Forests-For-Water Management Mapping

Forests have been shown to help regulate a suite of water management issues including but not limited to flood control, land stabilization, sedimentation, water quality, and water temperature. (Gartner et al., 2013; and Leticia et al., 2013).

Our focus was on erosion risk mapping and mitigation, as erosivity of soil impacts the efficiency of water treatment plants and hydroelectric power plants globally. (Miranda and Mauad, 2014; and Hession, 2000). All of which have implications in mitigating risks and reducing costs to cities, corporations, and utilities alike. Forests for particular watershed's benefit can be categorized and evaluated with potential datasets such as:

- Forests for Erosion Risk Mitigation **(Developed in Beta Prototype)**
- Forests for Municipal Risk Mitigation **(Developed in Beta Prototype)**
- Forests for Flood Risk Mitigation
- Forests for Sedimentation Risk Mitigation
- Forests for Fire Risk Mitigation

Our efforts thus far focused on Forests for Erosion Risk and Municipal Risk Mitigation, given established estimation methods in literature, availability of GIS data, and the value of potential results. While the Erosion Risk Map carries implications for threats utilities and energy development (such as hydroelectric power facilities). Municipal Risk is currently population weighted erosion risk, and carries implications for threats to cities and drinking water supplies (such as water treatment plants).

Globally mapping erosion risk was based upon the Revised Universal Soil Loss Equation (RUSLE), which is an erosion model designed to predict the longtime average annual soil loss carried by runoff given specific terrain and landscape conditions (Equation 1) (Renard et al., 1997).

Equation 1

$$A = R * K * LS * C * P$$

- A is the estimation of average annual soil loss [t ha^{-1} yr^{-1}]. caused by sheet and rill erosion;
- LS is the combination of the slope steepness factor and slope length factor measurements [unitless];
- R is the rainfall erosivity factor [MJ mm ha^{-1} h^{-1} yr^{-1}] which accounts for the energy and intensity of rainstorms;
- K is the soil erodibility factor [t ha h ha^{-1} MJ^{-1} mm^{-1}] which is a measure of the susceptibility of soil to erode under a standard condition and is adjusted to accommodate variation in soil moisture content;
- C is the cover and management factor which estimates the soil loss ratio (SLR) at seasonal intervals throughout the year, accounting for effects of prior land use, canopy (forest or crop), surface cover, surface roughness and soil moisture;
- P is the support practice factor, calculated as an SLR, which accounts for tillage techniques, strip cropping and terracing (land under cultivation), and understory burning, cattle grazing and road construction (under forested canopy).

Widespread use has substantiated the usefulness and validity of RUSLE for this purpose, and it is also applicable to nonagricultural conditions. (Renard et al., 1997). Modifications to RUSLE have enabled it to be employed extensively under additional scenarios (Aroussi and Jabrane, 2013). Application of the RUSLE within a various watersheds affords the following advantages: data requirements are not too complex or unattainable within a developing country, it is compatible with GIS, and it is easy to implement and understand from a functional perspective (Wischmeier and Smith, 1978). Because of which, Runoff (R), Slope (LS), Soil Erodibility (K), and Land Use Factor (C) were repurposed in a GIS suitability model. The results of which became our Global Erosion Risk Map. And adjusting for Population (P), the results became our Global Municipal Risk Map.

Slope Input

Erosion increases as slope length increases (Wischmeier and Smith, 1978; Renard et al., 1997). In RUSLE both slope length (L) and slope grade (S) are input factors, but given time constraints, only slope grade was considered as a factor for our suitability analysis. For adapting RUSLE to model soil erosion in watersheds, replacement of slope length with upslope drainage area per unit of contour length is recommended (Kirkby and Chorley 1967, and Desmet and Govers 1995).

Digital Elevation Model (DEM) data was used to calculate Global Slope data. In order to minimize error in the slope calculation caused by the map projection's land surface distortion (Figure 2) additional steps needed to be taken in the geographic processing.

Recall that slope is the calculation of 'rise over run' (i.e. elevation over horizontal distance). And this horizontal scale distortion can vary with bearing, and thus play an effect when calculating slope at a global scale depending on the users current map projection. In order to compensate for this scale distortion, all relevant data was projected in a conformal projection of *WGS 1984 World Mercator*, in which angles formed by lines are preserved, and distortion varies merely with latitude. The resulting slope was then adjusted by dividing by the cosine of the latitude, and the results of which was projected back into *WGS 1984* (Figure 2). The Resulting slope data was then reclassified on a 0 – 10 scale based upon Table 1.

In lieu of reclassifying the data, the influence of slope steepness on erosivity can also be characterized by a continuous function (Equation 3) which has been field tested measuring slope's effect on soil erosion (Nearing 1997). It is recommended that future iterations of the project consider this as a basis for assigning the slope suitability score.

