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THE POTENTIAL OF RAINFALL AND ITS IMPACT TO GROUNDWATER STORAGE IN JAVA ISLAND

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ABSTRACT

The objectives of the study are to map the distribution of rainfall in Java, to analyze its potential and the impact to groundwater storage. To achieve those goals, rainfall distribution is mapped using isohyet method. From the average distribution of monthly rainfall, the annual potential of rainwater on every watershed was calculated. Afterwards, the groundwater storage was analyzed and counted by applying the water balance concept. The results of the study show that the mean of the highest annual rainfall is 4082 mm which occurs on Cisadane-Ciliwung watershed and the lowest one is 1421 mm on Citarum Hilir watershed. From the rainfall potential, Cisadeg-Cikuningan watershed has the highest rainfall potential at the amount of 25342 million m^3*/month and Grindulu Panggul watershed has the lowest potential at the amount of 3678 million* m^3*/month. Meteorologically, Cisadeg-Cikuningan watershed has the highest groundwater storage at the amount of 6088 million* m^3*/year and the lowest amount of it occurs on Madura watershed at 78 million* m^3*/year.*

Key words: rainfall distribution, groundwater storage, water balance, Java

INTRODUCTION

Indonesia is the largest archipelago in the world constituting of approximately 17,508 islands with coastal line stretching nearly 81,000 km and surrounded by the ocean as wide as 5.8 millions km^2 which becomes the biggest part of the country. As a tropical region, Indonesia is mostly affected by the monsoon wind. Rainy season starts from December to February when the wet wind rich with water vapour blows from the west and northwest. On the other hand, dry season starts from June to August indicated by the coming of the dry East and South East wind. In between of those seasons is the transitional season.

Being seen from its rainfall condition, Indonesia has a variety of rainfall characteristics from one area to another [*Oldeman*, 1975]. According to *Linsley et al.* [1980], the difference of rainfall distribution is affected by the latitude, the distance from the source of humidity and the orographic effect. The result of *Aoyama* study [1986] shows that the geographic distribution of rainfall is deeply influenced by the climate, the course of the wind, the convective movement of the wind and the air pressure on the variety of land altitude. Some researchers assumed that the height of the area, the course and speed of the wind and the gradient of sea temperature are among factors that might affect the difference. The different rainfall distribution might influence groundwater availability in certain areas because rainwater is its main source [*Wilson*, 1969]. Information on the distribution is beneficial for the accuracy of meteorological prediction concerning the potential of groundwater resources. The Objectives of the research are: 1) To map the rainfall distribution in Java Island; 2) To analyze the distribution and potential of rainfall in Java Island; 3) To analyze the effect of rain to the availability of groundwater Java Island.

THE METHODS

The main material for this study is the data of rainfall that occurred in a period starting from 1977 to 2006. The data were collected from all rain stations across the island of Java. In addition to that, data of water flow in all rivers of any watershed area in Java at that period was also collected. Both data were obtained from Water Resources Management Board (BPSDA) Department of Infrastructure in each province.

Rainfall mapping is conducted using isohyet method, as it has the highest accuracy in determining the average rainfall in a particular region. Moreover, this method has also considered the impact of orographic rain due to topographical differences. All rain stations situated in the research areas together with the amount of rainfall were plotted inside the map. Then, places with similar amount of rainfall were connected with a line called isohyet line. The width of the area bordered by two adjacent isohyet lines was measured and the average amount of rainfall was calculated using the average rainfall in the region. By considering the width of the analyzed area and the number of rain stations, the average monthly rainfall distribution is mathematically calculated using the following formula:

$$Rmean = \frac{R_1 + R_2 + R_3 + \ldots + R_n}{N}$$

with R_{mean} as the average rainfall in every station, R_1, R_2, R_3, …, R_n as the amount of monthly rainfall on rain stations and N as the number of rain station. This formula enables the researcher to make consideration on the impact of orographic rain caused by topographical differences.

The annual rainfall potential on each watershed area can be determined after the average monthly rainfall distribution is calculated. Groundwater storage can be calculated based on water balance concept in drainage basin [*Seyhan,* 1975; *Griend,* 1979]:

$$\Delta s = P - Ea - Q$$

Where, Δs is groundwater storage, P is precipitation, Ea is evapotranspiration and Q is discharge.

