UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

Escuela de Ciencias de la Tierra, Energía y Ambiente

TÍTULO: QUALITATIVE ANALYSIS OF EXOGENOUS GEOLOGICAL PROCESSES IN THE CIUDAD DEL CONOCIMIENTO, IMBABURA

Trabajo de integración curricular presentado como requisito para la obtención del título de Geología

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DEDICATORIA

Quiero dedicar el presente trabajo de titulación a mis ya difuntos abuelos, de quienes aún ahora siento el apoyo y en quienes me siento reflejado.

Le dedico a mi Pagilito, quien siempre hubiera querido llegar a verme en este momento y de quien aprendí el cariño y la sensatez. Le dedico a mi Papito Raúl, quien, aunque no lo decía, estoy seguro de que se sentía orgulloso y seguro de mí, de quien aprendí el deseo de avanzar y luchar por los sueños.

Le dedico este trabajo también a mis abuelas, a las que aún tengo conmigo y de quienes puedo disfrutar. A mi Mamilita, porque me enseñó lo que es la alegría y la pasión. A mi abuelita Martita a quien voy descubriendo y me va enseñando a través del consejo.

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Dedico, finalmente, un poco de todo esto a mi prima Chelita. Un corto pero necesario homenaje a una prima que fue como hermana. Siempre me vas a hacer falta, sobre todo para alegrarte por mí y celebrar conmigo nuestros triunfos.

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Carlos López
Quito, 13 de abril de 2021

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I may forget some of people but it was not on purpose. Feel my sincere thanks for being part of my process.

RESUMEN

El presente trabajo está enfocado en la evaluación de la erosión hídrica del suelo en la Ciudad del Conocimiento Yachay en un área de 4462 hectáreas mediante el uso de la Ecuación Universal de Pérdida de Suelo (USLE por sus siglas en inglés). Anteriormente, esta zona estaba dedicada a la agricultura y actualmente se encuentra deteriorando rápidamente debido al cambio de uso de tierra. Otro aspecto que favorece la aceleración de la erosión es la composición geológica del suelo, el grado de pendiente, la cantidad de lluvia y la cobertura vegetal, todos estos valores son computados por la USLE. El factor de erosión de la lluvia y escorrentía (R) que se calcula a partir de los datos de lluvia muestra un rango de 1624,48 - 3159,3 $\left(\frac{MJ \cdot mm}{ha \cdot hora \cdot año}\right)$ con una relación entre la altitud y la cantidad de precipitación. El factor de erosión del suelo (K) calculado a partir de las características físicas del suelo muestra un rango de datos de 0,0026 a 0,0692 $\left(\frac{Mg}{ha}\right) \cdot \left(\frac{MJ \cdot mm}{ha \cdot hora}\right)^{-1}$ para la ciudad sin un patrón importante dependiendo del orden del suelo. El factor de gradiente de pendiente (S) y el factor de longitud de la pendiente (L) calculados como un solo factor representan valores que van de 0 a 118,81 que muestran la relación entre la pendiente y la erosión. Cuanto mayor sea el grado de pendiente, mayor será el valor calculado. El factor de cobertura (C), calculado a partir de imágenes satelitales, oscila entre 0,054 y 0,952 y muestra una relación inversa entre la cobertura de vegetación y el riesgo de erosión por agua. Calculando los datos obtenidos de cada factor calculamos las tasas de erosión en la Ciudad del Conocimiento que tienen un rango de 0 – 3853,35 $\left(\frac{Mg}{ha \cdot year}\right)$. La clasificación usada describe una tasa de erosión muy alta sobre todo para pendientes inclinadas como las presentes en quebradas y lomas. Las áreas dedicadas a la agricultura muestran un nivel alto de erosión, a pesar de tener pendientes muy pequeñas, debido a las características del suelo.

Palabras clave: Ciudad del Conocimiento, ecuaciones, erosionabilidad, erosividad, grado de pendiente, imágenes satelitales, lluvia, manejo de cobertura, parametrización, partículas, suelo, Urcuquí, vegetación.

ABSTRACT

The present work is focused on the evaluation of soil erosion by water in the Ciudad del Conocimiento Yachay on an area of 4462 hectares by using the Universal Soil Loss Equation (USLE). In the past, this zone was dedicated to agriculture and now it is deteriorating rapidly associated with the change in land use. Another aspect that favors the acceleration in the erosion is the geological composition of soil, the degree slope, the amount of rain and the vegetation coverage, all these values are computed by the USLE. The rainfall and runoff erosivity factor (R) that is calculated from rainfall data shows a range between 1624,5 and 3159,3 $\left(\frac{MJ \cdot mm}{ha \cdot hour \cdot year}\right)$ with a relation between altitude and amount of precipitation. The soil erodibility factor (K) calculated from the physical characteristics of the soil shows a range data from 0,0026 to 0,0692 $\left(\frac{Mg}{ha}\right) \cdot \left(\frac{MJ \cdot mm}{ha \cdot hour}\right)^{-1}$ for the city with no major pattern depending on the order of soil. The slope gradient factor (S) and the slope length factor (L) calculated as one factor, depict values that ranges from 0 to 118,81 showing the relation between the slope and erosion. The higher the degree slope, the higher the value calculated. The cover management factor (C) calculated from satellite imagery ranges from 0,054 to 0,952 and shows the inverse relation between the vegetation coverage and the risk of erosion from water. Computing the data obtained from each factor we calculate the erosional rates in the Ciudad del Conocimiento that ranges from 0 – 3853,35 $\left(\frac{Mg}{ha \cdot year}\right)$. The classification used describes a very high rate of erosion mainly at high slopes degrees as located in ravines and hills. Agricultural areas show a very high level of erosion, although they are in areas with low slopes, due the characteristics of the soil.

Keywords: Ciudad del Conocimiento, cover management, equations, erodibility, erosivity, parametrization, particles, rainfall, satellite imagery, slope degree, soil, steepness, Urcuquí vegetation.

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1. INTRODUCTION

1.1 Introduction to the study area

The former project Ciudad del Conocimiento was a project of national interest that was articulated by an academic, scientific, and industrial component (E.P., 2018) based on the experience of other planned cities around the world as the Massachusetts Institute of Technology (MIT) in the United States or the Incheon Free Economic Zone (IFEZ) in South Korea. The idea was to join the academy with the industrialized sector that will be developed in the northern part of Ecuador in the Imbabura province, specifically at the Urcuquí canton (Figure 1). This city was planned in 4462 hectares that are part of former estates (also called haciendas) dedicated to agriculture for a long time in the past. The west limit of the city are 3 main ravines that from north to south are La Banda ravine, Añaburo ravine and Pigunchuela ravine. In the southern part the limits of the city match with the city of Urcuquí as the cantonal head, the Chalta ravine and the Ambi river while the east limits with the Ambi river as the limit of the canton between Urcuquí and Ibarra. The north part of the Ciudad del Conocimiento limits with the cantonal limit of Urcuquí canton with Ibarra canton (Figure 2).

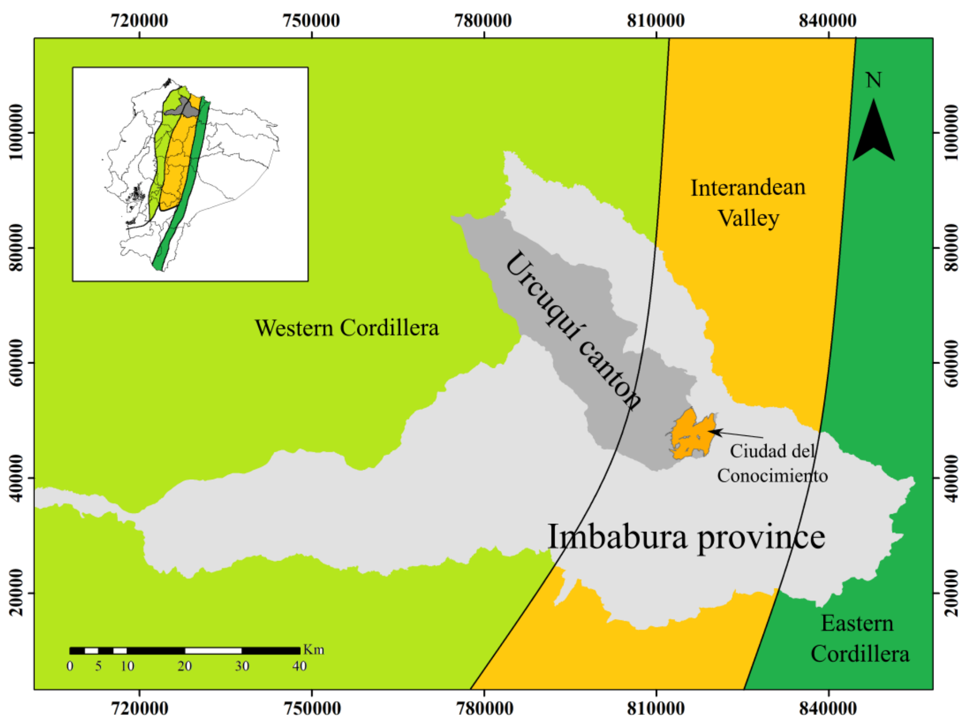


Figure 1. Location of the Ciudad del Conocimiento in the southern part of Urcuquí canton in the Imbabura province northern part of Ecuador. Sketch of the Cordillera Occidental and Cordillera Real showing the location of the city in the Interandean Valley. The sketch does not represent the actual form or accurate location of both Cordilleras. Modified from Aspden & Litherland, 1992

The first phase of construction of the city includes the recuperation of two of the main estates, San José and San Eloy, for the construction of Yachay Tech University and the Siembra Public Company, respectively, former Ciudad Yachay. Siembra Public Company was the institution in charge of the construction of the Ciudad del Conocimiento (E.P., 2018). Both haciendas were dedicated to sugar cane harvesting, being the Hacienda San José the most important estate for the northern part of the country's sugar industry from 1920 to 1992 (Yachay Tech, n.d.). The construction of the educational component starts in 2013 with the construction of the University Yachay Tech, the Instituto Tecnológico Superior "17 de Julio", the "Escuela del Milenio Yachay," and the "Centro Infantil del Buen Vivir" (CIBV), among other facilities as a hospital, library, sports fields, access roads, sewerage and also student housing buildings with their water treatment plant and electrical components.

Although the construction of the City is referred to a small part of the 4,462 hectares where we have an evident change in land use from agriculture to construction, the rest of the land is almost abandoned until the project continue their construction or authorities decide to redistribute it to people or communities that can start with agricultural activities again. Since 2013 the land was the property of the Ecuadorian State and their Public Enterprise former "Ciudad Yachay" now "Siembra" EP, who was in charge of the City construction and maintenance. Since 2020, due the closure and liquidation of "Siembra EP", the 4,462 hectares that belongs to the Ciudad del Conocimiento project now belong to the Secretaría de Educación Superior, Ciencia, Tecnología e Innovación (SENESCYT) and its use has an uncertain future. Inside the Ciudad Yachay polygon we have the presence of small villages that are part of the culturalism of the canton. They are San Antonio de Purapuchi and Tapiapamba villages. In fact, there are more small settlements that are cataloged as neighborhoods however they are not taken into account in Figure 2.

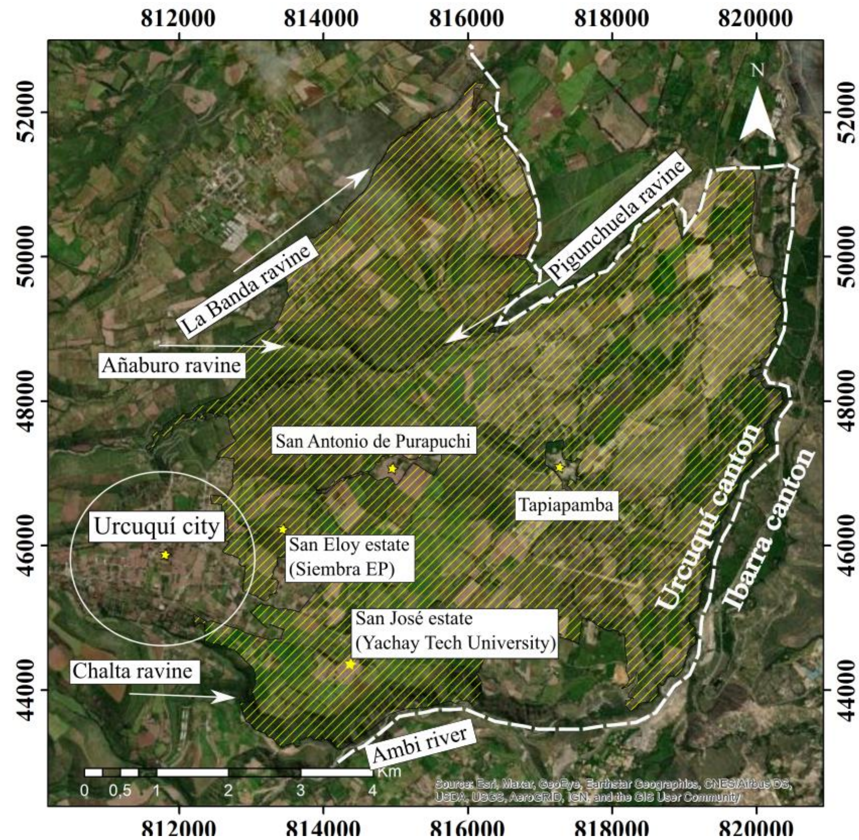


Figure 2. The hatched lines polygon refers to the 4,462 hectares that form the Ciudad del Conocimiento. The limits of the Ciudad del Conocimento are: on the north and east the city limits with the Ibarra Canton. At the south with the Ambi river and the Chalta ravine. On the north-west the limits are three ravines: La Banda, Añaburo and Pigunchuela. On the south-west the limit is the city of Urcuquí that is surrounded by a white circle. San Eloy and San José states are represented with a yellow star. Also, the internal limits with small villages, as San Antonio de Purapuchi and Tapiapamba, are showed with a yellow star at the location of those villages.

1.2 Background

Due to changes in land use, erosion of the soil is a significant phenomenon that affects the Andean regions where we found volcanic-derived soils (Zehetner & Miller, 2006). Erosion is defined in the Dictionary of Earth Sciences as "the movement of soil and rock material by agents such running water, wind, moving ice or gravitation" (Allaby, 2008). The land of the San José estate that in the past was dedicated exclusively to agriculture today is deteriorating at a rapid rate associated with the change in land use and the abandonment of cultivated lands that are currently exposed. Figure 3 shows the agricultural land use in the Ciudad del Conocimiento (MAGAP, 2002) with the main agricultural activities in the zone in 2002 as well as the sources of water in the form of irrigation canals and ditches. We can see that the major part of the land is dedicated to agriculture, being sugar cane the crop that occupies the most land associated with the irrigation from canals. Just a little proportion of land at the south can be considered as bush vegetation and near the Chalta ravine and the Ambi River. Short-cycle crops and corn are also an important part of the agriculture at the place combined with the harvesting of sugar cane, also we can notice that in this land it is more common to have ditches for irrigation. We can look also that some of the villages around the city are located in areas of influence of several crops. For example, San Antonio lies on corn crops, while Tapiapamba is over areas of influence of corn and sugar cane. As mentioned before, due to the expropriation of this land, some of these cultivated land is abandoned or exposed to build part of the Ciudad del Conocimiento as the University. In Figure 3 we can notice that San José and San Eloy estates were located in important areas dedicated to the sown of a mixture of short-cycle crops and sugar cane. Also it is important to notice that there are places named as natural protected areas that are some of the hills and ravines located at the city where agriculture has not taken place due to the presence of bush vegetation and the difference in the slope between hills and cultivated areas. Associated with the construction of Yachay Tech University infrastructure (buildings for homes, laboratories, library, road access, sewerage, among others) in this area, erosion and weathering rates have been increased due the deterioration of the topsoil and direct exposure of the soil to external agents such as sun, water and wind. Another aspect that favors such acceleration is the geological constitution, which shows the fine and little consolidated fraction of the pyroclastic deposits, lahars, debris avalanches and lava flows according to the "Plan de Ordenamiento Territorial" of Urcuquí and the Geological Map of Ecuador (2017) (Figure 5). This material is refered to the Yanahurco Volcanic Geological Formation (Manrique & Rosero, 2011) and previous eruptions of the Chachimbiro volcanic complex (Bernard et al., 2014).

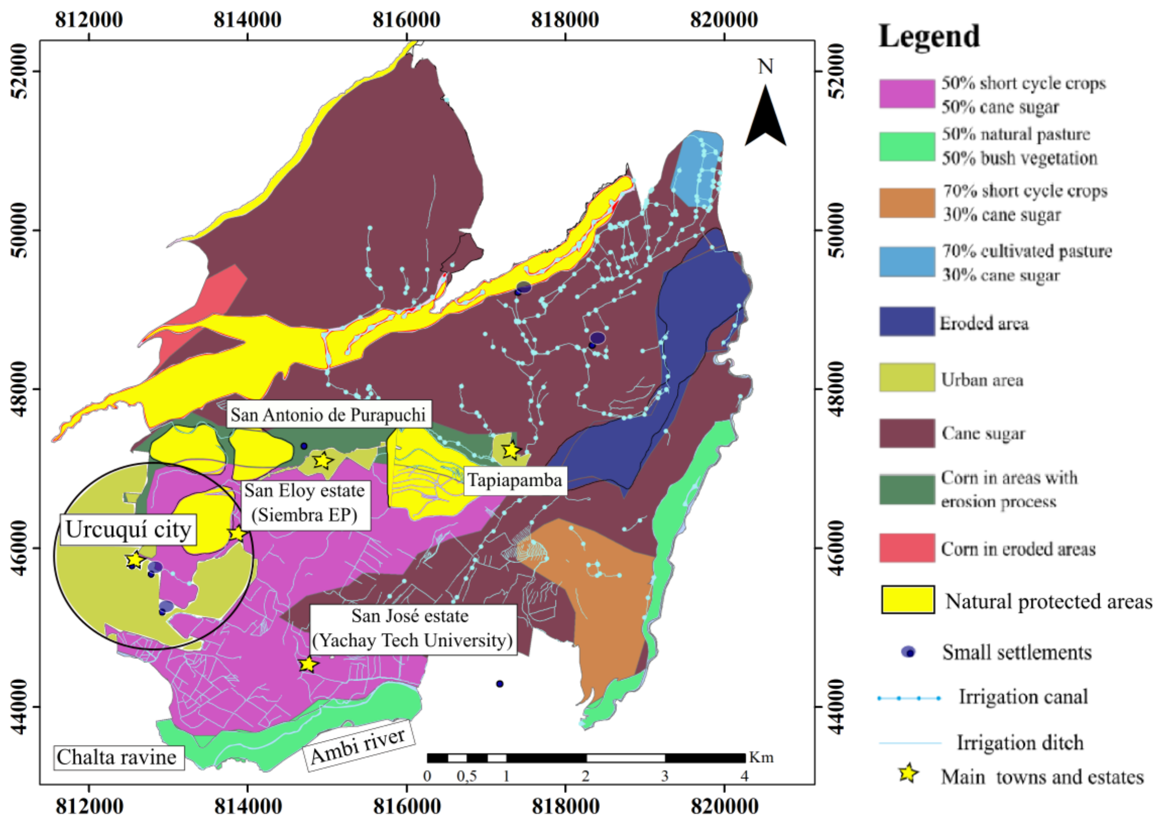


Figure 3. Agricultural land use in la Ciudad del Conocimiento in 2002 (MAGAP, 2002). The map shows the different land use combining the information with canal irrigation and ditches as well as the location of Urcuquí City, some villages and settlements, the location of the main estates and natural protected areas associated to hills and ravines where there is not presence of agricultural activities.

1.3 Problem statement

The erosion of soil is a widespread problem all over the world. One of the most important factors that affect the soil is the change in land use (Lal, 2001). In the province of Imbabura, a new ambitious project wants to change the economical perspective of the country. Along with this idea, it comes the construction of a completely new city called Ciudad del Conocimiento in former estates dedicated completely to agriculture in the past. This change in land use combined with the abandonment of land for cultivation and the fine volcanic material that forms the soil could increase the normal erosion rates (Zehetner & Miller, 2006). The economical implication of recover the land could be greater than the cost of maintain or protect the soil (Pimentel et al., 1995). This makes important to understand how erosional processes act over the Ciudad del Conocimiento and the rate of erosion that these processes provokes on the land. Currently, there are qualitative methods that assess erosion in certain areas using information of rain, slope, soil cover and other factor that are involved in the calculation of the soil loss with the aid of satellite information and fieldwork.

1.4 Objectives

1.4.1 General objectives

The aim of the present work is to approximate values for the water erosion rates in the Ciudad del Conocimiento associated to changes in the land use using the Universal Soil Loss Equation (USLE) as a qualitative method combined with information of the soil obtained in the field

1.4.2 Specific objectives

In order to achieve the best results with the information given, it is important to:

- Analyze in the field the characteristics of the soil as the proportion of sand, silt and clay and the amount of organic matter.
- Use updated Geographical Information Systems (GIS) to analyze the slope and length of the terrain and the soil coverage.
- Obtain satellite data for the monthly and yearly amount of rain with a good resolution that facilitate data interpolation.

2. THEORETICAL BACKGROUND

2.1 Geological framework

The Urcuquí canton, where the Ciudad del Conocimiento is located in the Interandean Valley between the Cordillera Occidental and Cordillera Real (Figure 1), and is part of the Mira river basin. The temperature in the canton oscillates between 14°C to 19°C (GAD Municipal de Urcuquí, n.d.-a). The average precipitation also oscillates between 10 mm in the lower zones to 1750 mm in the higher zones (GAD Municipal deUrcuquí, n.d.-b). The canton has an altitudinal gradient between 1600 masl to 3180 masl and the Ciudad del Conocimiento, specifically, has an altitude gradient between 1615 masl to 2374 masl (Figure 4). Geomorphologically, the 4,462 hectares belongs to the foothills of the Chachimbiro Volcanic Complex at the west where we have the highest altitudes and is one of the flattest part of the Urcuquí canton to the east coinciding with the Ambi river valley. The slope exhibits a tendency to decrease from the west to the east and north-east. The presence of several ravines and hills are the most relevant relieve form that constitutes the geomorphology of the city. In the western part of the city we have 3 main ravines, where the elevation level decreases, that from north to south are La Banda, Añaburo and Pigunchuela. In the southern part the limits of the city match with the Chalta ravine and the Ambi River while the eastern limit is the Ambi River as the cantonal limit between Urcuquí canton and Ibarra canton. The north part of the Ciudad del Conocimiento limits with the cantonal limit of Urcuquí. Inside the city we can recognize six major hills, where the elevation level increases, those are: “San Eloy”, “El Churo de Pucará”, “La Gorda”, “La Llamarada” and a pair of hills located near the Hacienda de Tababuela and San Pedro de la Huerta called “La Ensillada” and “Chusquilla”. Also inside the city there are several minor ravines that help transporting water and sediments to the lower zones of the city. Figure 4 also shows the main water channels at the city. The main and unique river at the area of study is the Ambi River in the south and east limit. There are no major rivers inside the city. Ravines transport water from outside and inside the city mainly from rain, they are no constant sources of water, rather, seasonal. The drainage system of the city appears to be parallel between rivers and ravines.

