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RESEARCH ARTICLE

THE TIPLING RIVER FLOW ANALYSIS TO ASSESS MICRO HYDRO POWER AND DIVERSION BASED IRRIGATION POTENTIAL

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Abstract

Micro hydropower projects and diversion based irrigation projects are dependent on the amount of water flowing in the river of concern. Analyses of historical River Flow information are crucial to understand its pattern, frequency and predictability. Statistical analysis is the basis for a better scientific comprehension of the river flow system. Based on this information designing of such projects as well as making management plans for any future eventualities are possible. In this paper historical discharge information for a period of 19 years is collected and analyzed. Based on the water level and volume of discharge information of the river for the year 1995, various stage discharge rating curves are prepared. The best fitted curve is used for the estimation of the discharge for the remaining years where only the stage information is available. Daily discharge hydrographs for 19 years is prepared along with annual discharge computation for each of the 19 years of observation period. Preparation of flow duration curve helped to understand what is to be expected minimum from the river and what could be the most risky situation for a river project in this river and make necessary allowances for designing such project. Finally seasonal and monthly time series models are prepared so that the future discharge could be scientifically forecasted for predicting the future of such projects.

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Introduction:-

The Tipling River is a West to East flowing stream in the Tinsukia District of Assam. It flows through the District till it confluences with the Burhi Dihing River that is flowing South to North to meet the mighty Brahmaputra finally. Tipling is a small river with the stream length of a little more than 25 Kilometers.

Near the confluence point of the Tipling and the Burhi Dihing River, a Gauge Station of the P.W.(F.C) Department is situated and is being administered by the Dibrugarh Sub-Division of Upper Assam Investigation Division, Jorhat. Apart from collecting daily stage information of the river flow since 1994, the station has also collected the Discharge Data for the year 1995 by measuring daily water level (stage), cross-section and average velocity with the help of float method.

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On 24th September 1995, Tipling River recorded the maximum discharge on that year with 26.229 Cumecs. The total discharge of Tipling River for that day was 22, 66,186 Cu M.

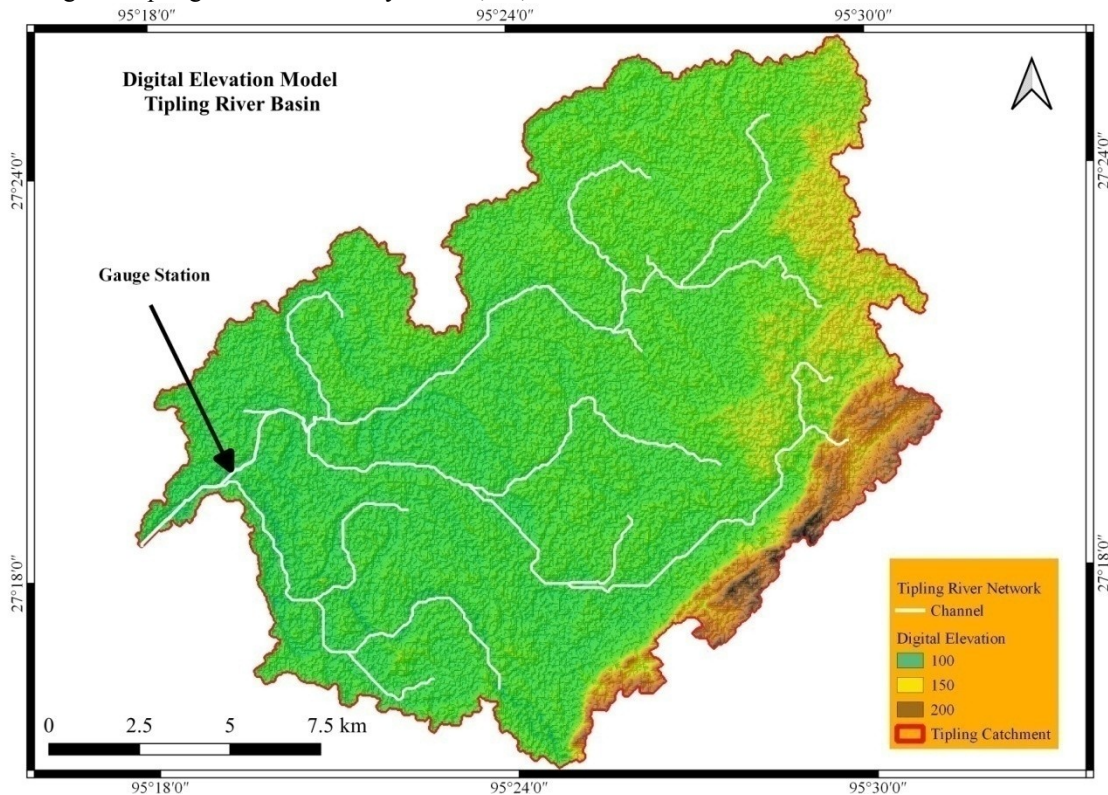


Fig-1:- Tipling River Network and Digital Elevation Model of the Basin.

On the contrary, 4 consecutive days in the month of February 1995, from 12th February to 15th February, the Tipling River recorded the minimum discharge with 1.914 Cumecs only. The total discharge for each of those 4 days was recorded as 1, 65,370 Cu. M. only.

Data procurement and Processing

The information of the Tipling River discharge is collected from the office of the Upper Assam Investigation Division, Jorhat of P.W.(F.C) Department. It maintains an archives of the information collected from the discharge and gauge station on the Tipling River situated near the confluence point of the Tipling River with the Burhi Dihing River at 27°19'40.2"N, 95°18'14"E coordinate.

At the time of data gathering, Gauge information of the River was available from 1994 to 2012 along with discharge information for the year 1995. Gauge information was recorded 3 times a day, at 8.00 AM, 12.00 Noon and at 4.00 PM every day. In the year 1995 Discharge information was collected datewise in a table with Water Level in the site measured in meters, Cross Section area in square meters and Average Velocity in meter per second along with Discharge in Cumecs (Cubic Meter per Second).

All these information was photocopied and collected before digitizing it in to the excel sheets. The volume of data gathered for this river composed of 228 pages covering information for 19 years.

The discharge information for the year 1995 was the base for calculating, processing and assessing the discharge information of the rest of the years. Hence, a detail analysis of the discharge information for the year 1995 was carried out hereunder.