RESULT AND DISCUSSION

Based on Koppen climate type classification, the Island of Java has three types of climate e.g. Af, Am and Aw. Af type is tropical rain forest climate without a single dry month. The amount of rainfall in each month is more than 60 mm. The Am climate type is monsoon tropical rainy climate with one or more dry months. At this climate type, the amount of rainfall in wet months can balance the short dry season. Therefore, although an Am climate type area has one or two dry months, the vegetation have no effect because the amount of rainfall on other months are sufficient enough to balance it. The Aw climate type is savanna tropical rainy climate having dry season for 4–8 months in a year.

Rainfall in Banten and West Java

In order to find out the potential of rainfall resources in the province of Banten and West Java, an analysis on monthly rainfall data from the period of 30 years (1977–2006) was conducted on all rain stations across the districts and municipalities. Based on the analysis on the rainfall data from 31 rain stations, generally the rainy season was started in October and the dry season was started in June. The rain type in Banten and West Java was monsoonal rain with the characteristics of one peak and one valley. It meant that in a year there was one dry season and one rainy season. The rainy season happened at the same time with the coming of the wet West Monsoon wind and the dry season occurred when the dry East Monsoon wind arrived.

Based on the rainfall data of every station, an isohyet map concerning the potential of rain water resources in Banten Province could be drawn (Fig. 1). The classification is as follows: (1) low: rainfall < 1500 mm annually, (2) medium: rainfall between 1500 – 2500 mm annually, and (3) high : rainfall between 2500 –

5000 mm annually and (4) very high: rainfall > 5000 mm annually. The isohyet map can be used to determine the average amount of monthly rainfall on every watershed area as presented in Table 1.

The isohyet map shows that high rate rainfall generally happens in high topographical areas such as Bogor and Puncak. Other areas such as along the west coast of Banten and on the coastal areas of Karawang region the rainfall were also significantly high.

Based on the analysis of monthly rainfall data in every watershed area, the highest amount of rainfall happened in January (from 236 mm to 502 mm). The lowest level of monthly rainfall occurred in August at approximately 5 mm to 202 mm. The highest average of annual rainfall happened on Cisadane-Ciliwung watershed at the amount of 4082 mm, and the lowest level occurred on Citarum Hilir watershed at the amount of 1421 mm.

Base on Table 1, it can be calculated the potential of rainfall on each watershed by multilplying rainfall and its area (Table 2). Seeing from the rainfall potential, Cisadeg-Cikuningan watershed had the highest potential that could reach 25,342 million m^3/month. The lowest potential was on Cisanggarung watershed where it could only reach 5,080 million m^3/month.

Rainfall in Central Java and Yogyakarta

In order to find out the rainfall potential in Central Java, an analysis on monthly rainfall data for the period of 10 years (1994 – 2003) from all rain stations across the region was conducted. The isohyet map on rainwater potential in Central Java and Yogyakarta is presented in Figure 2. There it can be seen that generally the distribution of the potential of rainwater resources on both provinces is in accordance with the physiographical type of the areas.

High potential of rainwater resources can be found at the region surrounding the mountainous areas or the volcanic areas e.g. around Mount Slamet, Mount Sindoro and Mount Sumbing. The medium potential of rainwater can be found at the low slope areas and on the alluvial plain. Some alluvial plains and alluvial plain on coastal areas generally have low potential.

