Soil erosion risk estimate using RUSLE-GIS model: A case study of Cañete River Basin

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Abstract:** The erosive advance of soils due to the development of human-derived activities, such as agriculture and livestock, has caused soil erosion to gain importance in different countries around the world. According to the Food and Agriculture Organization of the United Nations (FAO), this problem has been at its most serious for the past 20 years. Latin American countries, such as Peru, show greater progress in this problem due to the scarcity of studies and the lack of measures for the conservation and adequate use of soil. The Revised Universal Soil Loss Equation (RUSLE) model provides quantitative results for soil loss estimation. In this context, the present study evaluates the erosion rate in the Cañete river basin between the years 1981 - 2016. For this purpose, remote sensing data obtained on rainfall, temperature, soil types, topography and vegetation cover from various national and international satellite sources with 12.5km x 12.5km resolution are integrated into a Geographic Information System (GIS). According to the results, the study showed that the factors R (rainfall erosivity factor) and LS (topographic factor) have the highest values, 1244.623 MJ.mm.ha^{-1}.h^{-1}.y^{-1} and 116 respectively, recorded in the areas of the upper Cañete River Basin, also have the greatest influence on soil erosion rates for the B. The lower and upper areas of the basin are not favored by the type of vegetation cover "cultivated land" that has the highest value for this factor (0.63). The results suggest the implementation of soil conservation practices for the middle and upper sub-basin of the study area. The average rate of soil erosion obtained between the years 1981-2016 was 10.81 t.ha^{-1}.year^{-1}, which is considered moderate erosion according to the FAO classification.

Keywords-- RUSLE, GIS, Soil Erosion, PISCO, Cañete River.

I. INTRODUCTION

It is known that worldwide, the availability of agricultural land is constantly decreasing, for this reason the productive capacity of soils depends on the maintenance and improvement of the current conditions of this resource, which is already vulnerable to accelerated erosion processes [1]. In Peru, soil erosion is relevant due to the presence of various topographic factors, climates determined by the Andes Mountains, meteorological events such as the "El Niño" phenomenon that increase the intensity of rainfall in the coastal zone and the continuous change of its use in areas related to industrial activities.

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In response to this problem, different hydrological models have been developed to estimate and predict erosion rates and its main effects [2,3,4,5]. A study in Peru applied the RUSLE equation throughout its territory [6]. In the processing of their data, they focused on the evaluation of the R and C factors, since they are considered critical parameters in the modeling of developing countries. As a result, it showed a significant erosion increase in the northern part of the coastal region in 2010. Using (1), the RUSLE model quantifies the soil loss by integrating the effects of five variables.

$$A = R \times K \times LS \times C \times P \qquad (1)$$

Where A represents total soil loss (t.ha^{-1}.year^{-1}), R is rainfall erosivity factor (MJ.mm.h^{-1}.ha^{-1}.year^{-1}), K is soil erodability factor (t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}), LS, topographic factor, C, vegetation cover factor and P, conservation practices factor. The latter are dimensionless.

As an objective of the present study, soil losses between 1981 - 2016 are evaluated through the development of an erosion map in the Cañete River basin, in order to identify the potential risk of water erosion in the study area.

II. DATA AND METHODS

A. Study area

The Cañete River basin is part of the provinces of Cañete and Yauyos in the Lima region. It has a territorial extension of 6049.5 km^2 and is divided into Upper, Middle and Lower Basins, between 4,000 and 5,800 m.a.s.l, 350 and 4,000 m.a.s.l, 0.0 and 350 m.a.s.l, respectively. It is also delimited by the coordinates 11°58'19" and 13°18'55" in south latitude and 75°30'26" - 76°30'46" in west longitude. Its water resources are derived from rainfall, lagoons, and snowmelt from the snow-capped mountains in the highlands [7]. To collect the necessary data on precipitation, temperature and other parameters, the meteorological stations shown in Fig. 1, located in the Cañete River Basin and surrounding areas, were used as reference coordinates.

