## まえがき

B. Datta 氏は，インド国立水文研究所の研究員であり，UNESCO（ユネスコ）の援助（UNDP－IND／74／045）を受けて，昭和58年2月中旬から7月中旬までの5カ月間当センターに滞在し，タンク・モデル及び貯留関数法を用いての流出解析，水文学の各種の知識，技術についての研修を行った．

特に，当センターが開発したタンク・モデルの習得を兼ねて，インド，デカン高原北部を流れるNarmada川の支川，Jamtara 流域とBelkheri 流域の流出機構を，タンク・モデルによって求めた．

この報告は，この二つの流域についての日流量解析及び洪水解析の結果の報告であり，Datta 氏の研修報告書というべきものである．

第4研究部　渡辺一郎

# RUNOFF ANALYSIS OF TWO INDIAN BASINS USING TANK MODELS

BHASKAR DATTA*

## ABSTRACT

Tank models as developed by Dr. M.Sugawara has been used to obtain Tank models of two Indian basins Jamtara and Belkheri located in the Central part of India. These two basins are the sub-basins of Narmada river basin. Narmada river is the largest west flowing river of peninsula and is the fifth largest basin of India. The basin Jamtara is a part of the Narmada river basin from its source at Maikala hill range upto Jamtara discharge measuring site having a catchment area of 16575 sq.km. The basin lies between east longitudes 79°-45' to 81°-45' and north latitudes 21° 20' to 23° 45'. The basin falls in the upper hilly zone of Narmada basin and experiences average annual rainfall of 1480 mm. Upper reaches of the basin is well forested and covered with good quality sal and Teak Woods. Soil of the basin is loamy clay in general with red, yellow and black variety. The basin Belkheri is the drainage basin of river Sher, a tributory of river Narmada, from its source at Mahadeo hills upto Belkheri discharge measuring site having a catchment area of 1508 sq.km. The basin lies between east longitude 79° 15' to 79° 45' and north latitudes 22° 24' to 22°57'. The basin experiences average annual rainfall of 1340 mm.

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*Scientist-C, National Institute of Hydrology, Roorkee-247667, U.P., INDIA; worked mainly on Tank model with Indian data under the guidance of Mr. I.Watanabe, Director, Fourth Research Division, NRCDP, Japan during his five months training at NRCDP from mid February to mid July'83 under UNDP programme.

Upper reaches of Belkheri basin is mainly covered with Teak woods. Soil of the basin is loamy clay of deep black variety. Both the basins experience about 90% of average annual rainfall in five Monsoon months from June to October and comparatively long dry period of seven months from November to May. The basins do not experience any snowfall. From the available hourly data of Monsoon period for 1978 and 1979 of Jamtara basin, four floods have been selected and using six hourly rainfall, runoff and evapotranspiration values, Tank model for flood analysis of the basin has been obtained and six hourly runoff values have been simulated. It is observed that the overall fit of the computed hydrograph is quite good, specially fit for the second and third floods. From the available hourly data of Monsoon period for 1978 and 1980 of Belkheri basin, two floods have been selected and using three hourly rainfall, runoff and evapotranspiration values, Tank model for flood analysis of Belkheri basin has been obtained and flood hydrograph has been simulated. It is observed that the overall fit of the computed hydrograph is quite good. Using available daily rainfall, runoff and monthly mean of daily evapotranspiration values for 1978 and 1979 of Jamtara basin, Tank model for daily analysis has been obtained and daily flow is simulated. Then dividing the basin into four parts and using the data for the same period, 4x4 Tank model for daily analysis has been obtained and daily flows are simulated. Performance of the two models are then compared to find suitability of the model. It is observed that the 4x4 Tank model has given better simulated runoff both for peak flows in the five rainy Monsoon months and low flows in the remaining seven dry months. From this analysis, it is seen that the Tank model for flood analysis and 4x4 Tank model for daily analysis can suitably be used for Indian basins.

## 1.0 INTRODUCTION

Different rainfall runoff models are in use in India for simulation of flood and/or daily runoff. Use of Tank models for simulation of flood and daily runoff are comparatively new in India. Only a few basins have been analysed by Tank models so far. Hydrometeorology varies widely in India from place to place. Topographically India can be divided broadly into two parts, Gangetic plains and Deccan plateau. Besides innumerable small and medium mountains, there are number of big mountain ranges like Himalaya, Western Ghat, Eastern Ghat, Vindhya, Aravalli etc. which influence the hydrometeorology to a great extent. Annual rainfall varies from less than 200 mm in the Western desert area to more than 4000 mm in the north eastern and in the Westernghat area. Almost throughout India, southwest Monsoon is responsible for 75% to 90% of annual rainfall in five months from June to October and mainly dry weather prevails in the remaining seven months. Only small parts of India, Easternghat and eastern Himalayan and sub Himalayan areas experience quite reasonable winter rainfall. Northern Himalayan and sub Himalayan areas experience medium to heavy snowfall in winter months. In the eastern part of India, Cherrapungi, a gauging station situated in the Khasi hill district, experiences maximum annual rainfall in India and has three world highest records of five-day, one month and one year rainfall. India can be divided into eight climatic regions like polar, hot desert, cold humid winter, tropical savannah, dry winter hot summer followed by heavy rain etc.

Two sub basins of Narmada river basin, Jamtara and Belkheri located in the Central part of India have been selected to undertake flood and daily analysis by Tank models. The two basins fall in the tropical Savannah Climatic region. Catchment area of the

Jamtara basin is comparatively large and is 16575 sq.km. For Jamtara basin available hourly rainfall values of the three self recording raingauge stations (SRRG) at Jamtara, Mandla and Pendra Road for 1978 and 1979 and daily discharge and hourly stage values for Monsoon period of 1978 and 1979 of river Narmada at Jamtara have been used to obtain Tank models for flood analysis, daily analysis and 4x4 Tank models of the basin. Simulated hydrographs have been compared with observed one to find the suitability of the models for such hydrometeorological conditions. There are number of ordinary raingauge stations (ORG) in the basin but the available data are very much discontinuous, where as SRRG data are available continuously. So, daily rainfall values are also computed from three SRRG stations data. For Belkheri basin, data of three SRRG Stations at Lakhandon, Harrai and Narsinghpur for 1978 and 1980 and daily discharge and hourly stages of Monsoon period for 1978 and 1980 of river Sher at Belkheri have been used to obtain Tank model for flood analysis. Discharge hydrograph is simulated and compared with observed hydrograph to know the suitability of the model. Available discharge data are very much intermittent, so could not be used for daily analysis. Study of these two basins by Tank models can further be continued when longer period data will be available.

