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ASSESSING EFFECT OF WET AND DRY YEAR DATA ON OPTIMAL MODEL PARAMETERS OF A CONCEPTUAL RAINFALL-RUNOFF MODEL

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ABSTRACT

The rainfall-runoff models are essential tools for the prediction of river flows over a wide range of climatic conditions. Changing climatic situations have greater influence on the model parameters and thus also on the prediction ability of the model. Potentially, there will be large uncertainties in the model simulations. Therefore, it is important to have a reliable prediction from hydrological models to develop tools for water resources management in the future. Inview of this, the present study investigates the effect of the wet and dry period data on the hydrological model parameters and on catchment hydrological response. The study uses ARNO Rainfall-Runoff model to Malaprabha sub-basin of Krishna basin using time series of rainfall, discharge and evaporation available for 21 year period. The wet and dry periods were identified through available long-termrainfall data using differential split-sample test (DSST) that were used for calibration andvalidation of ARNO model. The results indicate that,the model parameters show no significant variations under the changing climatic conditions. It was also noticed that, the transfer of model parameters (Wet to dry and Dry to wet) have smaller influence on hydrological response from the catchment. Also, the calibration of model on wet/dry year and validation on dry/wet climate show over-estimation of mean stimulated runoff (volumes) for few occasions. These results are indicative of applicability of ARNO model for prediction of hydrological responses under changing climates which are very important for future studies.

Keywords: *Hydrological model, ARNO, Rainfall, Runoff, Malaprabha River*

INTRODUCTION

The Conceptual Rainfall-Runoff (CRR) models are widely used for forecasting the river flows and estimation of the essential parameters to enable calculations of flood warning, drought forecasting and optimal operation of the reservoirs and for assessing the impact of climate and land-use change on water budget (Lui and Han 2010 and Li et al., 2013). It is widely believed that, the longer data (>30 years) is required for a better calibration and to obtain most realistic model parameters to represent the catchment hydrologic processes (Li et al., 2010). In general, model users tend to use the longest available data series for model calibrationin order to achieve more representative calibration (Boughton 2007). Sometimes, it is not possible to get continuous hydrological data for longer periods. In such cases, Sorooshian et al. 1983, reported that, it is not the length but the quality of data plays major role in identifying optimal model parameters that in turn can characterize the hydrology of the river basin under study. Studies by Boughton (2007) and Perrin et al., (2007) had observed that, the calibration of the rainfall runoff models using fewer data including wet and dry condition is enough to get a robust and stablemodel parameter. A study by Choi and Beven 2007, found that the optimal parameters derived from one cluster were not suitable on another cluster of catchments while calibrating the TOPMODEL for few south Korean catchments. Further, Li et al., (2012) had shown that, the model parameters were more sensitive to the choice of the data for calibration than length and quality. Such observations strongly recommend careful selection of data sets for calibration and pick up the sub-set of data that is dominating the hydrological processes and to evaluate effect of change of climate on the model parameters.

Recently, researchers are focusing more towards understanding the significance of variation in the climate (Wet and Dry periods) on the model parameters and its performance (Post and Jakeman, 1999; Vaze et al., 2010). Further, Yapo et al. (1996) and Gan et al. (1997) observed that, the model performance can significantly be improved when only the data length representing the wettest period are used for calibration.This raises the following questions, viz., (i) How the model perform, when the entire length of available data is used for calibration (ii) How different are the model parameters when Dry period data used for calibration and validated under the wetter condition and reversed (i.e., wet calibration and dry validation); and (iii) how would the transfer of model parameter benefit the simulation for entirely different climatic regime. The answers to these questions will help us in deciding whether there is a need to carry out future prediction using the parameter values obtained from these calibrations and also to estimate uncertainty range when such models are used for prediction/forecasting with the General circulation model projected data. Presently, most of the climate change impact studies were increasingly dependent on the use of Conceptual Rainfall Runoff (CRR) model for prediction where initial calibrations were carried out using historical hydro-climatic data. However, the simulation obtained through these models exhibits some uncertainty in their results due to changes in the nature of hydro-climatic data

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and transportability of the model parameters. Therefore, there is a need to analyze how the change in nature of data and transportability of model parameters impacts the model simulation and forecasts.

