

# RUN-OFF CHARACTERISTICS OF SMALL RIVERS IN NORTH-EAST BRAZIL

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## 1. Introduction

North-east part of Brazil, extending over an area of about 1,600,000 km<sup>2</sup>, is much less advanced than the southern part of Brazil. This underdeveloped state seems to be partially attributed to the atmospheric conditions of this area. Fig.1 shows an isohyet<sup>1)</sup> of the north-east part of Brazil, extending from 2° to 18° of south latitude and from 35° to 48° west longitude. Areas with a precipitation of about 2000 mm per year are in the eastern coast which may be called humid, however in the interior, there are areas with precipitation less than 400 mm per year. As shown in Fig.1, almost all the area in the interior has an annual precipitation of less than 800 mm. This semi-arid area is called "polygon of droughts". The rainfall in this area concentrates in the rainy season which continues for about three months, with no rainfall in the dry season. Therefore, in the dry season, there is no discharge in the rivers of the interior, except in big rivers such as the San Francisco river.

The annual precipitation shown in Fig.1 gives only the average values, and these vary greatly from year to year. It happens that there is little rainfall for several years. As for the potential evaporation, it reaches about 3000 mm per year over a large part of the interior<sup>2)</sup>. Under such severe atmospheric conditions described above, north-east Brazil has been suffering from the severe damage from droughts. As per records, there were nine prolonged droughts in the 18th century and eight in 19th century, some of which continued several years. And in the 20th century, ten droughts were reported to have caused serious social and economical problems. The most recent drought, which continued for four years from 1979 to 1983, caused severe damages to the economic base of north-east Brazil. Because the north-east has been attacked by a drought almost once every ten years, it is necessary to develop water resources of this part of Brazil. In planning the projects of water resources development, hydrological data such as rainfall data and records of water discharge of rivers are basically necessary. Although data about rainfall have been rather extensively collected for this area, the same for water discharges of relatively small rivers have not been observed. Therefore, the run-off analysis which correlates water discharge with rainfall is of utmost importance for the develop-

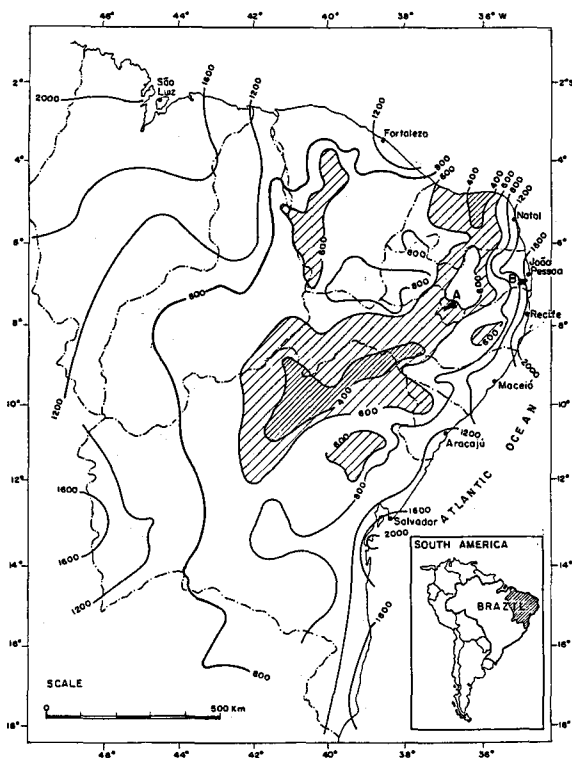


Fig. 1 Mean annual isohyet  
north-east Brazil.

ment of water resources in this area.

In this paper, the characteristics of run-off in the rivers of north-east Brazil are discussed, analyzing the data of precipitation and water discharge observed in two typical river basins - one in the semi-arid area (point A in Fig.1) and the other in the humid area (point B in Fig.1). Detailed discussions are at times unwarranted for fairly large river basins, without detailed data about the soil, geography, vegetation etc. in the basins. Here, the tank model<sup>3)</sup> in which all the unknown factors are considered as coefficients to be determined by trial and error method, using the observed data of rainfall and river discharge for the purpose of calculation of discharges corresponding to the precipitations.

