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An Observation on the Relationship between Climate Variability Modes and River Discharges of the Citarum Basin, Indonesia

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Synopsis

The climatology of stream-flow at the Nanjung gauge station of the Citarum River in Indonesia shows significant flow during November to April and very less flow during June-September. The variation in this seasonal stream-flow significantly affects the human population. So, it is important to understand the underlying mechanisms that cause that variation. Due to its spatial location, Indonesia is influenced by both modes. Although climate conditions are important for the rainfall variability, the actual river discharge is dependent on several other factors including the characteristic of the river basin. Therefore, in this study a scientific analysis is made to link the discharge variability with the rainfall and sea surface temperature (SST) variations over the Indian and Pacific Oceans on seasonal basis. Since the variability of climatic conditions in the tropical Indian and Pacific Oceans are main driver of the rainfall variability over the Maritime Continent, their roles in river stream-flow is explored in this study. A scientific analysis is made to link the stream-flow variability with the rainfall and SST variations over the Indian and Pacific Oceans. The observed stream-flow discharge data from 1974-2008 (35 years) at the Nanjung station, the down most outlet of the upper catchment, shows a strong correlation with the Indian Ocean Dipole (IOD) and the El Niño /Southern Oscillation (ENSO) events.

Keywords: Climate variability, Citarum, IOD, ENSO, Streamflow

1. Introduction

The climate pattern of Indian Ocean rim countries has been influenced by the Indian Ocean Dipole (IOD) and El Niño Southern Oscillation (ENSO) along with Asian Monsoon and other local patterns. Spatially located Indonesia has been influenced by both the IOD and ENSO as well. The western Indonesia is influenced by the Indian Ocean and Eastern Indonesia is influenced by the Pacific Ocean because of their proximities to the respective ocean basins. A positive (negative) IOD event brings drought (wet) to the Indonesian region. Likewise, an El Niño (La Niña) causes drought (flood) over the region. The main focus on this research is to make a scientific analysis to link the discharge variability with rainfall-runoff and Sea Surface Temperature (SST) variations of both the ocean basins on seasonal basis. Historically ENSO has a strong relationship with Indian Monsoon (Bjerknes, 1969; Wright, 1979).

However, in the last couple of decades the frequent IOD occurrence has weakened the ENSO and Monsoon relationship (Kumar et al. 1999; Saji et al. 1999; Behera et al.1999). Many studies have been done on the relationship between interannual variability of the Asian Summer Monsoon and ENSO (Shukla and Paolino, 1983; Ailikun and

Yasunari, 2001) and influence of IOD on Southern Oscillation (Luo et al. 2010). Both IOD and ENSO have wide range of environmental and socioeconomic impacts on the global to local climate.

Recent studies has found that IOD events have strong influence of the climate of East Asia (Saji and Yamagata 2003), East Africa and Indonesia (Saji et al. 1999), Indian summer monsoon (Ashok et al. 2007), Australia, Brazil and the Mediterranean region (Saji and Yamagata 2003), the recent southeast Australian "Black Saturday" bushfire in the state of Victoria in February 2009 also caused by the positive IOD (Cai et al. 2009). In this paper we like to study the influence of climate variability on river discharges.

Apart from the climatic conditions influenced the rainfall variability, there are other factors which influenced the river discharges like as sediment deposit, topography, land-use change and one in all the river basin characteristics. In this paper we investigated the climatic impact on streamflow discharges on seasonal basis. We applied statistical methods to assess the impact of IOD/ENSO events on runoff variability across the Upper Citarum river basin. The observed discharge at the Nanjung gauge station the down most outlet of the Upper Catchment before the streamflow has been linked to three reservoir i.e. the Saguling, Cirata and Jatiluhar (Juanda) reservoirs has shows a strong correlation with the IOD and ENSO events.

2. Study Area

The Citarum River has an important role in the life of the West Java people.The river plays a vital role for the economic development and livelihood of the people by supporting for agriculture, fisheries, hydroelectric power generation, public water supply and industrial establishment of West Java Province and Jakarta City (Fares and Yudianto, 2004). The has a catchment area of 12,000 square kilometers, runs through 269 kilometers and home to millions of people (Mashudi, 2001).

