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EL NINO-SOUTHERN OSCILLATION (ENSO): RECENT EVOLUTION AND POSSIBILITIES FOR LONG RANGE FLOW FORECASTING IN THE BRAHMAPUTRA-JAMUNA RIVER

N. JAHAN* *Department of Water Resources Engineering*
A.T.M. HASAN ZOBEYER *BUET*
M.A. BHUIYAN *Dhaka 1000, Bangladesh*

*to whom all correspondence should be addressed:
e-mail: nasreenjahan@wre.buet.ac.bd

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ABSTRACT

The El Nino-Southern Oscillation is the dominant pattern of short-term climate variation, and is therefore of great importance in climate studies. Some recent studies showed the teleconnection between stream flow and the El-Nino Southern Oscillation (ENSO) of the equatorial Pacific Ocean. This paper presents an overview of the relationship between ENSO and stream flow in the Brahmaputra-Jamuna and the potential for wet season flow forecasting. This seasonal forecast of stream flow is very invaluable to the management of land and water resources, particularly in Bangladesh to improve the predictability of severe flooding. Over the years, large investments have been made to build physical infrastructure for flood protection, but it has been proved that it is not feasible, both economically and technically, to adopt solely structural mitigation approach. The choice of non-structural measures in this country focused mainly on flood forecasting because many of the non-structural measures including flood plain zoning, compulsory acquisition of flood prone land, relocation etc have also been proved inappropriate for Bangladesh.

The aim of this research is to find out an effective and long-lead flow forecasting method with lead time greater than hydrological time scale, using El Nino-Southern Oscillation index. Some studies indicate that SST can be predicted one to two years in advance using several ocean/ coupled ocean atmosphere models, therefore the ability to predict flow patterns in rivers will be highly enhanced if a strong relationship between river discharge and ENSO exists, and is quantified. With this view, to assess the strength of teleconnection between river flow and ENSO, at first correlation analyses between ENSO indices of any year and wet season flow of that year have been done. Here sea surface temperature (SST) has been used as ENSO index. This correlation analysis demonstrates a noteworthy relationship between natural variability of average flow of the months July-August-September (JAS) of the Brahmaputra-Jamuna River with SST of the corresponding months. Then discriminant prediction approach, also known as “Categoric Prediction” has been used here for the assessment of long range flood forecasting possibilities. This approach will be able to forecast the category of flow (high, average or low) using the category of predictor (predicted SST) at a sufficient lead time. In order to judge the forecast skill, a synoptic parameter “Forecasting Index” has also been used. This discriminant approach will improve the forecasting lead-time while the hydrologic forecast through rainfall-runoff modeling could provide a lead time on the order of the basin response time, which is several days or so. As the Ganges–Brahmaputra river basin is one of the most populous river basins of the world and is occupied by some developing countries of the world like Bangladesh, any reduction in the uncertainty about the flood in the Brahmaputra-Jamuna River would contribute a lot to the improvement in flow forecasting as well as to the economic development of the country.

KEYWORDS: El Nino-Southern Oscillation, Brahmaputra-Jamuna River, sea surface temperature, teleconnection, flow forecast, lead time, forecasting index.

1. INTRODUCTION

The Ganges-Brahmaputra river basin is one of the most populous river basins in the world and is occupied by some developing countries of the world like Bangladesh. Sustainable water management is very critical in this basin due to increasing population & accelerating economic development activities. Floods in this basin affect directly or indirectly, the fate of nearly one-sixth of the population of the world. Being a lower riparian country, the situation is the worst for Bangladesh.

A large scale coupled ocean-atmosphere oscillation in the Pacific Ocean known as El Nino - Southern Oscillation (ENSO) is related to interannual variations in precipitation and stream flow in several regions of the world. El Nino events are warming episodes and La Nina events are the cooling episodes of the equatorial Pacific Ocean that influence the global climate. It is also recognized that the ENSO temperature signal pervades the entire tropical belt. Recent studies indicate that ENSO events can be predicted one to two years in advance using several ocean/ coupled ocean atmosphere models such as Coupled General Circulation Model, Statistical Model (Canonical Correlation), Linear Inverse Model etc. Therefore the ability to predict flow patterns in rivers will be highly enhanced if a strong relationship between river discharge and ENSO exists, and is quantified.

