EROSION VULNERABILITY OF THE ZARATI SUBWATERSHED (PANAMA)

Undergraduate Honors Thesis

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1.0 ABSTRACT:

In Panama, the Penonome Water Treatment Plan draws water from the Zarati River to serve a population of 20,000 people. However, excessive loads of sediments in the river cause frequent system and supply stoppages. This study aims to evaluate the vulnerability of the Zarati subwatershed to erosion with the purpose of determining areas that experience high rates of soil loss and therefore could be large sources of sediment in runoff. Datasets for land cover, rainfall, type of soil, and slope of the terrain where processed in ArcGIS and used as factors in the Revised Universal Soil Loss Equation (RUSLE) in order to estimate the annual soil loss in each grid cell. Inputs were obtained from a number of organizations that are acknowledged in this report. Two areas located in the middle and upper part of the subwatershed were identified as the most vulnerable to erosion based on an area-based weighted average of 102.3 and 36.0 tons ha^{-1} $year^{-1}$, respectively. When compared to other global watersheds, the erosion rates results were ranked as high. The results of this study, along with a list of recommendations for land practices, can help to better focus current efforts to control erosion in the subwatershed.

2.0 INTRODUCTION

Treating surface water to meet drinking standards under tropical weather conditions is known to be challenging due to the seasonal variations in rainfall (Vasyukova et al., 2012). This is because exacerbated soil erosion during the wet season has an adverse impact on water quality (Arekhi et al., 2012; Lu et al., 2004). A study conducted in Brasília, Brazil evaluated the influence of these seasonal variations in the quality of the surface water sources used for drinking water production in the district. Researchers pointed out erosion, and consequent runoff, as the most common cause of high levels of turbidity and color in the water (Vasyukova et al., 2012). Turbidity has no health effects, but it is targeted in water treatment because it is an indicator of the presence of disease-causing organisms and the production of disinfection by-products, which are carcinogens (EPA, 2013; Viessman et al., 2009). A study conducted in the Delaware River, USA found that increased concentrations of *Giardia*, *Cryptosporidium* and a variety of other microorganisms were associated with rainfall. This increase was in part attributed to erosion and consequent surface runoff of particulate matter, re-suspension of river bottom and storm drain sediments (Atherholt et al., 1998). Another concern is the transport of nutrients, pesticides and other harmful farm chemicals into water bodies, which also decrease water quality and can cause eutrophication (Kouli et al., 2009).

Soil erosion is a natural process that contributes to the formation of the earth surface over both short and long time scales (Rozos et al., 2013). However, soil erosion is now greatly exacerbated by inappropriate agricultural practices, deforestation, overgrazing and construction activities (van der Knijff et al., 2000; Arekhi et al. 2012; Kouli et al., 2009). These and other anthropogenic activities have made erosion a very serious environmental problem in many areas (Rozos et al., 2013). At the same time, increasing global population and the impacts of climate change are putting stress on water resources (Anderson et al., 2011). In developing countries, where water agencies struggle to afford high-cost water treatment technologies to cope with water quality issues, it becomes imperative to promote integrated water resources management (IWRM) as the most feasible and sustainable solution (Kalbus et al., 2012). IWRM has been defined as “a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (Kalbus et al.,

2012). However, this approach becomes harder to enforce due to the high economic dependency that populations within watersheds have on extensive agriculture (Pandey et al., 2007). In order to better allocate management efforts, there have been several studies that have used erosion risk assessment maps to determine what areas need more attention in a given watershed, region, country, or even a continent (van der Knijff et al., 2000; Anderson et al., 2011; Arekhi et al., 2012; Kouli et al., 2009; Pandey et al., 2007; Ozsoy et al., 2012; Rozos et al., 2013; Bonilla, 2010, Lu et al., 2004).

The use of factorial scoring and area delineation are two "expert-based" approaches to soil erosion risk assessment that rely on field observations. Factorial scoring is the assignation of scores based on established classes, the scores are multiplied, and the result is used to determine the level of vulnerability to erosion (van der Knijff et al., 2000). Montier et al. (1998) developed an erosion map for the whole of France using this method. A problem with most methods based on scoring is that the results are affected by the way scores are defined, the number of classes used, and the expertise of the person doing the study. In addition, variables are given equal weight, which is not realistic (van der Knijff et al., 2000). As an alternative, there are a wide variety of model-based methods used to assess soil erosion (Pandey et al., 2007; van der Knijff et al., 2000; Lu et al., 2004). These models vary in spatial and temporal scale and applicability (van der Knijff et al., 2000). "The choice for a particular model largely depends on the purpose for which it is intended and the available data, time and money" (van der Knijff et al., 2000).

A popular model-based method, the Universal Soil Loss Equation (USLE) was developed in 1978 by the United States Department of Agriculture (USDA) as an empirical method to evaluate the annual long-term average erosion produced by rainfall and runoff in crop lands (Renard et al., 1997). USLE was later modified in 1997 to "broaden its application to different situations including forest, rangeland, and disturbed areas" giving what is known today as the Revised Universal Soil Loss Equation (RUSLE) (Lu et al., 2004). Researchers have applied it in a wide variety of scales highlighting its relative simplicity and robustness (van der Knijff et al., 2000; Ozsoy et al., 2012). For example, several studies have used the RUSLE to assess erosion risk in the Mediterranean region where "erosion has reached a stage of irreversibility and in some places erosion has practically ceased because there is no more soil left" (van der Knijff et al., 2000; Rozos et al., 2013). This is due to intensive rainfalls, following long dry and warm

periods that exacerbate erosion caused by human activities, especially on steep slope areas occupied by loose formations and low vegetation cover (Rozos et al., 2013; Greece, Ozsoy et al., 2012; van der Knijff et al., 2000).

Anderson et al. (2011) conducted a regional study in Latin America and the Caribbean where they examined the potential impacts of climate change on surface water runoff under a wide range of future precipitation scenarios. For this purpose they developed a rainfall-runoff model based on curve numbers, a simplified version of the RUSLE and the result of different climate change models. The study concluded that erosion in the region is expected to increase since future climate models indicate drier conditions, broken up by intense storms, and a decrease in soil moisture due to higher temperatures. This trend combined with existing rates of soil loss and sediment caused by poor land management were considered as strong motivations to continue performing this type of study at lower geographical scales in Latin America. The present study will focus on using the RUSLE to assess the vulnerability to erosion of the Zarati Subwatershed located in Panama.

3.0 MATERIALS AND METHODS

3.1 Study Site

Panama is located in Central America between Colombia and Costa Rica. It is bordered by the Caribbean Sea on the north and the Pacific Ocean and on the south. The Zarati subwatershed is situated at UTM X: 563000 and 595000 North latitude, UTM Y: 935000 and 958000 West longitude and is part of the larger Rio Grande watershed located on the Pacific side of the country (Figure 1). The Penonomé Water Treatment Plant uses water from the Zaratí River to serve a population of 20 000 consumers. Figure 2 shows the location of the water intake for the plant and the division of the subwatershed into three parts: low, middle, and upper. The slope in the subwatershed increases from southwest to northeast, where it becomes part of the Central Mountain Range (Figure 3).

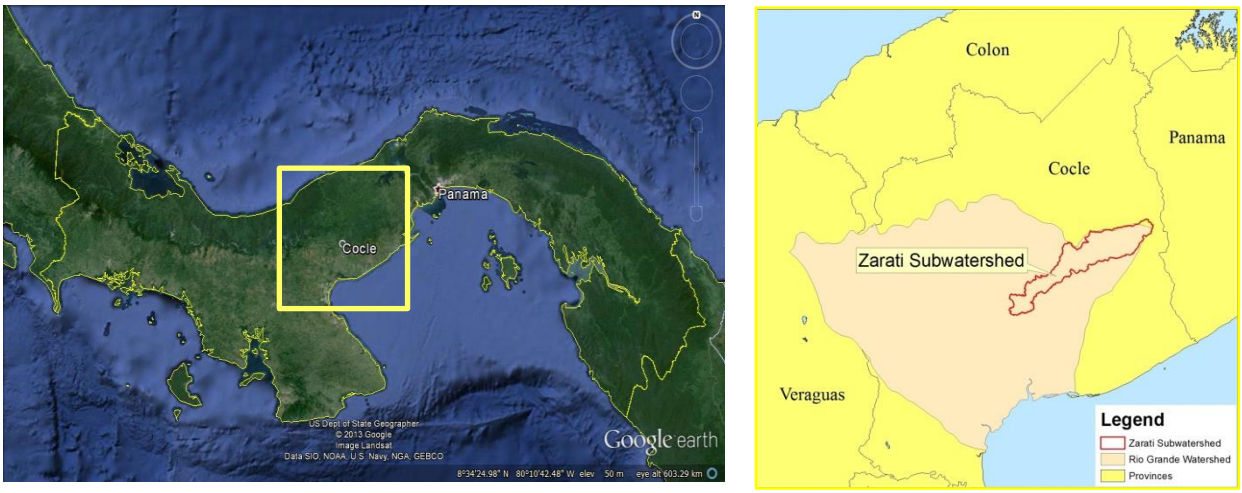

Figure 1. Location of the Zarati subwatershed in Panama

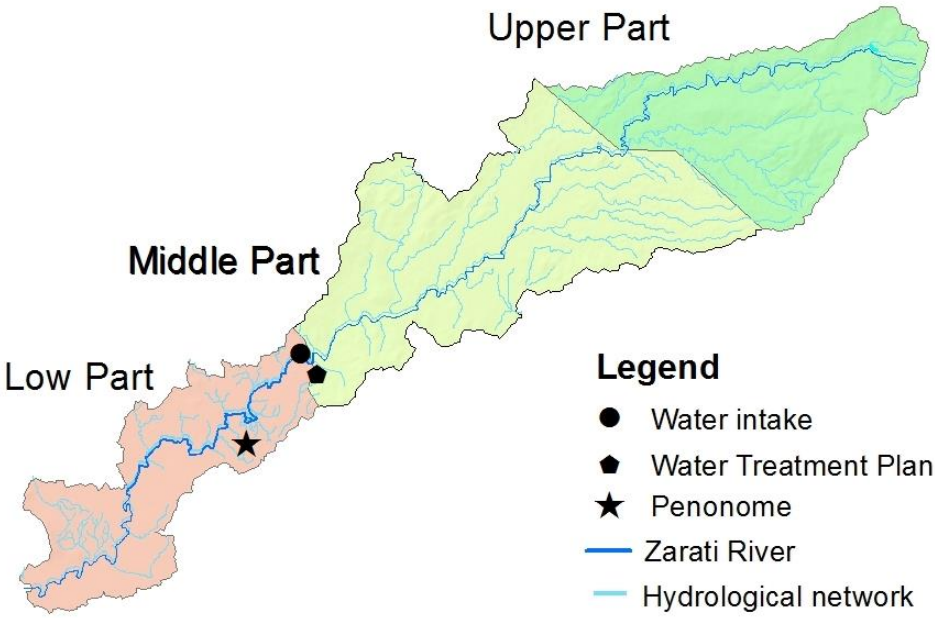

Figure 2. Sections of the subwatershed and important landmarks.

