Hydro-meteorological Hazards in Bandung City, Indonesia

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RDI Team:
Saut Sagala, Nadiya Pranindita,
Danang Azhari, Nabilla K. Ishadi

Sheffield University:
Juan Miguel Kanai

Lincoln University:
Alex Lechner

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<td>Bandung Metropolitan Area</td>
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<td>Badan Meteorologi Klimatologi dan Geofisika</td>
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<td>Badan Nasional Penanggulangan Becana</td>
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<td>Badan Pusat Statistik</td>
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<td>Data dan Informasi Bencana Indonesia (Disaster Information Management System)</td>
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1. Introduction

Global analysis of records reported that 91% of disaster events from 2000-2019 were climate-related disasters including disasters categorized as meteorological/climatological and hydrological (UNDRR, 2020). Due to rapid climate change, the unusual phenomenon of atmospheric and hydrological nature occurred and have resulted in glacial retreat, global sea levels rise, and extreme precipitation which may cause loss of life, and lead to hydro-meteorological disasters (Gupta et al., 2009; Jayawardena, 2015; UNISDR, 2009). The high precipitation causes flooding, landslides, and debris flow while droughts happen when it is too low, while the high air pressure in the atmosphere has led to different forms of cyclones, heat waves, and cold waves (Jayawardena, 2015). In addition to these primary causes, poor land-use planning, and other related development processes have made the risks even worse (Gupta et al., 2009).

Hydro-meteorological disasters account for over 75% of disruption to normal life, such as economic losses and infrastructure damage (Jayawardena, 2015; Paul et al. 2018). Flood is the primary type of disaster that has caused the highest fatalities for approximately 41% (1.65 billion) of people affected in 20 years, followed by droughts, accounting for roughly 35% (1.43 billion) of those affected (UNDRR, 2020). The vulnerabilities to these disasters are also influenced by the low socio-economic conditions of the communities, which significantly increase the losses to life, property damage, and loss of livelihoods and services (Gupta et al., 2009). Economic losses as a percentage of GDP tend to be higher in poorer nations compared to rich countries (UNDRR, 2020).

Since the majority causes of hydro-meteorological disasters are highly related to the water and wind, regionally, the countries lying between Oceans suffer more, one of which is Indonesia (Jayawardena, 2015). According to data compiled by BNPB, it can be seen that more than 78% (11,648) of disasters in the period 2005-2015 were hydro meteorological disasters (BNPB, 2016). Indonesia has experienced severe losses in the economic and non-economic aspects due to hydro-meteorological disasters. Increase in the vulnerability of people as a consequence of hydro-meteorological disasters impacts has driven the risk-reduction point of view to be a crucial concern. However, there is rare statistical evidence of hydro-meteorological disasters occurrences as essential information for risk reduction planning.

This White Paper is arranged to build a database related to hydro-meteorological hazard in Indonesia with Bandung City as a case study. Bandung is chosen as its high risk of flooding occurrence, an increase in the affected area and more significant economic losses due to its topographic character as an intermontane basin city multiplied by the lack of water catchment area due to rapid growth of population and intensive human activities. Bandung City is part of West Java, one of the provinces in Indonesia with the highest vulnerability to climate-related hazards including hydro-meteorological disasters in Southeast Asia after Sumatra. The focus will be on the type
2. Bandung in Glance

Located in the western part of Java Island, Bandung City is the capital of West Java Province. Bandung City is the fourth-most populous city in Indonesia after Jakarta, Surabaya, and Medan (BPS Kota Bandung, 2020). It is a part of Bandung Metropolitan Area (BMA), bordered by Bandung Regency in the north, south and east side, Cimahi City in the west side, and West Bandung Regency in the north side.

As seen in Figure 1, from north to south, the city is divided by the Cikapundung River, a branch of Citarum River which is the basin’s main river (Tarigan et al., 2016). The land’s use and topography are varied, with the northern part of the city being hillier than the rest. Due to long-term volcanic activity from the Tangkuban Perahu volcano, the northern part of the area is filled with fertile andosol soil which is perfect for rice, fruit, tea, tobacco, and coffee plantations (Raharjo, 2017).

Bandung City is situated at 768 meters above the sea level and has a total area of 167.31 km². Administratively, the municipality's area is divided into 30 sub-districts and 151 urban villages. According to Statistics Indonesia (2020), Bandung City has a
population of approximately 2.5 million – the sixth-largest population in West Java Province, with a growth rate of 0.17% during 2018-2019. Along with the increasing rate of population growth, Bandung City has attracted various investments, contributing to the city's rapid development in public services, infrastructures, as well as several business sectors: tourism, manufacturing, textiles and apparel, pharmaceutical, food, and entertainment (Firman, 2009).