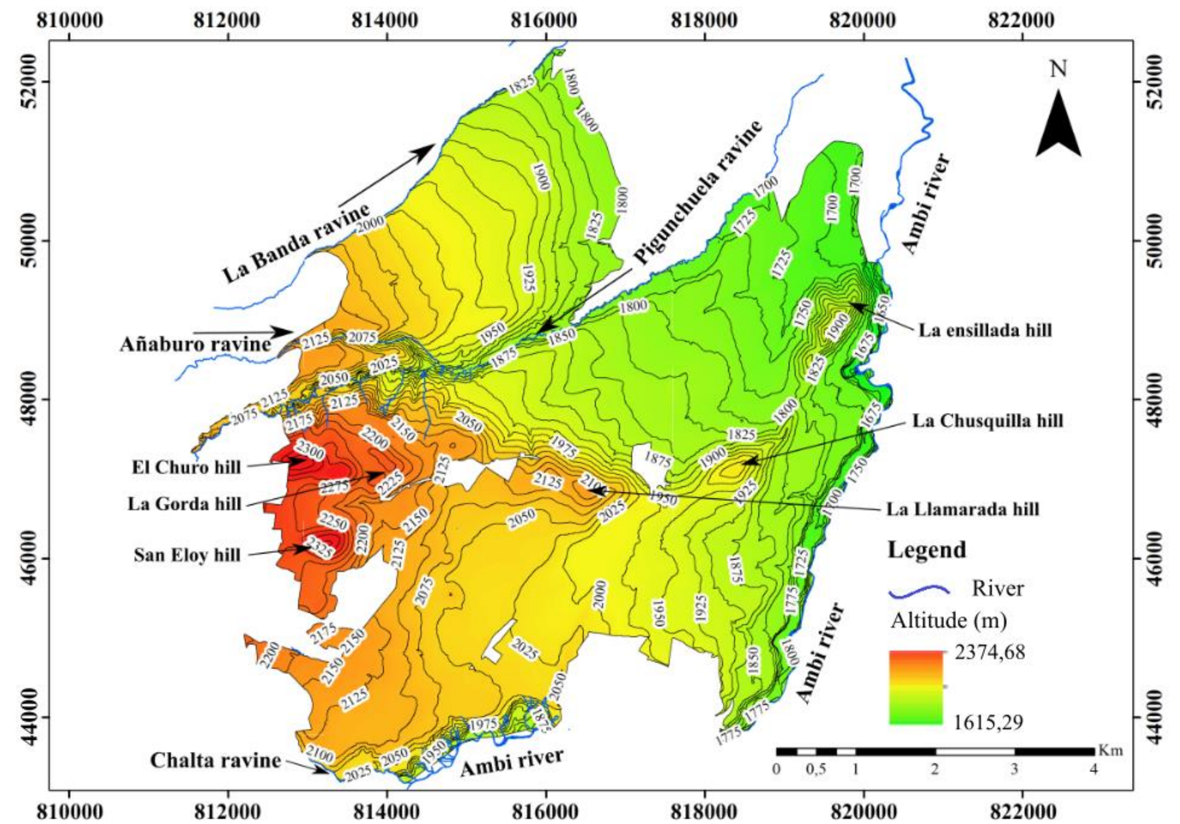


Figure 4. Contour map of la Ciudad del Conocimiento with the main structures. The basemap is a DEM of the city with a 3m resolution (SIGTIERRAS, 2016). The highest elevation is located at the western part of the study area (2374m at the San Eloy hill) while the lowest altitude is located at the eastern limit (1615m at the Ambi river). The contour map has a spreading interval of 25 m. The main geomorphological structures inside the city are pointed with and arrow. Rivers and water channels are drawn in blue color.

The Ciudad del Conocimiento Yachay is settled over volcanic soils derived from successive eruptions from the Chachimbiro Volcanic Complex during the Holocene age (Bernard et al., 2014). Also, this fine volcanic fraction is usually referred to as eruptions from the Yanahurco Volcano in the Pliocene (Manrique & Rosero, 2011). The geological scheme for the Ciudad del Conocimiento, modified from the geological map of Ecuador 2017 (Figure 5) shows that the Ciudad del Conocimiento is settled on primary pyroclastic deposits of tephra, pyroclastic flows and "cangahua". Also we have the presence of debris avalanches, lahars and lava flows (Eguez et al., 2017). Although the geological map of Ecuador (2017) does not classify the soils of Urcuquí as part of a specific formation, as in the past, the pedogenesis of the soil that we can find in the area is volcanic and is constituted by andesitic lavas and pyroclastic products. Also some hills located in Urcuquí, San Blas and Tapiapamba are constituted by massive flows of breccias (Manrique & Rosero, 2011). Bernard (2014) also says that the soil shows the action of pyroclastic density currents (PDC) and pyroclastic fall deposits. The PDC near the town of Urcuquí have a thickness between 23 to 105 cm (Bernard et al., 2014). From these events we have several layers of fine material that creates the actual soil in the study area. There are not major geological faults presented in the Ciudad del Conocimiento according to the different geological maps consulted and it is not well defined the type of geological contacts presented between the volcanic deposits. Figure 5 shows the occurrence of volcanoes at the west part that belongs to the Western Cordillera. The pyroclastic deposits, lahars, debris avalanches and canguahua that form the Ciudad del Conocimiento are part of the Interandean Valley in the depression between the two Cordilleras (Figure 1). From the Western Cordillera we have the highest pics in the Urcuquí canton, where we can see the decrease in altitude and therefore in slope from the Chachimbiro Volcano to the plains at the east part of the Ciudad, related to the Ambi River Valley (Figure 4).

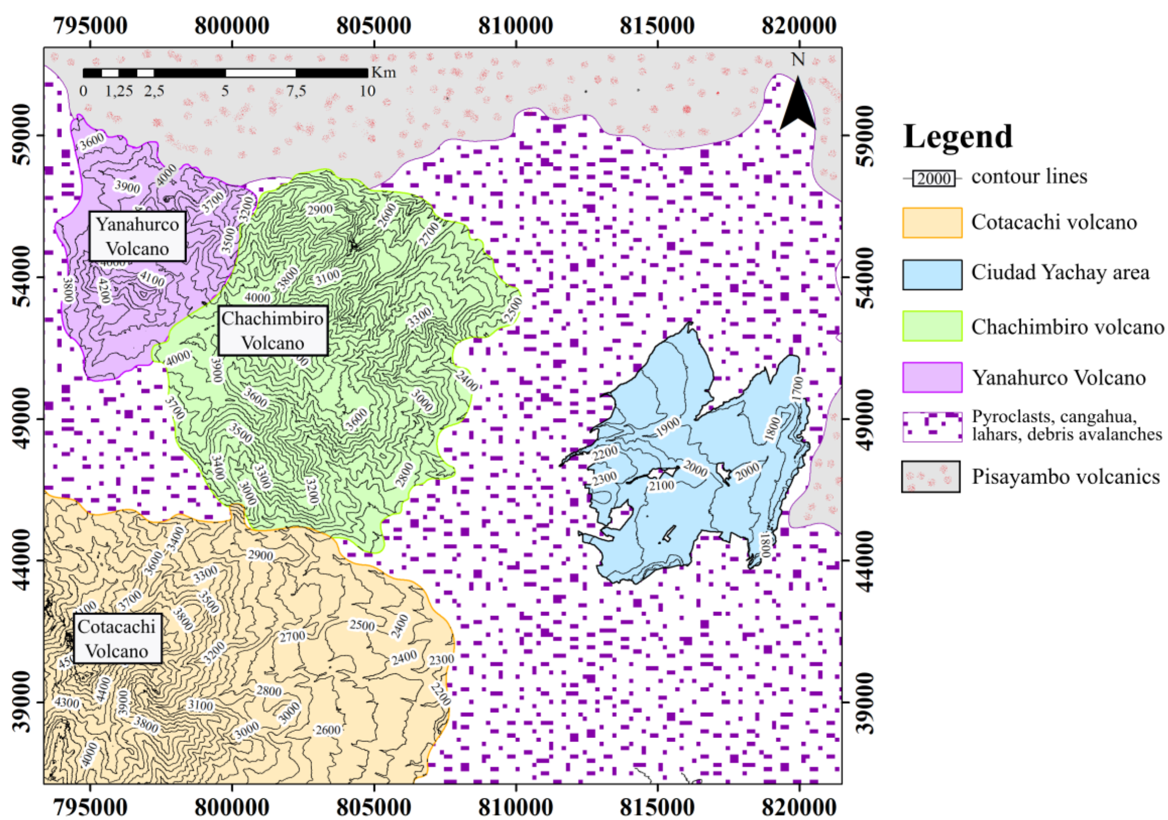


Figure 5. Geological map of Imbabura. The purple, green and orange polygons describes the volcanic edifices of Yanahurco volcano, Chachimbito volcano and Cotacachi volcano respectively. Blue polygon is the Ciudad del Conocimiento area. The soil where the city is located is referred as pyroclastic deposits. Retrieved from: Instituto de Investigación Geológica y Energética del Ecuador (IIGE, 2019)

2.2 Soil Taxonomy

According to the Dictionary of Earth Science (2008), soil is the natural, unconsolidated, mineral and organic material that occur on the Earth surface, usually above bedrock; also the medium for the growth of biota (Allaby, 2008). Soil, also called regolith, is a layer of non-cemented, weathered material, including rock fragments, mineral grains, and all other superficial deposits, which rests on solid bedrock that also contain organic material. As mentioned before, soils are composed by: clastic particles, organic material in various stages, living organisms, water and gases (Schaetzl & Anderson, 2005). The formation of the soils starts with the weathering of parent material by biochemical (decomposition) and physical (disintegration) processes that break up rocks and minerals and transform it to finer fragments and soluble products (Weil & Brady, 2016). The Soil Survey Staff in 1999 says that the soil is characterized by distinguishable horizons or layers and the ability to support plants in the environment. Soils formed from volcanic eruptions used to be light and porous with the ability to accumulate organic matter. Also volcanic ash tends to weather rapidly into allophane (type of clay) (Weil & Brady, 2016).

The study of the soil is a century-old science that can be study from a geological perspective, as a product of factors and processes of soil formation and as an open system that supports life and ecosystems (Buol et al., 2011). In this sense there are many systems to study the soil that are used worldwide. In this case we are going to use Soil Taxonomy from United State developed by the United State Department of Agriculture (USDA). The objective of classified the soil is to established hierarchies of classes that permit to understand the relationship among soils and between soils and the factors that are responsible for their character (Soil Survey Staff, 1999). The idea is to correlate the information from the soils of one place to another. The Soil Survey Staff creates a nomenclature for the soil that categorize depending on the level of detail of the information of the soil. From less information to a detailed characterization of properties we have the next categories: Order – Suborder – Great Group – Subgroup – Family – Series (Buol et al., 2011). For the purpose of this study we are going to use the Order of the soils at the Ciudad del Conocimiento given by the Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAGAP) in the form of geographical information. The Orders of soils from the USDA are listed in Table 1 where the column order reflects the name of the order and the column of formative element are the abbreviation that is used for the order of soil and that was used to sample.

Table 1. Orders of soils according the United State Department of Agriculture (USDA)

Order	**Formative Element**	**Order**	**Formative Element**
Alfisols	Alfs	Inceptisols	Epts
Andisols	Ands	Mollisols	Olls
Aridisols	Ids	Oxisols	Ox
Entisols	Ents	Spodosols	Ods
Gelisols	Els	Ultisols	Ults
Histosols	Ists	Vertisols	Erts

According to the MAGAP the predominant soils in the Ciudad del Conocimiento are: Andisols, Entisols, and Mollisols (Figure 6), where almost all the agriculture takes place in short-cycle crops, sugar cane crops, and pasture land combined with bush vegetation (Figure 4-8). The Andisols are soils formed from more than 60% of volcanic or pyroclastic deposits as the parent material that is presented in the upper 60 cm of the soil. Entisols are soils that are weakly developed (no presence of horizons), usually sedimented on young surfaces or eroded sites. Mollisols are base-rich soils that have a thick, dark A horizon, formed under grasslands or savanna, a base saturation percentage at pH 7 (presence of NH_4OAc). The definitions where constructed using information from Soils: Genesis and Geomorphology (2005), Soil Taxonomy: A Basic System of Soil Classification for making and interpreting Soil Surveys (1999), Soil Genesis and Classification (2011) and Mapa de órdenes de suelos del Ecuador (Ministerio de Agricultura y Ganadería, 2017).

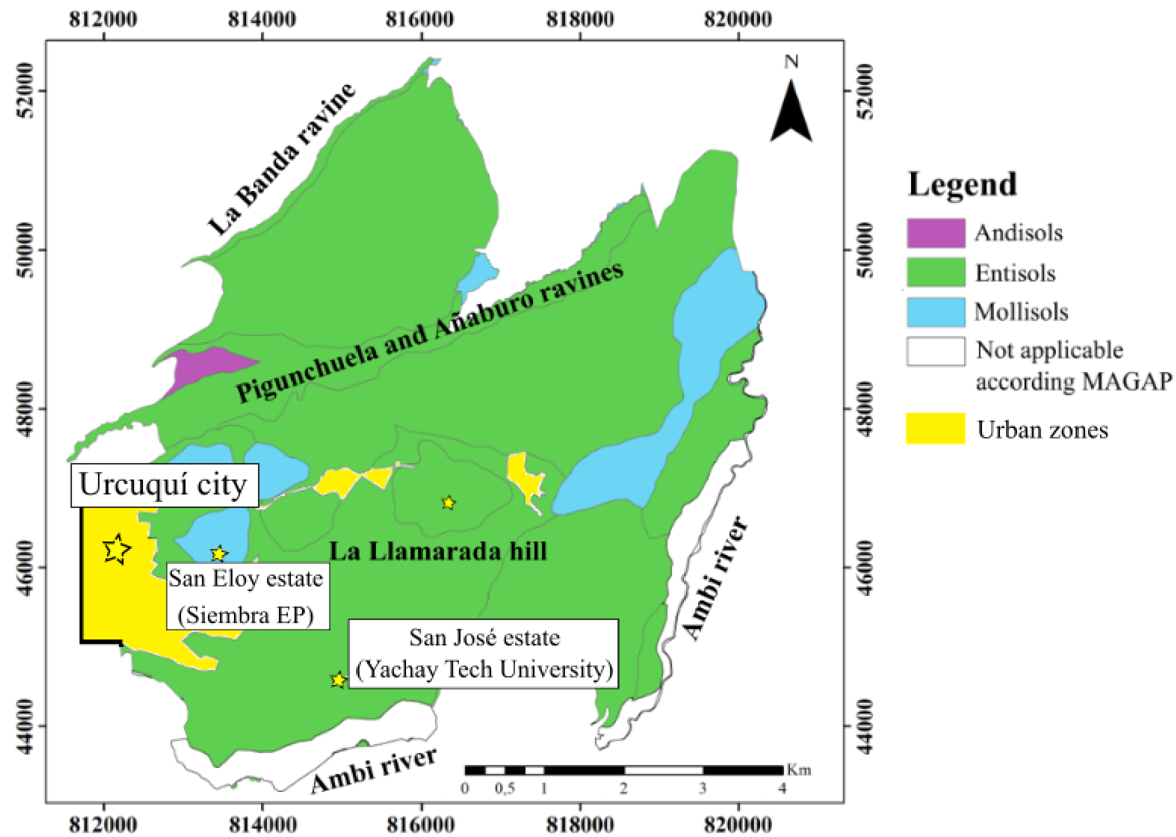


Figure 6. Orders of soils in la Ciudad del Conocimiento. There are three orders displayed in the legend: andisols, entisols and mollisols. Although for the purpose of the study we use the order description, in the map also we have the internal lines that are associated to suborders of soil in different structures as the La Banda, Pigunchuela and Añaburo ravines and La Llamarada hill. Mollisols described the structures of other hills described in figure 4. There is no information about the soil in the Not Applicable polygon which is near to the limits to the Ambi River. The white tags correspond to the urban zones at the city.

2.3 Erosional processes

Erosion is defined in the Dictionary of Earth Sciences as " the movement of soil and rock material by agents such running water, wind, moving ice or gravitation" (Allaby, 2008). The movement of this material, also called sediments, is a natural process that occurs on the surface of the Earth and has shaped the actual landscape of the planet (Pierre, 2010). The processes responsible for shaping Earth are called geomorphic processes and are divided into endogenic (endo, inside; genic, originating) and exogenic (exo, external; genic, originating) (James et al., 2011). Endogenic processes are the mechanisms that act from inside the Earth. The Encyclopedia of Astrobiology explains that this process occurs mainly in the planets' mantle or core and is related to faulting, folding, and magmatism. In contrast, exogenic processes occur on the planet's surface by weathering, erosion, transportation, and sedimentation (Gargaud et al., 2011).

The present work is focused on the impact of water on the erosion rates which is a natural process but lately increased by exogenic processes, mainly associated with the changes in land use. In Ecuador, this is a widespread problem, accounting that 50% of the country is affected by erosional processes (De Noni & Trujillo, 1986). Highlands are at high risk of erosion due to the steep slopes presented in the topography, rainfall intensity, and soil composition (Zhao et al., 2014). The main erosive pattern, calculated to be 15%, is presented in land dedicated for agriculture in the Interandean Valley, while the other 35% is presented in coastal regions and the agricultural frontiers on the highlands (De Noni & Trujillo, 1986). This idea takes us to another problem: the deforestation of significant areas to increase the agricultural frontier and cattle grazing land. According to data from the United Nations Food and Agriculture Organization (FAO), Ecuador is the most deforested country in South America (FAO, 2015). We can notice that the increasing global pressure on the soil due to population growth and food demand also includes countries like Ecuador. Figure 7 shows the agricultural pressure or land use conflict on the Ciudad del Conocomiento as part of Urcuquí canton according to the Plan de Desarrollo y Ordenamiento Territorial 2011-2031. There are three main symbols to follow: W, O+ and O. It seems like there is an equal representation of each symbol being W in light green the most representative color. W refers to land used within its ability to use. It is important to see that a good part of land is underutilized showed by O-symbol and greenish-brown color. Although this is a territory dedicated to agriculture and compared with the land use map (Figure 3) we can see that these underutilized land is mainly on land dedicated to the harvesting of sugar cane, corn and short-cycle crops, and it is not necessarily because the absence of ditches for irrigation. Finally, in dark green with O+ symbol is the land severely exploited, which belongs mostly to sugar can and short-cycle crops. The “-” symbol shows areas associated to hills and ravines (Figure 4) where agriculture do not take part. The tendency to exploit land for agriculture leads to a degradation of quality in the soil that is difficult to recover. Figure 8 shows a broad vision of the land dedicated to agriculture in the Ciudad del Conocimiento at 2010 according to the PDOT. This map does not take into account the differences between the type of crops or the places where they are located in the city.

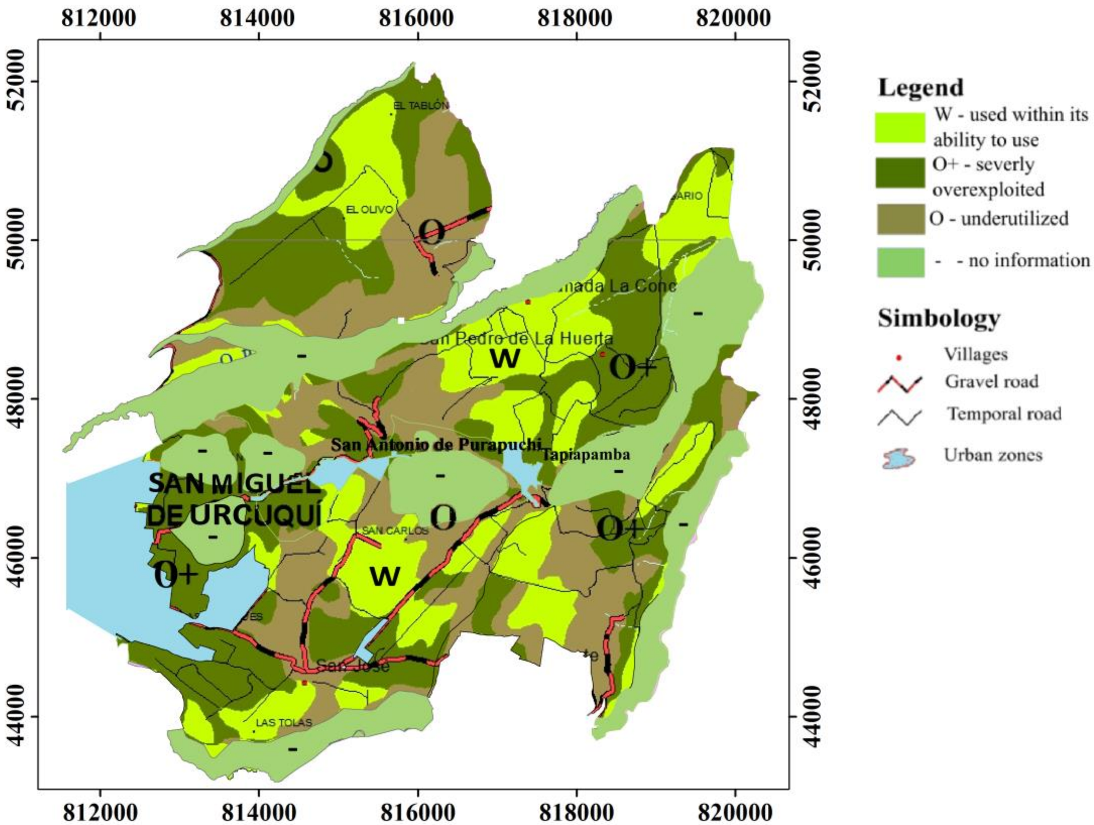


Figure 7. Land use conflict or agricultural pressure on land. The map shows the area where the land is used within its ability to use, severely exploited or underutilized. Also it is combined with information of the access road and urban zones. Extracted from: PDOT Urcuquí 2011 – 2031

The final product of a bad handling associated to deforestation, change in land use and erosion is the degradation of the soil. Soil degradation is defined as the long-term decline in soil productivity (Lal, 2001). This problem is directly related to soil characteristics and anthropogenic activity. According to Lal (2001), the manifestations of soil degradation can be physical (decline in soil structure leading to an increase in bulk density, decrease in porosity, infiltration reduction, increasing in erosions by water due to runoff), chemical (salinization, alkalization, leaching, acidification, and illuviation) or biological (decline in the soil biodiversity in terms of microorganisms and reduction in humus quality and quantity). The result is a reduction in biomass productivity, water pollution, contamination and eutrophication, a decline in air quality or emission of trace gases to the atmosphere, among others in the short-term and long-term (Lal, 2001).

