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LONG TERM HYDROLOGIC BALANCE OF THE CITARUM BASIN AND JAVA ISLAND

(Keseimbangan Hidrologi Jangka Panjang DAS Citarum dan Pulau Jawa)

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ABSTRAK

Analisis keseimbangan hidrologi sederhana telah dilakukan untuk menunjukkan hubungan jangka panjang antara curah hujan dan debit aliran bulanan dari daerah aliran sungai Citarum hulu dengan luas 6000 km^2 yang merupakan DAS representatif untuk pulau Jawa. Data curah hujan bulanan yang digunakan adalah dari 35 stasiun dengan masa pengamatan 1896 sampai 1994, di mana sembilan stasiun memiliki pengamatan lebih dari 60 tahun. Data aliran diperoleh dari sepuluh stasiun hidrometri dengan lama pengamatan antara 8 sampai 39 tahun, di mana lima stasiun mencatat lebih dari 30 tahun. Dari peta hidrologi, wilayah DAS dibagi ke dalam sembilan sub DAS, dan hubungan curah hujan-limpasan bulanan ditetapkan dari data yang ada, kemudian keseimbangan hidrologi wilayah dianalisis untuk menunjukkan tren perubahan jangka panjang. Pembahasan mempertimbangkan adanya tekanan penduduk dan pembangunan wilayah yang berlangsung cepat, yang membawa dampak pada perubahan tataguna lahan dan peningkatan permintaan akan air. Dari analisis tren data curah hujan untuk masa 1896-1994 diperoleh hasil bahwa telah terjadi penurunan curah hujan wilayah secara konsisten sebesar 10 mm/tahun yang diikuti oleh penurunan debit limpasan sebesar 3 mm/tahun sepanjang masa pengamatan. Evaluasi lebih lanjut terhadap data series curah hujan untuk wilayah Jawa Selatan diamati tren serupa. Hal ini seiring dengan terjadinya peningkatan intensitas dan frekuensi banjir dan kekeringan. Sehingga dipertimbangkan kemungkinan telah terjadinya perubahan iklim, dan untuk itu dievaluasi hubungannya dengan fenomena ENSO dengan mengkorelasikan curah hujan bulanan dengan deret SOI. Hasil analisis menunjukkan bahwa perubahan dramatik dari deret SOI untuk dua dekade terakhir juga diikuti oleh perubahan musiman dari curah hujan pulau Jawa. Kekeringan parah dicirikan oleh berkurangnya curah hujan tahunan sampai 50% dengan sebaran pengurangan sampai 75% untuk musim kemarau dan pengurangan 50% pada musim penghujan. Hal ini berkorelasi kuat dengan peningkatan gejala ENSO dekade terakhir ini.

Kata kunci: Keseimbangan hidrologi, Regim aliran, DAS Citarum, Pulau Jawa, Perubahan jangka panjang

ABSTRACT

A simple hydrologic balance analysis was performed correlating the longterm series of monthly rainfall and strem flow data from a representative river basin of the Java island that is the Upper Citarum basin with a drainage area of approximately 6000 km^2. Thirty five rainfall stations were identified representing the whole Citarum watershed with long term observations covering the period of 1896 to 1994, of which nine stations have more than sixty years of records. Stream flow data were obtained at ten hydrometric stations with records ranging between eight to 39 years of monthly series, with five stations have more than 30 years of records. From the hydrologic map, the watershed was sub-divided into nine sub-basins, and rainfall-runoff relationship was established, and regional hydrologic balance was extrapolated. Correlation analysis between ENSO and Indonesia seasonal rainfall was also performed to confirmed the long term changes of hydrologic regimes of Java island. Attention was paid on population pressure and recent rapid regional development, which implied extensive land use changes and increased water demands. From the trend analysis for the rainfall data over the period of 1896 to 1994, it was found that consistent decline of annual rainfall occurred with approximately 10 mm/year reduction during the observation period and accompanied with 3 mm/year

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reduction of runoff. Evaluation of more rainfall series over the South Java areas also gave the same trend of reduction of annual rainfall and stream flow. However, more intensive droughts and floods were experienced also with increased frequencies. Therefore, possible impact of climate change was considered and relationship with ENSO phenomena was evaluated. From long term SOI series it was found that dramatic change of the SOI patterns for the past two decades was reflected by seasonal changes of Java rainfalls. Severe droughts were characterized by drops of total annual rainfall by 50 % of normal value that was distributed by reduction up to 75% during dry season and 50% reduction during wet season rainfalls. These have been associated strongly to recent increase of El Nino events.

