CLIMATE RISK COUNTRY PROFILE

INDONESIA

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ACKNOWLEDGEMENTS

This profile is part of a series of Climate Risk Country Profiles developed by Climate Change Group of the World Bank Group (WBG). The country profiles aim to present a high-level assessment of the climate risks faced by countries, including rapid-onset events and slow-onset changes in climate conditions, many of which are already underway, as well as summarize relevant information on policy and planning efforts at the country level.

The country profile series are designed to be a reference source for development practitioners to better integrate detailed climate data, physical climate risks and need for resilience in development planning and policy making.

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Unless otherwise noted, data is sourced from the WBG's Climate Change Knowledge Portal (CCKP), the WBG's designated platform for climate data. Climate, climate change and climate-related data and information on CCKP represents the latest available data and analysis based on the latest Intergovernmental Panel on Climate Change (IPCC) reports and datasets. The team is grateful for all comments and suggestions received from climate and development specialists, as well as climate research scientists and institutions for their advice and guidance on the use of climate related datasets.

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FOREWORD

Development progress has stalled in many countries amid low growth, increased fragility and conflict, pandemic-related setbacks, and the impacts of climate change. Droughts, extreme heat, flooding and storms push millions into poverty annually, causing unemployment and risking unplanned internal and cross-border migration. Every year, an estimated 26 million people fall behind due to extreme weather events and natural disasters. These shocks have the potential to push a total of 130 million into poverty by 2030.

The World Bank Group (WBG) is supporting countries to meet these challenges. As part of our vision to end poverty on a livable planet, we are investing in development projects that improve quality of life while creating local jobs, strengthening education, and promoting economic stability. We are also helping people and communities adapt and prepare for the unpredictable and life-changing weather patterns they are experiencing, ensuring that limited development resources are used wisely and that the investments made today will be sustainable over time.

Having access to data that is accurate and easily understandable is of course critical to making informed decisions. This is where the report you are about to read comes in.

Climate Risk Country Profiles offer country-level overviews of physical climate risks across multiple spatiotemporal scales. Each profile feeds into the economy-wide Country Climate and Development Reports and draws its insights from the Climate Change Knowledge Portal, the WBG's 'one-stop-shop' for foundational climate data.

Guided by World Bank Group data and analytics, developing countries can conduct initial assessments of climate risks and opportunities that will inform upstream diagnostics, policy dialogue, and strategic planning. It is my sincere hope that this country profile will be used to inform adaptation and resilience efforts that create opportunities for people and communities around the world.

Valerie Hickey, PhD
Global Director
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KEY MESSAGES

Indonesia, one of the rainiest regions globally, experiences frequent and intense rainfall year-round, which supports rich biodiversity but also causes challenges like flooding, landslides, and soil erosion. El Niño leads to drier conditions, increasing the risk of droughts and wildfires, while La Niña brings wetter conditions, resulting in flooding. Agriculture is vital to Indonesia's economy, largely driven by small family-run farms producing staple foods like rice, corn, and cassava, along with cash crops such as palm oil and cocoa.

Over the past decades (1971 to 2020), average temperatures have risen by 0.28°C per decade, with a projected increase of 0.25°C per decade from 2000 to 2050. Rising temperatures contribute to higher energy demands for cooling, reduced crop yields, and increased water demand, while also creating favorable conditions for pests. The increased heat also puts additional stress on livestock. Night temperatures, experienced in small islands and low-lying coastal areas, are expected to rise, impacting agriculture, particularly crops like rice, corn, and soybeans. Extreme heat and humidity also raise the risk of heat-related illnesses and crop spoilage.

