarios (Tatarko et al., 2013). The Wind Erosion Prediction System is a much more recent development. The model is more accurate when compared to measured soil loss (Tatarko et al., 2019), and it can even simulate the changes in the soil surface over time (Wagner, 2013). Unfortunately, The model does not support abnormal field shapes or rolling terrain (Wagner, 2013), so there is still

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room for improvement within the Wind Erosion Prediction System. The Revised Wind Erosion Equation is based on the concept that wind erosion only occurs if the force of the wind is stronger than the friction forces of the soil particles (Fryrear et al., 2000). It is able to predict short term or long term soil loss (Fryrear et al., 2001a). One drawback is the Revised Wind Erosion Equation uses averages in the climate factors, which can cause some inaccuracy due to the natural fluctuations of weather (Youssef et al., 2012). Overall, the Revised Wind Erosion Equation was the best model of these three to be integrated into a model using ArcGIS Pro due to its low amount of required inputs and accuracy when compared to measured wind erosion. This decision is also supported by previous studies which have successfully combined the Revised Wind Erosion Equation with geographic information systems (Borrelli et al., 2017; Guo et al., 2013).

2. Objectives

The objective of this report is to suggest a wind erosion prediction tool in ArcGIS Pro which could be developed for use over large areas in any place in the world. To begin this development, it is required to adapt RWEQ model into a form transferable into ArcGIS Pro. The five main factors composing the final equation to calculate average soil loss each have their own equations and variables. Therefore, many steps are taken to complete the calculation, and though they are not overly complicated, they can still be simplified to better suit their purpose in ArcGIS Pro. An additional objective of this development is the resulting tool will be as quick and easy for people to use as possible. A tool available for everyone would be more widely used than a tool requiring training or advanced knowledge. The final suggestion of the wind erosion prediction tool is based on test runs from locations in the Czech Republic where sufficient input data has been collected. The level of success of these test runs will reveal what improvements need to be made in the continued development of the tool.

3. Review

There have been many wind erosion models developed throughout the years, each with its own advantages and shortcomings. The very first was an empirical model called the Wind Erosion Equation (WEQ) to be used for calculating annual soil loss of fields (Woodruff and Siddoway, 1965). It was largely based on work by Dr. W. S. Chepil, and published by Woodruff and Siddoway in 1965 (Tatarko et al., 2013). In 1986, the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) began to develop a new Wind Erosion Prediction System (WEPS) to improve upon WEQ and allow for future technology to be incorporated (Fryrear et al., 2001a). This was a serious undertaking, so in the meantime, ARS was requested in 1991 to revise WEQ. The Revised Wind Erosion Equation (RWEQ) was developed to maintain similar inputs as WEQ, but increase the accuracy of estimates, and was released in 1998 (Fryrear et al., 2001a). After the completion of RWEQ, focus was returned to the development of WEPS. It took the USDA over twenty years to develop and refine WEPS to a point that met their expectations (Wagner, 2013). These three wind erosion models are the focus of this review, although they are not the only notable models in existence.

3.1 WEQ

As stated, the WEQ model was designed by Dr. W. S. Chepil. The WEQ model was the result of almost 30 years of research spent determining the most important factors of wind erosion (Woodruff and Siddoway, 1965). The factors were determined to be soil and knoll erodibility (I'), soil ridge roughness (K'), local wind erosion climate (C'), field length (L'), and vegetation cover (V) (Woodruff and Siddoway, 1965). These factors can be further broken down into the variables of soil erodibility (I), knoll erodibility (I_s), soil ridge roughness (K_r), wind velocity (v), surface soil moisture (M), distance across field (D_f), sheltered distance (D_b), quantity of vegetation cover (R'), type of vegetation cover (S), orientation of vegetation cover (K_o) (Woodruff and Siddoway, 1965). In Table 1, the main factors are connected to the specific factors that they require for their calculation and the variables are displayed for each.

Main Factor	Variable	Specific Factor	Variable
Soil and knoll erodibility	I'	Soil erodibility	I
		Knoll erodibility	I_s
Soil ridge roughness	K'	Soil ridge roughness	K_r
Local wind erosion climate	C'	Wind velocity	v
		Surface soil moisture	M
Field length	L'	Distance across field	D_f
		Sheltered distance	D_b
Vegetation cover	V	Quantity of vegetation cover	R'
		Type of vegetation cover	S
		Orientation of vegetation cover	K_o

Table 1: WEQ factors and their corresponding variables. (Woodruff and Siddoway, 1965)

Being the first wind erosion model made WEQ a stepping stone for other researchers to improve the accuracy of their own models, but it also means WEQ has the most flaws of any wind erosion model. First, Cole et al. point out WEQ cannot be accurate because most of its development was conducted through minutes-long wind tunnel measurements which couldn't measure the soil flow rate (1983). Also, the soil erodibility factor assumes a wide, unsheltered, and isolated field with a bare, smooth, and non crusted surface (Woodruff and Siddoway, 1965), which is rarely the case for most fields. Another false assumption the WEQ model makes is the transport mass of wind can increase without any limit (Fryrear, 2001b). This assumption directly opposes Chepil's statement: "Rate of soil flow increased with distance downwind until, if the field was large enough, it reached a maximum that a wind of a given velocity can carry" (Fryrear et al., 2001b ex. Chepil, 1957). Throughout the years, WEQ has gone through many alterations and improvements from its original equation. The work of Lyles and Allison helped improve WEQ by taking into account effects of plant stubble and non-erodible aggregates (1975). The effects of wind breaks were researched and developed by Woodruff et al. (Tatarko et al., 2013 ex. Woodruff et al., 1976). Armbrust et al. helped understand the impacts of crop type and tillage methods on soil aggregates, which in turn impacts wind erosion (1982). Despite these improvements, wind erosion researchers still recognize a number of

flaws with the model (Tatarko et al., 2013). When the performance of the WEQ model was tested against the performance of its replacement, RWEQ, the results were not favorable toward WEQ. From 15 test sites, WEQ had almost no correlation ($r^2 = 0.01$) when predicted soil loss was compared to measured soil loss (Fryrear, 2001b). RWEQ fared significantly better with very high correlation ($r^2 = 0.927$) between predicted and measured soil loss (Fryrear, 2001b). Due to the false assumptions and inaccurate predictions, WEQ is not suitable to be transferred into ArcGIS Pro and used over larger areas.

3.2 WEPS

WEPS began development in 1986 by the Agricultural Research Service of the USDA (Fryrear et al., 2001a). The model only requires the user to input four variables: location, shape, soil information, and management practices. WEPS organizes the inputs from the interface, gathers the necessary information from its various databases, runs the calculations, and then user-friendly outputs are provided (Wagner, 2013). This model can calculate total wind erosion, creep plus saltation, suspension, and estimate PM_{10} particles as well (Wagner, 2013). Another benefit of WEPS that sets it apart from other wind erosion models is it takes into account the changes in the soil surface throughout the simulated time period (Wagner, 2013). It can also compare multiple erosion simulation runs. The WEPS multiple run manager allows for easy comparison between simulations which can help with conservation planning and sustainable management practices (Tatarko et al., 2019). This model has been an amazing improvement to the previous wind erosion models, but it's still far from perfect. The field geometry input of the model is extremely limited compared to the numerous different agricultural field shapes which actually exist. The only available inputs are rectangles, circles, half-circles, and quarter circles, but even the erosion of non-rectangular fields is calculated by converting the geometry into a rectangle with an equivalent area (Wagner, 2013). This makes it difficult for users with abnormal field shapes to get an accurate estimate. Another difference between the model and reality comes from assuming a flat field. WEPS is not able to take into account any rolling landscape in its calculations (Wagner, 2013). Overall, WEPS has proven to be accurate when tested against measured wind erosion (Tatarko et al., 2019), which would make it a better candidate for development in ArcGIS Pro than

the WEQ model. However, the extreme complexity behind the user-friendly interface makes it unrealistic for a successful transfer.

3.3 RWEQ

RWEQ made its debut in 1998 as an improved wind erosion model (Fryrear et al., 2001a). The concept of RWEQ was based on the fact that if friction forces are stronger than the force of the wind, wind erosion will not occur (Fryrear et al., 2000). This means wind erosion doesn't occur if the soil is wet, covered in snow, or if the wind speed is too low to move the soil (Fryrear et al., 2000). While these constraints might seem obvious, they were an important addition to the RWEQ model to set it apart from WEQ. If wind erosion is possible, RWEQ calculates a maximum transport capacity to be used throughout the chosen time period. The chosen time period is generally 1-15 days (Fryrear et al. 2000), but can be as long as multiple years (Fryrear et al., 2001a). As stated previously, RWEQ was significantly more accurate than WEQ when tested against measured soil loss. The 15 test sites resulted in a very high correlation ($r^2 = 0.927$) between predicted and measured soil loss. These results concluded that as long as RWEQ is given quality inputs, it gives quality results (Fryrear et al., 2001b). There was also significant correlation ($r^2 = 0.805$) during the initial testing of RWEQ against 45 test sites of varying climates, surfaces, and vegetation cover (Fryrear et al., 2000). Despite the clear improvement from the WEQ model, RWEQ also has some drawbacks. This model uses weather files created based on locations in the United States (Skidmore and Tatarko, 1990), which does not necessarily translate to locations in other parts of the world. In addition to this, areas with weather periods which often stray from the average can experience some inaccuracy in their erosion estimates. This is because RWEQ uses an average of the weather over the chosen time period (Youssef et al., 2012), which does not closely follow the actual weather of some climates. Overall, the RWEQ model gives relatively accurate results without requiring complicated or excessive inputs. This makes it the best model to be used for a wind erosion prediction tool developed in ArcGIS Pro.

4. Methodology

The process of calculating average soil loss using RWEQ in ArcGIS Pro was broken down and completed in a series of steps to be more manageable. The methodology considers two scenarios:

1) with corn as the chosen crop and
2) bare soil, or no crop throughout the simulation

Step one was to find and understand the inputs and equations required for the calculation. Next, it was necessary to find data to fulfill these necessary inputs. After the data was collected, it was organized and cleaned to be realistically used in the equations. Then, primary calculations for each of the main variables could take place. Finally, average soil loss was calculated and displayed in ArcGIS Pro, and total soil loss for the experimental field was calculated. These steps are explained in greater detail throughout the following sections.