Previous studies have shown that ENSO is correlated with the interannual variability of rainfall and river flow in several regions of the world. Ropelewski and Halpert (1996) have identified 19 regions throughout the world whose precipitation characteristics are related to the ENSO phenomena. Indian subcontinent is one of those 19 regions. Studies by Rasmusson and Carpenter (1983); Shukla and Paulino (1983) also explored the possible relationships between ENSO and precipitation in Indian subcontinent. A study by Whitaker et al. (2001) showed that Ganges floods are correlated with ENSO and flood events are correlated with La Nina events, which is the cold phase of ENSO. The relationships between ENSO and riverflow have also been established in many other researches. Eltahir (1996) used ENSO as a predictor of natural variability in the flow of the Nile River; Simpson *et al.* in 1993 related the Australian Murray-Darling River discharges with ENSO.

Floods in the major rivers of Bangladesh are mainly due to the heavy rainfall in the upper riparian countries. Deficiency of adequate and authentic data from those countries hinders flood forecasting in our country. Moreover hydrologic forecasts of the basin through rainfall-runoff modeling could provide a lead time on the order of the basin response time, which is several days or so. Such a short forecasting lead time is not adequate to plan for extreme events (floods). To facilitate basin wide planning and management of water resources, it is desirable to capture river discharge variability with a forecasting lead time of a few months to a year.

Considering this importance of flood forecasting and limited scope of rainfall-runoff modeling, it has become essential for Bangladesh to develop a flow forecasting method which will be able to forecast flow with a lead time of at least few months. This research aims at assessing the possible teleconnection between ENSO and Brahmaputra-Jamuna river flow and developing a method to forecast the category of average flow of July-August-September (JAS) season which will allow few months to one year forecasting lead time, based on relationships between flows in the Brahmaputra-Jamuna River and El Nino- Southern oscillation (ENSO) index.

2. DATA

The riverflow data of Brahmaputra-Jamuna has been collected from Bangladesh Water Development Board, BWDB for the time period 1977 to 2003, recorded at the Bahadurabad discharge measuring station. In this research sea surface temperature (SST) of Nino 4 region of equatorial Pacific Ocean has been used as ENSO index to identify the ENSO signal. The SST data has been collected from National Centre for Environmental Prediction (NCEP) of National Oceanic and Atmospheric Administration (NOAA). The SST forecast data of Linear Inverse Model has been collected from NOAA-CIRES/Climate Diagnostic Centre, Colorado.

3. TELECONNECTION BETWEEN ENSO AND THE BRAHMAPUTRA-JAMUNA RIVER FLOW

The Brahmaputra-Jamuna River has a distinct dry season and wet season flow. The monthly averages are shown in Figure 1, which shows that most of the flow occurs between July to September. Floods in this river may occur any time during this period. For this reason average flow of these three months, July-August-September (JAS) have been used for identifying the teleconnection with ENSO and flood forecasting analysis.

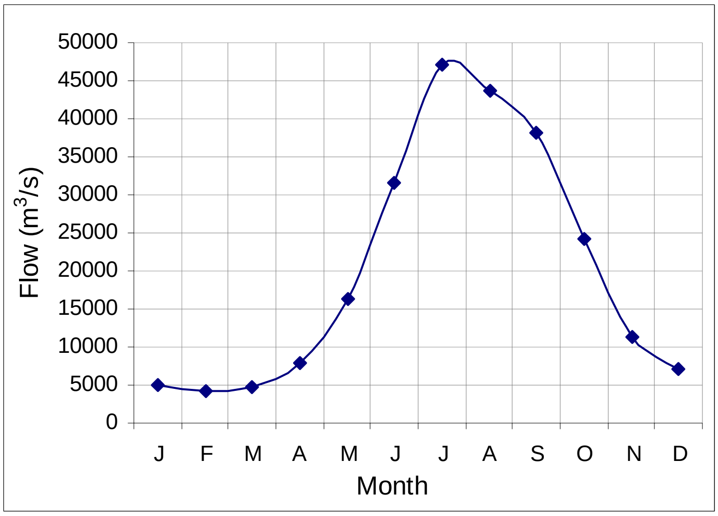

Figure 1. Monthly average flow of Brahmaputra-Jamuna

To identify the possible teleconnection between ENSO and Brahmaputra-Jamuna River flow, cumulative frequency distributions of standardized annual river flow are plotted in Figure 2. The riverflow is standardized by deducting the mean value and dividing by the standard deviation. Figure 2 shows that for the annual flow, for example, in a given year, the probability of exceeding the long term average annual flow is 0.40. For the standardized time series the long term average corresponds to zero. During the El Nino year, this probability drops to approximately 0.22; while for La Nina years the probability rises to around 0.6. This shows the clear influence of ENSO events on the annual flow of Brahmaputra-Jamuna.

