Estimating the soil erosion risk of the UMBC landscape.

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Abstract
This study analyzes the potential soil erosion risk across the campus of University of Maryland, Baltimore County at 1-meter resolution. Using a simplified Universal Soil Loss Equation, slope, soil erodibility, and land cover factors were used to calculate the erosion risk across campus. The results of this study were compared to current lower resolution maps that have already been made, such as the Global Forest Watch erosion map that showed higher levels of erosion on the north side of campus. It was found through this study that there are high risk areas all around campus, specifically the southern and eastern sides of the study area. Each of the factors played large roles in the final risk calculation. Where there where high slopes with little vegetation there was high risk of erosion, and where there were high slopes with heavy vegetation there was low risk of erosion. The results of this study show very specific locations around campus that are potentially at risk of soil degradation that will affect the functionality of the campus and the health of the surrounding environment. This erosion map, although just an estimate, clearly shows areas that are in need of stabilization if there aren't already management practices being implemented. It is shown that vegetation has a large impact on the structural stability of the soil and that it helps immensely decrease the erosion risk.

1. Introduction

University of Maryland Baltimore County (UMBC) has become increasingly more of an urban landscape over time, which has changed the way that sediment moves across the landscape. With all of this development, the erosion potential of the soil surrounding UMBC, has increased, but the question is where. This project aims to assess the soil erosion risk of UMBC by locating the highest risk areas, and then proposing solutions that would help stabilize those high-risk areas. This is important to the functionality of the landscape of UMBC because the less stable soil becomes, the more erosion occurs, which leads to higher sediment runoff and therefore, increased pollution. Soil erosion also diminishes the quality of the soil and reduces productivity, which then damages the microbes and plants that utilize the nutrients (Pimentel 2005). The features implemented in the hotspots of erodibility will provide ecosystem services to the campus by mitigating runoff and stabilizing the surrounding soil. Global soil erosion maps from Global Forest Watch Water include UMBC but are at a 450-meter resolution. This resolution is good for creating a global map like they did, but this study aims to create a 1-meter resolution map. The Global Forest Watch Water map shows that the northern area of campus has a higher erosion risk value than that of the southern side of campus. Because the resolution is so big, key factors could have been missed that would have caused the south side of campus to also have high risk. The finer resolution mapping done by this study will help to either confirm or deny the data shown by the Global Forest Watch Water map, as well as potentially identify new areas of high risk around campus. A study done in the Koppel District in India uses the Universal Soil Loss Equation (USLE) to map out this type of data (Chandramohan et al. 2002). Another study, at a much larger scale, was done for the entire European continent, in which they also used USLE, but was more of an estimate, and was almost entirely done using remote sensing and known European soil data (Panagos et al. 2015). This equation is used mainly by the USDA to calculate the annual loss of soil in rural and agricultural areas. Despite it not normally being used in urban areas, it is still a good equation to use to create an estimate of the risk of soil erosion in any area. The Universal Soil Loss Equation includes 6 factors: R factor for annual rainfall, K factor for soil erodibility, LS factor for slope and slope length, C factor for cropping/land cover, and P for management practices factor (Stone et al. 2005). Since this project takes place on a much more local scale, the erosion potential map will be produced using only a few of these variables. Rainfall will be held as a constant since the study area is small enough that rainfall amounts will be the same across campus. The P factor will be held constant since the study is looking specifically at an urbanized area. This project will deal with the rest of the factors that make up the equation: soil type, slope, and land cover to carry out the analysis. The extent of the project will include the UMBC campus as well as a 40-meter buffer outside of Hilltop Circle, as shown in Figure 1. This area was chosen because the study aims to analyze the interior, more urbanized part of UMBC, and the 40-meter buffer outside serves as a comparison since it is less urbanized. UMBC plans to develop much more in the coming years as observed by the Master Plan provided by Facilities Management. This study will be an introduction to many more soil studies to be done in the future. As more impervious surfaces are created, and soil is disturbed and moved around, the data provided by this study will be changed and will have to be reexamined. This study still gives an estimate as to the erosion potential across campus at this point in time and will clear a path for a more in-depth study to be done in the future.

2. Data

2.1 Aerial Imagery

Aerial Imagery downloaded from the USGS Earth Explorer website, and provided by the United States Department of Agriculture, was used to provide a high-resolution imagery of the campus. It is NAIP GEOTIFF imagery at 1-meter resolution with 4 bands. There was imagery of the entire state of Maryland, but this specific clip was selected and downloaded since only the campus was needed. The imagery is from 2017 and provides the most accurate view of the campus. This imagery was only being used for a reference when creating soil sampling points, as well as a reference map for the final erosion risk map that was made.