4.1 Find Inputs and Equations

The first step of this process is to find the inputs and equations required for the ArcGIS Pro RWEQ model to run. Thanks to Fryrear et al. (2001a), a complete set of equations and their respective inputs is available. The final equation calculates the average soil loss (S_L) in kg/m^2 for the set area and time period. Average soil loss is shown in equation (1) as well as in Table 2, which shows all the equations for the ArcGIS Pro RWEQ.

$$S_L = Q_{max} \bullet (1 - e^{-(\frac{z}{s})^2}) \bullet z^{-1} \tag{1}$$

Equation (1) requires maximum transport capacity (Q_{max}) and critical field length (s), which are both calculated from five wind erosion factors and can be found in equations (2) and (3) respectively.

$$Q_{max} = 109.8(WF * EF * SCF * K' * COG) \tag{2}$$

$$s = 150.71(WF * EF * SCF * K' * COG)^{-0.3711} \tag{3}$$

The factors used in equations (2) and (3) are wind (WF), erodible fraction (EF), soil crust (SCF), roughness (K'), and crops on ground (COG). Most of the equations were

taken directly from Fryrear et al. (2001a) without any alterations. The wind factor (WF) equation was the only one to be simplified for easier use. The calculation for WF used by Fryrear et al. (2001a) is shown in equation (4).

$$WF = Wf \cdot \frac{\rho}{g} \cdot SW \cdot SD \tag{4}$$

By breaking down each variable into its respective equations, equation (4) becomes equation (5). There is also an equation used in Fryrear et al. (2001a) to calculate the potential evapotranspiration (ET), but that equation was removed in favor of using ET values from collected data.

$$WF = \frac{\sum_{i=1}^{N} U_2 (U_2 - 5m/s)^2}{N} \cdot Nd \cdot \frac{\rho}{g} \cdot \frac{ET - (R+I)\frac{Rd}{Nd}}{ET} \cdot \left(1 - \frac{Sd}{Nd}\right) \tag{5}$$

The next step to simplify the WF equation is based on the fact that WF is only calculated for RWEQ when certain requirements are met. These requirements are 1) the wind speed is greater than the threshold velocity (5 m/s), 2) potential evaporation is greater than the total precipitation, and 3) the depth of any existing snow on the ground is less than 25.4 mm. If any of these requirements are not met, the WF value is 0 and no erosion is able to occur. Following these requirements with the collected data made it possible to calculate an hourly WF value. Calculating hourly values rather than an average over the time period allows for the removal of the SD factor in equation (4) and the ratio of rainy days in equation (5). This adjustment gives equation (6).

$$WF = \frac{\sum_{i=1}^{N} U_2 (U_2 - 5m/s)^2}{N} \cdot Nd \cdot \frac{\rho}{g} \cdot \frac{ET - (R+I)}{ET} \tag{6}$$

Hourly calculations also remove the need for multiple wind speeds. This changes the Wf factor from equation (4) and provides equation (7).

$$WF = v(v - 5m/s)^2 \cdot \frac{\rho}{g} \cdot \frac{ET - (R+I)}{ET} \tag{7}$$

Finally, the adjusted factor must be divided by 24 to convert the value into hourly. The result of these alterations is equation (8). Therefore, the WF value for the entire time period is the sum of all the hourly WF values.

$$hourly\ WF = v(v - 5m/s)^2 / 24 \cdot \frac{\rho}{g} \cdot \frac{ET - (R+I)}{ET} \tag{8}$$

The equations for the rest of the five factors were used without alterations, so the complete list of equations can be seen in Table 2, and the complete list of variables required for the equations in Table 2 are displayed in Table 3.

Name	Equation
Average soil loss (kg/m²)	$S_L = Q_{max} \bullet (1 - e^{-(\frac{z}{s})^2}) \bullet Z^{-1}$
Maximum transport capacity	$Q_{max} = 109.8(WF * EF * SCF * K' * COG)$
Critical field length	$s = 150.71(WF * EF * SCF * K * COG)^{-0.3711}$
Hourly Wind factor	$hourly\ WF = v(v - 5m/s)^2/24 \bullet \frac{\rho}{g} \bullet \frac{ET-(R+I)}{ET}$
Erodible fraction	$EF = \dfrac{29.09 + 0.31Sa + 0.17Si + 0.33\frac{Sa}{Cl} - 2.59OM - 0.95CaCO_3}{100}$
Soil crust factor	$SCF = \dfrac{1}{1 + 0.0066(Cl)^2 + 0.021(OM)^2}$
Roughness factor	$K' = e^{1.86(KrRc) - 2.41(KrRc)^{0.934} - 0.124Crr}$
	$Kr = 4 \bullet \dfrac{(ridge\ height)^2}{ridge\ spacing}$
	$Crr = (1 - \dfrac{horizontal\ measure}{length\ of\ chain}) \bullet 100$
	$Rc = 1 - 0.00032A - 0.000349A^2 + 0.00000258A^3$
Crops on ground factor	$COG = e^{-0.0438(SC)} \bullet e^{-0.0344(SA)^{0.6413}} \bullet e^{-5.614(CC)^{0.7366}}$
	$SA = (Ns)(Ds)(Hs)$

Table 2: Equations to calculate average soil loss. (Fryrear et al., 2001a)

Variable	Definition	Units	Origin
v	Hourly wind speed	m/s	Database
ρ	Air density	kg/m³	Constant
g	Acceleration due to gravity	m/s²	Constant
R	Rainfall	mm	Database
I	Irrigation	mm	User

ET	Potential evapotranspiration	mm	Database
Sa	Sand	%	Database
Si	Silt	%	Database
Cl	Clay	%	Database
OM	Organic matter content	%	User
$CaCO_3$	Calcium carbonate content	%	Database
Ridge height	Height of plow ridges	cm	User
Ridge spacing	Distance between plow ridges	cm	User
A	Angle of ridges	°	User
Horizontal measure	Direct distance between chain ends	cm	User
Length of chain	Total length of chain over rough surface	cm	User
Z	Downwind distance	m	User
SC	Land covered by flat crop residue	%	User
CC	Soil surface covered by crop canopy	%	User
Ns	Number of plant stalks in 1 m^2	---	User
Ds	Average diameter of plant stalks	cm	User
Hs	Height of plant stalks above ground	cm	User

Table 3: Complete list of variables necessary to calculate average soil loss. (Fryrear et al., 2001a)

4.2 Collect Data

The second step is to find the data to fulfill the input requirements. Each of the variables required to calculate average soil loss can be found in Table 2, and falls into one of three categories: constant, database, or user. Constant and database variables are provided in these steps, and user variables need to be entered by the user. The two constant variables are air density (ρ) and acceleration due to gravity (g). According to the American Meteorological Society, when water vapor is ignored, air density is essentially constant up to an elevation of at least 50 kilometers (American

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Meteorological Society ©2017). That constant value is 1.293 kg/m^3, therefore, the constant value of air density used in the calculations is 1.293 kg/m^3. Acceleration due to gravity has a value of approximately 9.81 m/s^2 on Earth, so that is the value used for g in the calculations for average soil loss (National Air and Space Museum ©2015).

There are a number of variables whose values were found on public databases. Meteoblue (https://www.meteoblue.com) was able to provide hourly time-step data for many of the variables necessary for WF (Meteoblue ©2024). The values of hourly wind speed, hourly wind direction, total precipitation, potential evapotranspiration, snow fall, and snow depth were taken from Meteoblue's database in the form of a csv file which could be easily used in RStudio. To access this information, Meteoblue was contacted to request a history+ subscription from them. This subscription allows the user to select any location in the world and download all the information previously stated for any year since 1940. After the subscription was approved, the "Manage Locations" page of the Meteoblue website was visited to add the desired town, which can be seen in Figure 1. Then, in the "Data Download" page, the desired time period, location, and variables were chosen, which can be seen in Figure 2 and 3.
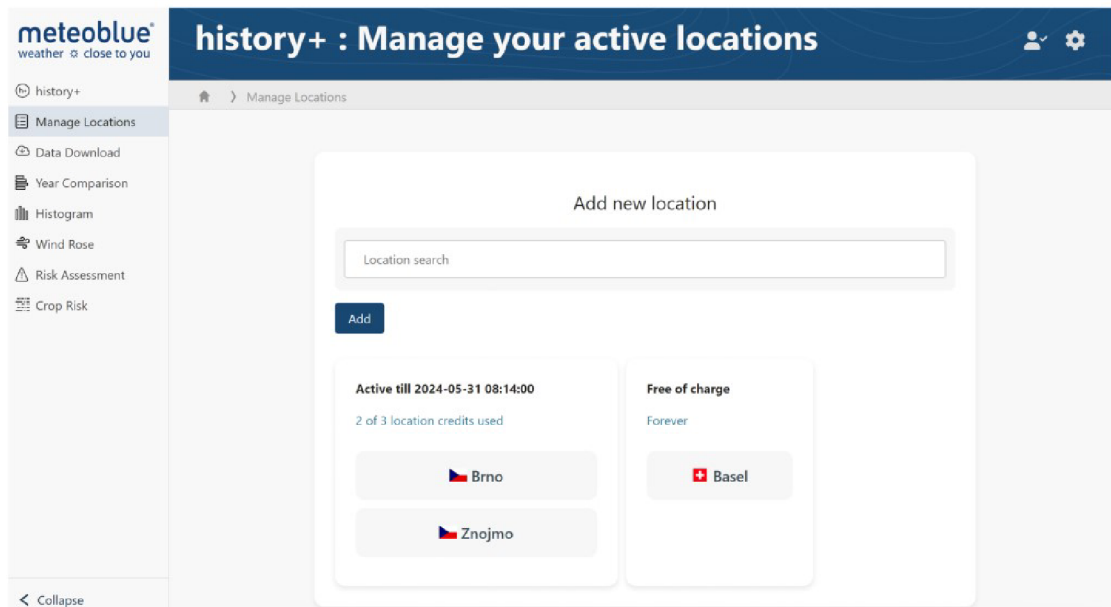
Figure 1: "Manage Locations" page of Meteoblue website with location search bar and two previously selected locations in the Czech Republic, Brno and Znojmo (Meteoblue ©2024).

