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Methodology for the Calculation of the Runoff Coefficient with the Arrangement Tirado

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Abstract

For this research work, an adequate methodology was sought for the calculation of the runoff coefficient with the Tirado arrangement. To achieve this, first, the variables that affect the runoff coefficient were identified, then the model was described with the Tirado arrangement, and as a third part for the calculation of the runoff coefficient, the Tirado model is proposed. From the theory for the calculation of the runoff coefficient, the equation of the weighted coefficients and the expression of Nadal were manipulated, resulting in the following relationship $C = \frac{C_1 + C_2 + \cdots + C_n}{0.25 * I}$, considering this as the expression for the arrangement Tirado. The expression is tested $C = \frac{C_1 + C_2 + \cdots + C_n}{0.25 * I}$ with different intensities, the magnitudes correspond to 150, 200, 250 and 300 mm/hrs, resulting in runoff coefficient 0.82, 0.87, 0.89, 0.91 respectively. This means that, the higher the intensity, the runoff coefficient will be higher, logically the characteristics of the basin affect that this coefficient has variation in the space studied.

Keywords

Runoff Coefficient, Land Use, Soil Type, Land Slope, Nadal, Rawls

1. Introduction

The physical conditions of the soil vary in the geographical space of a certain area, in which the type of soil, the slope of the land, and the use of the soil are identified. As urban growth advances in the four cardinal points, according to the circumstances and socioeconomic habits of the population of a place, this value varies in time and space, managing to have an impact on the soil structure, that is, how much The higher this value is, the greater surface runoff it will have.

The study of this parameter indicates that there is a concern to have the runoff coefficient updated in real time since it presents greater uncertainty for its determination, in this sense the changes in land use that advance in an accelerated manner, cause havoc in the water behavior of a given hydrographic sheet.

On the other hand, the relationship of the flow that exists between the runoff coefficient is directly proportional, and inversely proportional with the area and intensity, and, consequently, in the water behavior. This relationship is magnified when the frequency of floods increases due to a natural and artificial physical imbalance of a certain hydrographic unit, when the vegetation cover is partially or totally eliminated.

In this sense, the importance of studying the runoff coefficient variable brings with it the update of this value applied in regulations for the hydrological calculation in force in each country, where recommended values for the runoff coefficient to be used in the studies and designs, the magnitude of the runoff coefficient will say at which level we will have more or less surface flow over a given area. The runoff coefficient has its main application in the use of the Rational equation. In other words, the greater importance of the runoff coefficient is induced to the application of a methodology adapted to the conditions of each country, and it is done under current conditions, resulting in reference values.

For this research work, an adequate methodology was sought for the calculation of the runoff coefficient with the T arrangement, the T arrangement is considered as the Tirado arrangement, it is a new, more detailed calculation procedure that originates from the vector maps, and its application is focused on calculating the runoff coefficient directly from said maps. To achieve this, firstly, the variables that affect the runoff coefficient were identified, then the model with the Tirado arrangement was described, and as a third part for the calculation of the runoff coefficient, the Tirado model is proposed.

Finally, for the preparation and support of said research, previous studies have been considered and consulted, such as a methodology for estimating the runoff coefficient in urbanized areas through remote sensing (2018), simulation of runoff and sediment production applying SWAT in micro-watersheds 7 and 13, sub-basin 3, southern basin of Lake Managua, Nicaragua (2004), evaluation of water erosion and surface runoff, under agroforestry systems, on hillside lands, Turrialba, Costa Rica (1993), and the work on flow behavior in the Santa Inés micro-basin, Honduras (2020).

2. Objectives

2.1. Objective General

Develop a methodology for calculating the runoff coefficient with the arrangement Tirado.

2.2. Objective Specific

Identify the variables related to the runoff coefficient.

Describe the model with the arrangement Tirado.

Determination of the runoff coefficient from the model arrangement Tirado.

3. Methodological Design

3.1. Kind of Investigation

This article was designed under the methodological approach of the quantitative approach using the descriptive methodology of the case, since this is the one that best adapts to the characteristics and needs of the investigation.

The quantitative approach used data collection and analysis to answer research questions and test previously established hypotheses, and translates into

> "the sequential and probative. Each stage precedes the next and we cannot 'jump' or avoid steps. The order is rigorous, although of course, we can redefine some phase. It starts from an idea that is being delimited and, once defined, objectives and research questions are derived, the literature is reviewed and a theoretical framework or perspective is built. From the questions hypotheses are established and variables are determined; a plan is drawn up to test them (design); variables are measured in a certain context; The measurements obtained using statistical methods are analyzed, and a series of conclusions are drawn regarding the hypothesis or hypotheses" [1].