## 2.0 Basins And Data

Jamtara and Belkheri basins are the Sub basins of Narmada river basin. Data of Jamtara basin were utilised for flood and daily analysis by Tank models and data of Belkheri basin were utilised for flood analysis by Tank model.

## 2.1 The Basins:

Narmada river basin is the fifth largest basin of India and is the largest west flowing river of the peninsula. Total length of river is 1312 km and catchment area is 98796 sq.km. The basin lies in the northern extremity of the Deccan plateau between east longitudes $72^{\circ}$ 32' to $81^{\circ}45'$ and north latitudes $21^{\circ}20'$ to $23^{\circ}45'$. Fig.-1 shows the location of Narmada basin and Jamtara and Belkheri sub basins. The Narmada basin is bounded on the north by Vindhya hill ranges, on the east by Maikala hill ranges on the south by Satpura hill ranges and on the west by the Arabian sea. The hills sorrounding the basin are not very high and the heights vary from 600 meter to 1000 meter. The basin has an elongated shape with a maximum length of 953 km from east to west and a maximum width of 234 km. from north to South. The basin has five well defined physiographic zones and they are upper hilly areas, upper plains, middle plains, lower hilly areas and lower plains. The river has 41 tributories of which 22 are on the left bank and 19 on the right. The river Narmada rises from the Amar Kantak Plateau of Maikala hill ranges at $22^{\circ}40'$ north latitude and $81^{\circ}45'$ east longitude at an elevation of 900 meter from MSL. The river has number of falls in its head reaches. Flowing in a generally south Westerly direction in a narrow and deep valley the river takes pin head turn at places. Close to Jabalpur City, 404 km. from the source, the river drops nearly 15 meter at Dhaundhara falls, after which it flows through a narrow channel carved through the famous marble rocks. Emerging from the marble rocks, the Narmada enters the upper furtile plains and receives river Hiran from right at 464 km. Continuing to flow in a westerly direction through upper and middle plains, the river receives several tributories like Sher, Shakkar, Dudhi, Tawa, Ganjal

Tendoni, Barna and Kolar. Flowing further west, the river enters the lower hilly regions and flowsthrough 113 km long gorge and receives the river Goi from left and the Uri and the Hatni from the right. The garge is formed by Converging the Vindhya hill ranges from the north and the Satpura ranges from the south. Emerging from the gorge, the river enters the lower plains and meanders in broad curves. The Karjan from left and Orsang from right are the two important tributories joining the river in this reach. The valley then widens into an estuary and joins into the Gulf of Cambay.

Jamtara basin is the part of Narmada basin from its source at Maikala hill range upto Jamtara stage and discharge gauging station, containing 399 km of main Course of the river Narmada. This falls in the upper hilly zone of Narmada basin. Catchment area of the Jamtara basin is 16 575 sq.km. The basin lies between east longitudes $79^{\circ}45'$ to $81^{\circ}45'$ and north latitudes $21^{\circ}20'$ to $23^{\circ}45'$. Fig.-2 shows the details of Jamtara basins. In this basin, two important tributories, Burhner and Banjar meet the river Narmada from left at 248 and 287 km reaches near Mannot and Mandla respectively. The river Burhner rises in the Maikala hill range at an elevation of about 900 meter at north latitude $22^{\circ}32'$ and east longitude $81^{\circ}22'$ and flows generally westerly direction for a total length of 177. km. The river Banjar rises in Mahadeo hills of Satpura hill range at an elevation of 600 meter at north latitude $21^{\circ}42'$ and east longitude $80^{\circ}50'$ and flows generally north westerly direction for a total length of 184 km. Soil of Jamtara is loamy clay, in general with about 60% area having red and yellow variety, about 25% area having deep black variety and rest portion having medium black variety. Upper reaches of the basin is well forested and covered with good quality Sal and Teak woods. Population density of the basin is

quite low and is only 66 per sq.km. against 182 for India as a whole.

The basin Belkheri is the drainage basin of river Sher upto the discharge measuring site at Belkheri having a catchment area of 1508 sq.km. and next sub basin west of Jamtara sub basin. The Belkheri basin lies between east longitude $79^{\circ}15'$ to $79^{\circ}45'$ and north latitude $22^{\circ}25'$ to $22^{\circ}55'$. Details of the basin is shown in Fig.-3. The river Sher rises from Mahadeo hills of Satpura hill ranges at an elevation of 600 meter at north latitude $22^{\circ}31'$ and east longitude $79^{\circ}25'$ and flows in a generally north westerly direction. The upper reaches of Belkheri basin is mainly covered with Teak woods. Soil of the basin is loamy clay of deep black variety.

## 2.2 Hydrometeorology

Major part of the Narmada basin lies just below the tropic of cancer. The climate of the basin is humid and tropical although at places extremes of heat and cold are often encountered. The basin falls in the tropical Savannah Climatic region. In the year four distinct seasons occur in the basin and they are cold, hot, southwest Monsoon and post Monsoon. In the cold weather, the mean temperature varies from $17.5^{\circ}C$ to $20^{\circ}C$ and in the hot weather from $30^{\circ}C$ to $32.5^{\circ}C$. The maximum and minimum temperatures at Mandla and Jabalpur Cities for four periods are given in Table 1.

Table-1: Maximum and Minimum Temperatures of Mandla and Jabalpur in $^{\circ}C$

| Station | For: Jan-Mar | | For: April-June | | For: July-Sept | | For: Oct. - Dec. | |
|---|---|---|---|---|---|---|---|---|
| | Max | Min | Max | Min | Max | Min | Max | Min |
| Mandla | 34.9 | 9.0 | 40.2 | 19.6 | 29.1 | 21.7 | 29.4 | 6.8 |
| Jabalpur | 36.2 | 10.1 | 42.1 | 21.0 | 30.6 | 23.1 | 30.5 | 7.7 |

Table-2 : Annual and Monthly Average Rainfall of Jamtara and Belkheri Basin in mm

| | Jamtara Basin | Belkheri Basin |
|---|---|---|
| January | 33.5 | 20.0 |
| February | 35.0 | 24.5 |
| March | 24.0 | 18.0 |
| April | 18.0 | 12.5 |
| May | 15.5 | 13.5 |
| June | 190.0 | 171.0 |
| July | 440.0 | 425.0 |
| August | 420.5 | 367.5 |
| September | 221.0 | 210.5 |
| October | 57.0 | 49.5 |
| November | 18.0 | 18.5 |
| December | 7.5 | 9.5 |
| Annual Average Rainfall | 1480.0 | 1340.0 |