For this study, the time frame selected was the year 2023, the location selected was Znojmo (Czech Republic), and the variables chosen from the list were Precipitation amount, Snowfall amount, Snowdepth, Wind speed [at 10m height], and

Potential evaporation. These selections on the "Data Download" page can be seen in Figure 2. Finally, the information was downloaded as a csv file using the button in the upper right of the page, which can be seen in Figure 3.
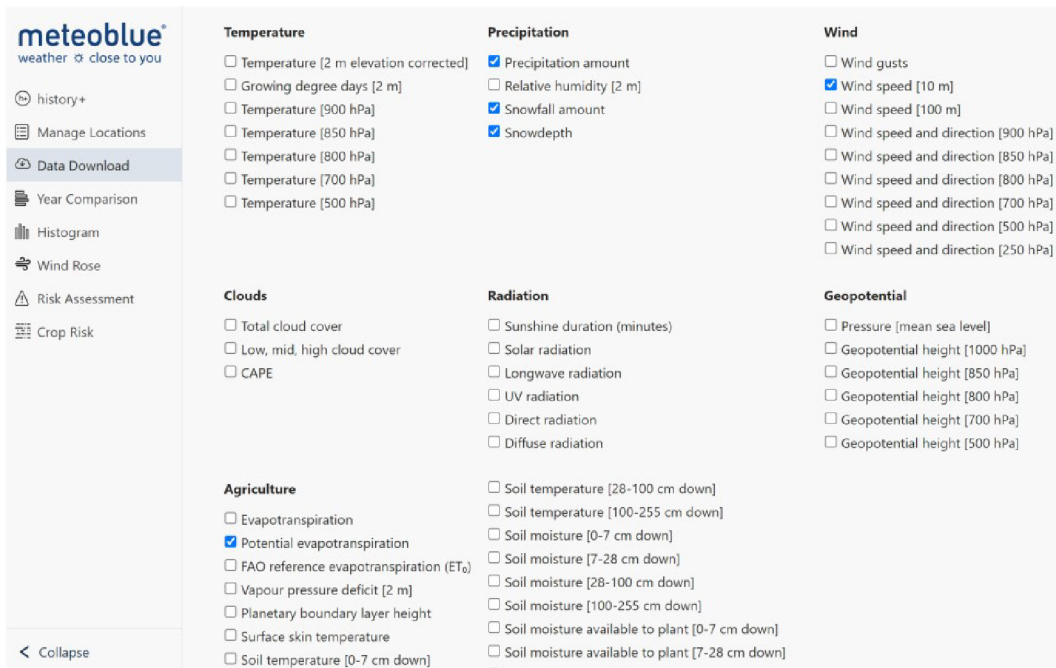

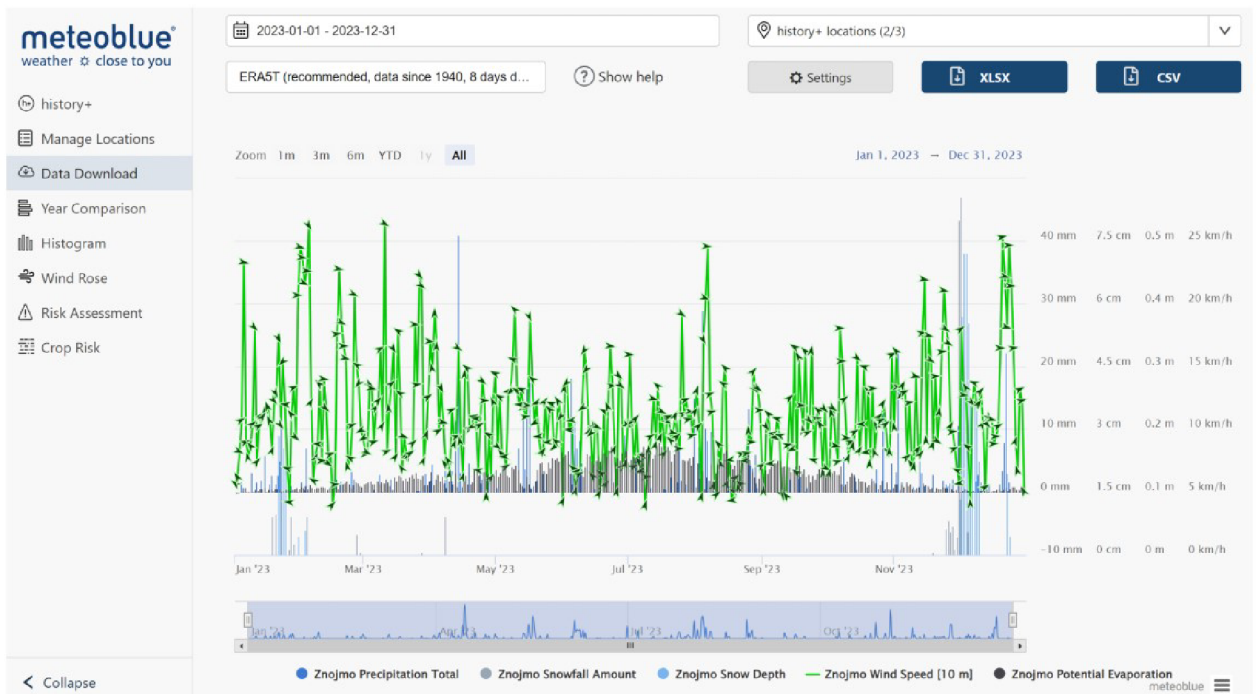Figure 2: Variables selected for data download on Meteoblue website (Meteoblue ©2024).

Figure 3: Graph displaying selected variables for the year 2023 before download as csv file (Meteoblue ©2024).

The European Soil Data Center (https://esdac.jrc.ec.europa.eu/) provided access to many different types of soil data, some of which was used to fulfill the variable requirements for EF and SCF (European Soil Data Center ©2024). Silt, sand, and clay percentages were found for most of Europe in the work of Ballabio et al. (2016), and later, the work of Ballabio et al. (2019) produced a map of $CaCO_3$ values, which also covered most of Europe. From these two databases, the values for sand, silt, clay, and calcium carbonate content were provided for the calculation of average soil loss. To access this information, it was necessary to visit the European Soil Data Center website. Under the "Soil Data" header on the left side of the main page, there is a drop down section called "Datasets" and the option "European Soil Database and soil properties" was selected. On that page and in Figure 4, two data sets can be found:

1) Maps of Soil Chemical properties at European scale based on LUCAS 2009/2012 topsoil data

(https://esdac.jrc.ec.europa.eu/content/chemical-properties-european-scale-based-lucas-topsoil-data) and

2) Topsoil physical properties for Europe (based on LUCAS topsoil data) (https://esdac.jrc.ec.europa.eu/content/topsoil-physical-properties-europe-based-lucas-topsoil-data).
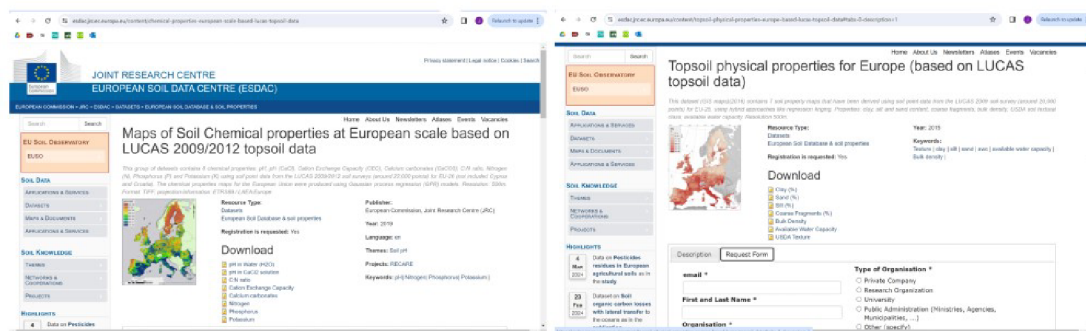
Figure 4: Web pages from the European Soil Data Center showing Maps of Soil Chemical properties at European scale based on LUCAS 2009/2012 topsoil data (left) and Topsoil physical properties for Europe (based on LUCAS topsoil data) (right) (European Soil Data Center ©2024)

The first provides data about the calcium carbonate content of the soil, and the second provides information about sand, silt, and clay content of the soil. To download this information, a request form was submitted for each dataset. After the request was approved, an email was sent to the address specified in the request form and the necessary information was downloaded following the link provided.

The final type of variable necessary for the calculation of average soil loss is the user entered variables. Irrigation must be added to rainfall within the WF equation, and therefore must be entered as the hourly irrigation in millimeters. For this study, irrigation was assumed to be zero to model a non-irrigated field. Organic matter content must also be entered by the user. For this study, the organic matter content was assumed to be 3% because measurements could not be taken from the selected field. The next few user entered variables also require some field measurements. To calculate the surface roughness, there are two types of measurements which need to be taken: plow ridge roughness and random roughness. The height of plow ridges and distance between plow ridges should be measured in the same units. Here, it is suggested to use centimeters, but as the two values are divided during the calculations, the actual units do not matter as long as they match. Figure 5 shows more clearly how these measurements should be taken. For this study, the measurements of the height of plow ridges and distance between plow ridges were set to 10 cm and 75 cm respectively. The distance between plow ridges was set to 75 cm to follow the study of Kelly (2015). The random roughness is measured using the chain method, which is described by Saleh (Fryrear et al., 2001a ex. Saleh, 1993). The chain method uses some sort of chain or rope to measure the random roughness of the surface parallel to the plow ridges. The chain is laid along a ridge, and a horizontal measurement is taken directly from one end of the chain to the other. In the calculations for K', this horizontal measurement is divided by the actual length of the chain when laid perfectly flat. Figure 6 demonstrates how the random roughness measurements can be taken. Like the ridge roughness measurements, the random roughness measurements can be taken in any units, as long as those units match. For this study, the measurements of the horizontal measurement and the length of the chain were set to 270 cm and 300 cm respectively.
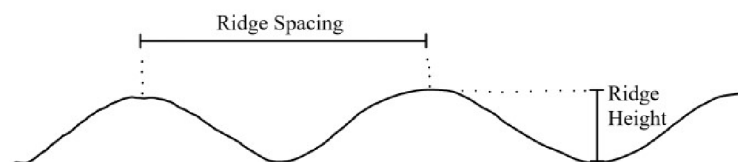

Figure 5: Ridge spacing and height measurements to calculate ridge roughness.
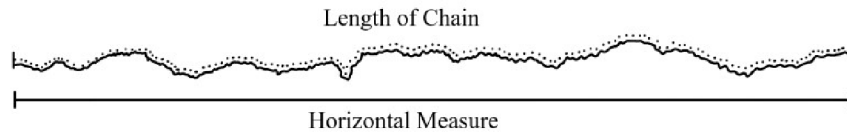
Figure 6: Length of chain and horizontal measurements to calculate random roughness.