2.2 LiDAR Imagery

LiDAR imagery received from Professor Erle Ellis of UMBC was used to create the slope map of campus. The LiDAR image is 1-meter resolution and covers the entire UMBC campus as well as the Conservation and Environmental Research Area (CERA). The imagery was previously made into a Digital Elevation Model (DEM) of campus, that showed the ranges of elevation across the area. The collection the LiDAR imagery was organized by Professor Erle Ellis and was done in the UMBC Baltimore area and the Edgewater area. This was used to create a map showing slope around campus.

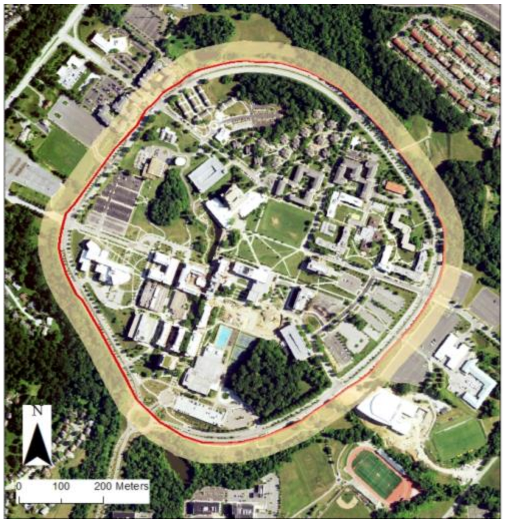

Figure 1: This map shows the study area, which includes the campus within the red line around Hilltop Circle, and the 30-meter buffer. NAIP GEOTIFF imagery courtesy of US Geological Survey.

2.3 Land Cover Data

Campus land cover data was gathered from the Chesapeake Conservancy Land Cover Data Project. This project was finished in 2016 and took over 10 months to complete. The project analyzed 100,000 square miles of land around the Chesapeake Bay watershed, which also included the UMBC campus. The project was aided by the University of Vermont and Worldview Solutions, and was created for the Chesapeake Bay Program. The Chesapeake Conservancy states that this project provides "900 times the amount of information as conventional 30-meter resolution land cover data". This project was able to distinguish things that normally would be generalized in a larger resolution map, such as tree cover over impervious surface, or individual streets and small vegetative patches. Land use/cover data was originally going to be collected from the GIS Specialist at Facilities Management, Will Wiley, and Professor Joe School. This data was from around 2015 and didn't include new features that had been added to the campus. It included impervious surfaces that were split up into different categories, and also included vegetative areas. The issue with this data was that since there was some construction occurring around campus at the time, there were some large portions of vector data missing. Much of the data was also overlapping since it had never been used to make a map like the one being created in this study. After working with this data for some time, it was decided to look for something that was more current and easier to use. The Chesapeake Conservancy project provides 1-meter resolution land cover data for the UMBC campus, in which the vector data was much cleaner and allowed for a better analyzation.

2.4 Soil Texture Data

Soil type data was collected in the field using the simple technique of soil particle separation in a jar to gather percentage of sand, silt, clay and organic matter. Previous soil texture studies have been done for the Baltimore area, but they were very generalized and were not at the extent that this study was at. Data will be collected in order to analyze the different soil textures around campus, especially the interior of campus versus the exterior. The values from this field work will be used in the K factor equation for soil erodibility. Other factors for this equation such as permeability class and soil structure code will be determined using techniques from Tilligkeit (2012).

3. Methods

3.1 Slope Factor Map

The DEM made from LiDAR Imagery was used to create the slope map of campus. The data was first downloaded and then loaded into ArcGIS. Accessing the Spatial Analyst Toolbox in ArcGIS, the slope tool was used to create a map of slope from the DEM. This tool measures the change in elevation from each cell, and then assigns a new number between 0 and 90 degrees to each cell. These values were used as the slope factor for the final equation. The actual factor in the Universal Soil Loss Equation is LS, or slope and slope length. This factor also includes the length of the slope, not just the angle of the slope. For the purpose and simplicity of this study, only the slope angle was used for the effect of slope on soil erosion risk. Higher degree slopes will still produce higher soil erosion risks and lower degree slopes will still produce lower soil erosion risk despite the length component being removed. This is proven by a study done by Duley et al. (1932) in the Journal of Agricultural Research, where 3 different slopes were created to see how erosion differed on each. The conclusion was that soil erosion was not only dependent on the texture of the soil, but also the degree of slope that was at play (Duley et al. 1932). The slope map was completed as shown in Figure 6, and the raster was then used in the final calculation for soil erosion risk.

