Estimation of the runoff of the hills of the city of Portoviejo-Ecuador to assess the degree of flooding in the region

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Abstract. Portoviejo, capital of the province of Manabi is one of the oldest cities on the Ecuadorian coast. It is characterized by a stable temperate climate with an average annual temperature of around 24ºC, with annual rainfall patterns of up to 500 mm. It is a city located in a valley, with average height of 40 m. It is surrounded by hills that have heights that reach up to 280 meters above sea level, which potentiates that the continuous runoffs that occur in the rainy season causes problems related to landslides and floods in the lower part. In the present work an estimation of the runoff coming from the hills located in the northeastern areas of the city where the parishes and citadels Progreso, Cevallos, San Pablo and Briones are located. The capacity of conduction of existing rainwater collectors in comparison with the runoff values obtained is also analyzed. The results obtained constitute an approximation of runoff values for return periods of 1, 2, 5, 10, 20, 50 and 100 years, which are an input for the repowering of existing works and for the design of infrastructure works complementary to the control of floods and landslides in the area.

Key words: hydrology, rainfall, return periods, climate change, runoff control

1. Introduction

Portoviejo, capital of the province of Manabi, founded on March 12th, 1535, is one of the oldest cities on the Ecuadorian coast. It is characterized by a stable temperate climate with an annual average temperature of around 24ºC. The average rainfall for the years 2000 to 2009 is 596.20 mm per year, the wettest years are 2000 with 733 mm and 2008 with 823 mm; while the driest are 2001, 2003 and 2009 with rainfall below 500 mm. Maximum precipitation values were obtained in the years 1997 and 1998 during the El Niño phenomenon [1].

The subject of floods has been the subject of study by professionals and institutions at a regional and international level, however, for the city of Portoviejo-Ecuador, it is a very specific problem from which little or nothing has been done until now.

As an example of studies related to flooding and excess of runoff lamination in urban areas in different parts of the world, among others, we can mention that in the Atemajac river basin, in the State of Jalisco-Mexico, Rubén Ernesto Hernández et al. They analyze the problem of overflowing the river and its possible damages while presenting a methodology where they try to standardize the factors that intervene in environmental vulnerability from a social and economic approach [2].

On the other hand, in Buenos Aires-Argentina, the Economic Commission for Latin America and the Caribbean, analyzes the problem of flooding and overflow of the Salado River in the province of Santa Fe with the purpose of proposing projects for the rehabilitation of affected homes by floods and to meet needs related to water disasters that have occurred [3].
ZW Kundzewicz et al, members of the Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters / School of Geographical Science, Nanjing University of Information Science and Technology (NUIST), Nanjing, China, in the article "Flood risk and its reduction in China" analyze that the growth of flood risks in China is due to anthropogenic and climatic factors [4].

Related to the floods, Mohammed Sarfaraz Gani Adnan, in the journal Science of The Total Environment, in his article entitled "Have coastal embankments reduced flooding in Bangladesh?", analyzes the effect of polders on the increase of the flooded pluvial area [5].

A very interesting investigation is carried out by Leila Goodarzi et al, where a flood warning system based on forecasts of atmospheric assemblies is developed [6].

Among the investigations related to the topic of floods that have taken place in Japan, we have the one of Tomahiro Tanaka et al, where it is highlighted that the frequency of an extreme flood happening with greater probability is linked to the treatment that happens upstream of the hydrographic basin, so if in the city of Kyoto, specifically in the Yodo River, control is achieved through a digital model of flood - inundation floods that happen upstream are regulated by hydraulic regulation works, it will be less likely to happen an extreme flood within the big cities [7].

Worldwide, many researchers deploy their work with topics related to hydrological studies aimed at determining the risks and solutions for surface runoff that cause flooding in inhabited territories [8-13].

For the city of Portoviejo-Ecuador, for the first time, the problem of floods is approached as a result of the rolling of the runoff from the hills. In these moments in which the situation of the floods has worsened, the Technical University of Manabí has assigned us the task of technically substantiating the problem and proposing guidelines to solve the problem, which is the reason for the present investigative work.

The city is located in a valley, whose average elevation has been estimated at 40.00 meters above sea level, and in the northeast and southwest areas it is limited by hills whose maximum levels oscillate between 250 ~ 300 meters above sea level.

The parishes of Progreso, Pacheco, San Pablo and Briones are located in the lower part of the hills of the northeast sector. During the rainy season they experience landslide problems, with consequent flooding due to surface runoff and water erosion. zone.

For the control of runoff there is a sewer system, which is insufficient, since the lower area is flooded, causing year-to-year urban problems of vehicular and human traffic, in addition to material losses.

With the purpose of contributing with design elements that allow to diagnose the current situation of the runoff and its control works, in the present work, based on the methodology proposed by the Soil Conservation Service of the United States (Department of Agriculture United States. USDA Natural Resources Conservation Service Soils. 2015) (Soil Conservation Service – SCS), complemented with the techniques of Geographic Information Systems (GIS), runoff has been estimated by sectors for return periods 1, 2, 5, 10, 20, 50 and 100 years.