Southwest Monsoon from June to October is the principal rainy season for the basin accounting for about 90% of the annual rainfall. During this period a series of tropical storms originating in Bay of Bengal move west, northwest towards the basin and sometimes move parallel along the length of the basin and emerge at Arabian sea. Average annual rainfall over the Narmada basin is 1230 mm. Rainfall decreases from more than 1550 mm in the eastern part to 750 mm in the western part. The rainfall is heavy in the upper hilly area and upper plains of the basin.. It gradually

decreases towards lower plains and lower hilly areas and again increases towards coastal plains. July is the rainiest month with a third of the annual, closely followed by 27% in August. Rainfall in the post rainfall season from October to December is about 5% of the annual total in different parts of the basin; the amount ranges between 30 mm to 100 mm. Rainfall in the winter two months, January and February accounts to 4% of the annual in the eastern part with an average of 60 mm. Over most of the reminder of the basin, it is negligible being less than 10 mm. Rainfall in the period from March to May is negligible except in upper hilly zones which receives about 50 mm. The basin average is only 27 mm. Average annual rainfall and approximate mean monthly rainfall for two basins Jamtara and Belkheri are given in Table-2. Coefficient of variation of annual rainfall for stations Mandla and Lakhandon are 21% and 19% respectively.

2.3 Method of Measurement And Data Used:

There are two types of rainfall measuring instruments in the basin, firstly ordinary rain gauge (ORG) which gives daily rainfall and secondly self recording rain gauge (SRRG) which continuously record the rainfall. Hourly rainfall data are tabulated from such continuous record. In Jamtara basin there are number of ORG stations but data of ORG stations are not available continuously where as SRRG stations data are available continuously. For Jamtara basin available hourly rainfall data of three SRRG stations namely Jamtara, Mandla and Pendra Road for 1978 and 1979 have been used for both flood and daily analysis. The station Pendra Road lies little outside, east of the basin but very close to the basin; so data of this station is also considered for analysis. In Belkheri basin there are three SRRG stations at Lakhandon, Harrai and Narsinghpur. The station Narsinghpur lies

little outside of the basin and downstream of Belkheri, the discharge measuring site of river Sher. Available hourly rainfall data of the three stations Lakhandon, Harrai and Narsinghpur for 1978 and 1980 have been used for flood analysis by Tank model. SRRG data of Narsinghpur station is also considered as it is very close to the basin.

The discharge of river Narmada at Jamtara is measured with current meter once in a day at 8 O'clock in the morning and is available as daily discharge. Discharge is measured once in a day in the morning, generally at 8 O'clock, throughout the year in all important sites of major rivers and hourly gauges are measured only in the Monsoon months from 1st June to 15th October to monitor peak flows in flood season. For this Jamtara site daily discharge and hourly gauges are available only for the Monsoon months and available data of 1978 and 1979 have been used for analysis. Daily evaporation values are available from two class A type pan evaporimeter situated both sides of Jamtara basin at Pendra Road and Jabalpur. Average daily evaporation values of these two stations have been used as daily evaporation values of Jamtara basin. Evaporation values of Jabalpur station have been used for Belkheri basin. The two basins Jamtara & Belkheri do not experience any snowfall in winter months and there is no snow covered mountain peaks. Topographic, vegetation and soil maps of the basins have been consulted to find the basin area, to judge the orographic effect, to divide the basin into number of zones for 4x4 Tank model and helps in selecting initial set of parameter values for first trial run.

## 3.0 ANALYSIS RESULT AND DISCUSSION

For Jamtara basin flood analysis, daily analysis and 4 x 4 Tank model for daily analysis has been done using available data of 1978 and 1979. For Belkheri basin only flood analysis has been done from the available data of 1978 and 1980. Available daily discharge data of Belkheri basin for Monsoon months are too discontinuous to be used for daily analysis.

### 3.1 Flood Analysis

For flood analysis, Tank model with three tanks laid vertically in series with top tank having three side outlets has been considered for both Jamtara and Belkheri basin.

#### 3.1.1 For Jamtara basin

Available daily discharge data of Monsoon period i.e. from June to mid October of 1978 and 1979 of Jamtara basin have been plotted in semilog paper and therefrom four floods, three medium and one large, have been selected for flood analysis. The four floods that have been selected are for the following periods:

(i) First flood ( medium) : From June 22 to July 13, 1978
(ii) Second flood (medium) : From August 1 to August 20, 1978
(iii) Third flood ( medium): From August 20 to September 2, 1978
(iv) Fourth flood ( Large): From June 21 to August 29, 1979.

Time unit for flood analysis of Jamtara basin has been selected as six hours. Using available daily stage and discharge values, stage-discharge relationship is established from the straight line fit obtained from H vs $\sqrt{Q}$ plot. Six hourly discharge values for the selected flood periods have been calculated from the corresponding stage values taken from available hourly stage records. Six hourly precipitation values have also been calculated for the flood

periods for the three SRRG stations namely Jamtara, Mandla and Pendra Road. Mean evapotranspiration value of 1 mm/6 hour has been considered. The value of $\alpha = 0.15$ has been calculated from observed hydrograph. Using this value of $\alpha$, the initial value of parameters of the three tanks has been selected for first trial run as below.

For: Top Tank $A_0 = A_1 = A_2 = A_3 = 0.075$
$HA_1 = 15$, $HA_2 = 25$, $HA_3 = 40$

2nd Tank $B_0 = B_1 = B_2 = 0.015$, $HB = 15$

3rd Tank $C_0 = C_1 = C_2 = 0.003$, $HC = 15$

Initial values of coefficient of precipitation ( $C_p$) and weight of discharge ( $W_e$) of the three rainfall stations have been considered as unity.

From subsequent trials, it is observed that the rainfall of Pendra Road station has no effect on runoff of Narmada at Jamtara and effect of raingauge station of Jamtara is 25% i.e. $W_e = 0.25$. Base flow component for four floods has been considered as zero in the first run and then the values have been provided from the result of first run. The lag time for rainfall station Mandla is found to be unity i.e. 6 hour. In subsequent trials other parameters have been adjusted till a best fit computed hydrograph with observed one is obtained. Fourteen trials have been made to arrive at the final Tank model for flood analysis of Jamtara basin. Fig-4 shows the model with different parameter values. The final computed hydrograph with observed one are shown in Fig-6. It is observed that the overall fit of the computed hydrograph with observed one is quite good. The first flood is slightly overestimated; the fit for second and third floods are good. The peak flow of the fourth flood has matched nicely but the fit for the low flows are not good. For flood analysis, emphasis is to be given more on the match for peak flows. The model has simulated peak flows nicely for the fourth

flood also.