## 2. Summary of river basins

The Gangorra river basin<sup>4)</sup> (Fig.2(a))

This basin is situated in the semi-arid area (point A in Fig.1) with an area of  $137.4 \text{ km}^2$ , almost all of which is with pastures. In this, the average annual precipitation is 500 mm and the rainy season is limited to February - April. During the dry season, there is very little rainfall and the potential evaporation is of the order of 3000 mm per year. The surface of this basin is covered with a soil consisted of sand and silt with a depths less than 1.5 m, beneath which a layer of crystalline rock is formed. Because of this soil structure, there is little storage of groundwater and no discharge in rivers in the dry season. But in the rainy season, the discharge of rivers is relatively large. Such run-off characteristics are common to the rivers of semi-arid area.

The Mamuaba river basin<sup>5),6)</sup> (Fig.2(b))

This basin is situated in the humid area (point B in Fig.1) with an area of  $117.0 \text{ km}^2$ , which is used mainly for agriculture. The average annual precipitation is 1500 mm which concentrates during the rainy season extending from March to August. In the dry season, there is little rainfall and the potential evaporation is relatively small and is about 1200 mm per year. Almost all of the basin is made of alluvial plain and the thickness of the sedimentation is more than 100 m, which is common to the coastal area. Therefore, the capacity of groundwater storage is relatively large in this basin and even in the dry season, it never happens that the discharge of rivers near the sea becomes zero.

The basin characteristics of these two rivers are listed in Table 1.

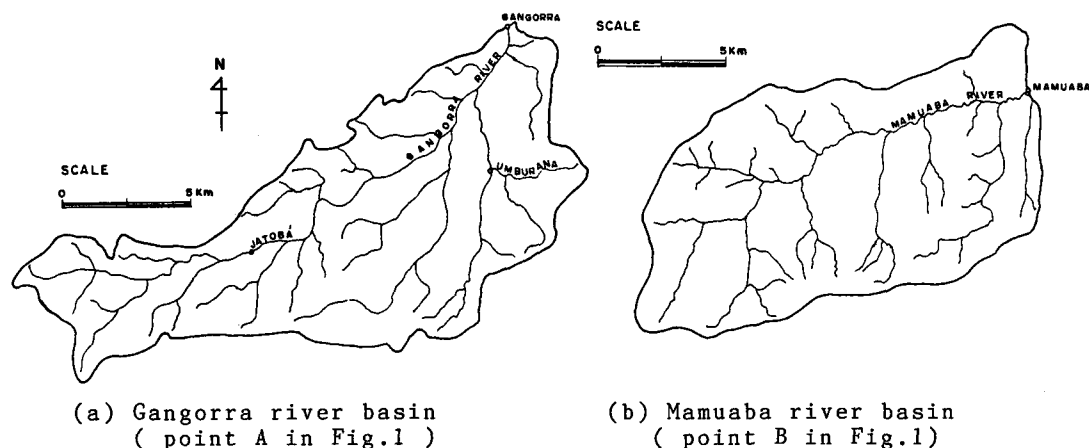


Fig. 2 Basins of Gangorra river and Mamuaba river.

Table 1 Characteristics of the two river basins.

river	point (Fig.1)	basin area (km <sup>2</sup> )	river length (km)	mean pre- cipitation (mm/year)	mean temp. (°C)	potential evap. (mm/year)	climate
Gangorra	A	137.4	30.2	550	24	3,000	semi-arid
Mamuaba	B	117.0	26.0	1,500	27	1,200	humid

### 3. Determination of run-off mechanism

A run-off mechanism of a series storage type, which Sugawara<sup>3)</sup> has been using over the last two decades, is presently named as the tank model. This may be applied for river basins where detailed geological informations are not available. It is important to know the conditions of geology, soil, vegetation etc. for the run-off analysis, because this analysis is fundamentally to pursue water movement on ground surface and underground after rainfall, which is determined by these conditions. But, in most cases it is impossible to get all the detailed data about geological conditions over such a wide and complicated form as the river basin. Once the run-off mechanism (coefficients of the tank model) is determined in certain river basin, the discharge of rivers of other basins, geologically similar to the simulated basin can be estimated from the rainfall data, using the determined tank model.