With this background, the present study is carried out for Malaprabha river basin in Northern Karnataka using hydrological and meteorological data for 21 years i.e. 1980-2000, covering both dry and wet conditions. The specific objectives of this study are (i) to gain insights into behavior of the model when used for dry and wet years covering both extremes and (ii) to understand the level of uncertainty of the model prediction. In order to achieve the objectives, the following strategies were employed; i.e., (i) the model was calibrated using the longer period of data; (ii) calibrated using the wet period data and validated for dry period data and reversed (i.e., dry period calibration and wet period validation). The dry and wet period data was identified using the method namely, differential split-sample test, and the performance of model was evaluated using the NSE, RMSPE, MAPE and Coefficient of Determination (R^2) as performance indicators. Further, the influence of optimized model parameters along with the model performance was discussed under each of the condition.

Study Area

Malaprabha river catchment is a major tributary of RiverKrishna, which originates from Chorla Ghats in Belgaum district of Karnataka. The catchment area up to Khanapur gauging station lies between 74°15' and 74°35' East longitudes and 15°30' and 15°45' North latitudes, covering a geographical area of 520 km^2. Figure 1 show the Malaprabha river system up to Khanapur where the discharge measurement is being carried out with no major or minor impoundment or any human interventions.This catchment is the major source of water for the Naviluteertha dam. The catchment, up to dam site is drained by several small streams. Theses streams, including the main Malaprabha river, are seasonal and cause enough scours, gullies, etc., in the catchment thus, adding substantially to the inflow of sediments into the reservoir.

Geologically, the area comprises of tertiary basalt over 96 % of area and sedimentary formations of Pre-Cambrian age. There are two types of soils found within the basin; red loamy soil, which covers about 80 % of the basin and medium black soil. About 63 % of the total area is covered by forests, 17 % by agricultural lands and the rest by shrubs and fallow land.

The climate of the Malaprabha basin is influenced by the south-west monsoon (June-September), which accounts for 91 % of the total rainfall. The average annual rainfall of the catchment is 3259 mm. The temperature varies between 19.2°C to 29.5°C and the mean annual evaporation is 1496.9 mm. The average annual discharge at Khanapur gauge site is 8953.6 cumec.

The catchment can be topographically divided into three units. The first unit between altitudes 662 to 1038 m, forming the upper most reaches, is a narrow and deep valley bounded by the high hills. The slope in this region varies from 30 % to 50 %. The streams in this region are located in this valley and are characterized by rocky beds and wide streams having large discharges. The second unit is comparatively less undulating and the slope varies from 10 % to 30 %. Most of this region is covered by forests and with small isolated villages and agricultural fields in between. This region, identified between the hills and the valley plains have narrow and gently sloping streams with low discharges. The third unit comprises plain lands with gentle slopes of less than 5 % in the plains and increasing to 10 % towards the hilly regions. Streams in this region are wide with rocky bottoms and low velocity.

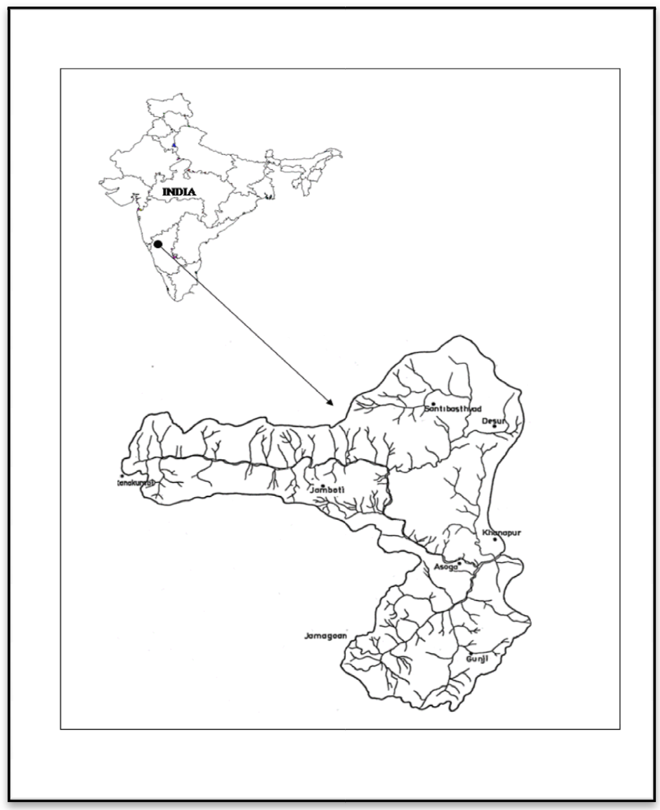

Figure 1: Index map of Study area.