3. Threats of Hydro-meteorological Hazards

The OPERANDUM (2019) defined hydro-meteorological hazard as a natural phenomenon or processes involving atmospheric, hydrological or oceanographic components that could bring loss of life, health impacts, property damage, loss of livelihoods and services, social and economic disruptions, or environmental damage. This phenomenon is caused by extreme meteorological and climatic events, bringing hazards such as floods, droughts, hurricanes, tornadoes, or landslides to the scene (Wu et al., 2016). To date, especially due to the implication the climate change brings, hydro-meteorological hazards have spatially and temporally developed to significantly damaging the public facilities and taking up millions of lives globally (Cai et al., 2015; Kundzewicz et al., 2019; Morrison et al., 2018).

Figure 2. Top 5 Countries with the highest number of disasters reported (UNDRR, 2020)

In the 20 years between 2000 and 2019, EM-DAT recorded 7,348 events, in which 91% of them were climate-related disasters (UNDRR, 2020). Hydro-meteorological disasters account for over 75% disaster occurrences annually, dominated by floods and storms. In terms of affected countries, China and USA, 577 and 467 events, respectively, have the highest numbers of reported disaster events, followed by India, The Philippines, and Indonesia (Figure 2). All of these countries have the same underlying fact, highlighting high population density as well as a huge and diverse landmass.
One potential cause of hydro-meteorological hazards is climate change affected by global warming due to GHG emissions. Extreme changes of climate are often indicated by two elements of climate, temperature and precipitation, which are the primary causes of hydro-meteorological hazards such as flood and drought (Reza Milanda and B. Setiawan, 2019). The changing temperature rate covers the most extreme high and low-temperature events to span heatwave duration in a year. At the same time, precipitation captures the number of consecutive dry days to figure out the potential of drought and the greatest precipitation events to predict floods (Frich et al., 2002).

The anomaly of global average temperature (the combined average near-surface air temperature over land and sea surface temperature) in 2019 is reported by Japan Meteorological Agency (JMA) 0.43°C warmer than 1981-2010 average and was the second warmest after the 0.45°C increase in 2016 (JMA, 2020). The higher temperature, especially in the ocean, can force more evaporation in which if it is associated with the increase in moisture in the atmosphere, it will activate the tropical cyclone (Harvard SEAS, 2019). This tropical cyclone is what causes hydro-meteorological hazards such as heavy rain and strong wind with various intensity, size, and location.

Beside anomaly in average temperature, an abnormal change in precipitation is also the main cause of threatening hydro-meteorological hazards. Annual global precipitation by hemisphere has been fluctuating in the 1930s, 1950s, and remains high since the mid-2000s in the northern hemisphere (JMA, 2020). Heavy precipitation can bring hydro-meteorological hazards, such as floods, but it would cause drought in some areas when it is less than average and affect water supply (BBC, 2020).

A threatening remark of climate change has placed Indonesia in the 12th rank of 35 countries with the highest risk from multiple hazards (Global Risk Analysis by the World Bank). The average annual temperature is reported by Indonesia’s Meteorological, Climatological, and Geophysical Agency (BMKG) increasing by 0.03°C per decade since 1990 and is predicted to keep increasing until in total at 0.9-2.2°C by 2060. Observational data from BMKG stations in each province note that 2016 was the hottest year with an anomalous value of 0.8°C from the 1981-2010 baseline, followed by 2019 and 2015 in 0.58°C and 0.5°C, respectively (BMKG, 2020). Deviations in rainfall patterns from the same baseline also occurred in the last ten years in Indonesia. Rainy days have different trends in their locations and are influenced by the rainy and dry season periods. The west and south of Sumatra and western and eastern Java in Indonesia were exposed as some of the most vulnerable areas in Southeast Asia to climate-related hazards especially floods, landslides, drought, and sea-level rise (Yusuf and Francisco, 2009).
Bandung City, as one of the regions in West Java, is also experiencing an increase in average temperature and precipitation in recent years as the impact of climate change phenomenon and has resulted in climate-related hazards such as floods, landslides, and drought. According to BPS Kota Bandung (2020), the annual average precipitation in Bandung City was fluctuating in which significant increases in the average rainfall amount were noticed in 2013 and 2016 by 223.45 mm and 295.80 mm respectively along with a high number of flood events in these years. Meanwhile, the annual average temperature in Bandung was recorded slightly increasing in the past seven years in which the highest temperature was taken down during June until October or the dry season when the droughts usually happened.