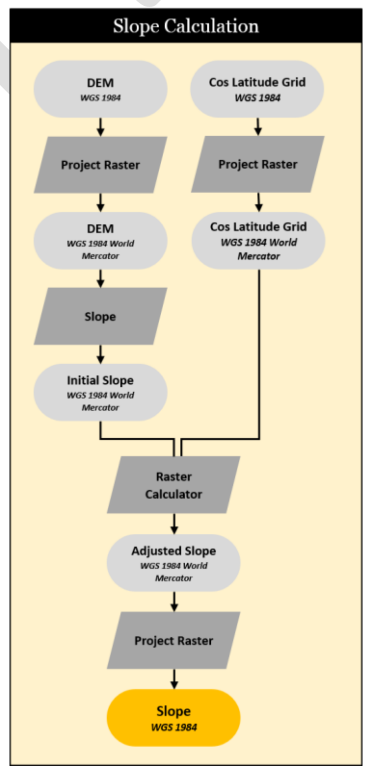


Figure 2

Equation 3

$$S = -1.5 + \frac{17}{1 + e^{2.3 - 6.1 sin\theta}}$$

Where θ is the slope angle [degrees] of the cell, and S is the non-normalized slope score.

Soil Type Input

Soil texture, percentage of organic content, soil structure, and drainage all affect soil erodibility given by Equation 4 (Wishchmeier and Smith 1978).

Equation 4

$$K = 2.1 * 10^{-6} * M^{1.14}(12 - a) + 0.0325(b - 2) + 0.025(c - 3)$$

- K is the soil erodibility factor [t h/MJ mm]
- M is the particle-size parameter: percentage of silt (0.1-0.002 mm) times the quantity 100 minus percent-clay
- a is the percent of organic matter
- b is the soil-structure class (very fine granular = 1, fine granular = 2, coarse granular = 3, lattice or massive = 4)
- c is the drainage class (fast = 1, fast to moderately fast = 2, moderately fast = 3, moderately fast to slow = 4, slow = 5, very slow = 6)

This equation was not able to be fully utilized due to availability of global datasets. The Digital Soil Map of the World (DSMW) has data on the dominate soil type and percentage of: sand, silt, clay, and organic content. However it is not compressive globally, and was thus omitted from the analysis of in classifying the soil's effect on erosivity. If this soil type can be integrated into the analysis it is recommended in future iterations of the suitability analysis but currently remains omitted. In its current state, soil erodibility is based upon the soil drainage class (i.e. soil porosity and soil permeability). Soil porosity measures the faction of the volume of void space over the total volume of a given soil structure and can range from 0 to 1. Soil permeability is the measure of the ease with which a fluid such as water can move through a porous soil structure and can range over many orders of magnitude (Freeze and Cherry 1979). Soil porosity data from GLDAS was normalized (Equation 2) and soil permeability data from the University of British Columbia was reclassified (Table 1). The geometric mean was then taken and the results of which became the soil factor in the erosion risk suitability model (Equation 3).

Land Use Intensity Input

Land use intensity such as urban development or roadway systems have been shown to increase soil erosion (Renard et al., 1997). WRI's land use intensity data was reclassified (Table 1) and the results of which became the land use factor in the erosion risk suitability model (Equation 5).

Runoff Input

Erosion increases as runoff increases (Wischmeier and Smith, 1978). Global surface and global subsurface runoff data [kg/m²/s] was downloaded from the GLDAS Giovanni system and processed into mean meters per year from 1980 to 2010. The output was multiplied by the Area Grid to get volume and then normalized (Equation 1). The result was the Global Runoff Factor used in the erosion risk suitability model (Equation 5).

Population Input

Unlike our previous inputs, that relate to the likelyhood of erosion risk, the population input relates to the impact of that erosion risk. Global population data enables users to prioritize where risk from land erosion will affect the most people. Population data was created by the WRI Aqueduct team. It was summed from the Gridded Population of the World Version 3 (GPWv3) and summed into the global watershed catchments.

Data Results

Global Erosion Risk

Description: Global Erosion Risk represents the global risk of potential sedimentation transport caused by unstable terrain conditions and water based erosion.

Calculation: Global Erosion Risk is the geometric mean of the erosion potential scores Slope, Land Use Intensity, Soil Conditions, and Global Runoff, with each parameter rescaled on a 0 – 10 scale based on their potential erosivity. Calculated in ArcGIS 10.1 using tools from the Spatial Analyst Toolbox. (Figure 3 and Equation 2).