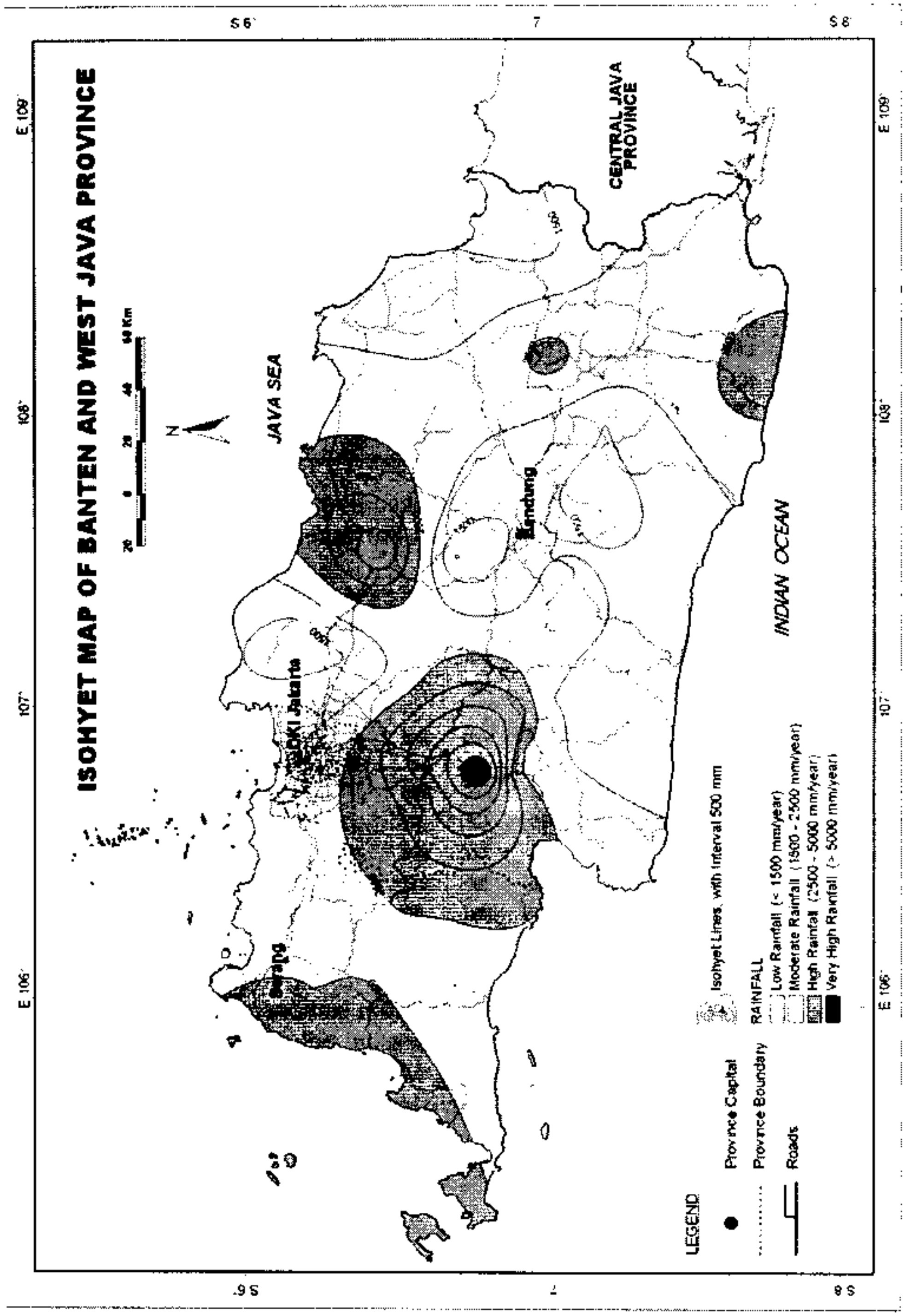

Figure 1. Isohyet Map of Banten and West Java Province

Table 1. Monthly and annual average of rainfall in each watershed in Banten and West East Java Provinces

Watershed	Area (km²)	Ammount of Rainfall (mm)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des	Total
Labuhan Merak	2474	367	340	251	260	120	85	81	98	132	174	297	398	2603
Ciujung	2499	357	269	314	312	218	123	110	83	118	195	301	319	2719
Cisadeg Cikuningan	10121	339	350	254	188	210	101	88	92	97	171	293	321	2504
Cisadane Ciliwung	4012	502	438	424	361	339	218	181	202	264	381	417	356	4082
Upper Citarum	4073	299	216	328	279	113	105	50	43	121	144	361	317	2375
Lower Citarum	7994	393	237	125	95	67	50	33	26	35	52	114	195	1421
Cimanuk	4341	413	322	430	308	167	92	72	38	32	90	232	383	2579
Ciwulan	6510	326	430	253	205	137	86	45	35	35	120	219	246	2136
Cisanggarung	2573	332	293	257	272	87	40	40	13	13	134	251	243	1975

Table 2. The potential of rainfall according watershed in Banten and West Java Provinces