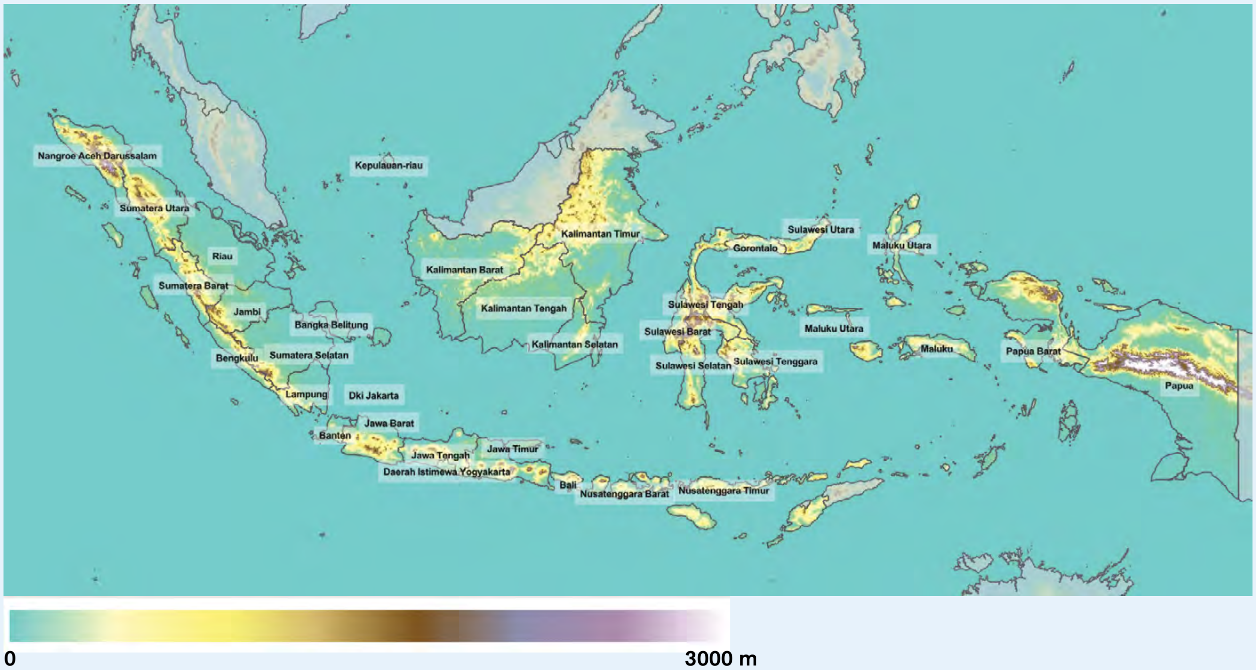
Precipitation trends show an increase in the northern provinces of Sumatra, northern Kepulauan Riau, Kalimantan Barat, Sulawesi Tengah, and Papua, and a decrease in the southern regions of Sumatra (including Lampung), Java, Bali, and Nusa Tenggara, particularly during the dry season. Reduced rainfall during this period increases the demand for irrigation, disrupting planting and harvesting cycles. Additionally, intense rainfall events and flash floods are expected to increase everywhere, damaging crops, food storage, and distribution systems.

Indonesia's marine biodiversity, which supports fisheries and coastal protection, is also at risk due to declining fish populations, biodiversity loss, and shifts in species. Rising sea levels and more intense storm surges pose a growing threat to coastal, low-lying populated regions.

COUNTRY OVERVIEW

The Republic of Indonesia is the world's largest archipelagic state, consisting of more than 17,500 islands with over 81,000 kilometers (km) of coastline (**Fig. 1**). The country's islands are home to an extremely varied geography, topography, and climate, ranging from sea and coastal systems to peat swamps and montane forests.

FIGURE 1. Topography of Indonesia (in meters) (GMTED2010[1]) and Subnational Boundaries (ADM1 level, World Bank Cartography)

