# Estimation and Analysis of Return Flows: Case Study

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**Abstract:** Return flows from irrigation form an important component in the overall management of water in a basin. The Nagarjunasagar irrigation project is one of the biggest irrigation projects in India. At the Nagarjunasagar project formulation stage, the return flows were assumed to be 7.5% of the total water drawn into the command area (area irrigated under the canal), which could be approximately $538.08 \times 10^6$ m$^3$. This paper aims to calculate the return flows from the Nagarjunasagar canal command areas. At present, the calculations are made during the period 1982–2004 by using multiple linear regression analysis. Return flows form 15% of the total releases from the canals for the whole study period. During wet, normal, and dry periods, return flows are 29, 20, and 10%, respectively. Similarly, they are 29 and 18% during the kharif (June–October) and rabi (October–February) seasons, respectively. **DOI: 10.1061/(ASCE)HE.1943-5584.0000736.** 

**CE Database subject headings:** Return flow; Irrigation; India; Case studies.

**Author keywords:** Return flows; Irrigated area; India; Linear regression.



## Introduction

Nagarjunasagar reservoir and its canal system is one of the biggest irrigation projects in India and is situated at Nandikonda village of Nalgonda district in Andhra Pradesh. The construction of the dam was started in 1955 and completed in 1974. The project consists of a dam and two main canals, namely the NagarjunaSagar Left Canal (NSLC) and Nagarjunasagar Right Canal (NSRC). The gross capacity of the reservoir is $11{,}550 \times 10^6$ m$^3$ at full reservoir level of 179.832 m above mean sea level (AMSL), and the active storage capacity is $6{,}840 \times 10^6$ m$^3$ at dead storage level of 121.92 m AMSL. Although both canals started serving the command area (area irrigated under the canal) from 1967, the dam construction was completed in the year 1974.

The Nagarjunasagar left canal runs over a length of 178 km, and it further continues another 117 km as a main branch canal with command area of 0.364 million ha. Similarly, the Nagarjunasagar right canal runs over a length of 203 km, beyond this point the main canal is continued for a length of 82 km as a main branch canal with the command area of 0.45 million ha (Fig. 1). The distribution network system was completed by the end of 1991. The Prakasam Barrage is situated 184 km downstream from the Nagarjunasagar Project (Jauhari 2002). The travel time for river water to reach Prakasam Barrage from Nagarjunasagar is reported to be 25–40 h, depending on the river stage and flood conditions. An intermediate catchment of 36,058 km$^2$ between NagarjunaSagar and Prakasam barriage contributes substantial additional inflows to River Krishna as surface runoff (Andhra Pradesh Government 1998).

The amount of water released to irrigation from Nagarjunasagar Left and Right canal command areas is not entirely consumed in the irrigation process, but some water flows back to the downstream reservoir (Prakasam Barrage), which are considered to be return flows owing to canal command areas. Return flows from irrigation form an important component in the overall management of water in a basin. Return flows are that portion of the irrigation water that travels directly from the irrigated fields as surface runoff, as well as the water which has infiltrated into the soils, and part of it joins downstream as a result of seepage from the soil and discharge from the aquifers. Return flows assume greatest significance as they affect both quality and quantity of the available water downstream.

At the Nagarjunasagar project formulation stage, the return flows were assumed to be 7.5% of the total water drawn into the command area, which could be approximately $538.08 \times 10^6$ m$^3$. However, with the present level of utilization and the higher rates of seepage losses, the return flows are estimated to be approximately 849.60 million m$^3$ million cubic metres (MCM). Considering the current "closed" status of the basin, almost all the runoff is utilized within the basin leaving little or no runoff joining the sea for the Krishna basin (Biggs et al. 2007); and its consequences, such as competing water demands between upstream and downstream water users, estimation of return flows has assumed the greatest significance in recent times. The growing problem of nonavailability of canal waters to the command areas in the lower reaches is obvious. The government of Andhra Pradesh formed an expert committee in 1980 to go into the problem of tail-end areas and to suggest ways and means to remedy the situation, particularly that of utilizing the return flows. Based on the recommendations of the committee, detailed investigations were made for lifting or diverting the return flows from the major drains, and new schemes have been taken up for both NSRC and NSLC for the utilization of approximately 623.04 MCM (Jauhari 2002).