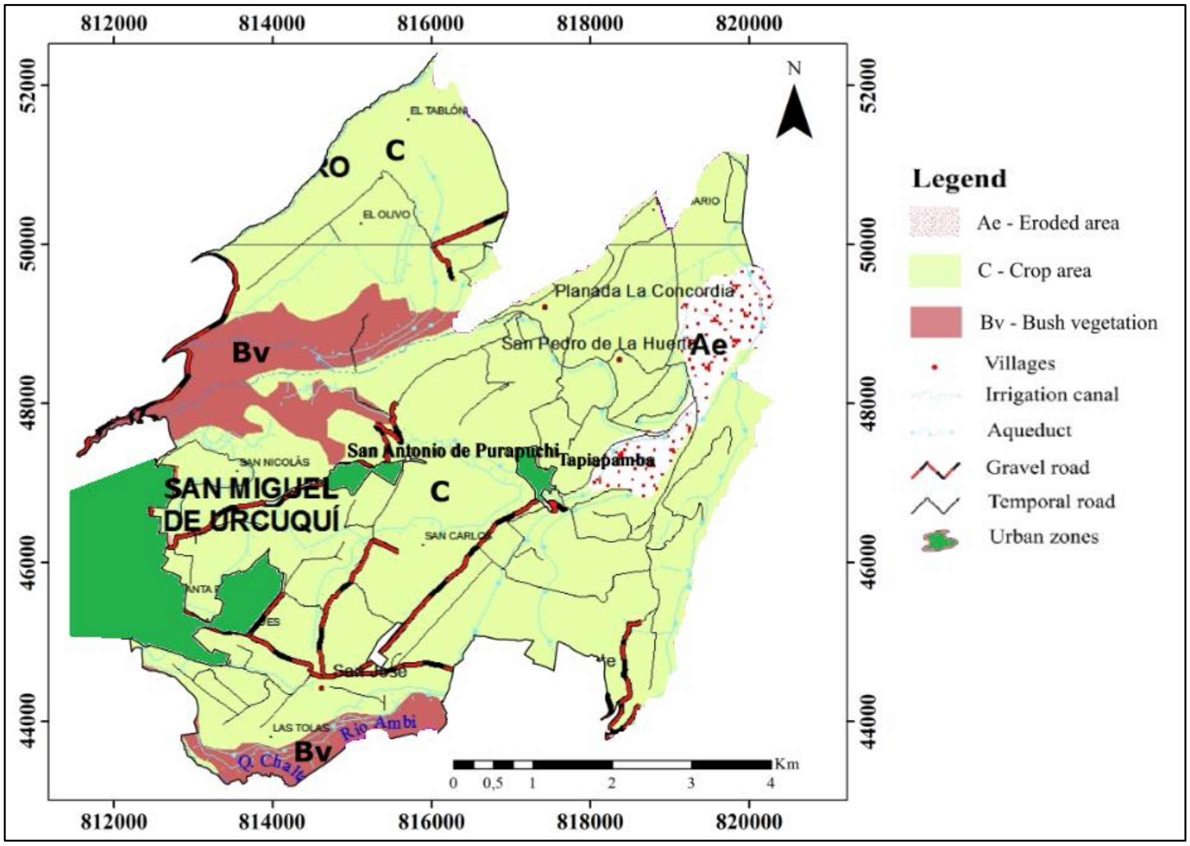


Figure 8. Broad vision of the land use in la Ciudad del Conocimiento in 2010 according the PDOT Urcuquí. We can notice that almost all land in the city was dedicated to agriculture (pale green). We have certain areas of bush vegetation associated to ravines and an eroded area associated to La Ensillada and La Chusquilla hills (Figure 4) Extracted from: PDOT Urcuquí 2011-2031.

Because of the mentioned problems of soil degradation, it is essential to create mitigation plans or protect the land from erosion. It is difficult to control the natural factors of degradation, such as soil characteristics, climatic features, cover vegetation, and ecoregional characteristics (Lal, 2001). However, we have control over the anthropological disturbances on soil degradation as the land use, soil management, farming/cropping systems, land tenure, marketing, or institutional support. All these activities can be more affected by poverty or agriculture for subsistence (Lal, 2001). Using suitable agriculture forms protects the soil from natural factors and avoids land-use changes (i.e. deforestation to create grazing land). Figure 8 shows the predominant land use in la Ciudad del Conocimiento in 2010 according to the PDOT of Urcuquí 2011 – 2031. A good example to study, in terms of agriculture, is the United States. The United States had spent around $196 per hectare to control on-site erosion and maintain the productive land. All over the country, it finally has an economic cost of $44 billion, where $20 billion were spent for replacement of nutrients (fertilizers and pesticides) and $7 billion for replacing surface water to pumping water, and $17 billion is attributed to off-site problems of erosion as siltation, dredge of sediments from waterways and sandblast from wind erosion (Pimentel et al., 1995). The cost could vary depending on the access to water in each country, and the cost to replace nutrients may be much higher in developing countries that do not have the necessary infrastructure (Pimentel et al., 1995).

Erosion by water

As mentioned before, erosion is the movement of material by different agents. Erosion by water, therefore, is the movement of surface particles (mainly) by the action of water. Soil erosion by water, mainly rainfall erosivity is an important driving force for the degradation of the ecosystem (Han et al., 2011; Zhu et al., 2009). The source of water could be from rain (water drops), rivers, irrigation canals for agriculture or other tributaries. But the mechanism of action is the same and can be described in two steps before the deposition of particles (Weil & Brady, 2016). Soil erosion starts with the detachment of particles as the first step and transportation of them (Ellison, 1948). The detachment of particles is caused by breakdown of the aggregates due to raindrop impact, shearing or drag force of water, or dissolution of cementing agents through chemical reactions (Lal, 2001). The transportation of the detached particles downhill is done by floating, rolling, dragging, and splashing (Weil & Brady, 2016). And the deposition may range from a few millimeters to thousands of kilometers from the source when the velocity of water decreases by the effect of slope or ground cover (Lal, 2001). There is a limit for the amount of sediment that can be carried by runoff, when that limit is reached the water have to increase its velocity or increase the depth of the watercourse, this variables determines sedimentation (Saavedra, 2019). Soil erosion by water is associated with tillage agriculture, improper grazing on sloping lands and deforestation (Weil & Brady, 2016). Also the particles are more susceptible to erosion depending in their size and aggregation. In this sense, sand (2mm – 0.05mm) have a low susceptibility unless it is fine sand, silt (0.05 – 0.002) have a high susceptibility and for the case of clay (<0.002mm) depends on the degree of aggregation (Schaetzl & Anderson, 2005; Weil & Brady, 2016). As a consequence of the detachment a superficial seal is produced and this reduces the infiltration capacity of the soil (Saintraint, D., Sloot, M., Henricus, 1993).

Raindrops have a huge influence on erosion. Larger raindrops can achieve a terminal velocity of 30km/h, transmitting their kinetic energy to soil particles, detaching them, destroying granulation and transporting them from the splash (Weil & Brady, 2016). When precipitation is higher than the infiltration rate of water it produces a retention of surface water what is known as surface runoff (Saintraint, D., Sloot, M., Henricus, 1993). Surface runoff is the main soil transport agent of erosion, for this reason water erosion processes are closely related to the routes that water follows as it passes through the vegetation cover and its movement over the surface (Saavedra, 2019)

Vegetation has properties to control soil erosion by water. Roots, shoots, growth cycle, growth habit and growth rate are some of the properties of plants. For example, a vigorous development of roots close to the surface can reinforce the resistance to erosion. A dense green shoots in the soil surface impact in the flow of water reducing its velocity. The growth cycle, habit and rate relate the amount of roots and shoots that growth to protect the soil, not only runoff but also raindrop impact, and the importance of a rapid establishment of these plant species (Morgan, 2005)

Although the present thesis work is focused on water erosion as one driver of the erosional processes at Ciudad del Conocimiento there are certainly more natural drivers for erosion due to the geology, weather and vegetation cover. Wind erosion is another factor that influences the erosional rates in the city. The driver force in wind erosion is the velocity of moving air, due to the roughness from the soil, the vegetation and other obstacles the wind tends to be lowest near the surface (Morgan, 2005). The particle-size susceptibility to wind erosion is moderate to sand, high for silts and low for clay, depending in the cohesion of the soil, the humidity ant the vegetation coverage (Buol et al., 2011). Wind erosion can also be parametrized using quantitative perspectives and equations (Woodruff & Siddoway, 1965).

2.4 USLE Equation

Usually, erosion can be studied from a qualitative and a quantitative perspective (Saavedra, 2019). The study of erosion is carried by quantitative methods divided into direct and indirect measurements. Direct measurements are on-site studies developed in parcels of land with some methods that calculate the amount of current erosion and the accumulation of erosion in a period (Lal, 2001). Indirect measurements are related to erosive models that can be physical, statistical, or parametrization. The idea of parametrization is to estimate empirical relationships (soil dispersion, infiltration rate, soil permeability, particle size, among others) to calculate soil erosion (Lal, 2001). The final product is an empirical equation that can be applied for large areas with geographical information systems (GIS). Scientists have developed several methods or equations to calculate soil erosion. For example, Zingg (1940) described mathematically the effect of slope length and slope steepness on erosion, Horton (1945) added the influence of cover and management into the Zingg's equation. Some of these equations were also developed, and some other factors were added to have a better mathematical approximation for soil erosion. Nowadays, the most used parametrization method is the Universal Soil Loss Equation (USLE) (Saavedra, 2019) developed by Musgrave in 1945, modified several times to have a better approximation. Renard et al. (1997) finally described the Revised Universal Soil Loss Equation (RUSLE) that relates soil erosion with different variables that include: rainfall and runoff erosivity factor (R), soil erodibility (K), slope gradient (S), slope length (L) and vegetation cover (C). The Universal Soil Loss Equation (USLE) is the base of the present work that wants to parametrize the amount of erosion in the Ciudad del Conocimiento due to the change in land use.

$$USLE\ Equation = R \times K \times L \times S \times C \qquad (Equation\ 1)$$

Where: ***A*** *is the computed spatial average soil loss and temporal average soil loss per unit area,* ***R*** *is the rainfall and runoff erosivity factor,* ***K*** *is the soil erodibility,* ***S*** *is the slope gradient,* ***L*** *is the slope length and* ***C*** *is the vegetation cover.*

The units of each factor is following described:

$$USLE\ Equation : \left(\frac{Mg}{ha \cdot year}\right)$$

Where the units of the resultant equation are: Mega gram per hectare per rear

$$USLE\ Eq = R\left(\frac{MJ\ \cdot\ mm}{ha\ \cdot\ hour\ \cdot\ year}\right) \times K\left(\left(\frac{Mg}{ha}\right)\ \cdot\ \left(\frac{MJ\ \cdot\ mm}{ha\ \cdot\ hour}\right)^{-1}\right) \times L(no\ units)$$
$$\times S(no\ units) \times C(no\ units)$$

*Where the units are: **R** in mega joules times millimeter per hectare per hour per year and **K** in mega gram per hectare over mega joules times millimeter per hectare per hour. **L**, **S** and **C** are dimensionless factors.*

Nowadays, several of these factor can be calculated using different software's and satellite images. Each of the factor are calculated separately and differ among different regions based on the accessibility to data about climate, rainfall, climatological stations or resolution of Digital Elevation Models and satellite images.

3. MATERIALS AND METHODS

3.1 Materials

R-factor

For the calculation of the rainfall and runoff erosivity factor it was needed several data of rainfall to the zone of Urcuquí canton. Due the fact that the only climatological station in the canton is out of the study area and that the data obtained from other climatological stations could not represent the real data for the Ciudad del Conocimiento, the data to calculate the R-factor was extracted from satellite data. The International Research Institute for Climate and Society from the Columbia University has a readily available database from the Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS, Funk et al., 2015) that we can use to obtain the data for precipitation. For the purpose of the study we use the annual average precipitation from the years available that was from January 1981 to February 2015. It was also necessary the data of the monthly average precipitation for the zone. The coordinates of the zone were (0.375 – 0.475) °N and (-78.2 – -78.1) °W used in UTM to adjust to the map. Appendix 1 shows the average annual precipitation while Appendix 2 shows the average monthly precipitation for more than 30 years studied.

K-Factor

In order to calculate this factor, we need several information of the soil from the Urcuquí canton. In this case the soil texture (M), the amount of organic matter (OM), the soil structure (S) and the permeability (P).

For the soil texture or the percent of sand-clay and silt in the soil is determined by empirical particle fraction as field experimentation as described by the FAO (n.d.-a), so the materials used are:

- 2-mm sieve
- 500ml test tube
- Water
- Metal spatula
- 150g of soil

The amount of organic matter is going to be measured by the Loss of Ignition Method (Dean, 1974), so the materials are:

- Hayang Scientific Muffle Furnace
- Practum Sartorious Analytical Balance
- Glass desiccator
- JP Selecta Incubator
- Mortar with pistil
- 10g of soil

Soil structure and permeability can be calculated in the field and inferred from the information of the texture of the soil given by MAGAP and the indications of FAO for the study of the soil. Table 2 shows the code used for the type of structure and permeability to use into the calculation of the K-factor (Saavedra, 2019).

Table 2. Structure and Permeability coding proposed in the nomograph of Wischmeier & Smith (1979)

Structure	Code
Granular very fine	1
Granular fine	2
Coarse granular to medium	3
Massive	4

Permeability	Code
High	1
Medium high	2
Medium	3
Medium low	4
Low	5
Very low	6

LS factor

For the calculation of the topographic factor or LS-factor a Digital Elevation Model (DEM) of 3m resolution for the study area is needed. The DEM was available from the Ministerio de Agricultura. From the DEM we are going to develop several maps as the slope map in degrees at the Ciudad del Conocimiento, the flow direction of water depending from the slope and the flow accumulation from the water direction map created before. These are the materials needed for the method calculation described below in the methods section.

C-factor

For the calculation of the cover-management factor or C-factor a Landsat 8 satellite image for the area of study are needed. The Landsat image used came from the Earth Explorer service from the United State Geological Service (USGS). The image was taken on November 11, 2016 and is composed of 11 bands, where band 4 is called visible band and band 5 is the near infrared band, both are going to be used to the calculation of C-factor.

3.2 Methods

The application of the USLE equation (Equation 1) involves the calculation of several parameters of the soil and it is the characteristics to understand the potential soil loss. The equation developed by Musgrave (1945) and then revised by several other scientist is the accumulation of factors that affects soil erosion as: rainfall and runoff erosivity factor, the soil erodibility, the slope gradient, the slope length and the vegetation cover.

Each of the factor is calculated following the Manual for application of RUSLE equation developed by Renard in 1997, some of the factors are calculated with the aid of other manuals validated by several studies that contrast the factors obtained by several forms of calculation. The proposed calculation method for obtaining each of the factors is described below:

R = rainfall-runoff erosivity factor

The rainfall erosion index is a factor for any significant runoff. It can be calculated using the Modified Fourier Index (MFI) as follows (Arnoldus, 1980):

$$\textit{Modified Fourier Index (MFI)} = \frac{\sum_{i=1}^{12} p_i^2}{P} \qquad \textit{(Equation 2)}$$

Where p_i^2 is the average monthly precipitation and P is the average annual precipitation.

With the data obtained in Appendix 1 and 2 we can build a grid of 9 points overlying the Ciudad del Conocimiento fits. Using Kriging interpolation method in ArcGis we can interpolate the data of each point of the grid and construct a map of monthly and annual precipitation over the city based in this geostatistic method. By using the tool Raster Calculator in ArcGis we can apply Equation 2 to obtain the value of MFI for each point. Renard (1994) suggest the use of the Modified Fourier Index to calculate the rainfall erosivity factor for regions with limited data of rainfall (Apaydin et al., 2006). Arnoldus (1980) demonstrate that the MF-index is a good approximation for the R-factor. Those factors shows a linear correlation with an $r^2 = 0{,}83$ (Ferro et al., 1999; Renard & Freimund, 1994). Also the factors can be adjusted following an exponential distribution (Angulo-Martínez & Beguería, 2009). The values obtained from the calculation of the Modified Fourier Index can be tabulated as follows (Table 3) in order to have an idea of the rainfall erosivity at the study zone (Boardman & Poesen, 2006; Gabriels, 2006)

Table 3. Classification of the erosivity index by using the Modified Fourier Index according Gabriels (2006)

MFI range	Description
< 60	Very low
60 – 90	Low
90 – 120	Moderate
120 – 160	High
> 160	Very high

The approximation from MFI to the R-factor is described by Renard & Freimund (1994) for values greater than 55 millimeters. The suitability of this method in the case of Ecuador is documented by Ochoa-Cueva et al. (2015) following the next equation:

$$R = 95{,}77 - 6{,}018 \cdot MFI + 0{,}4770 \cdot MFI^2 \qquad \textit{(Equation 3)}$$

Finally, using the Raster Calculator we can built our R-factor map based in Equation 3 in the ArcGis software.

K = soil erodibility factor

The soil-loss rate per erosion index for a specified soil is defined as a 22.1m length of uniform 9% slope in continuous clean tilled fallow. Also it can be calculated as follows and described by Wischmeier and Smith (1979):

$$K = [2.1x10^{-4}(12 - OM)M^{1.14} + 3.25(s-2) + 2.5(p-3)]\ /100 \quad \textit{(Equation 4)}$$

Where: $\boldsymbol{M} = (100 - \%\ clay) * (\%\ silt + \%\ sand)$
OM = organic matter
S = classes for structure (value from 1-4)
P = permeability (value from 1-6)

In order to characterize the soil at the Ciudad del Conocimiento is important to understand several parameters of the soil. The workflow below (Figure 9) describes, in a gross way, the step-by-step fieldwork, laboratory work and results of the data obtained.

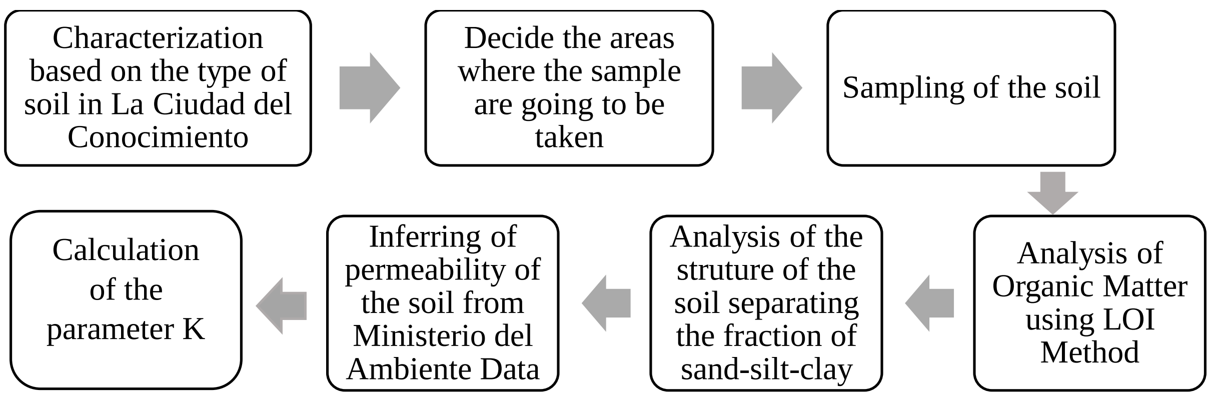


Figure 9. Workflow for the calculation of the K-factor

As the workflow shows, the characterization where done based on the type of soil described in Figure 6. It is so, we decided to obtain 32 samples of soil distributed all over the city (Appendix 3). For the types of soils that are minority (Andisols, Mollisols) we try to sample each place in the map showing that type of soil twice while for Entisols we sample spatially based on Figure 10. Some places where difficult to sample due the fact that are now private concessions, mainly in the middle part of the city.

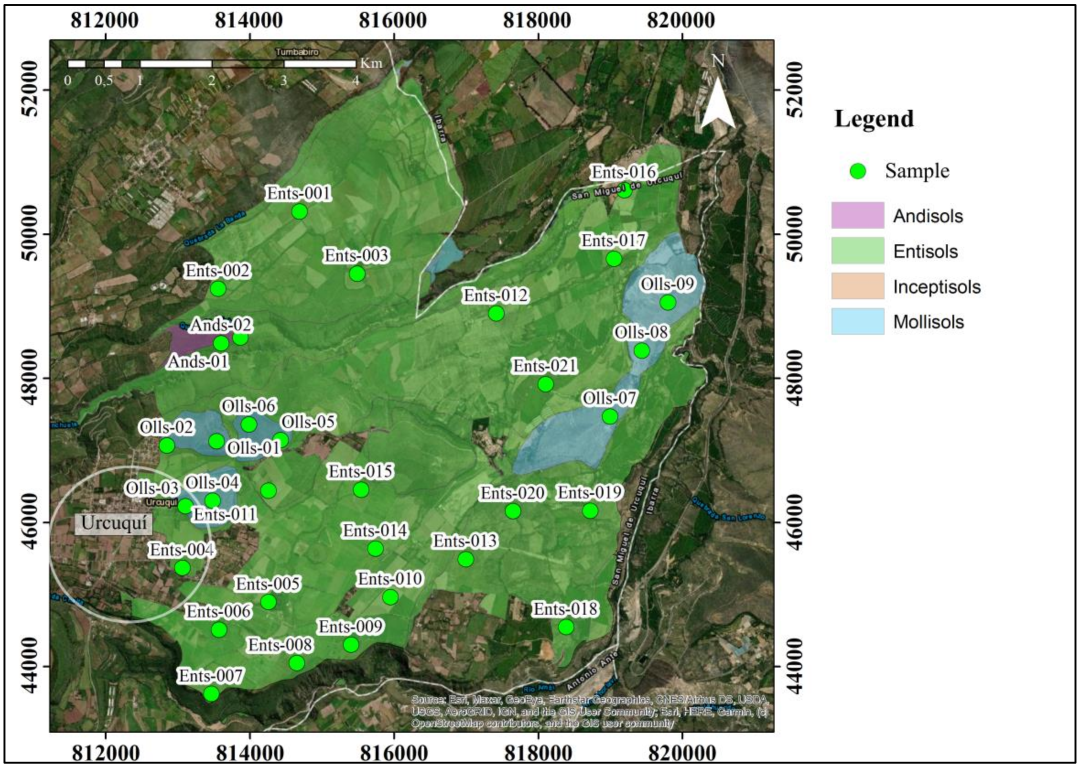


Figure 10. Sample points of soil at the Ciudad del Conocimiento. The order of the soil was an important factor at the time to decide where to sample. Mostly all the entisols where covered. To have a representative sample of the other types of soil we have more points in mollisols and two in the little area where andisols are located. The location of the points where stored as GPS points for further uses.