3.1.2 For Belkheri Basin

Available daily discharge data of Monsoon period for 1978 and 1980 have been plotted in semilog paper and two floods, one medium and other small, for the periods July 5 to September 2, 1978 and June 24 to July 8, 1980 respectively have been selected for flood analysis by Tank model. Available data of 1979 is too discontinuous to be used for analysis. Time unit for flood analysis of Belkheri basin is considered as three hours. Using the rating curve established from observed daily rainfall and runoff, three hourly discharge values for flood periods have been computed from available gauge records. Three hourly precipitation values for flood periods have also been calculated for three SRRG stations Lakhandon, Harrai and Narsingpur from available hourly rainfall values. Evapotranspiration value of 0.5 mm/3 hour has been considered. From observed hydrograph, value of $\mathcal{L} = 0.104$ has been computed and in similar way as done in case of Jamtara basin, initial set of parameter values for first trial run has been considered. From the result of initial trial, value of base discharge for first and second flood has been considered as 0.02 mm and 0.005 mm respectively. From the result of subsequent trials it is observed that, though the rainfall station Lakhandon lies within the Belkheri basin, it has no effect on runoff of river Sher at Belkheri. It appears that there are some errors in observed rainfall data of Lakhandon or the raingauge station is under the influence of orographic effect. Though the Narsinghpur raingauge station is little outside the basin and at downstream side of river Sher from Belkheri, rainfall of this station has direct influence on the runoff characteristics of river Sher at Belkheri. The weights of discharge of rainfall stations Lakhandon, Harrai and Narsinghpur have finally been taken as 0.0, 1.0 and 1.0 respectively. Time lag of the station Harrai is found

to be 4 units i.e. 12 hours. After six trials final Tank model for Belkheri basin has been obtained and is shown in Fig-5. The final computed hydrograph with observed one are shown in Fig-7. It is observed that the overall fit of the computed hydrograph with observed one is quite good. The first flood has matched very nicely almost throughout the flood period considered, except for the last seven days where it is slightly underestimated. This may be due to relatively high rainfall in ungauged upper hilly reaches. The overall fit of the computed hydrograph for second flood is good; the rising part and the peak flow have matched nicely with observed hydrograph. Flow is slightly overestimated in the recession part.

### 3.2 Daily Analysis

Tank models for daily analysis applicable to humid basin and 4 x 4 Tank model for daily analysis applicable to non-humid basin have been obtained for Jamtara basin using daily rainfall, runoff and evapotranspiration values for 1978 and 1979. Using the models, daily runoff have been simulated and performance of the two models has been compared.

#### 3.2.1 Daily Analysis of Jamtara Basin by Daily Analysis Tank Model

For the Jamtara basin, Tank model for daily analysis applicable to humid basin is considered to contain four tanks laid vertically in series. Top tank contains two side outlets. Available daily rainfall of the three stations Jamtara, Mandla and Pendra Road from June 1978 to December 1979, daily runoff for Monsoon months of 1978 and 1979 and monthly mean of daily evapotranspiration values for respective months from January to December have been considered for analysis. Mean daily rainfall values of the basin have been calculated for the period. From the observed runoff hydrograph the value of coefficient $\alpha$ is calculated to be 0.23 and the initial set of parameter values considered for first trial run are

For, Top tank $A_o = A_1 = A_2 = 0.115$

$HA_1 = 15$, $HA_2 = 40$

2nd Tank $B_o = B_1 = 0.023$, HB = 15

3rd Tank $SC_o = C_1 = 0.0046$, HC = 15

4th Tank $D_o = 0.0$, $D_1 = 0.001$, HD = 0.0

Other parameters considered for initial trial are

(i) primary and secondary soil moisture storage of top tank: $S_1 = 50$ mm, $S_2 = 250$ mm.

(ii) Water supply rates $K_1 = 2.0$ and $K_2 = 20.0$

(iii) Coefficient of precipitation $C_p = 1.0$ and weight of runoff $W_e = 1.0$

(iv) monthly mean of daily evapotranspiration values considered for different months are (in mm/day)

| | | |
|---|---|---|
| Jan. = 2.3 | May = 6.6 | Sept. = 3.5 |
| Feb. = 3.3 | Jun. = 5.5 | Oct. = 3.5 |
| Mar. = 4.5 | Jul. = 3.3 | Nov. = 2.6 |
| Apr. = 5.6 | Aug. = 3.3 | Dec. = 2.1 |

From the result of first trial run, it is observed that the calculated flow is underestimated for the complete Monsoon periods of 1978 and 1979. The precipitation stations are located in the plains or low altitudes, where as there may be heavy rainfall in upper mountain reaches. The mean rainfall values calculated from the SRRG stations seem to be low, so the $C_p$ is increased and by trials, it is observed that $C_p = 1.2$ gives good result.

Fifteen trials have been made to arrive at the final model structure and is shown in Fig.8 with parameter values. Using this model the runoff hydrograph for the period from June'78 to December'79 has been simulated and is plotted togather with observed hydrograph as shown in Fig.10. Overall fit of the computed hydrograph with observed one for 1978 and 1979 is good.

The fit for 1979 is better than that of 1978. Two major peak flood occured in 1979, one in July and the other in August. The July flood is overestimated where as August flood is underestimated. Fit of low flow for Monsoon months of 1979 is better than that of 1978. The low flow computed for the dry months from November 1978 to May 1979 shows a graduall fall of the rate of flow and it has reduced to zero by the end of first week of May. But in reality river Narmada has a steady base flow in dry season. So the model has not simulated low flow properly. As the dry season continues, the saturated area of the basin gradually reduces and only the area nearer to the river bed remains in saturated state. Soil moisture reduces as the distance of the place from river bed increases. As the Jamtara basin experiences long dry period of seven months, 4x4 Tank model suitable for non humid basin or basin experiencing long dry period is tried next by dividing the basins into number of zones to judge the suitability of the model.

3.2.2 Daily Analysis of Jamtara Basin by 4x4 Tank Model.

The 4x4 Tank model for Jamtara basin is considered by dividing the basin into four zones. Each zone contains four tanks laid vertically in series. So in total, the model contains 16 tanks. Three side outlet model for the top tanks of each zone is considered. Daily rainfall runoff and evapotranspiration values for the same period as has been considered in previous daily analysis model, has been considered for this model also. Taking $\alpha = 0.23$, initial set of parameter values for all the four zones has been fixed in a similar way as has been done in case of previous daily analysis model. The initial set of other parameter values considered for 4x4 Tank model for first trial run are:-

(1) ratio of area of different zones $S_1 : S_2 : S_3 : S_4 : = 0.675 : 0.225 : 0.075 : 0.025$

(ii) initial storage height of secondary soil moisture of each of the top tank, XS = 5 mm.

(iii) saturation height, HS = 600 mm.

(iv) multiplying factor of basin precipitation for each month from January to December as unity.