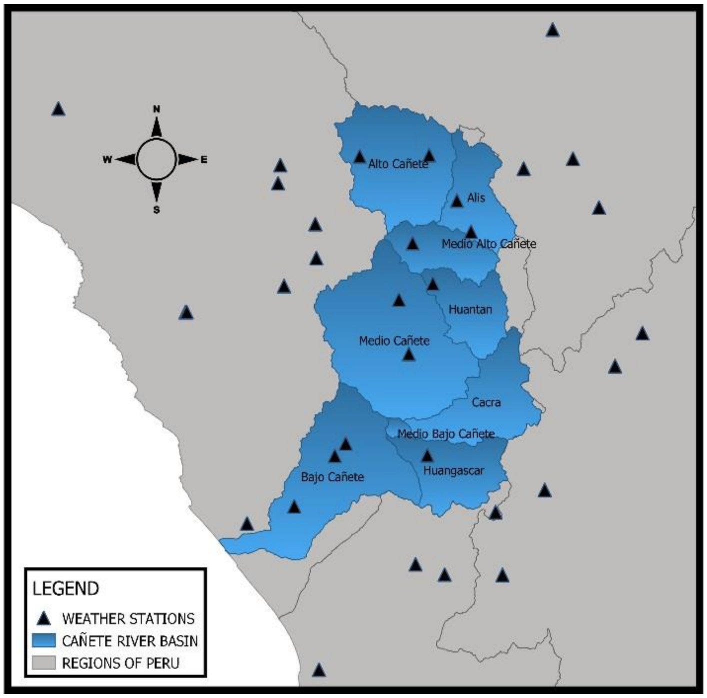

Fig. 1 Delimitation of the Cañete River Basin and location of meteorological stations for the study

TABLE 1
GEOGRAPHICAL DESCRIPTION OF THE SUB-BASINS OF THE CAÑETE RIVER

Hydrographic unit	Denomination	Area (Km^2)	%Area
Sub Basin	Alto Cañete	943.43	15.60
Sub Basin	Alis	447.47	7.40
Sub Basin	Medio Alto Cañete	365.16	6.04
Sub Basin	Medio Cañete	1510.26	24.97
Sub Basin	Huantan	421.22	6.96
Sub Basin	Cacra	617.02	10.20
Sub Basin	Medio Bajo Cañete	31.59	0.52
Sub Basin	Bajo Cañete	1194.86	19.75
Sub Basin	Huangascar	518.44	8.57
Total Basin	Cañete	6049.45	100.00

B. Data

For the case of the Cañete River Basin, the erosion rates were estimated for the years between 1981-2016 and the input data are presented in table 2.

TABLE 2
INPUT DATA USED TO ESTIMATE THE SOIL EROSION MAP FOR THE YEARS 1981-2016

NAME	SOURCE	SCALE	YEAR
Rainfall Data	PISCO-SENAMHI	Monthly	1981-2016
Sand, Silt and Clay Content Maps	ISRIC - World Soil Information	1km	2013
Organic Carbon Content Map	ISRIC - World Soil Information	1km	2013
ASTER Digital Elevation Model	ALOS PALSAR – ASF - Alaska Satellite Facility	12.5km	2011
Land Cover	GlobeLand30-2010	30km	2010
Vegetative Cover Peruvian map (shapefiles)	Ministerio del Ambiente, MINAM		2010

C. Methods

The perimeter of the Cañete River Basin was defined using QGIS software and an area of 6049.5 km^2 was obtained.

