ABSTRAK

PENGARUH DISTRIBUSI CURAH HUJAN YANG TIDAK MERATA SECARA RUANG DAN WAKTU TERHADAP DEBIT SUNGAI CILIWUNG

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Sungai Ciliwung merupakan sungai terbesar yang melintasi wilayah Daerah Khusus Ibukota (DKI) Jakarta. Pemahaman proses hujan limpasan penting dalam pengembangan model aliran sungai untuk Daerah Aliran Sungai (DAS) Ciliwung. Dalam penelitian sebelumnya, curah hujan seringkali dianggap stasioner. Namun diketahui bahwa curah hujan di DAS Ciliwung memiliki variasi yang signifikan, baik secara ruang (spasial) maupun waktu (temporal). Selain pola diurnal yang sudah diketahui dengan baik, pola semidiurnal juga telah teridentifikasi terjadi pada beberapa kejadian banjir. Namun pengetahuan variasi pola ini dan pengaruhnya terhadap debit Sungai Ciliwung masih terbatas. Penelitian ini bertujuan untuk meningkatkan pemahaman tentang signifikansi variasi semidiurnal pada pola harian curah hujan dan pengaruhnya terhadap debit Sungai Ciliwung, terutama pada kejadian banjir parah (*severe flood*).

Penelitian ini menggunakan tiga pendekatan, yaitu: 1) analisis pola harian curah hujan, 2) analisis karakteristik debit hulu dan hilir, serta 3) analisis peranan pola curah hujan terhadap debit puncak. Ketiga tahapan tersebut dilakukan berdasarkan data curah hujan, data debit, dan simulasi hidrologi. Data curah hujan meliputi: data observasi permukaan (2004-2008), *Tropical Rainfall Measuring Mission* (TRMM) *Multisatelite Precipitation Analysis* (TMPA, 1998-2017) dan *Global Satellite Mapping of Precipitation* (GSMaP, 2000-2014), sedangkan data debit didapatkan dari Stasiun Katulampa (hulu) dan MT Haryono (hilir) pada periode observasi 2004-2017.

Pola harian curah hujan dianalisis sebagai siklus harian berdasarkan rata-rata intensitas curah hujan dalam jangka waktu yang lama untuk durasi satu atau tiga jam. Kondisi klimatologis pola curah hujan analisis secara bulanan dan musiman dalam tiga wilayah, yaitu: hulu, hilir, dan pesisir. Hidrograf Sungai Ciliwung dari dua stasiun observasi, hulu dan hilir, dianalisis untuk mendapatkan pola harian dan debit puncak. Perbandingan langsung dan analisis korelasi silang antara debit hulu dan hilir dilakukan untuk memperkirakan *travel time*. Selain itu, analisis perbandingan debit hulu-hilir dilakukan pada kelompok kasus diurnal dan semidiurnal. Kedua pola tersebut ditentukan berdasarkan hidrograf hulu yang memiliki bentuk lebih sederhana dibandingkan hilir. Pengaruh dari variasi pola curah hujan semidiurnal terhadap debit sungai dikaji pada kasus banjir parah. Pada kasus ini, simulasi hidrologi dengan menggunakan model *Gridded Surface*

Subsurface Hydrologic Analysis (GSSHA) dilakukan untuk mengatasi keterbatasan data observasi.

Pola harian curah hujan di DAS Ciliwung dicirikan oleh variasi diurnal yang terjadi di wilayah hulu pada siang hingga malam (13.00-22.00 WIB) hari hampir di semua bulan. Pada periode DJF, variasi diurnal di wilayah hulu terjadi pada jendela waktu yang lebih lebar yakni siang hingga dini hari (13.00-01.00 WIB), sedangkan wilayah pesisir berpeluang terjadi pada pada waktu yang berbeda yakni malam hingga pagi hari (22.00-10.00 WIB). Pada bulan-bulan tersebut, hulu DAS Ciliwung juga mempunyai pola semidiurnal yang cukup signifikan, yang ditandai hujan pagi (01.00-08.00 WIB) dengan nilai frekuensi relatif sebesar 20,8%. Adapun wilayah hilir DAS Ciliwung merupakan wilayah transisi yang dipengaruhi pola temporal di pesisir dan hulu, sehingga curah hujan berpeluang untuk terjadi dua kali atau lebih dalam sehari. Variasi semidiurnal pada pola hujan harian di hulu maupun hilir semakin kuat pada bulan Januari-Februari yang merupakan periode terjadinya interkoneksi antara sistem hujan di darat dan laut.