3.2 C Factor Map

The first land cover map was made using a method from a study done by Chatterjee et al. (2014) in Jharkland, India. The study assigns C factors to 5 specific land use/land cover classes which was replicated in this study and used in the final erosion risk calculation. The 5 classes include: Built Up, Agricultural Land, Dense and Sparse Vegetation, Barren Land, and Water Bodies (Chatterjee et al. 2014). The C factors for these classifications were matched up to the classes provided by the Chesapeake Conservancy. The data that was collected uses specific land cover classifications and was more specific than the 5 classes that were being used. A new field was created in the attribute table for this raster, and the corresponding C Factor was assigned to each of the 10 classes. This assigned the 10 different classes 4 different values. This raster was placed into the erosion risk calculation and it was observed that the value field containing values 1-12 was being used in the calculation instead of the C factor field. To get around this, the Lookup tool was used in ArcMap which creates a new raster from a certain field in another raster. Using this tool, a new raster was created that mapped only the 4 different C factor classes. The map was completed as shown in Figure 5 and used in the final erosion risk calculation. Each land cover class and its corresponding C factor is shown in Table 2.

3.3 Collection of Soil

Soil collection was done using stratified random sampling with 200 meter by 200 meter plots. In ArcGIS, the Fishnet tool was used to create the grid, which included 28 squares to cover the study area. The Create Random Points tool was then used to generate random points within each of those squares. Once the points were made, they were then modified to either be within the study area or moved from an impervious surface to a surface with soil. The collection took two full days to complete with both collection days within two weeks of each other. A GPS was used to navigate to each location, and 28 jars were filled with soil from each point. The jars were then filled with water and a teaspoon of soap and shaken until the soil particles are suspended. After 1 minute, the sand composition was measured with a ruler in centimeters. After 6 hours, the silt composition was measured. After 24 hours, the clay composition was measured. The remaining organic matter floated to the top and was estimated. The percentage of each particle was calculated, dividing the found particle amount by the total depth of soil sample.

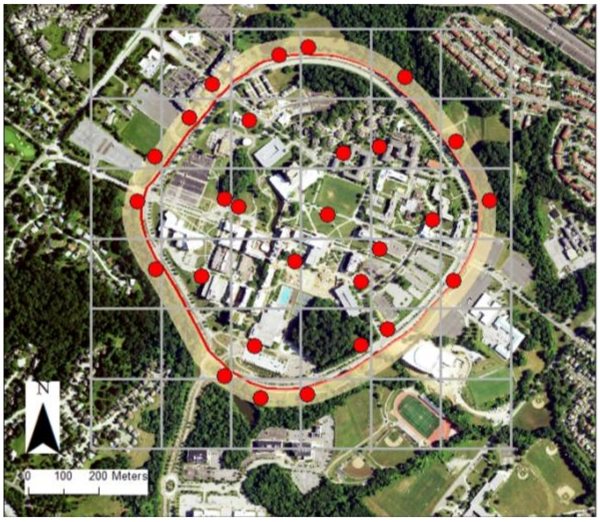

Figure 2: Map showing the stratified random sampling done for the UMBC campus. Includes 28 points that will be sampled. NAIP GEOTIFF Imagery courtesy of USGS.

3.4 K Factor Map

Once all the data was collected, it was recorded into a spreadsheet for analyzation. Using the USDA Soil Texture Calculator, the soil texture was calculated for each point. This calculation is done by taking the percent of sand, silt, and clay, and plugging those numbers into the soil texture triangle as shown in Figure 3, which was retrieved from the USDA Soil Survey Manual (SSDS 2017). After this was done, the permeability rates were determined for each soil texture using information from a soil infiltration presentation by C. Chavez's of the NRCS. These permeability rates were then used to calculate the permeability code of each texture. The permeability codes for each permeability rate were gathered from J. Tilligkeit (2012), where the values ranged from 1 (rapid) to 6 (very slow). The soil structure was then determined using a field book from the NRCS that shows the different structures and their names (Schoeneberger et. al 2012). Once the structure was determined, structure codes were then used from J. Tilligkeit (2012), where the values ranged from 1 (very fine granular) to 4 (blocky). The percent of sand, silt and clay, the permeability code, and the structure code will then be placed into Equation 1 and 2 to determine the K factor for each soil sample of campus. These equations were gathered from Addis et. al (2015) who originally obtained it from Wischmeier and Smith (1978). J. Tilligkeit (2012) also used this equation in their analysis. Equation 2 is calculated first, where C is percent clay, L is percent silt, and Armf is percent sand. This equation creates the M factor which is then used in Equation 1, where OM is percent organic matter, M is the M factor, St is the structure code, and Pt is the permeability code. The data was then used in these equations which then produced the K factor for each sample point. The data and results are shown in Table 1. The data spreadsheet containing all of this information was then loaded into ArcMap and joined to the soil points shapefile. One this was done, the Spatial Analyst IDW tool was used to interpolate the points for the study area. When this was done, an IDW map was created, but wasn't ready for use in the final erosion risk calculation. The IDW was in WGS 1984 projection since that was the projection the GPS points were in. The resolution was also not the same as the other created rasters. Using the Project Raster tool in ArcMap, the IDW was projected to NAD 1983 UTM Zone 18N, and resolution was decreased to 1 meter by 1 meter. The final K Factor map is shown in Figure 4.