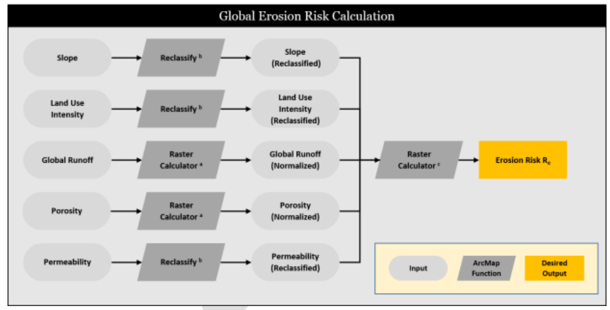
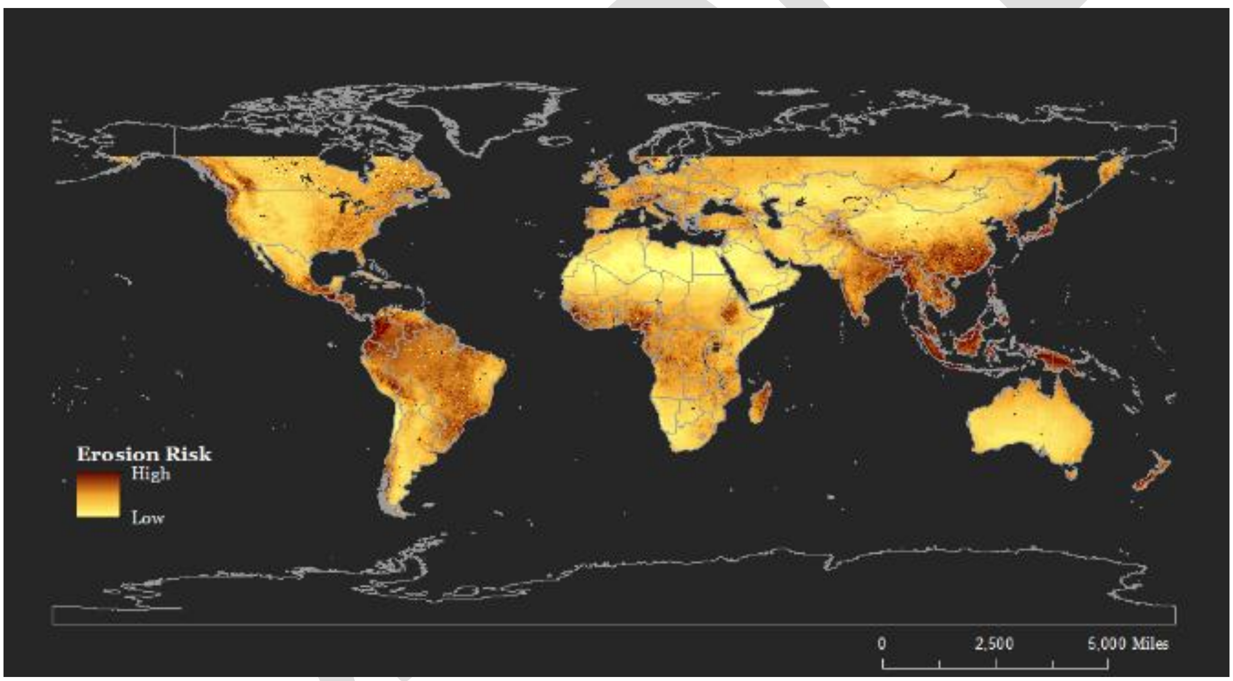
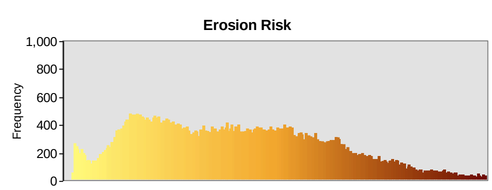


Figure 3

a) Input values from the following rasters were normalized on a 1–10 scale using Equation 1
b) Input values from the following raster were reclassified to a 1–10 scale using Table 1
c) The geometric mean of the values from the following rasters were then calculated using Equation 2



Variable	Global Erosion Risk
Authors	WRI – Natural Infrastructure
Native Format	Floating Point Raster GRID
Publication Year	2014
Temporal Extent	
URL	
Resolution	1 kilometer
Spatial Extent	Global Land Surface between 60 N, -60 S Latitude
Notes	



Equation 5

$$\underbrace{\left(\underbrace{P_o^{1/2}}_{Porosity} * \underbrace{P_e^{1/2}}_{Permeability}\right)^{1/4}}_{Soil\ Factor} * \underbrace{S^{1/4}}_{Slope\ Factor} * \underbrace{Q^{1/4}}_{Runoff\ Factor} * \underbrace{C^{1/4}}_{Landuse\ Factor} = \underbrace{R_e}_{Erosion\ Risk\ Value}$$