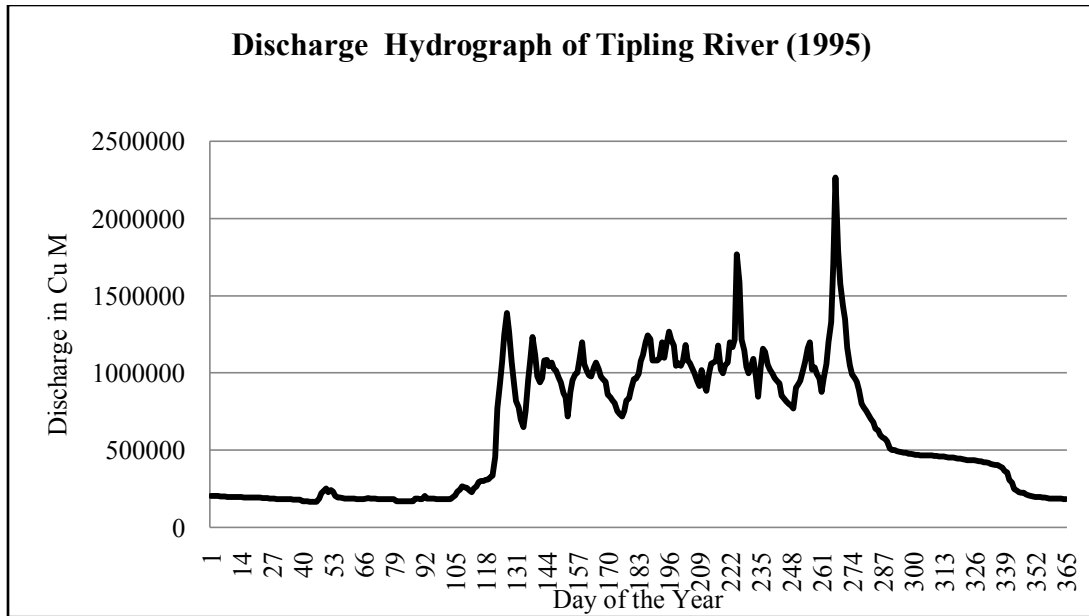


Fig. 2:- Discharge Hydrograph of Tipling River for the year 1995.

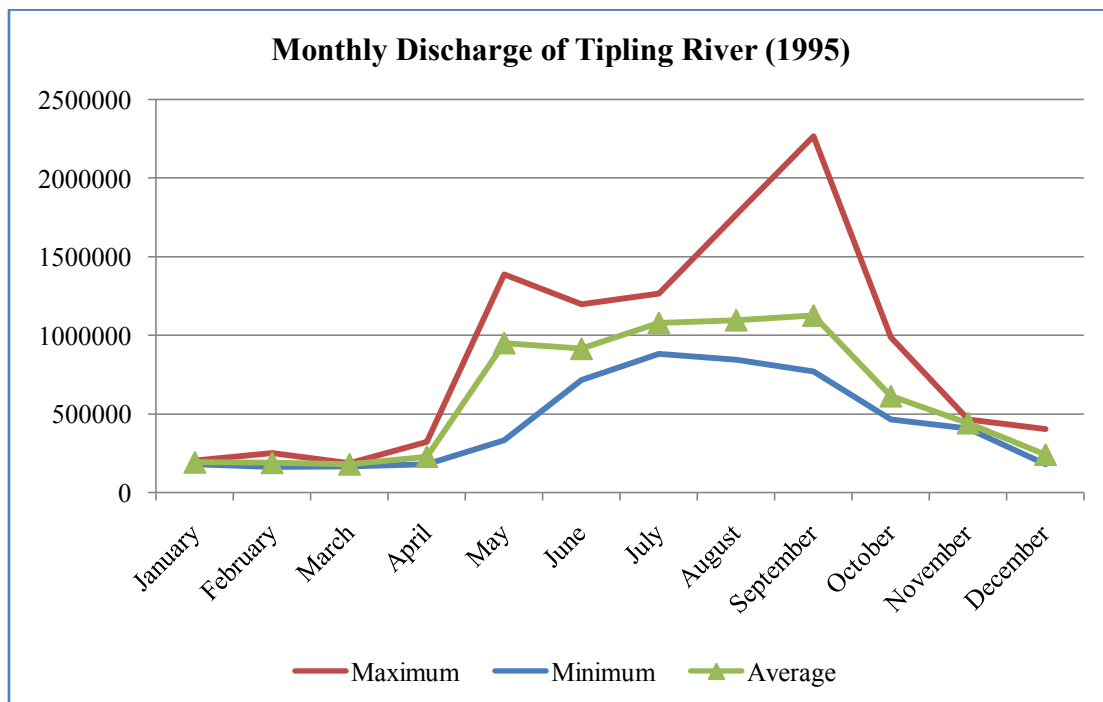


Fig. 3:- Monthly Minimum, Maximum and Average Discharge of Tipling River for the year 1995.

The discharge information in Cumecs is calculated to find out the amount of water discharged every day in Cu. M. by the Tipling River in the 365 days of the year. The information so derived is plotted in the Discharge Hydrograph for a better visualization of the information. From the month of May to September, the River has very high discharge indicating monsoon precipitation in this period. From the month of October to the month of April the discharge is substantially low. In the months of February and March the Tipling River recorded the extremely lean discharge.

The hydrograph of the Tipling River demonstrated 3 peaks in its discharge. First peak was shown on 7th of May with 100 thousand Cu M of more discharge than it's previous and its next day. The second peak is observed on 13th

August where the discharge on this day was 500 thousand Cu. M. more than its previous days discharge. The 3rd peak was observed on 24th September which was extended for around 10 days starting from 22nd September to 30th September. In these period the discharge was increased by around 1200 thousand Cu. M. indicating a sustained flood.

The monthly discharge for the 12 months of the year was calculated and plotted the maximum, minimum and average monthly discharge was plotted in a graph. During the lean discharge period, the difference of minimum and maximum discharge was around 20 thousand Cu. M. only. However, from the month of May to the month of September, the variation of discharge between the minimum and maximum is ranged from 1 million Cu. M. to 1.5 million Cu. M.

Building Stage-Discharge relationship:

The measurement of discharge of a river is time consuming, tedious and cost prohibitive. A mathematical and statistical solution could be established to generate scientific stage-discharge relationship. Based on the bank line of the gauge and discharge station, the relationship could be varied. Nevertheless, an established modeling of Stage-discharge relationship could reduce the pain of collecting discharge data in a daily basis, but information of the gauge data or stage could effectively generate the discharge information in the past and in the future course. However, the bank line will have to remain the same for any past or future assessment.

Stage Discharge Rating Curve:

Gauge reading of the Tipling River and its corresponding discharge information for the 365 days of the year 1995 was scatter plotted in a graph to understand its trends. The stage discharge rating curve was prepared for linear regression model, logarithmic regression model, exponential regression model and power regression model (Hussain, T.A., 2017). Interestingly, in all these models the R^2 value is found to be around 0.98 indicating very high correlation and goodness of fit. The linear regression model is selected for all the future calculation and assessment of discharge of the Tipling River. The mathematical relationship of linear stage-discharge rating curve is found to be $y=4.034x-483.5$, where 'y' represents the 'discharge' and 'x' represents the 'stage'. The value of $R^2 = 0.981$