The Cumulative frequency distribution of JAS flow in Figure 3 also supports the influence of ENSO. From the frequency distribution of JAS flow it has also been found that during El Nino years the probability of exceeding the long term average JAS flow is only around 25% while during La Nina years this probability rises to about 77%.

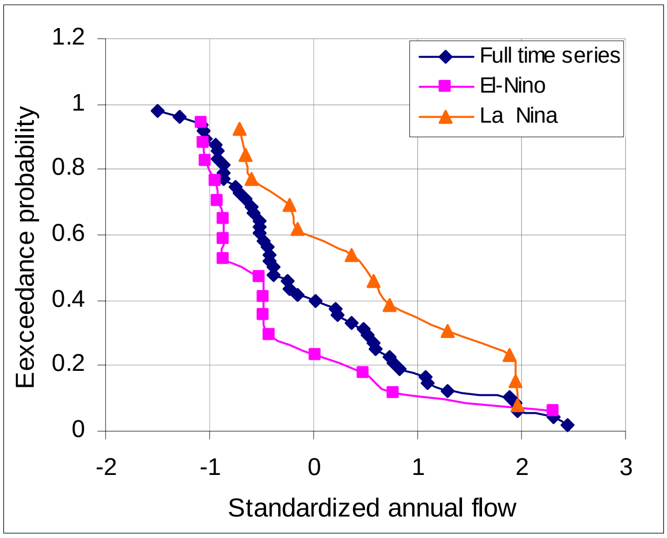

Figure 2. Cumulative frequency distributions of standardized annual flow

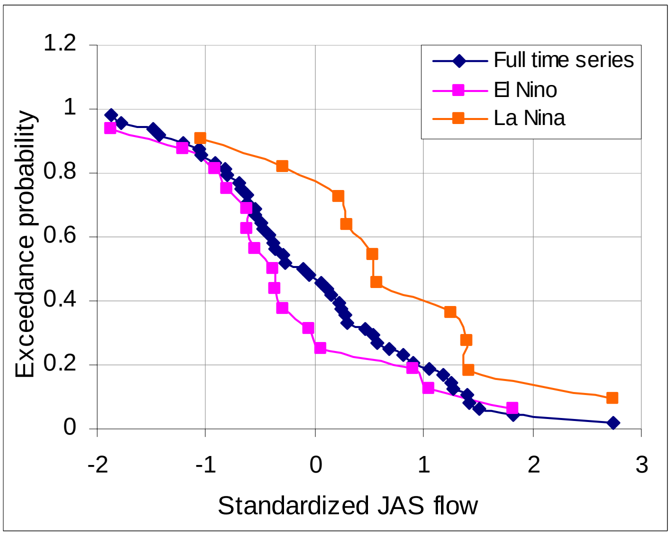

Figure 3. Cumulative frequency distributions of standardized JAS flow

The relationships between ENSO and flow encouraged a closer look at the correlation between ENSO indices and the flow. The ENSO indices are averaged over different seasons of the year. Table 1 shows the correlation coefficients between the JAS flow in the Brahmaputra-Jamuna and the ENSO index of different time periods of the same year. From table 1, it is clear that JAS SST has notable influence on JAS flow.

Table 1. Correlation coefficients (R) between the JAS flow in the Brahmaputra-Jamuna and the SST of different time periods of the same year (1977-2003)

Dependent Variable	**Independent variable**	**R**	**R^2**	**F statistic**	**P statistic**
JAS Flow	May-June-July (MJJ) SST	-0.328	0.107	3.006	0.095
	June-July-August (JJA) SST	-0.444	0.197	6.133	0.035
	July-August-September(JAS) SST	-0.494	0.244	8.061	0.015

4. FLOW FORECAST POSSIBILITIES USING DISCRIMINANT PREDICTION APPROACH

The discriminant prediction approach, also known as “Categoric Prediction” has been used here for the assessment of long range flood possibilities. This approach forecasts the categoric probabilities of the predictand (river flow) according to the categories that the predictors (SST) fall into. Using the strong correlation between the JAS flow in the Brahmaputra-Jamuna and the JAS ENSO index (JAS SST), a conditional probability table is prepared to forecast the JAS flow or flood flow. Both of the series are standardized by deducting the mean value and dividing by the standard deviation. The annual flow is categorized into high, average and low by using plus and minus half standard deviation to define the class boundary. On the other hand SST is categorized into warm, normal and cold by using plus and minus one standard deviation to define the class boundary.