The texture of the soil where calculated based on the recommendations of FAO for the texture in the field (FAO, n.d.-a) and also corroborated graphically with information of the soil texture of the land at the city from the Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAGAP, 2018). The factor M were calculated based on Equation 4 developed by Wischmeier and Smith (1979). In order to calculate the texture of the soil, it was need separate the fine portion of the samples taken. With the aid of a 2-mm sieve we sift the around 150g of sample to obtain the finer particles of the soil. Then in a 500ml test tube we put the samples and water. The mud created were agitated manually for 5 minutes and then left to rest for at least 20 hours. The particles start to sediment at the bottom of the test tube depending on the size of the grains and its different densities. Some horizons can be distinguished between the size particles, at the bottom the coarse grains and at the top the finest grains. The different layers were measured and the values recorded in Appendix 4 where the values of the percent of the sand, silt and clay where calculated and subsequently the value M (Equation 4). Figure 11 describes the procedure at the laboratory.

Figure 11. Process for obtaining the texture of the soil. [A]. Samples sedimented into the test tubes after 20 hours. [B]. 2-mm sieve with sample to be sifted. [C]. Formation of horizons with the different sizes of the particles by the density of each of its.

For the analysis of the organic matter we used the Loss of Ignition Method described by Dean (1974). First, it was needed to grind the samples manually with the aid mortar and pistil. Second, the 10g of powdered soil where putting on a pre-weighed crucible and where dried on the JP Selecta Incubator at 105°C for one hour and then cooled in the glass dissector at room temperature, this was the dry weigh at 105 (DW_{105}) (Appendix 5). Third, the crucible where putted on the muffle furnace at a temperature of 550°C for 4 hours (Santisteban et al., 2004) and then weighed, this was the dry weigh at 550 (DW_{550}) (Appendix 5). Then the percentage of organic matter or LOI at 550 where calculated using Equation 5 as showed by Santisteban (2004):

$$LOI_{550} = \left(\frac{DW_{105} - DW_{550}}{DW_{105}}\right) \times 100 \quad \textit{(Equation 5)}$$

The value of permeability and soil structure were obtained from the information of the texture of the soil given by MAGAP and also the characteristics of the soil described by FAO for permeability and soil structure (FAO, n.d.-b). Due to the fact that the area of study is not too large and shows almost the same geological characteristics and with a textural value not too different between the samples taken (Appendix 4), the permeability values were set to a value of 3 for a sandy loamy texture with moderate permeability (Figure 15). The structure was set to a value of 3 for a loamy sandy texture with a coarse granular structure and certain values to 2 where the amount of sand is lower than 50% (fine granular) and 4 where the amount of sand is more than 70% (massive structure) (Table 5).

For the construction of map of the K-factor the interpolating tools in the ArcGis software was used. This tool constructs polygons (Thiessen polygons) around the sample points with the K-factor value on each polygon of influence.

LS = slope length and steepness factor

The ratio of soil loss from the field slope length to soil loss from a 22.1m length under identical conditions and the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

The factors L and S are usually calculated at the same time because of their relation. There are a wide variety of forms to calculate these parameters. Actually, with the aid of a DEM we can do it by using ArcGis. The following equation relates both parameters depending in the flux accumulation of water in each cell, the cell size, the sine of the slope angle and exponents of length and slope steepness (Moore & Burch, 1986; Renard et al., 1997; Wischmeier & Smith, 1979; Zhang et al., 2013):

$$LS = (m+1) * \left(\frac{FA\ x\ cellsize}{22{,}13}\right)^{m} * \left(\frac{sin(slopeangle(\theta) \times 0{,}01745)}{0{,}09}\right)^{n} \qquad \textit{(Equation 6)}$$

Where: - *Exponent of length (**m**) =* $\beta/(1+\beta)$*; where* $\beta = (\sin(\theta))/[3 \cdot (\sin(\theta))^{0,8} + 0{,}56]$

- *Exponent of slope steepness (**n**) = 1,3 (stream flow)*
- ***FA**: flux accumulation (obtained from the algorithm of ArcGis). First we need to identify the direction of the flux with the tool Flow Direction in ArcGis*
- ***Cellsize**: size of the cell of the data in the DEM (for example a 30m DEM)*
- ***Slope angle (θ)**: angle of the slope in degrees. With the aid of the tool slope in ArcGis*
- *22.13, 0.09, and 0.01745 are fixed values*

C = cover-management factor

The ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

The USLE manual developed by Renard (1997) suggest the calculation of the C-factor by the computation of five different subfactors: prior-land-use (PLU), canopy-cover subfactor (CC), surface-cover subfactor (SC), surface-roughness subfactor (SR) and soil-moisture subfactor (SM). The calculation of each factor could be difficult to achieve for big areas as the Ciudad del Conocimiento.

Van der Knijff, Jones and Montana (2000) described another method to assess the value of the C-factor from the Normalized Difference Vegetation Index (NDVI). With the aid of satellite images from Landsat 8 satellite imagery we can built the NDVI map in the ArcGis software using the equation bellow that take into account the intensity of radiation from certain bands of the electromagnetic spectrum. The calculation of the NDVI factor is between the near infrared ($\lambda \sim 0{,}8\ \mu m$; which the vegetation reflects strongly) and the red light ($\lambda \sim 0{,}6\ \mu m$ which the vegetation absorbs), all this information is obtained from bands 5 and 4 respectively from the Landsat 8 image (Carlson & Ripley, 1997; Rouse et al., 1974)(Rouse et al., 1974). Finally, we have values of the NDVI ranges between: -1 and +1. Where, values highest than zero represents vegetated zones, due to the amount of chlorophyll. The greatest the amount of chlorophyll, the highest the NDVI-value (Yengoh et al., 2015). The Earth Observing System (n.d.) describes the difference in NDVI-values and the cover vegetation shown in Table 4. The equation of NVDI is as follow:

$$NDVI = \frac{IR_{near} - Red_{visible}}{IR_{near} + Red_{visible}}$$ *(Equation 7)*

Table 4. Cover of soil according the NDVI-value according the Earth Observing System (n.d.)

NDVI-value	**Cover of soil**
> 0	Cloudiness, water, snow, rocks or bare soil
0 – 0,1	Bare soil without rocks, sand
0,1 – 0,2	Small crops
0,2 – 0,3	Bushes and grasslands
0,3 – 0,6	Bigger plants and crops

Then, the relationship between the NDVI and the C-factor according to Van der Knijff et.al. (2000) is as given by:

$$C = exp^{\left(-2*\frac{NDVI}{1-NDVI}\right)} \qquad \textit{(Equation 8)}$$

This equation is calculated with the Map Algebra tool in the ArcGis software to create a map for the cover-management factor.

The following chart (Figure 12) shows the pathway followed to obtain each of the parameters in order to calculate USLE equation. It is a summary chart about the methodology used and some of the materials needed to obtain the results.

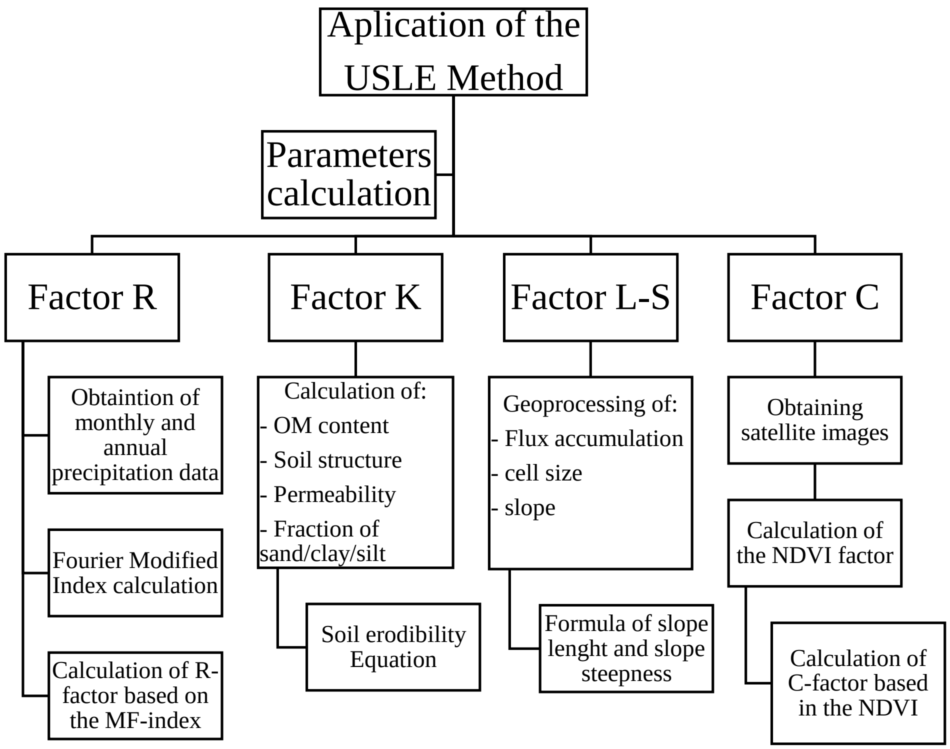


Figure 12. Summary of the steps taken to calculate the USLE equation from the methodology presented.

4. RESULTS AND DISCUSSION

R-Factor

The rainfall-runoff factor shows that the soil losses from field are directly proportional to a rainstorm parameter (Renard et al., 1997). This is a natural factor that is not depending on human modification as other parameters calculated (Angulo-Martínez & Beguería, 2009). The R value must quantify the raindrop impact effect and provides information about the rate of runoff associated to the rain (Wischmeier & Smith, 1979). The units of R-factor are in mega-joules per millimeters over hectares per hour $\left(\frac{MJ \cdot mm}{ha \cdot hour \cdot year}\right)$.

The USLE-manual developed by Renard (1997) describes a way to calculate this factor using the total storm energy and the maximum 30-min intensity. Due to the fact that we do not have a weather station near the study zone, we have to use interpolation tools from precipitation data in the last 34 years that has a resolution of 0,05° in both axis (Funk et al., 2015). This resolution creates a grid of 9 points around the Ciudad del Conocimiento. Arnoldus (1980) developed a way to calculate the R-factor from the Modified Fourier Index as described in the methods section in order to maintain some precision in the calculation with the data used for those calculations (Appendix 1-2).

The satellite information retrieved from the Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) were useful to interpolate the average monthly precipitation (Appendix 6) and the average annual precipitation (Appendix 7) in the ArcGis software to build the Modified Fourier Index map (Figure 13). According the classification used in Table 3 we have a low erosivity index for the Ciudad del Conocimiento. There is a tendency to decrease the MFI values from west to east. This can suggest that we have more precipitation in the west part of the city, associated to a higher altitude zone than in lower or flat zones located at the east part of the city. The units are in millimeters for which it is necessary to apply Equation 3 depicted in the methods section to approximate the MFI values to the R-factor and to the units used for the USLE.

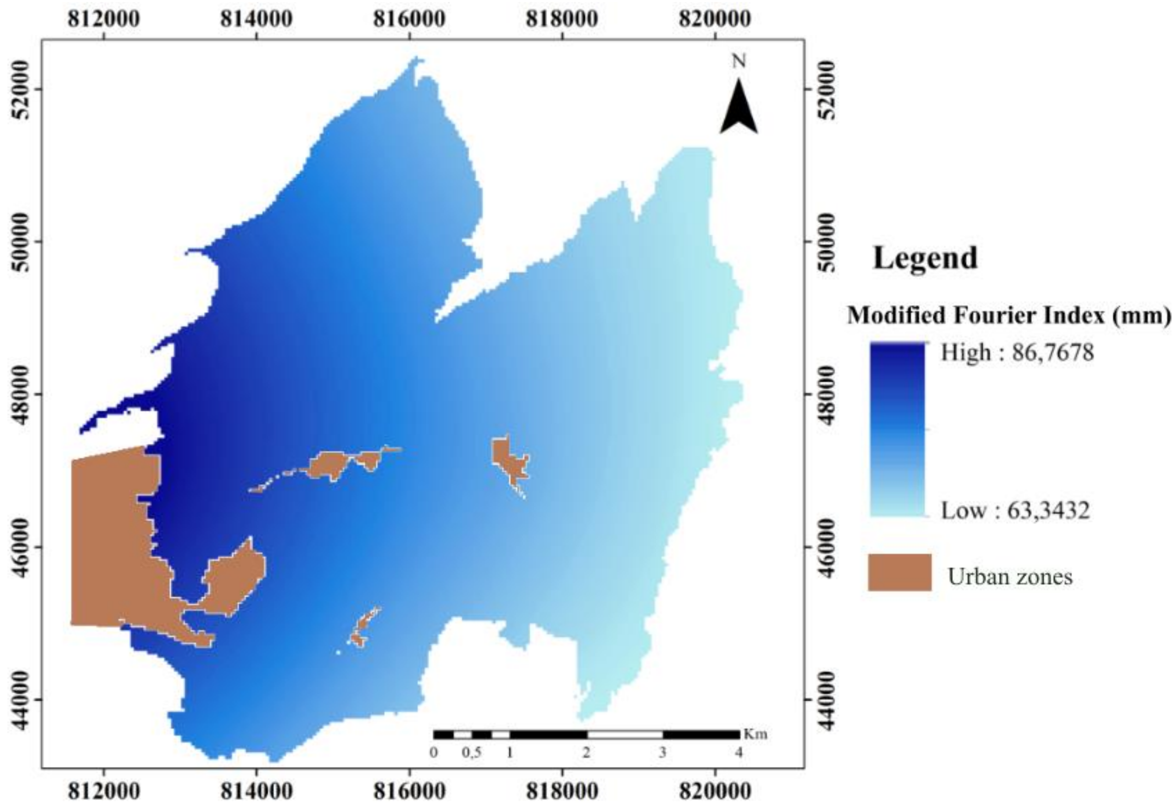


Figure 13. MFI-values for the Ciudad del Conocimiento. It shows the highest values in the west while the lower values are in the east. It was constructed using Kriging interpolation from the precipitation data. In brown color are the urban zones at the city.

The result is the rainfall-runoff erosive factor shown in Figure 14. The impact of water into erosion starts with the impact of raindrops that disaggregates the soil and have a direct correlation with the kinetic energy of the rain. As mentioned before, when the water cannot infiltrate more into the ground it starts the runoff and the erosion due the transport of particles that moved the already disaggregates particles. Depending on the roughness, slope and cover vegetation it can be more easily for water to erode a bare ground. The erodibility from rain depends strongly in the intensity of the precipitation. The map bellow shows the erodibility in the Ciudad del Conocimiento. The interval of precipitation erosivity is between 1624,48 and 3159,3 having the higher values at the western part of the city while the lower values are at the eastern part of the map. This talks about the impact of the altitude into the amount of rain and therefore in the R-factor. In the high areas we have a large amount of rain in one hand and in the other hand powerful events due the fact that the R-factor is more related to the kinetic energy of rain than with the amount of rain in a certain area. With the development of the rest of the equation we are going to see how erosion is going to change depending on the characteristics of the soil, the slope and steepness of the study zone and the cover management at the Ciudad del Conocimiento.

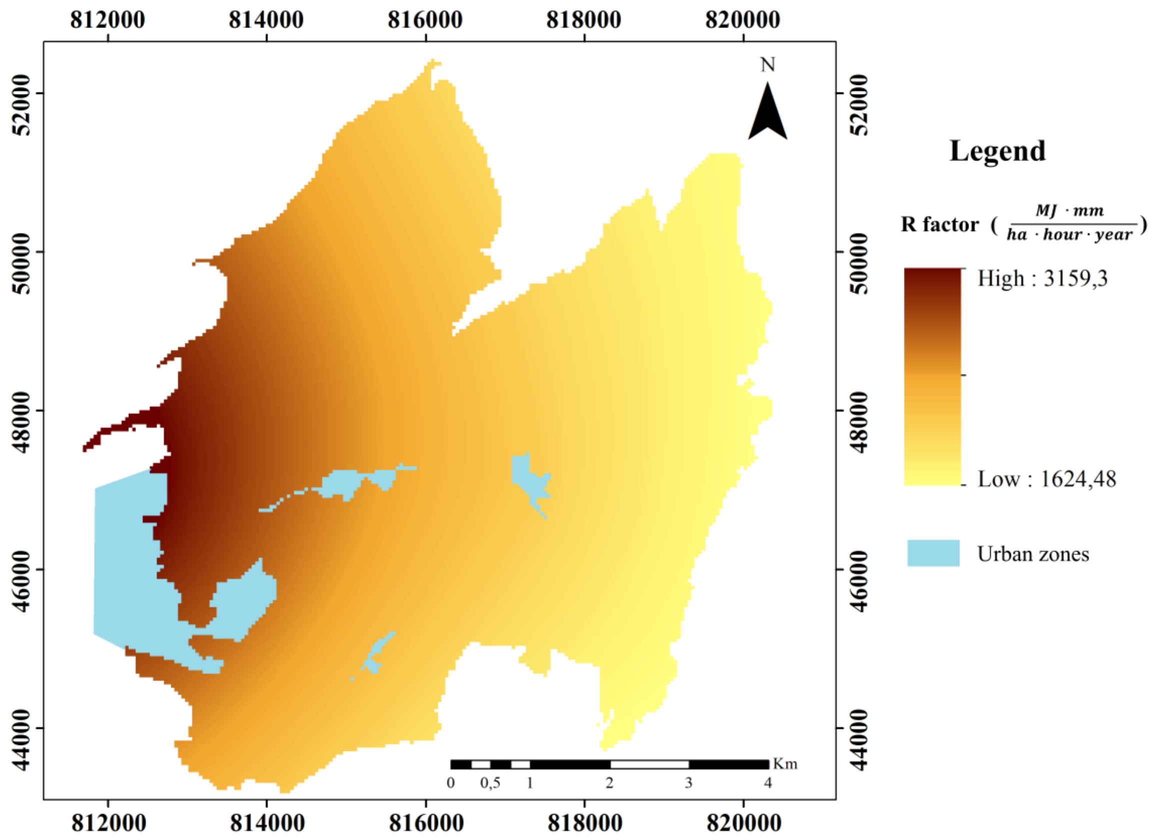


Figure 14. R-factor calculated from the IMF. The highest values of erosivity from rainfall-runoff are presented at the western part of the map while the lower ones at the east coinciding to the altitude of the map. At the east the lower zones (lower R-values) and at the west the highest zones (higher R-values) which suggest a relation between the precipitation, the altitude and, therefore, the R-factor. In light-blue color are the urban zones located at the Ciudad del Conocimiento.

K-Factor

The soil-erodibility factor or K-factor is the rate of soil loss per rainfall erosion index unit (Wischmeier & Smith, 1979). It is correlated with the R-factor in terms of units. K-factor is in function of four parameters or variables according the equation used to calculate the values. These variables are: permeability (P), soil structure (S), soil texture (M) and organic matter (OM). The units of K-factor are: mega grams per hectare per rainfall erosion index $\left(\frac{Mg}{ha}\right) \cdot \left(\frac{MJ \cdot mm}{ha \cdot hour}\right)^{-1}$. Each variable has a different role in the calculation of the factor being able to increase or decrease the erodibility of the soil. Table 5 summarizes the values obtained of each parameter in each sample that allows to build our map for the erodibility factor base on the equations depicted in the methods section.

Table 5. Summary of the values of texture (M), organic matter (OM), structure and permeability of the samples analyzed at the Ciudad del Conocimiento.

Sample	M	%OM	Structure	Permeability
Ents-001	89,124163	0,57	3	3
Ents-002	90,181668	0,73	4	3
Ents-003	90,702948	0,51	3	3
Ents-004	92,261080	0,46	3	3
Ents-005	89,341340	0,83	3	3
Ents-006	90,328529	0,86	3	3
Ents-007	89,536363	0,59	3	3
Ents-008	77,743092	0,40	3	3
Ents-009	95,699433	0,79	3	3
Ents-010	90,702948	0,58	3	3
Ents-011	89,049792	0,63	3	3
Ents-012	84,833795	0,94	3	3
Ents-013	92,160000	0,61	4	3
Ents-014	80,300219	0,52	2	3
Ents-015	91,727832	0,55	3	3
Ents-016	93,335248	0,63	3	3
Ents-017	93,444444	0,58	4	3
Ents-018	53,930664	0,48	3	3
Ents-019	92,549271	0,82	3	3
Ents-020	89,750693	0,36	4	3
Ents-021	93,065744	0,96	3	3
Olls-01	62,015625	0,70	2	3
Olls-02	76,002630	0,64	3	3
Olls-03	65,741417	0,51	3	3
Olls-04	74,683737	0,62	3	3
Olls-05	61,361111	0,43	3	3
Olls-06	83,364839	0,57	4	3
Olls-07	79,912764	0,76	4	3
Olls-08	80,380499	0,56	3	3
Olls-09	75,111111	0,43	3	3
Ands-01	70,140625	0,79	3	3
Ands-02	78,734378	0,57	3	3

The organic matter was calculated using the Loss of Ignition method described before. The results of OM oscillate between 0,36% and 0,96% (Appendix 5). No one of the samples exceed the 1% of organic matter. The organic matter is composed by complex organic molecules from the decomposition of microbial material, plants and animals (University of Illinois at Urbana-Champaign, 2006). OM is directly proportional to the erodibility of the soil decreasing it. A 5% of organic matter in the soil is consider a rich soil for agriculture while values less than 1% are considered poor to extremely poor soils for agriculture (AgriNovaScience, 2019). We can cluster the information of our sample-soil to look at the different values depending on the order of soil. By doing this also we can notice that there is a wide distribution for example in the Andisols where we have a difference of 0,22% between each sample. The same for Mollisols where the sample with less organic matter has 0,43% and the one with more organic matter has 0,70%. Not to mention the difference in the Entisols. It is better to look at the data with the information of the frequency of some intervals in a histogram. The following chart (Figure 15) shows the amount of samples that fit in different intervals of organic matter. There are 6 intervals with a spacing of 0,10% between them starting at 0,36% and finishing at 0,96%. The most common values of the percentage of organic matter are in the Interval 3 where we have 11 of the 32 samples, more than one third of the samples. Also, it is more common to have values under Interval 3 than over it. Only 10 samples have bigger values than 0,66% of organic matter.