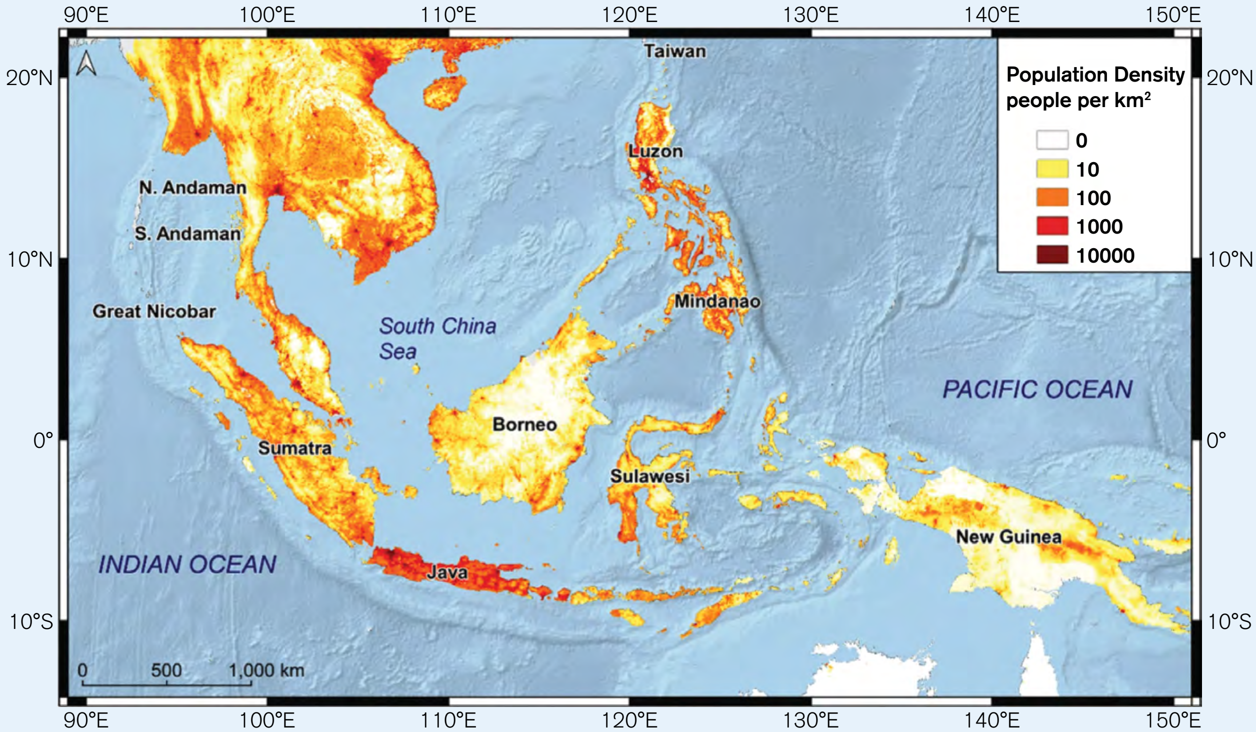


The western and southern archipelagos of Indonesia are located along the Ring of Fire, as evidenced by the presence of numerous mountain ranges. The Maluku region is also prone to continuous seismic activity, frequently experiencing earthquakes.

As of 2023, Indonesia had a population of over 281 million (World Bank Data), with more than half—approximately 150 million—residing on the island of Java (**Fig. 2**).

[1] Global Multi-resolution Terrain Elevation Data GMTED2010 https://pubs.usgs.gov/of/2011/1073/

FIGURE 2. Indonesia's Population Density from Reid and Mooney (2023)[2]



Map of population density. Density scale is logarithmic. Many coastal regions are densely populated, as are regions of high tsunami hazard and regions undergoing subsidence such as parts of Luzon, Java, and Sumatra. Population data is from WorldPop (2018)

In Indonesia, 29% of total employment is in agriculture[3], highlighting the sector's significance to the national economy. The agricultural industry is largely dominated by small family-run farms, which make up 93% of farmers and produce most of the country's staple foods like rice, corn, and cassava, along with cash crops such as palm oil, rubber, cocoa, coffee, spices, tea, coconuts, fruit, and tobacco. Although smallholders are diversifying their income through non-agricultural activities or self-employment, challenges remain in terms of productivity and access to technology. Rice is the main staple, and Indonesia ranks as the third-largest rice producer globally. Despite growth in food crop production, the country continues to rely on imports for grains, especially wheat, and other agricultural products like horticulture[4].

Indonesia's monsoon climate and even rainfall allow for the cultivation of similar crops across the country, though less than one-fifth of the land is used for farming[5]. Rice and cash crops dominate, with intensive cultivation

[2] Reid, J.A. and Mooney, W.D. Tsunami Occurrence 1900–2020: A Global Review, with Examples from Indonesia. Pure Appl. Geophys. 180, 1549–1571 (2023) https://doi.org/10.1007/s00024-022-03057-1 (Fig. 6, population data fromWorldPop, 2018)

[3] World Bank Development Indicators https://databank.worldbank.org/source/world-development-indicators

[4] Laura Schenck, Food and Agriculture Organization of the United Nations FAO, Small Family Farming in Indonesia - a country specific outlook, 2018 https://www.fao.org/family-farming/detail/en/c/1111082/

[5] Britannica https://www.britannica.com/place/Indonesia

concentrated in Java, Bali, Nusa Tenggara, and some parts of Sumatra and Sulawesi (Celebes). In Java, much of the northern coastal and central plains are dedicated to rice cultivation. In the drier eastern region of Java, crops like corn, cassava, sweet potatoes, and peanuts are commonly grown. Sumatra, especially the northeast, focuses on estate-raised cash crops like tobacco, rubber, palm oil, and coffee. Indonesia also has vast tropical forests, especially in Kalimantan and Papua, with a significant timber and palm oil industry. Aquaculture, including shrimp and milkfish farming, is grown in western Java and southern Sumatra, and open-sea fishing targets scad, tuna, and mackerel.

