Mathematical model to determine the runoff coefficient based on precipitation and curve number data, in the Manabi hydrographic demarcation, Ecuador

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Abstract. During the last five decades, the forests and natural resources have been highly disrupted by human activities, causing a significant decrease of the plant coverage, consequently resulting in an increase runoff and soil erosion. Likewise, since 1989 non-basic information related to these topics has been obtained from the field, which does not allow appropriate hydraulic structure design. The purpose of the current paper is to determine the relation between the Curve Number CN and runoff coefficient C, from information of the 34 meteorological stations located in the Manabi Hydrographic Demarcation (MHD), during the period 1963-2013. This work is developed using information provided by several State institutions, and support of Geographic Information System. The information is processed using lineal correlation analysis to find an equation that relates the CN a C values.

Key words: rainfall, runoff coefficient, curve number, multiple lineal correlation.

1. Introduction

The capacity of the planet to support all the human activities is getting smaller. It is estimate that about 47 % of the Ecuadorian land has soil degradation problems, caused basically by erosion, overgrazing, deforestation and changed land-uses. The current percentage, 22.9 % corresponds to soil susceptible to desertification, part of which belongs to the coastal zone, specially Esmeraldas and Manabi provinces. In fact, according to United Nations, Manabi is one of the most affected regions by desertification.

Manabi is the only province of Ecuador which does not receive water from the hydrographic network of the snow-capped Andes [1]. In addition to this, geographical characteristics, such as the non-temporary rainfall distribution has led to serious economics and environmental effects on this region. In fact, more of the 70% of the rainfall take place in the period from January to April [2]. As a result, agriculture, the more important socioeconomic practice for the population, has been affected by this phenomenon. Public and private institutions have considered this situation to apply several measures to full fill their roles.

Due to many reasons, during the last five decades, the forests and natural resources have been highly disrupted by human activities, causing a significant decrease of the plant coverage resulting in an increase runoff and soil erosion. In this sense, since 1989 , there has not been enough studies to support and update the Hydraulic Plan [3], because non-basic information has been obtained from the countryside. For this reason, in order to design hydraulic structures, planners have to use parameters and coefficients belong to others geographic realities of the world.
The purpose of the current paper is to determine the relation between the Curve Number \( CN \) and runoff coefficient \( C \), from information of the 34 meteorological stations located in the Manabi Hydrographic Demarcation (MHD), for the period 1963-2013.

The figure 1 shows the location of the MHD [4, 5].

![Figure 1. Location of Manabi Hydrographic Demarcation – Ecuador.](image)

2. Materials and method

To develop this study, MHD is as a regional planning unit considering the following materials: 1) monthly rainfall corresponding to 34 meteorological stations for the period 1963-2013 [6], taken from Meteorological and Hydrological National Institute (INAMHI). 2) digital information developed by the institution in charge of water resources, SENAGUA, Ministry of Agriculture and Livestock (MAG), Ministry of Environment and Geographic Military Institute (IGM) [7].

For the period and the data sets mentioned, the tasks were completed according the following steps: 1) by using the orthogonal correlation method [8, 9], missing information of rain was filled; 2) average annual precipitations were calculated; 3) for making morphologic study 56 water sheets were considered, which are distributed on 11484.00 km\(^2\) approximately, subdivided according Pfafstetter methodology. The morphologic parameters were obtained using both, digital elevation model with 3.00 m of resolution and vegetation coverage information provided by MAG. 4) with the aid of Soil Conservation Service [10, 11] method the values of runoff and maximum potential difference between \( P \) and \( Q \) were calculated by applying the following equations [12]:

\[
Q = \frac{(P - 0.2S)^2}{P + 0.8S}
\]  
(1)

\[
S = \frac{25400}{CN} - 254
\]  
(2)

\[
S = \frac{25400}{CN} - 254
\]  
(2)
where $Q$ - Surface runoff height, mm; $P$ – Rainfall, mm; $S$ - Maximum potential difference between $P$ and $Q$, mm. $CN$ - Curve Number.

Using scale 1:100000, on the base of vegetation coverage and soil use maps of Ecuador 2013-2014 developed by MAG and MAE [13], $CN$ values corresponding to each micro basin, are obtained.

The runoff coefficient $C$, is calculated as the relation between surface runoff $Q$ and rainfall $P$, as follows:

$$C = \frac{Q}{P}$$  \hspace{1cm} (3)

Once $C$ and $CN$ values have been determined, lineal correlation is applied to these two parameters. And, in order to analyze rainfall influences, multiple lineal correlation was carried out, considering runoff coefficient $C$ as dependent variable [14], being rainfall $P$ and $CN$ independent variables [15, 16].