Key words : Hydrologic balance, Flow regime, Citarum watersed, Java island, Long term change

INTRODUCTION

Java is the most populated island in the world and has been known as island village to say that the whole island has become almost completed inhabited at about 1000 inhabitants per square kilometers, which causes high pressure to land. The population increase was obvious in the last two centuries started with only about four million people at the beginning of nineteenth century to about forty million at the beginning of the twentieth century and at present the population of Java is about 130 millions. This population increase had caused a drastic change in Java land uses, with obvious desertification found at the upper catchment areas of Java, although the forest land coverage is still reported at 20 %. Change of land use development is marked especially during the last three decades with extensive physical development and high flux of urbanization in Java. It is believed that this land use changes had direct impacts to changes in hydrologic regimes. These long term changes that are of interest in this writing, and analysis would be based primarily on long records of rainfall data in Java and some river discharge data series from the Citarum basin.

Two runoff generating factors that directly influenced these long term changes of Java hydrologic regimes were suspected: land use changes and regional climate change, though it is realized that the second factor above is still speculative and need further evidence, especially for Indonesian conditions with the so-called 'maritime continent' and humid tropic region of lower latitudes.

DATA AND METHODS OF ANALYSIS

Long term series of monthly rainfall were obtained for a number of stations all over Java, with more than fifty year of records at approximately 50 stations. Several of these have records since the early history of rainfall recording in Indonesia in 1879. Descriptive statistics that include means, standard deviations, skewness, and kurtosis were first calculated for each station data, and trend analyses were performed using graphic techniques. Consistency of data was checked using double mass curves. Correlation and simple regression analysis were performed with river discharge data from Citarum river basin (see Figure 1), where basin average values were established at available hydrologic stations and the corresponding rainfall stations (see Tables 1 and 2). To investigate the impact of ENSO on Indonesia seasonal rainfall, simple exploratory/graphical technique showing correlative relationship between monthly rainfall series and the corresponding southern oscillation index (SOI) was performed. SOI data for the period January 1900 till July 1998 was obtained from the Australian Bureau of Meteorology's internet homepage and assumed to represent the ENSO behaviors. Several rainfall stations located from west Java area, central Java and Eastern Island of Lombok, with long term observations were collected covering the period from 1900 to 1978. And some more data representing Java's areal averaged monthly rainfall series for the period of 1951-1980, additional station rainfall data series during 1969-1998 period were also analyzed and compared. Following BMG Classification, the Java and Madura islands were subdivided into 69 seasonally homogeneous rainfall regions and denoted as type 1 through type 69 rainfall regions. Regions type 3, 4, and 6 located in west Java were selected for the same analysis. And for consistency, the long term series were split into two periods for different analyses. To evaluate the rainfall climate anomalies, only data after year 1950 were used, and to see possible long term changes of the rainfall climate, both periods of earlier half of the century and the later period were compared graphically.