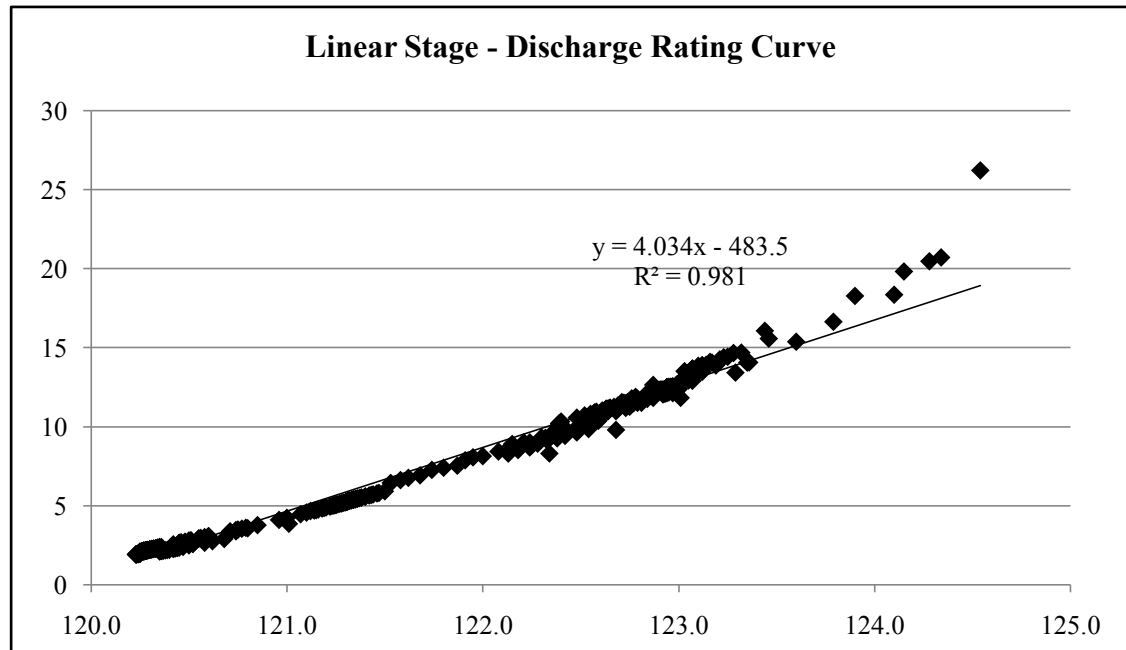


Fig. 4:- Linear Stage Discharge rating curve of Tipling River for the year 1995.

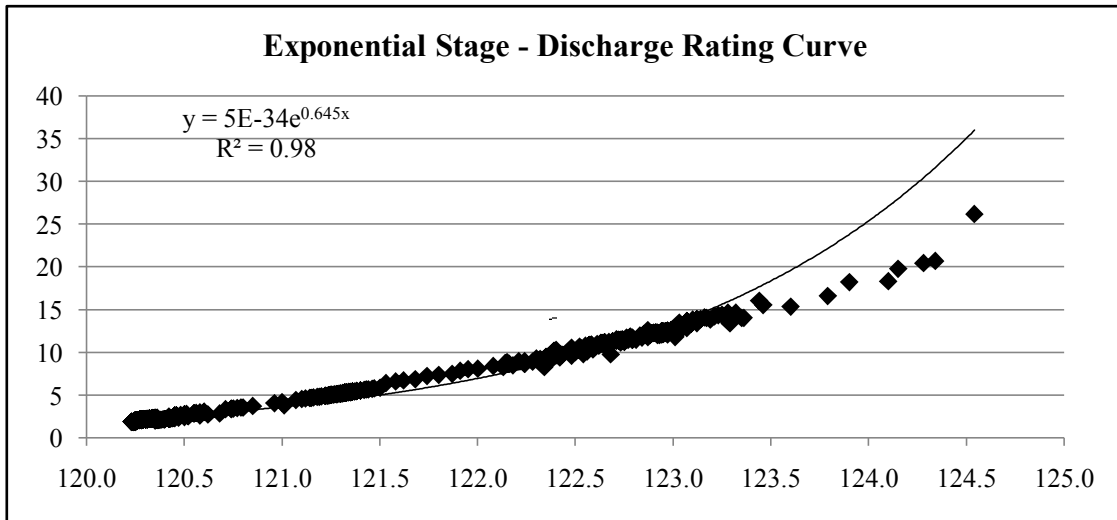


Fig. 5:- Exponential Stage Discharge rating curve of Tipling River for the year 1995.

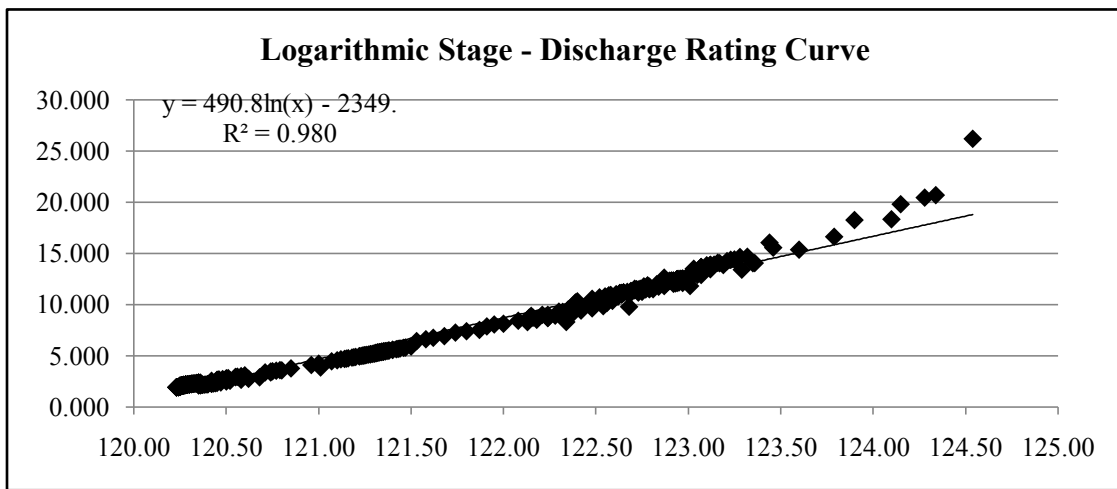


Fig. 6:- Logarithmic Stage Discharge rating curve of Tipling River for the year 1995.

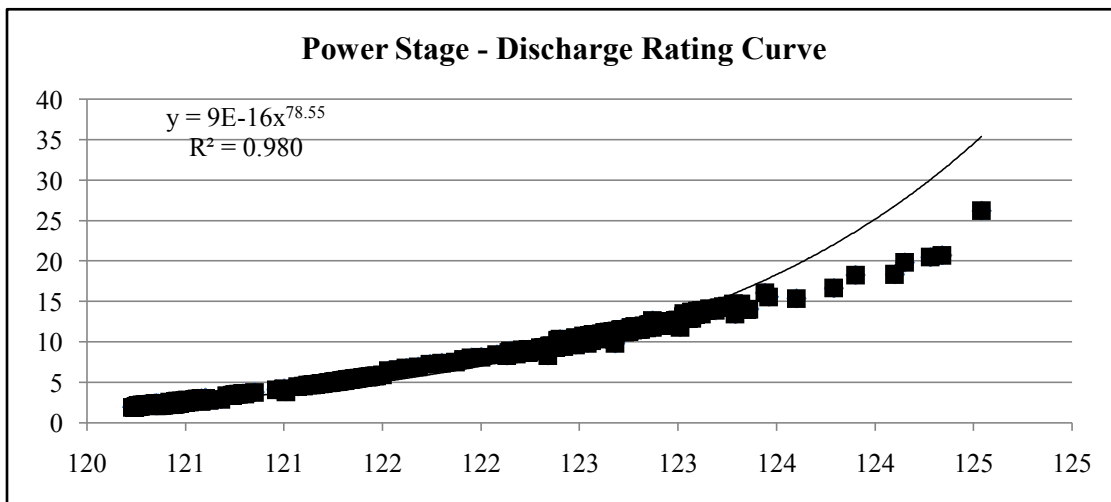


Fig. 7:- Power Stage Discharge rating curve of Tipling River for the year 1995.