Daily rainfall and discharge records for three years from 1976 to 1978 for Gangorra river<sup>4)</sup> and from 1972 to 1974 for Mamuaba river<sup>5)</sup> are used to analyze the run-off characteristics of these two river basins. Hourly data may be necessary to precisely analyze flood discharges because these basin areas are relatively small. But, from the viewpoint of water resources development, as a relatively long term run-off plays an equally important role as the short term run-off, the daily data may suffice for the analysis.

The coefficients of the tank-model are determined by the trial and error method, using the data of precipitation and river discharge. Various rainfall intensities such as of heavy, medium and small rains should be included in the data for the determination of the coefficients of the model. Here, a model with three tanks is considered as shown in Fig.3. The seepage per unit time from a tank to the lower tank  $q_s$  and the outflow per unit time from a tank to the river  $q_o$  are expressed as follows;

$$q_s = \beta S, \quad q_o = \alpha (S - H)$$

where  $dS/dt = R - q_s - q_o$ ,  $S$  is the water depth in the tank,  $t$  is the time,  $\alpha$ ,  $\beta$ , and  $H$  are coefficients characterized by the geology of the basin.  $R$  is the rainfall per unit time or  $-E$  (where  $E$  is the evaporation per unit time) for the uppermost tank. For the second and the lowest tanks,  $R$  is the seepage  $q_s$  from the upper tank (plus  $-E$ , only if there is no water storage in the upper tank).

$S$ ,  $R$ ,  $E$ ,  $q_s$  and  $q_o$  are expressed in length units (usually in mm). The uppermost tank is meant mainly for the heavy rains (flood) and the lowermost tank is for the small rains or base discharge. And the second tank is used to adjust the discharge of medium scale. Figs.4 and 5 show the determined coefficients of tank models and examples of run-off simulations for Gangorra and Mamuaba rivers, respectively.

In the Gangorra river basin which flows in a semi-arid area of the interior (Fig.4), the outflow coefficient  $\alpha_1$  and the seepage coefficient  $\beta_1$  of the uppermost tank are dominant. In almost the whole of the

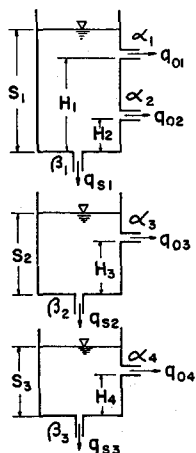


Fig. 3  
Notations.

basin, a layer of crystalline rock is formed with a thin layer of sandy soil on the top, which results in the dominance of  $\alpha_1$  and  $\beta_1$ . In the calculation using the tank model, an evaporation of 4 mm/day is assumed to occur from the uppermost tank with some storage of water. The height of the uppermost outlet  $H_1$  where  $\alpha_1$  is dominant is relatively large, which signifies that the initial rainfall loss after a long time without rainfall becomes large. But if the storage exceeds the height  $H_1$  with heavy rainfalls, the outflow discharge becomes large. And if there is no rainfall for several days, the discharge of the river becomes zero, because of the large evaporation and the small outflow from the underground. As shown in Fig.4, the run-off characteristics simulated by the tank model coincide with those of observed data and the structure of the tank seems to correspond to some extent to the geological structure of the basin. One of the major run-off characteristics of Gangorra river is that the surface run-off is dominant and although the storage of surface soil layer is relatively large, the outflow from the groundwater is very small.

This tank model designed herein for the Gangorra river basin is expected to be applicable to similar basins in the semi-arid north-east Brazil.

As for the Mamuaba river basin which flows in the humid coastal area (Fig.5), the seepage coefficients  $\beta_1$  and  $\beta_2$  are relatively large, which means that the seepage loss to the underground is large. In the calculation, the daily evaporation (with no rainfall) is assumed to be 3 mm/day.