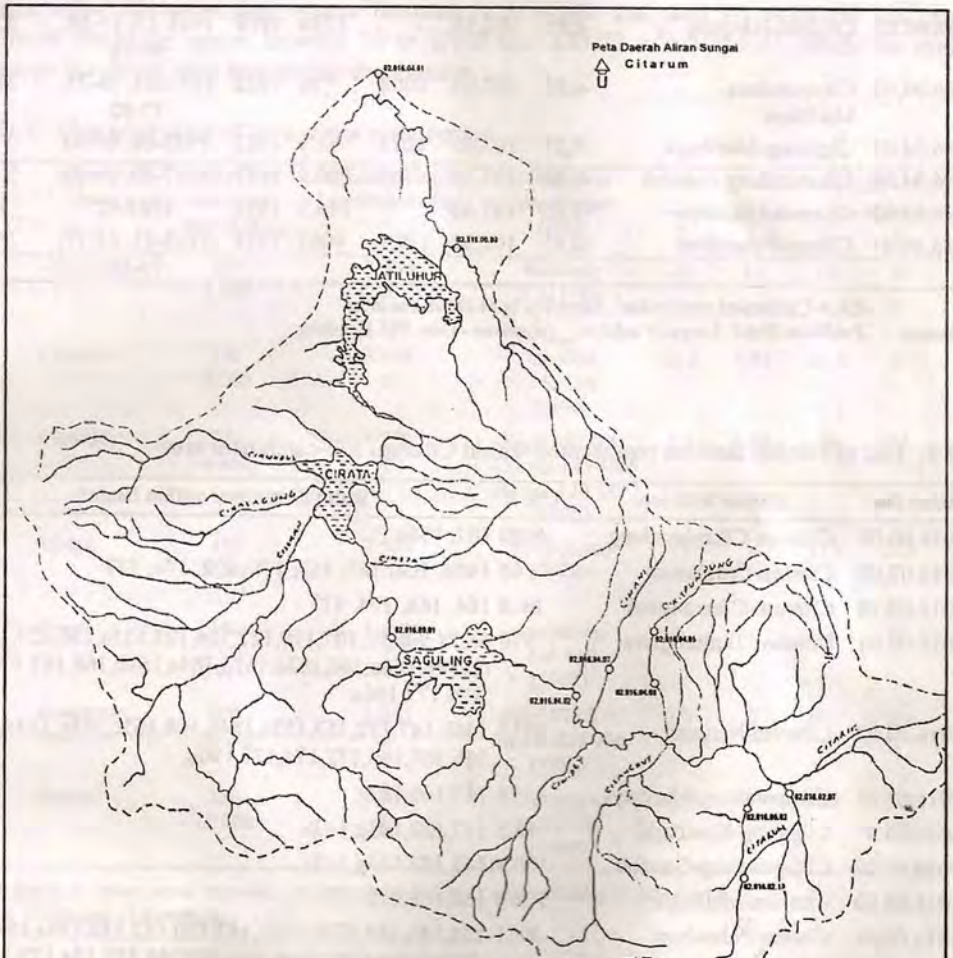

Figure 1. Map of drainage network and hydrologic observation stations of the Citarum basin

Table 1. List of hydrological observation stations in the Citarum basin

Station no.	Station location	Lat.	Long.	Elev	CA	Start	Periods of observation	Length of record
02.016.00.03	Citarum-Cikaobandung	-	-	-	4600	1953	1953-61	9
02.016.02.07	Cirasea-Cengkrong	-7,06	107,73	_	64	1984	1984-92	9
02.016.02.10	Citarum-Cibarengkok	-7,10	107,67	_	86.8	1985	1985-92	8
02.016.04.01	Citarum-Tanjungpura	-6,32	107,32	_	5970	1959	1959-62, 69-73, 77, 92	15
02.016.04.02	Citarum-Nanjung	-6,95	107,53	_	1718	1918	1918-35, 73-88, 90-92	35
02.016.04.05	Cikapundung-Maribaya	-6,85	107,63	1008	76	1952	1952-67, 70-75, 77-92	38
02.016.04.07	Cigulung-Maribaya	-6,83	107,63	1071	43.3	1952	1952-66, 69-92	37
02.016.04.08	Cikapundung-Gandok	-6,88	107,51	749	100.9	1957	1957-89, 91-92	35
02.016.05.02	Citarum-Majalaya	-7,05	107,66	_	176.5	1984	1984-92	9
02.016.09.01	Citrum-Palumbon	-6,85	107,33	139.7	4061	1922	1922-43, 62-77, 79-80	39

Note : CA = Catchment area in km^2, Elevation in m above sea level

Data Source : Publikasi Debit Sungai, Puslitbang Pengairan - Dep. PU, Bandung

Table 2. List of rainfall stations represented within Citarum sub-catchment area

Statiun No.	Statiun location	CA	Rainfall stations within basin*
02.016.00.03	Citarum-Cikaobandung	4600	107, 156a
02.016.02.07	Cirasea-Cengkrong	64	146b, 166, 167, 168, 170, 172, 174, 177
02.016.02.10	Citarum-Cibarengkok	86.8	166, 168, 174, 177
02.016.04.01	Citarum-Tanjungpura	5970	66,74,90a,91,107,119,122,124,125,125a,126,127,147,1 0,154b,156a,160,163c,163g,164a,164b,166,167,170,17 ,174,177,196a
02.016.04.02	Citarum-Nanjung	1718	146b,147,152,153,153a,154b,160,163c,163g,163x,164a 166,167,168,172,174,177,196a,
02.016.04.05	Cikapundung-Maribaya	76	147,160,163x
02.016.04.07	Cigulung-Maribaya	43.3	147,152,163g,163x
02.016.04.08	Cikapundung-Gandok	100.9	147,152,163g,163x
02.016.05.02	Citarum-Majalaya	176.5	166,168,172
02.016.09.01	Citrum-Palumbon	4061	124,126,127,127a,146b,147,150,152,153,153a,154b,16 ,163c,163g,163x,164a,166,167,168,172,174,177,196a