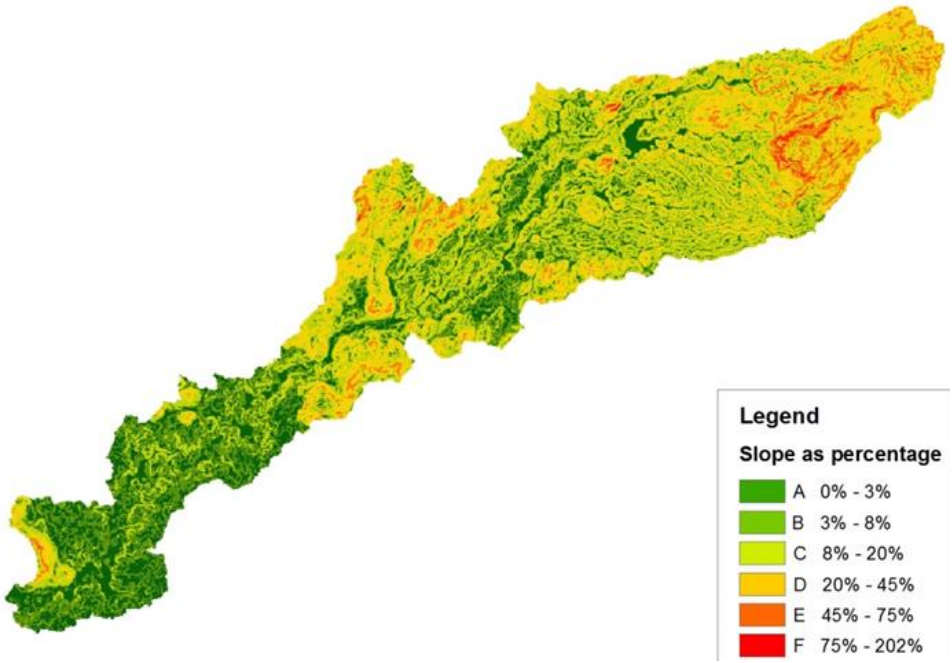

Figure 3. Percent slope distribution.

According to the most updated map created in 2008, land use in the subwatershed is divided into secondary forest, impacted forest, subsistence farming, stubble, agricultural use, and others (Figure 4). The average rainfall is 2275 mm (89.5 in); October is the rainiest month with an average precipitation of of 340 mm (13.4 in) and February is the driest month with only 22 mm (0.9 in) (Figure 5). The main economic activities within the watershed are agriculture, subsistence farming, pig and poultry farming, and to a lesser extent livestock. Commercial and artisanal activities are concentrated in the town of Penonomé, the largest city within the watershed and capital of the province of Coclé.

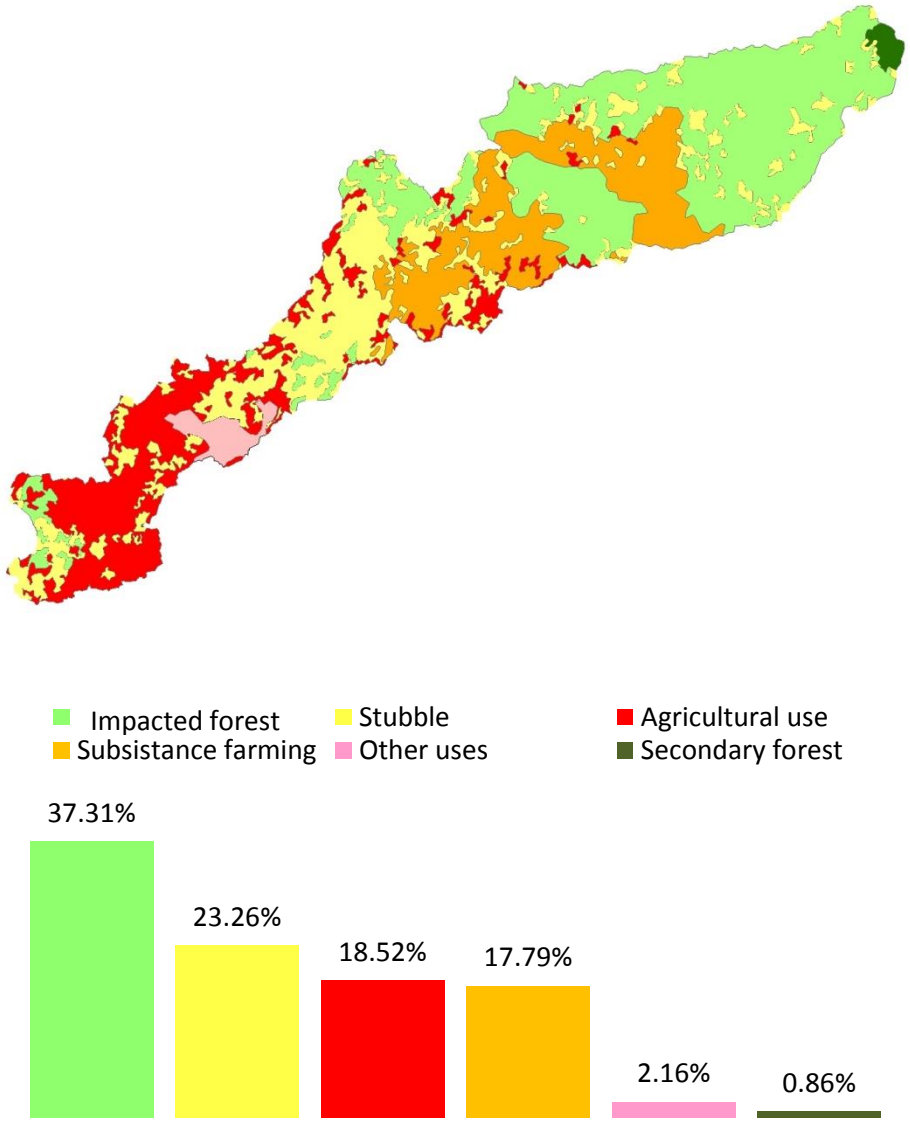

Figure 4. Types of land use as percentage of total area and location in the subwatershed.

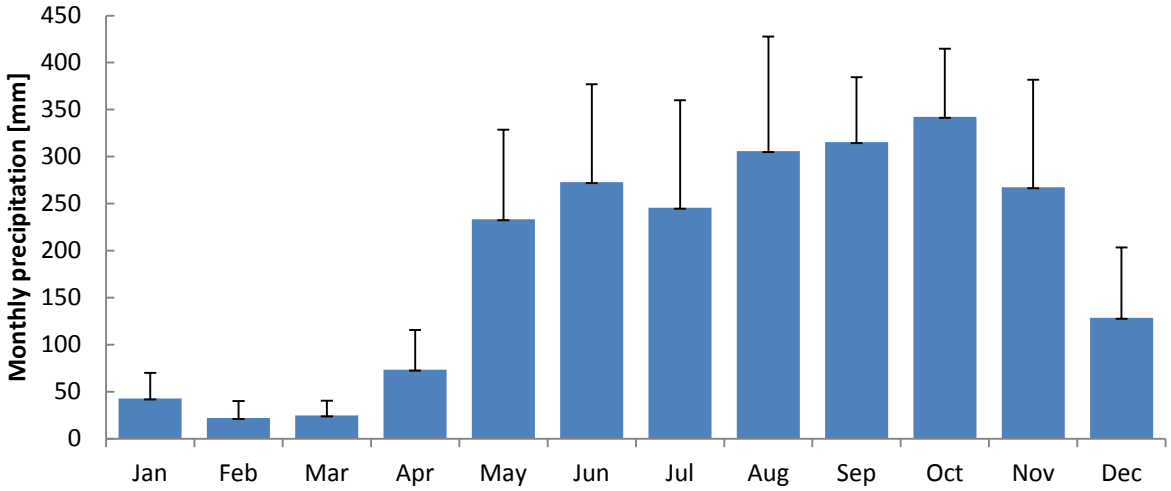

Figure 5. Monthly rainfall distribution.

3.2 The RUSLE Model

RUSLE is the multiplication of five factors that have been directly related to soil erosion (Eq. 1) (Renard et al., 1997):

$$A = R \times K \times LS \times C \times P \qquad \textbf{Eq. 1}$$

where:

A [tons ha^{-1} $year^{-1}$]: Average annual soil loss

R [MJ mm ha^{-1} $hour^{-1}$ $year^{-1}$]: Rainfall erosivity factor

K [tons ha h ha^{-1} MJ^{-1} mm^{-1}]: Soil erodibility factor

LS [dimensionless]: Length-slope factor

C [dimensionless]: Land cover factor

P [dimensionless]: Support practice factor

Each factor will be explained below in order to give more details about the equations used, list equation sources, and describe data processing. ESRI ArcGIS Desktop 10.0 was used as the software platform to perform cell calculations required by the RUSLE and consequently obtain the relative vulnerability to in the Zarati Subwatershed. Figure 6 gives an overview of the overall analytical methodology.

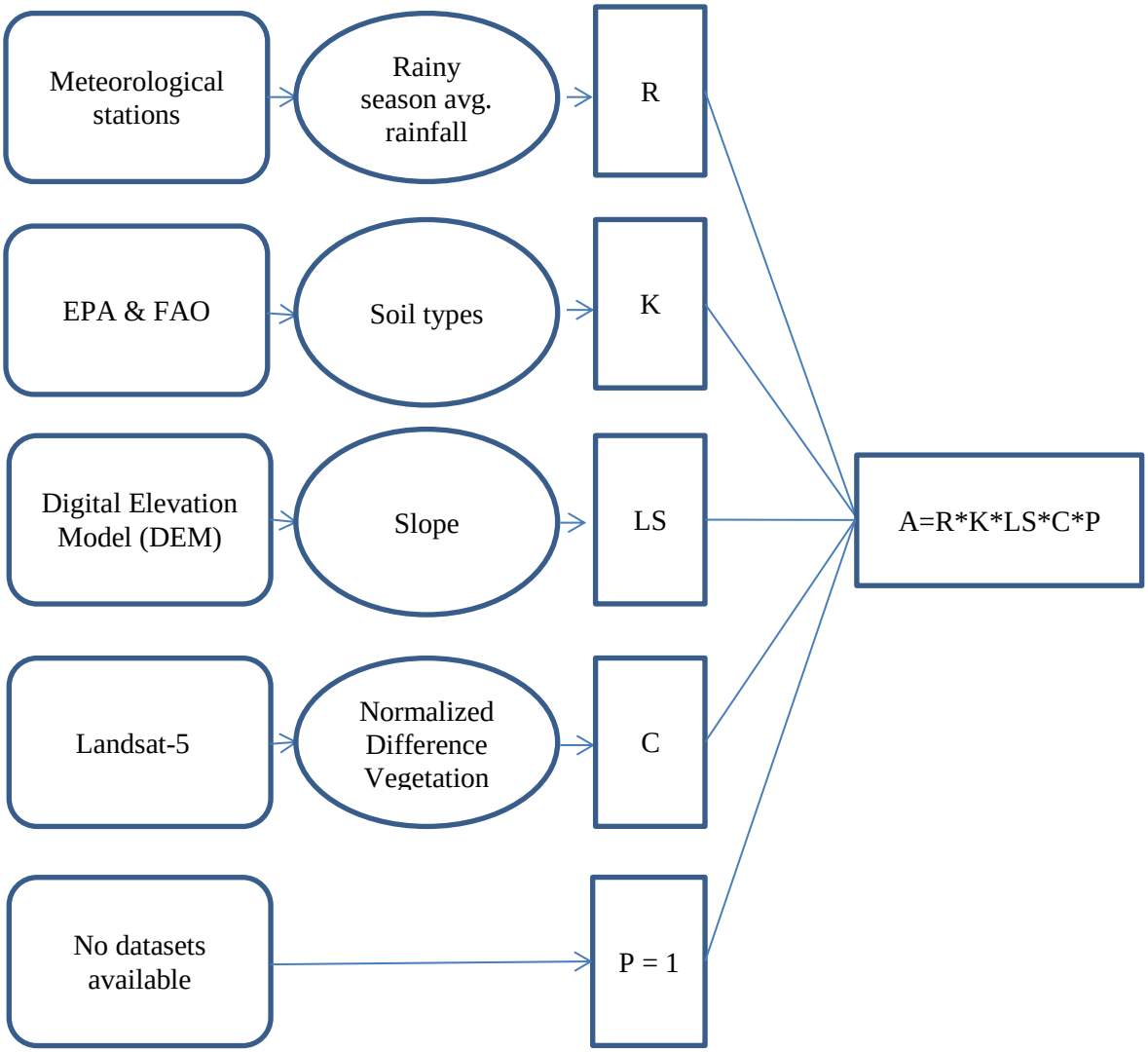

Figure 6. General overview of the RUSLE inputs for each factor.