Hydrograph of the Tipling River for 19 years:

Based on the linear stage discharge rating curve and its mathematical relationship, discharge values were calculated for the available stage information of the Tipling River for the period of 1994 to 2012. Initially, the average of daily 3 gauge record is being calculated for stage value of each day of the 19 years duration. The linear regression equation of the stage-discharge rating curve, i.e. $y=4.034x-483.5$, is used to calculate the y value of each day in Cumecs. It is further processed to estimate the per day discharge in Cu. M. before plotting it to create the 19 years Hydrograph of the Tipling River as presented hereunder.

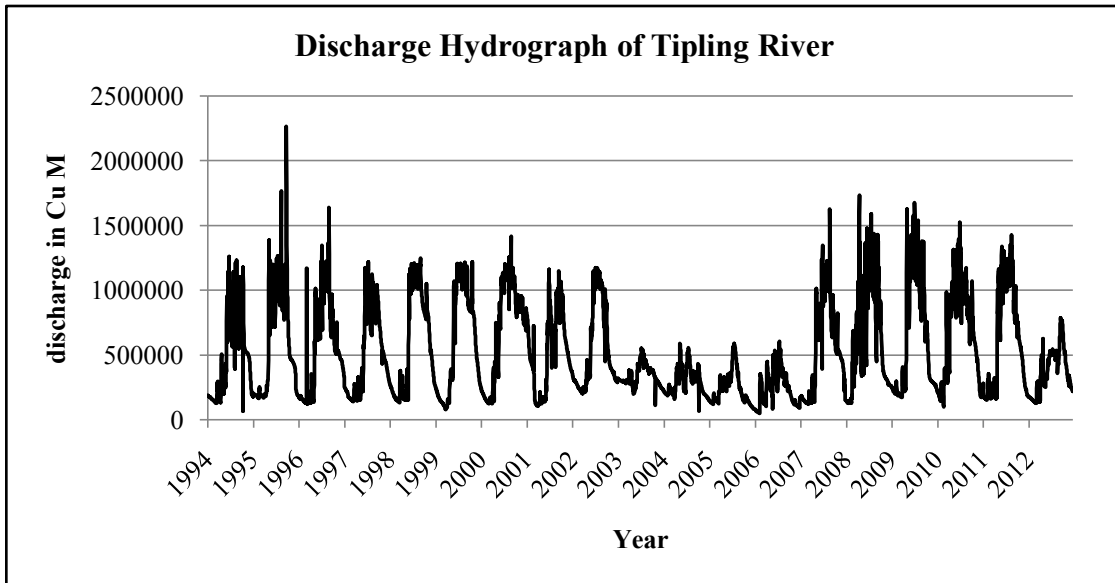


Fig. 8:- Nineteen Years’ Discharge Hydrograph of Tipling River.

In the study period of 19 years, the annual discharge of the Tipling River is not homogeneous. From the year 1994 to 2002, the annual discharge is observed to be around 200 Million Cu. M. However, in the year 2003, the annual discharge of the Tipling River had a sudden drop of around 80 Million Cu.M. The lean discharge is continued for next 3 years before it comes back to its original level of 200 M. Cu. M. discharge in the year 2007.

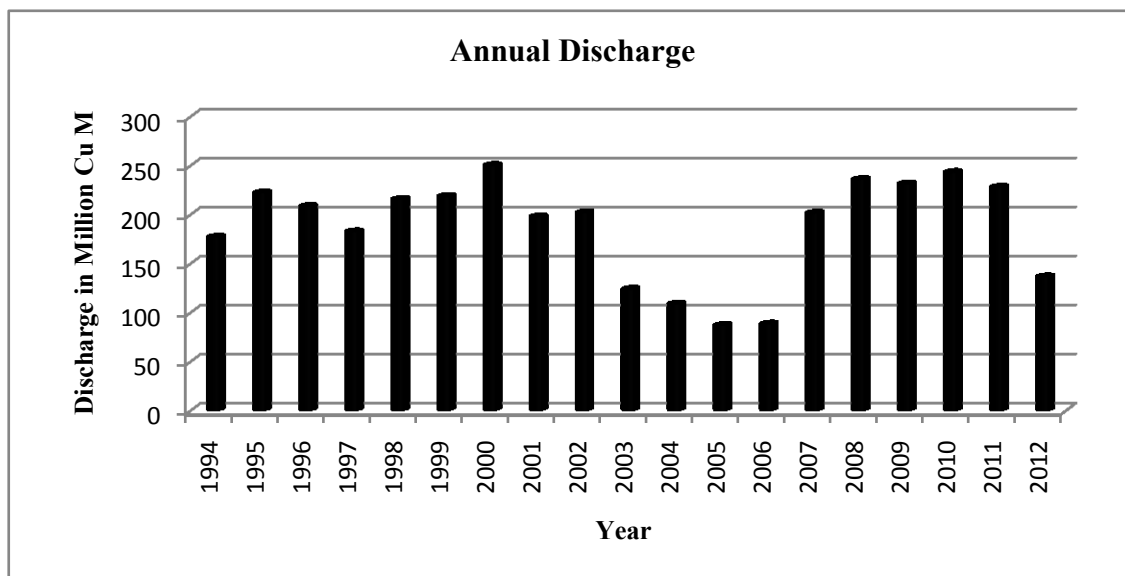
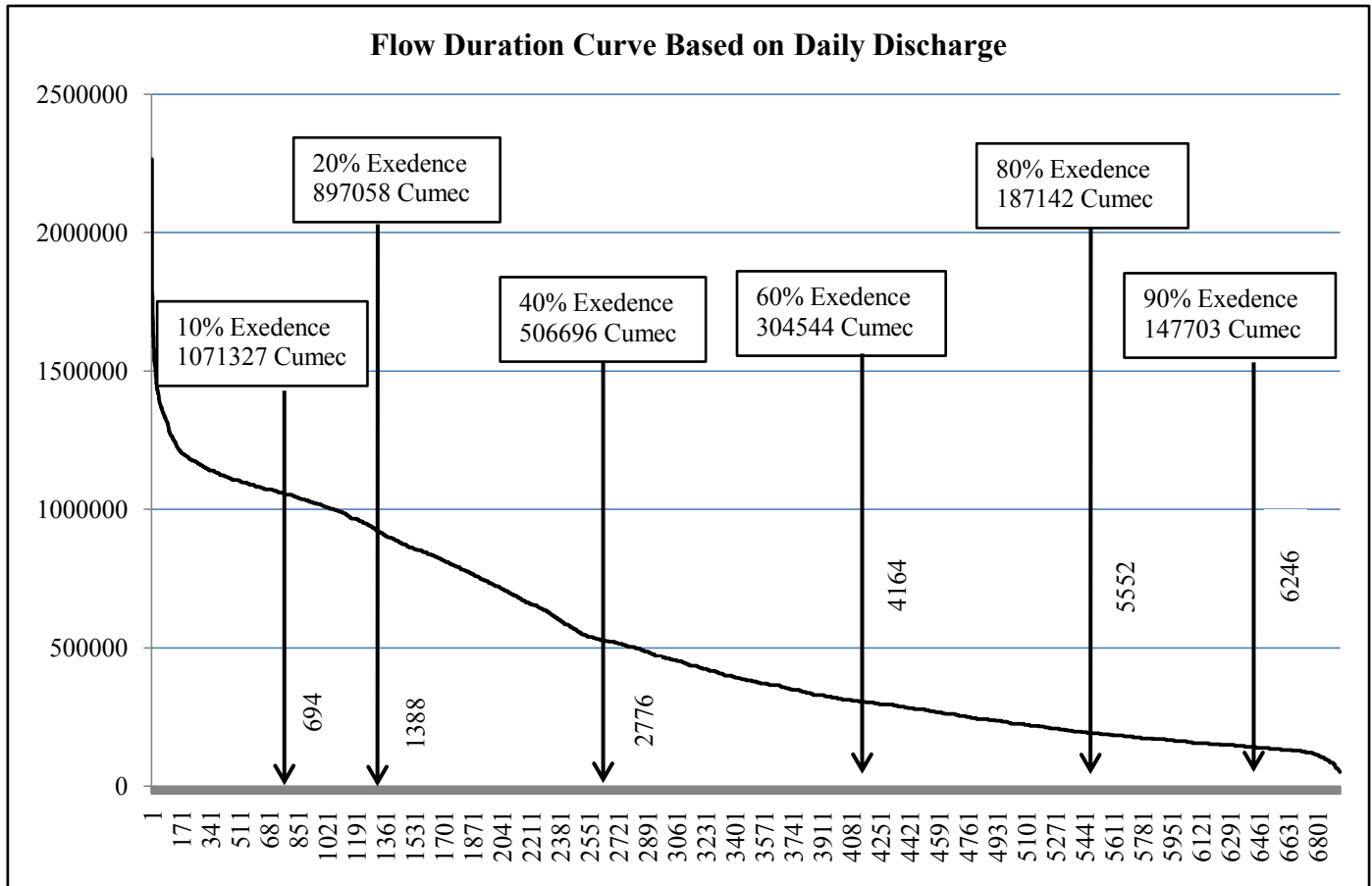