Watershed	The Potential of Rainfall (million m³/month)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des	Total
Labuhan Merak	908	841	621	643	297	210	200	242	327	430	735	985	6439
Ciujung	885	672	785	779	545	307	275	207	295	487	752	797	6786
Cisadeg Cikuningan	3431	3542	2571	1902	2125	1022	891	931	982	1731	2965	3249	25342
Cisadane Ciliwung	2014	1757	1701	1448	1360	874	726	810	1059	1528	1673	1428	16378
Upper Citarum	1218	879	1336	1136	460	428	203	175	493	586	1470	1291	9673
Lower Citarum	3142	1895	999	759	536	399	264	208	279	416	911	1559	11367
Cimanuk	1792	1398	1867	1337	725	399	312	165	139	391	1007	1663	11195
Ciwulan	2122	2799	1647	1334	892	559	293	228	228	781	1426	1601	13910
Cisanggarung	854	754	661	699	224	103	103	33	33	345	646	625	5080

Based on the analysis of rainfall data from 382 rain stations spread across Central Java and Yogyakarta, generally the rainy season began around October and November and the dry season began around May or June. This is in accordance with the general pattern of other areas in the island of Java situated at the southern hemisphere and on the west part of Indonesia in which the rainy season comes at the same time with the coming of the wet West Monsoon wind and the dry East Monsoon.

From the analysis on the average amount of monthly rainfall in both provinces, it can be seen that the highest level of rainfall generally happened in January (about 325 mm to 497 mm). The lowest level generally occurred in August (18 mm to 62 mm). The highest average of annual rainfall was in the Serayu watershed at the amount of 3577 mm and the lowest was in the upstream of Bengawan Solo watershed at the amount of 2032 mm. The result of calculation on the average amount of monthly and annual rainfall in Central Java is presented in Table 3.

Table 3. Monthly and annual average of rainfall in each watershed in Central Java and Yogyakarta Provinces

Watershed	Area km^2	Ammount of Rainfall (mm)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des	Total
Pemali Comal	4936	545	525	414	258	149	105	61	40	39	158	283	341	2918
Buyaran	3113	497	369	347	257	188	108	83	62	80	145	240	329	2705
Serang Lusi	3794	402	355	279	191	84	69	38	16	31	125	235	320	2145
Juana	3558	411	315	275	170	122	74	57	48	61	116	193	301	2143
Citanduy	5226	340	341	338	246	163	125	87	52	71	325	349	330	2767
Serayu	3769	471	484	464	326	188	149	83	41	60	362	524	425	3577
Lukulo Dulang	3681	395	409	375	234	101	100	51	18	32	312	426	384	2837
Progo	2762	407	384	362	234	129	87	48	37	30	200	310	339	2567
Opak-Oya	2622	325	307	226	250	174	103	85	30	43	161	237	182	2123
Upper Bengawan Solo	10010	351	365	332	202	70	64	29	18	13	126	234	228	2032

Base on Table 3, it can be calculated the potential of rainfall on each watershed area by multilplying rainfall and its area (Table 4). The highest potential of annual rainfall was in the Citanduy area at the amount of 14460 million m^3/month and the lowest was approximately 5566 million m^3/month in Opak-Oya watershed.

Table 4. The potential of rainfall according watershed in Central Java and Yogyakarta Provinces

Watershed	The Potential of Rainfall (million m^3/month)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pemali Comal	2690	2591	2043	1273	735	518	301	197	192	780	1397	1683	14400
Buyaran	1547	1149	1080	800	585	336	258	193	249	451	747	1024	8419
Serang Lusi	1525	1347	1058	725	319	262	144	61	118	474	892	1214	8139
Juana	1462	1121	978	605	434	263	203	171	217	413	587	1071	7625
Citanduy	1777	1782	1766	1286	852	653	455	272	371	1698	1824	1724	14460
Serayu	1775	1824	1749	1229	709	561	313	154	226	1364	1975	1602	13481
Lukulo Dulang	1454	1505	1380	861	372	368	187	66	117	1148	1568	1413	10439
Progo	1124	1061	1000	646	356	240	133	102	83	552	856	936	7089
Opak Oya	852	805	593	655	456	270	223	79	113	422	621	477	5566
Upper Bengawan Solo	3513	3653	3323	2022	701	641	290	180	130	1261	2342	2282	20338