The present work aims to calculate the return flows from the Nagarjunasagar canal command areas that are joining the Prakasam Barrage, which is situated downstream. In this process, one has to

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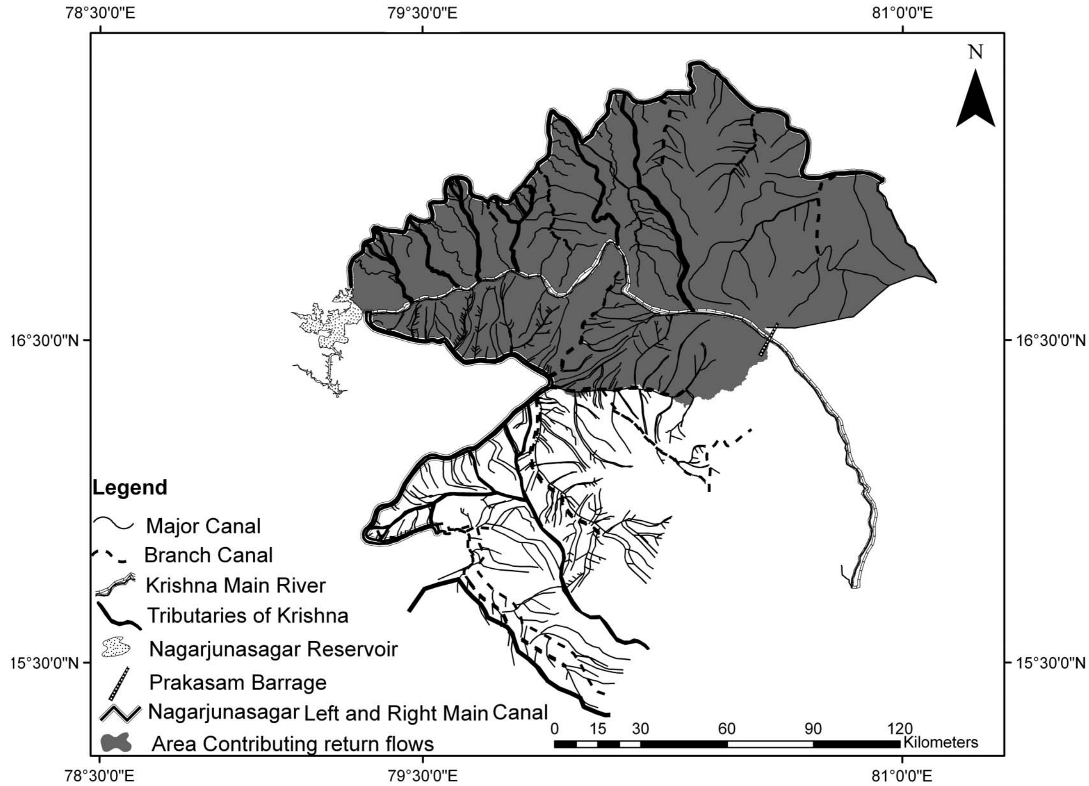


**Fig. 1.** Nagarjunasagar command area

consider the runoff from the intermediate catchment and direct releases from the Nagarjunasagar to the Prakasam Barrage.

## Literature Review

Return flows are understood in the broader context of interaction of surface and groundwater flow systems, although the definition for return flows vary slightly according to the context. Several studies have shown that irrigation system seepage and percolation have recharged groundwater aquifers (Schmidt and Sherman 1987; Fernald and Guldan 2006). Interestingly, efforts to increase water-level efficiency may reduce groundwater recharge as has been observed by Harvey and Sibray (2001) in the case of lining of irrigation canals and Venn et al. (2004) in the case of changing the irrigation method from flooding to sprinkler. Several quantifications of various components of return flows are reported by Fernald et al. (2007), in which up to 16% of the canal flow was lost, whereas Schoups et al. (2005) put the same at 15–20%. At the field level, irrigation waters have been shown to percolate below the crop-root zone. Willis et al. (1997) calculated that 31 and 23% of total applied water for irrigation goes as a deep percolation in two different soil types. A study in Methow River Valley in the state of Washington showed that canal and field seepage recharge to shallow groundwater and subsequent return flow provided up to 20% of the total river flow (Wissmar 2004). In Montana, 50% of irrigation water becomes deep percolation and groundwater recharge, and that recharge in return became groundwater return flow that augmented the river flow (Kendy and Bredehoeft 2006). In one of the experimental watersheds in Korea, the estimated average annual return flow in the paddy fields is approximately 25.7% of the annual irrigation water (Kim et al. 2009).

In all the aforementioned studies, either one or two components of return flows are estimated, either singularly or in combination. Quite a few have considered the linear relationship between various hydrologic variables. Wide variation of return flows in the cases presented is attributable to variations in soil, geology, and climatic conditions from case to case. The present study attempted to estimate most of the components of return flows, including direct runoff from the irrigation fields, seepage losses from canals and fields, as well as the groundwater discharge in a lumped model. This was possible because of the availability of observed values at two places i.e., at the Nagarjunasagar reservoir site and at the Prakasam Barrage site.