From the result of the first trial run, it is observed that the higher flows has matched reasonably well and the low flows at the initial stage has been underestimated. So the initial storage value has been considered as 75% of storage that remained at the end of May'879. All the parameter values have been adjusted in the successive trials till an overall good fit is obtained. The final 4x4 Tank model for Jamtara basin with channel deformation has been obtained after 16 trials and the model is shown in Fig.9 with different parameter values. Other parameter values of the model are:

For zones

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| XA | 0.0 | 0.0 | 0.0 | 0.0 |
| XS | 6.0 | 6.0 | 7.0 | 7.0 |
| XB | 0.0 | 0.0 | 0.0 | 0.0 |
| XC | 0.0 | 9.0 | 120.0 | 360.0 |
| XD | 0.0 | 120.0 | 390.0 | 840.0 |
| HS | 500.00 | 500.0 | 500.0 | 500.0 |

And PP = 1.0, PA = 1.2

PB (N) = 1.0 for N = 1 to 12

TB = 2.0, TC = 20.0 Lag = 0.0

Using this 4x4 Tank model, the runoff is simulated from June'78 to December'79 and plotted with observed runoff for Monsoon periods of 1978 and 1979 as shown in Fig.11. The overall fit of the computed hydrograph with observed one is good. Peak flows of the Monsoon period of 1978 and 1979 has matched nicely. Recession

slopes of the two major peak flows of 1979 has matched nicely. Overall nature of fit of the computed hydrographs of the Monsoon periods of 1978 and 1979 obtained from this daily analysis model is similar to that of the previous daily analysis model, except some mentionable improvement in the fit of the low flows of 1979. Response to small rainfall during low flow period is smoother from 4x4 Tank model. This justifies the fact that when some small storm rainfall occurs during continuation of low flows, initial part of the rainfall gets absorbed in the dry part of the basin. Most remarkable improvement about the performance of this model is that the model simulated a steady base flow for long dry season of seven months from November'78 to May'79, which justifies the fact. So the overall performance of the 4x4 Tank model for Jamtara basin is much better than that of the daily analysis model for humid basin.

## 4.0 CONCLUSION

In this study, overall performance of the Tank model for flood analysis for two basins Jamtara and Belkheri is found to be good. These two basins experience about 90% of average annual rainfall in five Monsoon months from June to October. Most of the basins in India experience 75% to 90% of annual rainfall in Monsoon months. So, Tank model for flood analysis can suitably be used to simulate peak flows of such Indian basins. Study on flood analysis has been made here considering four floods selected from two years data for Jamtara basin and two floods selected from two years data for Belkheri basin. But more number of floods from number of years are generally considered as sufficient to undertake such study.

It is observed that the overall performance of the Tank model for daily analysis for Jamtara basin is reasonably good. Jamtara

basin experiences long dry period in non Monsoon months from November to May. Performance of the model for high flows during Monsoon months is good but the performance of the model for low flows particularly for long dry period is not good. Performance of the 4x4 Tank model for daily analysis for the Jamtara basin is found to be better than that of the previous model both for peak flows and for low flows. So, from the present study, 4x4 Tank model is found to be a suitable daily analysis model for such basins experiencing long dry period. Study on daily analysis has been made considering two years data of one basin which cannot be considered as sufficient to take any general conclusion.

Study on flood analysis and daily analysis by Tank models will further be made when data for longer period will be available for these two basins. Study will also be made with data of other Indian basins selected from different hydrometeorological conditions.

## ACKNOWLEDGEMENT

The author expresses his deep sense of gratitude to Mr. I. Watanabe for providing guidance in taking the present study and also in extending all help and guidance during his five months training including four weeks field visits at Japan. The author also expresses his deep sense of gratitude to renowned hydrologist Dr. M. Sugawara for providing valuable suggestions and guidance on Tank model studies during his stay at NRCDP, Japan.

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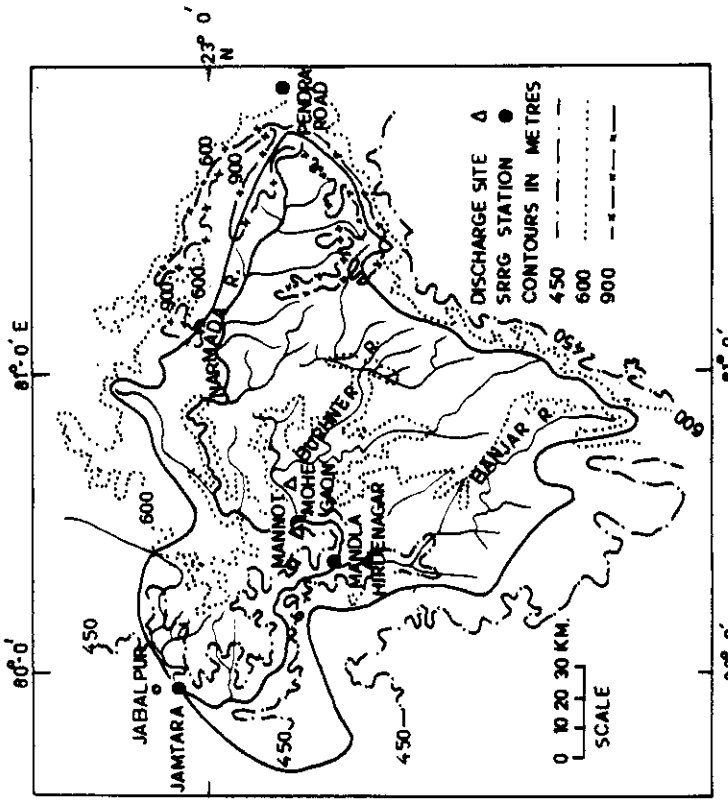