Data Used

There are seven rain gauges in the catchment with a well spread network, maintained by the Water Resources Development Organization(WRDO), Govt. of Karnataka. The daily rainfall data is available for a period of 21 (1980-2000) years. These data were used excluding the recent data due to the following reason, viz., (i) the discharge measuring site was relocated downstream of the existing one due to operational problem; (ii) the climate station measuring the temperature, evaporation and other parameter is shifted new place; and (iii) many small water conservation structure and water supply schemes have started post year 2000. Therefore authors have tried to make use of available data, as the flows are controlled after 2000 and do not represent the actual basin response to the rainfall. These data stations were digitized into a Geographic Information System platform in ArcView 10.4, and basin averages were computed using Thiessen polygon method. The basin average data were used for the study.

Daily flow was measured at Khanapur gauging station by WRDO, Govt. of Karnataka. Discharges were computed using the velocity-area method. The mean daily flows were computed by converting the measured water levels as discharged and averaging them for the day. The discharge for the same 21 year (1980-2000) as rainfall were used for the analysis. In addition to this, available the potential evaporation measured for same period using the Pan evaporimeter was also used. The observed rainfall, discharge and evaporation data have been checked for their consistency and homogeneity using the dedicated software called HYMOS which is widely used for this purpose and necessary corrections were made.

ARNO Rainfall-Runoff Model

The ARNO model (Todini, 1996) is a conceptual and semi-distributed Rainfall - Runoff model that simulates discharges at daily time step. This model has been developed using concept of spatial probability distribution of soil moisture capacity and of dynamically varying saturated contributing areas. The ARNO model is characterized by two main components: the first and most important component represents the soil moisture balance, and the second describes the transfer of runoff to the outlet of the basin. The relevance of the soil component emerges from the highly nonlinear mechanism with which the soil moisture content and its distribution control the dynamically varying size of the saturated areas mainly responsible for a direct conversion of rainfall into runoff. The second component describes the way in which runoff is routed and transferred along the hillslopes to the drainage channels and along the channel network to the outlet of the basin. Additional modules, such as water losses through evapotranspiration, snow melt and groundwater routines is a lumped representation of the catchment. Further descriptions of the model can be found elsewhere (Todini, 1996; Abdulla et al., 1999).

Model CalibrationandValidation

The ARNO model consists of ten model parameters that describe the hydrology of a catchment. These parameters have to be identified by calibrating model and by comparing the resulted discharge with that of the observed discharge. Out of the ten parameters, few parameters play major role in hydrological processes which are: base flow, linear reservoir coefficient (K), moisture holding capacity of soil (W_m) and the shape parameter (b). These parameters are important in estimating the overland flow, the most significant portion of the total runoff (Franchini and Pacciani, 1991). The present study employs initially the auto-calibration procedure to arrive at the model parameter values. Considering these values are the initial values, all the model parameters were optimized using the manual calibration method. This would allow the modelers to vary the parameter values within the physical range and to suit to the existing catchment conditions.

The entire available data on daily rainfall, discharge and evaporation for the period 1980-2000 of Malaprabha sub-basin of River Krishna were used for both calibration and validation of the model under study. Also, these data were used to identify the dry and wet period. The identified dry and wet period data has been used for calibration and validation of the ARNO to assess the predictive ability of model under different climatic conditions. In view of this, ARNO model has been setup for the following cases;

Case 1: The first case is setting up the model by calibrating using 15 years of data from 1980 to 1994 and validating the same using the remaining 6 years of data from 1995 to 2000.

Case 2: In the second case, the dry and wet years are identified using the rainfall data of the basin and then a cycle of consecutive wet years are used for calibration which is then calibrated against a set of consecutive dry years and vice versa. Also the performances of the models hence developed are compared.

Case 1: The total length of 21 years data is split into two groups, i.e. from 1980 to 1994 and 1995 to 2000. The first fifteen years data is used for the model calibration. Using the trial and error procedure the model parameters were optimized both in terms goodness of fit indices and in the visual analysis of simulated and observed hydrographs over the whole calibration period. The calibrated parameter values and the model performance indices are as shown in Table 1. The observed and simulated hydrograph for the calibration period is as shown in Figure.2.

The remaining six year data from 1995 to 2000 were used for validation of the above developed ARNO model for the Malaprabha basin. The comparison of simulated and observed runoff for the validation period has been done using the performance indices and using the hydrograph as shown in Table 2 and Figure 3 respectively.

Case 2: In order to assess the effect of the changing climate conditions on simulation of flows and on the model parameters, the rainfall-runoff model required to be tested under different climate period and then validate on other climate period. Such procedures allow to explore the capability of the model to simulate the flows under changing climatic conditions. To separate the wet and dry periods, a special case of split sample test, namely, Differential Split Sample Test (DSST) proposed by Klemes (1986) has been employed. This procedure adopts the long term mean annual rainfall to identify the wet and dry period (Hartmann and Bardossy, 2005). Further as suggested by Liz et al., (2012), the sub-periods with consecutive annual precipitation greater than the mean were selected as 'wet' (1980-1984) period and less than the mean were selected as 'dry'(1985-1987) period.