## Description of the Study Area

Based on topography, it can be assumed that the total Left Bank canal command area and 48% of the Right Bank canal command area contribute return flows to the Prakasam Barrage. Fig. 1 shows the total command area of Nagarjunasagar and the area contributing the return flows to Prakasam Barrage. The tributary rivers, namely Musi, Paleru, and Munneru, are contributing their outflows directly or indirectly into the downstream of Krishna River after meeting the water demand for irrigation. Only a few of the majors of Nagarjunasagar Right Canal are contributing their outflows into the downstream of Krishna River. (Fig. 1). Only a part of the command area under Nagarjunasagar Right Canal is considered for contribution of the return flows.

### *Climate*

The rainfall of the command area varies considerably over two monsoon seasons. The first spell of rain (Southwest monsoon) occurs in the Kharif season (June–October), and the second spell of rain (Northeast monsoon) occurs in the Rabi season (October–February). The annual rainfall of the command area



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ranges from 680 to 1110 mm. The temperatures range from a low of approximately 15°C (59°F) in December to approximately 45°C (112°F) in May. Relative humidity ranges from approximately 30 to 80% with a mean of approximately 60%. Monthly total evaporation ranges from approximately 145 mm in November and December to approximately 350 mm in May.

### *Soils and Hydrogeology*

The entire command area is covered mostly with black cotton soils (Vertisols) in lower elevations and the red sandy soils (Alfisols) in the higher elevated areas. The vertisols are generally with gently undulating topography (slope less than 1%) occurring over approximately two thirds of the Right Bank command area and over one third of the Left Bank command area. The Alfisols, accounting for the rest of the area, are in rolling topography (slopes are approximately 1–3%). Geologically, most of the area is covered by hard rocks. The basement is granitic gneiss. It has a four-layer system, namely topsoil, weathered layer, fracture layer, and basement. The water table occurs in the weathered layer and has hydraulic continuity up to the fracture layer.

### *Irrigation Pattern*

Under the Nagarjunasagar Project, irrigation is planned for water intensive or wet crop in Kharif season (June–October) and for less water intensive or irrigated dry (ID) crop in Rabi season (October–February). However, in practice, this is not followed, and farmers are going for wet crops, whether it is in Kharif or Rabi season. The irrigation pattern, i.e., wet crop to be raised or ID crop to be raised, is determined based on the availability of water in the system. For the Nagarjunasagar Left Canal command area, 25% is wet crop and 75% is ID crop, whereas for the Nagarjunasagar Right Canal, 37% is wet crop and 63% is ID crop (Jauhari 2002).

## Methodology for Computing the Return Flows

The excess amount of water that reaches the Prakasam Barrage (weir cum bridge constructed across the river to divert the pounded water for irrigation on either side of the river), other than the downstream release from the Nagarjunasagar reservoir, is considered as the combination of runoff owing to rainfall in the intermediate catchment area and return flows from both the canal command areas. The downstream releases from Nagarjunasagar include release through the spillway, release from chutes, and release from power generation through the main river.

In this analysis, only positive difference i.e., excess amount of water that has reached the Prakasam Barrage from Nagarjunasagar, has been taken into consideration for calculating the share of return flows. The same is depicted in the following water balance equation. The negative values in the calculation indicate the absence of return flows.

$$\text{Prakasam Barrage inflows} - \text{Nagarjunasagar outflows} = \text{runoff due to rainfall} + \text{return flows} \quad (1)$$

The annual downstream releases from the Nagarjunasagar reservoir to the main river are shown in Fig. 2. The Prakasam Barrage has no storage and is operated as a diversion structure by keeping the pond level sufficiently high for feeding the canal system and the Vijayawada thermal power station. The inflows at Prakasam Barrage are computed by adding all the observed releases from the barrage, i.e., Krishna west main canal release, Krishna east main canal release, water releases for Guntur, pumped water to Vijayawada city, and spill release. The annual estimated inflows