Fig. 9:- Nineteen Years’ Annual Discharge of Tipling River.

Similar drop of discharge is observed again in the year 2012 also. In the year 2011 the annual discharge of the Tipling River was recorded around 228 M. Cu. M. and in the year 2012 the discharged was reduced by around 90 M. Cu. M. and come down to 137 M. Cu. M. In the 19 years observation period, the year 2005 recorded the lowest annual discharge of around 87 M. Cu. M. only and the highest annual discharge is recorded in the year 2000 which is around 250 M. Cu. M. However, Flow Duration Curve is prepared to make the discharge information meaningful for engineering projects.

Fig. 10:- Flow Duration Curve of the Tipling River.



Flow Duration Curve of the Tipling River:

The flow Duration Curve of the Tipling River is prepared based on the daily discharge record of 19 years data points. The daily discharge information is tabulated in a descending order to prepare a smooth curve and corresponding percentage of exceedence is calculated. The ‘percentage exceedence’ implies that out of 100 days, how many days discharge is equal or more than the specific value.

From the flow duration curve of the Tipling River, it is observed that the daily discharge of the River is more or equal to 147,703 Cu. M. in 90% of the days in the observation period. It is further observed that out of 6940 days of data points across 19 year from 1994 to 2012, in 6246 days the discharge is more or equal to 147,703 Cu. M. per day.

This information is extremely helpful to design the micro hydropower or/and diversion based irrigation projects. Any project designed for the given discharge value of 147,703 Cu. M. will be having the full utilization opportunities of installed capacity in 90% days of a year. Only in 10% of the days the project might not utilize its full capacity. Here, the project designers have to make a critical choice of designing the project’s installed capacity and duration of its full utilization opportunity. Higher the installed capacity lower will be its full utilization opportunity (Hussain, T.A., 2018)

As for example, if the project is designed at 40% exceedence level where the daily discharge is 506,696 Cu. M., obviously the project will be comparatively a larger capacity project which will be operating only 40% days with its full utilization opportunity. Remaining 60% days the project will be operating in a lower value than its installed capacity.

The various daily discharge values at different percentage exceedence level of the Tipling River are shown in the table below along with number of days. Such exceedence is observed out of 6940 days of data points studied.

Sl. No.	Percentage Exceedence	Cu M	cumecs	No. of Days
1.	1%	1340863	15.519	70
2.	10%	1071327	12.400	694
3.	20%	897058	10.383	1388
4.	40%	506696	5.865	2776
5.	60%	304544	3.525	4164
6.	80%	187142	2.166	5552
7.	90%	147703	1.710	6246

High Discharge Occurrence Records:

Further analysis of the Flow Duration Curve and identification of the very high value discharges that composed of 1% exceedence could be interpreted as the flood situation in the river Tipling. More than 1,340,863 Cu. M. of daily discharge is observed in 1% exceedence and such high value discharge is recorded in 70 days out of the 6940 days of the study period of 19 years.

The flood situation is recorded from the month of April to September in different years. Only in 8 years out of the 19 years such flood situation is observed. Year and month wise number of 1% exceedence of daily discharge implying the flood situation is shown in the table below.

Years	April	May	June	July	August	September	Grand Total
1995		1			2	6	9
1996				1	2		3
2000					1		1
2007				1	2		3
2008	4		4	10	2	2	22
2009		3	5	9	4	3	24
2010			3	1			4
2011					4		4
Grand Total	4	4	12	22	17	11	70

Flood in the month of April and May is very rare in the Tipling River. Only in the year 2008 Flood was recorded in the month of April for 4 days. Similarly, the flood was recorded in the month of May in the year 1995 for one day and in the year 2009 for 3 days.

High discharge occurrence record of the Tipling River provides a good deal of insight for project formulation as well as for risk analysis and risk management of any micro hydropower or diversion based irrigation projects.

Time Series modeling of discharge of the Tipling River:

Time series modeling is a very useful tool to understand the discharge pattern of a river including its various components like central moving average, trend component, seasonal components and its irregularity or random components. Based on the available discharge information of the Tipling River, attempts were made to create Time Series Model on the seasonal basis as well as in the monthly basis. In both the cases prediction of discharge was made for a period where information is not available.