The next variable which is provided by the user is the angle of the ridges. This angle should be measured in reference to the line perpendicular to the prevailing wind direction. The prevailing wind direction is found by taking the average of the wind directions provided in the Meteoblue data. In this study, the prevailing wind direction was 203.68° from north, or approximately south southwest. For this study, the rows were assumed to be at an angle approximately 190° from north, so the angle used in the calculations was 80°. Another variable provided by the user is the downwind distance. Downwind distance is measured parallel to the prevailing wind direction. This value is calculated in ArcGIS Pro using a polyline perpendicular to the prevailing wind direction. To make the perpendicular to this wind in ArcGIS Pro, a new polyline shapefile was created by right clicking on the project file in the catalog pane. Then, in the "Edit" tab, the "Create" function was used. Finally, a line was drawn to intersect the south southwestern most part of the field polygon at an approximate perpendicular to the prevailing wind direction. To calculate the downwind distance from this polyline, the polyline was transferred to a raster using the "Rasterize Attributes" function. Then, the "Distance Accumulation" function was used with the new rasterized polyline as the source raster. For this study, the maximum accumulation was entered as 2500 meters because the entire length of the field was approximately 2000 meters. The "Distance Accumulation" function, relevant ArcGIS Pro components, and resulting raster can all be seen in Figure 7.
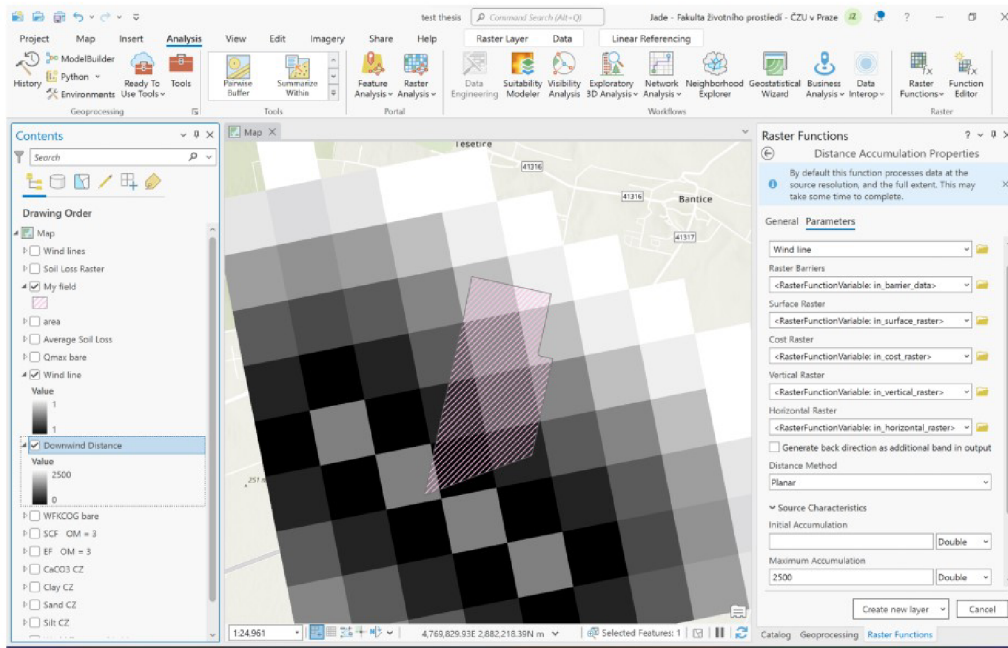
Figure 7: ArcGIS Pro window displaying the Downwind Distance raster (middle) created by using the Distance Accumulation function (right).

The last user entered variables are those involved in calculating crop cover information. The first is the percent of land covered by flat crop residue. This value should be estimated to the best of the user's ability. For this study, the value was estimated to be 10%. The remaining input variables are modeled in an hourly time step which will be explained in detail after the introduction of the variables. The percent of the soil surface covered by a crop canopy can be modeled based on the assumed time required to reach maturity. For this study, corn was the chosen crop, which reaches its full height approximately 85 days after being planted (Ransom and Endres, 2020). The number of plant stalks in a square meter area should be counted in an area that is representative of the whole field. The area should be roughly average, not clearly more or less dense than the rest of the field. This same square meter of field should be used to find the average diameter of plant stalks and average height of plant stalks in centimeters. If for some reason the stalks are not standing up straight, the height should not be measured as the full length of the stalk, but just as the height above the ground. For this study, all three of these measurements were based on a study in Oklahoma, which resulted in the stalks per square meter, average diameter in cm, and average height in cm to be equal to 4, 2, and 150 respectively (Kelly, 2015).

4.3 Organize Data

The next step of this process is to organize all the collected data so it can be used properly for the average soil loss calculation. First, it is important to create a new polygon to surround the field polygon. When clipping rasters, it is possible for some values along the edges to be lost and replaced with "No Data", so it is important to have a polygon larger than the agricultural field to avoid losing important values. To create a new polygon, the project folder in the catalog was right clicked, then "New", then "Shapefile" was selected. The shapefile was named, set to polygon, and the coordinate system set to match the existing shapefile for the agricultural field. Then, the "Create Features" function was used to draw in the new polygon surrounding the existing polygon. This function can be seen in Figure 8, along with the polygons representing the agricultural field (pink hatched), the slightly larger area (blue hatched), and the Silt raster behind both. The extra area extends large enough to be certain that all pixels used by the field are completely within the clipping area.
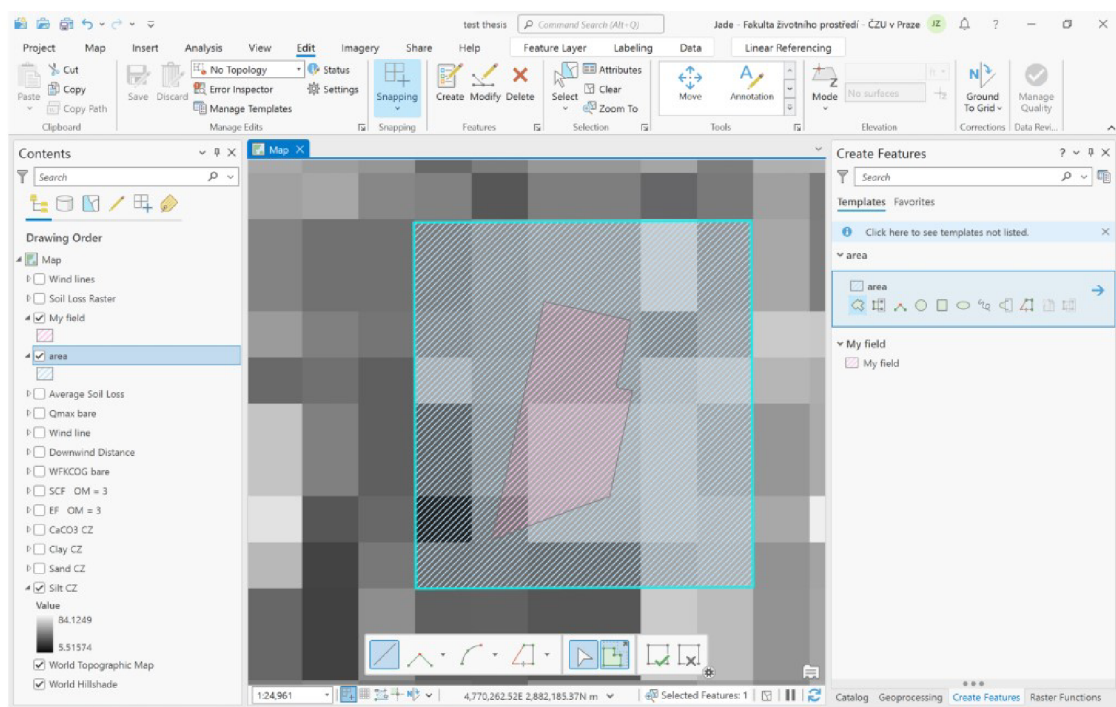
Figure 8: ArcGIS Pro window displaying a map with the chosen agricultural field, an extended area dedicated for future clipping, and the raster of silt content values to show pixel placement. The "Create Features" function can be seen on the right.

The weather data provided by Meteoblue was in the form of a csv file. This format made it difficult to work with efficiently in ArcGIS Pro, but perfect for use in

RStudio. Therefore, the file was read into an RScript as a data frame where it could calculate hourly WF values before being transferred into ArcGIS Pro. Before the data could be used for calculations, there were a few additions and adjustments which needed to be made. First, a variable called "numbers" was added to the data frame to make future "for" functions easier to use. This can be seen in line 5 of Figure 9. Next, the potential evaporation values were adjusted to change any negative values to 0 because RWEQ does not run properly with potential evaporation values entered as a negative number. This can be seen in lines 8-12 of Figure 9. Then, the wind speed values provided from Meteoblue were converted from the 10 m high wind speed to their correlating values at 2 m using equation (9) from FAO (1998),

$$u_2 = u_z \frac{4.87}{ln(67.8z - 5.42)} \tag{9}$$

where u_2 is wind speed 2 meters above earth's surface, z is the measured height above earth's surface, and u_z is the measured wind speed z meters above earth's surface. This can be seen in lines 15-17 in Figure 9. After these changes, all the data is ready to calculate the WF value which will be used to find average soil loss.

```
1  # load Znojmo data as city
2  city = read.csv("C:/Users/jadez/OneDrive/Documents/CZU/THESIS/Thesis/Znojmo 2023.csv")
3
4  # add numbers to make for functions easier
5  city$numbers = c(1:length(city$timestamp))
6
7  # fix potential evaporation values
8  for(x in city$numbers){
9    if(city$Potential.Evaporation[x] < 0){
10     city$Potential.Evaporation[x] = 0
11   }
12 }
13
14 # change windspeed to 2m instead of 10m
15 for(x in city$numbers){
16   city$Wind.Speed[x] = city$Wind.Speed[x] * 4.78 / log(672.58)
17 }
```

Figure 9: The organization of data from Meteoblue to prepare to calculate WF.