From the quantitative approach, the technique of basing the interpretation of data and their analysis using numbers and statistics was taken. It was carried out through the use of standardized procedures accepted by the scientific community in the comparison of the calculation of the runoff coefficient for a certain hydrological sheet, starting from the fundamental equation of the rational method for the Nandaime-Potosí micro-watershed in Nicaragua.

3.2. Execution Time

For the development of the research, there were three weeks to search for information sources for data collection, two weeks for data analysis, and two weeks to interpret the results and final writing of the report. This was done during the period from July to June 2022.

3.3. Technique and Methods of Data Collection

The method to analyze the runoff coefficient is described in the Rational Method of hydrology.

Primary Sources

- Maps made in ArcGis, from information provided by INETER.
- Main bibliography related to the calculation of the runoff coefficient.
- Scientific articles that provide information related to the calculation of the runoff coefficient.

Secondary Sources

Library of the Nicaraguan Institute of Territorial Studies (INETER). General

Directorate of Water Resources.

Library of the National Water Authority (ANA). General Directorate of Water Resources.

3.4. Universe

Hydrological basins with the Pfastetter methodology of Nicaragua.

3.5. Population

Selection of the Nandaime-Potosí hydrological unit.

3.6. Sample

The micro-basin delimited within the Nandaime-Potosí unit, the rivers with names Rio Ochomogo, El Dorado, and El Mojón.

3.7. Inclusion Criterial

It has been established as inclusion criterial, all that area that is circumscribed within the delimited line.

3.8. Exclusion Criterial

It has been taken as exclusion criterial, all that area that is outside the delimited line and that does not belong to the Nandaime-Potosí hydrological unit.

4. Theoretical Aspects

For [2], quoted from (Ministerio de Transporte, 2009, pp. 2-28, 2-40) the runoff coefficient C is defined as the relationship between the volume of water that it is lost by percolation in the ground or by evaporation, and the water precipitated on a surface of the ground. He continues to state [2], that this value is a function of factors such as the shape of the basin surface (basin slope), terrain characteristics (type of surface and coverage, soil type and impervious areas), storage and other detention features.

Another author, such as [3], establishes that the runoff coefficient is dimensionless and that these depend on the return period.

In this section, in my own words, the runoff coefficient (C) is defined as a dimensionless magnitude that relates surface runoff to the runoff volume of said basin. This coefficient relates the portion of the runoff volume to result in surface runoff. As dictated by the Rational Method, according to [4] the expression is:

$$Q = 0.278CIA \tag{1}$$

From Equation (1), the runoff coefficient is solved and the following equation is obtained:

$$C = \frac{Q}{0.278IA} \tag{2}$$

where:

Q = is the surface runoff in m^3/s;

I = is the intensity of rain in mm/h;

A = is the area of the hydrological unit in km^2;

C = dimensionless runoff coefficient;

0.278 = conversion constant.

Following [4], the intensity of the rain is obtained based on the Intensity-Duration-Frequency (IDF) curves that characterize the basin, its duration is equal to the concentration time (Tc) of the basin and a return period (Tr) that corresponds to the one adopted for the estimated maximum flow.

In another instance for [5], I develop a potential regression methodology for the estimation of the RPM curves, in which the following terms can be homologated: Intensity equals Magnitude; Duration equals Persistence; and the Frequency is equal to the Repetition, making it clear that there is another method for estimating the intensity such as the RPM curves.

In another aspect, for [6], there are many methods for calculating the runoff coefficient (all of them empirical in nature) that differ both in their reliability and in their complexity; Logically, the more information used, the more complexity and reliability and vice versa, but, in any case, it is essential to take into account the greater or lesser homogeneity of the basin.

Thus, for example, I refer to [6], a citrus terrace on a loamy soil (same use, same slope and identical soil) will present the same runoff coefficient throughout its surface while in a catchment basin it is difficult to find such uniformity. When the terrain presents different determining conditions for infiltration (relief, vegetation, soil, etc.), it is necessary to calculate the characteristic runoff coefficient of each one from a weighted average of these to obtain a single runoff value. For the whole area.