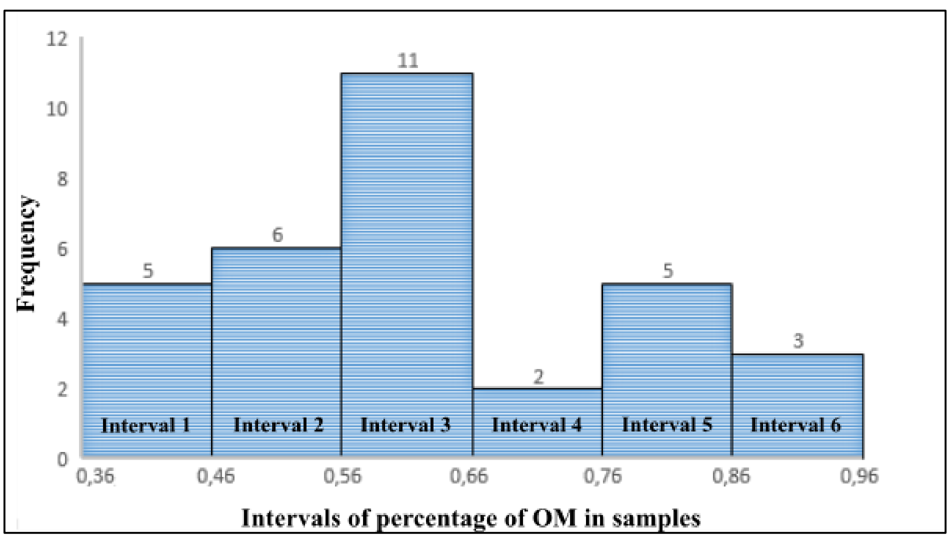


Figure 15. Organic Matter histogram of frequencies with 6 intervals depending on the percentage of organic matter in the samples taken at the Ciudad del Conocimiento. Each interval has a spacing of 0,10%. The most common interval of frequency is in Interval 3. Also, 22 of the 32 samples have lower values than 0,66% of organic matter leaving 10 samples to have the highest amounts of organic matter and only 3 of them near 1%.

The texture of the soil or M-value (Appendix 4) were calculated based on the proportion of sand-silt-clay in the samples with the methods described above. The textural factor is directly proportional to the erodibility of the soil. When the soil presents more primary minerals and a lower quantity of clay, the textural factor increases the erodibility of the soil and increase the water erosion. Figure 16 shows the spatial distribution of texture of the samples in a ternary textural diagram and allow us to classify it (USDA, n.d.). The spatial distribution tends to a sandy loam texture of the soil where 26 of the 32 samples fit. All the soil-samples have more than 50% of sand. Thereof, they are regarded as coarse grained soil although it still remains below the 2-mm size particle. There are 2 samples catalogued as sandy clay loam because the occurrence of more than 20% of clay. Another 2 samples fit as loam soil with less sand than the other samples. Finally, 2 samples fit at a loamy sand soil due the highest amount of sand (more than 70%), between 10-20% of clay and a little proportion of silt. Appendix 4 shows with detail the percentage of sand-silt-clay in each sample. With this data we can calculate the K-factor using Equation 4 described in the methods section.

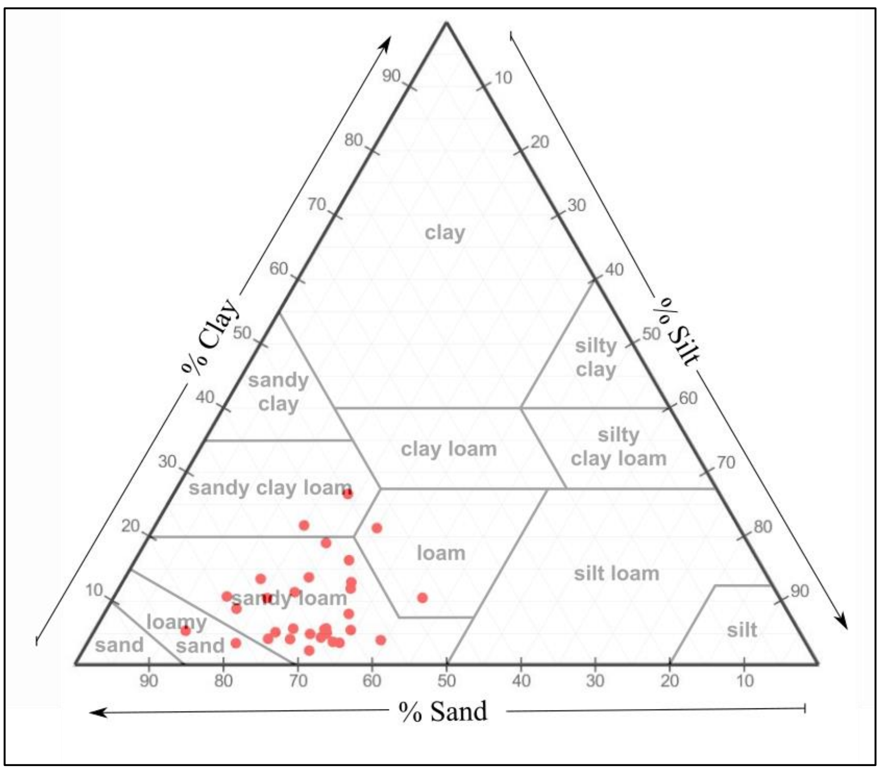


Figure 16. Ternary textural diagram used to classify the soils (retrieved from: USDA). Each side represent an amount of sand-silt-clay that defines the textural characteristic. The red point are the different values of the samples. The different areas of the diagram represent the limits of the textural characteristics of the soil. For the case of the Ciudad del Conocimiento almost all the samples fit in the sandy loam texture or a type of loamy texture.

The structure and permeability of the soil, as the other factor calculated, are directly proportional to erosion. Structures of the soil from coarse grained to massive (Table 2) gives the soil more erodibility, therefore, the vulnerability of the soil to water erosion is higher. Permeability is related with the ability of water to infiltrate into the soil. Soils with lower permeability (Table 2) have more vulnerability to erosion, due to the fact that it increases runoff, and hence, the erodibility of the surface layers of soil (Saavedra, 2019). The calculation of values for the structure and permeability of the soil are described in the methods section and the different values obtained are outlined in Table 5.

Having calculated the four factors of the equation for the erodibility, we can construct the following table where we have the certain values of erodibility for each sample (Table 6). It can be seen that, as in the factors used to calculate the K-factor, we do not have a consistency value for each order of soil although this time we have a shorter distribution of the data with the presence of some outliers. Table 7 shows the average value of K-factor for each order of soil in the samples taken at the Ciudad del Conocimiento.

Table 6. Values of erodibility in each sample taken at the Ciudad del Conocimiento

Sample	**K-factor**
Ents-001	0,03651107
Ents-002	0,06900778
Ents-003	0,03661529
Ents-004	0,03671261
Ents-005	0,03643034
Ents-006	0,03646792
Ents-007	0,03652567
Ents-008	0,03598478
Ents-009	0,03676816
Ents-010	0,03658917
Ents-011	0,03648679
Ents-012	0,03617040
Ents-013	0,06915348

Sample	**K-factor**
Ents-017	0,06923068
Ents-018	0,03478074
Ents-019	0,03659551
Ents-020	0,06911665
Ents-021	0,03656978
Olls-01	0,00262187
Olls-02	0,03582575
Olls-03	0,03535124
Olls-04	0,03576402
Olls-05	0,03515249
Olls-06	0,06871571
Olls-07	0,06848186
Olls-08	0,03606951

Ents-014	0,00357675		Olls-09	0,03583949
Ents-015	0,03665185		Ands-01	0,03549447
Ents-016	0,03670418		Ands-02	0,03598290

Table 7. Average values of K-factor depending on the order of the soil in the Ciudad del Conocimiento

Order of soil	Average K-factor value
Entisols	0,0431325
Mollisols	0,0393135
Andisols	0,0357387

As mentioned in the methods section, we can build our map of the erodibility factor based in the polygons of influence created by the tool: Interpolation – Create Thiessen Polygons in the ArcGis software. The data of the K-factor for each point is saved in each of the polygons of influence of each point. Figure 17 presents the erodibility factor at each polygon near the samples taken. The values obtained for each sample are listed in Table 5. We can see a great distribution of the values around the city. It is almost impossible to recognize a pattern of distribution of the factor inside the city. It is not possible either to have a pattern between the same order of soil. The lower value for the erodibility factor is accounting for 0,002622 while the highest value of K for the Ciudad del Conocimiento is 0,069231. If the K-value is high, the soil is more vulnerable to erosion. There is not a top or bottom value or an optimal intervals of values. Although there are lower values of K, the average values depending on the order of soil (Table 7) shows that for Entisols, we have an average value of 0,0431325 which is the higher value of the three orders of soils. For Mollisols, that presents some of the lowest values of K we have an average of 0,0393135. While Andisols have almost the same behavior and the average K-value is 0,0357387. As an average there is a medium to high erodibility of soil in the Ciudad del Conocimiento for the data used and obtained for Figure 17.

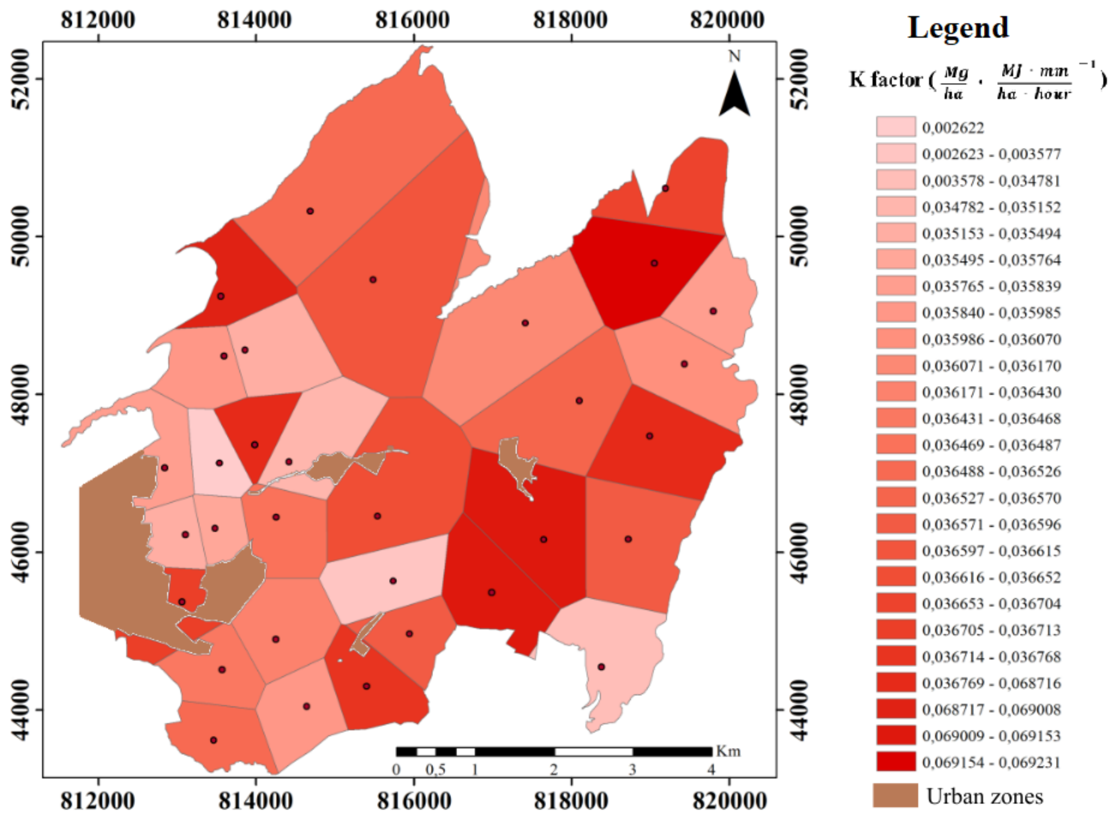


Figure 17. K-factor calculated for each Thiessen polygons. The data is presented as intervals to make the figure more understandable. There is no major pattern in the figure, the vulnerability of the soil is widespread in all the Ciudad del Conocimiento in lower or higher proportion depending on the polygon. For the calculation of this factor the equation proposed by Wischmeier & Smith (1979) was used. In brown color are located the urban zones at the city.

LS Factor

The LS-factor or topographic factor talks about the increase in erosion due to the slope length (L-factor) and the slope steepness (S-factor), (Renard et al., 1997). It is a dimensionless factor in the USLE equation. Wischmeier and Smith (1978) defines the slope length as the horizontal distance from the origin of overland flow to a point where the slope gradient decrease in order to deposit the sediments or the runoff starts to concentrate in a defined channel. While the slope steepness factor shows the influence of slope gradient on erosion. The effect of both parameters is sheet and rill erosion that is estimated by the USLE equation. In the past, these factors were calculated by hand with the aid of inclinometers, Abney level, or similar devices (Renard et al., 1997). Nowadays the calculation of both factors can be done by using Geographic Information Systems (GIS) as it is calculated in the present project and described in the methods section. By using a Digital Elevation Model (DEM), provided by the Ministerio de Agricultura, with a resolution of 3 meters we can calculate all the factors described in the Moore-Burch equation (1986). The starting point is the consideration of the construction of the slope-map from the DEM (Figure 18). We can see that the major part of the city presents a zero or very low degree slope while the change in slope is presented where we have geomorphological structures as hills and ravines around the Ciudad del Conocimiento (Figure 4) which is normal. In this sense, ravines are the structures with the highest slopes near to 82 degrees. Hills shows a medium degree slope represented by a yellowish color. Comparing with the DEM, the reddish areas are the location of hills all over the city while the blue areas are the location of ravines.

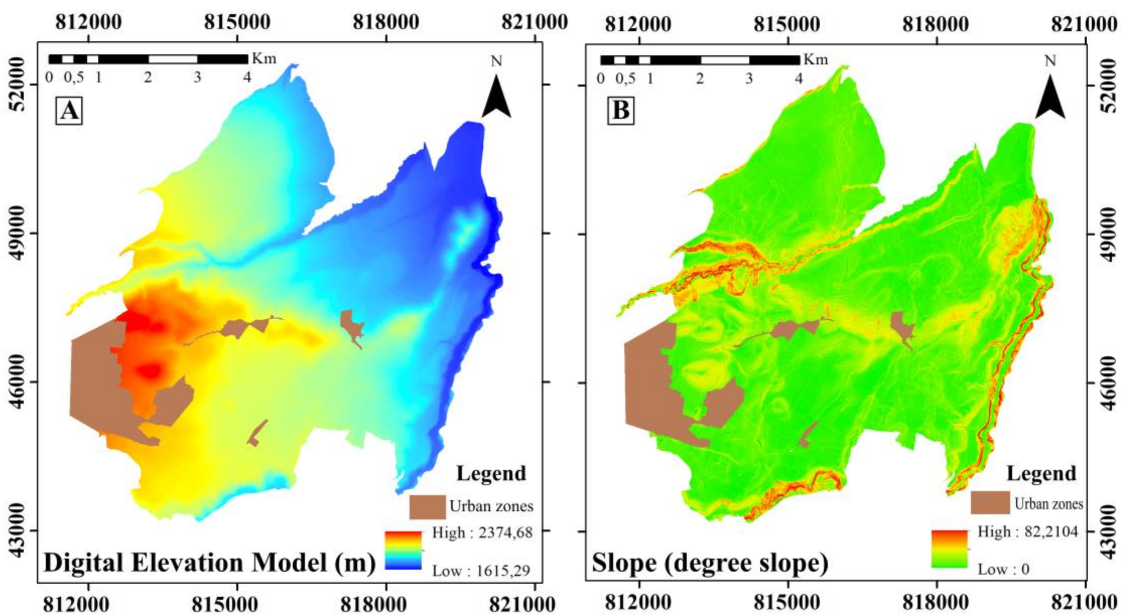


Figure 18. [A]. Digital Elevation Model (DEM) of 3m resolution (SIGTIERRAS, 2016) shows an altitudinal gradient between 1615 – 2374 meters. The reddish colors is associated to the highest parts of the map (hills) and the bluish colors represents the lower altitudes (ravines) in the Ciudad del Conocimiento. [B]. Slope map obtained from the DEM. we have a range of 0 – 82 degrees of slope near the ravines. The major part of the map shows a greenish color associated to low degrees of slope or flattest areas for mainly agriculture. Some of the geomorphological features can de distinguished. The brown polygons are urban zones around the city.

Having the slope degree map, we can build our flow direction map. Although the flow direction is not needed into the parameters of Moore-Burch equation, it is certainly needed to the construction of the flow accumulation map (Figure 19). The values of the flow direction range between 0 and 255 that are the value that each pixel could have depending on the orientation of the flow and the sum of pixels to each flow (Esri, n.d.-b). The values of the flow accumulation are wider due the fact that is the sum of all the pixels that falls into a water channel (Esri, n.d.-a). The high value is caused because the high slope that we have in the ravines. Although imperceptibles, there are lines in the flow accumulation map that shows the natural water channels at the city where the water from hills flows.

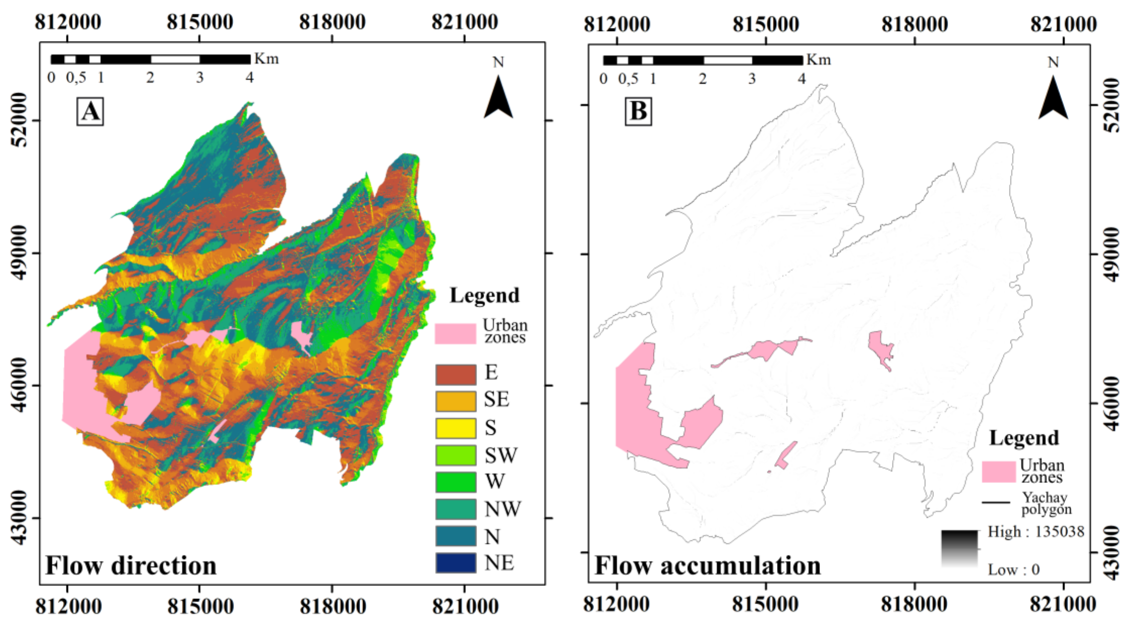


Figure 19. [A]. Flow direction map. It ranges between 1 and 255 that is the maximum value that a pixel can take into the direction of a certain flow. It is related with the slope and obtained from the slope raster map. High values shows a high flow into those cells. [B]. Flow accumulation map. Calculated based on the flow direction. It is the sum of pixel values that flows into a certain water channel. Most of the map shows a value of zero because the accumulation occurs at the ravines and zones of hydrological discharge inside the city. The pink color shows the urban areas around the Ciudad del Conocimiento.

Finally, our topographic factor map (Figure 20) where constructed by the aid of the Raster calculator in the ArcGis software by using the Moore-Burch equation. We can see a range of 0 to 118,8. The map show mostly very low values of LS-factor due to the fact that there are flat areas with lower slopes, some of them zero or near to zero. The high values of LS are located at the ravines and is inherited from the high slopes (Figure 17) and high amount of flow accumulation (Figure 19). It is normal to have those values due the slope length and steepness. The greater the length of a slope, the greater the water erosion product of the topography. The values near to zero or zero are zones of deposition of sediments, including the white areas that appear in some places of the Ciudad del Conocimiento due the low degree slope. Certainly, the most important parts where we are interested into know the work of the topographic factor is in the flattest areas dedicated mostly to agriculture around the city (Figure 3-4). Although we have lower values in these areas, it is an important factor in case of several rainfall events or in months with high amount of rain (Appendix 1-2). Having this values, we already calculate the sheet and rill erosion on cultivable soil because the action of the length and steepness of the slopes at the Ciudad del Conocimiento. The LS factor act as an enhancer of the erosivity from precipitation in the final calculation of the USLE due the to the multiplicative effect that has among the other factors (Saavedra, 2019).

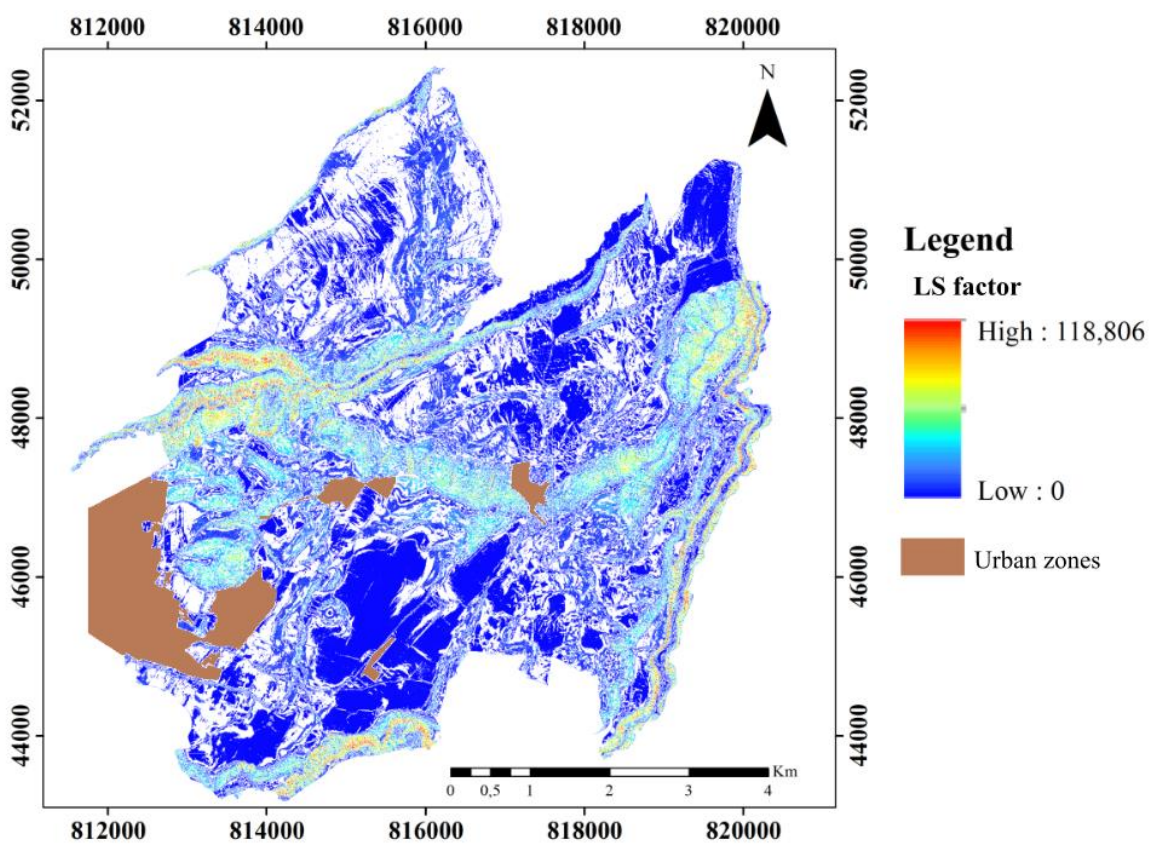


Figure 20. LS factor map. Shows the topographic influence into the erosion of the soil. It is an important factor because can enhance the action of rainfall precipitation into the soil. Following the pattern of the maps used to calculate this factor, we have higher values at the ravines where we have a high slope and a high flow accumulation. Agricultural or flattest areas shown low values of LS factor which implicates less sheet and rill erosion because the lower slope presented. The brown polygons are the urban zones in the city.