For this case, the dry and wet years are identified following Klemes (1986) and Hartmann and Bardossy (2005) and Liz et al., (2012), i.e. by plotting the annual rainfall values against the normal rainfall (Average rainfall estimated using 21 years) as shown in Figure 4. The years having the annual rainfall values above the Normal value line are considered

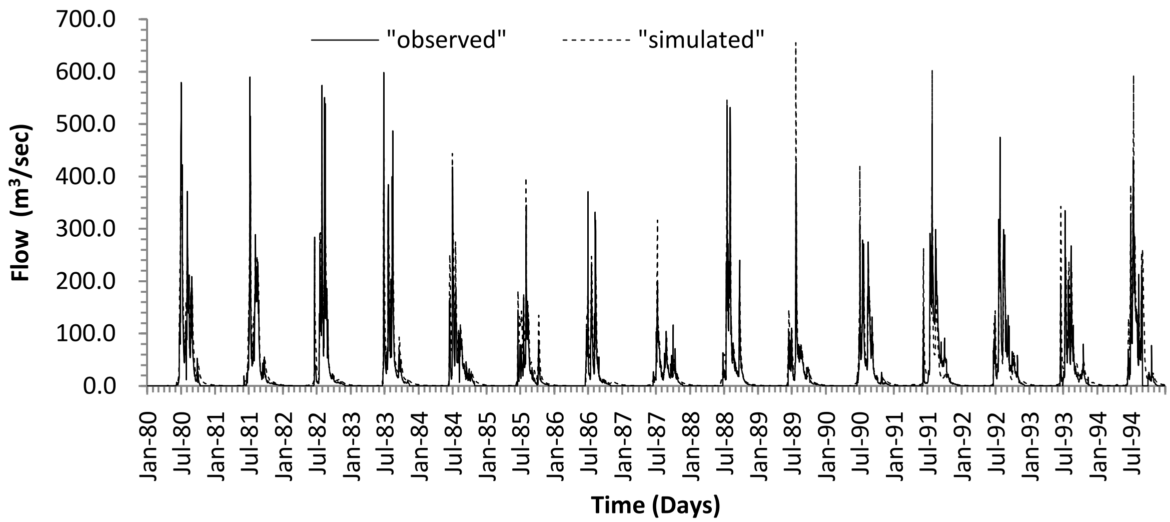

Figure 2: Plot of Observed and Simulated Discharge (Runoff) For Calibration Period of Case 1

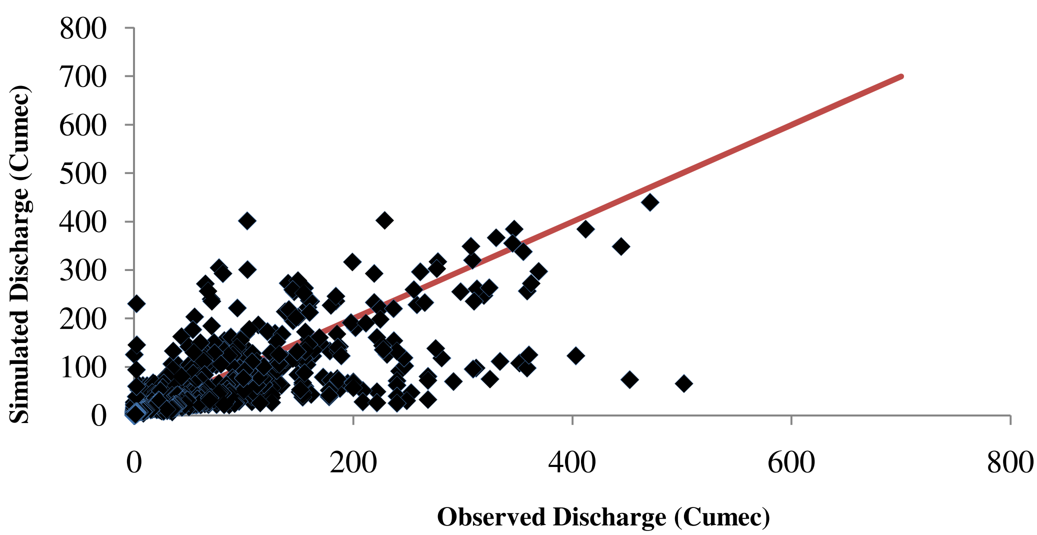

Figure 3: Plot of Observed and Simulated Discharge (Runoff) For Validation Period of Case 1

as wet years, those below the Normal value line are taken as dry years and those coinciding with the Normal value line are marked as normal years. From the Figure 4., the years from 1980 to 1984 have been considered as wet years and 1985-1987 as dry years for the present analysis. This method adopts the following steps: (1) a small number of sub-periods are selected according to one climate characteristics; (2) the calibration-validation test applied on these sub-periods; (3) the validation performances are computed to evaluate whether they vary significantly when climatic characteristics differ between calibration and validation period.