1. Determination of factors

To obtain the R factor, the rainfall data from six PISCO and SENAMHI stations are first correlated to validate the data (r> 0.7) using Pearson correlation. Then the monthly data is estimated and subsequently the annual precipitation data is calculated. With these values, using (2) the values of the MFI (Modified Fournier Index) can be obtained.

$$\mathrm{IMF} = \sum_{i=1}^{i=12} \frac{pi^2}{P} \quad (2)$$

Next, the equation of Renard and Freimund is calculated using (3), which estimates the value of the R factor in coastal areas with low precipitation rates [8] and in contexts where detailed climatological data do not exist.

$$R_{RF} = 0.07397 IMF^{1.847} \quad (3)$$

For the K-factor, data was obtained from the SoilGrids system with a resolution of 250m, which provides global predictions for standard numerical soil properties (organic carbon, bulk density, soil texture fractions, coarse fragments, etc.) at seven standard depths (0, 5, 15, 30, 60, 100 and 200 cm).

Subsequently, this information is imported into QGis software to obtain maps of silt, clay and sand percentages for each weather station coordinate point. Consequently, soil texture is classified according to FAO throughout the Cañete River Basin. After downloading the images from Alos Palsar and importing them into the QGIS program, the slopes in degrees (°) and percentages (%) are obtained to determine the values of "m". Likewise, with the digital elevation images acquired by the aforementioned satellite, the direction and accumulation of flow are found, respectively, to obtain the value of landa using (4).

$$\lambda = \left(\frac{flow\ accumulation\ x\ pixel\ length}{3.1416}\right)^{0.5} \quad (4)$$

Using (5) proposed by Weischmeier and Smith (1978) [9], the value of LS can be obtained.

$$LS = \left(\frac{\lambda}{22.13}\right)^m x\ (0.065 + 0.045s + 0.0065s^2) \quad (5)$$

For the classification of vegetation cover, factor C, satellite images were obtained from GlobeLand30 - 2010 in raster format. Then, they are converted to vector format, keeping the polygons, in order to visualize the classifications by areas, determine the types of coverage according to the model used in the satellite and reclassify the values according to MINAM (Ministry of Environment in Peru).

A vectorization is made to the reclassified map of the LS factor and the values of the P factor are added, taking the data corresponding to the "Contour" type of conservation, due to the lack of precise data to evaluate the use of other conservation practices in the soils of the Cañete River Basin. Based on this criterion, the "Soil Conservation Practices" Map is obtained.

Factors K, L and S are considered static, since they remain constant over time, and factors R, C and P, which are time-sensitive, are considered dynamic.

2. *Erosion Map*

The maps of the previously estimated factors (R, K, LS, C, P) were imported in raster format to apply the RUSLE Equation using the raster calculator. Then, we verified that the output extent is in UTM WG84 Zone 18S coordinates and the pixel size at 12.5m x 12.5m. In this way, we obtained the thematic soil erosion map for the entire extension of the Cañete River Basin. Finally, the values of the erosion map were reclassified according to the erosion levels established by FAO.