2. Materials of research
The basis for this work is the 24 hour maximum rainfall records provided by the Ecuadorian Institute of Hydrology and Meteorology of Ecuador (INAMHI), meteorological station M005 located in the Botanical Garden of the Technical University of Manabi, latitude 01° 02’ 26” S, length 80° 27’ 54” W, period 1982-2013. Figure 1 shows the geographical location of the M005 station within the territory of the Manabi Hydrographic Demarcation (DHM) (Secretary of Water of Ecuador) [14].
The total records of maximum rainfall in 24 hours used in the investigation amount to 384. Table 1 presents the respective records, period 1982-2013 (National Institute of Hydrology and Meteorology. Meteorological Yearbooks) [15].

**Table 1.** Registration of maximum precipitations in 24 hours, mm, Portoviejo Station – UTM (M005) Period 1982 – 2013

| Year | P max 24, [mm] | Year | P max 24, [mm] | Year | P max 24, [mm] | Year | P max 24, [mm] |
|------|--------------|------|--------------|------|--------------|------|--------------|
| 1982 | 48.90        | 1990 | 37.80        | 1998 | 86.70        | 2006 | 56.70        |
| 1983 | 120.50       | 1991 | 20.90        | 1999 | 69.40        | 2007 | 46.80        |
| 1984 | 47.30        | 1992 | 69.70        | 2000 | 41.30        | 2008 | 53.30        |
| 1985 | 40.00        | 1993 | 25.30        | 2001 | 147.90       | 2009 | 26.50        |
| 1986 | 54.70        | 1994 | 66.50        | 2002 | 50.80        | 2010 | 52.30        |
| 1987 | 65.60        | 1995 | 60.10        | 2003 | 38.40        | 2011 | 37.00        |
| 1988 | 18.30        | 1996 | 40.80        | 2004 | 57.90        | 2012 | 59.30        |
| 1989 | 131.40       | 1997 | 131.10       | 2005 | 79.70        | 2013 | 107.60       |
For the determination of the morphometry of the micro watersheds, digital elevation models with a resolution of 3 meters were used, facilitated by the GAD of Portoviejo. Likewise, the aforementioned institution provided basic information regarding the vegetation cover and infrastructure works for the management of surface runoff in the zone.

Six zones of analysis have been considered (figure 2), each of them being the micro basin or micro basins in which each parish is located: Progreso, Pacheco, San Pablo and Briones. The physiographic parameters of the micro watersheds were determined with the help of specialized software for the management of geographic information. The total area of study has been estimated at 327.03 ha. Through the S.C.S. method, runoff is determined with the formula (1)

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

where \( Q \) – surface runoff height, mm; \( P \) – rainfall, mm; \( S \) – maximum potential difference between \( P \) and \( Q \), mm.

![Figure 2. Study zones.](image)

The parameter \( S \), the maximum potential difference between \( P \) and \( Q \), can be determined through the so-called \( CN \) curve number, which characterizes the soil types and vegetation cover of the area. The calculation formula in metric units is as follows:

\[ CN = \frac{25400}{254 + S} \]

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

For the valuation of the curve numbers of the micro basins, was used the map of coverage and land use of the continental Ecuador 2013-2014, scale 1: 100000, developed by the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP) with the Ministry of the Environment (MAE) (Applications in Land Management and Integral Management of Watersheds. 2015).

Surface runoff has been estimated at the discharge points where the steep slopes of the hills end, this is at Coronel Sabando and Avenida Seminario streets. Table 3 shows the coordinates of the projected discharge points in the UTM system WGS84, ZONA 17 S, M.

Based on the shapes of the storm sewer network, facilitated by the GAD-Portoviejo and with the digital elevation model of the area, the slopes of the main rainwater collectors were estimated, which were used to determine the maximum capacity of driving them. Then, the values obtained were
compared with the runoff of the micro basins of the study areas in order to validate the existing urban drainage network.

3. Results
The weighted results of the curve numbers for each of the micro-watersheds are contained in table 2.

The peak flows of surface runoff, for various return periods, were estimated for discharge points, whose coordinates are contained in table 3 and figure 3.

Table 4 shows the peak flows for return periods of 1, 2, 5, 10, 20, 50 and 100 years, expressed in m³/s.

Table 5 compares the maximum conduction capacity of the rainwater collectors with the runoff flows determined in this study, which should be received by the collectors located in Coronel Sabando and Av. Seminario streets.

