Water supply and demand of the hydrographic demarcation of Manabi, Ecuador

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Abstract. Manabi is the only province in Ecuador that does not receive contribution of the runoff coming from the thaw of the snow-covered of the Andes mountain. This situation impacts severely on the agriculture activities. This study presents an estimate of water supply and demand of the Manabi hydrographic demarcation based on the hydro meteorological data and the water needs of the population by 2050. The research topic is very topical since it contributes to providing the necessary inputs for the planning and use of water resources in order to generate projects that tend to cover the current water deficit. The methodology used to estimate the water supply is based on the precipitation-runoff model proposed by the Soil Conservation Service of the United States of America. In fact, in spite of the annual volume of runoff has been estimated at 9,658.83 hm³, against 2,388.93 hm³, which is the average annual volume of water to meet the demands, from July to November it can be seen that the deficit reach at 330.27 hm³. The results obtained constitute a valuable tool for specialists and governmental and non-governmental institutions responsible for the control, planning and development of water resources in the region.

Key words: hydrology, rainfall, runoff, water balance, planning and development

1. Introduction

At a global level, the subject of the study of water balances has been subject to various purposes and needs, which are related to the planning of water resources to meet consumptive and non-consumptive demands, for the control of water dynamics in the water environment and for different purposes.

Among the many existing investigations, we have the work of Moreira et al "Assessment of terrestrial water balance using remote sensing data in South America". This study investigated the potential of assessing the water balance in South America, at multiple scales, using satellite remote sensing precipitation and evapotranspiration datasets, terrestrial water storage changes from Gravity Recovery and Climate Experiment, and discharge measurements [1].

In the field of agriculture we have the work of Kisekka et al "Uncertainties in leaching assessment in micro-irrigated fields using water balance approach", where water balance is a common approach used to estimate leaching in agricultural fields and was applied in this study to assess field-scale leaching and the associated uncertainties for an almond orchard under drip and micro-sprinkler irrigation systems [2].

In the work "Impacts of projected change in climate on water balance in basins of East Africa" was observed and large-scale climate variables (predictors) are obtained from the national meteorological agency of Ethiopia and international databases. BROOK90, a physical-based hydrological model, is used to assess the impacts of the projected change in precipitation and maximum and minimum temperature (T-max, and T-min) on the water balance [3].
Manabi is one of the largest provinces of Ecuador, which has an area of 18,940 km$^2$ (6.70% of the national territory) and is considered "specialized" in agriculture compared to the other provinces of the country. The large size of the agricultural sector is the key to the development of the economy of Manabi. In addition, the agricultural sector is one of the most diverse in Ecuador, due to the size of the province, the stable climate and the topography of the lands suitable for cultivation. In Manabi an important series of agricultural products is cultivated, such as coffee, cocoa, bananas, citrus fruits (lemon, grapefruit, orange, tangerine and passion fruit), corn and rice. More than 14,000 hectares of land for irrigation produce pepper (2000 ha), tomatoes (3000 ha), watermelon (2000 ha), cassava (1000 ha), fine lemon (1000 ha), pearl onion (3000 ha) and fruit of the passion (2000 ha) [4-5].

To guarantee agriculture in the central area of the province there are 2 irrigation systems. The first of 15,000 ha has as source of supply the Poza Honda dam, and the second of 14,250 ha, which is supplied by the dam "La Esperanza". The two systems are part of the so-called Chone-Portoviejo Integrated System. All the rivers of the hydrographic demarcations of Ecuador, excepting those of the demarcation of Manabi, receive contribution of the runoff coming from the thaw of the snow-covered ones of the mountain range of Andes. This situation has a negative impact on the development of the province of Manabi, especially in the field of agriculture, because rainfall is distributed non-uniformly in the dry and rainy periods throughout the year. The rainy period, from December to May, is accompanied by excess runoff with serious flooding, while, in the dry period, from June to November, due to the absence of rains, when the flow in rivers is less than 1 m$^3$/s, there is a large water deficit, since the rivers practically dry up. Modular minor flows vary between 1.99 and 15.87 l/s/km$^2$, compared with the other provinces, having input thaws Andes, where these flow rates above 80 l/s/km$^2$ [6].