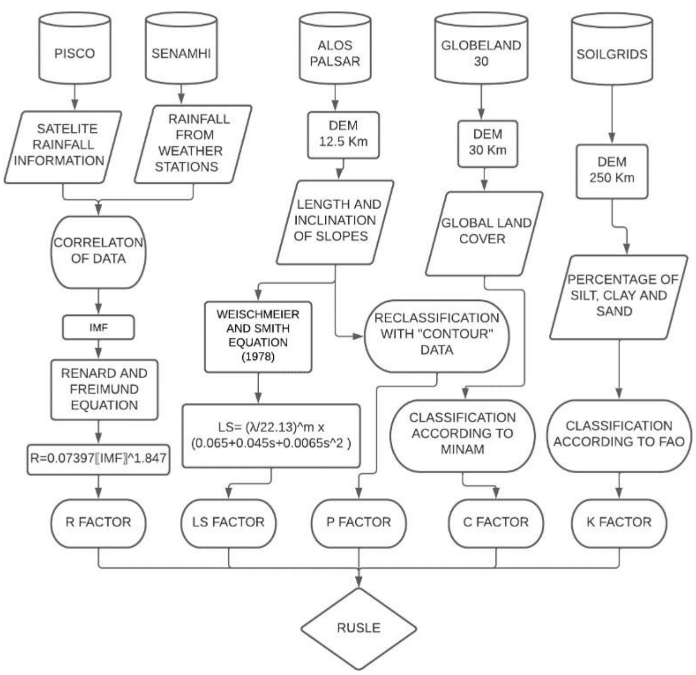

Fig. 2 Flowchart of the study methodology

III. RESULTS

Rainfall erosivity factor (R): The highest rainfall erosivity factor values are found at the Tanta (1114.262 $MJ.mm.h^{-1}.ha^{-1}.year^{-1}$), Huañec (1244.623 $MJ.mm.h^{-1}.ha^{-1}.year^{-1}$), Huarochirì (999.737 $MJ.mm.h^{-1}.ha^{-1}.year^{-1}$) and Huancata (1219.961 $MJ.mm.h^{-1}.ha^{-1}.year^{-1}$) stations, corresponding to the Alto Cañete sub-basin, as shown in Fig. 3.

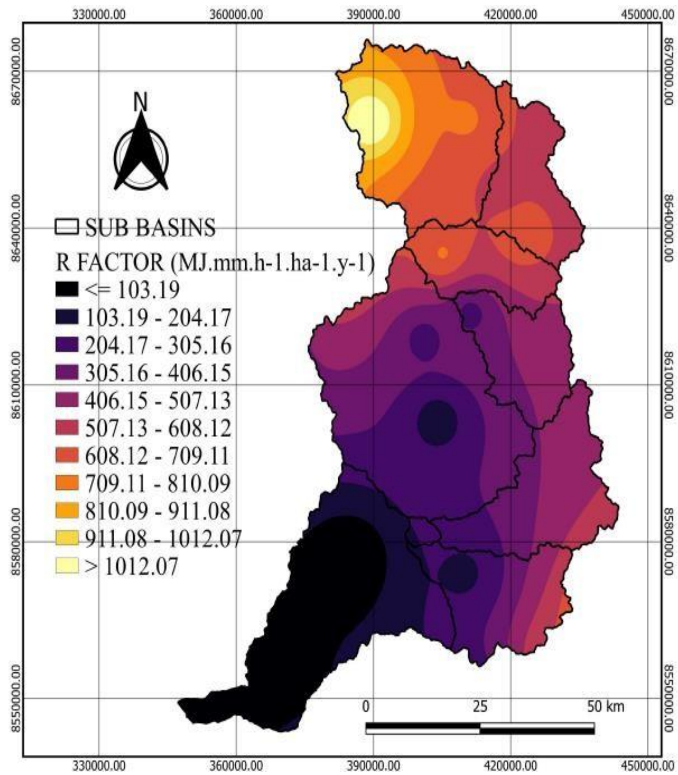

Fig. 3 R Factor

Soil erodability factor (K): The K-factor values with the highest susceptibility to erosion belong to the Vilca (0.04 $t.ha.h.\ MJ^{-1}.ha^{-1}.mm^{-1}$) and Tanta (0.04 $t.ha.h.MJ^{-1}.ha^{-1}.mm^{-1}$) stations, which are located in the Alto Cañete sub-basin and Yauricocha station (0.04 $t.ha.h.MJ^{-1}.ha^{-1}.mm^{-1}$), located in the Alis sub-basin. According to Fig. 4, these areas belong to the upper basin, which also has the highest rainfall in the entire basin.