2. Land-use Change

Adding-on to the climate-related phenomenon, inappropriate land-use, and other planning related development is also playing the main role in exacerbating the effect of climate change. High intensity of human activities especially in urban areas has led to the increase in demand for residential, infrastructure, commercial, and industrial processes, which has forced land conversion from green space into brownfields and built-up areas. As the third-largest city in Indonesia, Bandung is experiencing rapid growth, which has resulted in uncontrolled urbanization by reasons of its promising urban potentials.

Built-up areas dominate Land-use in Bandung, and the number keeps increasing within the past three decades, accounted for 82% in 2016, while the area of green open space in Bandung was reported 12.20% of the total area in 2017 and consisted of private green open space and public green open space (DLHK, 2020). Land conversion in Bandung City mostly occurs in water catchment areas, especially forests and agriculture, which only leaves 25% of the 30,000 Ha of forest and agricultural areas throughout Bandung City (Rianawati and Sagala, 2014). This condition also causes 95% of the rainwater runoff unable to be absorbed by the soil and brings out the increase in floods risk.

b. Hydro-meteorological Hazards in Bandung City

1. Flood

Floods are one of the hydro-meteorological hazards – a global phenomenon with the highest occurrence among all-natural disasters (Jha et al., 2012). There are several definitions of the flood, as defined by the World Meteorological Organization (2016): (1) An increase of water surface in the water bodies until certain level and proceeds to recede in a slower pace; (2) Relatively high-water flow in terms of stage height or discharge; and (3) A rising tide. Whereas according to the Ministry of Public Works
and Public Housing Regulation No. 28 year 2015 regarding the Establishment of River and Lake Borders, the flood is defined as an event when the river flows over the riverbed. Evolved from these definitions, flooding implies the event where overflowing occurs over areas that are not commonly inundated.

Flooding generally occurs as a result of various complex factors that can be categorized into natural causes and human causes and getting worsened by the existence of climate change (Birkholz et al., 2014; Xie et al., 2017; Zhou et al., 2016). According to countermeasure by the National Agency for Disaster (BNPB) (2016), the natural factors can be classified into two categories: static natural factors which include the morphology and geometry of the land as well as water bodies; and dynamic natural factors that cover the climatological events (extreme rainfall), sedimentation, or engineered process (river damming). Aligned with this, Mishra and Shah (2018) also mentioned that floods are mostly caused by various factors such as heavy rains, river overflows, tides, although the hazards they bring kept changing and evolving. Aside from these atmospheric aspects, population growth, anthropologic activities also contribute to the flood's occurrence, especially with the fluvial and pluvial floods. The human factors are mostly referred to the daily activities that are impacting the environment, such as land-use change, urban heat island, floodplain urbanization, and lack of drainage infrastructure maintenance (Lai et al., 2016; WMO, 2011).

By the causes, there are three common types of floods: coastal flooding, river (fluvial) flooding and land (pluvial) flooding (Jha et al., 2012; Maddox, 2014). Coastal flooding is defined as the inundation of land areas along the coast by seawater due to extreme offshore weather events, river (fluvial) flooding is strongly related to upstream rainfall and overflowing river onto the surrounding banks, shores and neighbouring land, and the last fluvial flood occur when intense rain saturates an urban drainage system and runoff or flowing water from rain falling on elevated terrain such as hillsides (World Bank, 2019). Over the past five decades, the number of flood events reported globally has steadily increased (Tanoue et al., 2016). It affects a growing number of people and causes significant economic loss and damage to the affected environment (Kundzewicz et al., 2014; López-Marrero and Tschakert, 2011; Tanoue et al., 2016).

With the ever-growing population and infrastructure development, Indonesia has been facing floods since the 17th Century. History recorded in 1621, when the country’s capital, Jakarta, was heavily inundated due to overflowing water from Ciliwung, Cisadane, and Angke rivers. Since then, floods have occurred almost annually for several cities, owing to the rapid population growth that drives the land-use changes along with poor maintenance on sewer networks (Marfal et al., 2015). According to Muis et al. (2015), these flood events may increase 166% in the next three decades due to the rapid expansion of urban areas. In the Bandung City context, the topographical character of the area, which is surrounded by mountains forming a kind of basin, coupled with the two rivers (Citarum and Cikapundung) that pass through the city, become some of the factors driving high numbers of flood events.
The Citarum river area is not only considered as an area with bountiful water resources but also has been a potential for disaster towards the community along the Citarum river, especially flooding. Beside Citarum River, the Citepus river that flows through the Citepus watershed flows from West Bandung District (upstream area) passes by the Bandung City with its length of 32.45 kilometers that disembogues in Bojong Citepus Village, Cangkuang Wetan Village, Dayeuhkolot Sub-district, and Bandung District (downstream area). Similar with Citarum River, the Citepus watershed area is also considered as a flood-prone area, where floods occur annually.