The main rivers of Manabi, from north to south are: Coaque, Don Juan, Jama, Briceno, Grande, Carrizal, Chico, Portoviejo, Salado, Sancan, Jipijapa, Buenavista and Ayampe. Since 2011, the development of Ecuador’s water resources is planned, not from its territorial-administrative base, but from its division by hydrographic demarcations (Figure 1). In accordance with this, 9 state entities have been created, called "demarcations", which work under the general direction of the Water Secretariat (SENAGUA). The total area of the Manabi hydrographic demarcation is 11,484 km$^2$.

This study presents an estimate of the water supply and demand of the Manabi hydrographic demarcation on the basis of hydro meteorological data and the water needs of the population by 2050 [7-8].

![Figure 1. Hydrographic demarcations of Ecuador.](image-url)
2. Materials and methods

For the execution of this work the following material was used: 1) Monthly rainfall of 34 meteorological stations located in the territory of the province of Manabí for the period 1963-2013 taken from the yearbooks and public institutional documents of the Institute of Hydrology and Meteorology (INAMHI); 2) Thematic digital GIS information of the Manabí hydrographic demarcation taken from the geoportals of the Water Secretariat (SENAGUA), the Military Geographical Institute (IGM) and the Ministry of Agriculture, Aquaculture and Fisheries (MAGAP) of Ecuador, 3) Water demands contained in the Plan for the Development of Water Resources of the Province of Manabí (PHIMA 1990).

In sequential order, the tasks that were carried out are: 1) Filling of missing data in the monthly rainfall records; 2) Estimation of multi-year average rainfall; 3) Distribution of monthly multi-year average precipitation; 4) Development of multi-year medium precipitation isohyet map; 5) Temporal distribution of annual rainfall; 6) Analysis of the variability of interannual precipitation; 7) Estimation of runoff and evapotranspiration by hydrological units of the Manabí hydrographic demarcation (DHM); 8) Estimation of the multi-year volume of water by precipitation (supply); 9) Estimation of annual average water demand; and, 10) Analysis of water balance: excess / deficit.

The main methods of approach and methodologies used to estimate the water supply and demand of the DHM, are sustained below.

For the filling of missing data in the monthly precipitation records for the period of analysis, the orthogonal correlation method was used, due to the fact that by applying this method, higher correlation coefficient values are obtained, giving greater reliability to the synthetic data generated.

On the basis of the digital files type shapes that were obtained through the geoportals of development institutions, such as: SENAGUA, INAMHI, IGM and MAGAP, with the help of specialized GIS software, digital elevation models with resolution of 3.00x3.00m, which were input, for the generation of important information for the achievement of the proposed objectives.

For the determination of the morphometry of the micro watersheds, digital elevation models with a resolution of 3,00 meters were used, facilitated by the MAGAP. Likewise, the aforementioned institution provided basic information regarding the vegetation cover and infrastructure works for the management of surface runoff in the zone.

Fifty-six sub-basins of analysis have been considered. 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 11484 km². Through the Soil Conservation Service (S.C.S.) method, runoff is determined with the formula:

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

where \( Q \) — Surface runoff height, mm; \( P \) — Rainfall, mm; \( S \) — Maximum potential difference between \( P \) and \( Q \), mm.

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 [9]:

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

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

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) [10].

Total evaporation, also called evapotranspiration, is a magnitude that includes transpiration, evaporation of soil and evaporation of water, contained in the stems and leaves of plants during rain. It
can be estimated by the water balance method, with which the annual evapotranspiration standard $E_0$ equals rainfall $x_0$ minus runoff $y_0$ [11-12]:

$$E_0 = x_0 - y_0$$ (4)

The multiannual volume of runoff by micro basin, which is the value corresponding to the annual average value of the water supply, is determined as the product of the runoff layer by the area of each of the hydrological units of the DHM, being the offer of the demarcation, the sum total of the partial values obtained.

The water demand was estimated on the basis of the Water Resources Development Studies of the Province of Manabi carried out in 1990 (PHIMA) by national institutions with cooperation of international organizations such as: Manabi Rehabilitation Center (CRM), National Institute of Water Resources of Ecuador (INERHI), National Development Council (CONADE) and the Organization of American States (OAS) [13].

The estimation of water demands was made on the basis of a projection of population growth until the year 2050. With this, the approximate population to the year 2020 was estimated at 2130000 inhabitants and total irrigated area at 51900.00 ha. Table 1 shows the demands considered in the PHIMA projects.