a) **Calibration using Wet Period data:** From the above plot, the first cycle of consecutive wet years data from 1980 to 1984 are chosen for calibration using the ARNO model. The model parameters are optimized using trial and error method such that the best fit is achieved. The model hence developed is used for the validation of the data for the chosen cycle of dry year from 1985 to 1987. The parameter values from the calibrated model and the performance indices for the calibration and validation period are as shown in Table 1 and Table 2 respectively. The plot showing the variations between observed and simulated discharges from the calibration and validation models are obtained as shown in Fig. 5 and Fig. 6 respectively.

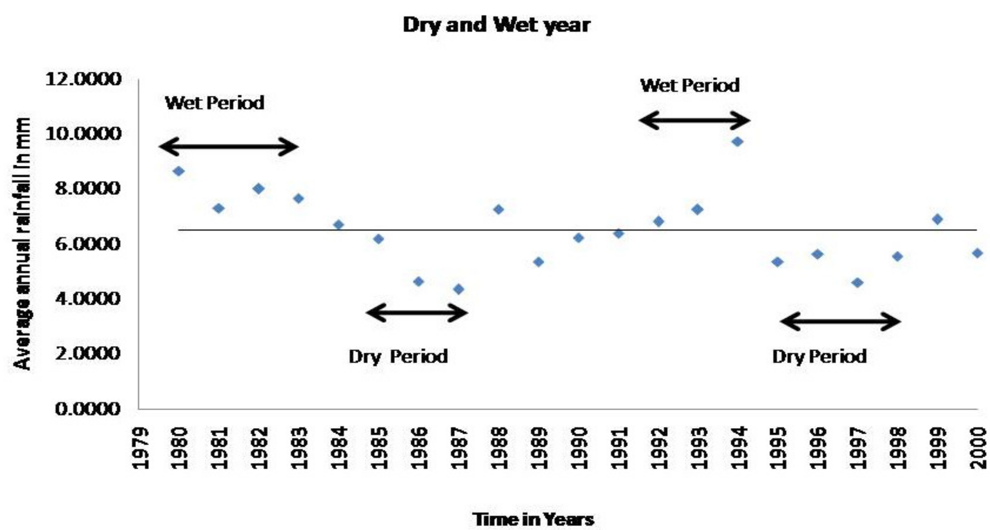

Figure 4: Plot for Identification of Wet, Dry and Normal Years

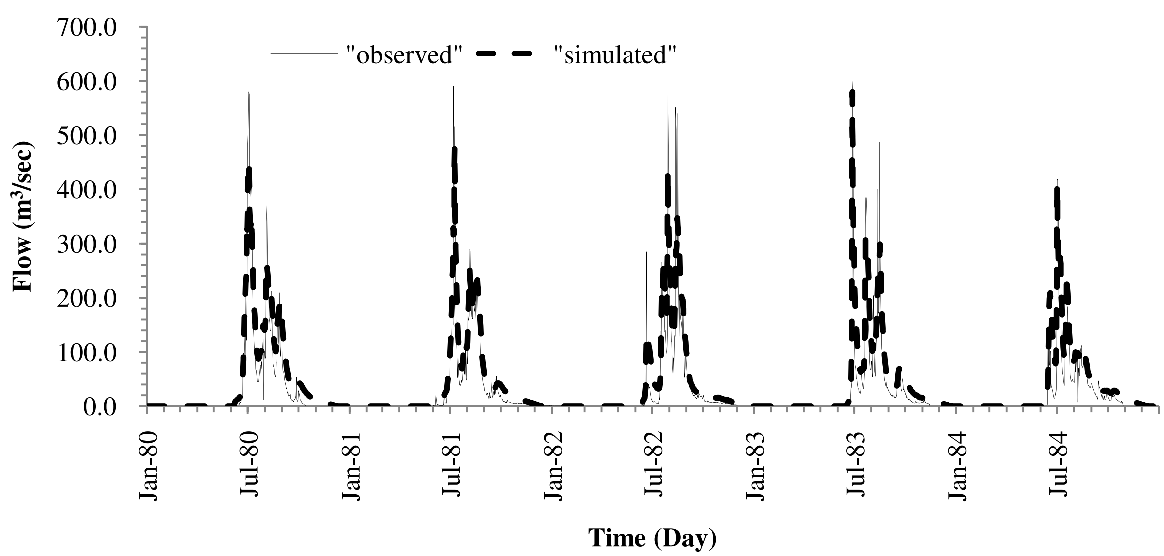

Figure 5: Plot of Observed and Simulated Discharge during Calibration Period using wet years data.