This Citarum river basin is one of the densely populated regions with increasing growth rate; hence the need for adequate and reliable river discharge analysis is of increasing concern on the livelihood of this basin. One likely cause is because of the substantial alterations in the distribution and variability of rainfall patterns. Streamflow in the Citarum river basin mainly comes rainfall from the monsoon wet season from October-May and peak is from November-March.

There have been several studies on rainfall variability over the Indonesian archipelago and its relation to large-scale climatic phenomena such as El Niño–southern oscillation and monsoon (Philander, 1983: Haylock and McBride, 2001). The influence of these climate phenomena varies across the region due to island topography and/or ocean–atmosphere fluxes, which are imposed by sea-surface temperature (SST) variability (Aldrian and Susanto, 2003).

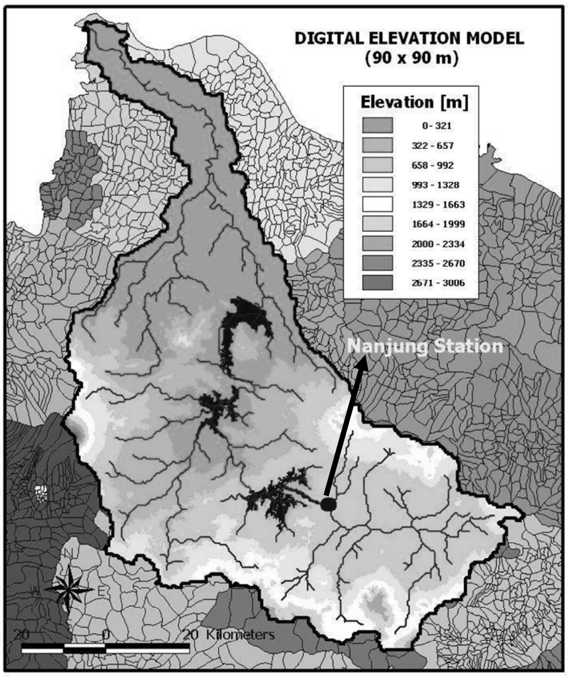


Figure 1 The Citarum river catchment with Nanjung gauge station and three reservoirs, the Saguling, Cirata and Jatiluhar (Juanda) from upper to lower stream respectively (Sahu et al. 2011).

3.Dam Effect and Time of Concentration

Keeping the anthropogenic activities such as dams/reservoirs or any artificial diversions on the streamflow, we select the Nanjung gauge station the down most outlet of the Upper Catchment, before the streamflow has been linked to three reservoir i.e. the Saguling, Cirata and Jatiluhar (Juanda) reservoirs (figure 1) for our study. The estimated time of concentration of the Upper Citarum catchment based on the topographic and basin characteristics has been calculated as less than 24 hours, which is insignificant for the climatic variability analysis.

4. Data and Methods

The observed discharge data has been used at the Nanjung gauge station of the Citarum river for the period from 1974 to 2008 (35 years) as a primary data set for this study. We calculated the climatology of the observed discharge data on daily scale. To pick up the high and low water events on a daily scale basis for the whole data series, we calculated 1.5σ (σ stands for standard deviation) for each high cases and 1σ for each low cases from the daily anomalies. Than to select the extreme events we took the persistence of positive values of 2- 3 days for both the events. The NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) global atmospheric reanalysis-1 zonal wind (850 hPa) dataset has been used. A detailed description of this data assimilation system has been given in Kalney et al. (1996).

The other major dataset used in this study is the global coverage NOAA interpolated of daily averages of outgoing longwave radiation anomalies (here after OLR) data on a $2.5^{\circ} \times 2.5^{\circ}$ grid at a standard pressure (Liebmann and Smith,1996). OLR is an indicator of both the warm surface of the earth and the clear atmosphere overhead. It determined from the Earth Radiation Budget Experiment (ERBE) and Advanced Very High Resolution Radiometer (AVHRR) sensors of NOAA satellite. In the longwave range warm surfaces radiate more. If there are clouds in the atmosphere OLR value is low. For simplicity, the sign of positive OLR anomalies represents the convective activity. In addition to this the SST anomalies are used based on the Reynolds SST dataset (Reynolds and Smith, 1994).