3.2.1 Rainfall erosivity factor (R)

For the purpose of this study, the R factor was calculated with an equation developed for the Pacific slope of Costa Rica (Eq. 5). This selection was based on two reasons. Firstly, the monthly rainfall in the Pacific slope of Costa Rica (Figures 5) follows a similar trend and has a similar magnitude to the monthly rainfall in the Zarati Subwatershed (Figure 7), which is located in the Pacific side of Panama. Secondly, a similar equation has not been developed for Panama.

$$R = 19.527 \times p_{sep} - 1.769 \times E \qquad \text{Eq. 5}$$

where:

R [MJ mm ha^{-1} hour^{-1} year^{-1}]: Rainfall erosivity factor

p_{sep} [mm month^{-1}]: monthly precipitation (mm) for September

E [masl]: elevation (m), represented by the DEM

Equation 5 only considers two variables: monthly precipitation for September (p_{sep}) and elevation. According to Jiménez-Rodríguez et al. (2014), "the choice of monthly precipitation depicts the importance of precipitation seasonality, while elevation introduces topography as a key variable that indirectly considers the effect of orographic rainfall in the R-factor definition." In addition, these authors found that "the R-factor for the Pacific slope is strongly affected by September's rainfall due to the high water volume just after the short dry season that takes place between June and July" (Jiménez-Rodríguez et al., 2014). As shown in Figure 5, the Zaratí subwatershed also experiences a short dry season in those months. However, the change from July to September is roughly 50 mm while in the Pacific slope of Costa Rica is 120 mm (Figure 7).

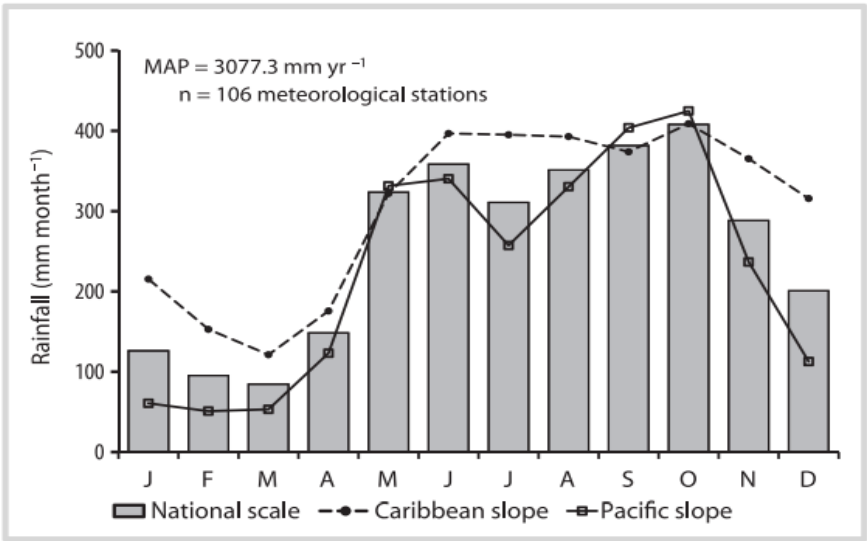

Figure 7. Monthly rainfall distribution in Costa Rica based on data from 106 stations .MAP: Mean annual precipitation; n: number of meteorological stations. Source: Jiménez-Rodríguez et al., 2014.

Monthly precipitation data was obtained from the Gerencia de Hidrometeorología de ETESA (http://www.hidromet.com.pa/). Table 1 and figure 8 summarize the information of the four

meteorological stations used for this study. All the stations have a minimum of 23 years of data. Figure 9 shows the location of the meteorological stations. Two of the stations, Chiguirí Arriba and La Pintada, are located outside the subwatershed. However, they were taken into account because they are relatively close, have no major topographical features that could cause drastic changes in weather patterns, and contribute data about the upper and lower part of the subwatershed.

Table 1. Meteorological stations used in the study.

Name	**Latitude**	**Longitude**	**Start Date**	**Final Date**	**Average p_{sep} (mm)**	**MAP (mm)**
La Pintada	8° 35' 00"N	80° 27' 00"W	1/12/1969	1/03/2000	315	1549
Sonadora	8° 33' 00"N	80° 20' 00"W	1/05/1955	Ongoing	289	1852
Churuquita Grande	8° 37' 00"N	80° 16' 00"W	1/04/1977	1/03/2000	279	1958
Chiguiri Arriba	8° 40' 22"N	80° 11' 15"W	1/07/1958	Ongoing	433	3739

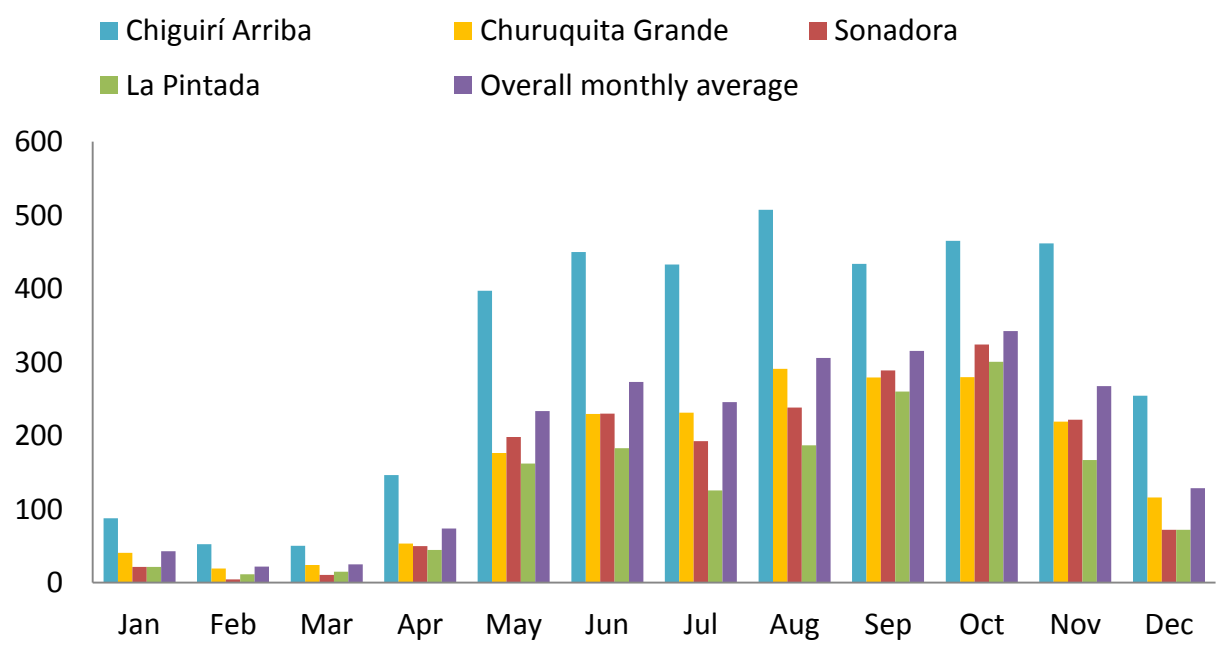

Figure 8. Average monthly precipitation for each station and their average.

The average precipitation for September in each station was managed as a data point in ArcGIS. Spatial rainfall distribution was obtained by using the interpolation tool Inverse Distance Weighted (IDW) in ArcGIS 10.0 with Power = 3. This exponent controls the significance of surrounding points on the interpolated value (Esri, 2012).

Figure 9. Location of meteorological stations.

3.2.2 Soil erodibility factor (K)

The dataset for the K factor was provided by the Center of Water for the Humid Tropics of Latin America and the Caribbean (CATHALAC). This dataset was generated based on K factor values determined by the EPA and the Food and Agriculture Organization (FAO), which published a database about types of soils and terrain in Latin America and the Caribbean in 2005. For the purpose of this study, it was assumed that the K factor and the DEM are constant over time. The possible geological changes that the area could have experienced are considered insignificant; although anthropogenic changes may be significant, they are not considered here. In addition, the spatial resolution of the DEM used (30 m) does not allow detection of topographical changes in the area of study.

3.2.3 Length-slope factor (LS)

The LS factor is the multiplication of the slope length factor (L) and the slope steepness factor (S). The L factor was calculated using Equation 2, which is in SI units (Renard et al., 1997):

$$L = \left(\frac{\lambda}{22.1}\right)^m \qquad \textbf{Eq. 2}$$

where:

L [dimensionless]: slope length factor

λ Lambda [m]: field slope length

m [dimensionless]: function of slope steepness

The size of the cell (λ) used was 30 meters. In order to facilitate the management of the data, specific values for the equation's exponent "m" where assigned based on ranges of values. A value of 0.5 was used for slopes greater or equal to 5%, a value of 0.4 was used for slopes between 5% and 3%, and 0.3 was used for slopes equal or lower than 3%. The same assumptions for field slope length were made by Pandey et al. (2007) based on a previous study conducted by McCool et al. (1978). The slope percentage was calculated by processing the Digital Elevation Model (DEM) with the analysis tool "Slope" in ArcMap. The DEM was obtained from the Water Center for the Humid Tropics of Latin America and The Caribbean and it was originally retrieved from the Shuttle Radar Topography Mission (SRTM). The DEM's original resolution (1 km) was reprocessed to 30 meters using the tool "Resample". The DEM was "burn" as part of a standard step and then "filled" to cover "sinks" (Butt et al., 2011).

The S factor was calculated using equations 3 and 4, according to ranges of slope (Renard et al., 1997; Pandey et al., 2007). The slope in degrees necessary for the trigonometric function in the formulas was calculated using the tool "Slope".

$$S = 10.8\ \sin\theta + 0.03\,, \quad s < 9\%\ (5.14°) \qquad \textbf{Eq. 3}$$

$$S = 16.8\ \sin\theta - 0.05\,, \quad s \geq 9\%\ (5.14°) \qquad \textbf{Eq. 4}$$

where:

S [dimensionless]: slope steepness factor

θ [°]: slope in degrees

3.2.4 Land cover factor (C)

The land cover factor was calculated using equations 6 and 7 (Van der Kniff et al., 2000; Kouli et al. 2009, Arekhi et al., 2012):

$$C = e^{\left[-\alpha \cdot \frac{NDVI}{(\beta - NDVI)}\right]} \qquad \textbf{Eq. 6}$$

$$NDVI = \frac{NIR - R}{NIR + R} \qquad \textbf{Eq. 7}$$

where:

C [dimensionless]: Land cover factor

NDVI [dimesionless] = Normalized Difference Vegetation Index

α, β [dimensionaless] = Constants (α = 2, β = 1) (Van der Kniff et al., 2000).

NIR [dimensionless] = Near Infrared (Band 4 for Landsat images)

R [dimensionless] = Red (Band 3 for Landsat images)

The NDVI is based on the processing of satellite images in two specific bands, Near Infrared (NIR) and Red (R). It helps to differentiate among different land cover types by measuring the spectral response of different surfaces. The NDVI has a range of values from -1 to +1. Areas with low or no land cover, as well as areas with inactive vegetation (unhealthy plants) will usually display NDVI values fluctuating between -0.1 and +0.1. Clouds and water bodies give negative or zero values and areas with photosynthetically active vegetation give positive values (Kouli et al. 2009).

The presence of clouds is a disadvantage for calculating the NDVI since it cover sections of the surface being studied. In the case of Panama, it is not easy to find satellite images in which the cloud coverage percentage is low. For this reason, it was necessary to use an image from March 27th of 2000. This image does not totally reflect the actual conditions of the site since it was taken 14 years ago. The source of the image is the satellite Landsat-5 and it was obtained through the GLOVIS website (http://glovis.usgs.gov/) of NASA.

The calculated C factor was overlaid with the map of land use (Figure 4) to calculate an average C factor for each of the six land use categories using the tool "Zonal statistics". These categories are defined by the National Environmental Authority (ANAM in Spanish) as follow:

- Mature Secondary Forest: These are closed natural formations. The vegetation is on secondary succession state as a result of the partial or complete removal of the primary vegetation due to anthropogenic or natural causes.
- Impacted and/or secondary forest: These forests can be homogeneous or mixed. More than 60% of the forest's cover has been altered or impacted by anthropogenic activities or other causes.
- Shrubs: These are closed natural formation. Its secondary succession state is on an initial development stage (Early successional community). This category includes herbaceous plants, reeds, and bushes. Other species with a low commercial value are also included, these species help to improve the soil and generate the necessary environmental conditions for the colonization of species of more advanced successive stages. The pioneer species present have a rapid growth rate, a dense and homogeneous canopy, and according to the legal norms these are formations less than 5 years old.
- Agricultural Use: All areas used for annual crops, semi-permanent or permanent, grazing, grasslands, shrubs and even some scattered areas of remaining forests.
- Subsistence farming: These are areas used for agricultural and livestock subsistence activities including those covered by shrubs and scattered areas of remaining forests. This category is principally found at river banks, access trails, and the opposite sides of colonization.
- Other uses: It includes urban, semi-urban, rural, industrial, mining, salt mines, shrimp breeding and barren land areas.