FIG. 2. MAP OF JAMTARA BASIN

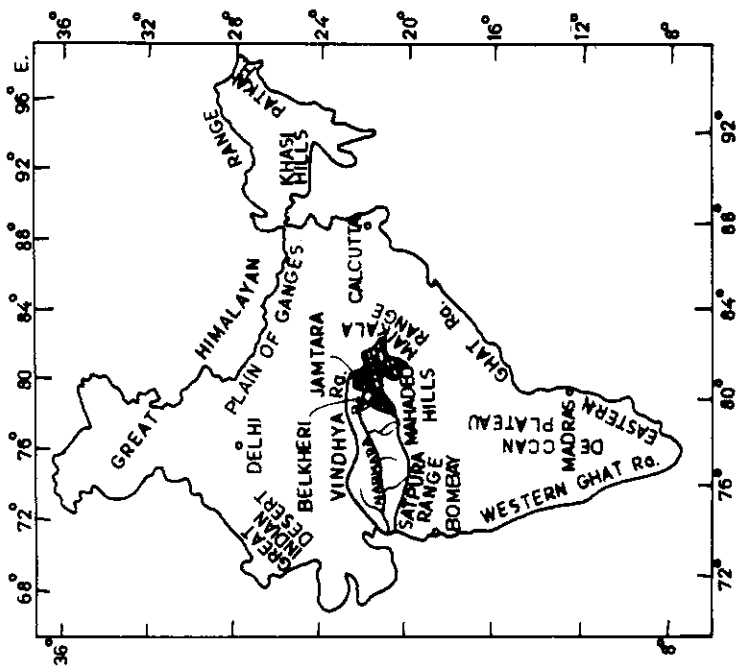


FIG.1. INDEX MAP SHOWING THE JAMTARA AND BELKHERI SUB BASIN OF NARMADA RIVER BASIN IN INDIA

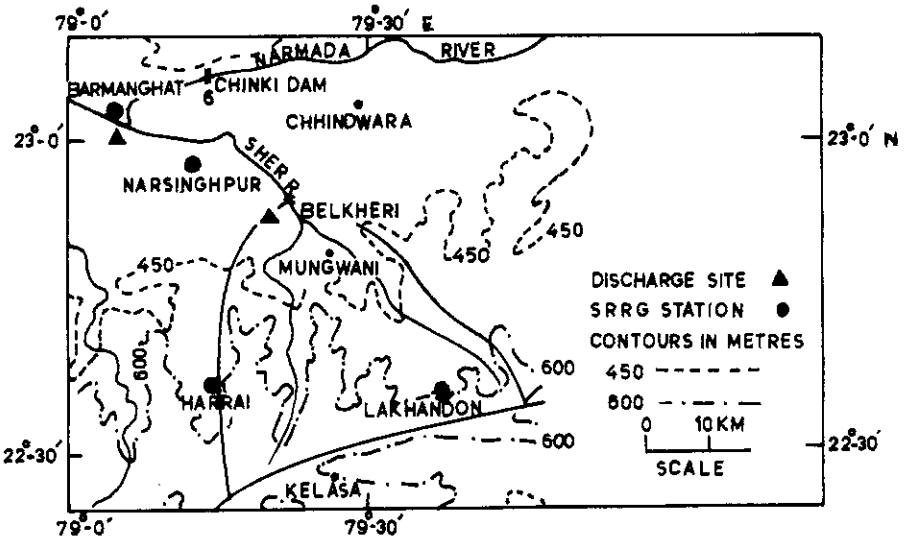


FIG. 3. MAP OF BELKHERI BASIN

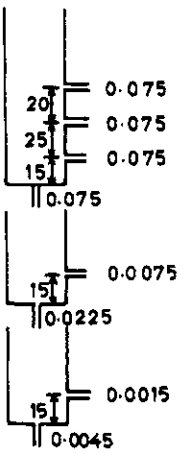


FIG. 4. TANK MODEL FOR FLOOD ANALYSIS OF JAMTARA BASIN

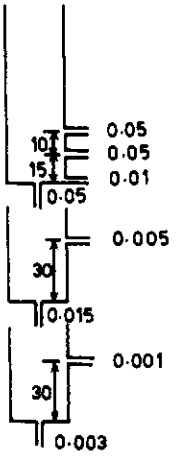


FIG. 5. TANK MODEL FOR FLOOD ANALYSIS OF BELKHERI BASIN

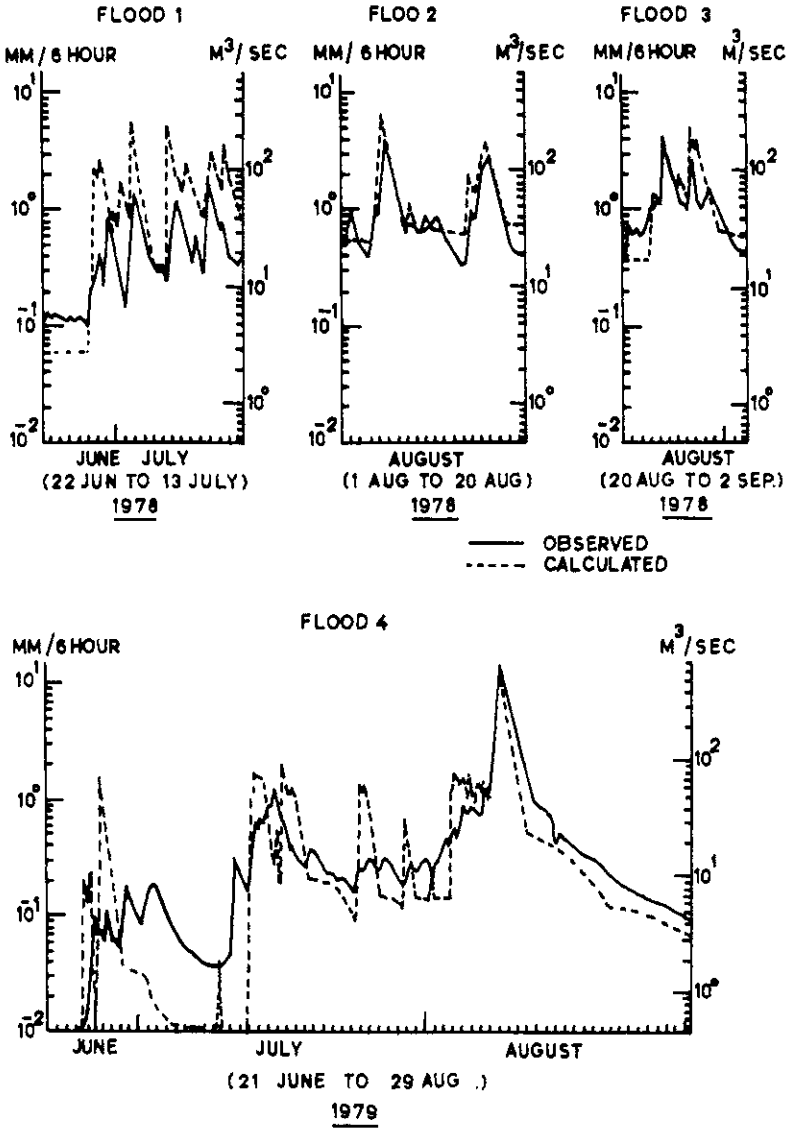


FIG. 6. FLOOD HYDROGRAPHS OF JAMTARA BASIN FOR 1978 AND 1979 OBTAINED BY TANK MODEL FOR FLOOD ANALYSIS.