Seasonal Time Series Modeling of the Tipling River Discharge:

The daily Discharge information of the Tipling River was recorded 3 times a day by the office of the Executive Engineer, Upper Assam Investigation Division, Flood Control Department, Government of Assam and collected and

tabulated before calculating the daily average discharge of the Tipling River for 6940 days extended over 19 years from 1994 to 2012.

For the Seasonal Time Series Modeling of the Tipling River, the daily discharge data was grouped into the calendar months and average monthly discharges were calculated for each year. Necessary precautions were taken for the calibrations of 30 days' months and 31 days' months along with different calculation for the February months in normal years and leap years.

The Monthly Average Discharge data is further grouped into four different groups each year corresponding to the four different seasons. The seasonal discharge comprises of January to March is denoted as the Q1 and so on to denote October to December discharge as Q4. The average Discharge of three consecutive months are taken as a seasonal discharge (Y_i) and total 76 seasonal discharges (t) are derived from the 19 years' daily discharge data of 9640 daily data points.

The Seasonal Time series modeling for the Tipling River is carried out to predict or forecast the future discharge value of the Tipling River based on historical observed discharged values.

Time Series of Tipling River can be interpreted in three different basic model forms: (1) the Moving Average model MA (q), in which q is the order of the moving average; (2) an autoregressive model AR (p), in which p is the order of the autoregression; and (3) the autoregression Moving Average model ARMA (p, q). In this modeling of Time Series Analysis of Tipling River ARMA is used.

The seasonal data composed of 76 data points are plotted in the excel sheet with the 'Line with Marker' method to understand the seasonal variations graphically. The Time series from the year 1994 to 2012 are plotted in the 'x' axis and the seasonal discharge value is plotted in the corresponding 'y' axis of the graph by line with marker.

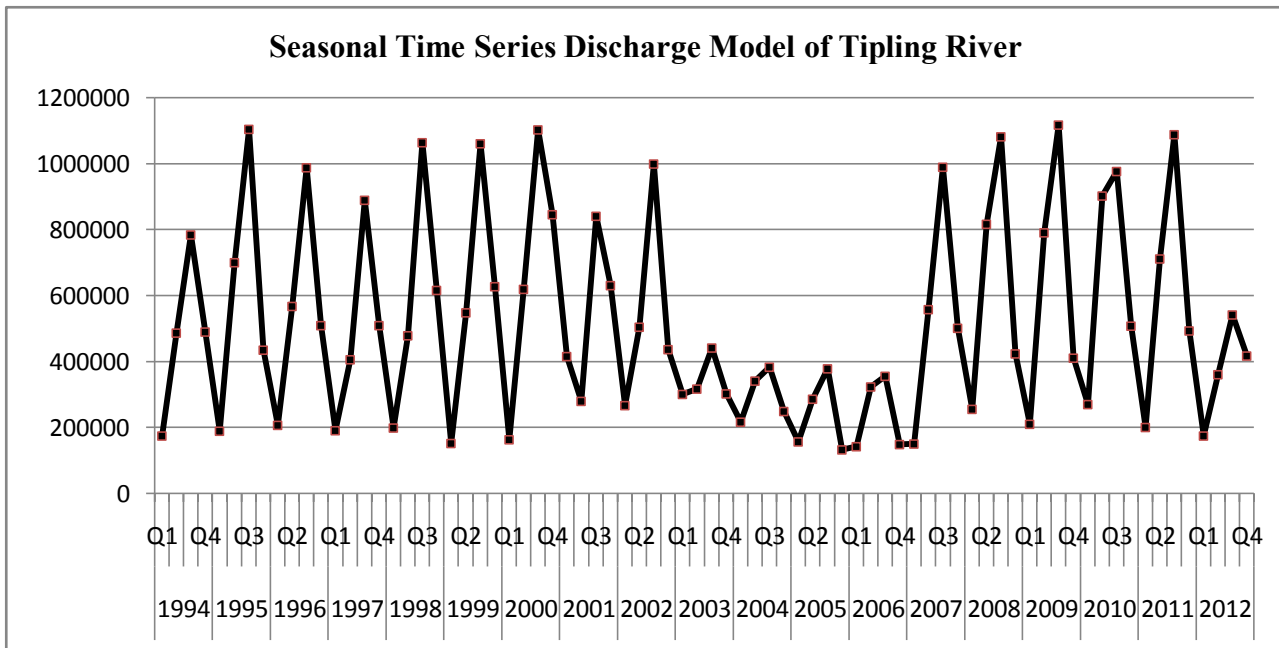


Fig. 11:- Seasonal Time Series Discharge Model of Tipling River.

The Seasonal Time Series Discharge of the Tipling River encompasses couple of unnecessary but inevitable components, like Seasonality component, Trend Component and Irregularity or random Component. It is important to mathematically and statistically filter those components to judicially forecast future discharge of the Tipling River.

On the process of removing these components from the historical data set of discharge of the Tipling River, first moving average (MA) of four data point is calculated as the annual data is divided in to four seasons. However, four is an even number and the mean of it could not be attributed against any Time Code Data (t) but fall in between two (t) values. Hence, as a second step of processing, Central Moving Average (CMA) is calculated to attribute the mean to its corresponding Time Code Data (t).

The initiative of calculating the Moving Average (MA) and subsequently calculating the Central Moving Average (CMA) has helped smoothing the curve up to a phenomenal extent to get rid of the eventual erroneous components of the Time series Data. The CMA data is super imposingly plotted in the Seasonal Time Series Data (Fig. 12) to understand the deviation of it from the historical data.

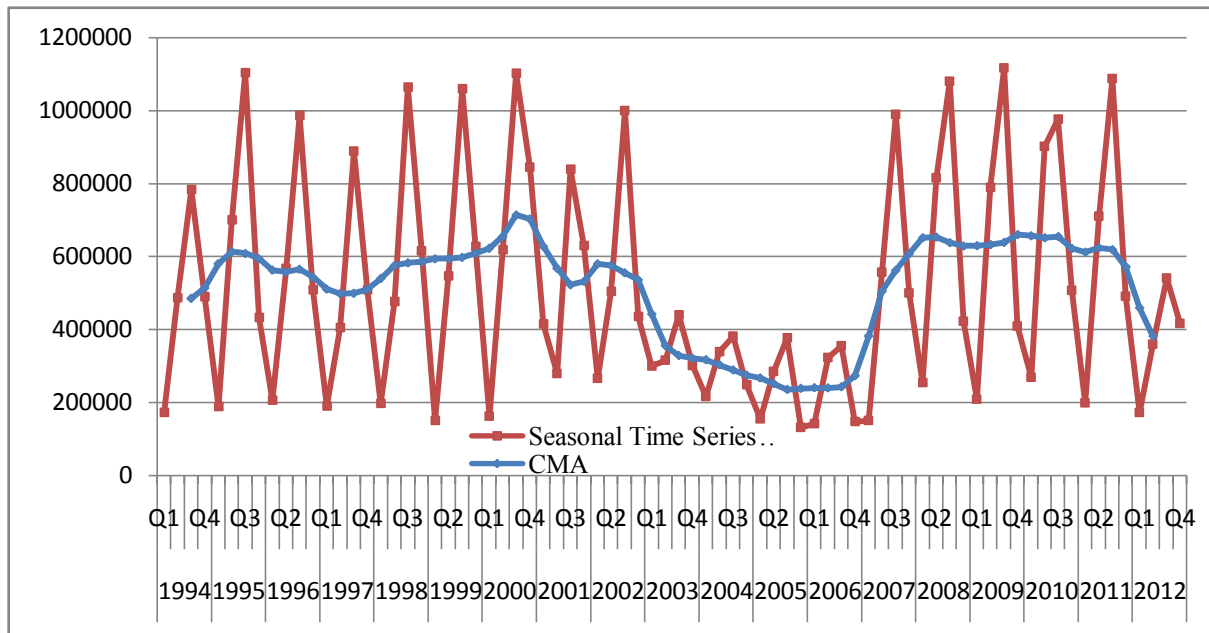


Fig. 12:- Central Moving Average (CMA) corresponding to the Time Series Discharge of the Tipling River.