5. Results and Discussion

The Java island has been influenced by the wet northwest (NW) monsoon from November to March and the dry southeast (SE) monsoon from May to September. The Walker cell warm pool near Indonesia plays very important role in determining rainfall variability in the maritime continent (McGregor,1992). The climatology graph (Figure 2) implies that DJF (December, January and February, where December is the preceding year and January and February are the following year) and MAM (March, April and May) are similar trend with one peak.

The actual daily average discharge is the highest in MAM and followed by DJF and SON. Whereas JJA (June, July and August) has very less stream flow discharges. If we take season into consideration; otherwise low discharges flow starts from June to October. When we compare the mean average with ± one Standard deviation it shows almost similar trend. There is very low variability in the discharge patterns.

Table 1 The seasonal extreme high and low discharges events where each event are selected from the persistent of positive values for 10 days or more. *,*,*,*,* symbols represents La Niña, nIOD, mEl Niño, El Niño, pIOD respectively.

Season	Year	No. of High Event Case	Year	No. of Low Event Case
Dec.	1975 -76*	1	1978-79	1
Jan	1988-89**	2	1981-82**	1
Feb	1989-90*	1	1982-83**	2
	1994-95**	1	1983-84	1
	2001-02*	1	1994-95**	1
	2002-03*	1	1997-98**	1
	2005-06**	1	1998-99	1
			2000-01	1
			2003-04*	2
			2004-05*	1
			2007-08**	1
Mar	1975 *	1	1974	1
Apr	1986**	1	1982**	1
May	1988 *	1	1996*	1
	1998	1	1997**	1
	2001	1	2000	2
	2005	2	2002*	1
	2007**	1	2006* *	1
			2008 **	1
Jun	1985	1	1978	2
Jul	1989 *	2	1984	1
Aug	1995	1	2003	1
	2000	1		

The climatology of the Nanjung gauge station shows a very strong coherent pattern with low variability. As mentioned on the table (1) the extreme events for both the high and low discharge cases has been calculated 2-3 days continuous wet or dry periods for one extreme event case.

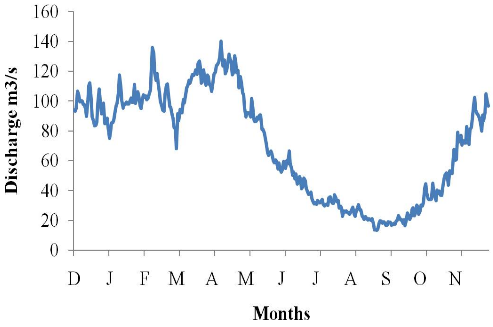


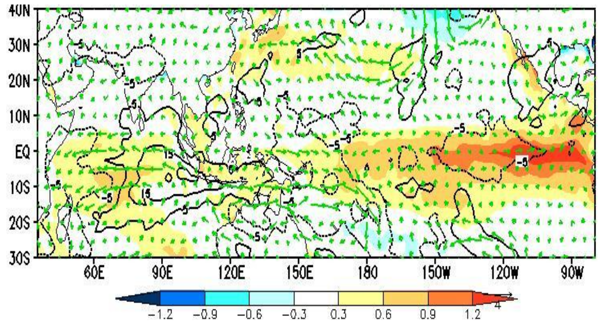
Figure 2 Discharge climatology at Nanjung station from 1974-2008.

In DJF for both the extreme high and low events most of the cases are coincides with the ENSO/IOD years. This shows that the seasonal influences on discharges in DJF are influenced by these climate variability. Out of the total eight high discharge events cases during DJF all are either influenced by ENSO or IOD. A few extreme high and low events in this season are also influenced by IOD because of frequent occurrence of IOD in recent decades and ENSO is changing to a new type El Niño Modoki, recently identified (Ashok et al., 2007).