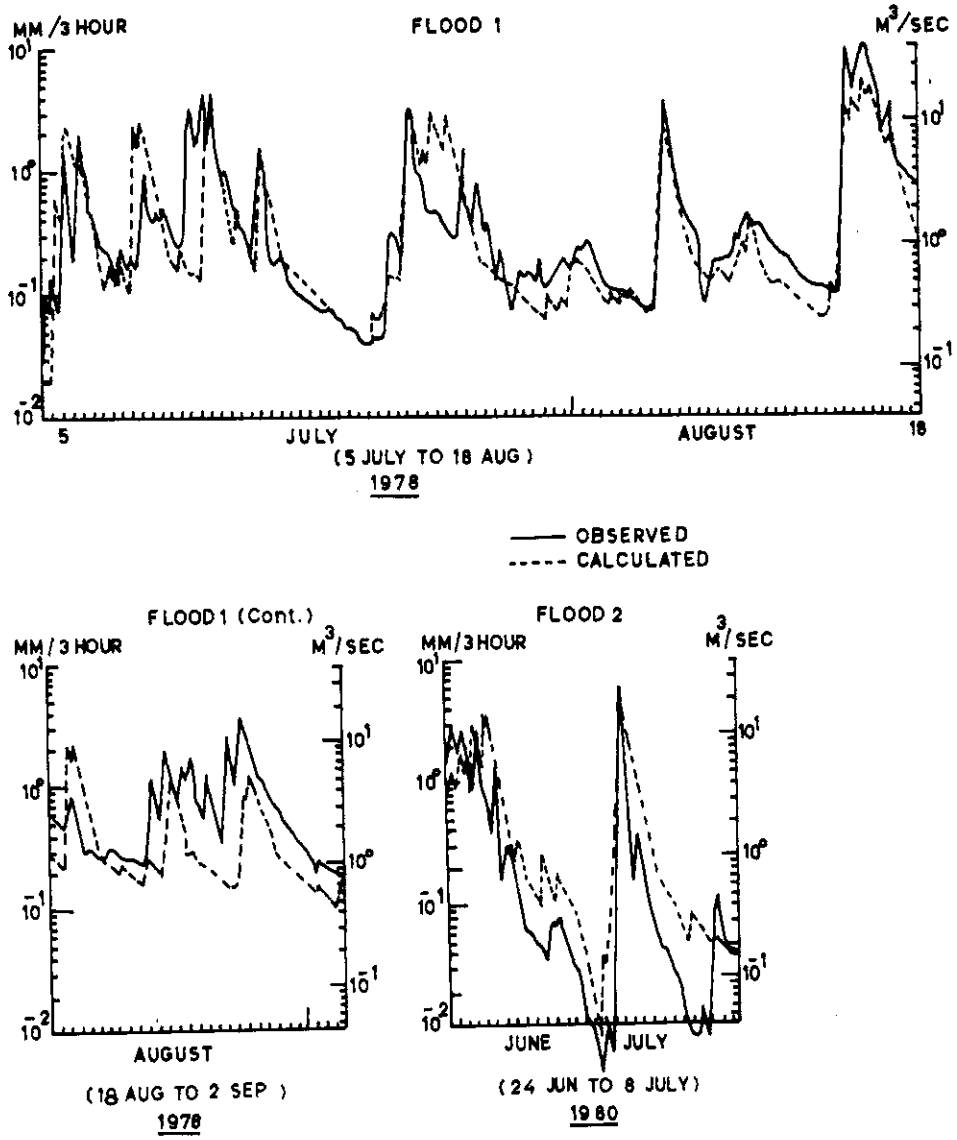


FIG. 7. FLOOD HYDROGRAPHS OF BELKHERI BASIN FOR 1978 AND 1980 OBTAINED BY TANK MODEL FOR FLOOD ANALYSIS.

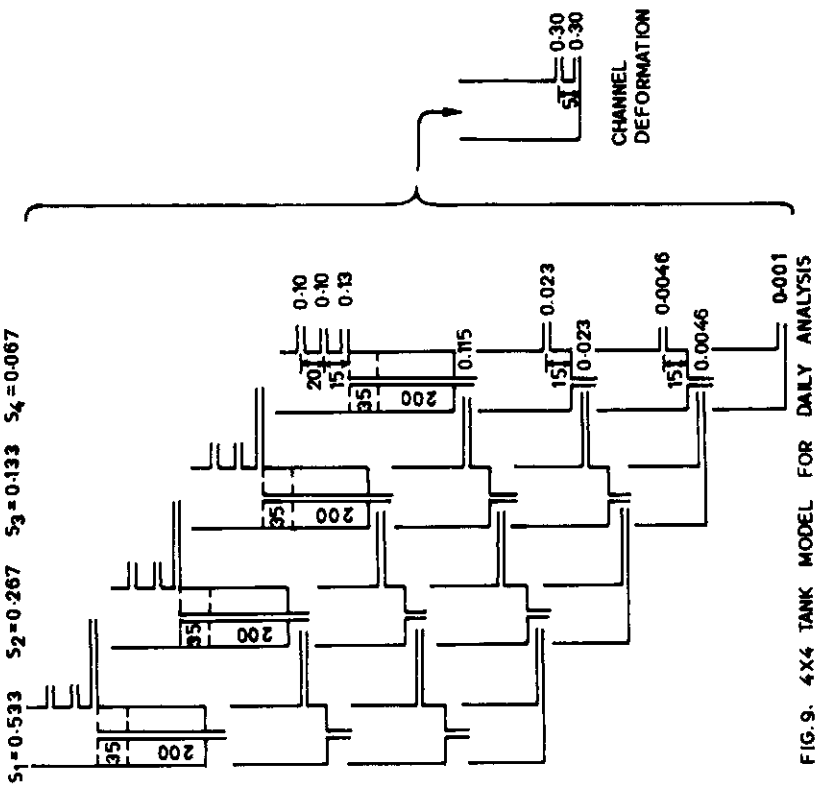


FIG. 9. 4X4 TANK MODEL FOR DAILY ANALYSIS OF JAMTARA BASIN.

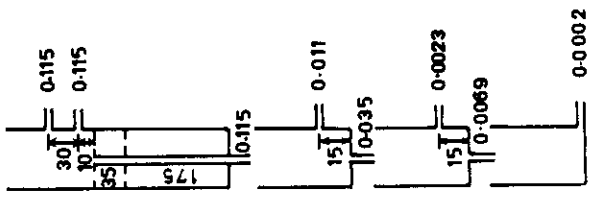


FIG. 8. TANK MODEL FOR DAILY ANALYSIS OF JAMTARA BASIN.