According to BNPB (Figure 3), almost 90% of Bandung City area are highly susceptible to flooding, especially the southern part of the municipality. Areas classified as high flood hazard are the areas with the most flood occurrences, which consequently have higher flood risk. Higher degree of flood risk indicates greater loss and damage due to flood and refers to vulnerability and capacity information of each area. There were 217 flood events recorded during the 2009-2019 period, with the highest number of floods occurring in 2010, 2013, and 2016 of 65, 54, and 23, respectively (DIBI, 2020).
2. Drought

Within the realms of extreme climate, opposite to flood is drought. Drought is usually exclusively affiliated to arid, semi-arid, and sub-humid regions, while in fact, it occurs in most countries, regardless of its climate (WMO, 2006). Generally, drought refers to a condition when a consequential decrease of water availability under the expected volumes for a certain time and should rather be considered as a relative condition (WMO, 2006). The World Bank (2005) classifies the drought terminology into several definitions, which describes its cause/source, conditions, and impacts: meteorological drought, hydrological drought, agricultural drought, and socio-economic drought.

Meteorological drought signifies a precipitation deficit compared to the long-term average in a specific region, taking into account that atmospheric conditions must be varied for each region. Hydrological drought often refers to a condition on a watershed or river basin scale, where there's a water supply shortage due to precipitation shortfalls. Agricultural drought occurs as the results of either meteorological or hydrological drought, addressing, for instance, the evapotranspiration differences, soil water deficits, reduced groundwater level, and precipitation shortages. Socio-economic drought concerns the failure to satisfy the water supply for the human and environmental needs in one area, affecting the rest of the economy and further the livelihood of the population. Drought in urban areas threatens natural resources and can pose a significant challenge to the urban water supply system (Szalinka et al, 2018). As seen in Figure 5, Most of the Bandung area has low levels of drought risk and hazard. However, drought is one of the problems that occur in Bandung City in almost every dry season.

In 2018, 31 administrative villages in the City of Bandung were recorded to experience drought by Perusahaan Daerah Air Minum Tirtawening (Firmansyah, 2018). However, it is projected that in the next 50 years the people of Bandung City could no longer use groundwater (Ranawati, 2019). It also is assumed that the cause of this area is decreased in the groundwater level in developed areas such as Gedebage, Majalaya, and Dayeuhkolot. In 2000-2009 land subsidence in Bandung has occurred around 9-14 cm per year in the Gedebage area, whereas in Majalaya and Dayeuhkolot areas by 4-7 cm, these phenomena caused by the increase the
degree of groundwater extraction in Bandung City (Gumilar, et al 2019). With the decrease in water sources level from 100m to 500m, the presence of rain did not provide much difference to the increase of water debit in Bandung City (Ridwan, 2019). Based on the drought index on a global scale, published by the NOAA in 2019, Indonesia in the majority has few spots experiencing a prolonged drought period. In Bandung City, hydrological drought occurs due to low precipitation during the long dry season which has caused water reserve and artesian wells to shrink. The most drought prone areas are Cidadap in the northern part and Gedebage for the southern part of the city (Figure 5). BNPB recorded drought twice in 2011, twice in 2012, once in 2013, once in 2018, and once in 2019.

![Drought Occurrence in Bandung City](image)

**Figure 6. Drought occurrence in Bandung City (2009-2019), (DIBI, 2020)**

### 3. Landslides

The definition of landslide varies, reflecting many disciplines involved in landslide phenomena. In general terms according to Highland and Bobrowsky (2008), landslide is denoted as the downslope movement of soil, rock, and organic materials under the effects of gravity and also the landform that results from such movement. The records include a range of both natural and man-made phenomena. The cause of landslides is critically triggered by physical causes which are intense or prolonged rainfall (Highland and Bobrowsky, 2008). Other causes include ground and morphological causes (weathered materials, river erosion) and artificial causes (sand mining, deforestation, etc).
From 2000-2019 worldwide occurrences of disaster, landslides are responsible for 5% of the total events (CRED, 2020). Major landslides occur every year and have taken lives and economic losses. According to Lacasse and Nadim (2009), most human casualties caused by landslides occur in developing countries, including Indonesia. BNPB (2016) recorded that there were 2,425 landslides occurred in Indonesia during 2011-2015, mainly in Central Java, West Java, East Java, West Sumatera and East Kalimantan. The disaster has caused 1,163 casualties, 112 missing people, 973 injured, and 48,191 evacuees. In Bandung City, most landslides occurred in 2013, with a total of 29 landslides incidents, followed by 2010 and 2014 with 20 and 19 incidents respectively (DIBI, 2020). The northern part of the city is the most landslide prone area, especially Cidadap, Ujungberung, and some part of Coblong and Cibiru districts (Figure 7).
During the last two decades, thousands of hydro-meteorological hazards were recorded, directly claiming millions of lives, injuring billions of people, and damaging countless infrastructures as well as public services. There were 510,837 deaths and 3.9 billion people affected by 6,681 climate-related disasters, exemplifying not only how enormous the affected was, but also the importance of understanding the disaster risk (UNDRR, 2020). According to Jha et al. (2012b), other than the direct impacts, floods also bring complications that follow its occurrence, such as the emergence of disease, erosion, decreasing quality of available and clean water, reducing education opportunities, community resilience, and delaying other development goals.