Any categoric probability can be computed by counting all the relevant data points, and normalizing it by the number of all data points that satisfy the condition. Here the main interest is on the conditional categoric probabilities. All the data points which fulfill the given condition (suppose cold, normal or warm) are counted; then those cases with a low, average and high flood are identified, and the relative frequency distribution are obtained. Then the forecasting probability of each flood category can be computed. Considering all possible combination of SST and riverflow, the total data points have been divided into nine groups.

Figure 4 and table 2 show the conditional probabilities of JAS flows using SST as predictor based on the observations from 1977-2003. The table reveals that the addition of ENSO information modifies the forecasting probabilities for the flood to a large extent. With the additional knowledge of a warm event (El Nino event), the probability of high flow drops to 0.25 and low flow rises to 0.63. For the same observations it has been found that during a cold (La Nina) year the probability of high flow rises to 1 and probability of low flow drops to 0.

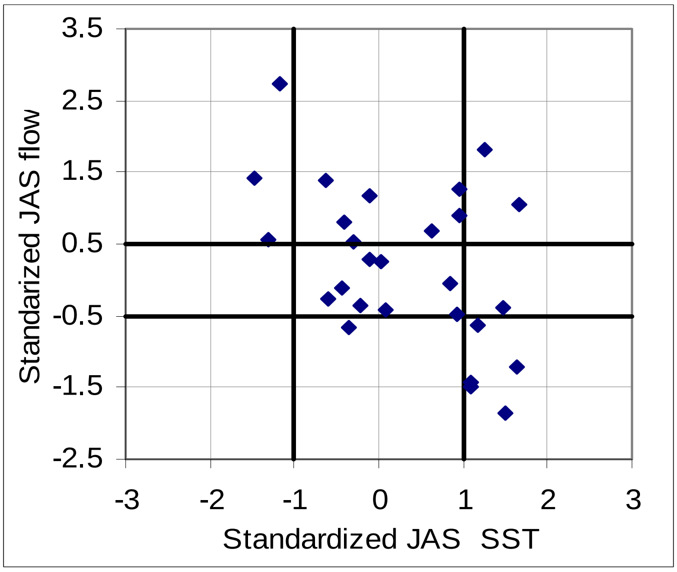

Figure 4. Categories of JAS flow of Brahmaputra-Jamuna and the JAS SST (1977-2003). All combinations of SST and corresponding flow are shown through nine groups

Table 2. Conditional probability of JAS flow of Brahmaputra-Jamuna River (1977-2003)

SST	**JAS Flow**		
	Low	**Average**	**High**
Cold	0	0	1
Normal	0.06	0.56	0.38
Warm	0.63	0.13	0.25

Several ocean or coupled ocean-atmosphere models are available now a day which can forecast SST with a lead time up to one year or even more. So from the observations it is very clear that if SST can be predicted accurately sufficiently long time before the flood event then using relationships between SST and wet season flow, the probability of high, average or low flow can be predicted from table 2, with an appreciable lead time.

5. ASSESSMENT OF FORECAST SKILL USING FORECASTING INDEX

5.1 Forecasting Index (FI)

In order to easily judge the forecast skill and to compare different forecasts, a synoptic parameter, the forecasting index (FI) can be used (Wang and Eltahir, 1999). This index can measure the forecast skill and have previously been used in many other discriminant forecasts. The FI value is defined as the average of the forecasting categoric probabilities for the categories that the observed flood in each individual year falls into during an n- year period. First of all, in each year j (j= 1, 2,…n), the ENSO index is categorized. Accordingly, the probability of each flood category can be forecasted by using table 2, and are denoted as the prior probability $P_r(i, j)$, where $i = 1, 2, 3$ stand for three flow conditions (low, average and high). Then the flood observation in that year is categorized, and the posterior probability $P_p(i, j)$ can be identified as [1 0 0] in a low flow year, [0 1 0] in an average flow year and [0 0 1] in a high flow year. FP (j), the forecasting probability of the flood category which describes the observed flood condition for that year, can be computed as:

$$FP(j) = \sum_{i=1}^{3} P_r(i, j) P_p(i, j)$$

The forecasting index, FI is the average of these probabilities over a certain period:

$$FI = \frac{1}{n} \sum_{j=1}^{n} FP(j) = \frac{1}{n} \sum_{j=1}^{n} \sum_{i=1}^{3} P_r(i, j) P_p(i, j)$$

A large forecasting index implies a more accurate forecast. A perfect forecasting methodology would have an FI of 1.0.