Table 2. Data of micro basins with weighted values of CN curve numbers.

| Micro basins | Name     | Area basin (ha) | CN weighted |
|--------------|----------|-----------------|-------------|
| 1            | Progreso | 100.74          | 74          |
| 2            | Pacheco  | 32.63           | 81          |
| 3            | San Pablo| 155.15          | 74          |
| 4            | San Pablo 2 | 22.00      | 81          |
| 5            | Briones 1 | 10.35           | 81          |
| 6            | Briones 2 | 6.16            | 81          |

Table 3. Sites of runoff discharge.

| Discharge | Zone      | UTM coordinates WGS84 |
|-----------|-----------|------------------------|
|           |           | X (m) | Y (m) | Z (m) |
| 1         | Progreso  | 561907.62 | 9883202.53 | 45.75 |
| 2         | Pacheco   | 561614.76 | 9883388.06 | 45.04 |
| 3         | San Pablo 1 | 561332.10 | 9883592.02 | 40.81 |
| 4         | San Pablo 2 | 561207.42 | 9883736.05 | 43.19 |
| 5         | Briones 1  | 561027.46 | 9884086.86 | 43.53 |
| 6         | Briones 2  | 561017.29 | 9884119.28 | 43.59 |

Table 4. Peak runoff estimated at Coronel Sabando and Av. Seminario streets expressed in m³/s

| Micro basins | Name      | Return Periods |
|--------------|-----------|----------------|
|              |           | 1 year | 2 years | 5 years | 10 years | 20 years | 50 years | 100 years |
| 1            | Progreso  | 0.0540 | 0.3205 | 0.8076 | 1.3456 | 1.9388 | 2.7195 | 3.4499 |
| 2            | Pacheco   | 0.0176 | 0.1799 | 0.4761 | 0.7148 | 0.9579 | 1.2657 | 1.5451 |
| 3            | San Pablo 1 | 0.0828 | 0.4919 | 1.2393 | 2.0651 | 2.9753 | 4.1734 | 5.2944 |
| 4            | San Pablo 2 | 0.0118 | 0.1200 | 0.3174 | 0.4765 | 0.6386 | 0.8438 | 1.0301 |
| 5            | Briones 1  | 0.0059 | 0.0300 | 0.0600 | 0.2383 | 0.3193 | 0.4219 | 0.5150 |
| 6            | Briones 2  | 0.0033 | 0.0338 | 0.0894 | 0.1343 | 0.1800 | 0.2378 | 0.2903 |
Table 5. Confrontation of capacity of collector of rain water with the runoff of the hills for several return periods

| Zone          | Collector Diameter [mm] | Collector Flow [l/s] | Runoff [l/s] | Return Periods |
|---------------|-------------------------|----------------------|--------------|----------------|
|               |                         |                      | 1 year       | 2 years        | 5 years        | 10 years       | 20 years       | 50 years       | 100 years      |
| Progreso      | 800                     | 2800                 | 54           | 321            | 808            | 1346           | 1939           | 2720           | 3450           |
| Pacheco       | 400                     | 140                  | 18           | 180            | 476            | 715            | 958            | 1266           | 1545           |
| San Pablo 1   | 500                     | 700                  | 83           | 492            | 1239           | 2065           | 2975           | 4173           | 5294           |
| San Pablo 2   | 200                     | 40                   | 12           | 120            | 317            | 477            | 639            | 844            | 1030           |
| Briones 1     | 200                     | 20                   | 6            | 30             | 60             | 238            | 319            | 422            | 515            |
| Briones 2     | 250                     | 80                   | 3            | 34             | 89             | 134            | 180            | 238            | 290            |

Figure 3. Micro basins of hills of Portoviejo city.

4. Conclusions
1. The total area of the micro basins in which the parishes Progreso, Pacheco, San Pablo and Briones are located amounts to 327.03 ha, corresponding to them, respectively, 100.74, 32.63, 177.15, 16.51 ha.
2. For return periods of 1, 2, 5, 10, 20, 50 and 100 years, the basin with the highest runoff is the one where the San Pablo parish is located (micro-basins 3 and 4), values ranging from 0.05 to 3.45 m³/s.
3. The lowest runoff values were obtained for the Briones basins (micro-basins 5 and 6), which are between 0.009 and 0.805 m³/s.
4. Minor values of surface runoff threw the micro basins where the Progreso and Pacheco parishes are located. For Progress zone were obtained values between 0.05 to 3.45 m³/s, and 0.018 to 1.55 m³/s, for the Pacheco parish.
5. The estimated values constitute an input for the institutions that are dedicated to the management of runoff from the hills, with the purpose of controlling landslides and floods in the zone.
6. It was determined that the collectors that receive the runoff from the micro-basins have sections that allow flow rates for periods of return of less than 5 years, with the exception of the collector of the Progreso citadel of 800 mm in diameter, which has a maximum driving capacity of 2800 l/s, close to the flow of 50 years of return period. This situation explains that, very often, in the rainy season, the lower parts of the study areas experience problems related to serious floods.
7. In terms of current regulations, contained in the Ecuadorian Construction Code, Part IX, Sanitary Works (Section 5.1.5 Rainwater Design Flows)( Water Secretariat, Ecuadorian Code for the Construction of Sanitary Works. 2012, Quito), for watershed micro drains, design flows of rainwater collectors must correspond to 10-year return periods, which is not true for existing conditions.
8. Based on the analysis carried out, the corresponding instances of urban development should consider this situation in order to deepen these studies in order to reinforce the existing works and / or propose complementary projects that tend to mitigate the environmental impacts caused by the insufficiency of the capacity of driving of the existing storm sewer.

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