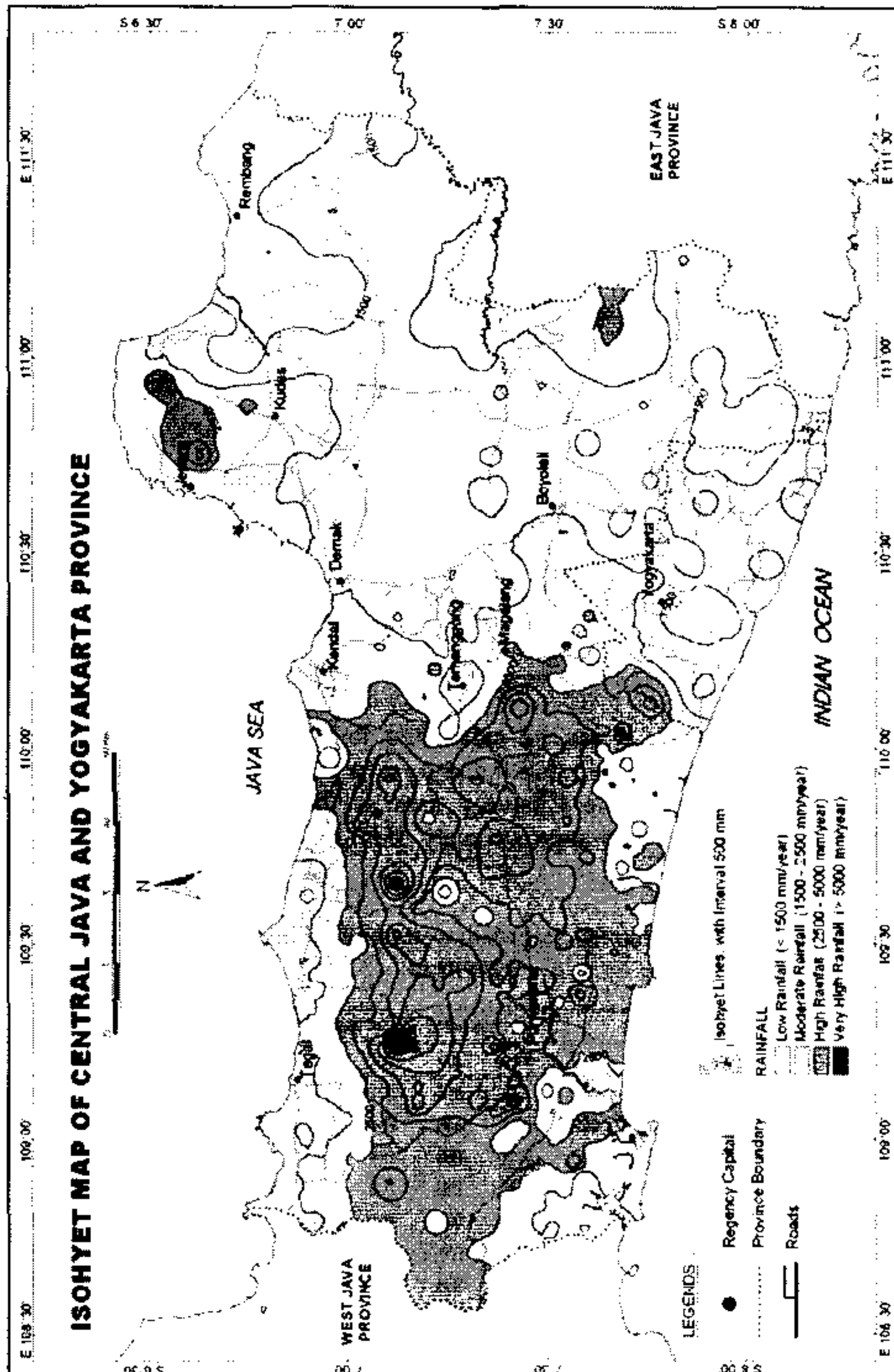

Figure 2. Isohyet Map of Central Java and Yogyakarta Province

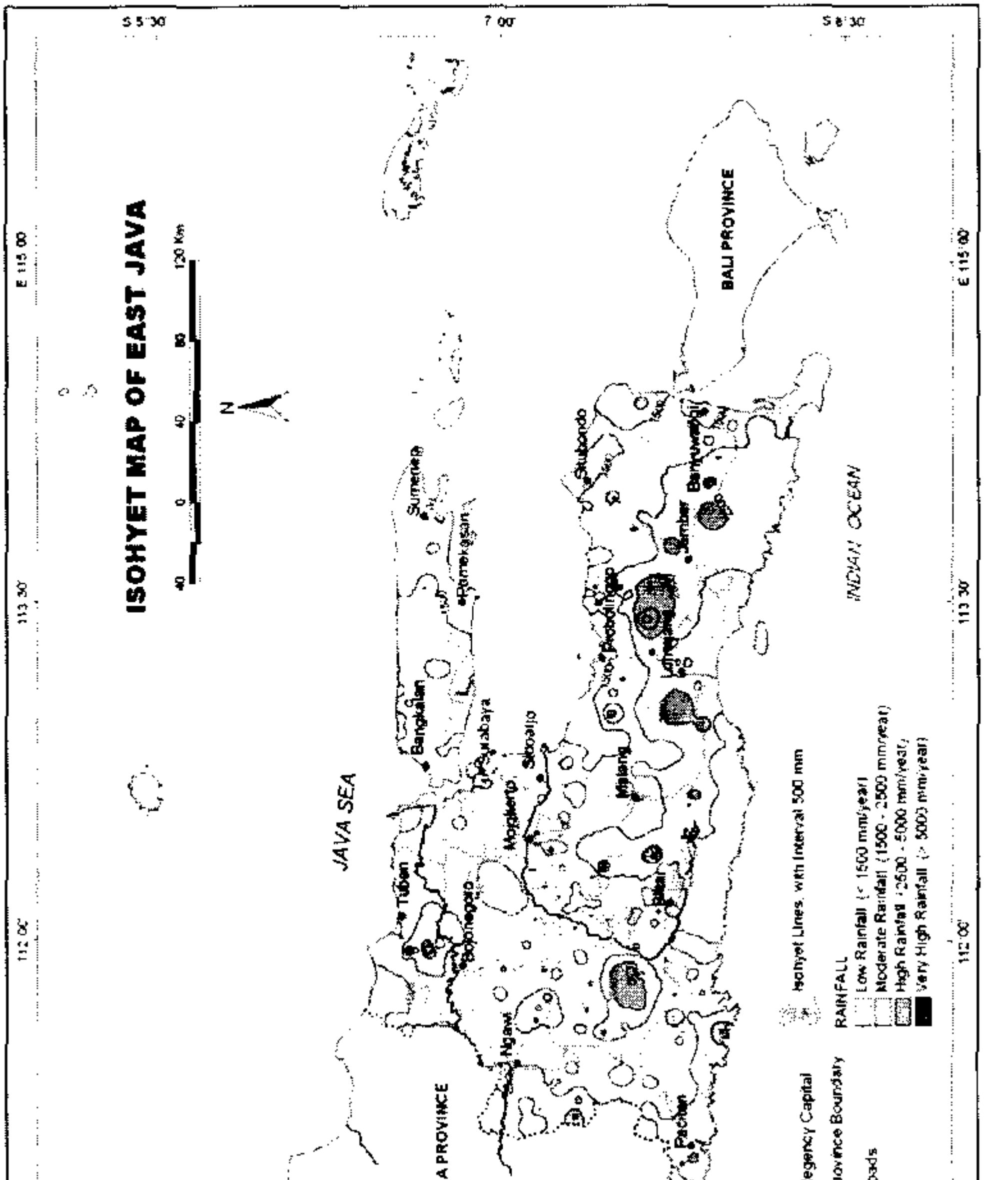

Figure 3. Isohyet Map of East Java Province

The Potential of Rainfall in East Java

The potential of rainwater resources in East Java was calculated based on the data of monthly rain for 10 years (1994 – 2003) from 524 rain stations spread across 38 regencies and cities. The isohyet map concerning the potential of rainwater in the Province of East Java is presented in the shape of a map with isohyet interval of 500 mm (Fig. 3). As in the rainfall pattern of Central Java and Yogyakarta, generally rainy season began around October or November and dry season started around May or June.

The result of the analysis on the average monthly rainfall in East Java shows that the highest average of monthly rainfall generally happened in January (between 248 mm to 371 mm). The lowest average occurred in August (4 mm to 26 mm). The highest level of annual rainfall was on Grindulu Panggul watershed at the amount of 2290 mm and the lowest was at Madura watershed at 1509 mm. The result of the calculation on monthly and annual average of rainfall in the province of East Java can be presented in Table 5.