Note : CA = catchment are in km^2; * rainfall station codes as given by BMG

HYDROLOGIC CONDITIONS OF JAVA ISLAND

Some basic information on the hydrology and water resources development of Java are available already in the three volumes of the Catalogue of Rivers, containing seven major river basins in Java which cover approximately fifty percents of the island. Table 3 provides some characteristics of these major river basins in Java, and Table 4 provides runoff characteristics of these river basins. It is obvious that these basins are among the most developed areas in Java with almost all of them are allocated for paddy field and other agricultural purposes, and forest area left is much less than 20 %. As this is of relatively recent conditions, with corresponding runoff characteristics as indicated on Table 4, measures of water availability can be obtained from the average river discharge that ranges between 4 $m^3/s/100\ km^2$ and 10 $m^3/s/100\ km^2$ and the maximum discharge ranges between 10 $m^3/s/100\ km^2$ and 77 $m^3/s/100\ km^2$. While the minimum discharge is relative very low during dry seasons.

Table 3. Characteristics of Java major river basins

No.	Name of river	Length [km] catchment area [km²]	Highest peak [m] Lowest point [m]	Main cities population (year)	Land use[1)] [%]				
					F	L	A	P	U
1.	Citarum	269 6 080	1 700 0	Bandung 2 513 000 (1992)	20	2.5	18	30	29.5
2.	Cimanuk	230 3 600	3 078 0	Cirebon 256 134 (1995)	22.8	0.01	29.8	36	6.6
3.	Citanduy	170 4 460	1 750 0	Tasik 187 609 Ciamis 145 406 Banjar 130 197 (1995)	9.3	0.08	48	24	16.6
4.	Serayu	158 3 383	2 565 0	Purwokerto 209 005 -	17	-	35.6	24.6	22.7
5.	Progo	140 2 380	1 650 0	Magelang 116 468 (1995)	4	-	32	45	19
6.	Bengawan Solo	600 16 100	3 265 0	Solo: 525 371 Ngawi:829 726 (1993)	3.0	.5	24.5	66	6.0
7.	Brantas	320 12 000	3 369 0	Surabaya 2 270 081 (1990)	22.1	-	19.8	29.2	28.9

1): F: forest; L: lakes, rives, marshes; A: agriculture fields; P: paddy fields; U: urban areas.
Source: Catalogue of Rivers, Vol. 1,2,3.

Table 4. Discharge characteristics of Java major rivers

No.	Name of River	Station	Catchment area(A) [km²]	$\bar{Q}$ [m³/s]	$\bar{Q}max$ [m³/s]	$\bar{Q}min$ [m³/s]	Qmax/A [m³/s/100km²]
1	Citarum	Nanjung	1 675	68.7	455	5.4	27.1
2	Cimanuk	Rentang	3 003	134.7	305.6	19.95	14.6
3	Citanduy	Cikawung	2 515	204.0	710.6	16.3	39.2
4	Serayu	Rawalo	2 631	273.4	1 497	58.8	76.8
5	Progo	Bantar	2 008	89.3	596.0	9.0	29.8
6	Bengawan Solo	Bojonegoro	12 804	362.9	2 127	19.0	17.0
7	Brantas	Jabon	8 650	258.7	866.1	46.6	10.0

Source : Catalogue of Rivers, Vol. 1, 2, 3.