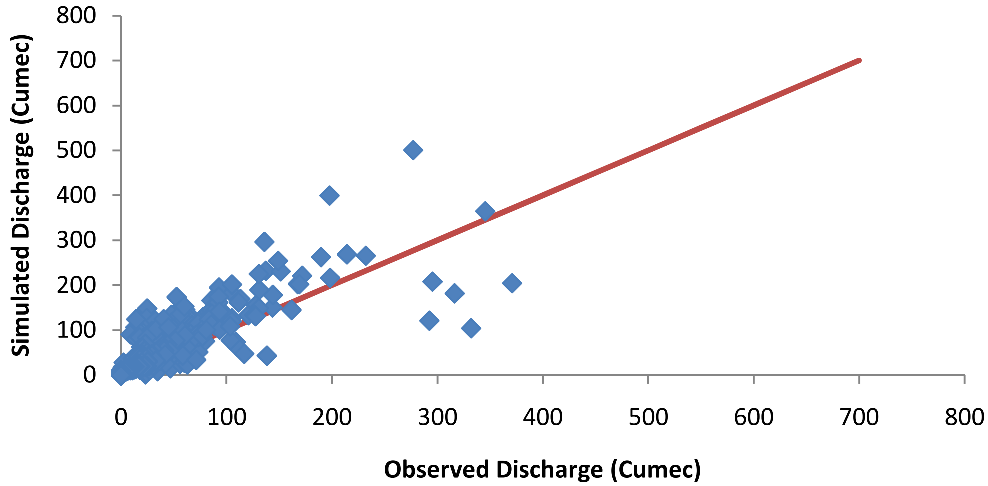

Figure 6: Plot of Observed and Simulated Discharge during Validation Period using dry year data.

b) **Calibration usingDry period data:** in this case, dry year data set (1985-1987) was used for calibration of the model and the 1980 to 1984 (wet year) data is taken for validation of the model. The model parameters obtained on calibration is given in Table1. The hydrographs representing the observed and simulated discharge values for the calibration and validation periods are as represented in Fig.7 and Fig.8 respectively.

Discussion

The previous applications of ARNO model elsewhere (Franchini and Pacciani 1991; Todini 1996; Venkatesh, 1998; Abdulla et al., 1999 and Sehti, et.al., 2015) noted that, the model is able to simulate the catchment response more accurately under various climatic condition using the data of various temporal scale. The ARNO rainfall-runoff model has been set-up for the Malaprabha sub-basin of Krishna basin using the 21 year daily data of rainfall, runoff and evaporation. As outlined earlier, the model was calibrated and validated for 2 cases, i.e., by using entire period of data and using the dry and wet period data. The performance of the model was assessed using Nash-Sutclieff (NS) Efficiency, Root Mean Square Percent Error (RMSPE), Mean Absolute Percent Error (MAPE) and Relative Volumetric Difference as suggested by Hwang et al., (2012). The results obtained through these cases are discussed in the following section.

Case 1: In this case, the ARNO model was calibrated using 16 years of continuous data and validated for 5 years. The plots of resulted hydrographhave been compared with the observed hydrograph in Figure 2 and Figure 3, and the optimised parameters are tabulated in Table 1. It can be observed from Figure 1 that the peak runoff values match with the observed values for some years and do not for few years. There is a slight shift observed in the timing of peak flows which could be possibly due to the representation of values in the moisture regime (i.e., the initial (W_o) and maximum (W_m) soil moisture regime) in the model. The Malaprabha catchment experience almost six months of dry