Table 5. Monthly and annual average of rainfall in each watershed in East Java Province

	Area	Ammount of Rainfall (mm)												
Watershed	(km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Lower Bengawan Solo	7989	312	315	316	208	65	59	37	9	16	118	228	226	1909
Grindulu Panggul	1607	371	384	366	203	63	76	56	16	20	165	271	299	2290
Upper Brantas	5830	327	305	301	200	73	58	24	15	20	95	209	229	1856
Lower Brantas	6275	265	324	305	166	61	39	18	4	6	54	163	227	1632
Luminu Penguluran	3073	368	333	309	201	94	62	35	19	30	180	290	272	2193
Pekalen Sampean	4759	361	384	267	177	58	46	26	6	10	54	145	270	1804
Bajul Putih	5068	309	296	218	156	74	68	57	26	38	102	151	256	1751
Bedadung	5142	363	329	299	196	89	59	33	18	29	172	283	266	2136
Madura	5669	248	218	226	189	62	47	38	6	17	69	134	255	1509

Base on Table 5, it can be calculated the potential of rainfall on each watershed area by multilplying rainfall and its area (Table 6). It can be seen that the highest potential of annual average of rainfall occurred in Lower Bengawan Solo watershed at the amount of 15248 million m^3/month and the lowest one was on Grindulu Panggul watershed at the amount of 3678 million m^3/month.

Table 6. The potential of rainfall according watershed in East Java Province

Watershed	The Potential of Rainfall (million m³/month)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Lower Bengawan Solo	2493	2516	2524	1661	519	471	296	71	128	943	1821	1805	15248
Grindulu Panggul	596	617	588	326	101	122	90	26	32	265	435	480	3678
Upper Brantas	1906	1778	1755	1166	426	338	140	87	117	554	1218	1335	10820
Lower Brantas	1663	2033	1913	1042	383	245	113	25	38	339	1022	1424	10240
Luminu Penguluran	1131	1023	959	618	289	190	108	58	92	553	891	836	6748
Pekalen Sampean	1718	1827	1271	842	276	219	124	28	48	257	690	1285	8585
Bajul Putih	1556	1500	1105	790	375	345	289	132	192	517	765	1297	8863
Bedadung	1866	1692	1537	1008	458	303	170	92	149	884	1455	1368	10982
Madura	1406	1236	1281	1071	351	266	215	34	96	391	760	1445	8552

The Impact of Rainfall to the Availability of Groundwater

In general, there are four factors influencing the amount of groundwater availability in a particular area, i.e. the rainfall, the slope, vegetation and *lithology*. The rainfall affects the availability of groundwater because the main source of groundwater is the rainwater that seeps or penetrates into the soil [*Todd*, 1980; *Wisler* and *Brater*, 1959; *Wannielista et al.*, 1997]. Through the process of infiltration and percolation, the absorbed rainwater will fill the groundwater aquifer or come out to the land surface as spring or seepage.

As is described above, the groundwater storage was calculated based on the rainfall, often called meteorological calculation. The calculation method was based on the concept of water balance [*Seyhan*, 1975; *Griend*, 1979].

$$\Delta s = P - Ea - Q$$

Where, Δs is groundwater storage, P is precipitation, Ea is evapotranspiration and Q is discharge. Using this method, the groundwater transbasins is disregarded because its value is relatively small and difficult to determine.

Some previous studies found out that the evapotranspiration rate in tropical areas was around 4 mm/day. The value of discharge could be obtained from the data of river flow on every watershed area where the research took place. Then the groundwater storage could be calculated on each watershed in the island of Java as presented in Table 7.