Citarum River Basin Characteristics

The Citarum river with 269 km length is draining an area of 6 080 km^2 that originates from Mt. Wayang (1.700 m) and flows through the middle area of west Java before discharging to the Java Sea. The upper catchment response is represented by discharge measurement at Nanjung hydrometric station, that has a catchment area of 1.675 km^2 and surrounded by mountains such as Tangkuban Prahu in the north, Patuha-Malabar in the south, Krenceng-Mandalawangi in the east, while in the west where the basin discharge occurs is characterized by irregular mountain complex. High points on those mountains are around 1700 meter. These upper catchment is characterized by high land plateau at 650 m elevation (60%) and rugged areas (40%). Slope classes varied from 0-8% over about 45% of the basin; 5 – 15% slope range cover 14%; 15 – 25% slope cover 15%, 25 – 45% slope cover 12%; and slope over 45% covering 13%. The main tributaries are Citarik, Cikeruh, Cisarea, Cikapundung, Cisangkuy and Ciwidey. Almost all of these tributaries are shorts and flowing on steep slopes, so that river flow characteristics are very different from that of the main river. For present study, the river basin is subdivided into the seven sub catchments above.

The river segment above Bandung is considered the upper reach which is mountainous and between Bandung and Jatiluhur is the middle reach and below Jatiluhur is considered the lower reach. The basin has an averaged annual rainfall of 2 300 mm and the annual discharge at Nanjung (1 675 km^2) is 68.7 m^3/s with maximum discharge can reach 455 m^3/s and the low flow less than 10 m^3/s. With these flow variations, the current water related problems are droughts during dry seasons (July – October) and floods in the wet seasons (November – April). For 5 year flood, approximately 22.5 km^2 area in south Bandung is likely to be inundated.

RESULTS AND DISCUSSIONS

As a basis of trend analysis to be performed for the observed monthly series data, descriptive statistics were first calculated for rainfall and river discharge for each of the seven sub-basin and the overall Citarum basin, and results of these are given on Tables 5 and 6. From the mean values, runoff coefficients are found at approximately 0.5 for annual data and varies between 30% and 60% for monthly values. While the coefficient of variation ranges between 20% to 60% for monthly rainfall and consistently much lower for monthly runoff or annual values.

Table 5. Descriptive statistics of average rainfall for Citarum basin

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug.	Sep	Oct	Nov	Des	Annual
Mean	293	257	300	269	194	116	99	88	123	210	290	290	2528
Median	286	249	298	265	190	108	88	74	108	205	282	292	2565
St. Dev.	73	70	77	61	65	60	61	54	69	84	69	67	334
Kurtosis	0,85	1,07	0,04	0,58	0,10	2,37	0,75	0,69	1,45	0,10	0,22	0,08	-0,13
Skewness	0,63	0,78	0,16	0,57	0,41	1,09	0,93	0,79	1,11	0,35	0,57	0,17	-0,12

Tabel 6. Descriptive statistics of average river discharge for Citarum basin

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des	Annual
Mean	135	125	153	163	123	83	62	49	48	69	108	145	1278
Median	134	124	152	161	121	81	60	47	46	68	105	146	1289
St. Dev	13	11	35	26	32	15	14	8	11	11	19	10	99
Kurtosis	0,85	1,07	0,04	0,58	0,10	2,37	0,75	0,69	1,45	0,10	0,22	0,08	-0,13
Skewness	0,63	0,78	0,16	0,57	0,41	1,09	0,93	0,79	1,11	0,35	0,57	0,17	-0,12

Trend Analysis of Rainfall and River Discharge

Long term changes of the hydrologic regimes were first explored graphically using trend analysis on the observed rainfall and river discharge series. For these all the available monthly data series were plotted and best fit regression lines were added. Figures 3, 4, and 5 shows the results for trends of annual rainfall and river discharge at Citarum-Nanjung, Cikapundung-maribaya, and Citarum-Plumbon. For the upper catchment as observed at Citarum-Nanjung (1918-1991), more intense reduction is found at 46 mm/year for rainfall and 6.9 mm/year for runoff. During 1952-1992 period at Cikapundung-Maribaya, a positive trends were found for rainfall and runoff series. And at Citarum-Plumbon (1922-1980), a negative trend for rainfall is matched with a positive trend for corresponding runoff series.