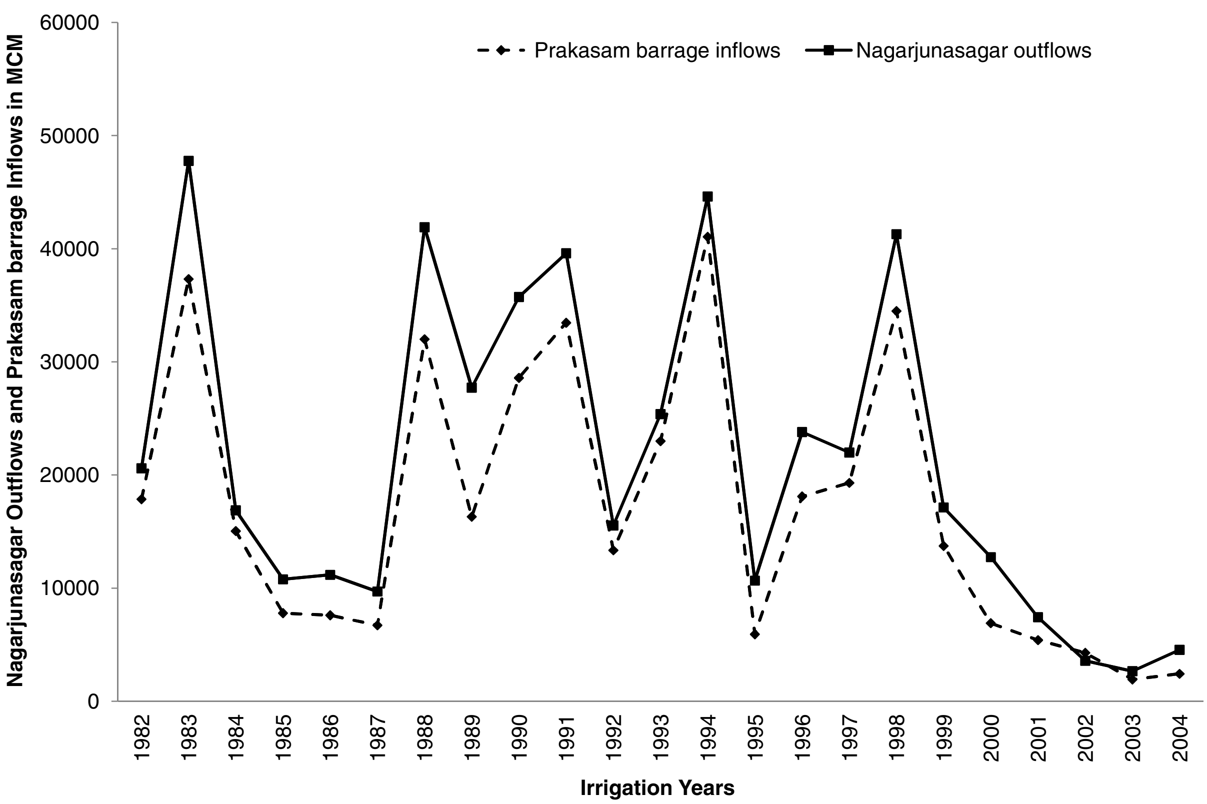


**Fig. 2.** Variation of Nagarjunasagar outflows and Prakasam Barrage inflows

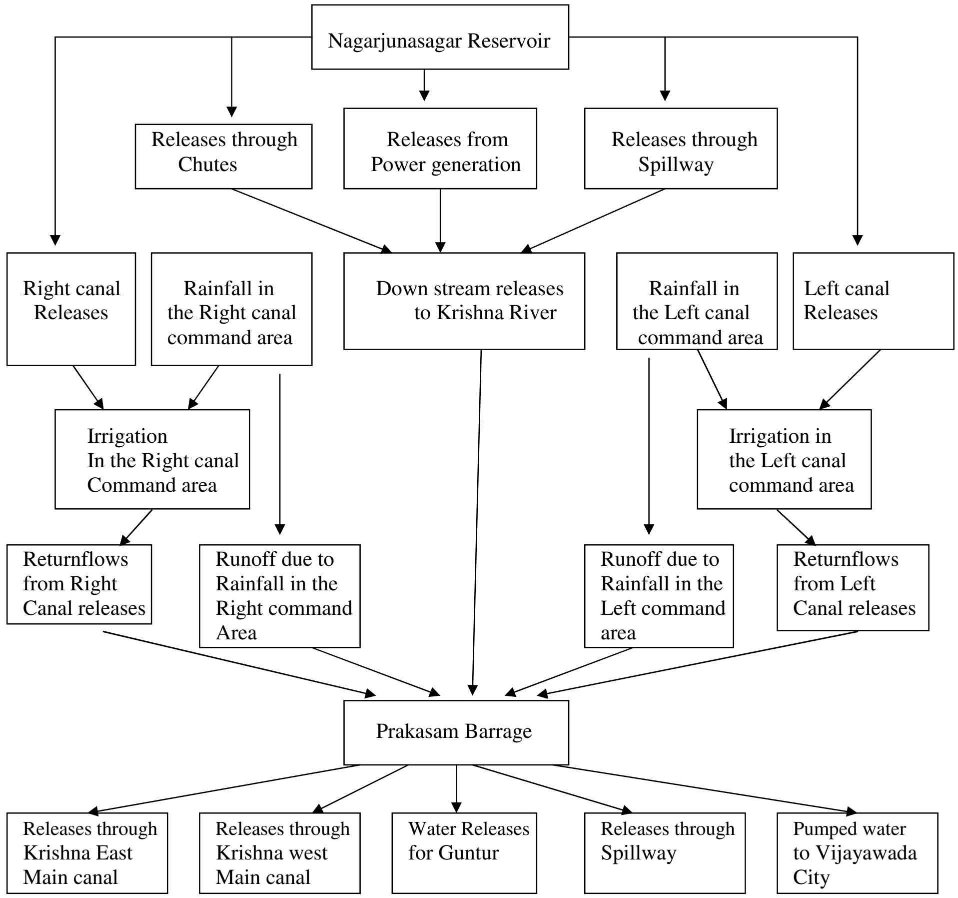


**Fig. 3.** Flowchart for computation of return flows

to the Prakasam Barrage are as shown in Fig. 2. The entire water balance scenario between Nagarjunasagar reservoir and Prakasam Barrage downstream is depicted in the form of a flowchart in Fig. 3. In the study area, the depth of rainfall in the intermediate catchment between Nagarjunasagar and Prakasam Barrage has been estimated by using the average weighted rainfall method.

### *Multiple Linear Regression Model*

The use of linear regression in estimating various components of hydrologic cycle can be found in the literature. For example, linear regression analysis was used by Haan (2002) to detect the presence of linear trends in annual seasonal runoff volume and annual peak flows from the watersheds. Similar works are reported by Venkateswara Rao et al. (2011) in estimating the runoff and sediment yield; Hearne and Deway (1988) calculated mean annual water yield against mean winter precipitation in the Rio Grande Basin of New Mexico; Prairie et al. (2005) used linear regression to develop a relationship between natural salt and natural flow in watersheds in the western United States; and Seelbach et al. (2005) have used multiple linear regression to estimate flow regimes for all rivers across Illinois, Michigan, and Wisconsin.

In the present work, the coefficient of runoff owing to rainfall in the command area and the coefficient of return flows from canal irrigation have been estimated with the multiple linear regression analysis by using the least squares method in the regression tool from Excel. A line is fitted through a set of observations by formulating an equation of the shape

$$Y = aX_1 + bX_2 + c \tag{2}$$

**Table 1.** Regression Summary

| Period | Regression equations | $R^2$ | Standard error |
|---|---|---|---|