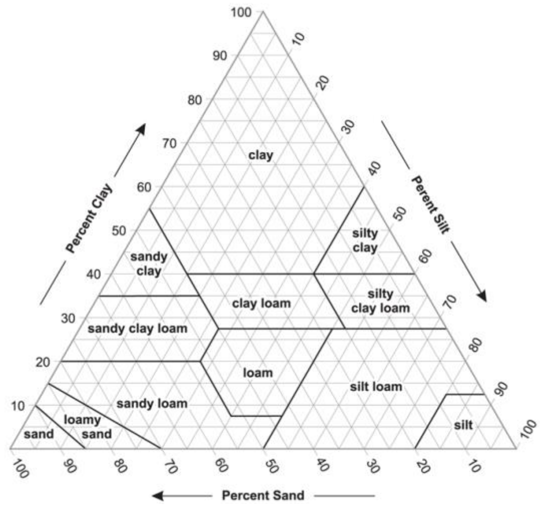

Figure 3: The soil texture triangle shows how the USDA calculator determines what the soil texture is based on the percent of each of the soil particles. Soil texture triangle courtesy of the USDA Soil Survey Staff.

$$K = [2.1 \times 10-4(12 - OM) \times M1.14 + 3.25 \times (St - 2) + 2.5 \times (Pt - 3)] / 100$$

Equation 1

$$M = [(100-C)(L+Armf)$$

Equation 2

3.5 Soil Erosion Risk Map

All of the raster images will be compiled into ArcGIS. Using Raster Math, the rasters will be overlaid. Values will be added to each other, which will create pixels with values that range from very high to very low. Pixels will be assigned a high to low risk based on the value they have. This will create a map that shows areas of soil that are at high risk of erosion or low risk of erosion based on the data gathered.