C-Factor

Cover vegetation is an important factor that control the rates of erosion in the soil due to the detachment of particles product of the impact of raindrops (Morgan, 2005). Cover vegetation is a dimensionless factor that is influenced by the natural cover vegetation, soil management and the vegetation residues obtained from agrological activities (Saavedra, 2019). The cover vegetation, therefore, study the soil loss rate in an area with ground cover (not necessary vegetation) or bare soil.

Nowadays, it is usual to use satellite imagery that takes into account the different bands of electromagnetic spectrum to interpret the coverage of the soil as mentioned in the materials and methods section. The Normalized Difference Vegetation Index (NDVI) is widespread used to estimate the quantity and even the quality of vegetation based in the radiation of certain bands in the electromagnetic spectra that vegetation emits or reflects (Saavedra, 2019). The NDVI shows the values for the Ciudad del Conocimiento based on Landsat 8 satellite imagery from November, 2016 with a resolution of 30 meters (Figure 21). The figure presents a range between: 0,023 – 0,593 which, according to Table 4, represents mainly bare sandy soil without rocks (bluish color) and small crops. There are also a good proportion of turquois and yellowish colors that are associated to values between 0,023 and 0,3 and related to bushes and grasslands for pasture. Our biggest values represented by the red color represents a high amount of vegetation but not compared to tempered forests, they could be biggest areas with agriculture purpose as harvesting of cane sugar mainly in the northern and eastern part of the study area. Figure 22 shows the values for NDVI factor differentiated according Table 4. It shows the land use at the city at November 2016 when the former Yachay Public Company was in charge of the construction of the Ciudad del Conocimiento. It is important to notice that the major part of the land have and NDVI value between 0,1 and 0,2 associated between bare soil and small crops. Most of the land were abandoned during the construction of some infrastructure and the value could be associated to small and short crops agriculture as well as weed growth as part of the abandoned land.

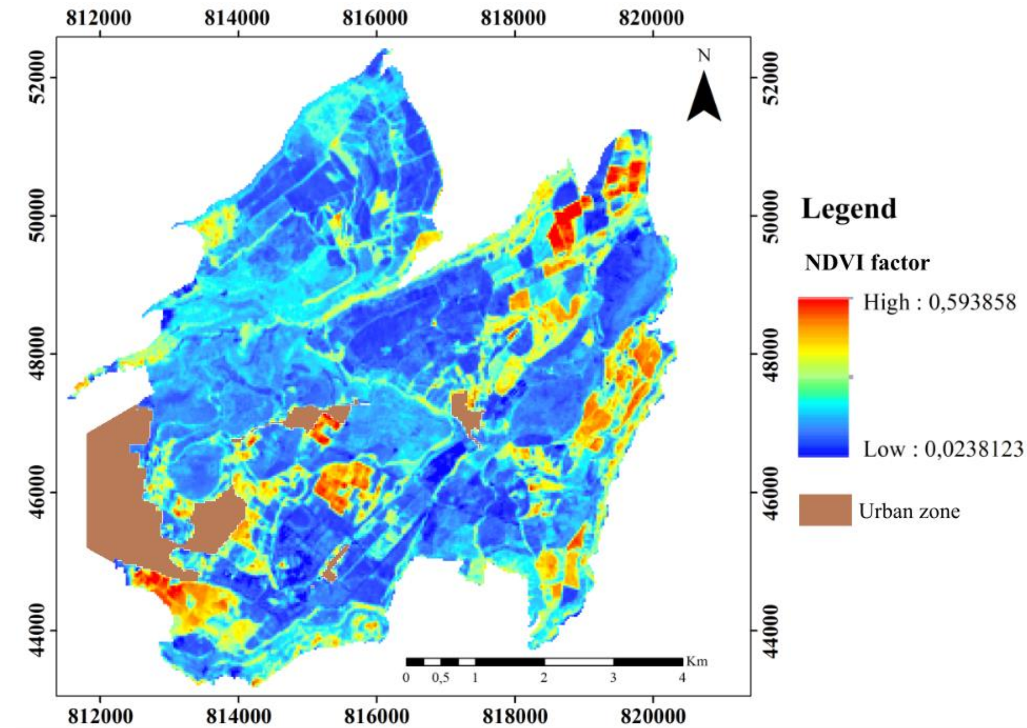


Figure 21. Normalized Difference Vegetation Index (NDVI) factor calculated from Landsat 8 satellite image from November, 2016 with a resolution of 30 meters. The values of NDVI could range from -1 to +1. Low values of NDVI shows mainly bare soil. Medium values (0,3-0,6) represents bush vegetation and grassland for pasture with other agricultural activities. The brown polygons are urban zones around the Ciudad del Conocimiento.

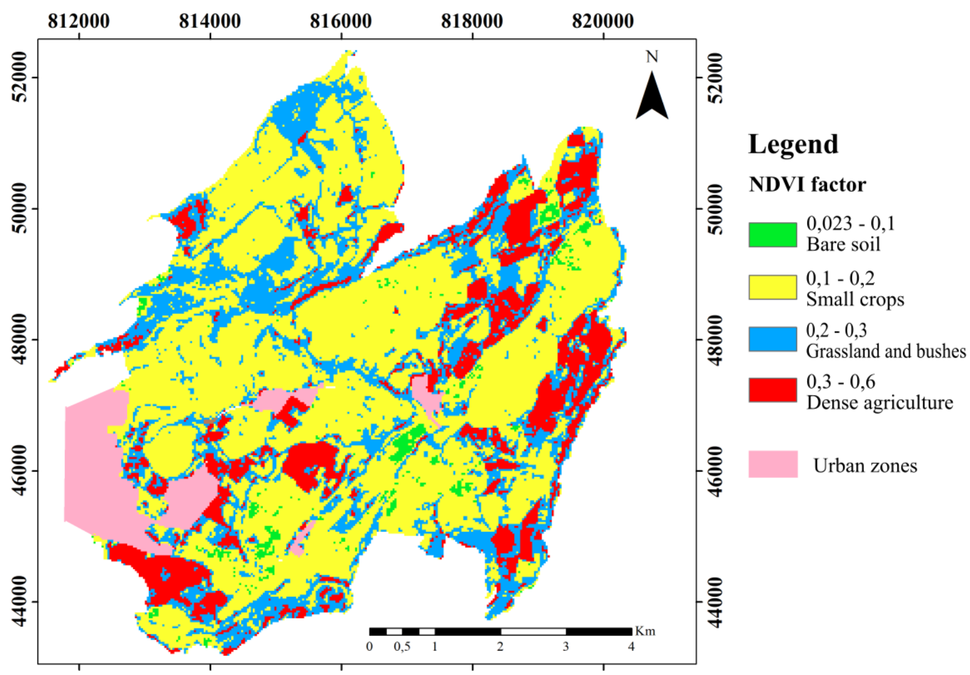


Figure 22. NDVI factor with the classification of Table 4. Green color represents bare soil, yellow color represents small crops, blue color represents grassland and bushes, in red the denser agriculture lands associated to bigger crops as cane sugar. It can be compared with land use at Figure 3 with a resolution of 30 meters all over the Ciudad del Conocimiento.

With the calculation of the NDVI values we can calculate our C-factor based on the Rouse et al. (1974) equation for the Ciudad del Conocimiento. By using the Raster calculator tool in the ArcGis software we can built our map of cover management of soil based on the Normalized Difference Vegetation Index (Figure 22). The relation between NDVI and C-factor is inversely proportional. The near the value of NDVI to 1, the near the C value to zero. This means that increasing the vegetation cover on the soil is going to decrease the erosion of soil from cover-management. In this sense we can see that the blue areas at Figure 21 are now converted in yellow-red areas (Figure 22), which is the bare-soil that has more probability to be eroded from the action of water. There are areas near to one (red color) that presents a high risk of erosion. The bluish areas are referred to zones were we have the presence of agriculture mainly. Another interesting fact is that ravines shows a lower C-value than the flat areas at the city, due to the bush vegetation presented in the ravines. Some hills present a high risk to erosion due to bare-soil.

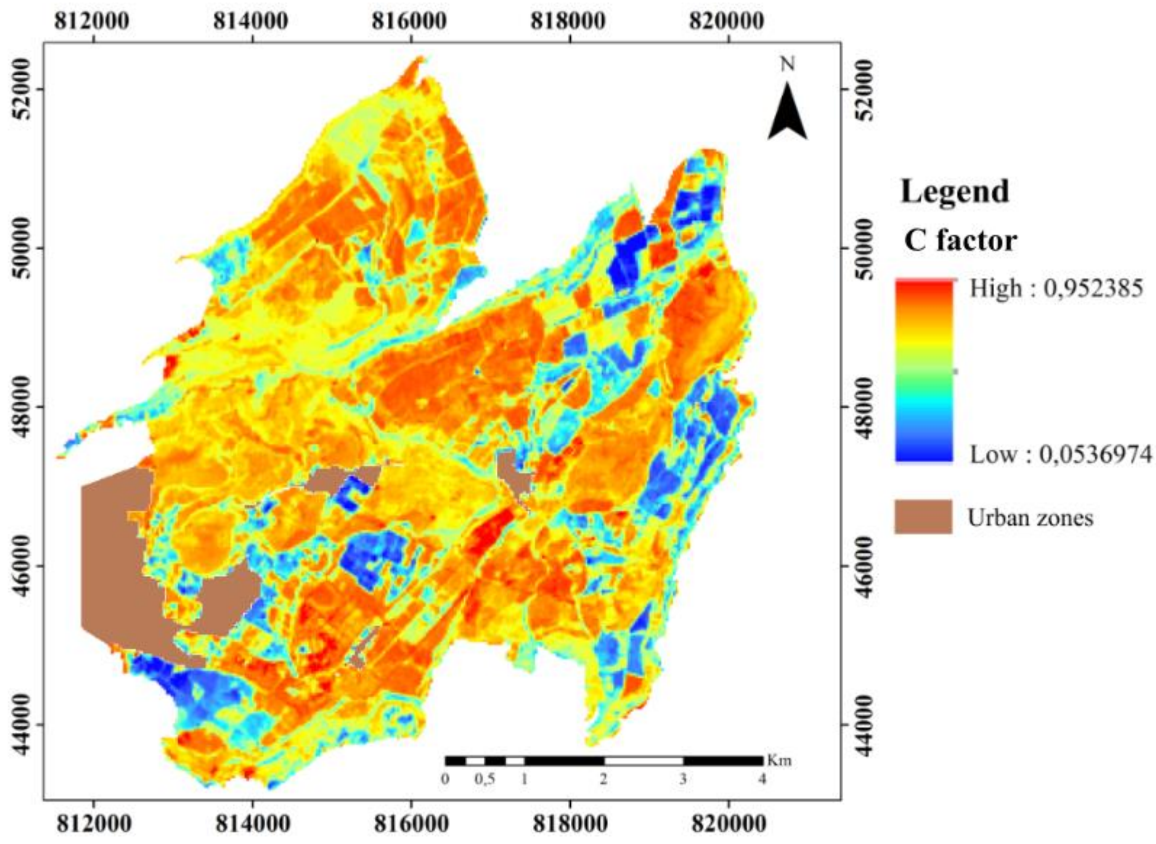


Figure 23. Cover-management factor calculated from the NDVI factor (Figure 21). The relation of both factors is inversely proportional. The near the value to one, the highest the risk to erosion in soil. Bare-soil (lower NDVI-values) present a high risk to erosion (red color). Areas with vegetation or some soil coverage (high NDVI-values) present a low risk to erosion (bluish color). The brown areas are urban zones in the city.

Parametrization of the erosion

The parametrization of erosion is very important to understand the possible rates of soil loss in a certain area. Although erosion is a natural process it could be affected by anthropogenic activity. Figure 23 shows some erosion in certain areas around the Ciudad del Conocimiento associated to anthropogenic action. For example, the erosion of the soil from the construction of a water channel. There is the occurrence of a gullies of 1m x 0,5m from the excavation of water. There are blocks of soil that are continuously eroded and where part of the soil level in the past (Figure 23A). The rain or water ditches removes the particles creating natural channels of water due the difference in the slope, an example of this is the construction of a paved pedestrian crossing in the right-side of the image that is the responsible of this erosion due to soil removal and subsequent flattening that reduces the bulk density. (Figure 23B). Erosion could be affected by a biological factor, for example the roots of the plants, although is a natural process it started because the construction of a road that exposes the roots that splits the ground. The splitting ground allows the infiltration of water creating little gullies that are going to increase in size and shape due the conditions of the soil described above (Figure 23C). Erosion could be seen in zones with low presence of people as in the Llamarada hill because this is not a very busy walking cross. The day after a rainstorm shows the formation of water channels that transport sediments for the upper part of the hill following the walking cross created by human activity in the zone. The difference from soil level is around 5-10 cm that could increase with more rain activity. There we can see the effect of vegetation in the erosion, the areas with vegetation cover do not show the effect of the rainstorm while the bare soil is the one that presents erosion (Figure 23D). The occurrence of gullies and the detachment of soil pieces (in yellow color) from the instability of the soil is a common result of erosion. This factor was created by the construction of a side walk and an access road to the student residences at Yachay Tech University. Also we can notice the low development of the soil with no recognition of any horizon in the soil (Figure 23E).

The visual evidence suggest that the anthropogenic activity has its influence into the erosion rates at the Ciudad del Conocimiento. Also, the bad agricultural practices and the farmland abandonment increase the soil deterioration at the city.

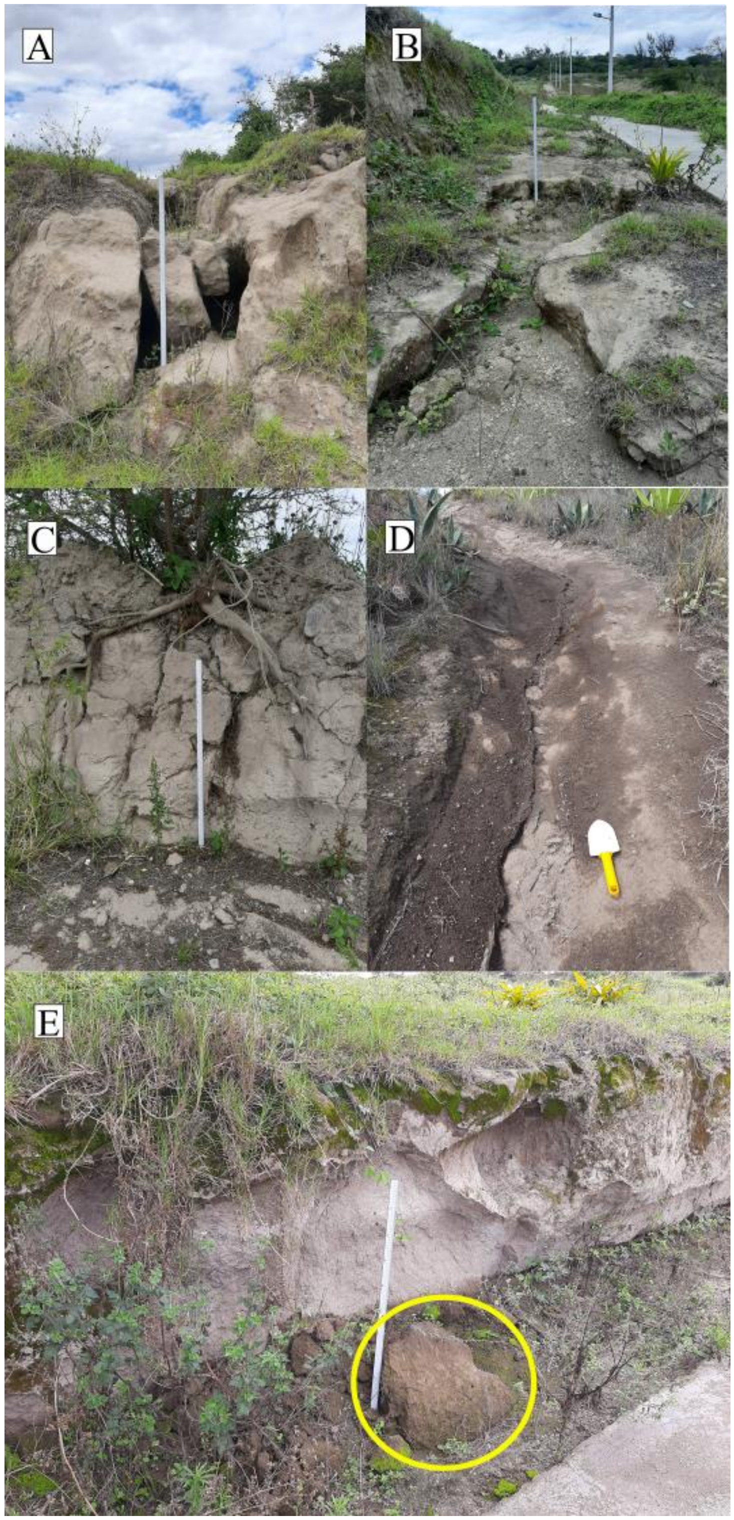


Figure 24. Erosion associated to anthropogenic activity. [A] Erosion of soil from the construction of a water channel. [B] Erosion of soil from the action of water and the construction of a paved pedestrian crossing in the right-side. [C] Plant erosion from the action of plants' roots and the occurrence of little gullies. [D] Erosion near a walking cross in the Llamarada hill the day after a rainstorm. [E] Occurrence of gullies and the detachment of soil pieces (yellow circle) from the instability of the soil.

The present work develops a way to estimate the rates of erosion at the Ciudad del Conocimiento. The importance of parametrization, more than an important knowledge achieved, is the tools that generate to create conservation practices for agriculture, construction and maintenance. The final product of developing the different parameters of the Universal Soil Loss Equation is the quantification of erosion in mega-grams per hectare per year $\left(\frac{Mg}{ha \cdot year}\right)$. The following map (Figure 24) show the erosion rates in the Ciudad del Conocimiento calculated using the USLE method. The erosion rates at the city ranges from 0 – 3853,35 $\left(\frac{Mg}{ha \cdot year}\right)$. The lower rates of erosion are located in the flattest zones around the city while the higher rates are located at hill and ravines (Figure 25). The media value of erosion is around 183,44 $\pm$ 282,97 $\left(\frac{Mg}{ha \cdot year}\right)$ which suggests erosion tends to low values rather than to high values. Lower values or near to zero could be associated to zones of deposition of sediments from places with high altitude. From Figure 24 we can infer that soil loss increases with altitude on one hand and due to high slopes on the other. The most important information that might be required is what happens in the flattest zone were we have agriculture. FAO, PNUMA, UNESCO (1979) develop a description (Table 8) for the levels of erosion in a certain area. With this we can now tell the areas that present high erosion rates inside the agricultural areas. Comparing Figure 24 with Figure 3 we can notice that we have a rate of erosion between 0 – 300 $\left(\frac{Mg}{ha \cdot year}\right)$ in land dedicated mainly to sugar cane harvesting in combination with short-cycle crops. The agricultural areas show a wide range from none erosion to very high, which is a problem in itself. Figure 3 shows a dark green stripe in the middle of the city associated to sowing of corn in eroded areas, what is proved by our analysis of erosion that presents erosion from 300 $\left(\frac{Mg}{ha \cdot year}\right)$ henceforth, very high erosion rate. The maps derived from the Plan de Desarrollo y Ordenamiento Territorial de Urcuquí 2011 – 2031 (Figure 3, 7, 8) shows an eroded zone at the east of the map where la Ensillada and Chusquilla hills are located and that match with our analysis of erosion. Figure 7 (Land use conflict) shows certain areas marked with O+ that are severely exploited areas for agriculture; comparing it with Figure 24, these areas are in blue to turquois colors where we have an erosion rate between 50 – 200 $\left(\frac{Mg}{ha \cdot year}\right)$. It is a high to very high level of erosion that could be associated with the low amount of organic matter presented in the soil, which makes it more vulnerable to become infertile than the rate of erosion or combined with it.