Palm oil is primarily produced in eastern Sumatra (especially Riau, 19%) and Kalimantan (Kalimantan Barat, 14%; Kalimantan Tengah, 13%)[6]. Rice is grown along the western-southern archipelagos, and Sulawesi Selatan and Kalimantan Barat, with southern Java being the largest producer (over 50%) and having three seasons of irrigated rice production. Corn is cultivated in Java, Sumatran Sumatera Utara and Lampung, Nusa Tenggara, and Sulawesi Selatan. Peanuts and soybeans are mainly grown in Java and Sulawesi. Rice, corn, peanuts, and soybeans are planted when rains intensify (Oct–Dec) and are harvested after the rain peaks (Feb–Apr). Rice can go to a second and third harvest. Corn and peanuts can also go through a second annual harvest.

Indonesia is highly vulnerable to climate change impacts, including extreme events such as floods and droughts, and long-term changes from sea level rise, shifts in rainfall patterns and increasing temperature. The country is also at high risk of earthquakes, volcanic activity and tsunamis.

Indonesia submitted its Third National Communication in 2017[7], the Third Biennal Update Report in 2021[8], and the Enhanced Nationally Determined Contribution in 2022[9]. These reports highlight land use change, peat, and forest fires as the primary sources of emissions, while emphasizing the need to prioritize the food, water, and energy sectors for adaptation and resilience. For a more comprehensive economic and development overview, refer to the Indonesia Country Climate and Development Report (2023)[10].

CLIMATE OVERVIEW

Data overview: Historically, observed data is derived from the Climatic Research Unit, University of East Anglia (CRU), CRU TS version 4.08 gridded dataset (data available 1901–2023) - stations data -, and from the ERA5 reanalysis collection from ECMWF (1950–2023).

[6] Foreign Agricultural Service, US Department of Agriculture (USDA). Indonesia profile, https://ipad.fas.usda.gov/countrysummary/default.aspx?id=ID

[7] Indonesia. National Communication (NC). NC 3. 2017 https://unfccc.int/documents/403577?

[8] Indonesia. Biennial update report (BUR). BUR3. 2021. https://unfccc.int/documents/403577?

[9] Enhanced Nationally Determined Contribution, 2022, https://unfccc.int/sites/default/files/NDC/2022-09/ENDC%20Indonesia.pdf?

[10] World Bank Group. 2023. Indonesia Country Climate and Development Report. CCDR Series https://openknowledge.worldbank.org/entities/publication/c6b1d872-f487-4579-be3a-3cb6ba55dffa

Indonesia is one of the rainiest regions in the world, experiencing frequent and intense rainfall throughout the year due to its tropical climate and location along the equator. This abundant rainfall supports rich biodiversity and lush landscapes but also presents challenges such as flooding, landslides, or soil erosion.

Indonesia's climate is shaped by the Monsoon System. The West Monsoon (October to April) brings moist air predominantly from the northwest, causing the wet season, while the East Monsoon (May to September) brings dry air from Australia, leading to the dry season, especially in the eastern and southern regions. The country's tropical climate is also influenced by its surrounding oceans, that bring humidity, and mountains, that collect rain. The northwestern regions experience rainfall year-round, while the southern parts have a shorter wet season with a greater contrast between wet and dry periods. Average monthly precipitation ranges from 40 mm in August to 345 mm in January (**Fig. 3**). The total yearly rainfall, on average around 3000 mm, is heaviest in the mountains, exceeding 6000 mm in Papua's highlands, and lowest in the plains, with as little as 1000 mm in some southern islands (**Fig. 4**).

FIGURE 3. Monthly Historical Climatology of Average Temperature (minimum, average, and maximum) and Total Precipitation (1991–2022) for Indonesia (CRU dataset)