4. Results

4.1 K Factor Map

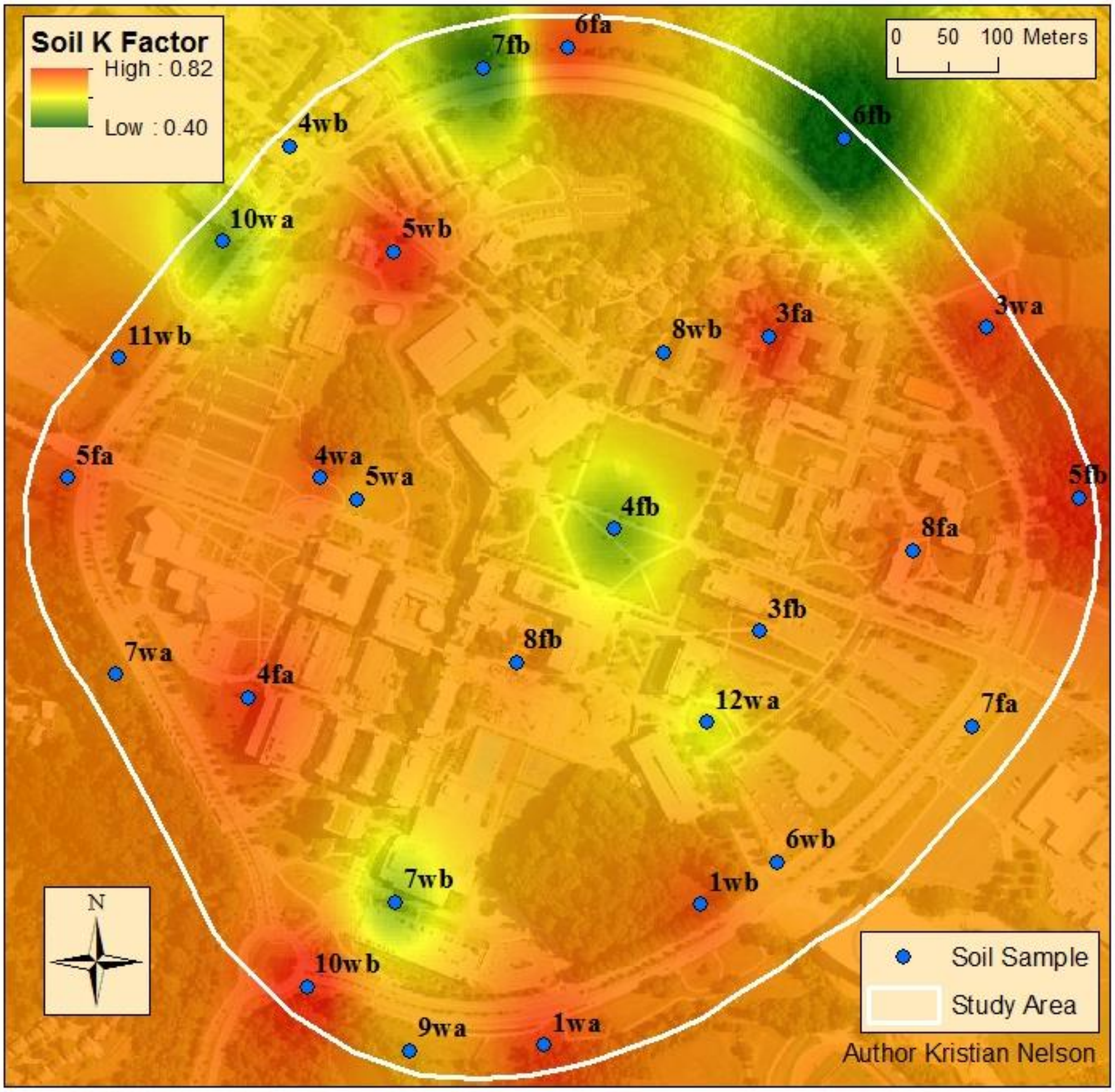

Figure 4: This map displays the interpolated K factor of all 28 sample points taken around UMBC Campus. The map corresponds with Table 1, where the higher K factors are displayed in red and the lower K factors are displayed in green. The higher the K factor, the more erodible the soil is. Map created by Kristian Nelson. NAIP GEOTIFF Imagery Courtesy of USGS.

4.2 K Factor Table

Location	% Sand	% Silt	% Clay	% Organic Matter	Soil Type	Permeability Code	Structure Code	K Factor
5fa	45	52	2	1	Silt Loam	3	2	0.7916432
4fb	42	53	1	4	Silt Loam	3	2	0.56877214
5fb	12	87	0	1	Silt	4	1	0.82165572
4fa	3	95	1	1	Silt	4	1	0.80277759
1wa	6	92	1	1	Silt	4	1	0.80277759
5wb	11	88	0	1	Silt	4	1	0.82165572
3fb	35	62	1	2	Silt Loam	3	2	0.72805333
3fa	10	88	1	1	Silt	4	1	0.80277759
6fa	48	49	1	1	Silt Loam	3	2	0.80085866
6wb	0	94	5	1	Silt	4	1	0.72969544
3wa	0	98	1	1	Silt	4	1	0.80277759
7wa	34	64	0	2	Silt Loam	3	2	0.74510422
7fb	0	95	0	5	Silt	4	1	0.49591047
6fb	70	21	3	6	Sandy Loam	2	3	0.40432362
10wa	13	83	0	4	Silt	4	1	0.57473524
12wa	0	96	1	3	Silt	4	1	0.64005272
7fa	0	97	1	2	Silt	4	1	0.72055333
4wb	54	43	0	3	Sandy Loam	2	3	0.6702986
10wb	28	71	0	1	Silt Loam	3	2	0.82915572
7wb	66	25	6	3	Sandy Loam	2	3	0.58179462
5wa	66	30	2	2	Sandy Loam	2	3	0.71872371
11wb	57	38	4	1	Sandy Loam	2	3	0.76260283
8fb	0	98	0	2	Silt	4	1	0.73760422
1wb	73	23	3	1	Sandy Loam	2	3	0.78075184
4wa	75	21	3	1	Sandy Loam	2	3	0.78075184
8wb	61	35	2	2	Sandy Loam	2	3	0.71872371
9wa	62	34	2	2	Sandy Loam	2	3	0.71872371
8fa	37	59	3	1	Silt Loam	3	2	0.77325184

Table 1: This table shows the data collected from each sample point around the UMBC campus. The percent of each particle is shown, as well as the soil type, structure code, permeability code, and final K factor. Table created by Kristian Nelson.