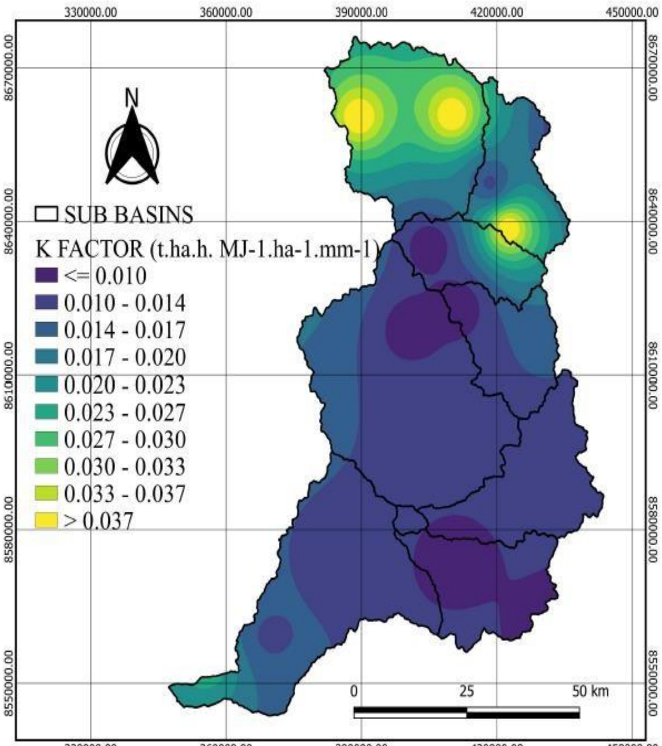

Fig. 4 K Factor

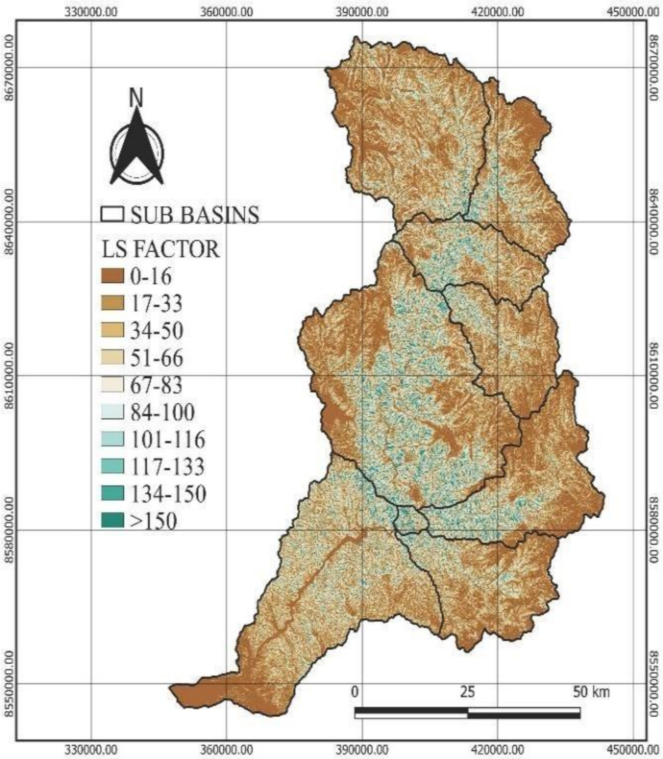

Fig. 5 LS Factor

Topographic factor (LS): The maximum values for the LS Factor were obtained through the characterization of the Cañete River Basin by means of a topographic map, where it was determined that, throughout the basin, the topographic factor (LS) is not greater than 116, due to its location in the coastal zone, with the Medio Cañete, Medio Alto Cañete and Cuenca Alis sub-basins presenting this range of higher values (between 101 to 116 approx. as maximum value), as indicated in Fig. 5.

Vegetation cover factor (C): The results indicate that values between 0.003 and 0.63 are present throughout the entire surface of the basin. This means that the predominant land cover types in the watershed are "Forest" (land covered by trees with 30% vegetation cover) and "Cultivated Land" (land used for agriculture, horticulture and gardens), respectively. The Fig. 6 shows that "cultivated land" is a type of cover with notable incidence in the trajectory of the Lower Basin (Factor value 0.63). This is due to the fact that considerable extensions of land around the Cañete River are used for agriculture and, in the upper zones of the basin, for cattle raising. On the other hand, the type of vegetation cover that has the least presence in the Cañete River Basin is Desolate Land (0.5046), that is, land with vegetation cover of less than l0%.