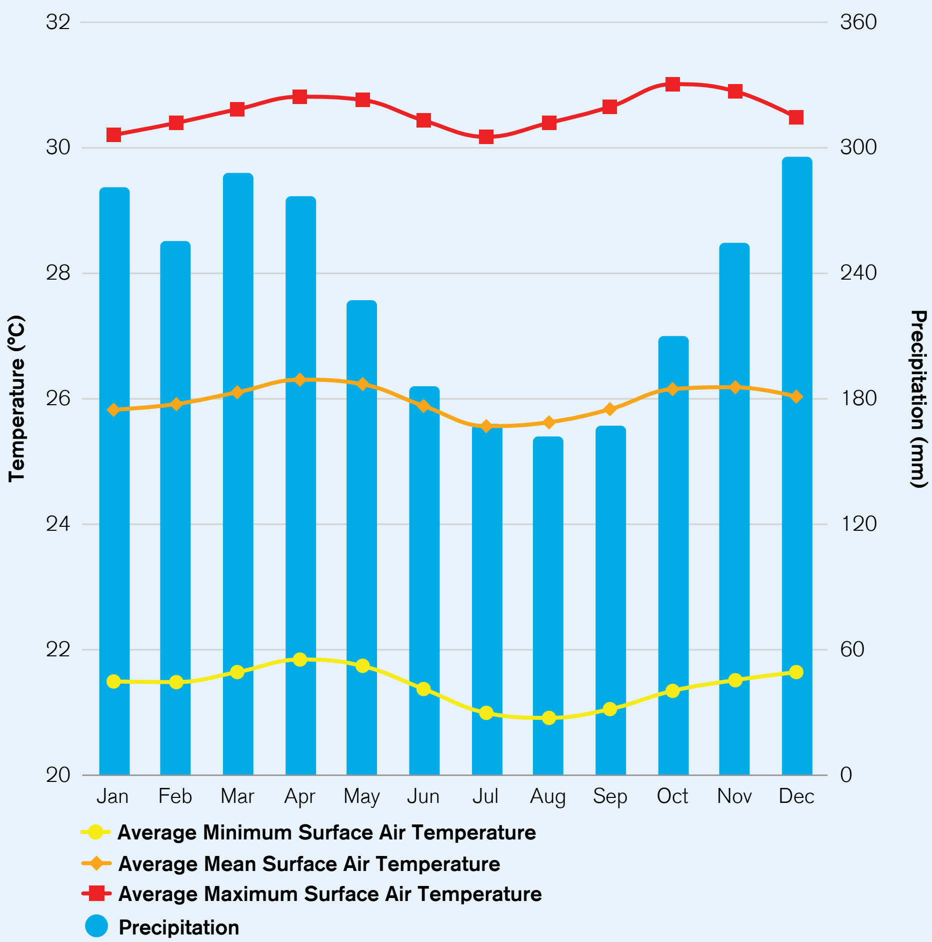


FIGURE 4A. Historical Averaged Surface Air Temperature (1991–2020) Across Indonesia (ERA5 dataset). ADM1 Subnational Boundaries are Overlayed. Note the Lower Temperatures Along Mountain Ranges.