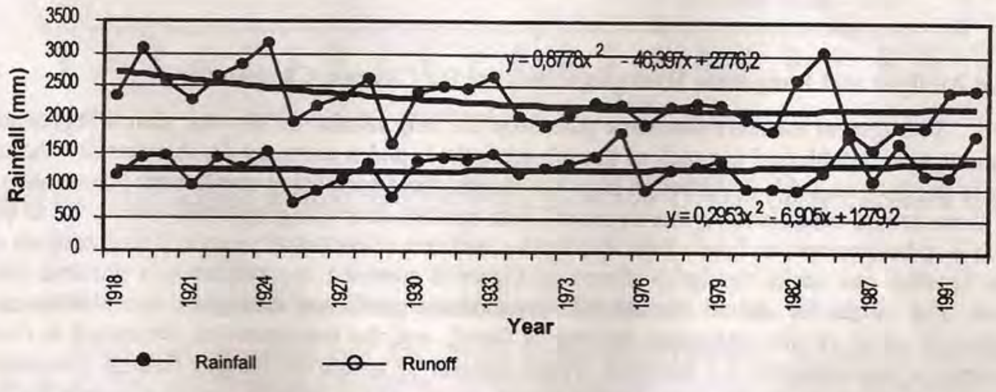

Figure 3. Long term variations of annual rainfall (o) and discharge (•) at Citarum – Nanjung

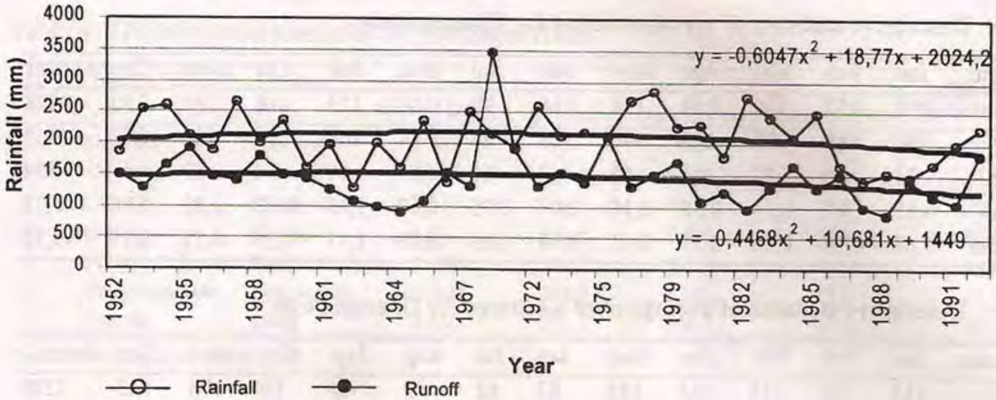

Figure 4. Long term variations of annual rainfall (o) and discharge (•) at Cikapundung – Maribaya 1952 – 1992

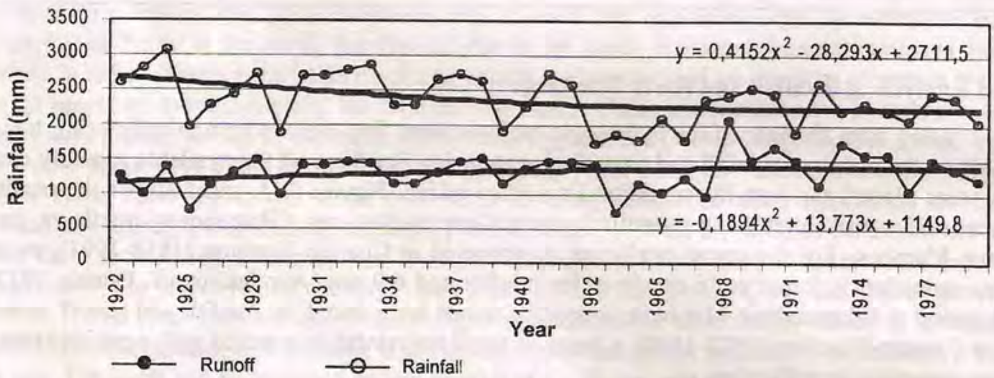

Figure 5. Long term variations of annual rainfall (o) and discharge (•) at Citarum - Palumbon 1922 – 1980

Trend Analysis and Long term Hydrologic Balance for Citarum Catchment

To augment the river discharge data from the long rainfall series data, simple regression equations were established for each of the sub-watersheds and a summary for the overall Citarum basin is as given on Table 7. Although only two months have correlation coefficients greater than a half, these results consistently generate runoff from rainfall data with proportion around 0.4 to 0.6 which is to be expected as found from descriptive statistics of historical records. Trend analysis of these resulted pair series results is shown on Figure 6 covering approximately a hundred year period. The results for annual rainfall over the Citarum catchment during the last century is a negative trend at 10 mm reduction per year is found, and the corresponding decreased in river discharge is approximately 3.1 mm/year. Trend analysis by month for January through December were also performed for the pair rainfall-runoff series, which indicate negative trends for all months except May and August.