| Overall period | $Y = 0.31 \times X_1 + 0.15 \times X_2 + 2{,}362.17$ | 0.98 | 0.09 |
| 1982 | $Y = 0.15 \times X_1 + 0.25 \times X_2 - 599.94$ | 0.93 | 0.21 |
| 1983 | $Y = 0.63 \times X_1 + 0.49 \times X_2 - 2{,}305.00$ | 0.94 | 0.154 |
| 1984 | $Y = 0.04 \times X_1 + 0.20 \times X_2 - 289.97$ | 0.94 | 0.14 |
| 1985 | $Y = 0.34 \times X_1 + 0.09 \times X_2 - 947.99$ | 0.95 | 0.17 |
| 1986 | $Y = 0.43 \times X_1 + 0.07 \times X_2 - 809.33$ | 0.98 | 0.1 |
| 1987 | $Y = 0.28 \times X_1 + 0.10 \times X_2 - 595.39$ | 0.97 | 0.13 |
| 1988 | $Y = 0.65 \times X_1 + 0.21 \times X_2 - 1{,}162.54$ | 0.96 | 0.08 |
| 1989 | $Y = 0.63 \times X_1 + 0.12 \times X_2 - 567.80$ | 0.96 | 0.09 |
| 1990 | $Y = 0.40 \times X_1 + 0.34 \times X_2 - 1{,}169.76$ | 0.95 | 0.13 |
| 1991 | $Y = 0.49 \times X_1 + 0.20 \times X_2 - 1{,}697.54$ | 0.97 | 0.08 |
| 1992 | $Y = 0.02 \times X_1 + 0.20 \times X_2 - 88.00$ | 0.98 | 0.05 |
| 1993 | $Y = -0.02 \times X_1 + 0.23 \times X_2 - 68.77$ | 0.98 | 0.06 |
| 1994 | $Y = 0.13 \times X_1 + 0.39 \times X_2 - 784.39$ | 0.92 | 0.2 |
| 1995 | $Y = 0.40 \times X_1 + 0.23 \times X_2 - 1{,}189.28$ | 0.93 | 0.13 |
| 1996 | $Y = 0.40 \times X_1 + 0.16 \times X_2 - 941.66$ | 0.98 | 0.06 |
| 1997 | $Y = 0.44 \times X_1 + 0.15 \times X_2 - 949.78$ | 0.94 | 0.15 |
| 1998 | $Y = 0.32 \times X_1 + 0.31 \times X_2 - 928.36$ | 0.94 | 0.11 |
| 1999 | $Y = 0.23 \times X_1 + 0.21 \times X_2 - 596.93$ | 0.90 | 0.16 |
| 2000 | $Y = 0.63 \times X_1 + 0.06 \times X_2 - 2{,}120.95$ | 0.98 | 0.06 |
| 2001 | $Y = 0.17 \times X_1 + 0.11 \times X_2 - 536.66$ | 0.91 | 0.14 |
| 2002 | $Y = 0.009 \times X_1 - 0.003 \times X_2 - 6.25$ | 0.89 | 0.17 |
| 2003 | $Y = 0.09 \times X_1 - 0.05 \times X_2 - 209.52$ | 0.96 | 0.08 |
| 2004 | $Y = 0.10 \times X_1 + 0.19 \times X_2 - 173.42$ | 0.96 | 0.06 |
| Kharif season | $Y = 0.36 \times X_1 + 0.29 \times X_2 + 2{,}965.59$ | 0.98 | 0.15 |
| Rabi season | $Y = 0.32 \times X_1 + 0.18 \times X_2 - 477.77$ | 0.98 | 0.05 |