Some methods that are used, the following stand out; runoff coefficient weighting, Rawls method, Molchanov method, Prevert method, Nadal equation and Keler equation.

In the case of the weighting of the runoff coefficient; it is calculated from the characteristics of land use, soil type and land slope of a watershed, the area portion that each one represents multiplied by its respective coefficient and all divided by the total portion, then the relationship:

$$C = \frac{c_1 * A_1 + c_2 * A_2 + \cdots}{A_T} \tag{3}$$

where:

c_1 = coefficient of portion 1;

c_2 = coefficient of portion 2;

A_1 = area of portion 1 in km^2;

A_2 = area of portion 2 in km^2;

A_T = total area in km^2.

Rawls' method resorts to the help of weighted tables, giving **Table 1** as results:

The Molchanov method is designed with forest plots, its results in summary form are represented in **Table 2**.

Table 1. Runoff coefficient according to rawls.

Description	*C*
Forest. wavy relief	0.18
Forest. broken relief	0.21
Grass. wavy relief	0.36
Grass. broken relief	0.42
Crops. wavy relief	0.60
Crops. broken relief	0.72

Source: Own elaboration based on the information provided by [6].

Table 2. Runoff coefficient as a function of soil characteristics according to Molchanov.

Runoff type	Land slope (in degrees)	Density and use of vegetation cover	soil type	C%
I	1˚ - 35˚	$D > 0.6$ no grazing	Loamy – sandy	5%
II	5˚ - 35˚	$0.5 > D > 0.4$ with occasional grazing	Loamy – stony	6% - 25%
III	5˚ - 40˚	$0.4 > D > 0.1$ With permanent grazing	Loamy – stony	25% - 50%
IV	5˚ - 40˚	$0.4 > D > 0.1$ with intensive grazing	Loamy – stony	50% - 75%
V	5˚ - 40˚	$0.4 > D > 0.1$ with intensive grazing	Clayey	>75%

Source: Own elaboration based on information provided by [6].

In relation to the Prevet method, it is widely spread in Europe and based, like the previous one, on experimental plots, **Table 3** is shown.

Nadal's equation establishes the following:

$$C = 0.25 * K_1 * K_2 * K_3 \tag{4}$$

where:

K_1 = is the factor of the extension of the basin;

K_2 = is the mean annual rainfall factor;

K_3 = is the factor of the slope and the permeability of the soil.

Keler's equation exposes the following:

$$C = a - \frac{b}{P} \text{ as long as } P > 500 \text{ mm} \tag{5}$$

where:

a is a coefficient that oscillates between 0.88 and 1, recommending the value of 1 for torrential basins;

b is a coefficient that oscillates between 350 and 460, taking the minimum for torrential basins;

P is the average annual precipitation in mm.

Table 3. Runoff coefficient based on soil characteristics according to Prevet.

land use	Earring (%)	Soil texture (%)		
		sandy-silty silty-sandy	Slimy silt-clay	Clayey
Forest	0 - 5	0.10	0.30	0.40
	5 - 10	0.25	0.35	0.50
	10 - 30	0.30	0.40	0.60
	>30	0.32	0.42	0.63
Pastureland	0 - 5	0.15	0.35	0.45
	5 - 10	0.30	0.40	0.55
	10 - 30	0.35	0.45	0.65
	>30	0.37	0.47	0.68
agricultural crop	0 - 5	0.30	0.50	0.60
	5 - 10	0.40	0.66	0.70
	10 - 30	0.50	0.70	0.80
	>30	0.53	0.74	0.84

Source: Own elaboration based on information provided by [6].

5. Results

The analysis was carried out in the Nandaime Rivas basin, delimitation using the Pfafstetter method.

The variables identified for the calculation of the runoff coefficient using the Tirado arrangement are: the intensity, the area covered by the basin, the flow, the use of the soil, the type of soil and the slope of the terrain.

Array Tirado consists of data structuring, which is capable of processing a collection of data of the same or different type, associating it with a sequential order number. It can be seen as a vector making use of maps for its characterization in space. In this case, processed maps provided by INETER will be used. This method is proposed by the author applicable to any basin, in which a simple way to determine the runoff coefficient of a basin is evidenced.