The centered moving average (CMA) of the seasonal discharge information of the Tipling River is smoothing of the historical time series data basically to remove the Seasonality (S_t) and irregularity (I_t) components of the time series. This has helped us to understand the variation of smoothed data from the original time series data by extracting S_t and I_t .

As we know that the Classical Multiplicative Time Series Model is represented by the equation

$$Y_t = S_t \times I_t \times T_t$$

Here, Y_t is the Time series value, S_t is the Seasonal component, I_t is the Irregularity component and T_t is the Trend Component.

The variation of CMA from the historical time series data of the Tipling River for the corresponding time value is caused due to the removal of S_t and I_t . Hence, mathematically the influence of S_t and I_t on the historical data could be derived by the formula

$$S_t, I_t = Y_t \div \text{CMA}$$

The S_t and I_t is the variation of CMA from the time series data for the corresponding time period. CMA could also be termed as the Baseline discharge of the Tipling River. In this calculation we practically achieved the percentage of deviation of the base line discharge from the actual time series discharge. Any value more than 1 indicates positive deviation and less than 1 indicates negative.

To get rid of the I_t and to find the S_t alone we need to calculate the average of all the different seasonal values separately. The method for this is to get the average of each seasonal deviation percentage value separately. For this, AVERAGEIF function of excel is used to calculate the average percentage of deviation of CMA from the historical data.

Months	Season	Seasonal Deviation
January to March	Q1	0.435
April to June	Q2	1.032
July to September	Q3	1.650
October to December	Q4	0.863

After calculating I_t free S_t Value, for all the four seasons, another column in the excel sheet is prepared where corresponding S_t Value is tabulated against each season. The use of VLOOKUP excel function was helpful on putting the corresponding seasonal component in the S_t Column.

To make the time series data free from the unwanted S_t Component, the next step of preparing deseasonalized column of data corresponding to each Time code (t) was obtained by the formula Y_t/S_t . The deseasonalized data column is the representation of historical data without S_t and I_t components. However, the deseasonalized data of the Tipling River Discharge is still loaded with the information of the Trend Component. Without removing this, prediction for the future is not practically possible.

The exercise of removing the trend component (T_t) is essentially filtering out the high and medium frequency fluctuations so that only the low frequency time series is retained. In order to calculate the Trend Component of the Analysis, A Simple Linear Regression (SLR) was carried out with the help of deseasonalized values as Y variable and Time Code Data (t) Value as the X variable.

Data Analysis Tool Pack of excel available in Data window was used for the purpose. The deseasonalized data was entered in Y variable and time code data (t) is entered in the X variable in the Regression, the operation of the Data Analysis Toolpack to find the following results.

ANOVA	df	SS	MS	F	Significance F			
Regression	1	1.77E+10	1.77E+10	0.028427	0.86657			
Residual	74	4.6E+13	6.22E+11					
Total	75	4.6E+13						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	809866.7	182667.7	4.433551	3.16E-05	445893.3	1173840	445893.3	1173840
t	-695.038	4122.364	-0.1686	0.86657	-8909.03	7518.951	-8909.03	7518.951

The most important and useful information derived out of the exercise was the value of the Coefficients. The Intercepts represents the 'Y' intercepts and 't' is the slope. With the help of these coefficients the Trend Component (T_t) of the discharge of the Tipling River could be ascertained. The formula used for the calculation is

$$T_t = \text{intercept value} + \text{slope value} \times \text{Time Code (t) of the row}$$

The derived Trend component (T_t) value is tabulated in a column corresponding to the Time Code (t). With this exercise we have reached almost the verge of predicting the future Seasonal discharge of the Tipling River.

In order to make prediction we need to combine all the components which we separated earlier. A column entitled Forecast is prepared where the Seasonal Component is multiplied with the Trend component of the historical data as shown below and extended to the year and season up to which we wanted to forecast.

$$\text{Forecast} = S_t \times I_t$$

In this exercise forecasting is made for next 5 years. The value of the forecast is plotted in the graph as shown in the Fig. 13. It is observed that the forecasted data is not coinciding with the historical data of the last 19 years appropriately demonstrating minimal accuracy for the prediction. The historical data from 2002 to 2006 has exceptionally low discharge value demonstrating a disconnect with the rest of the years' discharge of the Tipling River. It might be wise not to use this seasonal prediction for designing any micro hydro project or diversion based irrigation project based on this seasonal forecast.