4.3 C Factor Map

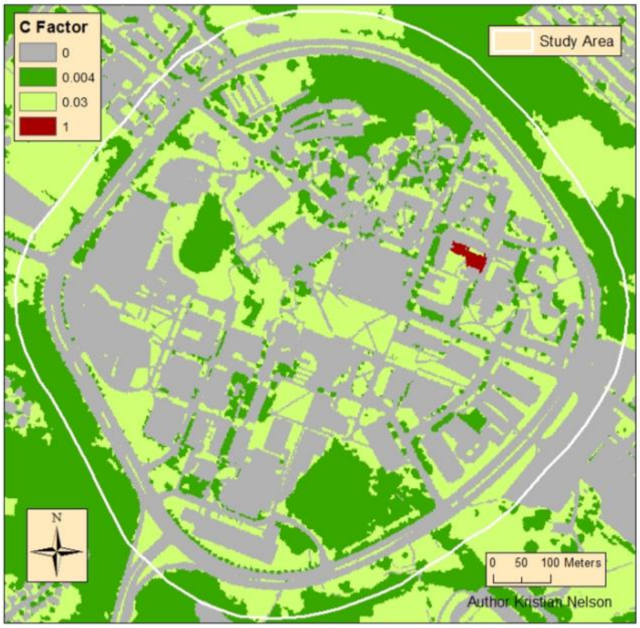

Figure 5: This map shows the C factor values for the UMBC campus. Factors were assigned to specific land cover classes as shown in Table 2. Land cover data, classes, and map provided by the Chesapeake Conservancy Land Cover Data Project. Map made by Kristian Nelson.

4.5 Slope Factor Map

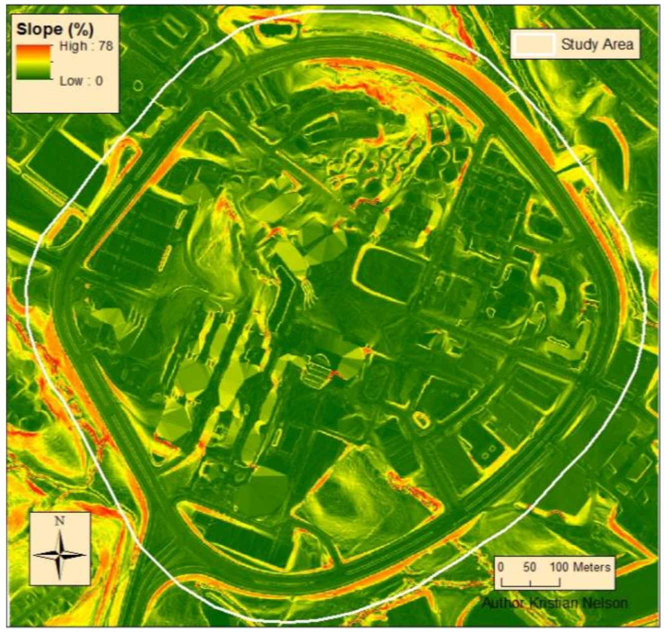

Figure 6: This map shows the Slope factor for the UMBC campus. Slope is shown in percent gradient, where higher percent slopes are in red and lower percent slopes are in green. DEM to create this map was provided by Erle Ellis of UMBC. Map made by Kristian Nelson.

4.4 C Factor Table

Land Cover	C Factor
Water	0
Tree Canopy	0.004
Low Vegetation	0.030
Barren	1
Structures	0
Impervious Surfaces	0
Impervious Roads	0
Tree Canopy over Structures	0
Tree Canopy over Impervious Surfaces	0
Tree Canopy over Impervious Roads	0

Table 2: This table shows the corresponding C factor for each land cover. This data is shown in Figure 5 using the Chesapeake Conservancy's Land Cover map. C factors obtained from Chatterjee et al. (2014).