3.2.5 Support practice factor (P)

The P factor represents the soil management and other cultural practices to control erosion. This factor was assumed to be 1 since no information was available about soil conservation practices. Other studies made the same assumption (Kouli et al. 2009; Lu et al., 2004; Bonillea, 2000; Rozos, 2013). This provides worst-case soil erosion estimates as soil conservation practices are

assumed to be inexistent in the subwatershed. Ramifications of the practice factor on erosion rates are presented in the Discussion section.

ESRI ArcGIS Desktop 10.0 was used as the software platform to perform cell calculations required by the RUSLE and consequently obtain the relative vulnerability to erosion along the Zarati Subwatershed.

3.3 Sensitivity analysis

A sensitivity analysis was conducted using a one-at-a-time (OAT) approach to evaluate the sensitivity of the model to each factor considered in the RUSLE. The method consisted of keeping three of the factors constant at their 50th percentile (i.e., median) values while varying the remaining factor based on their 10th, 25th, 50th, 75th, and 90th percentile values. Factors were multiplied following the RUSLE and a percentage difference relative to the results from the 50th percentile value was calculated. To illustrate: the 10th percentile of R was multiplied by the 50th percentile of K, LS and C and the result was compared to the product of the 50th percentile of R, K, LS, and C. While this approach is simple, OAT analysis is listed by the EPA as an appropriate evaluation tool for environmental models (EPA, 2009), particularly for simple models without interacting terms.

4.0 RESULTS

4.1 Individual RUSLE Factors

Figure 10 shows the histogram of the R factor calculated for each cell in the subwatershed. Calculated R values varied between 4713 and 7754 MJ mm ha^{-1} $hour^{-1}$ $year^{-1}$, with a mean value of 5780.Figure 11, shows the spatial distribution of the R and demonstrates that rainfall erosivity is greatest in the upper part of the subwatershed.

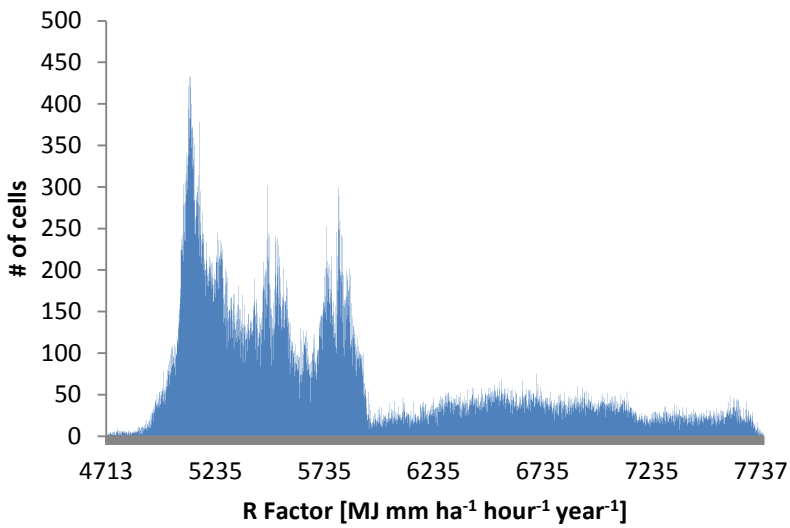

Figure 10. Histogram of the R factor

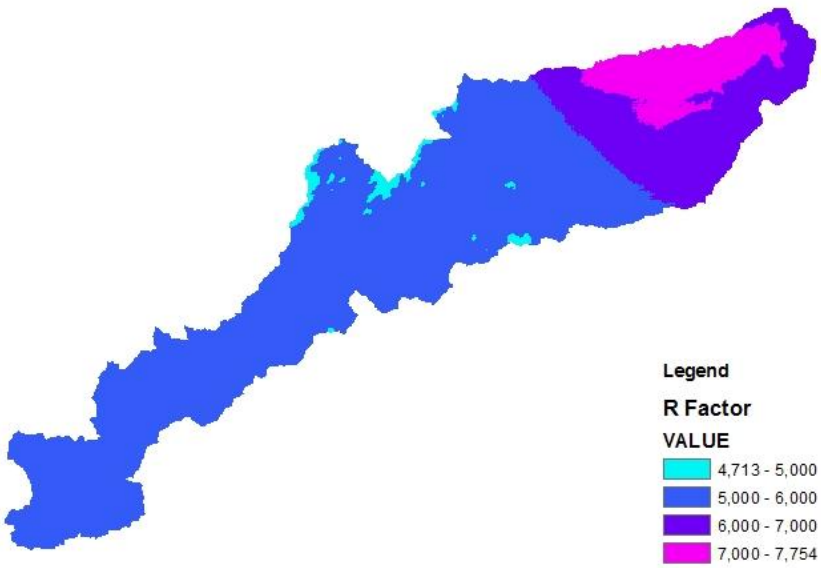

Figure 11. Map of the R factor

At the spatial resolution of available data, the watershed is characterized by only two soil types (Figure 12). Clay has a K factor of 0.0448 tons ha h ha^{-1} MJ^{-1} mm^{-1} and represents 93.6% of the area. Sandy clay loam has a K factor of 0.0474 tons ha h ha^{-1} MJ^{-1} mm^{-1} and characterizes the percentage left in the lower part of the subwatershed. A higher K factor indicates higher erodibility.

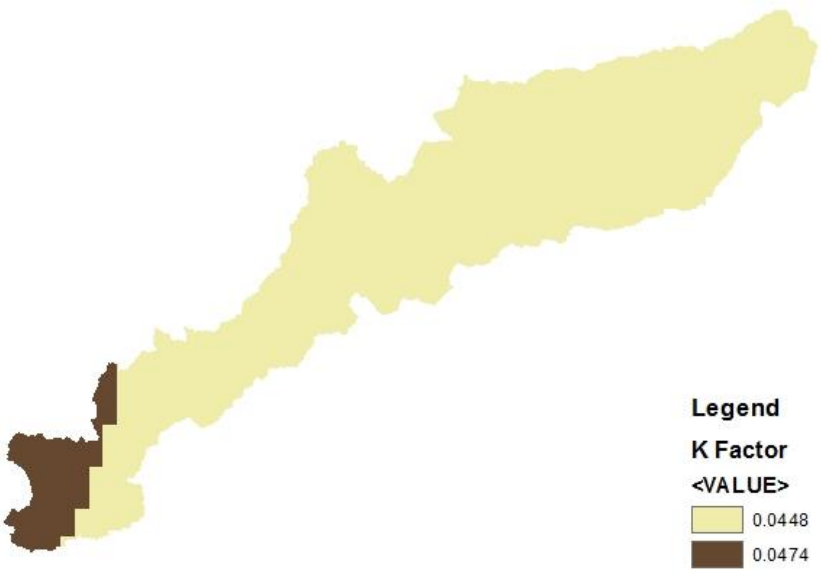

Figure 12. Map of the K factor

Figure 13 depicts the histogram of the LS factor, which is characterized by an exponential distribution with a range of values of 0.03 to 17.5. Low values indicate relatively flat areas. The average value of the LS factor was 2.95 and the median was 9.86, reflecting this right-skewed distribution. Figure 14 gives a better idea of how the values for the LS factor are distributed along the Zarati subwatershed.

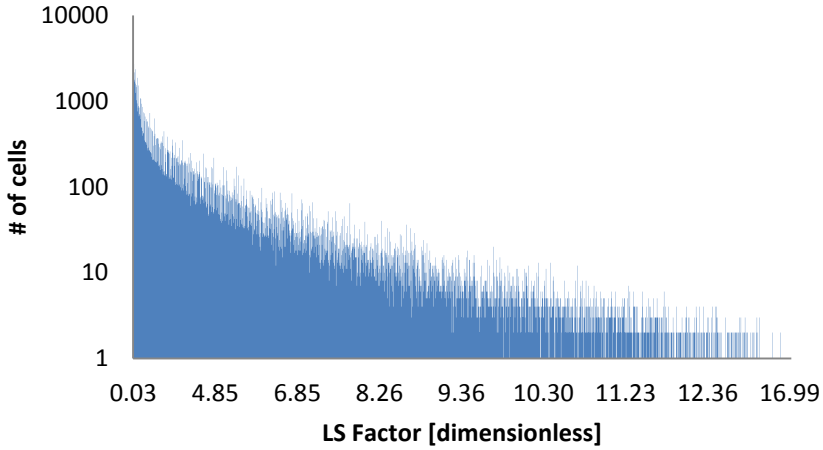

Figure 13. Histogram of the LS factor

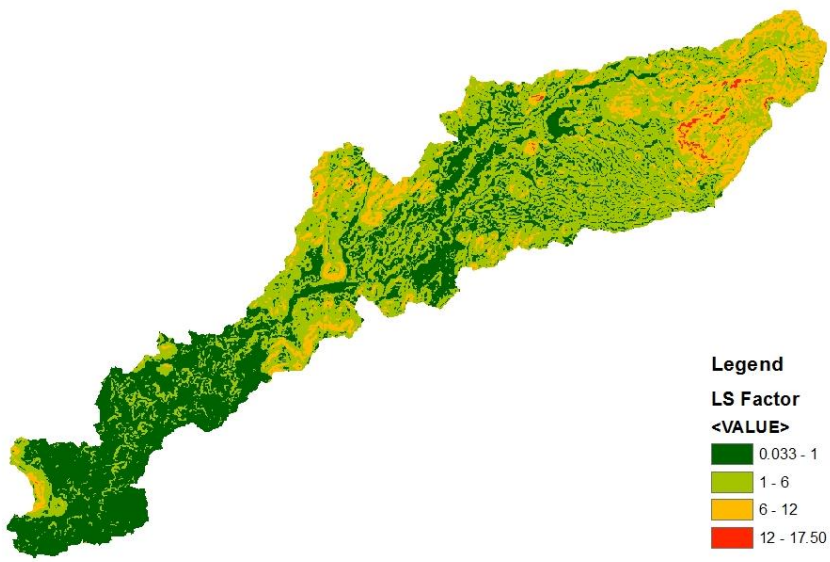

Figure 14. Map of the LS factor

Figure 15 shows the histogram of the C factor which has values between 0.03 and 1.00 in an overall flat bell distribution shifted to the left. The results of the overlay between the C factor and the land use categories (table 2) show that the areas of secondary forest and impacted forest have the lowest C values, which is consistent with the idea that vegetative cover decreases soil loss. On the other hand, the average C factor for areas with other uses was 0.55. This is three times larger than the value for secondary forest. Figure 16 shows the map of the C factor where three ranges were determined to indicate land covers with relative low vulnerability to erosion (e.g. mature secondary forest), medium (e.g. shrubs), and high (e.g. agricultural uses).