Table 7. Groundwater storage in each watershed in Java Island

No	Watershed	District	Water Balance (million m³/year)			
			Rainfall	Evapotrans	Runoff	Groundwater
1	Labuhan Merak	Cilegon, North Pandeglang	6439	3612	596	2231
2	Ciujung	Serang, North Lebak.	6786	3648	2929	209
3	Cisadeg Cikuningan	South Pandeglang, South Lebak, Sukabumi, South Cianjur, South Garut.	25342	14778	4476	6088
4	Cisadane Cilıwung	Tangerang, Jakarta, Bekasi, Bogor, North Cianjur	16378	5858	3120	7400
5	Upper Citarum	Bandung, Sumedang	9673	5947	908	2514
6	Lower Citarum	Karawang,Subang, Purwakarta	11367	11671		
7	Cimanuk	Indramayu, Majalengka, North Garut.	11195	6338	2725	2132
8	Ciwulan	Tasikmalaya, Ciamis Barat	13910	9505	1374	1844
9	Cisanggarung	Cirebon, Kuningan	5080	3757	1187	136
10	Pemali Comal	Brebes, Tegal, Pemalang, Pekalongan, West Batang.	14400	7206	6441	753
12	Buyaran	East Batang, Kendal, Semarang, Demak	8419	4545	510	3364
13	Serang Lusi	Jepara, Kudus, Grobogan	8139	5539	92	2508
14	Juana	Pati, Rembang, Blora	7625	5194	42	2389
15	Citanduy	Ciamis Timur, Cilacap	14460	7629	824	6007
16	Serayu	Wonosobo, Banjarnegara, Banyumas	13481	5503	5686	2293
17	Lukulo Dulang	Kebumen, Purworejo	10439	5374	874	4191
18	Progo	Temanggung,Magelang, Kulon Progo, West Bantul	7089	4033	1392	1664
19	Opak Oya	Sleman, Jogja, East Bantul, Gunung Kidul.	5566	3828	1023	715
20	Upper Bengawan Solo	Wonogiri, Sukoharjo, Solo, Klaten Karanganyar, Boyolali, Salatiga, Sragen	20338	14615	6316	2992
21	Lower Bengawan Solo	Ngawi, Bojonegoro, Tuban, Lamongan , Gresik	15248	11663		
22	Grindulu Panggul	Pacitan, South Trenggalek, South Blitar, South Malang.	3678	2346	1158	174
23	Upper Brantas	Magetan, Madiun, Ponorogo	10820	8511		
24	Lower Brantas	Surabaya, Sidoarjo, Mojokerto,Jombang, Nganjuk, Kediri, North Malang	10240	9161	3051	337
25	Luminu Penguluruan	North Trenggalek, North Blitar, Central Malang	6748	4486	41	2221
26	Pekalen Sampean	Pasuruan, Probolinggo, West Situbondo,West Bondowoso.	8585	6948	1327	310
27	Bajul Putih	East Situbondo, East Bondowoso, Banyuwangi	8863	7399	657	807
28	Bededung	Lumajang, Jember	10982	7507	1785	1690
29	Madura	Bangkalan,Sampang, Pamekasan, Sumenep	8552	8277	197	78

Table 7 reveals that meteorologically the highest level of groundwater storage occurred in Cisadeg-Cikuningan watershed at the amount of 6088 million m³/year, and the lowest was in Madura watershed area at the amount of 78 million

m^3/year. Cisadeg-Cikuningan watershed is in the region of Banten and southern part of West Java including Southern Pandeglang, Southern Lebak, Sukabumi, Southern Cianjur and Southern Garut, while Madura watershed covers the whole island of Madura.

CONCLUSION

1) In the province of Banten and West Java, the highest level of annual rainfall is 4082 mm that occurs in Cisadane-Ciliwung watershed and the lowest one is 1421 mm in the downstream of Citarum watershed. Base on the rainfall potential, Cisadeg-Cikuningan watershed has the highest potential of rainfall at the amount of 25342 million m^3/month while Cisanggrung watershed has the lowest potential at the amount of 5080 million m^3/month.
2) In Central Java, the highest level of annual rainfall is 3577 mm that occurs in Serayu watershed and the lowest one is 2032 mm in Upper Bengawan Solo watershed. Base on the rainfall potential, Citanduy watershed has the highest potential of annual rainfall at the amount of 14460 million m3/month while Opak-Oya watershed has the lowest potential at the amount of 5080 million m3/month.
3) In East Java, the highest level of annual rainfall is 2290 mm that happens in Grindulu-Panggul watershed and the lowest one is 1509 mm in Madura watershed. Seeing from the rainfall potential, Bengawan Solo Hilir watershed has the highest potential of annual rainfall at the amount of 15248 million m3/month while Grindulu-Panggul watershed has the lowest one at the amount of 3678 million m3/month.
4) Meteorologically, Cisadeg-Cikuningan watershed has the largest groundwater storage at the amount of 6088 million m3/year and the lowest groundwater storage occurs in Madura watershed at the amount of 78 million m3/year.

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