Table 7. Summary of simple regression analysis between monthly rainfall (X) and river runoff (Y) for Citarum basin

Month	Regression equation	R	R^2	Adjusted R^2	Std. Error	Obs.
Jan	Y=81,493+0,183(X)	0,297	0,088	0,074	34,432	66
Feb	Y=83,421+0,162(X)	0,257	0,066	0,052	33,796	66
Mar	Y=18,121+0,450(X)	0,558	0,312	0,301	45,408	66
Apr	Y=48,678+0,426(X)	0,470	0,221	0,209	40,584	66
May	Y=28,454+0,485(X)	0,617	0,380	0,371	38,505	66
Jun	Y=53,164+0,258(X)	0,396	0,157	0,143	31,295	66
Jul	Y=38,647+0,236(X)	0,367	0,134	0,121	31,919	66
Aug	Y=35,915+0,152(X)	0,257	0,066	0,051	30,334	66
Sep	Y=28,799+0,160(X)	0,310	0,096	0,082	31,852	66
Oct	Y=42,378+0,127(X)	0,218	0,047	0,033	40,094	66
Nov	Y=25,882+0,282(X)	0,410	0,168	0,155	39,537	66
Dec	Y=100,542+0,154(X)	0,227	0,052	0,037	41,989	66
Annual	Y=532,463+0,295(X)	0,335	0,112	0,098	254,339	66

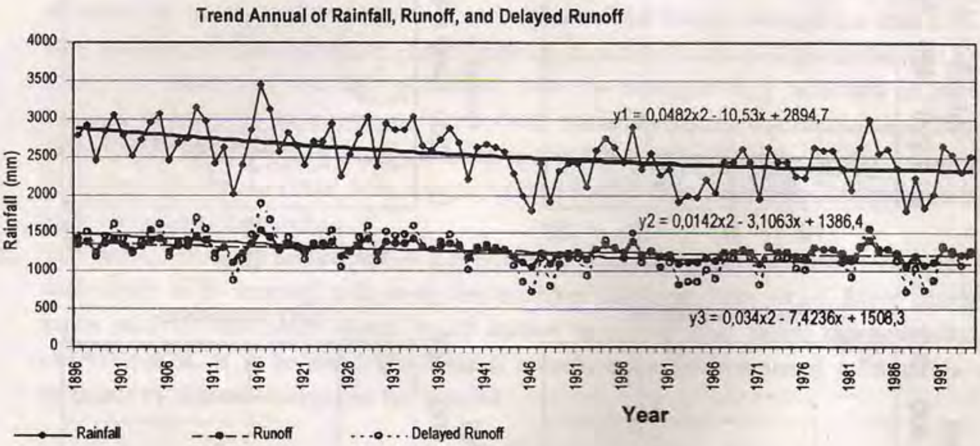

Figure 6. Trend analysis and long term hydrologic balance for Citarum Upper Catchment 1896 - 1994

Rainfall Climate Anomalies and Long term Climate Change

It has been recognized now that climate anomalies in Indonesia are strongly associated with the El Nino and Southern Oscillation (ENSO) phenomena. Severe droughts in Indonesia are characterized by the drop of total annual rainfall by up to 50 percents, not only for the dry season rain that can drop up to 50 to 75 percents, but also reduction of rainy season rain by up to 50 percents of normal rains, which is due to the delay of on set of rainy seasons. These have been associated with El Nino events. While for the wet years which are associated with La Nina events the increase of seasonal rains usually occur only during dry seasons that some times become quite wet compared to normal. For Central Java and Yogyakarta regions up to November 1997, the annual rainfall recorded only reached 905 mm that was less than a half of normal year rainfall that is 2095 mm. During the 1991 and 1994 drought years, the recorded rainfall of the areas were 1523 mm and 1580 mm, respectively. The different effects of ENSO on different areas in Indonesia are also important aspects to recognize. Negative SOI represents El Nino events and positive SOI represents La Nina events, and obvious that dry season rainfall is quite influenced (positively correlated) by El Nino, while for wet season rainfall only slightly affected.