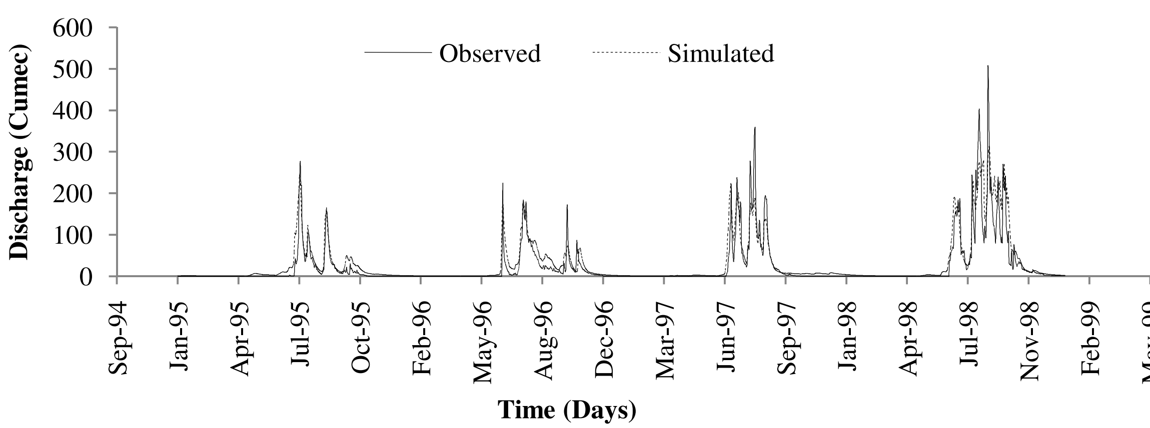

Figure 7: Plot of Observed and Simulated Discharge during Calibration Period of using the dry years data

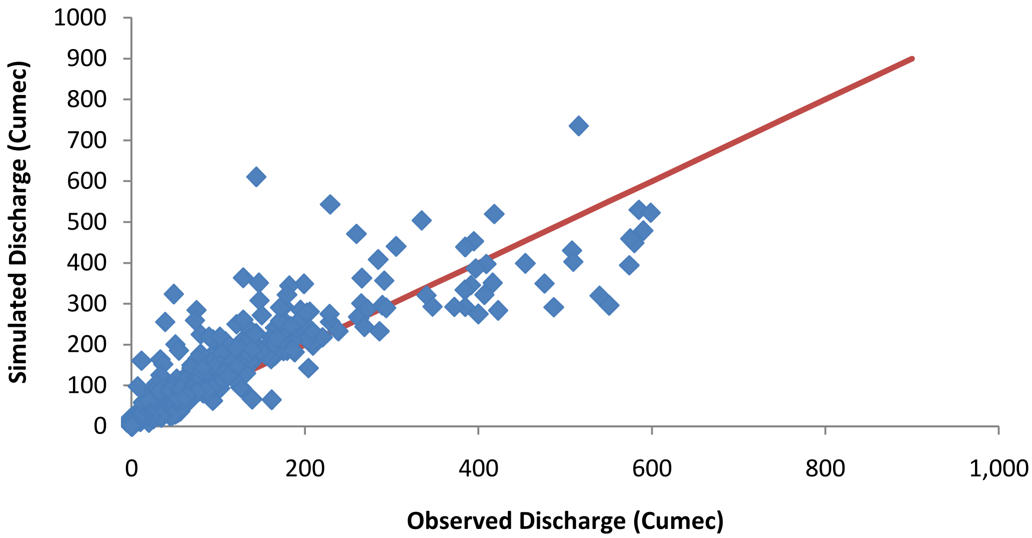

Figure 8: Plot of Observed and Simulated Discharge (Runoff) duringValidation Period using wet years data.

condition, and therefore, maximising the initial moisture content is difficult. Such influences can be seen in the hydrograph (Figure 2) and these could be due to specific drainage processes of the basin as well as threshold of infiltration values as seen from Table 1. The optimised values of infiltration and Drainage threshold parameters are on higher side of the allowable range of the model parameters (Franchini and Pacciani, 1991; Venkatesh 1998). The higher threshold values of these processes may reduce the peak flows and converts rainfall into more interflow and baseflow, which isevidentfrom the simulated hydrograph, where the simulated hydrographs show a smooth recession curves. The performance indices, evaluated to analyse the performance of the model, are listed in Table 1, and these values show a good fit of the model for both the calibration and the validation periods. The validation plot (Figure 8) shows that there is a equal spread of simulated values of discharge around the line of equality (45^o line). This indicates that the model is predicting the discharges well within the limits and also simulate the variation of flows as observed in the natural system.