Table 2. Land cover categories and C factor

Land cover categories	**Average C Factor**
Mature secondary forest	0.18
Impacted and/or secondary forest	0.19
Subsistence farming	0.21
Shrubs	0.30
Agricultural use	0.52
Other uses	0.55

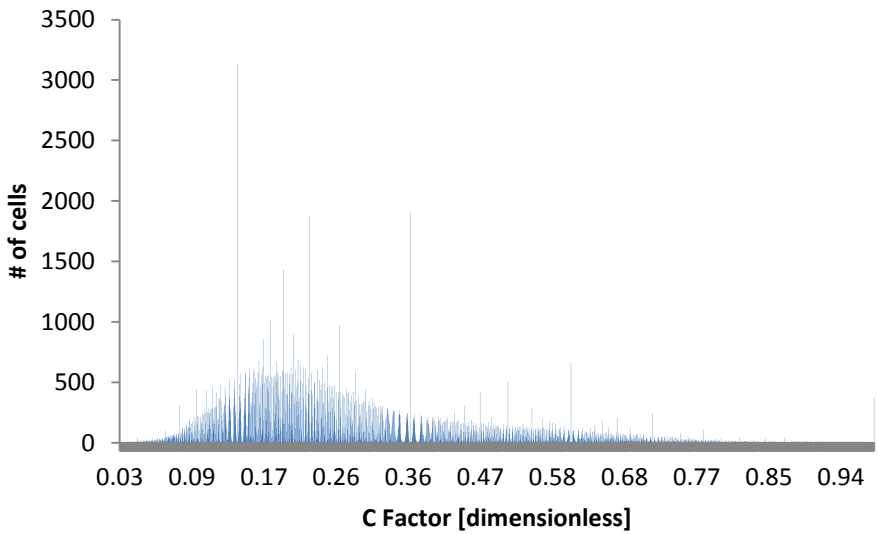

Figure 15. Histogram of the C factor.

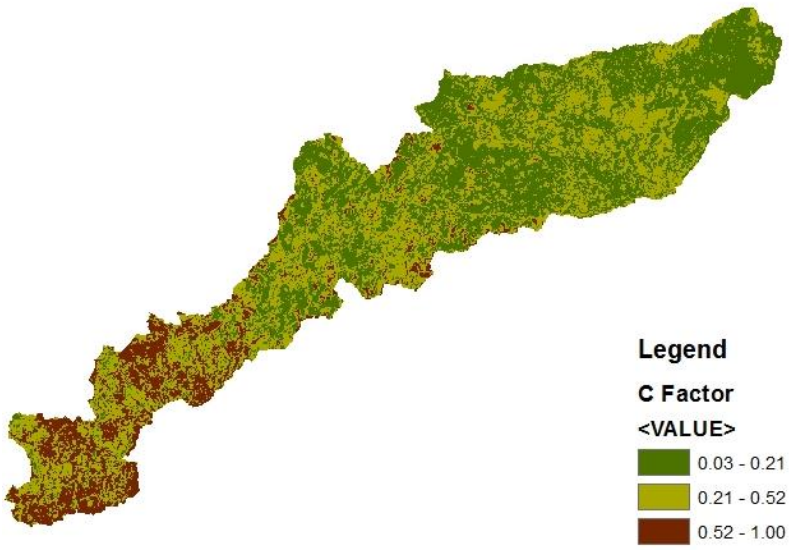

Figure 16. Map of the C factor.

Finally, Table 3 presents summary statistics for all the RUSLE factors previously discussed.

Table 3. Summary of statistical measures for R, K, LS, and C factors.

Parameter	**R** [MJ mm ha^{-1} $hour^{-1}$ $year^{-1}$]	**K** [tons ha h ha-1 MJ-1 mm-1]	**LS** [dimensionless]	**C** [dimensionless]
Max	7754	0.0474	17.50	1
Min	4713	0.0448	0.03	0.03
Mean	5780	0.0450	2.95	0.29
Median	5556	0.0448	9.86	0.23
SD	700	0	2.68	0.18

4.2 RUSLE results

Figure 17 shows the histogram for the RUSLE results, which follow an exponential distribution similar to that presented in Figure 5 for the LS factor, but with a more even distribution. Soil loss (A) in the subwatershed ranges from 0.3 to 2245 tons ha^{-1} $year^{-1}$. However, as soil loss increases in the x-axis, the number of cells representing the values decreases considerably to the point that only one cell in the output raster contains the value of 2245 tons ha^{-1} $year^{-1}$. Figure 18 helps to better understand the distribution of low and high values of soil loss by presenting the data based on the 50th, 90th and 100th percentile represented in green, yellow, and red respectively. From this, we can see that $A \leq 125$ tons ha^{-1} $year^{-1}$ in 50% of the 30x30 m cells that comprise the raster; $A \leq 425$ tons ha^{-1} $year^{-1}$ in 90% of the subwatershed and $426 \leq A \leq 2245$ tons ha^{-1} $year^{-1}$ in 10% of the watershed. The average soil loss was 180 tons ha^{-1} $year^{-1}$ with a standard deviation of 188.

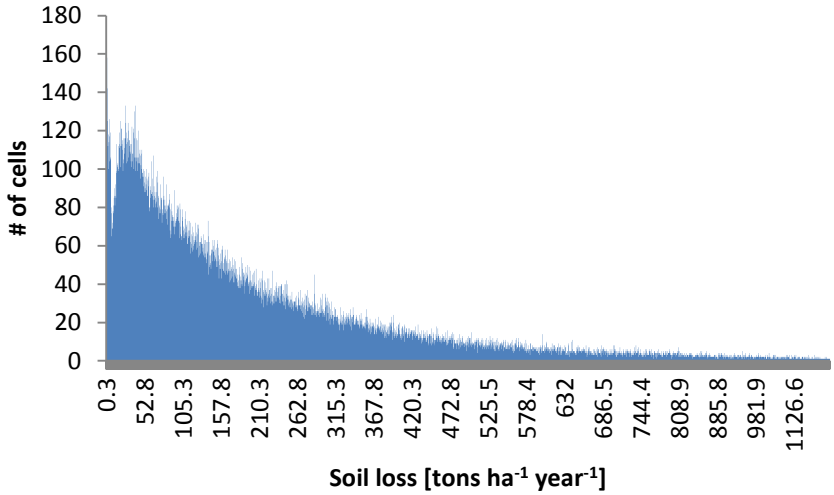

Figure 17. Histogram of soil loss predicted by the RUSLE.

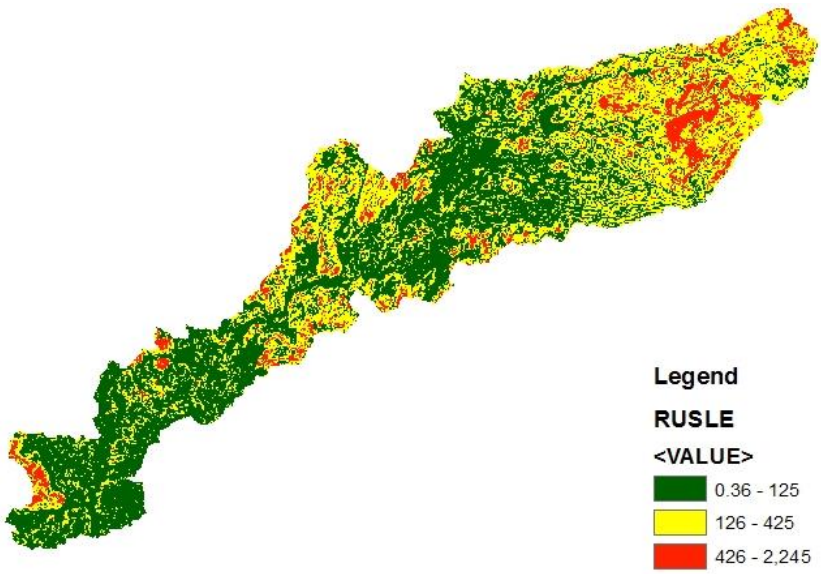

Figure 18. Map of soil loss predicted by the RUSLE with ranges based on the 50th (green), 90th (yellow), and 100th (red) percentile.

4.3 Sensitivity Analysis results

Table 4 presents the factor percentiles used for the OAT analysis and Table 5 summarizes the percent difference in soil erosion calculated using these factors. A comparison of the results shows that for this application, RUSLE was most sensitive to the LS and C factors. The model was also sensitive to the R factor, but the K factor presented no percentage difference because, as shown in Table 4, it maintains the same value for all the percentiles. Previous studies have also identified the LS factor as the most sensitive variable in their studies (Benkobi et al., 1994;

Biesemans et al., 2000). Therefore, minor changes or errors could have a significant effect on the estimation of soil loss.

Table 4. Summary of percentiles for the R, K, LS, and C factor.

Factor	**10th**	**25th**	**50th**	**75th**	**90th**
R	5110	5227	5556	6165	6943
K	0.0448	0.0448	0.0448	0.0448	0.0448
LS	0.312	0.701	9.857	14.785	17.742
C	0.120	0.161	0.231	0.378	0.578

Table 5. Percentage change relative to 50th percentile.

Constant factor	10th	25th	75th	90th
R	-8%	-6%	11%	25%
K	0%	0%	0%	0%
LS	-97%	-93%	50%	80%
C	-48%	-30%	64%	150%

5.0 DISCUSSION

5.1 RUSLE Factors

Among the four factors, the R factor had the highest magnitude and largest range. The minimum and maximum value were taken and compared to the results of seven studies that also used the RUSLE (or another equation based on the USLE) (Figure 19). The comparison shows that the values of the R factor for the Zarati subwatershed are significantly higher than the values obtained in the countries listed. This difference could be related to the fact that the Zarati subwatershed receives more rainfall than the watersheds in the studies reviewed. The Zarati subwatershed has a mean annual precipitation (MAP) of 2274.6 mm; the area that comes closest to this is a watershed located in east India, with a MAP of 1300 mm (Table 6) (Pandey et al., 2007). Based on this, the R factor for east India was expected to be the closest to the Zarati subwatershed, however, that is not the case. As listed in Table 6, Southern Greece is the study that occupies the second place for the R factor even though the reported MAP reported was only 900 mm (Kouli et al., 2009).

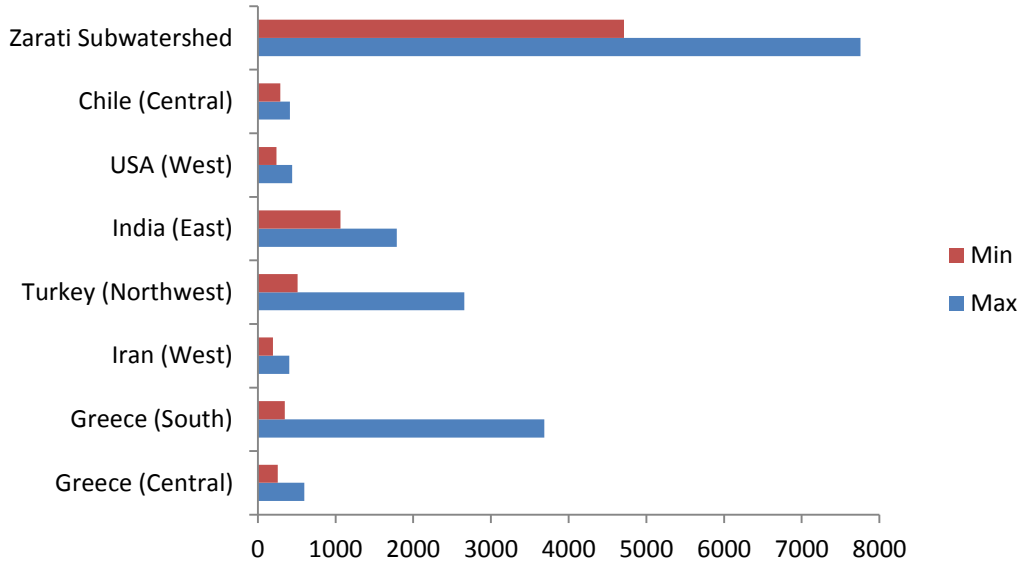

Figure 19. Comparison of the minimum (Min) and maximum (Max) values of the R factor in different countries. Chile: Bonilla et al., 2010. USA: Bartsch et al., 2002. India: Pandey et al., 2007. Turkey: Ozsoy et al., 2012. Iran: Arekhi et al., 2012. Greece (South): Kouli et al., 2009. Greece (Central): Rozos et al., 2013.

Table 6. Maximum value of R factor and mean average precipitation (MAP).

	Max R Factor	MAP*
Zarati Subwatershed	7754	2274.6
Greece (South)	3687	900
Turkey (Northwest)	2658	729
India (East)	1790	1300
Greece (Central)	600	1200
USA (West)	440	550
Chile (Central)	415	445
Iran (West)	404	593

For Grece, Turkey and USA precipitation was reported as a range in the respective studies. The upper limit of the range is presented in the table.