The soil data provided by the European Soil Data Center was in raster form, which was ideal for ArcGIS Pro. Because of this, the EF and SCF factors could be calculated completely within ArcGIS Pro, but before those calculations could be made, the data needed to go through some adjustments to make it more manageable. First, the calcium carbonate raster had some missing values which were filled in using the "Elevation Void Fill" function. For this study, the "Max Void Width" was set to 0 to fill in all empty spaces. Next, all the rasters were reprojected using the "Reproject"

function to match the projection of the field polygon. In this study, the S-JTSK Krovak EastNorth coordinate system was used for all rasters and polygons. Then, each of the four soil property datasets was clipped to the border of the Czech Republic using the "Clip" function and a polygon of the border. An example of the result is shown in Figure 10.
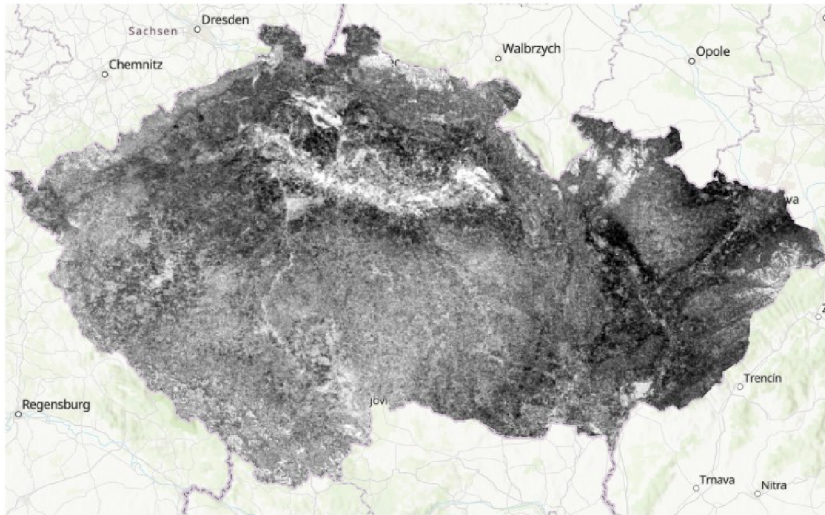

Figure 10: Percent of sand in soil content clipped to the border of the Czech Republic.

The rest of the input data, which consisted of constants and user entered values, was also entered into RStudio before being transferred into ArcGIS Pro so the process could be most efficient. The user entered values related to crops required to calculate the COG factor required some manipulation before they could be used in the equations from Table 2. First, the values for crop height, diameter, growing time, and number per square meter were entered into a data frame. Lines 65-75 of Figure 11 show the creation of the cropstats data frame. The height and diameter values were converted from their original units to meters, and can be seen in lines 66 and 67 respectively. The time of growth was reduced from 85 days to 60 days to account for the first 25 days after planting when there is no above surface growth. The 60 days were then multiplied by 24 to convert time into hours. This can be seen in line 68. The next step to organizing the crop data for calculations was to simulate the growth of the corn. Lines 73-79 in Figure 11 show the creation of a data frame to simulate crop growth. Each variable is set to a linear increase, although real growth isn't perfectly linear. Crop height starts at zero meters and increases a fraction of the final harvest height each hour of the time required to grow to full height. Lines 74 and 75 show this simulation. Crop diameter is the same, increasing from zero to full size by equal

intervals over the growing time, and can be seen in lines 76 and 77. Finally, crop canopy is calculated by finding the area of the stalk and then multiplying by 5 to account for the growing leaves. This is shown in line 79.

```
63   # Modelling corn growth
64   # harvest statistics
65   cropstats = c()
66   cropstats$height = 1.5   # m
67   cropstats$diameter = 0.02   # m
68   cropstats$time = 60*24   # hours (# of days *24)
69   cropstats$number = 4      # per sq m
70   cropstats = as.data.frame(cropstats)
71
72   # hourly time step of growth
73   crops = c()
74   crops$height = seq(from = 0, to = cropstats$height,
75                      by = cropstats$height/(cropstats$time-1))
76   crops$diameter = seq(from = 0, to = cropstats$diameter,
77                      by = cropstats$diameter/(cropstats$time-1))
78   crops = as.data.frame(crops)
79   crops$canopy = 5*pi*(crops$diameter/2)**2
```

Figure 11: Organization of crop data and modelling of crop growth.

4.4 Primary Calculations

The primary calculations are those that are required to define the five factors in equations (2) and (3). First is the calculation for hourly WF, which was completed in RStudio. Hourly WF values were calculated using a "for" statement and an "if" statement, which only calculated a value for WF when the three requirements described earlier were met. If any of the requirements were not met, the value for WF was set to zero because erosion was not possible during that time. Figure 12 shows the calculations for hourly WF values. Lines 21 and 22 show the requirements for a WF value to be calculated. Lines 23-25 contain equation (8) to calculate the hourly WF values.

```
19   # calculate hourly WFs
20 ▾ for (x in city$numbers) {
21     if(city$Wind.Speed[x] > 5 & city$Snow.Depth[x] < 0.024 &
22 ▾      city$Potential.Evaporation[x] > city$Precipitation.Total[x]){
23       city$WFs[x] = city$Wind.Speed[x]*(city$Wind.Speed[x]-5)^2 *
24         airdensity/g * (city$Potential.Evaporation[x] - city$Precipitation.Total[x])/
25         city$Potential.Evaporation[x] /24
26 ▴   }
27     else{city$WFs[x] = 0}
28 ▴ }
```

Figure 12: Calculating hourly WF values based on requirements and equation (8).

The next calculation is for K', the roughness factor, which can be seen in Figure 13. Lines 97-101 assign each variable with its corresponding value previously

stated. Then, lines 103-107 use the required equations from Table 2 to calculate K' and this value is saved under the name "K".

```
94   #  Calculate K'
95   #  K' is all user enter values
96
97   A = 80   # degrees from perpendicular to rows
98   RH = 10 # cm
99   RS = 75 # cm
100  displacement = 270 # cm
101  distance = 300      # cm
102
103  Rc = 1 - 0.00032*A - 0.000349*A**2 + 0.00000258*A**3
104  Kr = 4 * RH**2 / RS
105  Crr = (1 - displacement/distance) * 100
106
107  K = exp(1.86*Rc*Kr - 2.41*(Rc*Kr)**0.934 - 0.124*Crr)
```

Figure 13: Calculation of K' from values previously stated.

The final primary calculation in RStudio is for COG, the crop factor. Figure 14 shows the calculation of COG into an hourly time step to model corn growing. Lines 82-84 calculate the variables necessary for the COG equation in Table 2. Lines 86-89 separate the year into the different periods of crop growth. The growing period (line 86) uses all three variables calculated in lines 82-84 because this time period has flat residue from the previous year, standing residue in the form of growing crops, and a crop canopy from newly growing leaves. The periods before growth (line 87) and after harvest (line 89) use only the flat residue value because there is no standing residue or growing crops to affect wind erosion. The time period after growth (line 88) is only the final value of the growing time period because this is the time when the crops have reached maturity but are left in the field to dry before harvesting. In lines 91 and 92, these different time periods are put together with their corresponding amount of time to fill each hour time step of the 2023 year with a COG value.

```
81   # hourly COG
82   SC = 10   # percent soil covered by flat residue
83   CC = cropstats$number*crops$canopy # percent soil covered by crop canopy
84   SA = cropstats$number*crops$diameter*crops$height   # standing residue
85
86   growing = exp(-0.0438*SC/100)*exp(-0.0344*(SA**0.6413))*exp(-5.614*(CC**0.7366))
87   beforegrowth = exp(-0.0438*SC/100)
88   aftergrowth = last(growing)
89   afterharvest = exp(-0.0438*SC/100)
90
91   COG = c(rep(beforegrowth, 151*24), growing, rep(aftergrowth, 40*24),
92           rep(afterharvest, length(city$timestamp)-(191*24+length(growing))))
```

Figure 14: Calculation of hourly COG for a year.

To transfer these values into ArcGIS Pro the most efficiently, a final step must be taken to combine them into one value for the whole year. In the final calculations of equations (2) and (3), the five factors are multiplied together, so it is possible to multiply the WF, K', and COG factors before transferring them to ArcGIS Pro. For this study, two simulations were run: 1) with corn as the chosen crop and 2) bare soil, or no crop, which can both be found in Figure 15. This means the first value, named "GIScorn" in line 110, uses the calculated COG value, but the second value, named "GISbare" in line 111, doesn't use the COG value to show no impact on wind erosion from crops. For this study, GIScorn and GISbare were calculated as 3625.70 and 3686.79 respectively. These values were entered into ArcGIS Pro by creating a constant raster using the "Constant" function, and clipped to the area surrounding the field.

```
109   # value to put into GIS for the WF*COG*K'
110   GIScorn = sum(city$WFs * COG * K) # with corn
111   GISbare = sum(city$WFs*K)  # bare soil (no crop influence)
```

Figure 15: Combining WF, K', and COG into two values easily transferable into ArcGIS Pro.