4.6 Final Soil Erosion Risk Map

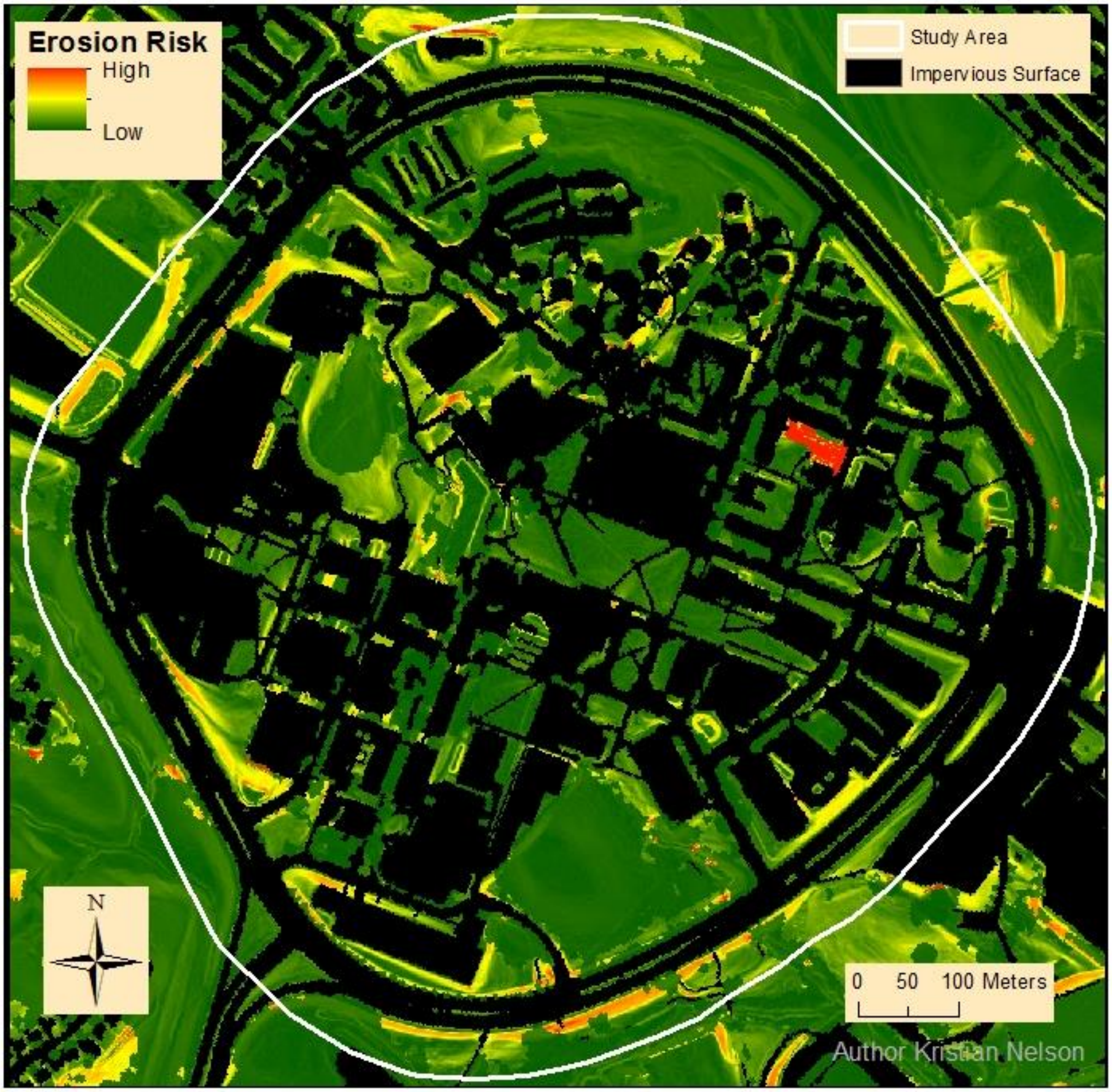

Figure 7: This map is the final erosion risk map for the UMBC campus. Using the C, K, and S factors and overlaying the map that was created for each, this map was made that shows areas of high risk in red and areas of low risk in green. Impervious surfaces are shown in black and are not used in the calculation since no erosion occurs on areas with no soil. The resolution is 1-meter and the extent is the white line depicting the study area. Map created by Kristian Nelson.

5. Discussion

5.1 Soil K Factor

The final erosion risk map shows a very clear picture to where there are areas around the UMBC campus that have a high risk of soil erosion. Each of the factors were used in the making of the final map and were all equally important. In Figure 4, the K factor is shown in an interpolated map of campus. The K factor, which is a measure of soil erodibility, only looks at the characteristics of soil and not where the soil is located, or the topography of the area. There are six distinct areas of soil with low K factors, three areas on the top of campus, one area in the center, and two in the lower area of campus. Other than those six areas, most of the soil around campus have high K factors. The reason for this could be that most of the soil around campus has been altered and degraded by anthropogenic processes. There were many areas where the soil sample contained very high amounts of silt with very little organic matter. Silt is a very erodible soil particle, especially without heavy vegetation stabilizing it and adding organic matter to the soil. The three areas on the top of campus, specifically where sample point 6fb is, are less altered than the soils that are within the campus boundaries. Although the whole area has at some point been altered by humans, those norther regions have been left to regrow and mature, which has led to an increase of organic matter in the soil and the diversifying of soil particles. Other than those six low K factor spots, the campus contains almost all fairly high K factors, as well as many extremely high factors. The reason for this, as previously stated, is that the soil around campus has been heavily degraded and altered by construction, development, and other anthropogenic processes. This has caused soils to be relatively homogenous with silt which makes them more erodible than soils in an undisturbed landscape. The K factor is very important when looking at soil erosion risk, because even if the landscape and vegetation are capable of preventing degradation, soils that are unstable based on their properties can still cause high risk of erosion.