R factor: MJ mm ha^{-1} $hour^{-1}$ $year^{-1}$

A review of the methodology of each study revealed the formulas used to calculate the R factor. By definition, the R factor is the product of the kinetic energy of a raindrop and the 30-minute maximum rainfall intensity (Pandey et al., 2007). Since these measurements are rarely available at standard meteorological stations, most of the studies estimated the R factor based on the Modified Forunier Index (MFI), including the study in Southern Greece (Eq. 8). One of the exceptions was India, where the information was available from the meteorological station. The formula used for the Zarati Subwatershed is also based on the MFI. However, the MFI was not included in Equation 5 because the choice of a monthly precipitation was found to better represent the seasonality in the region (Jiménez-Rodríguez et al., 2014). In addition, elevation was introduced to Equation 5 as "a key variable that indirectly considers the effect of orographic rainfall" (Jiménez-Rodríguez et al., 2014). Any of the equations used in the seven studies included elevation as a variable. Therefore, the difference in the magnitude of the R factor could be explained as the result of different MAP and the use of equations based on MFI but developed to fit regional data.

$$MFI = \frac{\sum_{i=1}^{12}(\bar{p}i)^2}{\bar{P}} \qquad \textbf{Eq. 8}$$

where:

$\bar{p}i$ [mm]: mean rainfall amount for month i

$\bar{P}$ [mm]: mean annual rainfall amount

In the study conducted by Vahrson (1990), the R factor was found to generally decrease as elevation increased (Eq. 5). Equations developed for Honduras use the same approach, with elevation negatively correlated with R (Eq. 9 - 10). Nevertheless, in the Zarati subwatershed, the R factor increased as elevation increased (Figure 11). The elevation in the subwatershed increases from southwest to northeast, reaching a maximum elevation of 1054 masl (Figure 20). Rainfall also increases from the lower to the upper part (Figure 21) suggesting that the orographic features that control local convective and frontal systems might be different from those observed in the Costa Rican uplands. Given that the R equation we selected (Eq. 5) multiplies September's monthly precipitation by a factor of 19.527 while elevation is multiplied by 1.769, it is possible to see that increases in rainfall from southwest to northeast will have a greater impact on the magnitude of the R factor than changes in elevation (Eq. 5). Figure 22 shows that even though there is a decreasing trend of R factor with elevation, there are points that do not follow that trend, especially in the range between 0 and 1000 masl. Therefore, the results obtained for the R factor in the Zarati Subwatershed respond to a heavy rainfall regime that develops at an elevation of transition.

$$R = 7696.0 - 4.095\,E \qquad \textbf{Eq. 9}$$

$$R = -699.3 + 7.0001\,P - 2.7190\,E \qquad \textbf{Eq. 10}$$

where:

P [mm yr^{-1}]: mean annual precipitation

E [masl]: elevation (m), represented by the DEM.

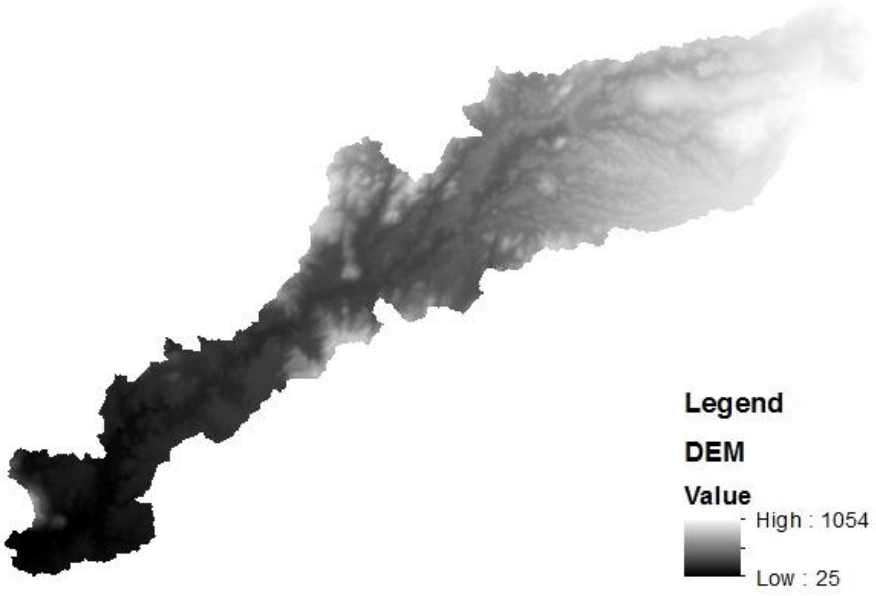

Figure 20. DEM of the Zarati subwatershed. Range is measured in meters above sea level (masl).

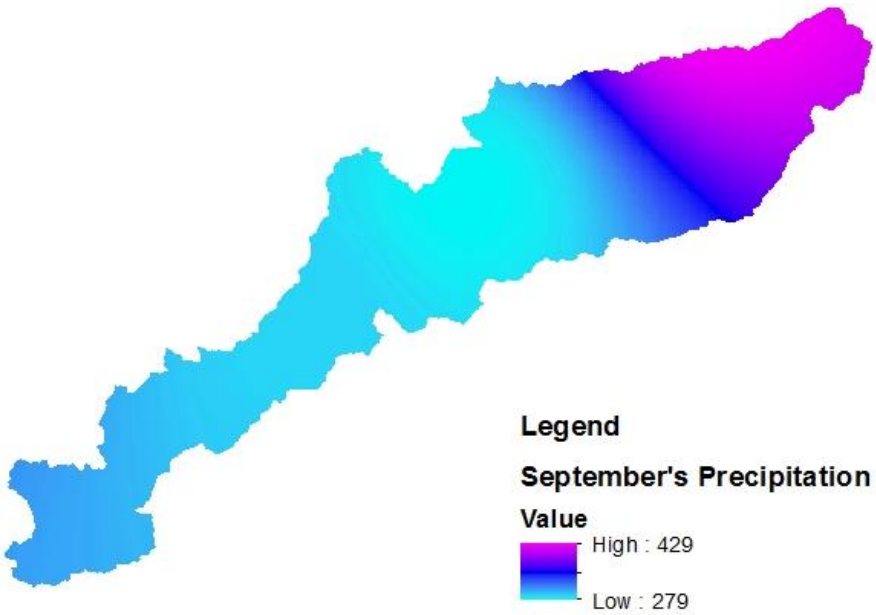

Figure 21. September rainfall interpolated (mm).

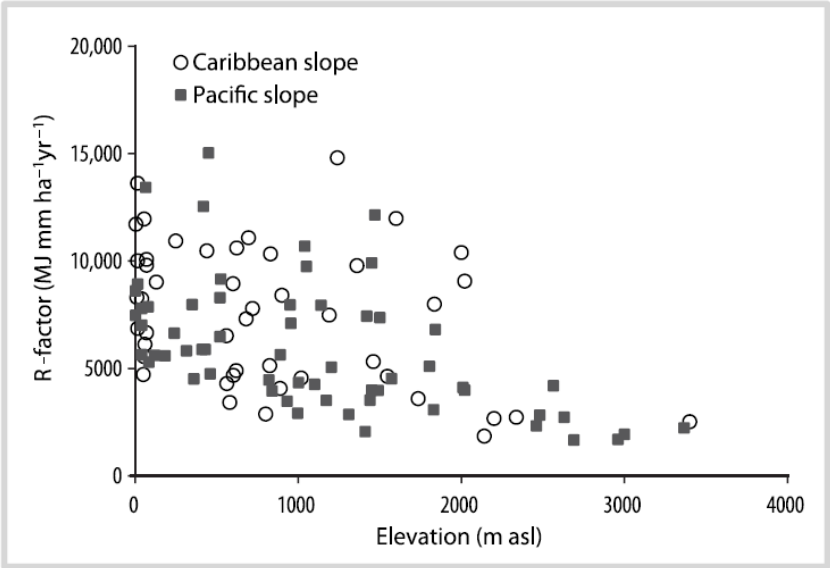

Figure 22. R-factor in relation to Costa Rica. Source: Jiménez-Rodríguez et al., 2014.

Similar to the comparison for the R factor, Figure 23 shows a comparison of the LS factor to seven other erosion vulnerability studies. In this case, the LS factor is in the range of maximum values that have been reported. Minimum values are not presented since they are either zero or very close to zero. Unfortunately, only two studies reported the slope in their respective areas of study and from these only the study in Eastern India presented the equations used for L and S, which are the same as those used for the Zarati subwatershed. The maximum slope in Eastern India was 22%,which is lower than the maximum slope of 202% in the Zarati subwatershed (Figure 3). This is consistent with the fact that the LS factor calculated for the subwatershed is higher (Figure 23). A review of the studies that listed the equations used to calculate the LS factor indicated that the main differences lie in the value given to the exponent ‘m’ in Eq. 2, whether or not the exponent is kept constant for different ranges of slope, and the equation used to calculate the S factor.

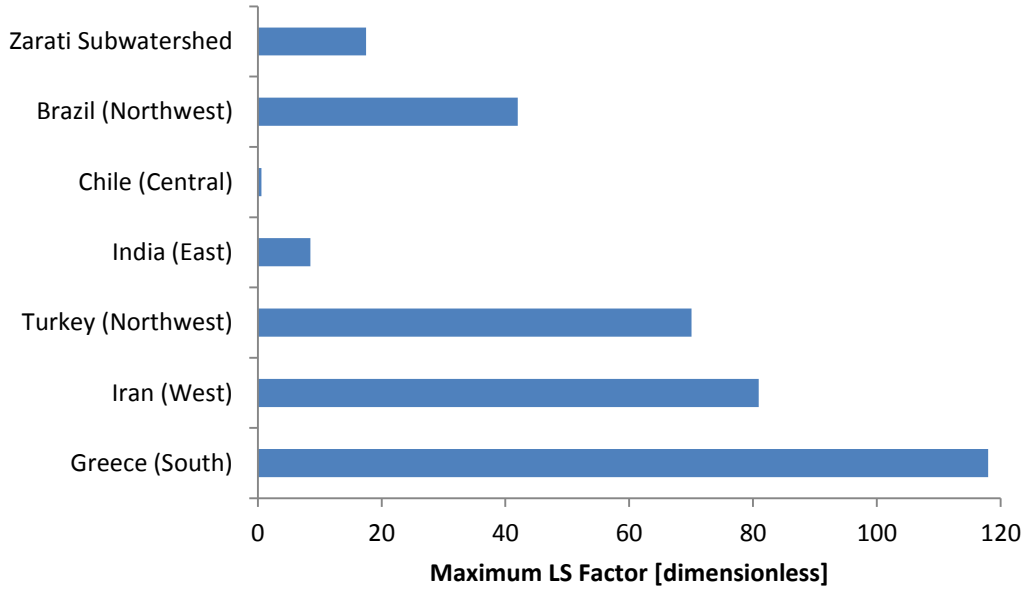

Figure 23. Comparison of maximum value for LS factor to existing studies. Brazil (Northwest): Lu et al., 2004.

The comparison of the K factor in Figure 24 shows that it is within the ranges that have been reported in the literature. Most of the studies calculated the K factor based in the formulas proposed by Renard et al. (1997) and Wischmeier et al. (1978). These formulas include specific soil characteristics such as percent organic matter, soil texture class, and particle diameter. Due to the lack of this information for the Zarati Subwatershed, tabulated values from the FAO & EPA study were used. According to FAO's classification, a K factor of 0.0448 corresponds to a type of soil with clay texture, a porosity of 0.475, and hydrological type D. Type D soils are soils with very slow infiltration rate, especially when thoroughly wetted, and with permanent high water table. On the other hand, a K factor of 0.0474 indicates a sandy clay loam texture, porosity of 0.398 and hydrological soil type C. Similar to type D, this type of soil has a low hydraulic conductivity. Type C soils are defined as "soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture" (NOAA, 2004).