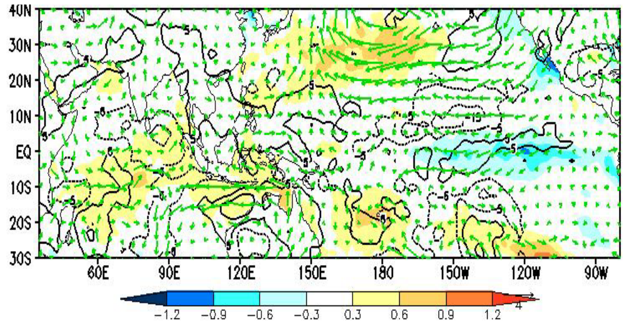
In DJF high discharges cases 50 percent events are occurred during the El Niño Modoki years. In low discharge cases of DJF, out of total 13 events nine events are occurred during either ENSO or IOD years. Among the nine events five are occurred during the pIOD year, which implies that pIOD influenced the extreme low discharges events.

In MAM the extreme low discharges cases 50 percent events are occurred during the normal year where as in the extreme low event cases six out of nine events are happened during these ENSO and IOD variation modes, pIOD influences four of such events along with El Nino in three occasions and once with La Nina, which is an exceptional cases.

JJA seasons are more like transition phases and dry period in Indonesia, hence only two events found during 1989 nIOD year in extreme low discharge case, out of total nine events in low and high extreme cases. The composite index of figure (3a) and (3b) shows the influence of ENSO and IOD are prominent. In the figure (3a) DJF drought seasons the shaded eastern Pacific shows warmer SST and western Pacific with colder SST influenced the atmospheric circulation and brings drought conditions over the Indonesia region along with pIOD in the Indian Ocean.. OLR with dashed contour showing negative values having more rainfall on the western Indian Ocean and OLR with continuous contour shows dry conditions over the eastern Indian Ocean and Indonesian region to



(a)



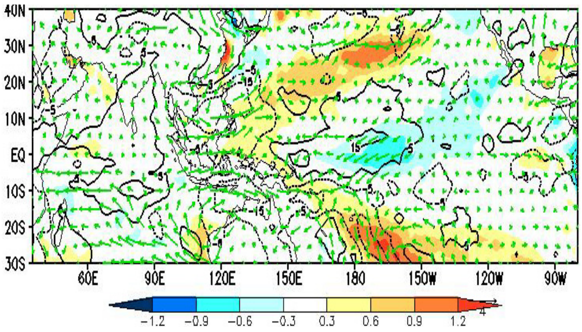
(b)

Figure 3 Composite index (includes the exact number of extreme events days one week ahead for both the Extreme high and low discharges cases and excludes all the events prior to 1981) of SST shaded), surface wind (vector) and OLR (contoured) for DJF (a) Extreme High and (b) Extreme Low discharges cases, respectively. Unit for SST is °C, for wind is m s^{-1}, and for OLR is w/m^2.

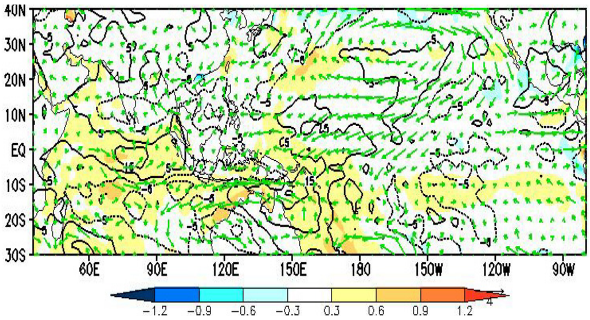
strengthen the fact. In figure (3b) a La Nina conditions with convergence of zonal wind near the eastern Indian Ocean region influenced the rainfall patters with maximum rainfall and river discharges during this season.

In MAM it seems as a mixed trend. Both the ENSO and IOD have influenced the rainfall pattern. Later part of this season can be considered as transition phase. In the composite index figure (4a) MAM drought seasons the shaded SST shows the warmer central Pacific with eastern and western sides having warmer El Niño Modoki conditions where as figure (4b) MAM flood seasons shows the general patterns. Discharges is continued to be higher until April and then decreases from May.