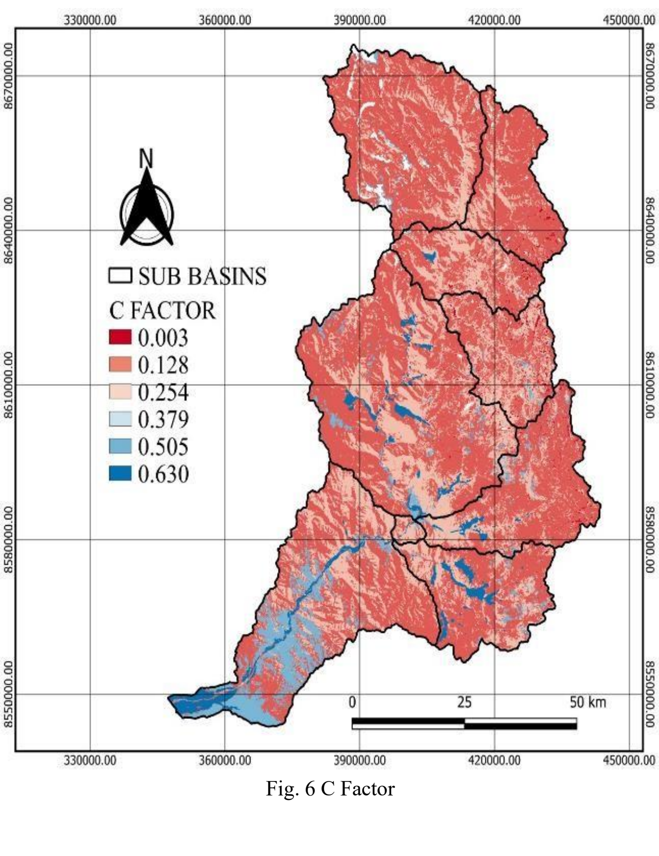

Fig. 6 C Factor

Conservation practices factor (P): The P factor presents a range of values from 0 to 1. The maximum value of 1 indicates the lack of soil conservation techniques and, therefore, represents the areas most exposed to erosion, as opposed to values close to 0, which indicate that at least one type of soil conservation practice is carried out in the area. The map obtained for this factor shows that the sub-basin that carries out conservation practices is Bajo Cañete, due to the fact that the area has a large extension of agricultural land.

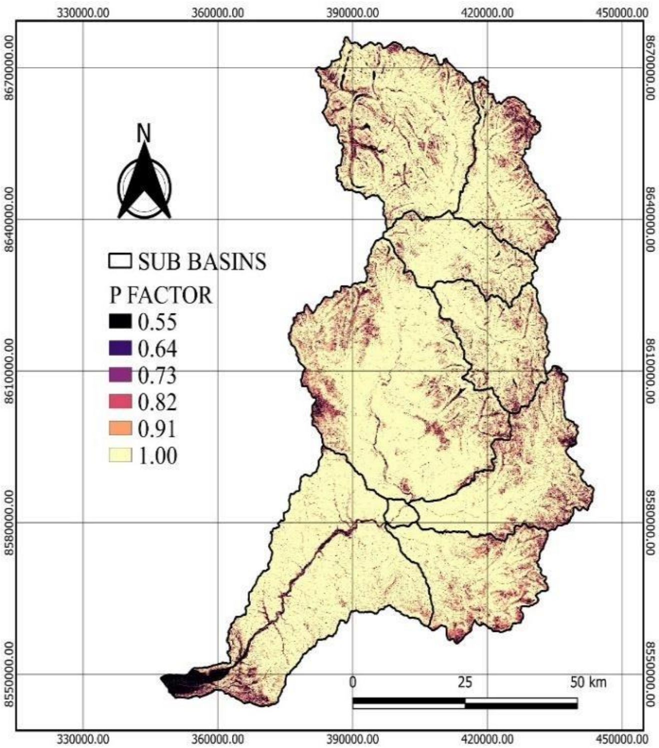

Fig. 7 P Factor

In the northern zone of the Alto Cañete sub-basin and in the Huantan Basin, conservation practices values of 0.78 were obtained, which correspond to the presence of agriculture for self-consumption and cattle raising. However, most of the soils in the basin under study have a color corresponding to value 1 (Fig. 7), in other words, there are no soil conservation techniques in place.