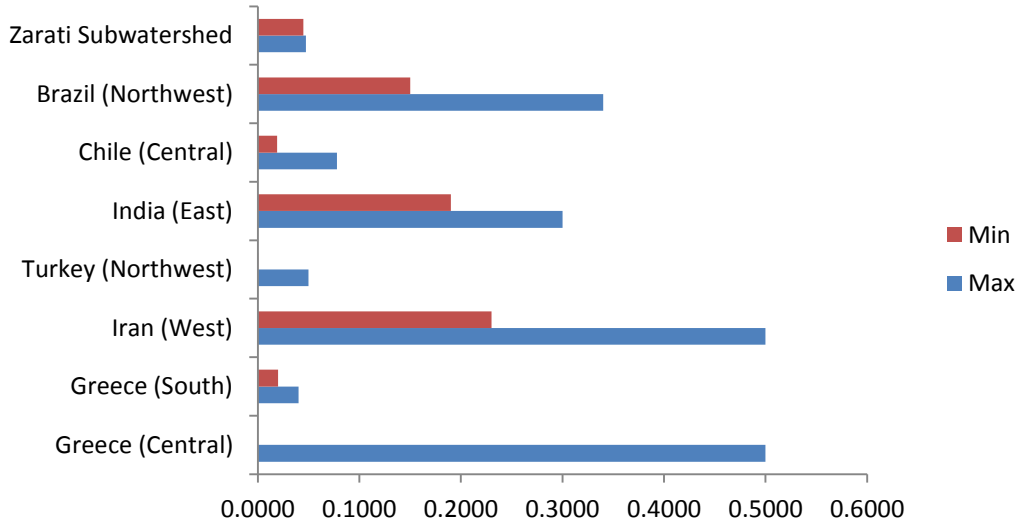

Figure 24. Comparison of K factor to existing studies. Minimum value for Greece (Central) is zero.

The C factor was also compared with other studies, all of which had a range of values from one to zero. Since the C factor was identified as a sensitive variable, future research should investigate how results are affected by a NDVI calculated with a satellite image taken during winter instead of summer. An approach that uses monthly NDVI to calculate a yearly average C factor would provide more representative results.

5.2 Annual Soil Loss

Table 7 presents a summary of the results of eight studies and the results for the Zarati subwatershed in descending order of average annual soil loss. Every hydrological system has its own characteristics, which limit the possibility of drawing direct comparisons among different systems without knowing if they are similar. However, Table 7 can help describe where the results lie in relation to other locations. The results of this study are in the high range of average annual soil loss and very close to the erosion potential reported for the Panama Canal watershed. While this provides confidence in our results, further analysis would be required to understand the similarities and differences between these systems. For the maximum value of soil loss, some studies did not specify a number but instead an open range. However, it is possible to see that the maximum value can be as large as three orders of magnitude higher than the average.

Table 7. Average, maximum, and standard soil loss in tons ha^{-1} $year^{-1}$ reported by different studies.

Location	Average	Maximum	SD	Study
Greece (South)*	205.5	4156	NS	Kouli et al., 2009
Zarati subwatershed	180	2245	188	This study
Panama Canal Watershed	140.9	220	44.6	URS, 2007
Greece (South)**	77.2	1150	NS	Kouli et al., 2009
Iran (West)	38.8	>80	110.4	Arekhi et al., 2012
Turkey (Northwest)	11.2	1508	NS	Ozsoy et al., 2012
India (East)	3.7	>80	NS	Pandey et al., 2007
Greece (Central)	NS	>15	NS	Rozos et al., 2013
Chile (Central)	NS	8	NS	Bonilla et al., 2010

NS: No specified

* The study conducted by Kouli et al. (2009) studied nine watersheds; values in this row are those for the watershed with the highest mean annual soil loss.

** Values in this row represent Greek watershed with the lowest mean annual soil loss.

As shown in Figure 25, the development of soil erosion risk (SER) classes is subjective and site specific. Different studies defined very low, low, moderate, and high vulnerability to erosion based on different ranges of annual soil loss. Instead of following this approach, the results of the RUSLE in this study were compared by *corregimiento*. A *corregimiento* is the lowest administrative level in the Panamanian political administrative divisions and can be compared with US counties . This presentation of the information allows an interpretation based on the administrative structure of the area and consequently facilitates the implementation of management efforts and land use planning. Figure 26, shows the location of the eight *corregimientos* that intersect the subwatershed and how they overlap with the results of the RUSLE.

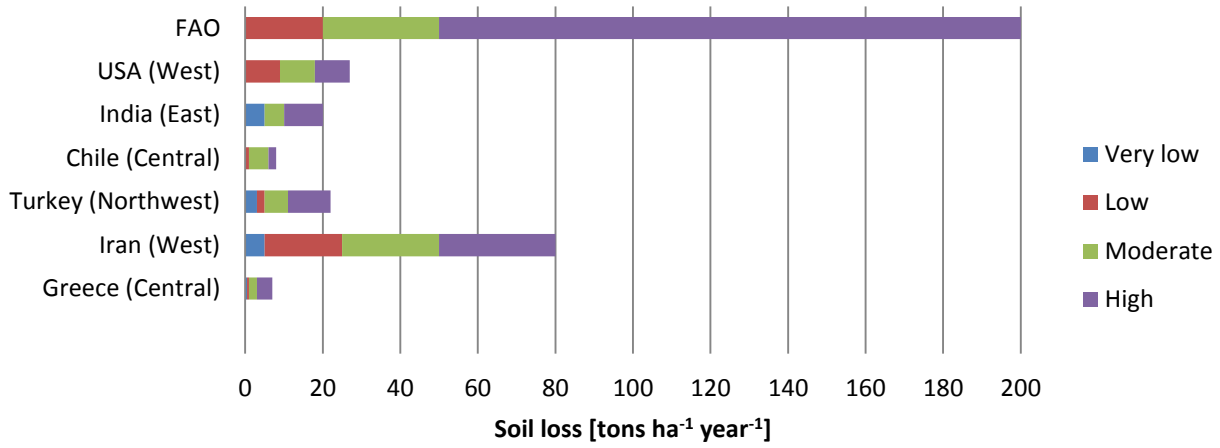

Figure 25. Soil erosion risk (SER) classes developed in different studies. FAO: FAO, 2004.; USA (West): Bartch et al., 2002

Figure 26. *Corregimientos* in the Zarati Subwatershed.

Table 8 is organized in decreasing order of vulnerability to erosion, following an area-based weighted average and summarizes statistical information for each *corregimiento*. Pajonal has the highest vulnerability to erosion among the eight *corregimientos* since it covers most of the middle and upper sections of the watershed. These two sections have a relatively low C factor due to the existence of secondary and impacted forest. However, the increase in vulnerability to erosion is mainly caused by an increasing LS factor and to a lesser extent to the increase in the R factor. Chiguirí Arriba is the second area with highest relative vulnerability. As shown in Figure 2, the Zaratí River headwaters are located in this mountainous region. Both Pajonal and Chiguirí Arriba lie above the water intake of the Penonome Water Treatment Plant (Figure 2). While this study did not explicitly model sediment transport to the river, a decrease in soil loss in these *corregimientos* will likely decrease the loads of sediment that are causing problems in the water pumping and treatment system of the Penonome water treatment plant.

Table 8. RUSLE results for each *corregimiento* that intersects the Zarati Subwatershed.

Corregimientos	Relative Vulnerability to erosion	Weighted Average [tons ha^{-1} year^{-1}]	Area		Annual soil loss [tons ha^{-1} year^{-1}]			
			[%]	[ha]	Mean	Min	Max	SD
Pajonal	High	102.3	55.64	9848	183.9	0.4	1957.0	185.5
Chiguirí Arriba	Moderate	36.0	12.39	2192	290.3	0.8	2245.1	188.7
Cañaveral		14.9	9.80	1734	152.6	0.8	1810.7	206.8
Penonomé (Cab.)		13.1	12.78	2262	102.3	0.5	1229.7	119.7
San Juan de Dios	Low	9.2	2.78	492	330.3	2.4	1423.8	220.6
Toabré		5.2	3.05	540	168.9	0.5	1418.5	169.4
Coclé		2.1	2.82	499	73.4	0.7	530.7	59.0
El Valle		1.8	0.74	131	246.1	8.0	1456.2	149.7

5.3 Recommendations

In order to properly manage the areas identified as vulnerable to erosion, this study proposes the continuation of initiatives that look at increasing the application of agricultural best management practices (BMPs) in the Zarati subwatershed. BMPs are "procedures and practices designed to reduce the level of pollutants in runoff from farming activities to an environmentally acceptable

level, while simultaneously maintaining an economically viable farming operation for the grower" (UNEP, 1998).

A previous study that looked at the aquifer recharge zones in the Zarati subwatershed estimated the percentage of farmers that were applying specific BMPs. These results were based on a field survey with 66 participants conducted in 2011 (Carrasco, 2011). Information collected in that study, along with other recommendations tailored to Central America, will be summarized in this section. The goal is to propose BMPs that fit both the physical aspects of the Zarati subwatershed and the social, economic, and cultural characteristics of its population.

Slash and burn is a culturally accepted common practice among Panamanian farmers and it is not controlled or restricted. In the Zarati Subwatershed, 88% of the farmers utilize this technique to clear their fields every dry season (Carrasco, 2011). Due to its relation to soil degradation, air pollution, and other environmental impacts, international organizations have developed alternative plans to educate farmers around the world in agroforestry practices. Instead of burning large areas, experts recommend partial, selective and progressive slash and prune, which allows the conservation of multipurpose timber, fruit trees, slashed shrubs, and a dense layer of mulch. This agroforestry approach should be integrated with permanent soil cover, no-tillage or low-tillage, crop rotation, and an efficient use of fertilizer (timing, type, amount and location) (Castro et al., 2009). For the case of the Zarati Subwatershed, it was found that more than 90.90% of the farmers use fertilizers in excessive quantities (Carrasco, 2011).

The existence of permanent or temporal vegetative cover helps to incorporate nutrients to the soil and protects it from excessive erosion by regulating soil moisture content. Improved fallows and protective blanket of leaves, stems and stalks from previous crops can be used as a temporal soil cover. For the Zarati subwatershed it was reported that 75.75% of the farmers do not follow this practice (Carrasco, 2011). The construction of fences with trees, live fences, instead of fences made out of wood or metal stakes is also considered a good practice. Trees serve as a windbreaker barrier, improve rainfall infiltration, and contribute to erosion control by providing shadow and keeping soil moisture content (FAO, n.d.). Unfortunately, these types of fences are not commonly used by the farmers of the subwatershed (Carrasco, 2011).

Up to 72.72% of the farmers practice no-tillage or low-tillage agriculture (Carrasco, 2011). This is a great contribution to erosion control since it has been reported that "tillage with tractors and ploughs is a major cause of severe soil loss in many developing countries" (FAO, 2011). No-tillage, also called "zero tillage", refers to simply drilling seed into soil with little or no prior land preparation. Historically, there has been the misconception that more tillage translates into higher yields. However, research studies show that soils in tropical countries generally do not need to be tilled in order to produce higher yields at lower costs (FAO, 2011).

Another BMP that is widely applied by farmers in the subwatershed is crop rotation. Crop rotation consists on planting series of different crops in the same field following a defined order. Crop rotation is the opposite of monoculture which focuses on one crop year after year (FAO, n.d.). Up to 80% of the farmers practice this technique, being rice with maize, rice with yucca, and maize with beans the most commonly alternated crops. In addition, they wait three or more years to allow soil regeneration (Carrasco, 2011). This practice comes with the benefits of greater production due to positive interactions between succeeding crops, reduction on the costs related to pests and diseases control, improved soil quality (more or deeper roots) and better distribution of nutrients in the soil profile thanks to the alternation between deep-rooted crops that can bring up nutrients from deeper levels and shallow-rooted crops that can absorb them more easily (UNEP, 1998; FAO, n.d.). Since crop rotation and zero-tillage are practices already by the farmers, efforts should focus on continue providing technical guidance in order to help farmers to make decisions that are specific to their field(s) characteristics.

Extensive agricultural practices are not common in areas of the subwatershed with a slope greater than 70%. However, there are still some steep areas where annual crops are planted. In these areas, some farmers place maize residuals as transversal contours in order to retain eroded soil (Carrasco, 2011). Other techniques that could be used are contour and cutoff ditches which besides controlling erosion can collect water, gully treatment which controls gully erosion by diverting water from entering the gully and allowing vegetative growth inside it. Also, stone lines, contour ridges and vegetative strips work as energy dissipators while collecting sediment (FAO, n.d.).