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**Table 2.** Runoff and Return Flows at Prakasam Barrage

| Irrigation year | Observed rainfall in the study area | Calculated runoff owing to rainfall | Observed canal releases | Calculated return flows | Calculated values of PBIF-NSOF = [NSOF = $[a \times (\mathrm{OR}) + b \times (\mathrm{OCR}) \pm c]$] | Observed values of PBIF-NSOF |
|---|---|---|---|---|---|---|
| 1982 | 9,487.97 | 1,489.61 | 9,941.44 | 2,525.13 | 3,414.79 | 3,204.61 |
| 1983 | 14,149.77 | 8,999.25 | 9,689.95 | 4,777.15 | 11,471.40 | 10,867.57 |
| 1984 | 8,415.29 | 3,677.48 | 11,936.32 | 2,423.07 | 2,500.85 | 2,427.66 |
| 1985 | 10,933.47 | 3,804.85 | 9,582.93 | 929.54 | 3,786.40 | 3,520.53 |
| 1986 | 9,695.01 | 4,256.11 | 11,101.4 | 799.3 | 4,246.07 | 4,073.94 |
| 1987 | 10,059.37 | 2,897.10 | 8,616.94 | 870.31 | 3,172.01 | 3,137.10 |
| 1988 | 13,663.00 | 9,003.92 | 11,650.85 | 2,446.68 | 10,288.05 | 9,940.55 |
| 1989 | 18,863.42 | 11,921.68 | 11,036.86 | 1,368.57 | 12,722.44 | 11,481.33 |
| 1990 | 11,228.96 | 4,491.59 | 11,513.98 | 3,995.35 | 7,317.18 | 7,175.93 |
| 1991 | 12,773.42 | 6,373.94 | 9,631.75 | 1,964.88 | 6,641.27 | 6,572.80 |
| 1992 | 9,101.67 | 191.14 | 11,763.2 | 2,352.64 | 2,455.78 | 2,534.25 |
| 1993 | 7,960.48 | 0 | 12,455.63 | 2,914.62 | 2,845.84 | 2,654.33 |
| 1994 | 12,458.60 | 1,719.29 | 11,884.9 | 4,742.08 | 5,682.91 | 5,389.01 |
| 1995 | 10,549.51 | 4,251.45 | 8,610.1 | 2,040.59 | 5,102.76 | 4,878.92 |
| 1996 | 11,918.77 | 4,862.86 | 11,287.3 | 1,828.54 | 5,749.73 | 5,729.40 |
| 1997 | 9,640.07 | 4,241.63 | 10,928.36 | 1,672.04 | 4,963.88 | 4,666.03 |
| 1998 | 12,278.49 | 3,953.67 | 13,118.94 | 4,066.87 | 7,092.18 | 6,780.63 |
| 1999 | 9,058.95 | 2,156.03 | 10,754.71 | 2,344.53 | 3,903.62 | 3,603.48 |
| 2000 | 11,866.70 | 7,511.62 | 10,858.5 | 673.23 | 6,063.89 | 5,934.69 |
| 2001 | 10,868.60 | 1,923.74 | 9,198.64 | 1,076.24 | 2,463.32 | 2,285.49 |
| 2002 | 7,008.63 | 28.03 | 2,250.42 | 0 | 56.82 | 17.87 |
| 2003 | 12,189.04 | 1,206.71 | 2,192.53 | 0 | 997.19 | 904.35 |
| 2004 | 7,735.63 | 789.03 | 8,541.68 | 1,682.71 | 2,298.32 | 2,139.02 |
| Average | 10,952.38 | 3,902.21 | 9,936.84 | 2,064.96 | 5,010.29 | 4,779.11 |