The next calculations define EF, the erodible factor, and SCF, the soil crust factor. These calculations are completed entirely within ArcGIS Pro. To calculate EF and SCF, the raster function "Calculator" was used to create custom raster functions using the newly organized data. To calculate EF using the "Calculator" function, the variables are set to refer to the sand, silt, clay, and $CaCO_3$ rasters. At this time, organic matter can also be entered as a variable. Then, the equation for EF in Table 2 is entered into the "Expression" box. This process can be seen in Figure 16. Note that the calcium carbonate variable is divided by ten, although that isn't the case for the EF equation in Table 2. This is due to the incorrect units of the calcium carbonate raster, which was provided in g/kg, but needed to be in % for the calculation of EF. The same process is used to calculate SCF, which can also be seen in Figure 16. One difference between the two is the only required variables for the SCF calculation are clay and organic matter. After the creation of the custom functions, they were both run to create new layers of raster values representing EF and SCF.
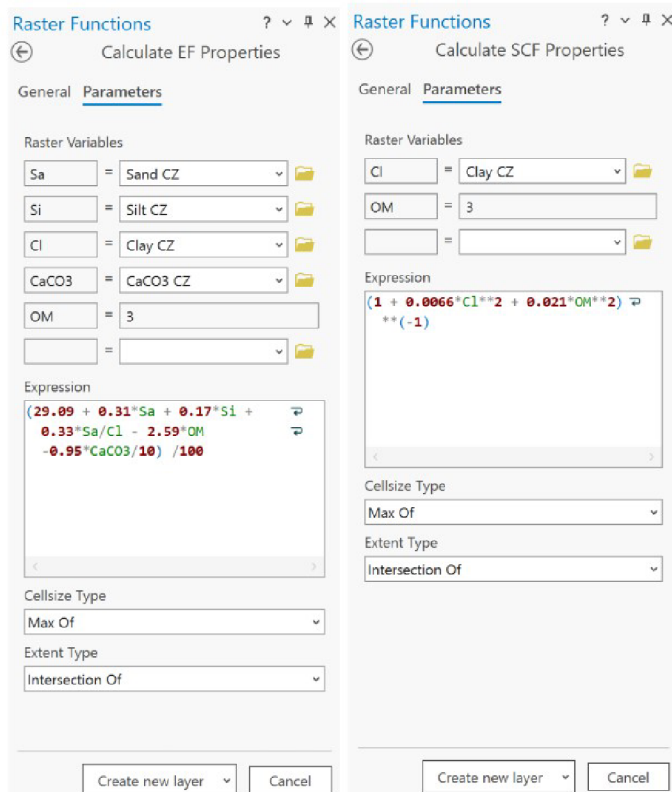
Figure 16: Properties of the custom function "Calculate EF" (left) and "Calculate SCF" (right).

4.5 Final Calculations for Average and Total Soil Loss

The final calculations are those which define maximum transport capacity, critical field length, and finally average soil loss. This final step utilizes equations (1), (2), and (3), which can also be found in Table 2. First was equation (2), maximum transport capacity. In ArcGIS Pro, the "Calculator" function will again be used, and equation (2) will be entered into the "Expression" box. In the previous step, the input rasters for this equation were created. The calculation of maximum transport capacity for the bare soil and the resulting raster in this study can be seen in Figure 17. The maximum transport equation can also be seen in Figure 18. Next was equation (3), critical field length, which uses the same process as before, only substituting equation (3). The calculation of critical field length for the bare soil in this study can be seen in Figure 18. Running both of these calculations produced a raster with their respective values.
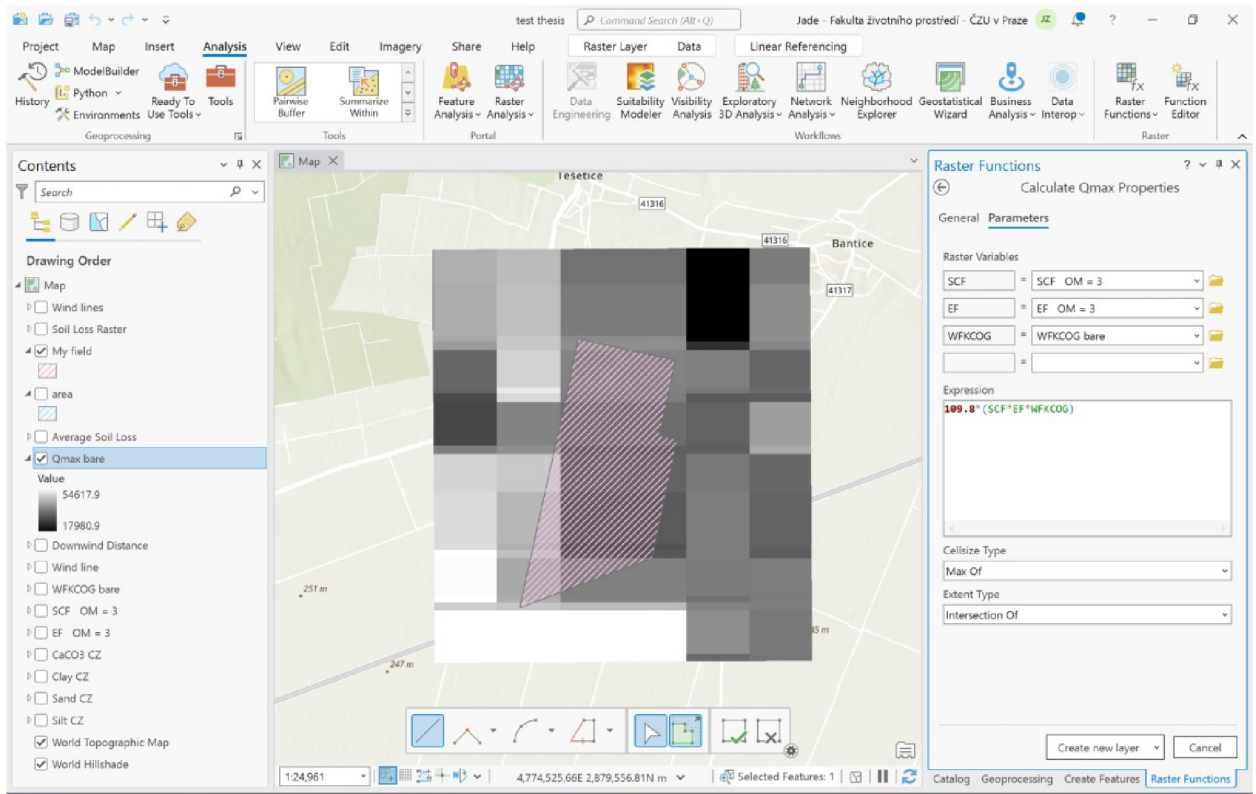
24

Figure 17: ArcGIS Pro window displaying the maximum transport capacity (Qmax) raster (middle) and the function used to create it (right).

Finally, the last calculation was performed with equation (1), average soil loss. The "Calculator" function was used a final time with inputs maximum transport capacity (Qmax), critical field length (s), and downwind distance (Z). Equation (1) was entered into the "Expression" box, and the result can be seen in Figure 18. The average soil loss raster layer produced can then be used to calculate total soil loss for the experimental field if desired. This calculation involves converting the raster layer into a polygon shapefile and making further calculations within the attribute table of the new polygons. More detailed instructions to find total soil loss are described in the results following the description of the average soil loss raster.
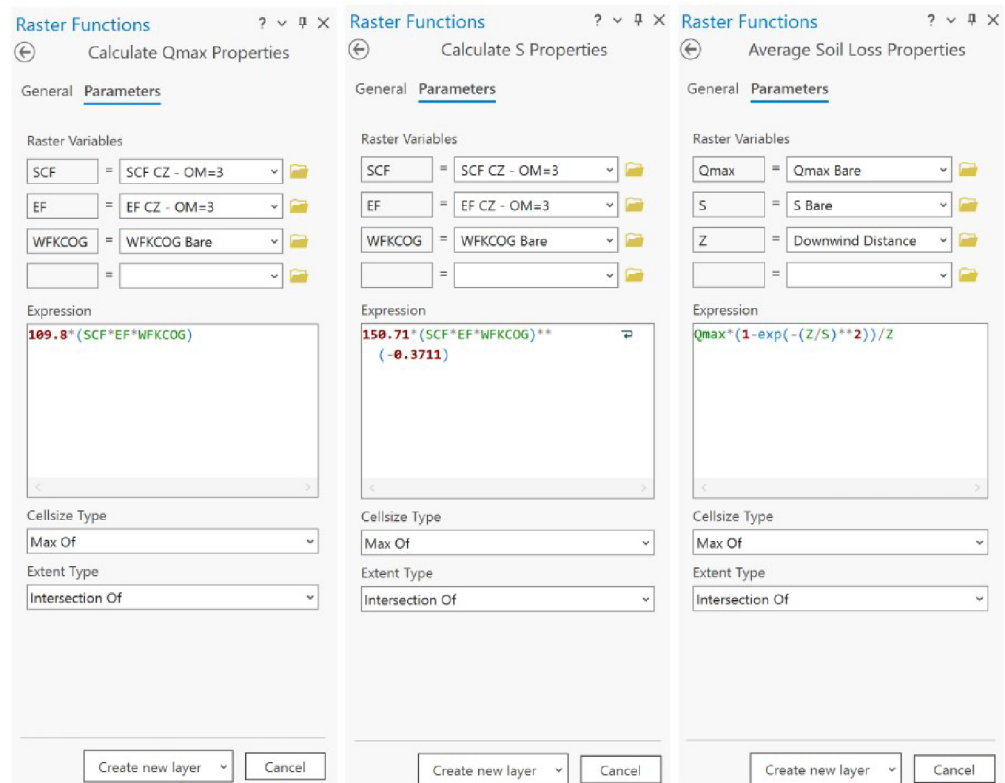
Figure 18: Calculation of maximum transport capacity (left) , critical field length (middle), and average soil loss (right) for bare soil.

5. Results

The main objective of this report was to suggest a wind erosion model using ArcGIS Pro. To accomplish this goal, an existing wind erosion model had to be chosen and modified to fit within ArcGIS Pro, which meant the chosen model had to be accurate yet relatively simple. From the literature review, the Revised Wind Erosion Equation (RWEQ) was obviously the best fit to meet those requirements. During the beginning stages of data collection and model building, it became clear that ArcGIS Pro would not be able to efficiently handle all the necessary calculations, so RStudio was added to the process to improve some primary calculations. In the end, two scenarios were considered, one with bare soil and one with simulated corn growth during the summer. Both took place on a field just outside the town Znojmo, which is located in the south of the Czech Republic and susceptible to wind erosion due to the surrounding flat landscape. The chosen time period was the year 2023.