JJA is the dry season in Indonesia so streamflow discharges are very low in this period as we can see in the climatology graph (Figure 2). The composite



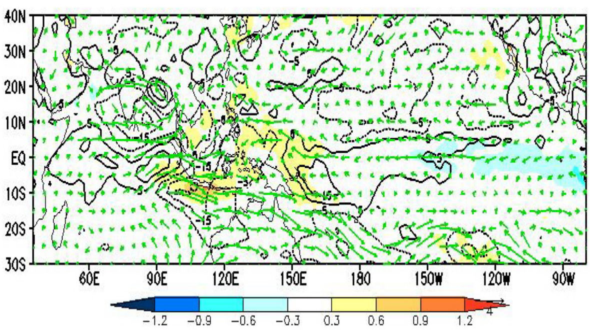
(a)



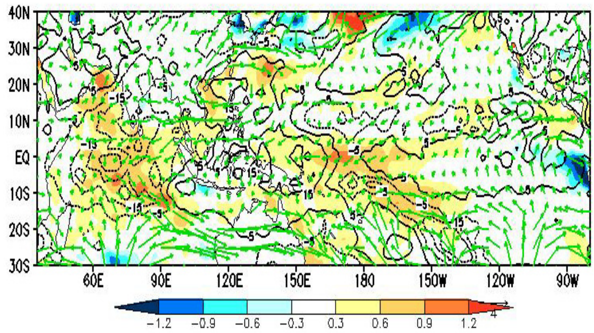
(b)

Figure 4 Composite index (includes the exact number of extreme events days one week ahead for both the extreme high and low discharges cases and excludes all the events prior to 1981) of SST (shaded), surface wind (vector) and OLR (contoured) for MAM (a) Extreme high and (b) Low discharges case, respectively. Unit for SST is °C, for wind is m s^{-1}, and for OLR is w/m^2.

index for the JJA extreme high (Fig. 5a) shows that La Nina conditions are approaching in the Pacific, however no such cases are found in our table. In the composite figure (5b) of JJA extreme low discharges events there are no significant affect of ENSO and IOD.



(a)



(b)

Figure 5 Composite index (includes the exact number of extreme events days one week ahead for both the extreme high and low discharges cases and excludes all the events prior to 1981) of SST (shaded), surface wind (vector) and OLR (contoured) for JJA extreme (a) high and (b) low discharges case, respectively. Unit for SST is °C, for wind is m s^{-1}, and for OLR is w/m^2.

6. Concluding Remarks

The statistical and composite index analysis method we used in this scientific study to assess the influence of climatic variability on river discharge shows the significant existence of IOD and ENSO impacts on the discharges over the upper catchment of the Citarum basin. There are several other phenomenons that need further investigation about the discharge patterns as river basin characteristics (soil, geology and land cover), also plays very important role to influence the streamflow discharges. According to Luo et al (2010) IOD can be predicted several months prior of the event therefore could be helpful for the river basin management. It needs good understanding of IOD and ENSO influences through atmospheric circulation (Walker circulation) to predict possible discharges flow related to high and low discharges events for the societal benefits.

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気候変動モードとインドネシアのチタルム流域の流量との関係の観察

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要　旨

インドネシアのチタルム川のナンジュネジ観測地の観測データによる流域の気候は，１１月から翌年４月までの期間で水が著しい流れているが，６月から９月の期間で水が非常に少ない流れている。この季節による大きな流域の流れの変動が，人口に影響を与えている。だから，その変化の原因となる基本的なメカニズムを理解することが重要である。気候条件は，降雨量の変動に重要であるが，実際の河川流量は，河川流域の特性を含むいくつかの他の要因に依存している。そこで，本研究では科学的な分析を用いて降雨や海表面温度（SST）の季節に基づいてインド洋と太平洋上の変化と河川の流量の変動をリンクした。本研究では熱帯インド洋と太平洋の気候条件の変動が海洋大陸の降水変動の主なドライバをされるので，川の流れに役割を立つと検討された。

キーワード：気候変動，チタルム川，IOD，エニーニョ，河川