The method of arrangement Tirado is deduced from expressions 2, 3 and 4, which are the closest to the working conditions, and their relationship is expressed as follows:

$$\frac{c_1 * A_1 + c_2 * A_2 + \cdots}{A_T} = \frac{Q}{0.278 * I * A} \tag{6}$$

$$0.25 * K_1 * K_2 * K_3 = \frac{Q}{0.278 * I * A} \tag{7}$$

Of the expressions 6 and 7, they have in common the relationship of the flow between the intensity and the area, for which the expressions are equal

$$\frac{C_1 + C_2}{A} = 0.25 * A * I * C \ \therefore C_1 + C_2 = 0.25 * C * I \tag{8}$$

$$C = \frac{C_1 + C_2 + \cdots + C_n}{0.25 * I} \quad (9)$$

This would be the arrangement Tirado, averaged as a function of the coefficients Cn and the intensity of the rain in mm/hrs.

According to the data provided by INETER, Nicaragua, we worked with the Nandaime-Potosí hydrological unit, it is a hydrological unit that belongs to basin 69. From the maps, the predominant areas with land use, type of soil according to its taxonomy and texture, and the slope of the terrain.

5.1. Land Use

In relation to land use, the land use layer for the Nandaime Rivas micro-watershed is presented, configuring itself as a vector map prepared in ArcGis using INETER data, and from the map describe the percentage of coverage according to its use. Next, the following **Figure 1** is presented where the layers of land use of the selected basin are observed. And **Table 4** portion in area for each land use.

The C_c is obtained by normalizing the column of the area, the maximum value is chosen and it is divided between each portion of the area, resulting in C_c.

From Equation (9), the following result is obtained:

$$C_c = \frac{0.81 + 0.09 + 1 + 0.02 + 0.02 + 0.29 + 0.05 + 0.05}{0.25 * I} = \frac{9.30}{I}$$