Traditionally, the discriminant forecast skill is measured using the proportion of correct forecasts, in which the right category of the predictand gets the highest predicted probability. Therefore, when the traditional skill measure is used, a forecast of 80% (wet), 15% (average), and 5% (dry) for a wet year is not different from a forecast of 40% (wet), 35% (average) and 25% dry. Because both of the model forecast is wet period. However, the skill measure used in this study can determine the 'accuracy' difference between these different forecasts, even if they might be all correct forecasts. This new measure skill provides a better tool to judge the quality of categoric prediction.

5.2 Evaluation of forecast skill

SST forecast models are forecasting regularly since 1990s. Linear Inverse is one of those models which are successfully forecasting SST of NINO 4 region since 1992. So predicted SST of Linear Inverse Model has been used in this research to forecast flow category. Subsequently a skill assessment of the proposed discriminant approach has also been made using the predicted SST for the time period 1993-2003.

The forecast skill of the proposed discriminant approach has been shown in table 3. The analysis (Table 3) for conditional forecasting shows that among the eleven events (1993-2003), the model predicts seven events correctly. It is also important to note that there were no cold SST with low flow and warm SST with High flow events, which have the lowest statistical probability. Especially the model shows excellent efficiency in predicting the cold events i.e. high flow events. From table 3 it has also been observed that the forecast index is 0.58. This result can be taken as successful forecast because any forecast having a FI greater than 0.5 can be considered as successful (Wang and Eltahir, 1999). This approach can also be used to forecast the flow with one year lead time as several SST forecast model now forecasts the SST with a lead time up to one year.

Table 3. Conditional forecasting of the JAS flow of Jamuna, based on predicted SST (lead time three month) and comparison with the observed flow (using conditional probability of Table 2).

Year	Predicted JAS SST* (^{O}C)	Predicted ENSO condition	Prior Probability			Observed JAS flow*	Observed flow category	Posterior probability	FP(j)	FI
			Low	Average	High					
1993	0.53	Normal	0.06	0.56	0.38	0.91	High	[0 0 1]	0.38	0.58
1994	1.05	Warm	0.63	0.13	0.25	-1.87	Low	[1 0 0]	0.63	
1995	0.57	Normal	0.06	0.56	0.38	0.30	Average	[0 1 0]	0.56	
1996	-0.12	Normal	0.06	0.56	0.38	1.18	High	[0 0 1]	0.38	
1997	1.35	Warm	0.63	0.13	0.25	-0.38	Average	[0 1 0]	0.13	
1998	-1.10	Cold	0.00	0.00	1.00	2.74	High	[0 0 1]	1.00	
1999	-1.19	Cold	0.00	0.00	1.00	0.57	High	[0 0 1]	1.00	
2000	-1.02	Cold	0.00	0.00	1.00	0.82	High	[0 0 1]	1.00	
2001	1.09	Warm	0.63	0.13	0.25	-1.49	Low	[1 0 0]	0.63	
2002	0.76	Normal	0.06	0.56	0.38	-1.21	Low	[1 0 0]	0.06	
2003	0.05	Normal	0.06	0.56	0.38	-0.49	Average	[0 1 0]	0.56	

* Standardized

6. CONCLUSION

In this research a strong link has been found between the wet season flow of Brahmaputra-Jamuna and ENSO. This association has been manifested as an increased propensity of low flow in the wet season during El Nino years and high flow during La Nina years. The correlation analyses between average flow of July-August-September (JAS) and seasonal SSTs show that JAS flow is highly correlated with JAS SST of Nino 4 region. Subsequently the discriminant analysis based on the observation of 1977-2003 also supports this strong relationship.

The discriminant prediction approach, proposed in this research exhibits remarkable efficiency in predicting the wet season flow. The overall forecast skill (FI = 0.58) of this approach is appreciable for three month lead time. It is also notable that the model is fully successful in predicting the cold events with high flow for the time period 1993-2003. This assures the practicality of the forecasting procedure proposed in this research for Brahmaputra-Jamuna River.

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