The whole basin is practically an alluvial plain with a thickness of more than 100 m and its

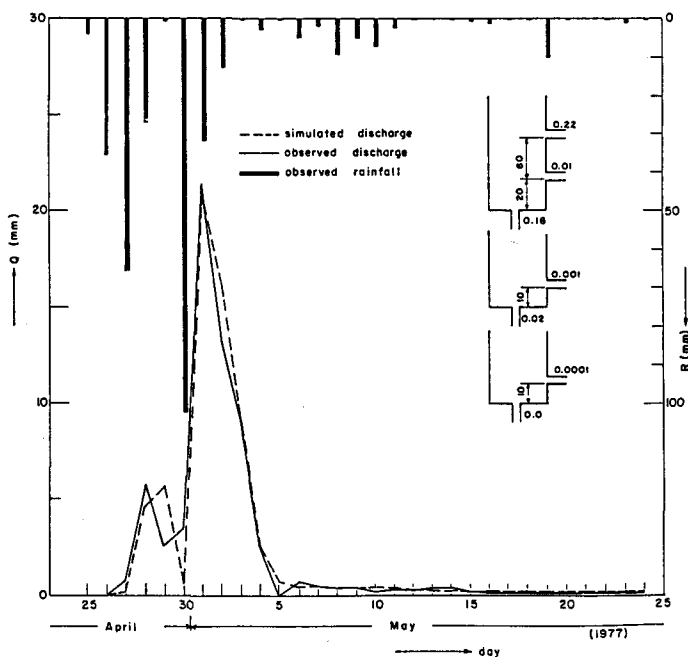


Fig. 4 Daily simulation of Gangorra river.

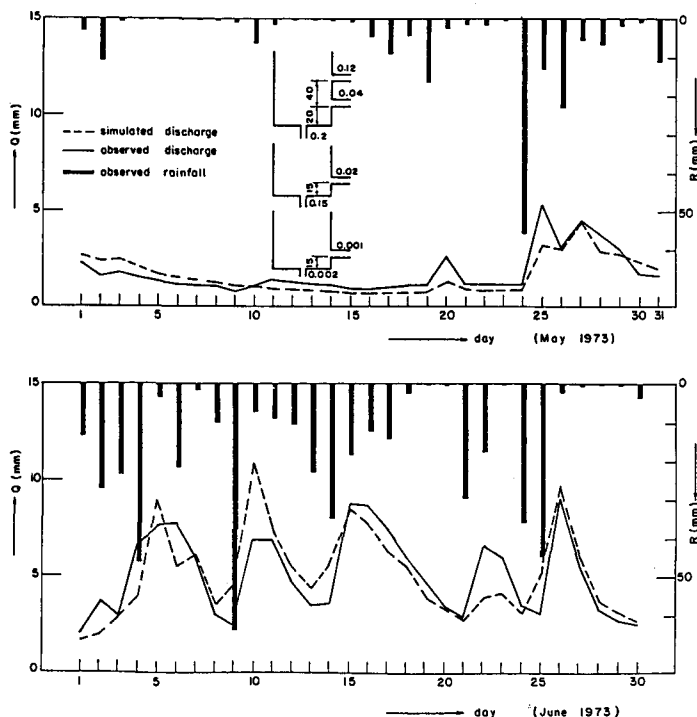


Fig. 5 Daily simulation of Mamuaba river.

permeability is very large. The storage of water in the lowest tank is large because of a large seepage coefficient  $\beta_2$  of the second tank. From the lowest tank which corresponds to the deeper part of the alluvial layer, the base discharge prevails constantly and even during the dry seasons, the discharge of the river never becomes zero.

This tank model seems to correspond to the geological structure of the alluvial basin common to the area near the coast and the simulation results about discharge variation with time concord with the observed data. The coefficients of the tank model developed for the Mamuaba river basin might be applicable to similar river basins in the humid area of north-east Brazil.

#### 4. Analysis of long-term run-off

In the case of water resources development, the long-term discharge or total discharge over a long term such as during a month will be important. Figs.6 and 7 show the monthly discharge variations of Gangorra and Mamuaba rivers, respectively. The simulated monthly discharge in the figures is the summation over one month of daily discharges calculated by the tank model determined above. It seems that the simulated monthly discharges coincide with the observed data fairly well. There is no discharge in the dry season in Gangorra river (Fig.6), which is one of the main characteristics common to the rivers in the semi-arid area of north-east Brazil. In this river, water flows only in the rainy season and concentrates over a period of three months from March to May. And the mean annual discharge height of Gangorra river is 37 mm/year which is only 5 percent of the mean annual rainfall of 705 mm/year during the analyzed period from 1976 to 1978 (Table 2). This implies that 95 percent of the rainfall mainly evaporates due to the climate conditions of the semi-arid area with a high rate of potential evaporation of more than 3000 mm/year.