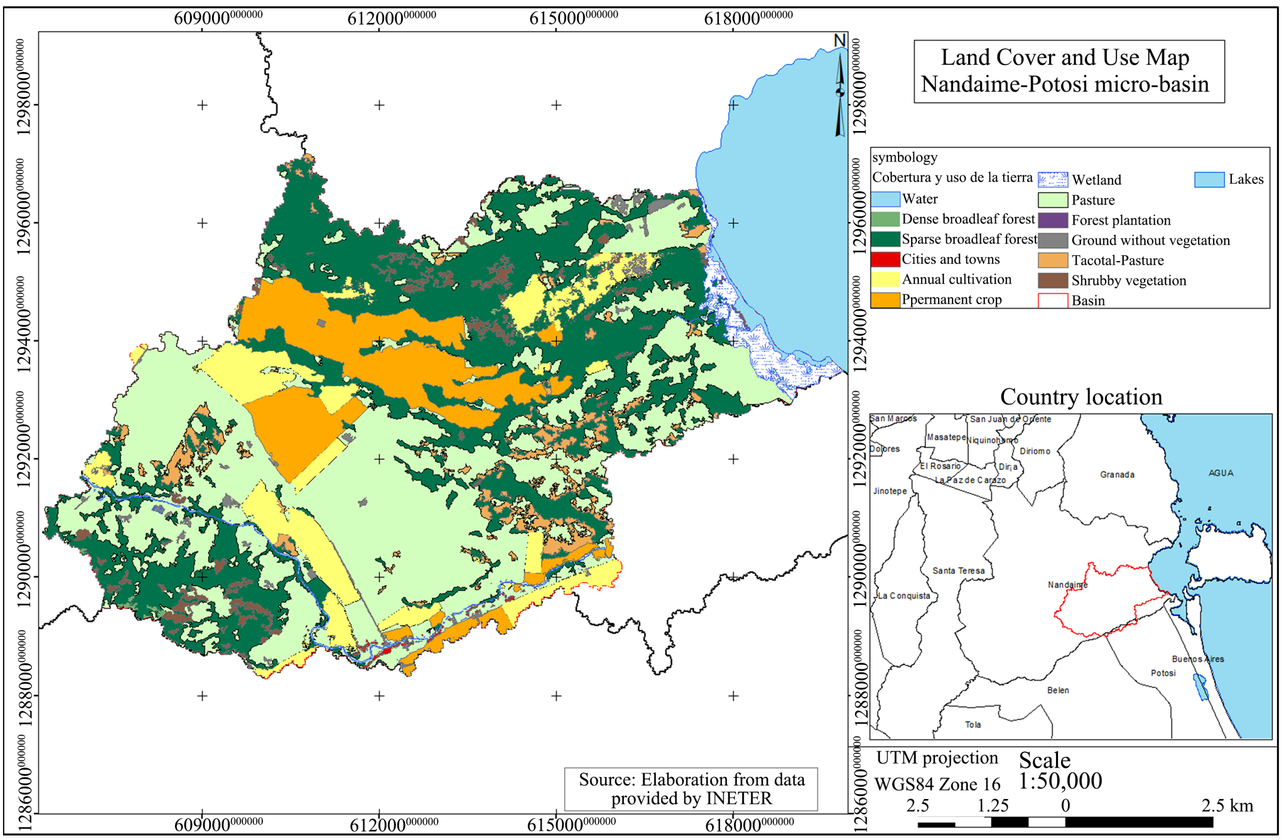

Figure 1. Land cover and use map, Nandaime-Potosí micro-basin. Source: Own elaboration based on data provided by INETER, Nicaragua (2023).

Table 4. Coefficient according to your coverage.

Gridcode	Area km^2	Land Use Description	C_c
2	21.4	sparse broadleaf forest	0.81
13	2.4	tacotal	0.09
7	26.4	Grass	1.00
14	0.6	ground without vegetation	0.02
17	0.5	Water	0.02
9	7.7	permanent crop	0.29
12	1.2	shrubby vegetation	0.05
15	1.3	wetland	0.05

Source: Own elaboration obtained from the vector map of land use.

5.2. Soil Type According to Its Taxonomy

In relation to the type of soil according to its Taxonomy, the soil type layer is presented according to its taxonomy for the Nandaime Rivas micro-basin, configuring itself as a vector layer elaborated in ArcGis from INETER data, and from the map they are expressed as a percentage. The type of soil according to its taxonomy. Next, the following **Figure 2** is presented, where the layers of the soil type are observed according to their taxonomy. And **Table 5**, portion in area for each type of soil.

The C_T is obtained by normalizing the column of the area, the maximum value is chosen and it is divided between each area portion, resulting in C_T.

From Equation (9), the following result is obtained:

$$C_T = \frac{0.135 + 0.002 + 1.00 + 0.075 + 0.002}{0.25 * I} = \frac{4.85}{I}$$

5.3. Land Slope

In relation to the slope of the terrain, the slope layer of the terrain for the Nandaime Rivas micro-watershed is presented, configuring itself as a vector layer elaborated in ArcGis from INETER data, and from the map the slope of the terrain is expressed as a percentage. Next, the following **Figure 3** is presented where the layers of the slope of the terrain are observed. And **Table 6**, portion in area for each slope.

The C_P is obtained by normalizing the column of the area, the maximum value is chosen and it is divided between each portion of the area, resulting in C_P.

From Equation (9), the following result is obtained:

$$C_P = \frac{0.93 + 1.00 + 0.55 + 0.23 + 0.09 + 0.05 + 0.03 + 0.01 + 0.01}{0.25 * I} = \frac{11.59}{I}$$

The next step is the sum of the calculated coefficients, leaving the runoff coefficient as a function of the Intensity (mm/hrs).