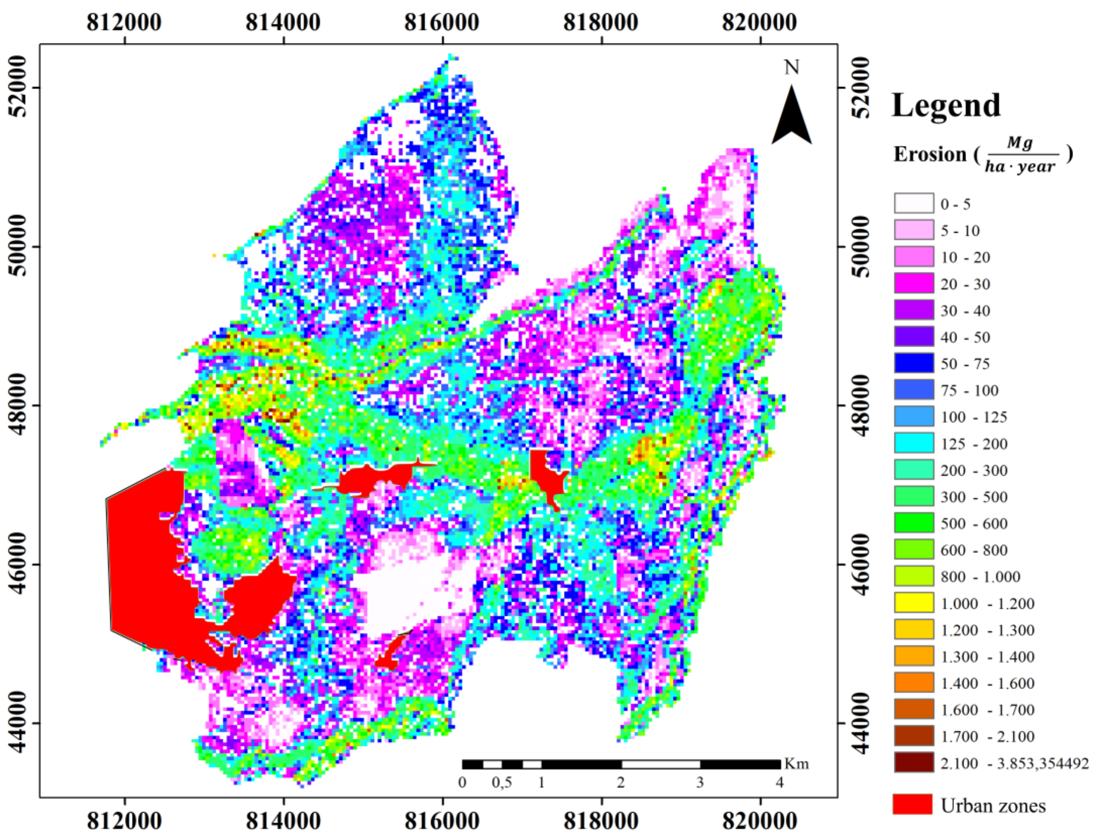


Figure 25. Soil erosion map by using USLE method. The erosion rates ranges from zero to 3853 $\left(\frac{Mg}{ha \cdot year}\right)$*. Zones with low or near to zero rate of erosion are mainly associated to zones of deposition of sediments. The highest values of erosion are presented in the hills and ravines around the Ciudad del Conocimiento. The zones dedicated to agriculture (mainly flat zones) have an erosion rate between 0 – 300* $\left(\frac{Mg}{ha \cdot year}\right)$*.*

Table 8. Description developed by FAO, PNUMA & UNESCO (1979) for the levels of soil erosion.

Level of erosion	$Mg \cdot ha^{-1} \cdot year^{-1}$
None or low	< 10
Moderate	10 – 50
High	50 – 200
Very high	> 200

We can also associate the levels of erosion with the description of places at the Cuidad del Conocimiento to understand spatially the location of areas with certain rate of erosion (Figure 25). As mentioned before, ravines show the highest rates of erosion due to the slope degree. Although the presence of bush vegetation at ravines could protect the soil from the action of the other factors, it is certainly affected by the slope mainly. Hills also shows a high rate of erosion, mainly La Ensillada and La Chusquilla hill located at the east part of the study area. This erosion is not provoked by the action of water, but by little or none vegetation combined with the high degree slope. This shows how each factor acts proportionally to give an idea of the erosion. The zone of Urcuquí is not located in the map, although the zones near to Urcuquí city present a medium to high level of erosion as all the agricultural zones in the Ciudad del Conocimiento. Yachay Tech University located in the former San José estate shows the same pattern of erosion as the flattest zones described above, with a tendency to become the rate of erosion even higher to the north.

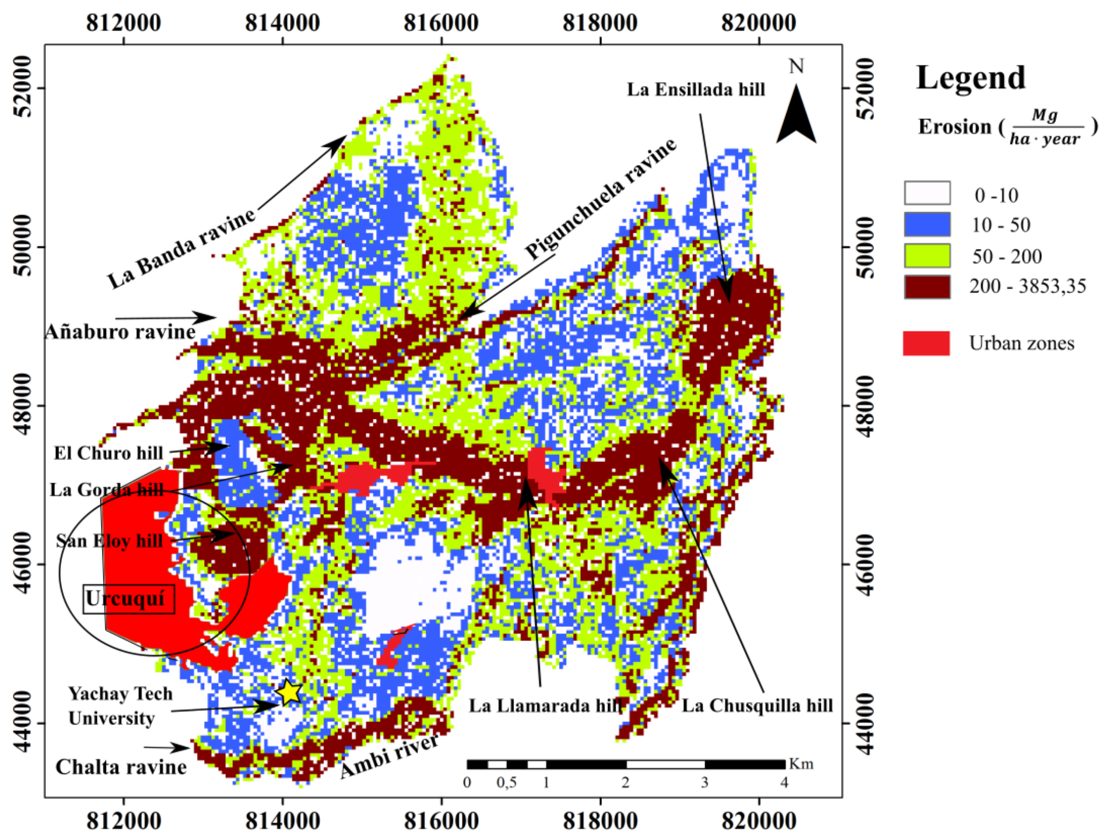


Figure 26. Map of the erosion levels at the Ciudad del Conocimiento according the level of erosion described by FAO, PNUMA & UNESCO (1979) labeled with the main geomorphological structures that show the highest levels of erosion and the location of Urcuquí city and Yachay Tech University which show medium to high levels of erosion.

The rates of erosion seem to match with another maps that describes the land use and the land use conflict in the Urcuquí canton. This suggests that the analysis of erosion has its own validity. However, the USLE method has their own limitations based on the validation of the data used. In order to know the real rate of erosion it is needed to do field calculations of simulation of rain in different orders of soils to know empirically the amount of sediment carried by precipitation. Another important factor to take into account is the amount of ditches created to transport water that can erode the shallow and deep soil. This factor does not depend on the amount of precipitation but on the amount of water that is transported to different areas in the city to maintain agriculture. The creation of ditches and water channels is a continuous anthropological disturbance of the soil that mobilize sediments from the upper parts of the Ciudad del Conocimiento, near Urcuquí city, to the lower parts of the city at the northern limits with the Ibarra canton (Figure 2).

Comparing the result of field calculations and the ones calculated using the USLE method we can assess the validity of the data. The data limitation could impact the final calculation of erosion, not only the lack of ground precipitation data; also the spatial and temporal resolution of the data given for the construction of some factors as well as the date of retrieval might influence into the spatial analysis for example. Nonetheless, the data used for the parametrization of erosion is intended to be accurate for a 34 years of average precipitation data for a study zone with a slope resolution degree of 3 meters with a sandy loamy texture of soil and calculated for a vegetation coverage from one satellite image from November, 2016.

5. CONCLUSIONS

1) The rainfall-runoff erosivity factor or R characterize the energy of rain on a certain area with a known precipitation. The method used allows to predict the value of R for the Ciudad del Conocimiento area from the Modified Fourier Index. The data shows an influence of the altitude in the amount of rain, being the highest areas the ones that present more precipitation and therefore a high amount of erosivity than the lower zones. The map shows a decrease pattern of R-factor from west to east according the altitudinal gradient and the data of precipitation used.

2) The soil erodibility factor or K take into account the variations in the soil from a granulometric point of view and the amount of organic matter. The laboratory studies of the different factors yield as a result the low amount of organic matter presented in the soil which is a problem in itself for agriculture. Another important result is the amount of sand presented in the soil. More than 50% of sand in all the samples taken, which depending on the size of sand could be very susceptible for erosion combined with low aggregated clay. The result shows a widespread value of soil erodibility factor depending on the area of the sample. The higher values have a great influence in the final calculation of erosion because of the direct proportionality of the factor with the erosion.

3) The slope-steepness factor or LS describes the influence of the slope into the erosion. In fact, we can see that areas with high degree of slope shows a high value of LS. The low or flat areas present a value near to zero, which does not mean that it is protected from erosion with vegetation cover, for example. This value shows a direct proportionality of the slope and the risk of erosion. With the aid of a Digital Elevated Model it is easier to construct a model that depends on the resolution of the map. The available DEM have a resolution of 3 meters which help to have a correct idea of the slopes in the Ciudad del Conocimiento.

4) The cover-management factor or C describes the influence of vegetation cover into the erosion risk. It is the only factor of the equation that is inversely proportional to erosion. The more the amount of coverage on the soil, the less the erosional risk. Suddenly, the Landsat 8 imagery shows a high risk for erosion due to the amount of bare soil in the City. Most of the areas present this problem in the city, and independently of the degree of the slope this soil can be affected by heavy rainstorms.

5) Parametrization of soil is needed to understand that erosion is a problem in lands dedicated for agriculture and we must protect the soil before we have to recover it. The visual evidence suggests that the land in the Ciudad del Conocimiento is greatly affected by human activity, not only because of the construction of the city but also because of agricultural practices and the abandonment of agricultural areas.

6) The result of the application of the USLE method to the parametrization of soil losses in the Ciudad del Conocimiento yields convincing results for the purposes of the proposed study but not for soil conservation in the city. The results show a rate of erosion between 0 – 3853,35 $\left(\frac{Mg}{ha \cdot year}\right)$. The codification used to understand the erosion rates dictates that from a soil loss bigger than 50 $\left(\frac{Mg}{ha \cdot year}\right)$ we have a high level of erosion. The media of the city ranks in 183,44 $\left(\frac{Mg}{ha \cdot year}\right)$ which suggest that the city is in high to very high risk of erosion. We have the highest values of soil loss in places with a high slope degree as hills and ravines, while the lowest values of soil loss appear on the flattest zones of the city that are mainly dedicated to agriculture. Lower values also can describe a risk of erosion as mentioned before.

6. RECOMENDATIONS

1) Some limitations are presented due to the method used to calculate erosion rates, however the data can be validated by comparing the results with the information retrieved from other maps as the Plan de Desarrollo y Ordenamiento Territorial Urcuquí 2011 – 2031. It is recommended to create further field studies to understand the real behavior of soil in order to compare with the data presented in this work.
2) The calculation of USLE method takes into account a conservation factor that was not calculated because the absence of conservation practices in the study zone. They have to be taken into account if the authorities decide to protect the land that is actually eroded. Inside the Ciudad del Conocimiento are areas that were and are being intervened for the construction of civil works such as buildings, sewers, access roads and houses, among others, mainly for the construction of the University Yachay Tech. It is recommendable to create soil protection plans that include the:
    a. Conservation and augmentation of vegetation coverage with native plant that do not require high amount of water for growing.
    b. Conservation of the original slopes in the construction of new infrastructure for the city and the University. This would maintain the natural water courses and it would avoid the appearance of gullies on the artificial slopes.
    c. Improve irrigation and garden maintenance system that currently erode the soil much more due to the high flow used.
    d. Avoid the peeling of parcels of land, removing the fertile layer and also increasing the risk of erosion due to abandonment of these same areas.
3) In the case of agriculture, it is recommendable to have another farming practices that avoid the erosion of the actual soil (Nova Scotia Farm Plan, n.d.), for example:
    a. Contouring farming.
    b. Cross-slope farming.
    c. Terracing farming.
    d. The construction of water channels to transport water from the higher zones.
    e. Mulching and cover cropping.
    f. Crop rotation.

7. FIGURE INDEX

8. TABLE INDEX

9. EQUATION INDEX

10. APPENDIX

Appendix 1. Annual average precipitation at the Ciudad del Conocimiento from 1981 – 2015 in millimeters.

	-78,2000	-78,1500	-78,1000
0,375000	56,9304	47,8651	57,1514
0,425000	70,1449	59,3140	53,1156
0,475000	66,9085	53,9430	39,9787

Appendix 2. Monthly average precipitation in la Ciudad del Conocimiento from 1981 – 2015 in millimeters.

January			
	-78,2000	-78,1500	-78,1000
0,375000	60,8286	35,6071	49,1614
0,425000	94,0611	66,4525	52,5460
0,475000	97,7970	75,8851	57,7968
March			
	-78,2000	-78,1500	-78,1000
0,375000	90,0382	78,0733	85,4835
0,425000	112,8480	91,4321	78,3345
0,475000	109,6900	86,5543	69,8704
May			
	-78,2000	-78,1500	-78,1000
0,375000	66,0787	53,7254	65,5319
0,425000	66,8450	71,2958	65,2100
0,475000	75,3402	78,9308	66,5548
July			
	-78,2000	-78,1500	-78,1000
0,375000	14,7019	14,5494	26,8007
0,425000	18,4740	17,9635	22,1980
0,475000	17,5709	16,4529	13,0330
September			
	-78,2000	-78,1500	-78,1000
0,375000	31,2883	20,5262	28,8871
0,425000	38,3734	35,9209	33,4692
0,475000	38,4015	36,6327	27,0045
November			
	-78,2000	-78,1500	-78,1000
0,375000	73,4028	68,2934	70,4992
0,425000	82,1995	69,7179	65,7218
0,475000	77,1751	60,2863	52,3800

February			
	-78,2000	-78,1500	-78,1000
0,375000	61,9260	54,9700	63,6533
0,425000	84,6329	68,4562	53,8370
0,475000	73,5690	51,2492	20,6677
April			
	-78,2000	-78,1500	-78,1000
0,375000	102,1710	87,8771	95,7677
0,425000	110,3080	97,4201	86,0868
0,475000	106,3400	84,1389	62,0150
June			
	-78,2000	-78,1500	-78,1000
0,375000	32,4462	35,3310	43,9229
0,425000	30,4199	35,5191	38,1376
0,475000	22,6912	22,1260	19,0637
August			
	-78,2000	-78,1500	-78,1000
0,375000	15,9200	11,9148	20,5234
0,425000	13,9561	16,5834	19,4214
0,475000	14,1151	15,8765	14,0535
October			
	-78,2000	-78,1500	-78,1000
0,375000	64,0052	60,9465	71,5338
0,425000	75,3223	67,1273	66,8840
0,475000	67,4580	55,4932	40,0241
December			
	-78,2000	-78,1500	-78,1000
0,375000	70,3579	52,5676	64,0523
0,425000	114,2990	73,8789	55,5412
0,475000	102,7550	63,6903	37,2807

Appendix 3. GPS information of the 32 samples around the Ciudad del Conocimiento

GPS Point	Code	Zone	Longitude	Latitude	Altitude
1	Ands-01	17 N	813861	48566	2099
2	Ands-02	17 N	813595	48489	2132
3	Ents-001	17 N	814684	50319	2012
4	Ents-002	17 N	813552	49244	2086
5	Ents-003	17 N	815485	49455	1970
6	Ents-004	17 N	813060	45370	2224
7	Ents-005	17 N	814251	44896	2117
8	Ents-006	17 N	813567	44511	2150
9	Ents-007	17 N	813461	43620	2119
10	Ents-008	17 N	814645	44048	2086
11	Ents-009	17 N	815402	44302	2059
12	Ents-010	17 N	815947	44965	2025
13	Ents-011	17 N	814252	46444	2156
14	Ents-012	17 N	817418	48901	1817
15	Ents-013	17 N	816991	45491	1993
16	Ents-014	17 N	815740	45636	2037
17	Ents-015	17 N	815542	46456	2055
18	Ents-016	17 N	819193	50613	1735
19	Ents-017	17 N	819053	49661	1724
20	Ents-018	17 N	818384	44548	1913
21	Ents-019	17 N	818721	46163	1871
22	Ents-020	17 N	817649	46158	1960
23	Ents-021	17 N	818101	47921	1828
24	Olls-01	17 N	813534	47127	2334
25	Olls-02	17 N	812841	47070	2324
26	Olls-03	17 N	813102	46224	2312
27	Olls-04	17 N	813478	46302	2339
28	Olls-05	17 N	814421	47144	2204
29	Olls-06	17 N	813981	47363	2263
30	Olls-07	17 N	818997	47472	1915
31	Olls-08	17 N	819435	48387	empty
32	Olls-09	17 N	819800	49056	empty

Appendix 4. Values for the calculation of the percent of sand, silt and clay for the soil structure.

Sample	Weight (g)	Sand (mm)	Silt (mm)	Clay (mm)	Longitude (mm)	%sand	%silt	%clay
Ents-001	291,06	97	38	8	143	67,83	26,57	5,59
Ents-002	253,96	98	34	7	139	70,50	24,46	5,04
Ents-003	280,45	97	43	7	147	65,99	29,25	4,76
Ents-004	291,06	105	41	6	152	69,08	26,97	3,95

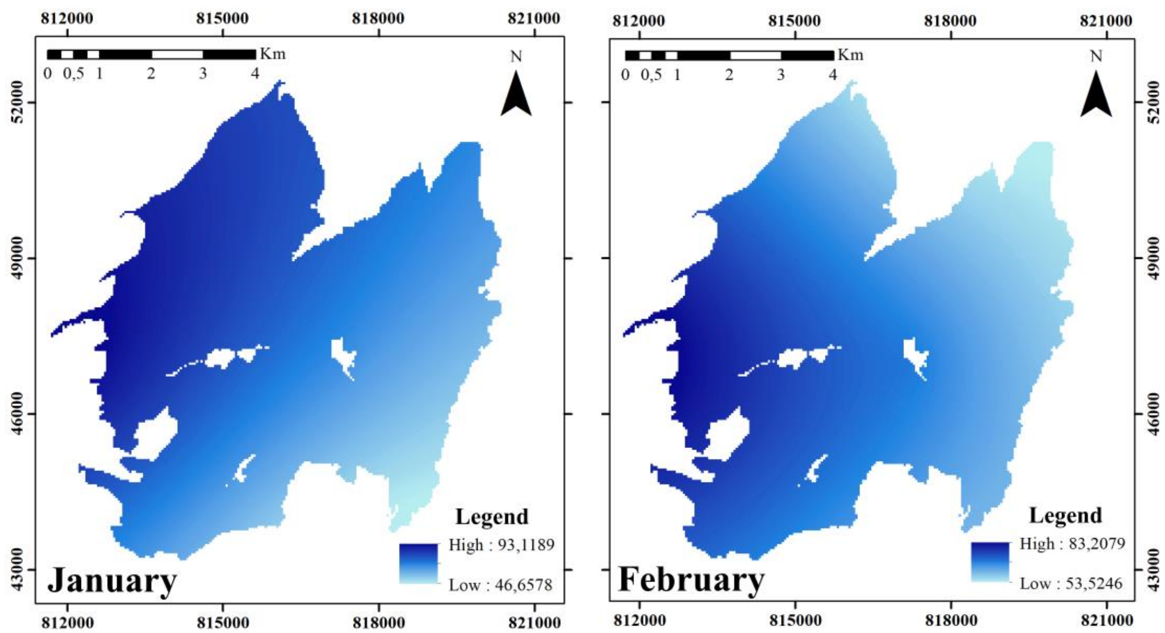
Ents-005	246,45	93	45	8	146	63,70	30,82	5,48
Ents-006	238,44	77	38	6	121	63,64	31,40	4,96
Ents-007	225,09	56	32	5	93	60,22	34,41	5,38
Ents-008	247,94	53	29	11	93	56,99	31,18	11,83
Ents-009	219,62	62	28	2	92	67,39	30,43	2,17
Ents-010	251,83	67	33	5	105	63,81	31,43	4,76
Ents-011	149,97	45	22	4	71	63,38	30,99	5,63
Ents-012	152,96	45	25	6	76	59,21	32,89	7,89
Ents-013	152,13	54	18	3	75	72,00	24,00	4,00
Ents-014	154,21	37	32	8	77	48,05	41,56	10,39
Ents-015	154,08	46	22	3	71	64,79	30,99	4,23
Ents-016	152,55	37	20	2	59	62,71	33,90	3,39
Ents-017	151,65	46	12	2	60	76,67	20,00	3,33
Ents-018	153,68	32	15	17	64	50,00	23,44	26,56
Ents-019	158,24	45	31	3	79	56,96	39,24	3,80
Ents-020	154,77	47	7	3	57	82,46	12,28	5,26
Ents-021	154,56	54	28	3	85	63,53	32,94	3,53
Olls-01	150,65	39	24	17	80	48,75	30,00	21,25
Olls-02	156,59	44	24	10	78	56,41	30,77	12,82
Olls-03	151,16	42	18	14	74	56,76	24,32	18,92
Olls-04	150,7	50	20	11	81	61,73	24,69	13,58
Olls-05	151,31	35	12	13	60	58,33	20,00	21,67
Olls-06	151,1	51	12	6	69	73,91	17,39	8,70
Olls-07	151,99	49	10	7	66	74,24	15,15	10,61
Olls-08	150,18	40	12	6	58	68,97	20,69	10,34
Olls-09	154,49	41	11	8	60	68,33	18,33	13,33
Ands-01	152,71	44	23	13	80	55,00	28,75	16,25
Ands-02	150,82	46	17	8	71	64,79	23,94	11,27

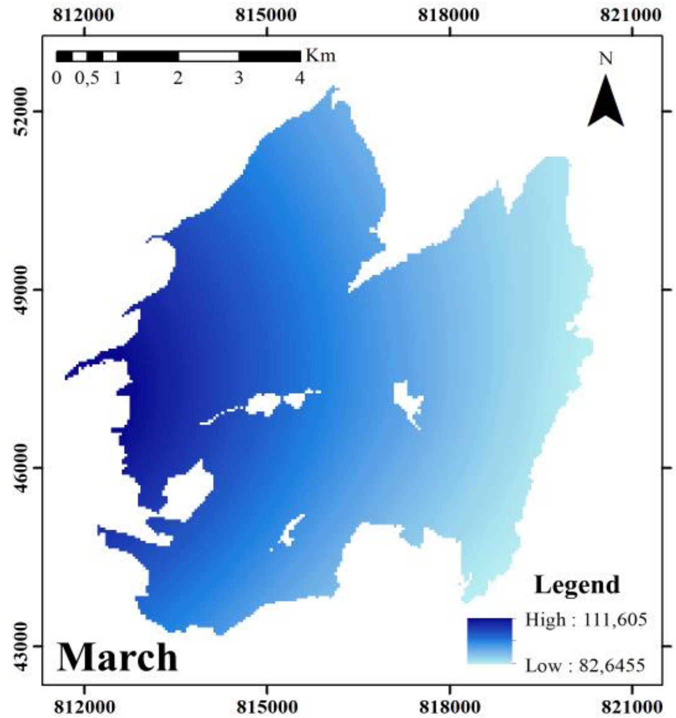
Appendix 5. Data obtained for the calculation of the Organic Mater