In the past 38 years since 1960, thirteen drought years were recorded with 1997/98 as the last and severe one. Each one of them was believed to be associated with El Nino years, and the wet years as the opposite of El Nino years was believed related to La Nina events, which occur less frequent. This increased frequency of El Nino years significantly reduced the amount of rainfall in Java in order of magnitude 1000 mm/year over Serayu river basin from 4 000 mm/year to 3 000 mm/year.

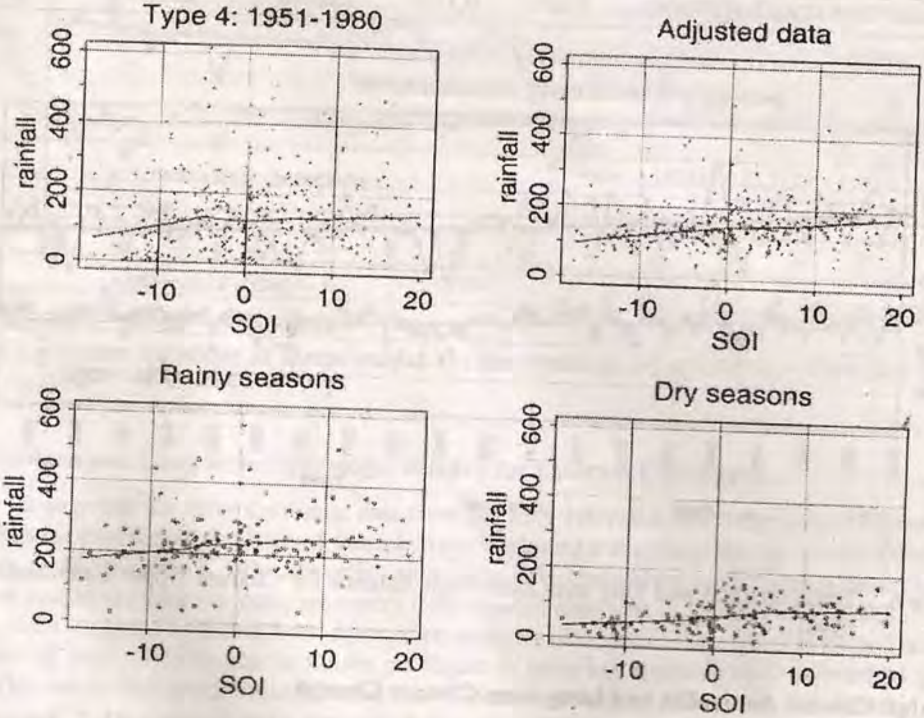

Figure 7. Scatter plots between monthly rainfall (mm) for north coast area of west Java and corresponding SOI series with averaged regression line

Comparing the graphical analysis the two periods of data series from Ciseureuh and Ampenan stations, it was obvious that there had been some climatic changes either the seasonal rainfall in west Java or in eastern island (see Figure 7). During period earlier in this century, negative SOI gave positive impact to rainy season rainfall in west Java, but no effect in eastern islands rainfall. But on the second period after 1950, negative SOI do not influence rainy season rainfall anywhere, and positive SOI gave negative impacts. While for dry season rainfall no changes were noticed between the two periods. The change of these climatic patterns is quite interesting and needs further scrutiny with more station rainfall for different areas in Indonesia. It has been suggested that division of areal analysis unit be localized to sub district levels. During this year La Nina event, some areas in east Java, South Sulawesi, Bali and Eastern islands have experienced heavy rainfalls causing severe floods, but not so serious in Sumatra, west Java and Jakarta areas.

CONCLUSIONS

1. Monsoon climate of Java island dictates the availability of water for many purposes and a massive population increase in the past century have pushed the carrying capacity of the island to its limits as obvious from the recent development of land uses with more than 50 % allocated for paddy field and other agricultural areas and forest coverage less than 10%. These land use changes have altered the hydrologic regimes that is also strongly influenced by ENSO events. A significant decrease of rainfall with the corresponding reduction in runoff was evident, and it was estimated at 10 mm/year reduction of annual rainfall and 3 mm/year reduction of annual runoff have occurred in the last century for the Citarum basin. A more severe conditions can occur from west to eastern part of Java with serious consequences to the increasing water demands.
2. The present study is considered as a preliminary analysis of the available long term rainfall data series to be coupled with more limited river discharge data series. More suitable time series analysis techniques would be of interest to reveal more detail characteristics in the observed data. It is believed that rainfall records store environmental information so that evidence of climate change can be revealed.

ACKNOWLEDGEMENT

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