5.2 Land Cover and C Factor

The C factor that was used in the making of the final erosion map played very critical part in determining the final erosion risk of certain areas around campus. In Figure 5 it is shown that there are only about 3 main heavily vegetated areas around campus, and the rest is on the exterior of campus. The interior of the school contains a lot of sparse vegetation and impervious surface. Sparse vegetation gets a C factor of 0.03, while heavy vegetation gets a C factor of 0.004, which causes a very significant decrease in erosion risk. Areas with heavy vegetation have large trees and shrubs to provide soil stabilization and heavy input of organic matter into the soil. This is important to remember when observing the final map, as areas with heavy vegetation can be seen to have a much lower risk of erosion.

5.3 Slope Factor

Figure 6 shows the areas around campus that have a very steep slope, and those that have little to no slope. Slope is a very important factor when observing soil erosion risk because the percent of the slope can have a large effect on the amount of forces acting on the soil at any given time. Soils on steep slopes have a much higher force of gravity pushing them down the slope, while soils on very mellow slopes or flat ground have gravity pushing them into the earth. Figure 6 shows areas of very steep slope in the northeastern, the southwestern, and south areas of campus. These slopes start at where the outskirts of campus are, and end where there is a river or stream. Slope plays a very important role in determining if a soil is at risk of erosion, and although the slope of an area may not be able to be altered, the vegetation cover can be changed, which can drastically change the risk of erosion a slope of soil has.

5.4 Soil Erosion Risk

The final erosion risk map (Figure 7) was aimed to just show where there are areas of high risk of erosion around the UMBC campus, but actually shows much more information than previously expected. When comparing the slope map (Figure 6) to the final map (Figure 7), there are key takeaways that are very important when it comes to landscape planning. In Figure 6, there are very steep slopes around the outside of campus that have very high values, but when those same areas are observed in Figure 7, those areas seem to have little to no risk. Looking back at Figure 5, it can be observed that there are areas of high vegetation where there are areas of steep slope. The vegetation provides so much stability that when the final value is calculated in Figure 7, there is very little risk of erosion on those areas of steep slope. It can be seen that where areas of low vegetation overlap with areas of high slope, there is very high erosion risk. For example, the southern, northeastern and northwestern areas have very high risk of erosion. In the field, it was observed that there was very little vegetation in the area, and because of the steep slope, it puts the area at high risk. This is a very important finding that can be studied more in depth, because it shows how important vegetation is to the overall risk of degradation of a landscape. In the Figure 7, there is a spot of very high risk in the north western part of campus. This part of campus is manmade volley ball courts which are filled with loose sand. The Chesapeake Conservancy classifies this area as "barren", which gets a C factor value of 1. Due to this high C factor, it shows up as a very high value on the final erosion risk map, but because it is an anthropogenic structure that is maintained, there is no risk of erosion, and no threat to the campus. Another part of the map to look at is Erickson Field, which is almost exactly in the center of campus. This field is classified as impervious surface by Chesapeake Conservancy, and therefore was not calculated in the final erosion risk of campus as it received a value of 0. The reason that this area might be classified as an impervious surface is because the soil might have been found to be hydrophobic, or repellent of water. Water repellence is sometimes a characteristic of soils in amenities such as parks or fields that are used for sports like Erickson (Hallett 2008). For this reason, the field is classified as impervious due to the fact that water cannot penetrate it. The final erosion risk map of UMBC produced by this study gives a good estimate of the risk around the campus and helps explain the importance that each of the factors have in affecting the threat of soil degradation in many areas.

6. Conclusion

This study aimed to look many different factors within the UMBC landscape and used them to find the overall risk of soil erosion across the areas. Orchestrated at a resolution of 1-meter, the final erosion map created from this study shows very fine details that have never been observed before at UMBC. Global Forest Watch has done an erosion map over this area, but it was at too low of a resolution to where you couldn't observe very small details in the landscape. The map goes to prove how important vegetation is in the managing of the landscape. Areas of high risk of erosion need to be looked at and planning needs to be done to implement vegetation that will help stabilize the soils. The map shows that areas with high slope had very little risk of erosion when there was dense vegetation, and it proves that this is a very effective way to prevent soil degradation. The results from this study can be used to for management and planning around campus, as well as further studies into how characteristics of many factors around campus affect the stability of the surrounding environment.

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