Of all the hydro-meteorological disasters, floods have claimed the most lives and economic losses (UNDRR, 2020). Floods that occur in urban areas will result in much greater losses compared to floods in rural areas, generally. In accordance with impact, Xie et al. (2017) admitted that growth in urban areas faces serious challenges related to the economic impact, extensive damage, and casualties from urban flooding. To this day, urban areas are still the centre of numerous human activities, reflected by the settlements’ localizations, state assets, businesses and public service facilities (Jha et al., 2012). The presence of this concentration of anthropological activities is also the fundamental difference between urban and rural flooding: land cover and number of existing vegetation (WMO, 2011).

As one of the most disaster-prone countries in the world, high-paced development in Indonesia coupled with climate change, are increasing the country’s exposure and vulnerability to disaster risk, particularly hydro-meteorological hazards. In the last 15 years, according to UNDRR (2020), Indonesia has lost $16.8 billion owing to the disaster events. Based on BNPB (2019) data release, Indonesia has a trend of disasters that are dominated by hurricanes that followed by floods in the last five years.

![Figure 9. Bandung City post-flood impacts in 2009-2019, (DIBI, 2020)](image-url)
In West Java Province, the Regional Disaster Management Agency (BPBD) noted that until the first semester of 2020, 918,961 lives are affected, 21 died, and 143,169 houses damaged (BPBD Jawa Barat, 2020). BNPB through DIBI noted that flood occurs at least once a year in Bandung District and generates loss and destruction each year, as well as evacuation and indirect impacts. A total of 609 houses were destroyed, 125 houses were damaged, and 134,502 had to be evacuated due to flood during 2009-2019.

For drought incidents, 31 areas in Bandung City were reported to experience drought in 2018 (Syarif, 2018), while in 2019, approximately 300 households had to receive clean water distribution in the dry season because the water reserves in the dam which is the main water resources and the residents’ artesian wells were shrinking (Permadi, 2019). Even though those are not classified as a severe drought, Bandung City still faces the threat of a shortage of clean water caused by the water reserve and artesian wells that are drying up.

Other than flood and drought incidents, 111 landslides were reported during 2009 to 2019 in Bandung City by DIBI. In general, the destruction of houses is among the most common post-landslides impact in Bandung City, with a total of 265 destroyed houses and 56 damaged houses in the last ten years. Nonetheless, landslides have also caused the deaths of 64 people, 52 people injured, 15 missing people, and 1,432 were evacuated, while the latest landslide occurred in 2019 in Kampung Cidadap causing one person’s death, 10 people were evacuated, and has destroyed 2 houses (Kusumah, 2019).

Figure 10. Bandung City post-landslide impacts in 2009-2019, (DIBI, 2020)
4. Conclusion

Extreme weather due to climate anomaly and land use conversion are the two main causes of hydro-meteorological hazards occurred in Bandung City. Based on the frequency data of hydro-meteorological disasters events in Bandung City, most of these are floods and threaten almost the entire city, while landslides are the most dominant hazards in the northern part. In addition, even though the drought that occurs in the Bandung City is not a severe drought, Bandung citizens are still facing the risk of clean water scarcity, especially during the dry season.

As the number of hydro-meteorological hazards increase, the loss and damage both in economic and non-economic aspects are likely to increase. Therefore, highlighting causes of the vulnerability have to be well done by utilizing the information of hydro-meteorological disaster type and its occurrences. The database of Hydro-meteorological hazards in Bandung City presented in this white paper would be the first step for interventions in reducing climate change impacts including hydro-meteorological disaster risk. The adequate and credible data and information are required to determine suitable adaptation and mitigation action for reducing the negative impacts.

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