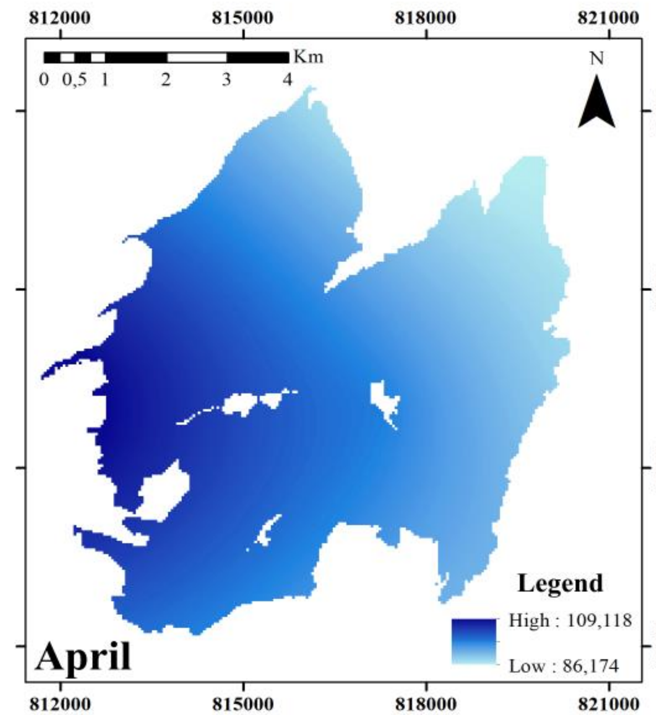
Sample	Crucible weight (g)	Crucible weight + sample (g)	Dry Weight at 105 (g)	Dry Weight at 550 (g)	Difference of weight (g)	LOI at 550
Ents-001	36,5837	46,7959	46,5703	46,3050	0,2653	0,57
Ents-002	44,9140	55,0725	54,8004	54,3993	0,4011	0,73
Ents-003	47,5106	57,8750	57,6934	57,4018	0,2916	0,51
Ents-004	48,1324	58,5842	58,3851	58,1166	0,2685	0,46
Ents-005	45,7880	56,0434	55,6979	55,2350	0,4629	0,83
Ents-006	45,3801	55,3846	55,1075	54,6310	0,4765	0,86
Ents-007	46,7428	57,0761	56,0667	55,7367	0,3300	0,59
Ents-008	47,9217	58,2051	57,2490	57,0222	0,2268	0,40
Ents-009	46,0681	56,4445	55,8333	55,3948	0,4385	0,79
Ents-010	45,0203	55,1940	54,7205	54,4040	0,3165	0,58

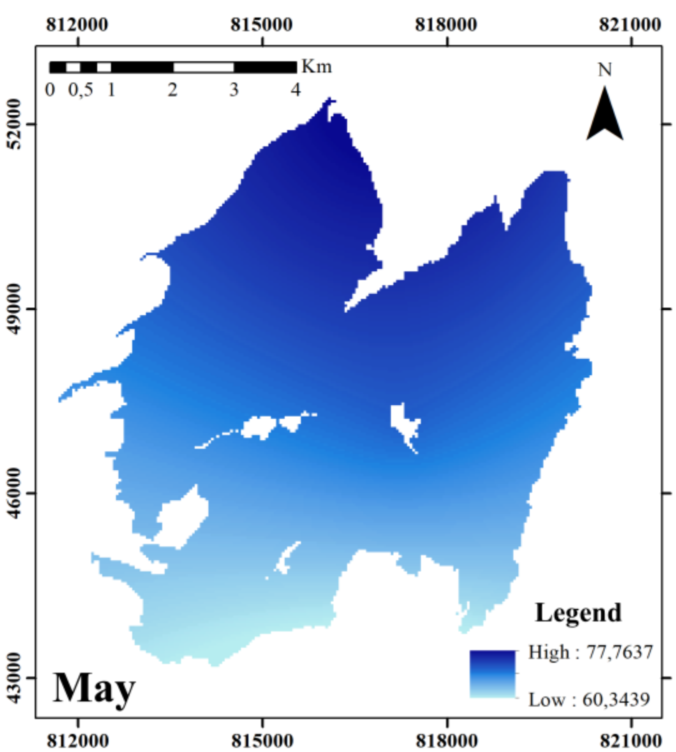
Ents-011	45,9459	56,1914	55,0463	54,7004	0,3459	0,63
Ents-012	39,2069	49,2531	48,4478	47,9945	0,4533	0,94
Ents-013	46,0689	56,0682	55,2645	54,9287	0,3358	0,61
Ents-014	44,9146	55,3025	53,5578	53,2786	0,2792	0,52
Ents-015	47,5108	57,5548	56,5973	56,2855	0,3118	0,55
Ents-016	48,1326	58,6117	57,2614	56,8984	0,3630	0,63
Ents-017	45,7881	55,9573	54,3682	54,0542	0,3140	0,58
Ents-018	45,3813	55,4734	54,7526	54,4914	0,2612	0,48
Ents-019	46,7433	56,9195	55,1145	54,6623	0,4522	0,82
Ents-020	47,9224	58,0552	57,5824	57,3737	0,2087	0,36
Ents-021	46,0693	56,1322	54,2692	53,7477	0,5215	0,96
Olls-01	39,2057	49,4432	49,2198	48,8735	0,3463	0,70
Olls-02	36,5820	46,7542	46,5779	46,2816	0,2963	0,64
Olls-03	44,9138	55,0830	54,9393	54,6614	0,2779	0,51
Olls-04	47,5105	57,7307	57,4981	57,1403	0,3578	0,62
Olls-05	48,1326	58,1578	57,3993	57,1510	0,2483	0,43
Olls-06	45,7886	55,8414	55,6478	55,3285	0,3193	0,57
Olls-07	45,3808	55,6728	54,6548	54,2372	0,4176	0,76
Olls-08	46,7427	56,8422	55,9536	55,6416	0,3120	0,56
Olls-09	47,9222	58,0762	57,3533	57,1040	0,2493	0,43
Ands-01	45,0218	55,1704	54,8946	54,4622	0,4324	0,79
Ands-02	45,9466	55,9996	55,7719	55,4547	0,3172	0,57

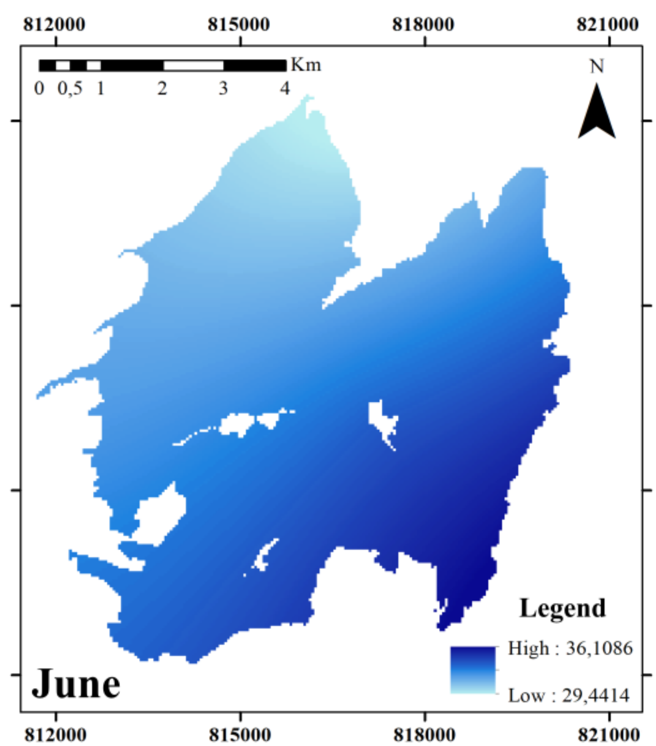
Appendix 6. Monthly precipitation in millimeters for the Ciudad del Conocimiento interpolated using Kriging interpolation.

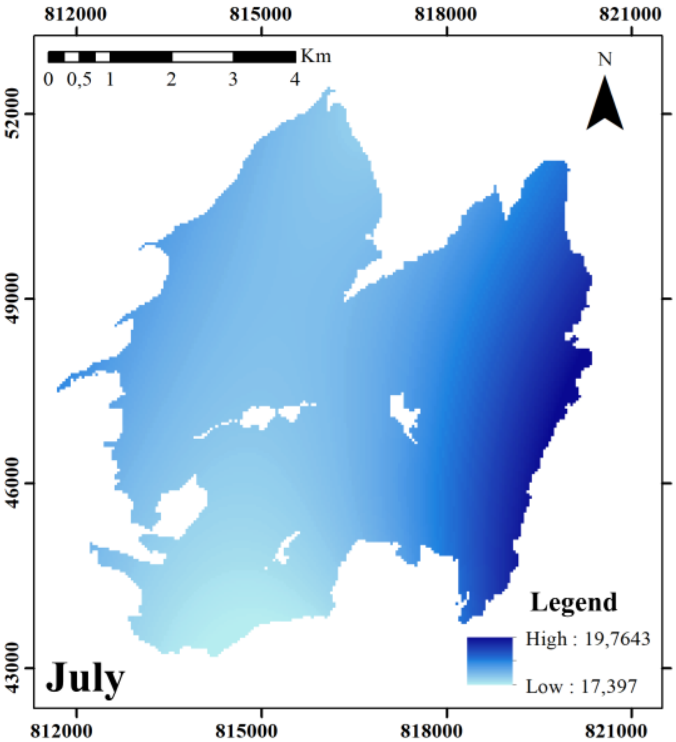


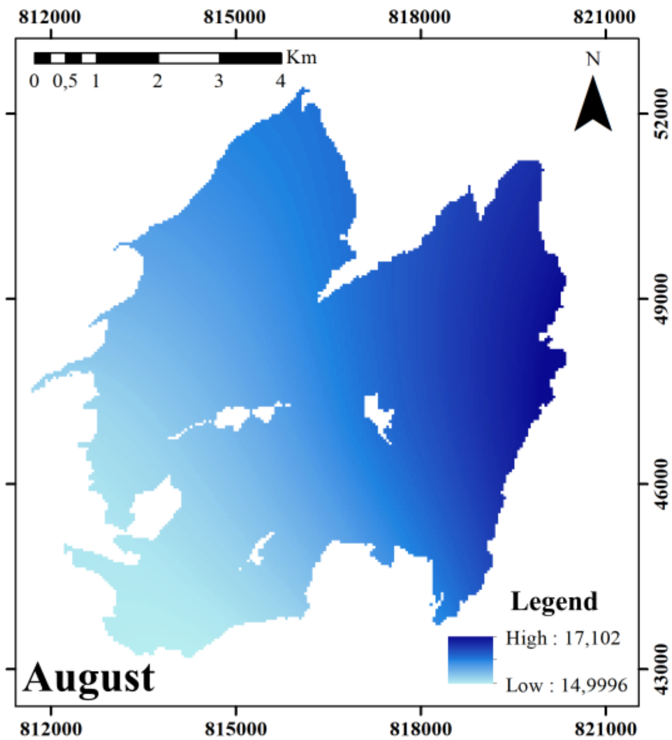

812000
815000
818000
821000
Km
0 0,5 1 2 3 4
N
52000
49000
46000
43000
Legend
High : 111,605
Low : 82,6455
March

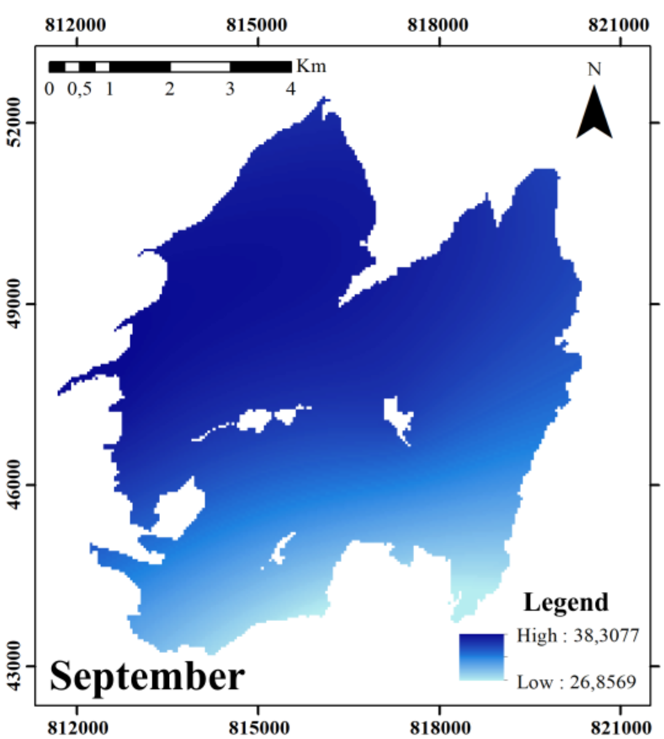

812000
815000
818000
821000
Km
0 0,5 1 2 3 4
N
52000
49000
46000
43000
Legend
High : 109,118
Low : 86,174
April

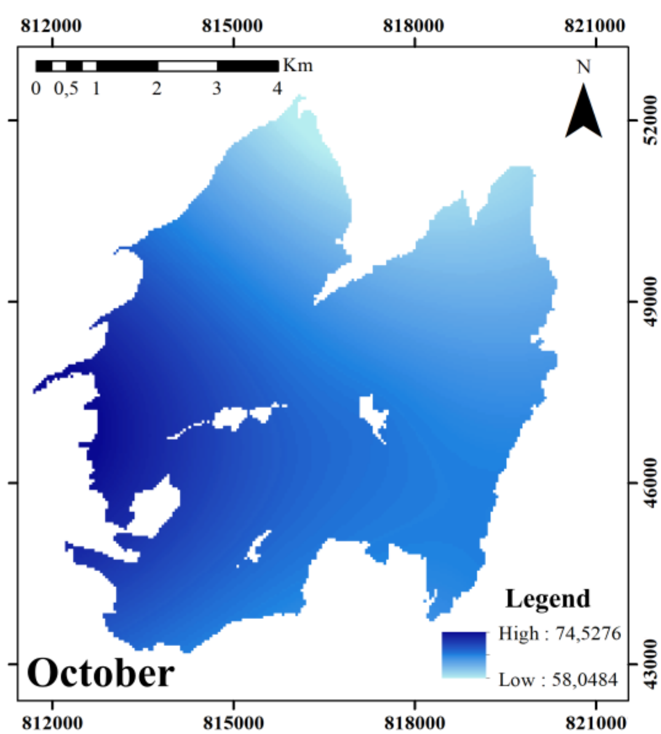

812000
815000
818000
821000
Km
0 0,5 1 2 3 4
N
52000
49000
46000
43000
Legend
High : 77,7637
Low : 60,3439
May

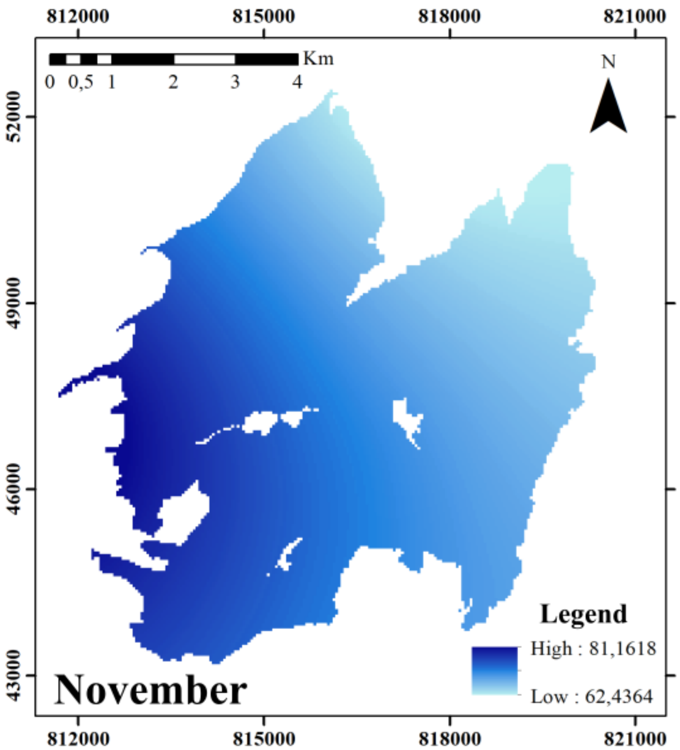

812000
815000
818000
821000
Km
0 0,5 1 2 3 4
N
52000
49000
46000
43000
Legend
High : 36,1086
Low : 29,4414
June

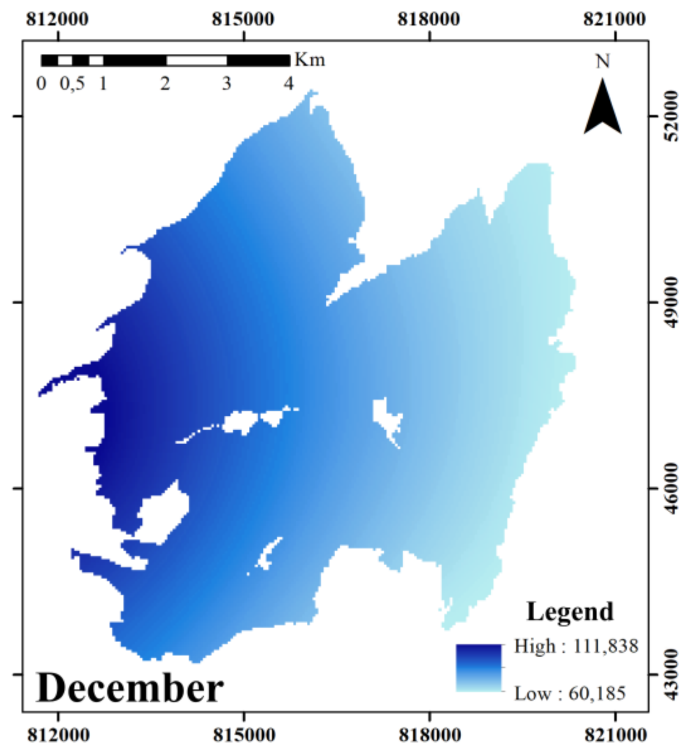

812000
815000
818000
821000
Km
0 0,5 1 2 3 4
N
52000
49000
46000
43000
Legend
High : 19,7643
Low : 17,397
July


812000
815000
818000
821000
Km
0 0,5 1 2 3 4
N
52000
49000
46000
43000
Legend
High : 17,102
Low : 14,9996
August

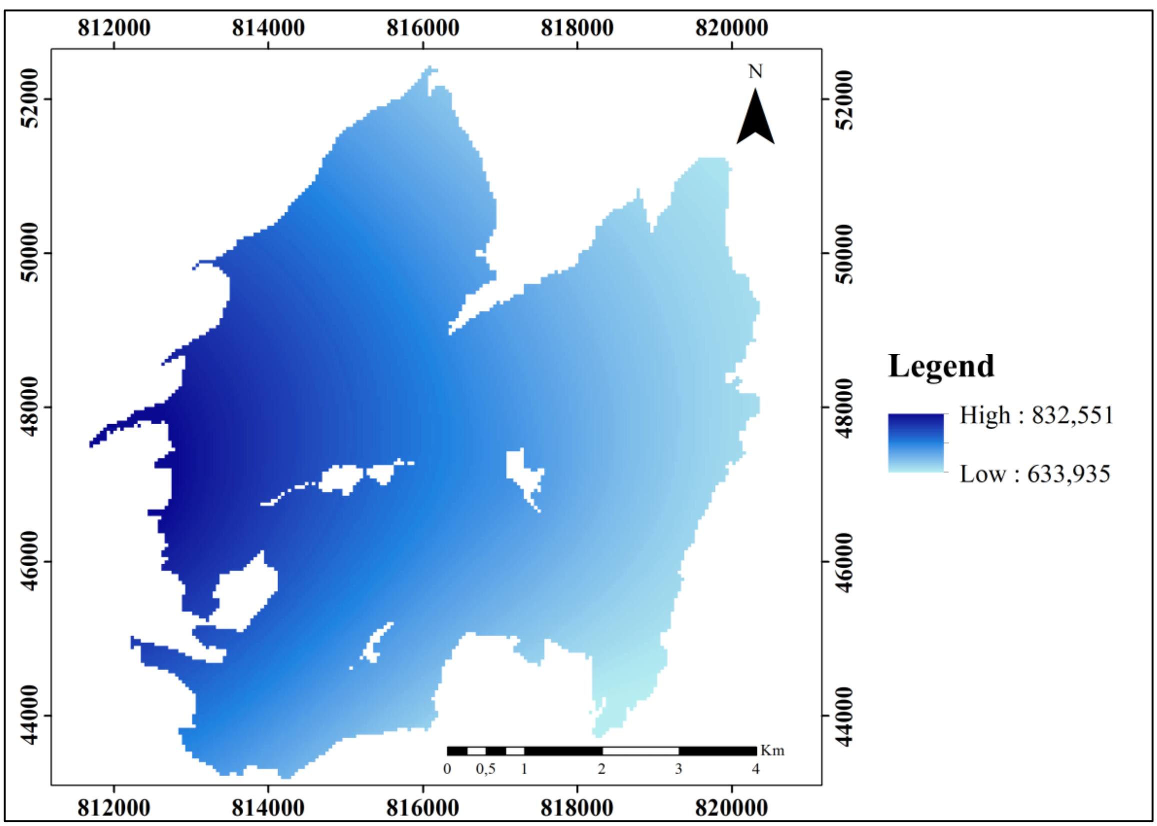

812000
815000
818000
821000
Km
0 0,5 1 2 3 4
N
52000
49000
46000
43000
Legend
High : 38,3077
Low : 26,8569
September


812000
815000
818000
821000
Km
0 0,5 1 2 3 4
N
52000
49000
46000
43000
Legend
High : 74,5276
Low : 58,0484
October





Appendix 7. Annual precipitation in millimeters at the Ciudad del Conocimiento interpolated using Kriging interpolation.



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