Pola temporal debit Sungai Ciliwung dicirikan oleh nilai *travel time* rata-rata antara hidrograf hulu dan hilir adalah 11 jam dan bervariasi antara 8-13 jam. Pola temporal debit Sungai Ciliwung juga secara umum dicirikan oleh variasi diurnal, tetapi khusus pada bulan Januari-Februari terdapat pula variasi semidiurnal di hulu dengan waktu kemunculan puncak kedua sekitar jam 10.00 WIB. Pada saat debit hulu berpola diurnal, variasi *travel time* berkorelasi dengan debit. Akan tetapi ketika debit hulu berpola semidiurnal korelasi maksimum antara debit hulu-hilir maupun *travel time* cenderung bervariasi secara acak. Keacakan tersebut berkaitan dengan kondisi debit hilir dominan, rasio debit hulu terhadap hilir kurang dari 0,5. Keacakan variasi tersebut disebabkan oleh dua factor: 1) superposisi dua atau lebih hidrograf hulu, dan 2) pengaruh kompleksitas variasi spasial-temporal hujan di hilir.

Pada kasus kejadian banjir di bulan Januari 2013 dan 2014, pola semidiurnal hujan di hulu DAS Ciliwung menghasilkan dua hidrograf dengan puncak yang berdekatan dan bersuperposisi di hilir sehingga menghasilkan debit puncak ekstrem. Meskipun tidak didapatkan data yang sesuai, hasil simulasi numerik menunjukkan bahwa pola hujan di hilir mempunyai kontribusi besar terhadap debit ekstrem yang memicu kejadian banjir.

Pemahaman terhadap pengaruh pola spasial-temporal curah hujan terhadap debit sungai dari hasil penelitian ini memberikan sudut pandang baru mengenai proses hidrometeorologi di DAS Ciliwung, yaitu: 1) dua hidrograf hulu yang terbentuk oleh pola semidiurnal hujan berpotensi menghasilkan debit puncak yang lebih tinggi di hilir melalui proses superposisi, b) hujan di hilir yang berpotensi terjadi dua kali (semidiurnal), bahkan lebih sering, dalam satu hari dan berkontribusi besar terhadap nilai debit ekstrem di hilir, 3) Karena wilayah hilir merupakan wilayah transisi antara pola semidiurnal pesisir (dipengaruhi sistem hujan laut) dan hulu (dipengaruhi sistem hujan darat), maka selain volume hujan peningkatan debit juga dapat terjadi karena pola propagasi sistem hujan di sepanjang DAS Ciliwung.

Kata kunci: Sungai Ciliwung, diurnal-semidiurnal, hujan, debit, banjir, spasial-temporal.

ABSTRACT

THE EFFECT OF NON UNIFORM SPATIAL-TEMPORAL DISTRIBUTION OF RAINFALL ON THE DISCHARGE OF THE CILIWUNG RIVER

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Ciliwung River is the largest river that runs across DKI Jakarta, the capital city of Indonesia. Understanding rainfall-runoff processes is important for developing stream flow models for the Ciliwung Watershed. In many previous studies, rainfall has often been assumed to be have stationary. It is known, however, that rainfall over the Ciliwung Watershed may have significant variations in both space and time. Beside the well known diurnal variation, semidiurnal mode in daily rainfall pattern has also been identified to occur in several flood events. Knowledge of the rainfall semidiurnal variation and the relationship with its spatial distribution is still limited. This study aims to improve understanding about the significance of semidiurnal variation in the daily rainfall patterns and how it may affect the Ciliwung River discharge, especially during severe flood events.

This study used three approaches, namely: 1) analysis of daily rainfall patterns, 2) analysis of the upstream and downstream discharge characteristics, and 3) analysis of the effects of rainfall spatiotemporal patterns in generating peak discharge. Those analyses were carried out using rainfall data, discharge data, and hydrological simulations. The rainfall data include: surface observational data (2004-2008), the Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA, 1998-2017), and The Global Satellite Mapping of Precipitation (GSMaP, 2000-2014), while the river discharge data were derived from water level measurements at Katulampa (upstream) and MT Haryono (downstream) stations in the 2004-2017 period.