Case 2: To assess the effect of data nature (wet or dry) on the model parameters, the available data was classified as wet period and dry period, and are used for calibration and validation. Case 2(a) as wet period data for calibration dry period data for validation and Case 2(b) where dry period data has been used for calibration and wet period data for validation. When wet years' data was used for calibration [i.e. Case 2(a)] the performance indices values obtained for the calibration period are very much similar to the values obtained for the validation period. This indicates that the model developed has achieved a very good fit and has predicted the discharges for the validation data efficiently. On the other hand, when dry years' data is used for calibration as in Case 2(b), the validation period of wet years gave a better performance in comparison to the calibration period. This difference can be easily inferred from the performance indices values mentioned in Table 1 and Table 2. This could have happened because the drier soil moisture conditions were not assumed in the model and a threshold infiltration always taking place into the soil profile. Due to which model development using wet year data showed good performance. Also from the analysis of the hydrographs in both the cases it is found that some of the simulated peak flows are lesser than the observed values. Similar analysis elsewhere (Vaze et al., 2010; Coron et al., 2012; Chiew et al., 2015) show that the model parameter values obtained from data of dry period calibration not necessarily simulate lower or higher runoff during the wet period and vice versa. All these studies reported that hydrological responses under dry and wet conditions mainly dependent on model parameters as well as the storage responses.

Given the potential impact of dry and wet period data on calibration, the Table 1, deduce that, the most significant model parameters such as Soil moisture capacity 'W_m', vary within the physically meaningful range. The value is lower in the drier period than that of the wetter period, as more water is available during the wet period for the storage. Another important parameter, the shape "b", does not vary significantly. However, the threshold values of parameters such as drainage, infiltration and deep percolation show significant variations. These observations imply that, the important model parameters are not highly sensitive to the changes in the input such as rainfall and evaporation, where as parameters which are responsible for runoff generation have been affected by the changes in the

Table 1: Comparison of calibrated model parameters for different scenarios analysed in the study.

SL No.	Parameters	Unit	Calibrated Model parameters		
			Longer Period data	Wet Year Data	Dry Year Data
1	Base flow, B	m^3/s	6	6	3
2	Soil moisture capacity, W_m	mm	330	370	310
3	Threshold for drainage, W_d	mm	65	210	45
4	Shape factor, b	-	0.015	0.015	0.04
5	Maximum drainage, D_{max}	mm/hr	35	14	16
6	Percentage of D_{max}	-	1	2	4
7	Threshold for infiltration, W_i	mm	100	10	1
8	Infiltration coefficient, α	-	0.005	0.005	0.1
9	Initial moisture content, W_o	mm	15	10	15
10	Drainage exponent, β	-	5	5	1
11	Nash-Sutcliffe Efficiency		0.85	0.85	0.82
	R^2		0.91	0.89	0.86
	Root Mean Square Percent Error (RMSPE)	%	82.11	97.91	106.84
	Relative Volumetric Difference	%	27.15	24.63	23.50
	Mean Absolute Percent Error (MAPE)	%	8.0	10.24	12.15

Table 2: Performance indices during Validation of the model.

Performance Index	Validation (case-1)	Validation	
		Wet Calibration – Dry Validation	Dry Calibration –Wet Validation
Nash Sutcliffe Index	0.84	0.82	0.83
Coefficient of Determination (R2)	0.78	0.8	0.88
Root Mean Square Percent Error (RMSPE)	101.95	121.84	184.22
Relative Volumetric Difference (%)	-5.15	18.94	16.76
Mean Absolute Percent Error (MAPE)	14.0	15.07	18.39

input. Overall it is worth mentioning that the model predictions are not greatly affected by the climatic variations of the study area. This is well proved by the model performance in all the considered cases for analysis.

SUMMARY AND CONCLUSION

Rainfall-runoff models are essential tools for the prediction of river flows. Many researchers working on understanding the behaviour of climate change have noticed that, these changes are marked by alternating wet and dry period in the coming century. Therefore, it is very important to know beforehand the uncertainty involved in using wet and dry period data on simulating catchment hydrologic response. The present study is an attempt to assess the impact of using wet and dry period data on model parameter and catchment hydrologic response using ARNO rainfall-runoff model.

The study identified wet and dry years following the procedure described by Klemes 1986, the data of identified period were used for both calibration and validation of ARNO Rainfall-runoff model. The results obtained show that, the ARNO model can predict the flows during the wet periods better than that during the dry situations. The model shows an agreeable fit when the wet years' data is used for calibration in comparison to the dry years' data. The differences in the model prediction indicate and exhibit nature of model behaviour and response to the changing climate conditions. However, the results in the present does not show a larger difference in the simulated and observed flows (Table 2).

Based on the results obtained from the analysis, it can be concluded that, the ARNO Model can be used for the prediction of flows at a catchment scale. Further, it can be concluded that, model simulations are not highly variable due to change in the climatic condition.

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