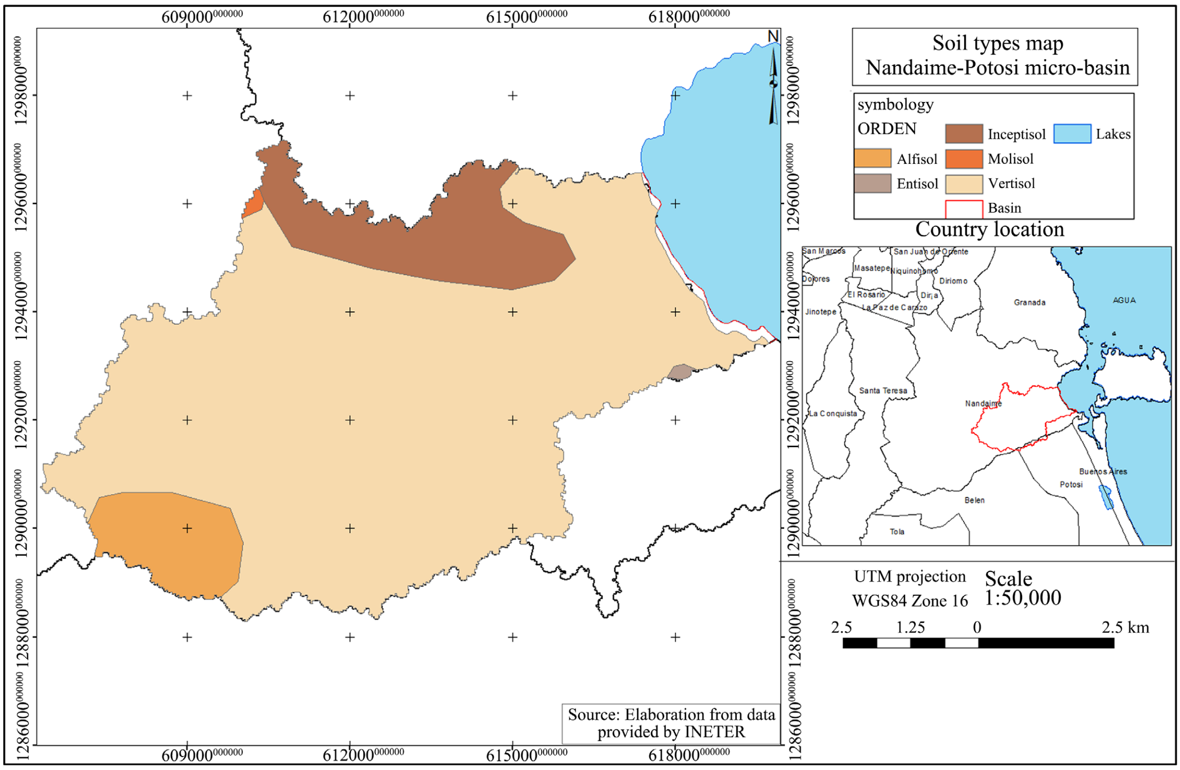

Figure 2. Soil taxonomy map, Nandaime-Potosí micro-watershed. Source: Own elaboration based on data provided by INETER, Nicaragua (2023).