Rainfall patterns have been mainly analyzed as the mean 24-hour cycles resulted from long-term averaging of 3-hourly or hourly rainfall intensity. The climatology of the rainfall patterns was analyzed by grouping the data into different months and seasons, over three subregions of the studied area i.e. upstream, downstream, and coastal area. The hydrographs of Ciliwung River discharge observed at two stations, upstream and downstream, were analyzed to obtain the daily pattern and peak discharge. Direct comparisons and lagged cross-correlation analyses between hydrographs of the upstream and downstream stations were also performed to estimate the travel time. Additionally, exploratory comparative analyses between upstream-downstream discharges were carried out by separating the data into diurnal and semidiurnal sample groups. The diurnal and semidiurnal events for Ciliwung River discharge was determined by using

upstream hydrograph only because of its simpler shape compared to that of the downstream. The effects of the semidiurnal rainfall variations on the river discharge were then investigated in case studies of severe flood event. In this cases, hydrological simulation using the Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model was performed to overcome the lack of observation data.

The daily rainfall patterns in the Ciliwung Watershed is characterized by diurnal variations that occur in the upstream area during the afternoon until night (15.00-21.00 LT) for almost all months. In the DJF period, diurnal variations in the upstream area occur at a wider time window, from afternoon to early morning (13.00-01.00 LT), while the coastal area has the chance of occurrence at different times, from night to morning (22.00-10.00 LT). In those months, the upstream of the Ciliwung Watershed also has a significant semidiurnal pattern, which was marked by rain in the morning (01.00-08.00 LT) with a relative frequency value of 20,8%. The downstream area of the Ciliwung Watershed is a transitional region that is influenced by the temporal patterns on the coast and upstream so that the rainfall has a chance to occur twice or more in a day. Semidiurnal variations in daily rainfall patterns in upstream and downstream are stronger in January-February which are the period of interconnection between rain systems on land and sea.

The stream flow in the Ciliwung River is characterized by an average travel time value of 11 hours, which varies between 8-13 hours, between upstream and downstream hydrographs. The temporal pattern of the Ciliwung River discharge is also generally characterized by diurnal variations, but specifically in January-February, there are also semidiurnal variations in the upstream discharge with the second peak occurrence time around 10:00 LT. When the upstream discharge is diurnal, the variation in travel time correlates well with the river discharge. However, when the upstream discharge has a semidiurnal pattern, the maximum correlation between upstream-downstream discharge and travel time tend to vary randomly. This is also related to the condition of the dominantly downstream discharge, in which the ratio of upstream to downstream relative peak discharge is less than 0.5. The random variation in travel time is likely caused by two factors: 1) a superposition of two or more upstream hydrographs, and 2) rainfall that occurred with complex spatiotemporal variations in downstream area.

In the flood events in January 2013 and 2014, the semidiurnal rainfall patterns in the upper Ciliwung Watershed produced two adjacent hydrographs, superimposed in the downstream, and produced extreme peak discharge. Although the rainfall and rivers discharge data are limited, the numerical simulation results show that downstream rainfall patterns have a significant contribution toward the extreme discharge that triggers flooding.

The understanding of the spatial-temporal rainfall patterns effect on river discharge from the results of this study provides a new perspective on the hydrometeorological process in the Ciliwung Watershed, namely: 1) two upstream hydrographs that formed by semidiurnal patterns of rainfall potentially produce higher peak discharge in the downstream through superposition process, b) downstream rain that has the potential to occur twice (semidiurnal), or even more frequently, in one day and contributes substantially to the downstream

extreme discharge, 3) because the downstream region is a transition region between coastal semidiurnal pattern (influenced by the sea rain system) and upstream (influenced by the land rain system), then besides rain volume, the increase in discharge can also occur due to the propagation pattern of the rain system along the Ciliwung Watershed.

Keywords: Ciliwung River, diurnal, semidiurnal, rainfall, discharge, flood, spatial-temporal