Erosion Map – RUSLE: For the present study, an average erosion rate of 10.81 $t.ha^{-1}.year^{-1}$ was determined for the total extension of the Cañete River Basin (between 1981 and 2016), which corresponds to a moderate potential water risk level, according to FAO classification. This value was obtained due to the difference between the low and high rainfall records of the R factor together with the minimum and maximum values of the LS factor (slope) between the high sub-basins (Andean region) and low sub-basins (coastal region). Annual soil loss has been categorized into 6 levels according to the 1984 FAO classification (Table 3). The Fig. 8 illustrates the Bajo Cañete sub-basin and shows the lowest average erosion level for the entire sub-basin from 1981 to 2016 with the value of 2.84 $t.ha^{-1}.year^{-1}$, which is considered as normal erosion according to FAO 1984 classification.

TABLE 3
SOIL LOSS CLASSIFICATION - FAO

CLASS	SOIL EROSION ($t.ha^{-1}.yr^{-1}$)	LEVEL OF DAMAGE	SURFACE	
			Area (Km^2)	Percentage (%)
1	<0.5	Normal	1418.77	23.49
2	0.5 - 5	Light	2132.11	35.30
3	5 - 15	Moderate	1387.33	22.97
4	15 - 50	Severe	850.30	14.08
5	50 - 200	Very Severe	231.53	3.83
6	>200	Catastrophic	19.46	0.32

Alto Cañete (944 km^2), Alis (448 km^2) and Medio Alto Cañete (365 km^2) sub-basins recorded high slopes and rainfall throughout the 1981-2016 period. Grasslands and scrublands characterize the vegetation cover of the sub-basins; these types of cover contribute to the reduction of soil erosion. Because they are very remote areas, there are no conservation practices. In spite of having cover that prevents soil erosion, natural phenomena, topography and the lack of conservation practices have generated severe erosion rates throughout the Cañete River Basin.

IV. CONCLUSIONS

According to the correlation analysis, an average relationship between SENAMHI and PISCO data of 0.9 was obtained for the Yauricocha and Carania stations, which correspond to the upper and middle sub-basins, respectively. It is important to note that this correlation value is adequate, since they show a high coincidence of data. However, the Cañete station has a relatively low correlation (0.003), which may be due to its location near the mouth of the basin and exposure to possible meteorological phenomena, such as "El Niño", for which there are no recurrent rainfall patterns.

The results obtained by the RUSLE model have determined that the Cañete River Basin has an average erosion rate of 10.81 $t.ha^{-1}.year^{-1}$ for the period from 1981 to 2016. This value has been influenced by the action of natural phenomena, topography of the area, population growth and the increase in infrastructure (housing, hydroelectric power plant and structures for various industrial activities). These variables generate negative changes in the use of soils by not leaving a superficial layer of natural vegetation to reduce the impact of the rains, so it is estimated that the value of the erosion rate is currently higher.