3. Results and discussion

With the complete series of the 34 rainfall stations, the average multiannual monthly rainfall for the period 1963 - 2013 was determined. After analyzing the results obtained, it is determined that the average monthly rainfall range between 0.96 - 229.75 mm. Of all the rainfall, for the dry season (June - November) corresponds 10.12%, and the remaining 89.88%, to the rainy season (December - May). This is illustrated in figure 2.

![Figure 2. Distribution of average monthly rainfall.](image)

The analysis shows that the average multi-year values of rainfall in Manabi vary from 200 mm in the west to 2800 mm in the east.

![Figure 3. Distribution of average annual rainfall.](image)
The total volume by evapotranspiration has been estimated at 822.12 hm$^3$ / year, which constitutes 7.84% of the total rainfall.

The annual average global volume by rainfall in the Manabi hydrographic demarcation (DHM) was estimated at 10480.95 hm$^3$, of which 9658.83 hm$^3$ correspond to runoff (92.16% of rainfall). The results of the average annual distribution of rainfall are shown in figure 3.

As a graphic result of the spatial analysis of the multi-year average rainfall, the isoheyet map of the area was obtained by means of triangulations (figure 4).

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4. Conclusions
1. The present study constitutes a diagnosis of the current situation of the hydrographic demarcation of Manabí in terms of supply and demand of water. The offer, based mainly on surface runoff, has been determined on the basis of consistent rainfall data of 51 years, while the demand includes needs to cover the consumption of potable water, industrial use, irrigation and hydroenergy generation.
2. According to the estimates made in 1989, the population growth of Manabi by 2020 amounted to 2130000 inhabitants, on the other hand, the projections of INEC 2010 to the year 2050, show a growth of 2085438 inhabitants, that is to say that there is a decrease, which is explained due to the global migratory processes. With these considerations, the average annual water demands of the province of Manabi for potable water and irrigation until the year 2050 amount to 2388.93 hm$^3$.
3. Considering a uniform monthly distribution of water demands for irrigation and AA.PP. and the percentage distribution of the average monthly rainfall, previously estimated, the general values of
excess and water deficit for the DHM were determined. With these results, on the one hand, the average annual volume of water to meet the demands is 2388.93 hm$^3$, on the other hand, the annual volume of runoff has been estimated at 9658.83 hm$^3$, meaning that the latter exceeds demand by 304%. At first glance, one might think that there is no deficit, but in fact there is, and it amounts to 330.27 hm$^3$. This is explained by the fact that there is a marked nonuniformity in the distribution of annual runoff, especially in the dry season (June-November), when the percentage of monthly distribution drops to 0.96% in the month of August. The results are shown in the table 1.

Table 1. Water excess/deficit.

| Month | Water demand (hm$^3$/year) | Runoff | Excess | Deficit |
|-------|---------------------------|--------|--------|--------|
| Dec   | 199.08                    | 481.92 | 282.84 | -      |
| Jan   | 199.08                    | 1575.83| 1376.75| -      |
| Feb   | 199.08                    | 2113.66| 1914.58| -      |
| Mar   | 199.08                    | 2174.28| 1975.20| -      |
| Apr   | 199.08                    | 1623.09| 1424.01| -      |
| May   | 199.08                    | 713.05 | 513.97 | -      |
| Jun   | 199.08                    | 311.88 | 112.80 | -      |
| Jul   | 199.08                    | 160.07 | -      | 39.01  |
| Aug   | 199.08                    | 92.50  | -      | 106.58 |
| Sep   | 199.08                    | 126.50 | -      | 72.58  |
| Oct   | 199.08                    | 124.18 | -      | 74.90  |
| Nov   | 199.08                    | 161.87 | -      | 37.21  |
| Total |                          |        | 2388.93| 9658.83| 7600.17| 330.27 |

4. Many times the decision making to allocate resources for the construction of hydraulic works must be based on solid diagnoses on the problem, and the results of this research lead to establish the need to project and build dams and reservoirs in the territory of the Hydrographic Demarcation of Manabí that allow to store in the rainy season the water and to use it in the dry periods, with which it would be giving solution to this oppressive and historical problem water shortage.

5. The results obtained constitute a valuable tool for specialists and governmental and non-governmental institutions responsible for the control, planning and development of water resources in the region.

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