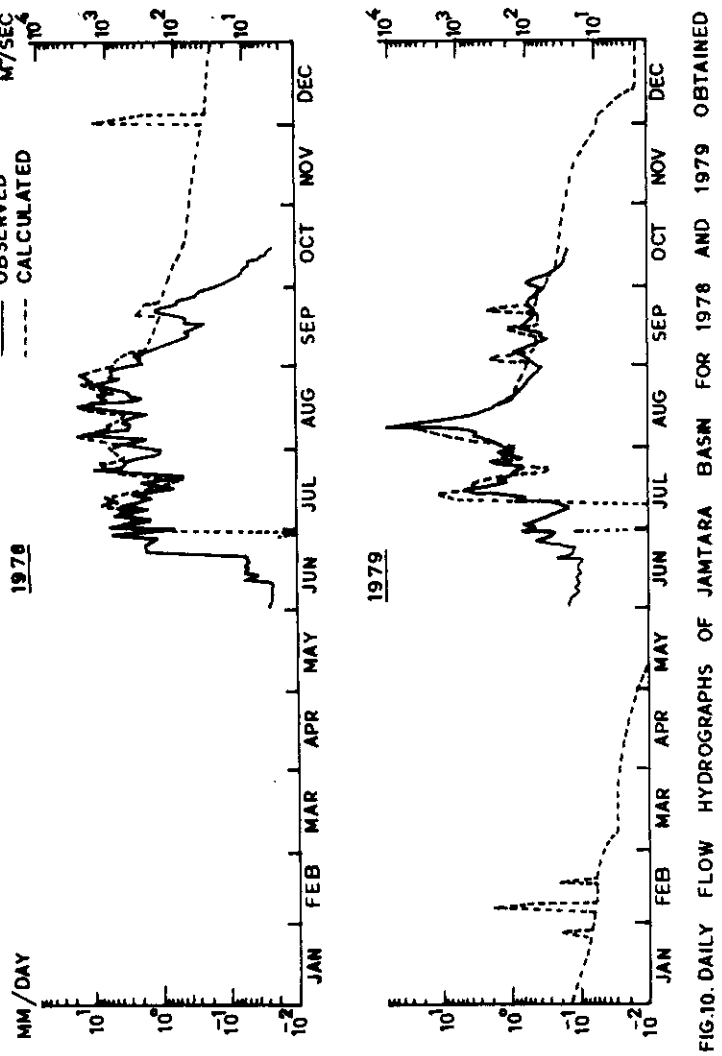


FIG.10. DAILY FLOW HYDROGRAPHS OF JAMTARA BASIN FOR 1978 AND 1979 OBTAINED BY TANK MODEL FOR DAILY ANALYSIS.

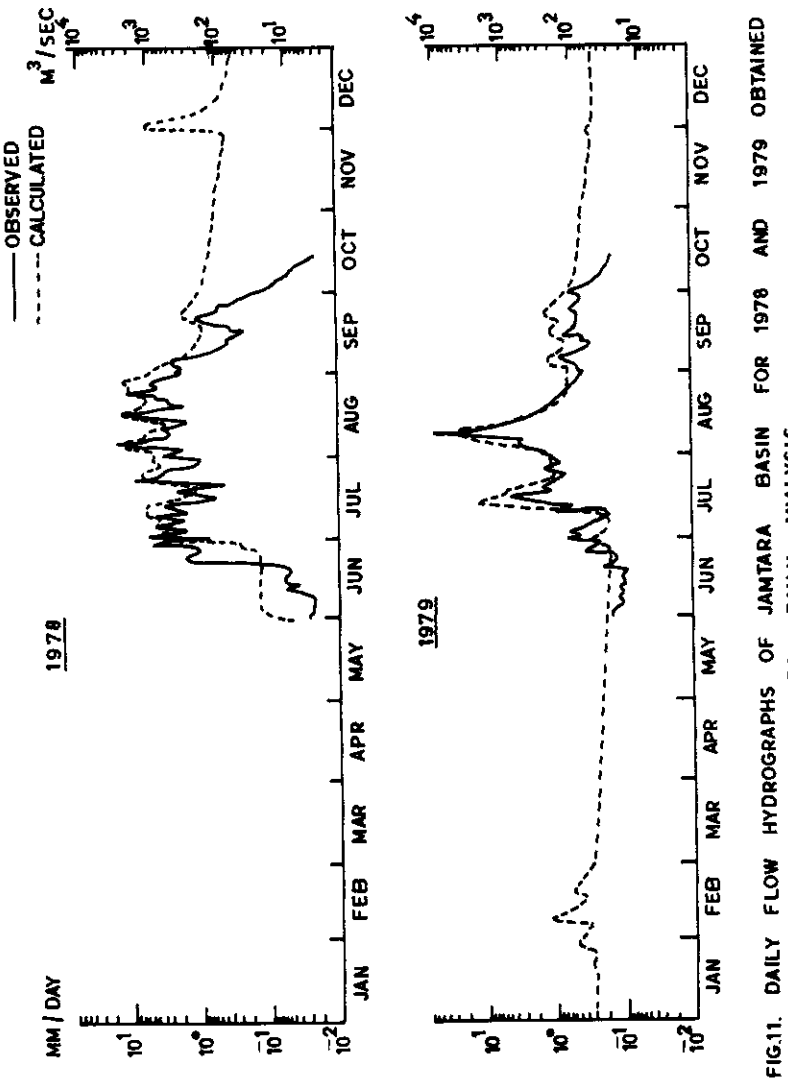


FIG.11. DAILY FLOW HYDROGRAPHS OF JAMTARA BASIN FOR 1978 AND 1979 OBTAINED BY 4X4 TANK MODEL FOR DAILY ANALYSIS.

Research Notes of the National Research Center for Disaster Prevention, No. 55, March 1984

556.16.048 : 681.3.06 (282.253)

# タンク・モデルを用いたインドの二河川流域の流出解析

Bhaskar Datta (バスカル ダッタ)*
国立防災科学技術センター

タンク・モデルを用いて，インド中部デカン（Deccan）高原の北部を流れるナルマダ（Narmada）川の二支流，ジャムタラ（Jamtara）川とベルケリ（Belkheri）川（Fig. 1）の流出解析を行った．

まず，この両河川のデータを用いて洪水解析を行ない，3段直列貯留タンクのタンク・モデル（Fig. 4, Fig. 5）を求めることができた．推定流量と実測流量との一致はほゞ良好であった（Fig. 2, Fig. 3）．

次にジャムタラ川のデータを用いて日流量解析を行った．4段直列貯留タンク方式（Fig. 8）と，4段並列4段直列方式（Fig. 9）の両者について解析を行った．推定流量と実測流量の一致性は，前者（Fig. 10）も良好であるが，後者（Fig. 11）の方が良く，4段並列4段直列方式のタンク・モデルが，この河川に適合していることがわかった．

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* インド国立水文研究所研究員（ユネスコのフェローシップを得て，昭和58年2月中旬より7月中旬まで，国立防災科学技術センターにおいて流出解析の研修を行った。これは，この研修結果の報告である。）