An important component of a BMP program is the construction of a partnership with the community which then allows knowledge transfer. The ANAM has been carrying an integrated management program for the Zarati subwatershed for seven years. This program consists on an alliance with the communities in the subwatershed to create and manage plant nurseries with the objective of promoting and executing reforestation efforts. Members of ANAM have conducted efforts to educate the community about conservation of natural resources in the subwatershed. In relation to this, community members have mentioned the importance of their role as multiplying agents (Carrasco, 2011).

Initiatives like the integrated management program for the Zarati subwatershed should be maintained and its promoters should take advantage of research studies that are being conducted in the area in order to identify its weaknesses. For example, only 50% of the farmers reported that they had participated on educational programs about conservation agriculture (Carrasco, 2011). It was also estimated that 86.36% of the farmers in the Zarati subwatershed do not have an organized sowing system. This has contributed to the degradation of the soil because the amount of crops per volume of soil is excessive. In addition, BMPs such as permanent soil cover, live fences, and efficient use of fertilizes need to be given attention since the percentage of farmers that do not practice them is high. Therefore, technical workshop and follow-up about agricultural planning could be of great benefit.

Forest conservation initiatives have had a relative high success in the Zarati Subwatershed, specifically in the upper part where all the secondary and impacted forest is located (Figure 4). The current Panamanian Forest Conservation law regulates the extraction of wood in the subwatershed. Permits are reviewed by the ANAM and the authorities assigned by the major's office in Penonome. The review process includes verifying that the trees are not located near or in river banks and are not classified as endangered species. One of the most important forest conservation milestones achieved was the establishment of two hydrological reserves, Cucuazal and Turega, which have a combined area of 896 ha (Carrasco, 2011). Even though there is a legal framework for forest conservation, constant supervision should be carried in order to identify and punish illegal deforestation actions. In addition, attention should be given to establishing a market for environmental services that could make sustainable the conservation activities executed in the upper subwatershed.

BMPs and forest conservation policies are important pieces to control vulnerability to erosion in the Zarati Subwatershed. However, it is also very important to develop a land use plan with the purpose of having control over the changes in land cover of the subwaterhed. Panama does not have a national law for land use planning. Currently, different laws define and regulate different situations related to land use. This causes different resolutions for similar cases, and disappointment from the public. A previous study in the subwatershed proposed a set of steps to implement and continue a land use plan, identifying which institutions should be involved in this effort (Carrasco, 2011). The primary objective should be to have a national unified legislation for land use before causing more division by developing regional legislations. Nevertheless, it is important to have case studies that will help on the rule making process. Therefore, a land use plan for the Zarati Subwatershed could be an excellent case study and it has the advantage of having a study that establishes guidelines for regulators.

6.0 CONCLUSIONS

This study evaluated the vulnerability to erosion of the Zarati subwatershed with the purpose of determining areas that experience high rates of soil loss and therefore could be large sources of sediment runoff; affecting the operations of the Penonome Water Treatment Plant. Four factors were determined as part of the RUSLE. The R factor had a mean value of 5780 MJ mm ha^{-1} $hour^{-1}$ $year^{-1}$, and the K factor had a value of 0.0448 in 93.6% of the area of the subwatershed. The LS factor was characterized by an exponential distribution with an average value of 2.95, meanwhile, the C factor presented a mean value of 0.29. When compared to other global watersheds all the values were within the ranges reported except for the R factor, which was significantly higher. However, its magnitude was found to be within the range presented by a study in the nearby country of Costa Rica. The LS factor was determined to be the most sensitive variable for this study, indicating that minor changes or errors in slope-length calculations could have a significant effect on the estimation of soil loss.

The average annual soil loss was estimated to be 180 tons ha^{-1} $year^{-1}$. When compared to other studies in different locations of the world, this result ranked as one of the highest but also very close to the erosion potential reported for the Panama Canal watershed. While this provided confidence in our results, further analysis would be required to understand the similarities and differences between these systems. Pajonal and Chiguirí Arriba were the two *corregimientos* with the highest relative vulnerability to erosion within the subwatershed. Both areas lie above the water intake of the Penonome Water Treatment Plant. While this study did not explicitly model sediment transport to the river, a decrease in soil loss in these *corregimientos* could possibly decrease the loads of sediment that are causing problems in the water pumping and treatment system.

Currently soil conservation practices include no-tillage or low-tillage, and crop rotation. On the other hand, there are practices such as partial, selective and progressive slash and prune, permanent soil cover, efficient use of fertilizer, live fences, and agricultural planning that have a low percentage of acceptance among the farmers of the subwatershed. Initiatives like the Integrated Management Program for the Zarati subwatershed have been put in place to educate the inhabitants about water resources and conservation. Since the results of this study were

adapted to the administrative structure of the area they could contribute to this and other initiatives focused on land use planning.

Future research could look at improving the outputs of the RUSLE by determining a dataset for the conservation practices factor, studying the impact of seasonal changes in the C factor, and developing an equation for the R factor based on data collected in Panama.

7.0 ACKNOWLEDGMENTS

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8.0 BIBLIOGRAPHY

Anderson, E. L. (2011). *Climate change impacts on surface water in Central America and Hispaniola.* Panama City, Panama: CATHALAC/SERVIR.

Arekhi, S., Bolourani, A. D., Shabani, A., Fathizad, H., & Ahamdy-asbchin, S. (2012). Mapping soil erosion and sediment yield susceptibility using RUSLE, remote sensing and GIS (Case study: Cham Gardalan Watershed, Iran). *Adv. Environ. Biol., 6*(1), 109-124.

Atherholt, T. B., LeChevallier, M. W., Norton, W. D., & Rosen, J. S. (1998). Effect of rainfall on Giardia and crypto. *American Water Works Association Journal, 90*(9), 66-80.

Bartsch, K., Boettinger, J., Dobrowolski, J., & Van Miegroet, H. (2002). Using empirical erosion models and GIS to determine erosion risk at Camp William, Utah. *Journal of Soil and Water Conservation, 57*(1), 29-37.

Basic Information about Pathogens and Indicators in Drinking Water. (2013, December 13). Retrieved from EPA: http://water.epa.gov/drink/contaminants/basicinformation/pathogens.cfm

Benkobi, L., Trlica, M., & Smith, J. (1994). Evaluation of a refined surface cover subfactor for use in RUSLE. *Range Manage, 47*, 74-78.

Biesemans, J., Gabriels, D., & Van Meirvenne, M. (2000). Extending the RUSLE with the Monte Carlo error propagation technique to predict lon-term average off-site sediment accumulation. *Journal of Soil and Water Conservation, 55*(1), 35-42.

Bonilla, C. A., Reyes, J., & Magri, A. (2010). Water erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Central Chile. *Chilean Journal of Agricultural Research, 70*(1), 159-169.

Butt, M., Mahmood, R., & Waqas, A. (2011). Sediments deposition due to soil erosion in the watershed region of Mangla Dam. *Environmental Monitoring and Assessment, 181*(1), 419-427. doi:10.1007/s10661-010-1838-0

Calvo-Alvarado, J., Jiménez-Rodríguez, C., & Jiménez-Salazar, V. (2014). Determining rainfall erosivity in Costa Rica: a practical approach. *Mountain Research and Development, 34*(1), 48-55.

Carrasco, W. (2011). *Manejo y protección de zonas de recarga hídrica y fuentes de agua para consumo humano en la subcuenca del río Zaratí.* Centro Agronómico Tropical de Investigación y Enseñanza.

Castro, A. et al. (2009). *Quesungul slash-and-burn agroforestry (QSMAS): Improving crop water productivity, food security and resource quality in the subhumid tropics.* Colombo, Sri Lanka: CGIAR Challenge Program on Water and Food.

EPA. (2009). *Guidance on the development, evaluation, and application of enviornmental models.* Washington DC: EPA.

ESRI. (2012). ArcGIS 10.1 Help Library .

FAO. (2001). *Zero tillage: when less means more*. Retrieved from http://www.fao.org/ag/magazine/0101sp1.htm

FAO. (2004). *Assesing carbon stocks and modelling win-win scenarios of carbon sequestration though land-use changes.* NR. FAO. Retrieved from http://www.fao.org/docrep/007/y5490e/y5490e00.htm

FAO. (n.d.). *Cercas vivas de árboles y rompevientos leñosos*. Retrieved from http://www.fao.org/ag/againfo/programmes/es/lead/toolbox/Tech/22Livef.htm

FAO. (n.d.). *Chapter 8 – Conserving soil and water.* Retrieved from www.fao.org/ag/ca/africatrainingmanualcd/pdf%20files/08WATER.PDF

FAO. (n.d.). *The importance of crop rotations*. Retrieved from http://www.fao.org/ag/ca/training_materials/leaflet_rotations.pdf

Kalbus, E., Kalbacher, T., Kolditz, O., Krüger, E., Seegert, J., Röstel, G., . . . Krebs, P. (2012). Integrated water resources management under different hydrological, climatic and socio-economic conditions. *Environ Earth Sci, 65*, 1363-1366. doi:10.1007/s12665-011-1330-3

Kouli, M., Soupios, P., & Vallinatos, F. (2009). Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environmental Geology, 57*, 483-497. doi:10.1007/s00254-008-1318-9

Lu, D., Li, G., Valladares, G., & Batistella, M. (2004). Mapping soil erosion risk in Rodônia, Brazilian Amazonia: Using RUSLE, remote sensing and GIS. *Land Degrad. Develop.*, 499-512.

McCool, D., Foster, G., Mutchler, C., & Meyer, L. (1987). Revised slope steepness factor for the universal soi loss equationl. *Trans of ASAE, 30*(5), 1387-1396.

Montier, C., Daroussin, J., King, D., & Le Bissonnais, Y. (1998). *Cartographie vdel'aléa "Erosion des Sols" en France.* Orléans: INRA.

NOAA. (2004). *Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT).* NOAA.

Ozsoy, G., Aksoy, E., Dirim, M., & Tumsavas, Z. (2012). Determination of soil erosion risk in the Mustafakemalpasa river basin, Turkey, using the Revised Universal Soil Loss Equation, geographic information system, and remote sensing. *Environmental Management, 50*, 679-694. doi:10.1007/s00267-012-9904-8

Pandey, A., Chowdary, V., & Mal, B. (2007). Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remoste sensing. *Water Resources Management, 21*, 729-746.

Renard, K., Foster, G., Weesies, G., McCool, D., Yoder, D., & Coordinators. (1997). *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE).* Tucson: United States Department of Agriculture.

Rozos, D., Skilodimou, H., Loupasakis, C., & Batherllos, G. (2013). Application of the revised universal soil loss equation model on landslide prevention. An example from N. Euboea (Evia) Island, Greece. *Environ Earth Sci, 70*, 3255-3266. doi:10.1007/s12665-013-2390-3

UNEP, U. N. (1998). *Best management practices for agricultural non-point source of pollution.* UNEP.

URS Holdings, I. (2007). *Panama Canal Expansion Project - Third Set of Locks.* Panama: Panama Canal Authority.

Vahrson, W.-G. (1990). El potencial erosivo de la lluvia en Costa Rica. *Agronomia Costarricense, 14*(1), 15-24.

van der Knijff, J., Jones, R., & Montanarella, L. (2000). *Soil erosion risk assessment in Europe.* European Soil Bureau.

Vasyukova, E., Uhl, W., Braga, F., Simões, C., Baylaõ, T., & Neder, K. (2012). Drinking water production from surface water sources in the tropics: Brasília DF, Brazil. *Environ Earth Sci, 65*, 1587-1599. doi:10.1007/s12665-011-1308-1

Viessman, W., Hammer, M. J., Perez, E., & Chadik, P. A. (2009). *Water Supply & Pollution Control.* New Jersey: Pearson.

Wischmeier, W., & Smith, D. (1978). *Predicting rainfall erosion losses: A guide to conservation.* Washington DC: United States Department of Agriculture.