Originally, a final raster layer was not able to be rendered due to unforeseen limitations of ArcGIS Pro. The exponential value in the final equation for average soil loss (equation 1) was too large for the calculation to successfully run. This limitation can be avoided by replacing the exponential value with -x and calculating the limit of the equation as x approaches infinity. Using this process, which can be seen in equation (10), an approximation can be made to produce a final raster layer.

$$S_L = \lim_{x \to \infty} (Q_{max} \bullet (1 - e^{-x}) \bullet Z^{-1}) \qquad (10)$$

As x approaches infinity, the factor e^{-x} approaches 0. Because of this, we can replace the e^{-x} factor with the number 0, which provides equation (11).

$$S_L = Q_{max} \bullet (1 - 0) \bullet Z^{-1} \qquad (11)$$

From this point, the equation can be further simplified to provide equation (12) which would be an approximation of the average soil loss.

$$S_L = Q_{max} / Z \qquad (12)$$

Using equation (12) in the "Calculator" function has the potential to produce a raster with "No Data" values due to imperfections with the downwind distance which was

manually created. Because of this, 50 meters was added to the downwind distance to remove any potential false zero values, which was experienced during this study. Therefore, the equation used to calculate approximate average soil loss was equation (13).

$$S_L = Q_{max} / (Z + 50) \qquad (13)$$

Equation (13) produced a raster with a minimum of 7.33283 and a maximum of 808.757 kg of soil lost per square meter for bare soil in the year 2023. Both the final raster and the function using equation (13) can be seen in Figure 19.
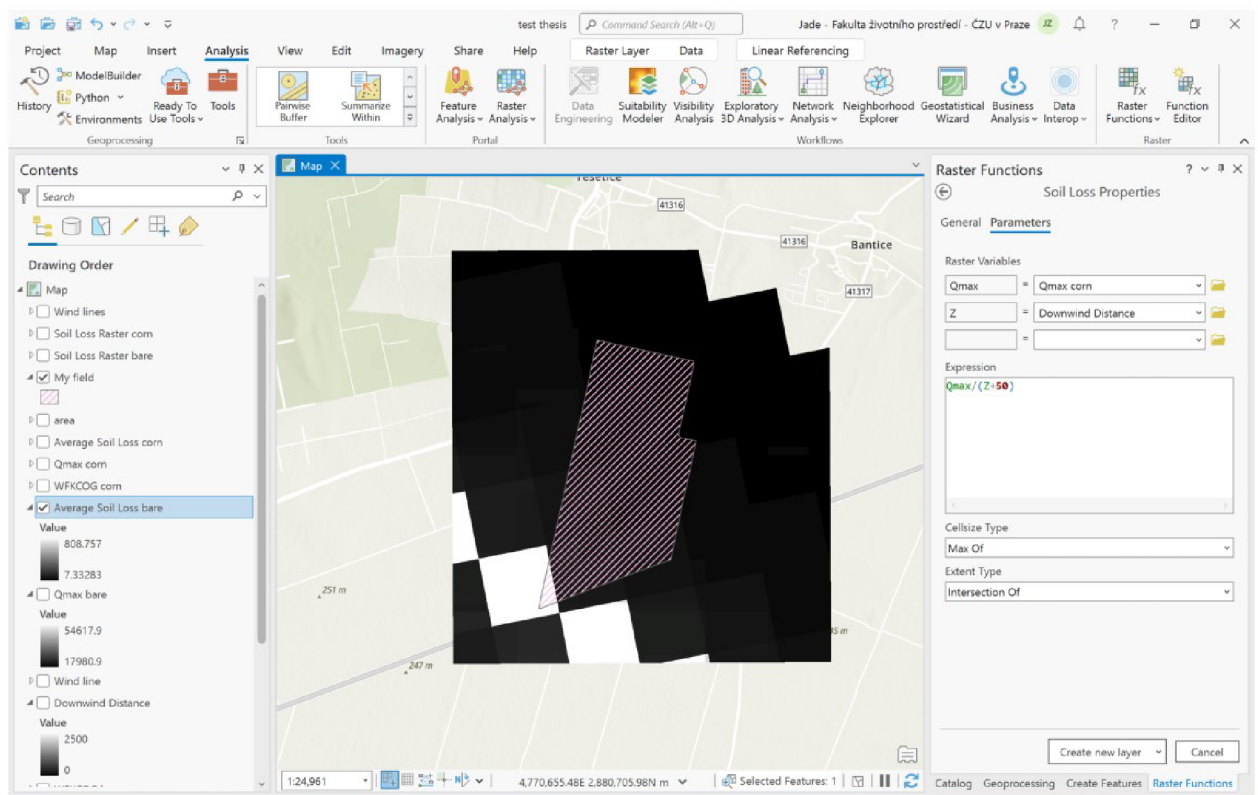
Figure 19: Final raster of average soil loss for bare soil with pink field geometry overlaid and custom raster function "Soil Loss" to approximate soil loss using equation (13).

The same calculation for the field with corn grown in the summer produced a raster with a minimum of 7.21132 and a maximum of 795.356 kg of soil lost for the year 2023, which can be seen in Figure 20. At first glance, the two produced rasters appear to be identical, with an unnatural range of values depicted by only two visually different colors. This is due to the extreme difference between the pixels where downward distance was calculated as zero meters compared to those farther from the start of the field, the smallest of which was 500 meters. The values for downwind

distance were the same for both calculations, and the reason for the large step between the white pixels and the black pixels in the rasters which would have been expected to show the whole range of grays between the black and white. Figure 21 is an example of a raster produced using equation (12), where some "No Data" values are calculated, but the range of other values can be more clearly seen by the color differences in the raster.
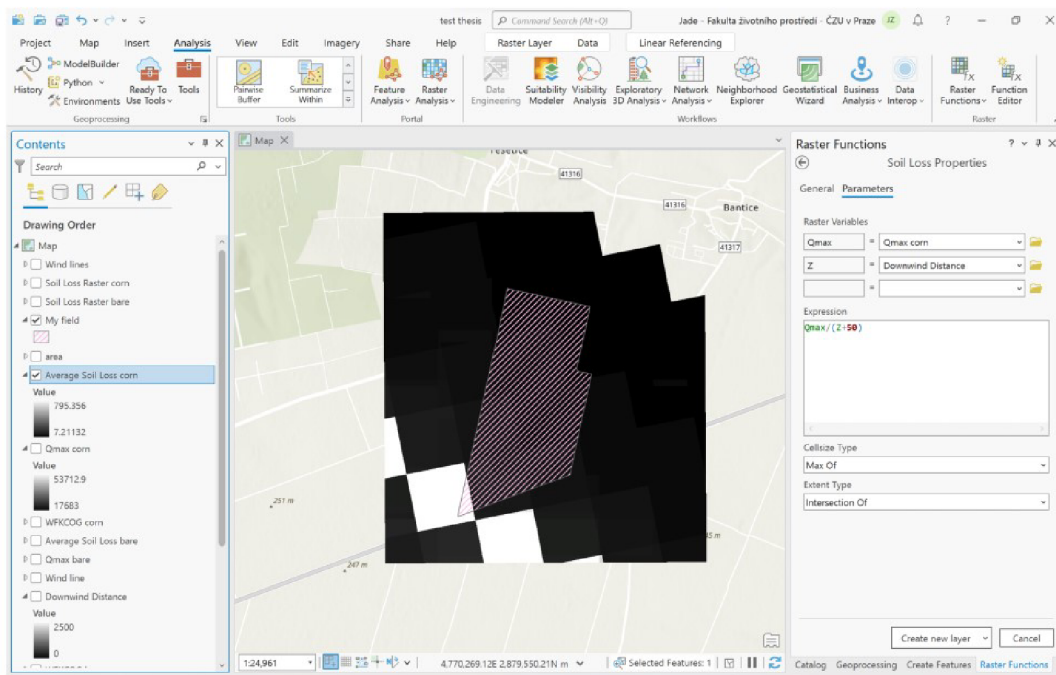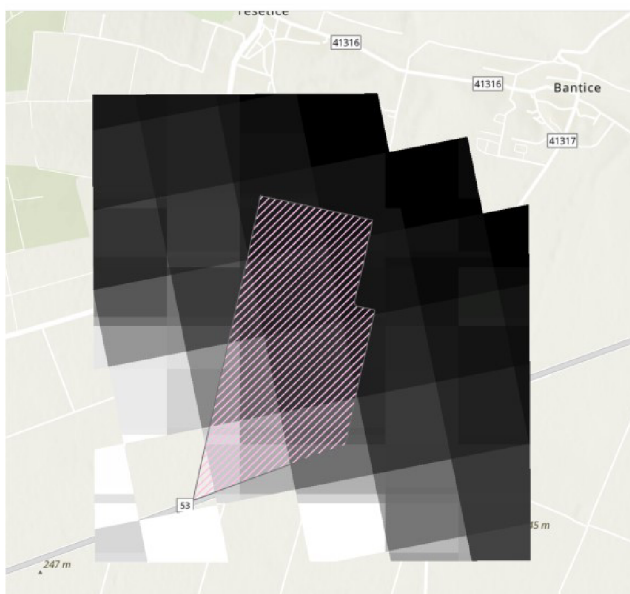

Figure 20: Final raster of average soil loss for soil with corn grown with pink field geometry overlaid and custom raster function "Soil Loss" to approximate soil loss using equation (13).

Figure 21: An example of the raster produced by equation (12). The southern corner of the agricultural field is located in a pixel with no data because the calculated downward distance was labeled as zero meters. This error is remedied by using equation (13), but then the range of values is not as easily seen as it is here by the different shades of gray visible throughout the raster.