On the other hand, there is a base flow with a discharge height of about 20 mm per month

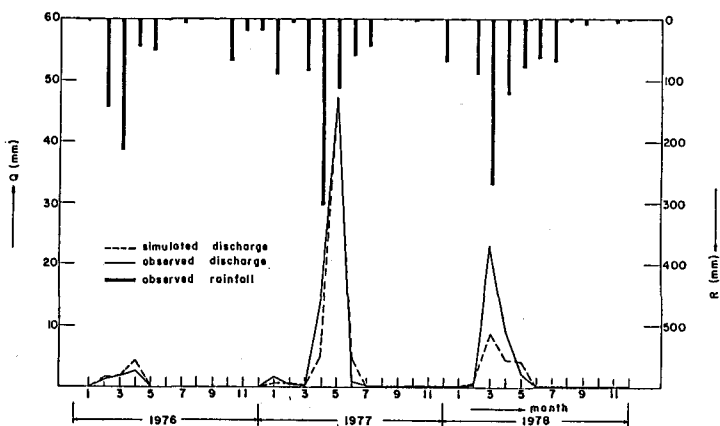


Fig.6 Monthly simulation of Gangorra river.

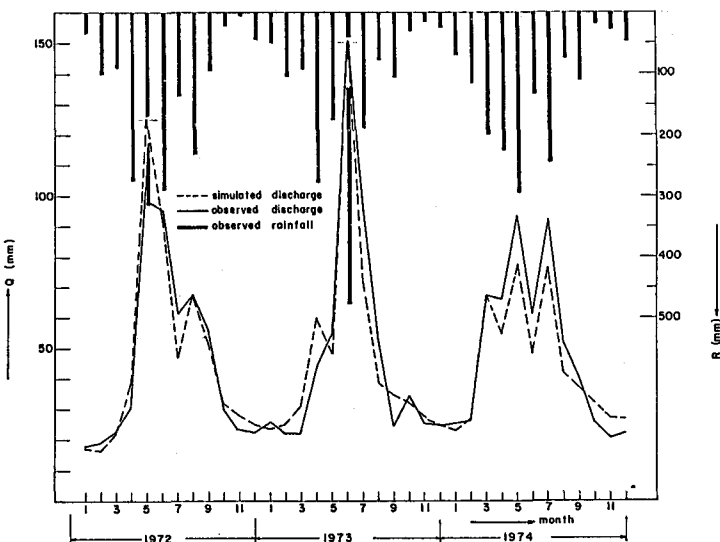


Fig. 7 Monthly simulation of Mamuaba river.

even in the dry season in Mamuaba river (Fig.7). This is common to the rivers in the humid area in north-east of Brazil, because the thickness of the sedimentation is generally more than 100 m and the storage capacity of groundwater is relatively large. The mean annual discharge height of Mamuaba river is 570 mm which is about 35 percent of the mean annual rainfall of 1618 mm during the period from 1972 to 1974 (Table 2). It appears that the evapotranspiration in the humid area is much smaller than the semi-arid area.

**Table 2 Run-off characteristics of the two rivers.**

river	mean annual rainfall(mm)	mean annual rainfall(mm)	run-off rate
Gangorra	705	37	0.05
Mamuaba	1618	570	0.35

## 5. Conclusions

The run-off characteristics in two small rivers of north-east Brazil were analyzed and following conclusions were obtained;

- 1) From the viewpoint of run-off characteristics, rivers in north-east Brazil might be divided into two groups: rivers in the semi-arid area characterized by crystalline rock and rivers in the humid area with sedimentation.
- 2) The run-off mechanism of these two types of rivers can be expressed fairly well by the tank models which conceptionally correspond to the geological conditions of each river basin.
- 3) The Gangorra river which is one of the typical rivers in the semi-arid area has flow discharges occurring only a few months and the annual mean run-off rate is only 5 percent, with the mean annual discharge height of only 37 mm. In the crystalline rock region, the storage capacity of groundwater is very small.
- 4) The Mamuaba river in the humid area of sedimentation has a base discharge of about 20 mm/month and the annual mean run-off rate amounts to 35 percent with the mean annual discharge height of 570 mm. The area with sedimentation has a big storage capacity of groundwater.

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