Note: Prakasam Barrage Inflows (PBIF); Nagarjunasagar outflows (NSOF) through main river; $a$, $b$ = coefficients of runoff and return flows, respectively; $c$ is representing the losses such as storage detention, seepage losses, and evaporation losses. Quantities are in $\times 10^6$ $m^3$.

where $Y$ = cumulative values of monthly excess water that reached the Prakasam Barrage in MCM, i.e., the difference between the observed values of Prakasam Barrage inflows (PBIF) and Nagarjunasagar outflows (NSOF); $X_1$ = cumulative values of monthly rainfall in MCM in the study area; $X_2$ = cumulative values of monthly Nagarjunasagr left and right canal releases in MCM; $a$ = coefficient of runoff owing to rainfall, which is greater than 0; $b$ = coefficient of return flows from canal releases for irrigation, which is greater than 0; and $c$ = losses such as storage detention, seepage, and evaporation.

The multiple linear regression analysis has been carried out for the overall period, for every year, and for Kharif and Rabi seasons. These regression equations are shown in Table 1.

Occasional negative values for the coefficients $a$ or $b$ are interpreted as absence of runoff or return flow during the low rainfall years or low canal releases as the case may be. It is also observed that, the constant, $c$, is positive for the overall period and Kharif season, whereas it is negative for every year and Rabi season. The possible explanation may be that the losses are few in Rabi season because of less rainfall and low canal releases. In Kharif season, the losses are greater because of high rainfall and more canal releases.

**Table 3.** Variation of Average Annual Inflows for Different Climatic Years

| Percentage of AAI at Prakasam Barrage | Climate year | Average annual inflows ($\times 10^6$ $m^3$) | Years |
|---|---|---|---|
| >125% | Wet | 39,791 | 1983, 1988, 1989, 1990, 1991, 1994, 1998 |
| 75–125% | Normal | 20,954 | 1982, 1984, 1993, 1996, 1997, 1999 |
| <75% | Dry | 8,880 | 1985, 1986, 1987, 1992, 1995, 2000, 2001, 2002, 2003, 2004 |

Note: Average annual inflows (AAI).

Because the monsoon rainfall contributes 70% of the yearly rainfall, for the overall period the constant, $c$, is turned out as positive, indicating the river bed losses, evaporation losses, and seepage losses.

By using the yearwise regression equations, the annual amount of runoff owing to rainfall, return flows that reached the Prakasam Barrage and the excess amount of water that has reached the Prakasam Barrage, other than the downstream release from the Nagarjunasagar reservoir, is calculated (Table 2). The calculated values of the excess amount of water that has reached the Prakasam Barrage, other than the downstream release from the Nagarjunasagar reservoir, by using regression equations are closely matching with the observed values.

To find the coefficient of runoff and coefficient of return flows for different climatic years, the historical data of inflows at Prakasam Barrage for the past 23 years have been divided into wet, normal, and dry years because the variations in runoff and return flows for different climatic years are important for the planning and management of agriculture and irrigation (Table 3). The climatic years are divided in such a way that if the percentage of average annual inflows (AAI) received at the Prakasam Barrage is greater than 125%, it is considered as a wet year; between 125 and 75%, it is considered as a normal year; and less than 75% is considered as a dry year.

The coefficient of runoff and coefficient of return flows for a wet year are calculated by taking the average of the runoff coefficients and return flows coefficients of wet years and expressed in a percentage. Similarly, the percentages of runoff and return flows are calculated for normal and dry years as well as for Kharif and Rabi seasons and are shown in Table 4.

## Discussion of the Results

The average annual outflows from Nagarjunasagar Reservoir are $17{,}066 \times 10^6$ $m^3$ and the average annual inflows at the Prakasam

**Table 4.** Percentages of Rainfall and Canal Releases As Return Flows Contributing to Prakasam Barrage Inflows

| Period | Rainfall in the canal command area contributing to Prakasam Barrage inflows (%) | Canal releases as Return Flows contributing to Prakasam Barrage inflows (%) |
|---|---|---|
| Overall | 31 | 15 |
| Year | | |
| Wet | 46 | 29 |
| Normal | 21 | 20 |
| Dry | 24 | 10 |
| Season | | |
| Kharif | 36 | 29 |
| Rabi | 32 | 18 |