3. Results and discussion

The values of the results of rainfall $P$, runoff $Q$ and curve number $CN$ obtained are showed in the following table 1.

| Code. Basin | 1513 | 1514 | 1515 | 1516 | 1517 | 1518 | 1519 |
|-------------|------|------|------|------|------|------|------|
| 1           | 350.00 | 276.92 | 78.08 | 550.00 | 485.53 | 81.28 | 400.00 |
|             | 250.00 | 174.18 | 75.98 | 400.00 | 298.39 | 71.15 | 300.00 |
|             | 850.00 | 805.64 | 86.88 | 1325.00 | 1261.93 | 82.37 | 800.00 |
|             | 575.00 | 525.93 | 85.39 | 550.00 | 476.21 | 78.92 | 400.00 |
| 2           | 750.00 | 676.82 | 79.52 | 850.00 | 682.81 | 80.82 | 550.00 |
|             | 900.00 | 796.84 | 75.21 | 950.00 | 781.69 | 77.03 | 1250.00 |
| 3           | 1000.00 | 1229.63 | 817.60 | 1372.37 | 1047.98 | 86.95 | 650.00 |
|             | 1300.00 | 1203.79 | 86.95 | 1563.18 | 1303.79 | 86.95 | 1205.38 |
| 4           | 1229.63 | 902.16 | 70.00 | 400.00 | 347.56 | 84.08 | 1000.00 |
|             | 297.79 | 203.61 | 85.68 | 300.00 | 203.61 | 71.00 | 400.00 |
|             | 948.59 | 751.23 | 85.11 | 800.00 | 313.83 | 71.00 | 800.00 |
|             | 585.86 | 313.83 | 75.03 | 550.00 | 463.19 | 75.03 | 1250.00 |
| 5           | 1000.00 | 1203.79 | 86.95 | 1563.18 | 1303.79 | 86.95 | 1205.38 |
|             | 750.00 | 682.81 | 75.21 | 950.00 | 682.81 | 77.03 | 650.00 |
| 6           | 1000.00 | 1229.63 | 817.60 | 1372.37 | 1047.98 | 86.95 | 1205.38 |
|             | 1300.00 | 1203.79 | 86.95 | 1563.18 | 1303.79 | 86.95 | 1205.38 |
| 7           | 527.28 | 933.06 | - | 898.25 | 84.08 | 83.24 | 1000.00 |
|             | 933.06 | 186.33 | - | 898.25 | 83.24 | 81.43 | 400.00 |
|             | 998.06 | 186.33 | - | 898.25 | 83.24 | 74.42 | 1200.00 |
| 8           | 79.33 | 81.28 | - | 85.00 | 600.00 | 80.22 | 1250.00 |
|             | 81.28 | 186.33 | - | 898.25 | 80.22 | 74.42 | 425.00 |
|             | 85.00 | 85.00 | - | 85.00 | 80.22 | 74.42 | 950.00 |
| 9           | 323.87 | 1162.77 | 1277.16 | 618.24 | 77.64 | 76.88 | 1050.00 |
|             | 1162.77 | 618.24 | 993.48 | 993.48 | 76.88 | 75.12 | 1050.00 |
|             | 338.41 | 618.24 | 993.48 | 993.48 | 76.88 | 75.12 | 1250.00 |
|             | 388.14 | 618.24 | 993.48 | 993.48 | 76.88 | 75.12 | 1250.00 |

| Code of basin | 1050.00 |
|--------------|---------|
| 15136        | 991.0   |
| 3            | Runoff $Q$, mm |
|              | 83.24   |
The equations obtained from correlation methods are showed below.

\[ C = 0.0126CN - 0.1255 \quad R^2 = 0.4852 \] (4)

\[ C = -0.0007CN^2 + 0.1266CN - 4.6239 \quad R^2 = 0.52 \] (5)

\[ C = 0.2033 + 0.0001P - 0.00777CN \quad \text{multiple corr. coef.} = 0.92 \] (6)

The multiple correlation equation (6) demonstrate that, when the precipitation values are less than 100 mm, the runoff coefficient variation is not significant relative with the burden of Curve Number CN. Considering this condition, the following figure shows the curves corresponding to each equation.

![Correlations of data C and CN.](image)

**Figure 2.** Correlations of data C and CN.

In comparison with the data set used, the lineal correlation equation (4) underestimates the runoff coefficient values when the curve number CN range between 70 and 90.

Low values of runoff coefficient are produced from the polynomic equation (5) when CN values are less than 60, while negatives values of C are obtained for values of CN less than 52. In the same way, when curve number CN range between 70 and 90, equation (5) fit the original data set quite well, but when the CN values are greater than 90, the runoff coefficient tends to decrease, which is contradictory.

The multiple correlation equation (6) presents no restrictions for any CN value. Moreover, the multiple correlation coefficient is acceptable and for CN values ranging between 70 and 90, as showed in the figure, the line of equation fits the data very closely.

4. Conclusions

On the basis of data filled by applying orthogonal correlation method and using multiple correlations techniques, the equation \( C = 0.2033 + 0.0001P - 0.00777CN \) is obtained to estimate the runoff coefficient C, where \( P \) multi-annual average precipitation mm, and \( CN \) is Curve Number.

The above equation offers more advantages than the others, because their results are consistent in the whole CN values range. Furthermore, it allows the addition of the variable \( P \) to determine the runoff coefficient \( C \), which is a basic parameter of Rational Method to perform the water runoff calculation in small river basins. Therefore, this equation is recommended to be used in Manabi Hydrographic Demarcation MHD.
The inclusion of variable Precipitation $P$ sustains the idea that low values of precipitation do not affect the runoff coefficient results and for high values the impact is not significant. Therefore, the increased dependence on runoff coefficient lies on the curve number $CN$.

From the previous conclusion, it can be said that soil of MHD does not have enough forest cover, becoming a severe state of human intervention in the territory, which confirms the high runoff coefficient values obtained of the record data analyzed, as can be seen in figure 2.

5. Acknowledgment
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