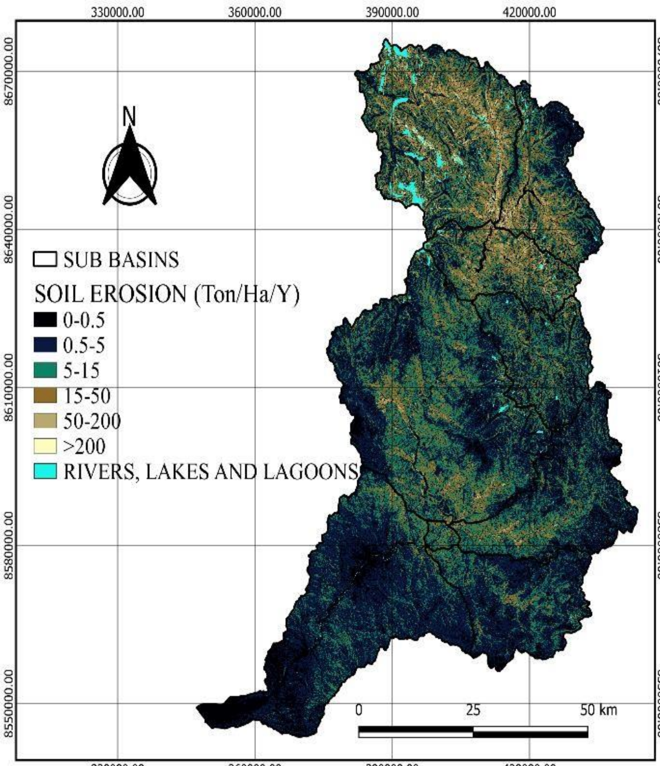

Fig. 8 Soil Erosion map in the Cañete River Basin

The values obtained indicate that, for this study, rainfall erosivity (R Factor) and the topographic factor (LS Factor) are considered as factors of greater incidence, since the integration of these parameters makes the area under study more susceptible to potential loss due to soil erosion in the area. This is due to the impact generated by rainfall on the soil and the constant flow that predisposes the slope inclination, generating furrows due to friction in the transport of water and sediments.

It is suggested that, in order to update the results, studies be carried out with recent data from different international sources and compare the results to calculate the progress of soil erosion in the Cañete river basin.

All hydrological modeling needs to calibrate and validate its data with field information in order not to overestimate the parameters being evaluated, especially in basins with very varied relief, such as those located near the Andes Mountains, in this case, the Cañete river basin. This is due to the fact that the data vary according to the altitude along the basin. As noted in the case of the Bajo Cañete and Alto Cañete sub-basins, which have different amounts of precipitation and annual temperatures, while, in static factors (LS, C and P), Alto Cañete has a steeper slope than Bajo Cañete. Likewise, land use in each sub-basin is different.

REFERENCES

[1] Ananda, J., & Herath, G., “Soil erosion in developing countries: A socio-economic appraisal”, *Environmental management magazine*, vol. 68, no. 4, pp. 343-353, 2003.

[2] Cisneros, J., Cholaky, C., Cantero, G., Gonzáles, J., Reynero, M., Diez, A., & Bergesio, L., “Erosión Hídrica: Principios y técnicas de manejo”, Río Cuarto, 2012.

[3] Hill, M., Clérici, C., Mancassola, V., & Sánchez, G., “Estimación de pérdidas de suelo por erosión hídrica en tres diferentes sistemas de manejo hortícola del sur de Uruguay”, *Agrociencia Uruguay*, vol. 19, no. 1, pp. 94-101, 2015.

[4] Kim, H. S., “Soil erosion modeling using RUSLE and GIS on the Imha watershed, south Korea”, Colorado State University, 2006.

[5] Pan, J., & Wen, Y., “Estimation of soil erosion using RUSLE in Caijiamiao watershed, China”, *Natural Hazards*, vol. 71, no. 3, doi:0.1007/s11069-013-1006-2, 2014.

[6] Rosas, M., & Gutierrez, R., “Sediment Yield changes in the peruvian Andes for the year 2030”, *XXVII Latin American Hydraulics Congress*, 2016.

[7] INRENA, “Evaluación y Ordenamiento de los Recursos Hídricos de la Cuenca del Río Cañete”, Lima-Perú: ANA, 2001.

[8] Gonzáles del Tánago, M., “La Ecuación Universal de Pérdidas de Suelo”, *Pasado, presente y futuro. Ecology*, pp.13-50, 1991.

[9] INDECI, & UNICA, “Mapa de peligros, plan de uso del suelo y propuesta de medidas de mitigación de los efectos producidos por los desastres naturales de las ciudades de la provincia de Cañete”, 2002.