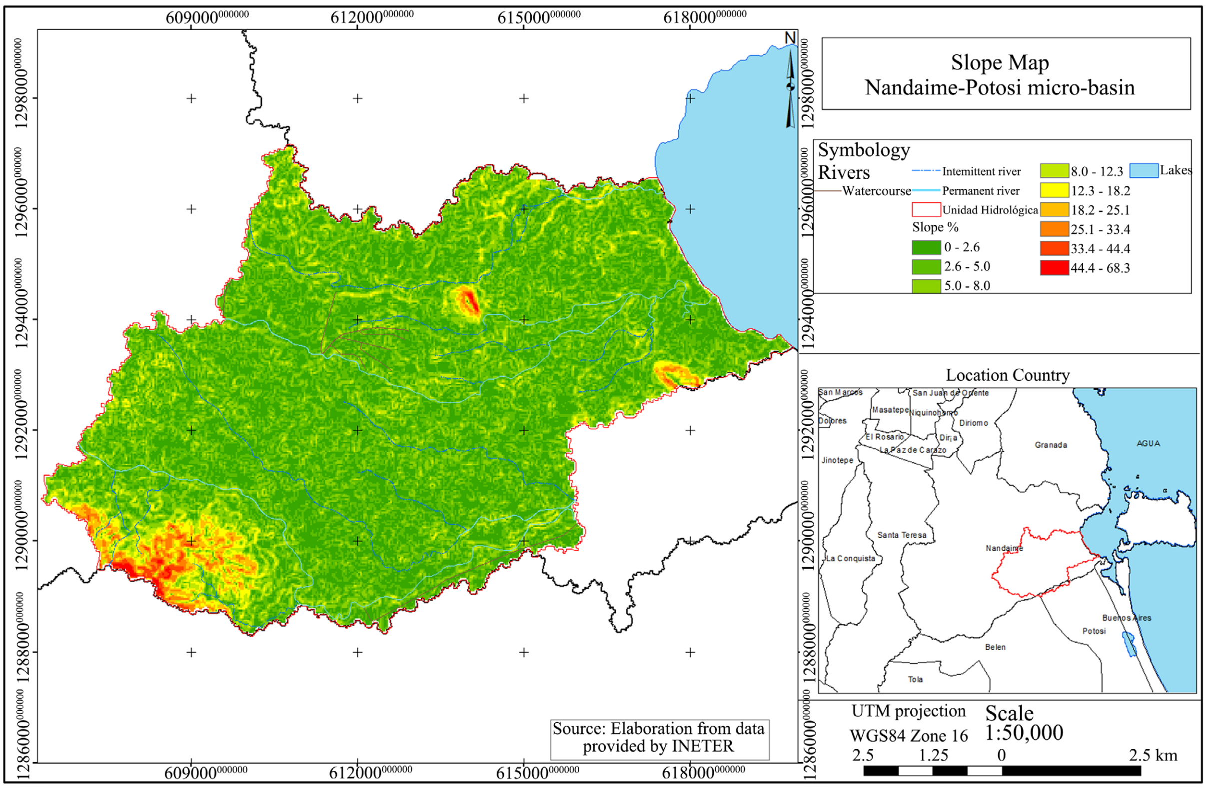

Figure 3. Land slope map, Nandaime-Potosí micro-basin. Source: Own elaboration based on data provided by INETER, Nicaragua (2023).

$$C_e = \frac{9.30 + 4.85 + 11.59}{I} = \frac{25.74}{I}$$

The arrangement consists of introducing values of I in mm/hrs, according to the return period, it is suggested to use the Repetition, Persistence and Magnitude curves of (Picado, 2020) and then subtract from 1, that is, see Table 7.

The frequent limitation that could be in place is obtaining the vector data available, and that can be supplied, and obtaining data from Remote Sensing. It

Table 5. Coefficient according to its Taxonomy.

FID	SUB_GRUPO	ORDEN	Area Km^2	C_T
0	Mollic Vitrandepts	Inceptisol	7.41	0.135
1	Udic Argiustolls	Molisol	0.11	0.002
2	Typic Pellusterts	Vertisol	55.05	1.000
3	Udic Haplustalfs	alfisol	4.11	0.075
4	Lithic Ustorthents	Entisol	0.09	0.002

Source: Own elaboration obtained from the taxonomy vector map.

Table 6. Coefficient according to the slope of the land.

Gridcode	Earring	Area	C_P
1	0% - 2.6%	21.07468	0.93
2	2.6% - 5.0%	22.725999	1.00
3	5.09% - 8.0%	12.462051	0.55
4	8.0% - 12.3%	5.222652	0.23
5	12.3% - 18.2%	1.963588	0.09
6	18.2% - 25.1%	1.192241	0.05
7	25.1% - 33.4%	0.765062	0.03
8	33.4% - 44.4%	0.311424	0.01
9	44.4% - 68.3%	0.123561	0.01

Source: Own elaboration obtained from the vector map of the slope of the terrain.

Table 7. Arrangement runoff coefficient T.

I (mm/hrs)	C_e	Arrangement T del $C_e = 1 - C_e$
150	0.172	0.82
200	0.129	0.87
250	0.103	0.89
300	0.086	0.91

Source: Own elaboration, proposal of the runoff coefficient according to Tirado.

is important to emphasize that you also have to be within the reach of technology to operate software such as QGis, ArcGis, SWAT. The source of error considered for the development of the methodology is personal systematic error, since vector maps must be developed by experts in the management of the aforementioned software.

6. Conclusions

Based on the identified variables, it was possible to vectorize maps into layers of land use, soil type, and terrain slope, synthesizing the results in summary tables of the portions for each of the variables.

From the theory for the calculation of the runoff coefficient, the equation of the weighted coefficients and the Nadal expression were manipulated, resulting in the following relationship $C = \frac{C_1 + C_2 + \cdots + C_n}{0.25 * I}$, considering this as the expression for the Tirado arrangement. For each of the variables, the portion corresponding to the covered area was determined, then it is normalized to find the relationship of C, finally the Tirado arrangement corresponds $C_e = 1 - C_e$.

The expression is tested $C = \frac{C_1 + C_2 + \cdots + C_n}{0.25 * I}$ with different intensities, to obtain the intensities it has been recommended to work with the Repetition, Persistence and Magnitude curves (Picado, 2020) the magnitudes correspond to 150, 200, 250 and 300 mm/hrs, resulting in runoff coefficient 0.82, 0.87, 0.89, 0.91 respectively. This means that, the higher the intensity, the runoff coefficient will be higher, logically the characteristics of the basin affect that this coefficient has variation in the space studied.

Finally, the practice and development of the method is considered, comparing it with the coefficient weighting methodology, Rawls, Preyet and Nadal, and being able to demonstrate its effectiveness.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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