To determine total soil loss from the average soil loss, each value needs to be multiplied by the area it covers on the field. This requires a few steps to be made. First, the raster needs to be multiplied by 100 to help keep more significant digits later. Using the "Calculator" or "Times" functions, the average soil loss can be multiplied by 100. Next, the newly produced raster must be converted into an integer type by using the "Int" raster function. Then, the integer raster needs to be converted into a polygon. This can be done by using the new raster in the "Raster to Polygon" tool in the "Geoprocessing" pane. The produced polygons can then be clipped to the size of the field and named "Soil Loss Raster". The polygons produced in this study can be seen in the "Map" pane of Figure 22. Finally, all extra rasters and polygons created in these steps can be deleted to clean up the "Contents" pane on the left side of the screen. The next steps are done in the attribute table of the Soil Loss Raster polygon, so it is required to right click on the name in the "Contents" pane and open the attribute table. In the attribute table, the "Calculate Field" function is used to multiply the average soil loss (now named gridcode) and the shape area together, and divide by 100 to return the value to the units kg/m^2. This variable should be set as a double and named "Soil Loss". The use of the "Calculate Field" function for this study can be seen on the right of Figure 22.
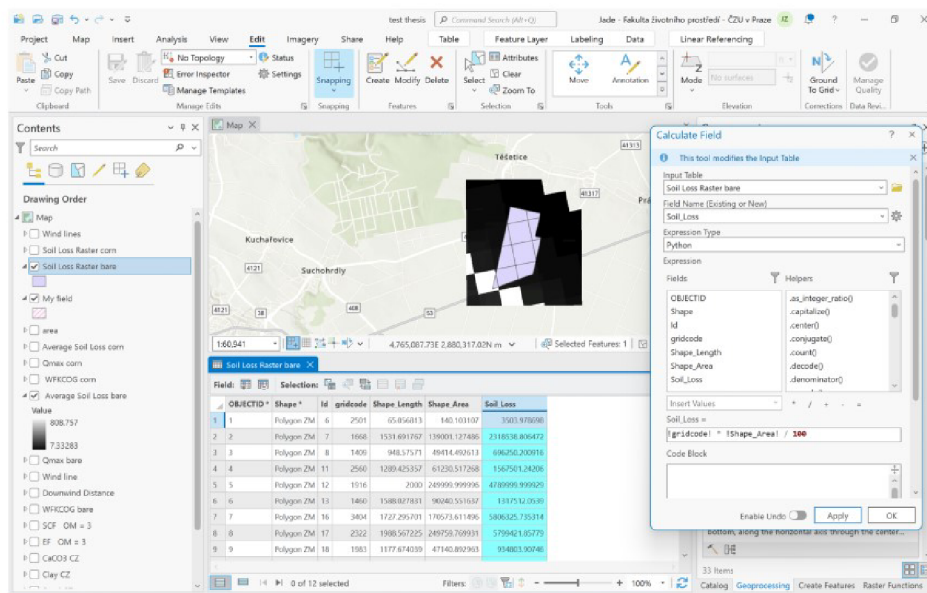

Figure 22: ArcGIS Pro window displaying the new shapefile named "Soil Loss Raster bare" which was used to calculate soil loss for the individual polygons (middle) by running the function "Calculate Field" (right).

Now each square in the field has a soil loss amount assigned to it, so the sum of all the areas is the total soil loss for the field. To find this value, it is required to right click on the "Soil Loss" column in the attribute table and select "Explore Statistics". A new window will open with various statistics for the polygons. The total soil loss is found by scrolling to the right to the "Sum" column, and the value is the total soil loss for the field in kg for the previously selected time period. The total soil loss for the bare field in this study can be seen in Figure 23.
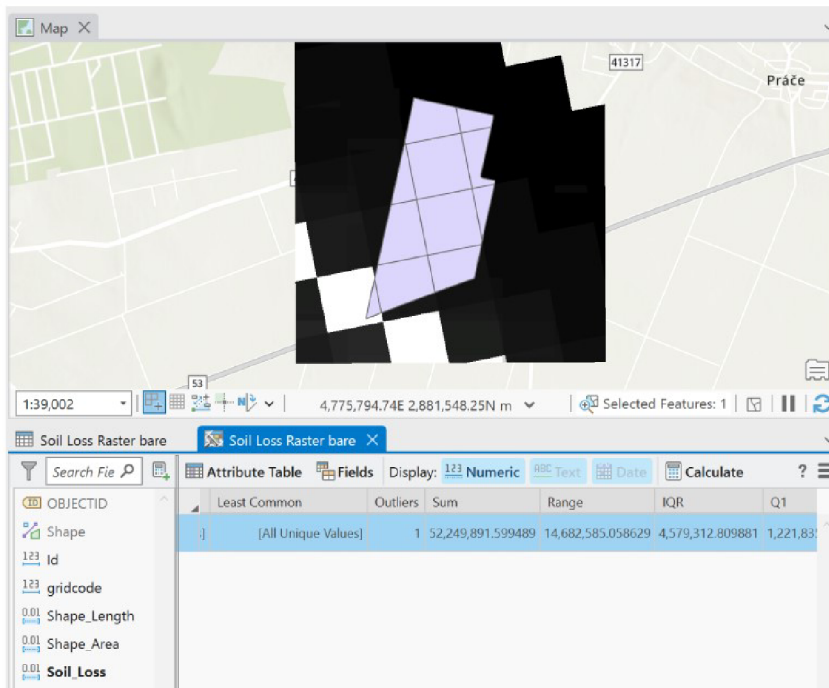
Figure 23: The total soil loss for a bare field near the village of Znojmo in the year 2023 was approximately 52,249,892 kg (57,595.65 tons).

The total soil loss calculated in the simulation of a field left bare for the year was approximately 52,249,892 kg (57,595.65 tons). The total soil loss calculated in the simulation of a field with corn grown during the summer months was approximately 51,384,969 kg (56,642.23 tons).

6. Discussion

For water erosion, it is possible to calculate a limit which defines when an amount of water erosion becomes unacceptable and mitigation measures must be taken (Li et al., 2009). As of today, the same cannot be said for wind erosion. Although a "tolerable" amount of wind erosion is mentioned in the work of Tatarko et al. (2019) related to wind erosion, this is still referring to the calculations associated with water erosion. Lacking a sustainable limit of wind erosion could be due to insufficient research on the topic, or it could be partially based on a very specific difference between the two types of erosion. While water erosion can only remove particles from an agricultural field, wind erosion has the ability to deposit particles onto the same area it has the ability to erode from (Sterk et al., 1996). This could make it difficult to set a limit of sustainable wind erosion because the erosion and deposition would both need to be taken into account. It is important for future work to find a limit of acceptable wind erosion in order to define when mitigation measures are necessary. Wind erosion modelling can calculate how much soil loss will occur, but without a threshold with which to compare calculated values, steps will not be taken to reduce soil loss.

For this study, hourly time step data was used. Wind speed is a factor with very high variability over time, and therefore could have been better if used as a daily value rather than hourly. In this case, it could have been beneficial to first modify the downloaded data to have a daily average calculated from the hourly values. This procedure could be performed using RStudio, similar to the other modifications made on the data before RWEQ calculations took place. The same process could be applied to values for precipitation and evaporation, which would result in daily values being calculated rather than hourly values, which might have introduced too much variability to the model process. To make this modification would likely require some previous knowledge of both ArcGIS Pro and RStudio. To follow the process as it is now does not require past experience in either application, although it could be beneficial.

In the two scenarios of this study, the field with no vegetation throughout the year experienced slightly more soil loss than the field with vegetation for part of the year. This conclusion is in agreement with previous studies and literature which state vegetation reduces wind erosion (Tatarko et al., 2019; Scheper, 2021). Scenario one,

with no vegetation, resulted in approximately 864,923 more kilograms of soil lost to wind erosion from the whole experimental field. This seems like a large difference, but in reality, both fields experienced such a large amount of wind erosion that scenario two, with corn, experienced approximately 98.3% of the amount that scenario one experienced. These values are much closer than expected, which could be due to the inaccuracy of the downwind distance raster. The pixel size of the downwind distance raster was 500 meters for both height and length, giving a total area of 250,000 square meters for each pixel. Each pixel of course has the same value, which means 250,000 square meters of field are generalized into one value which realistically should be hundreds of different values. This was an unexpected drawback which may be the source of the similar results from the two scenarios.

Despite being a relatively simple model with few required inputs, it was necessary to further simplify RWEQ to make the calculations manageable. These simplifications could have introduced some error in the calculations, which was not avoidable in this study, but should be avoided when possible in the future. It would also be beneficial for future developments to include an interface which could perform both the ArcGIS Pro and RStudio functions so the process is all in one place rather than using two applications. The creation of a weather database similar to the one created based on the United States would elevate the quality of the model as well. Overall, this study created a base which could be improved by future developments to include more detail and accuracy with similarly simple steps. With an increased number of scenarios, more information could be gathered about potential improvements of the ArcGIS Pro RWEQ model.

7. Conclusion

Wind erosion is a worldwide problem that causes soil degradation and reduces productivity of agricultural land (Zhao et al., 2021). Fortunately, certain measures can be taken to minimize wind erosion and its impacts on arable land. Modelling wind erosion can help discover which mitigation measures would be most efficient, which is why this study was focused on the development of a wind erosion prediction tool which could be used by anyone. Widespread use of a simple and accurate wind erosion model could greatly improve agricultural sustainability everywhere from the largest commercial farms to the smallest family-owned plots. To accomplish this goal, the Revised Wind Erosion Equation, ArcGIS Pro, and RStudio were combined into an easy-to-follow process for calculating average soil loss.

First RWEQ was studied and modified to better fit the requirements of ArcGIS Pro and RStudio. This step involved careful observation of source materials (Fryrear et al., 2001a), and implementation of algebraic conversions to change existing equations into ones to better suit the applications. Then, the data was actually collected. Much of the required data is extremely specific to the individual field that will be modelled, so that information must be manually entered. Some data, namely weather and soil data, was found on public databases. The weather data was provided by Meteoblue, and the soil data was provided by the European Soil Data Center. After the data was collected there was a small amount of preparation before the equations could be performed. Next, the equations were used, first in RStudio and then in ArcGIS Pro.

This study achieves its goal by providing a wind erosion model using GIS which could be used by people with any level of training or education. That accomplishment is an important step in the further development of user-friendly wind erosion models, and as such, this study is a base for future research to improve upon. A research project QK23020013 "Setting of DZES 5 measures to protect agricultural land from wind erosion and drying of the landscape" at the University of Life Sciences in Prague is taking place to further develop this concept, but development across Europe or even worldwide could be possible in the near future. Along with the development of wind erosion modelling, it is important that a wind erosion limit is established to create a threshold of tolerable soil loss for comparison for all future work.

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