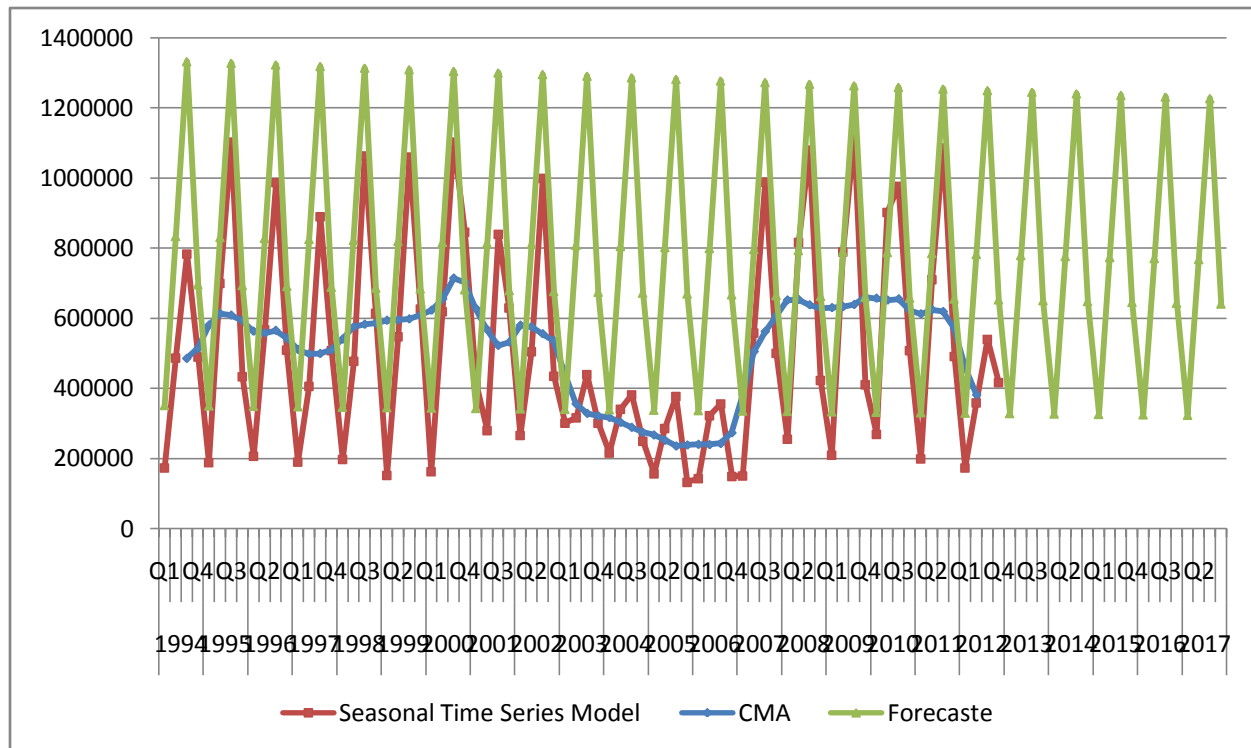


Fig. 13:- Seasonal historical Time Series, CMA and Forecast of the Tipling River Discharge.

Monthly Time Series Modeling of the Tipling River Discharge:

In order to verify the validity of prediction in a narrow window of time period to effectively use for any Micro Hydropower project or for any diversion based irrigation project in the Tipling River, monthly time series modeling is also attempted to formulate.

Here, the historical time series data Y_t is calibrated to accommodate the average monthly Discharge of the Tipling River for 19 years corresponding to the Time Code Data (t). In the exercise all total 228 data points are considered. The Moving Average of it is calculated with 12 points against the 12 months of each year. The calculation of Central Moving Average (CMA), and segregation of S_t , I_t and T_t is carried out as demonstrated in the Seasonal Time Series Modeling of the Tipling River earlier.

Appropriate measures are taken for the deseasonalization of the data in a monthly basis and Simple Linear Regression (SLR) was carried out to find the intercepts value and t value with the help of Data Analysis Tool Pack.

Forecasting of the Discharge Data carried out for 36 months, i.e. 3 years, based on the historical discharge information has shown comparatively more relevance than that of the seasonal forecasting (Fig. 14.)

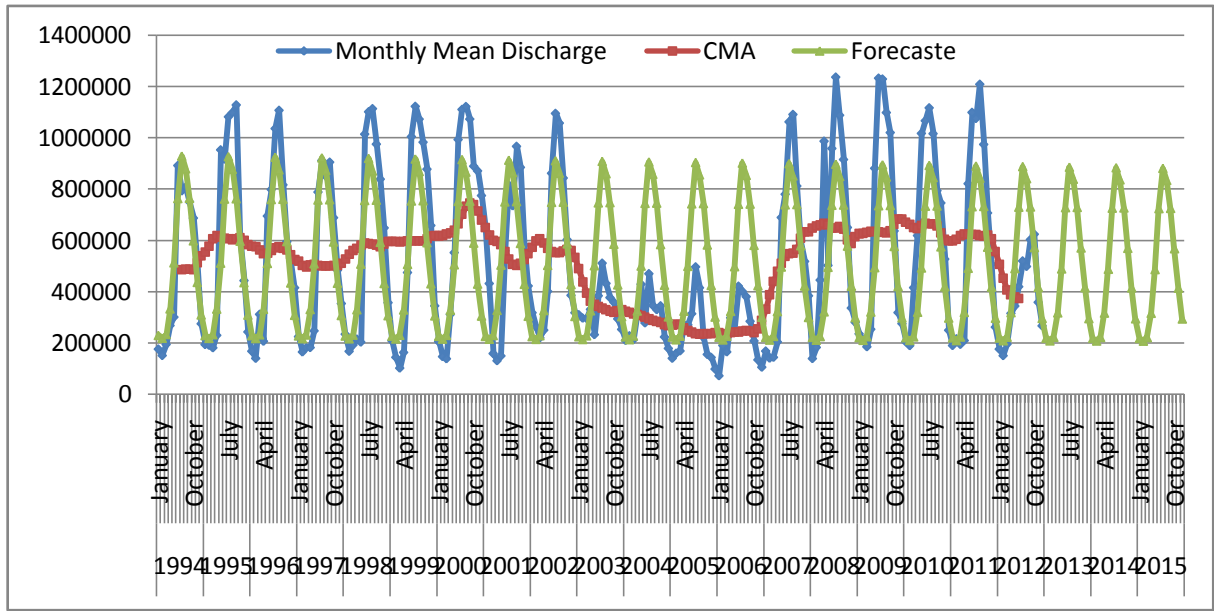


Fig. 14:- Monthly historical Time Series, CMA and Forecast of the Tipling River Discharge.

Conclusion:-

The daily discharge information of the Tipling River is collected for 19 years (from 1994 to 2012) and analysed for its flow pattern and assessed its potentiality for different engineering geological projects. Tipling River flow analysis envisages a good deal of hydropower and diversion based irrigation potentialities with average daily discharge of 5, 13,095 Cu. M.

Based on the available information of the stage, discharge velocity and cross sectional area 'Stage Discharge Rating Curve' was prepared with the help of scattered plots and various regression models. In this case Linear Regression has demonstrated the Goodness of Fit for preparing the best fit rating curve. Accordingly the stage-discharge relationship is established to estimate the discharge from the subsequent stage information of the stream.

Discharge hydrograph is prepared to understand the Tipling River flow pattern and its variations on Annual basis, seasonal basis as well as monthly basis. In the year 2000 Tipling River had the highest discharge and the year 2005 it had the lowest discharge. Every year Tipling River demonstrated high flow from the month of June to September, whereas in the months of November to February it shows lean discharge.

The Flow Duration Curve is prepared to estimate different percentage of discharge exceedence to build various confidence levels for hydropower or diversion based irrigation projects. It is observed that the Tipling River has at least 147,703 cubic meters per day discharge in 90% of the times if its flow history.

Analysis of high discharge occurrence records envisages that the Tipling River had more than 15.519 cubic meters per second discharge in 70 days during the study period of 19 years. Such a high level of discharge was shown only in 8 years and that is also spread from the month of April to the month of September only. Out of these 70 days of high flow 22 days were in the month of July followed by 17 days in the month of August. High discharge occurrence in the months of April and May is pretty nominal.

Time Series modeling was carried out to understand the influence of seasonal components, trend components and the irregularity or random components of the Tipling River Flow so that it could be effectively predicted for future flow. The modeling is done on the seasonal basis as well as on the monthly basis. The seasonal Time Series forecast model has expressed substantial variation with the historical data and found not fit for any prediction. However the Monthly Time Series Model has demonstrated comparatively more accuracy than that of the Seasonal Time Series model. Hence, the Monthly Time Series Model could be used for Micro Hydropower or Diversion based irrigation projects in the Tipling River for the discharge forecasting.

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