Barrage are $21{,}438 \times 10^6$ m$^3$. The variation of Nagarjunasagar releases and the Prakasam Barrage inflows are shown in Fig. 2, which shows that the Nagarjunasagar outflows and Krishna river inflows at Prakasam Barrage have drastically decreased since 1999. Because the outflows at Nagarjunasagar are matching with the inflows at Prakasam Barrage, the data for analysis is right. Regression analysis has been carried out for the overall period of 1982–2004, for different climatic years, and for different seasons. The regression analysis depicts that the runoff owing to rainfall that reached the Prakasam Barrage during the study period (1982–2004) is 31% of rainfall. It is also observed that runoff owing to rainfall in wet, normal, and dry years are 46, 21, and 24% of rainfall, respectively. In Kharif and Rabi seasons these values are 36 and 32% of rainfall, respectively. Because the Kharif season rainfall is more; hence, the runoff is more. Similarly, in Rabi season, rainfall is less; and hence, runoff is also less. However, the overall figure for runoff for the study period (1982–2004) is less than Kharif and Rabi figures because the Kharif and Rabi seasons represent a maximum of 8–9 months in a year. The remaining period of 3–4 months, the rainfall is minimum. Therefore, the runoff owing to rainfall for the overall period is less than the runoff in Kharif and Rabi seasons. Finally, the runoff owing to rainfall is maximum in a wet year and also in Kharif season. Similarly, it is minimum in normal and dry years and also in Rabi season. However, it is incompatible to observe that the runoff in dry years is more than normal years. The possible explanation is that the cropping area had considerably decreased during dry years leading to the increase in runoff (Sarala 2009).

The return flows from the Nagarjunasagar left and right canals to the Prakasam Barrage during the period 1982–2004 is 15% of total canal releases. In a wet year, it is high, i.e., 29%. In a dry year, it is 10%. Also, the percentage of return flows is maximum in Kharif season, i.e., 29% of total canal releases, but in the Rabi season, it is 18%. Finally, the return flows are maximum in a wet year and in Kharif season and minimum in a dry year and in Rabi season (Table 4). Rainfall can also influence the return flows because some infiltrated water from rainfall joins the return flows. This may be the reason for less return flows during dry seasons and Rabi seasons apart from low canal release during this period. Because the Kharif season crop area is large, canal releases are also high. Hence, return flows in the Kharif season are more than in the Rabi season, in which the cropping area is less, and consequently canal releases are also less. However, the overall figure for the return flow for the study period (1982–2004) is less than Kharif and Rabi figures because the Kharif and Rabi seasons represents a maximum of 8–9 months in a year, in which period, the canal releases are maximum. In the remaining period of 3–4 months, there are minimum canal releases. Therefore the return flows due to canal releases for the overall period is less than the return flows in the Kharif and Rabi seasons.

By using the yearwise regression equations, the annual amount of runoff owing to rainfall and return flows that reached the Prakasam Barrage is calculated (Table 2). The annual average runoff owing to rainfall in the study period has been calculated as $3{,}745.05 \times 10^6$ m$^3$. Because of low rainfall in the years 1993 and 2002, the generated runoff has not reached the Prakasam Barrage. The annual average return flows are $2{,}065 \times 10^6$ m$^3$. Resulting from low canal releases in the years 2002 and 2003, the canal water did not satisfy water requirements for irrigation. Table 2 shows that the runoff owing to rainfall that reached the Prakasam Barrage follows the trend of rainfall. Similarly, return flows are maximum when the canal releases are maximum. This shows the efficacy of the analysis that has been carried out.

## Conclusions

The regression analysis shows that the runoff for the overall period of 1982–2004 is 31% of rainfall in the canal command area that is joining the Praksam Barrage. During wet, normal, and dry periods, the runoff is 46, 21, and 24%, respectively. Similarly, the runoff is 36 and 32% during Kharif and Rabi seasons, respectively. It is incompatible to observe that the runoff in dry years is more than normal years. The possible explanation is that the cropping area had considerably decreased during dry years, leading to the increase in runoff.

From Nagarjunasagar outflows and Prakasam Barrage inflows, return flows of the Nagarjunasagar left and right canals are estimated during the period 1982–2004. On an average, the return flows form 15% of the total releases from the canals for the entire study period. During wet, normal, and dry periods, return flows are 29, 20, and 10%, respectively. Similarly, of total canal releases, they are 29 and 18% during Kharif and Rabi seasons, respectively. Rainfall can also influence the return flows because some infiltrated water from rainfall joins the return flows. This may be the reason for less return flows during dry seasons and Rabi seasons apart from low canal release during these periods. The method used in this paper to compute the return flows can be applicable for the similar hydrologic and hydrogeological settings elsewhere in the world if similar data sets are available.

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