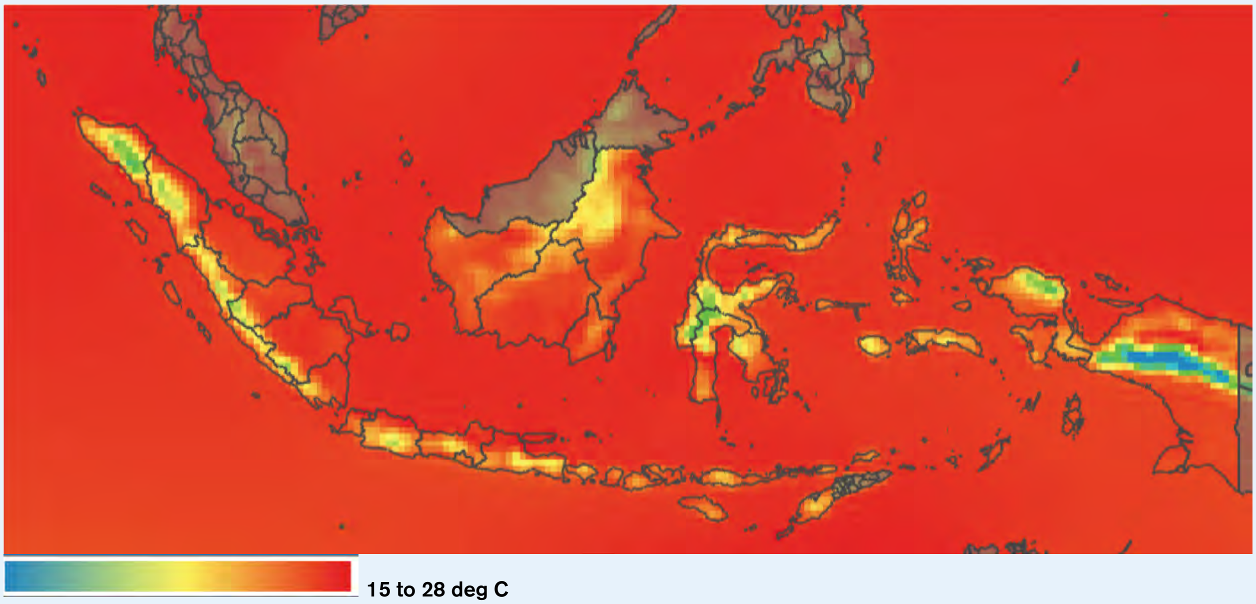
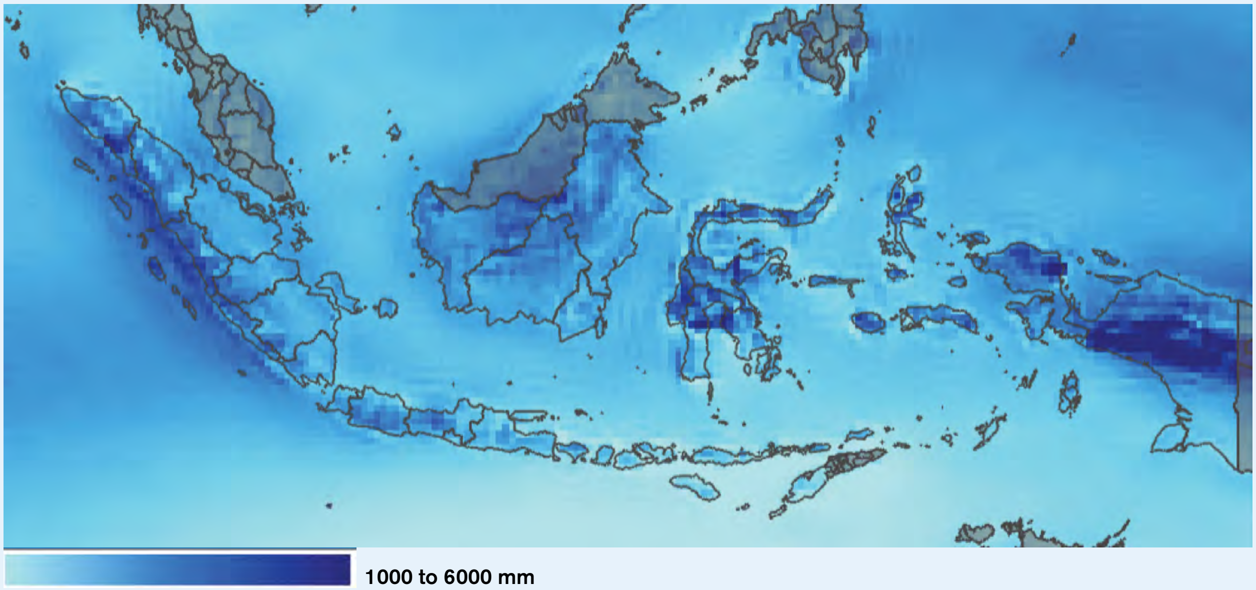


FIGURE 4B. Historical Annual Total Precipitation (1991–2020) Across Indonesia (ERA5 dataset). ADM1 Subnational Boundaries are Overlayed. Note the Higher Precipitation Along Mountain Ranges, and Lower Overall Rain Towards the Southern Islands.



Like many other countries with a tropical climate, there is little seasonal variation in temperature, ranging between 25 and 26°C on average. The minimum temperatures are between 20 and 22°C. The maximum temperatures stay around 30°C all year round. The average temperature is highest in the sea-level plains, around 28°C, and lowest in the mountains, dropping below 15°C in Papua's highlands. Temperatures are slightly higher towards the end of the Western Monsoon (April and May) and again towards the end of the Eastern Monsoon (Oct), during the transition seasons.

Tables A1 and A2 present the spatially aggregated historical temperature and precipitation values across subnational districts.

Indonesia's climate is influenced by several cyclical climate phenomena, most notably the El Niño Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the Madden-Julian Oscillation (MJO). These factors significantly impact precipitation and water availability on inter-annual, and inter-decadal timescales, leading to droughts, reduced groundwater availability, and major consequences for agriculture and food security. Most notably, El Niño (warm phase) leads to drier-than-normal conditions, increasing the risk of droughts and wildfires, and it can also disrupt the monsoon season, affecting agriculture and water resources. La Niña (cold phase) brings wetter-than-normal conditions, causing flooding and increased rainfall.

TEMPERATURE AND PRECIPITATION HISTORICAL AND PROJECTED TRENDS

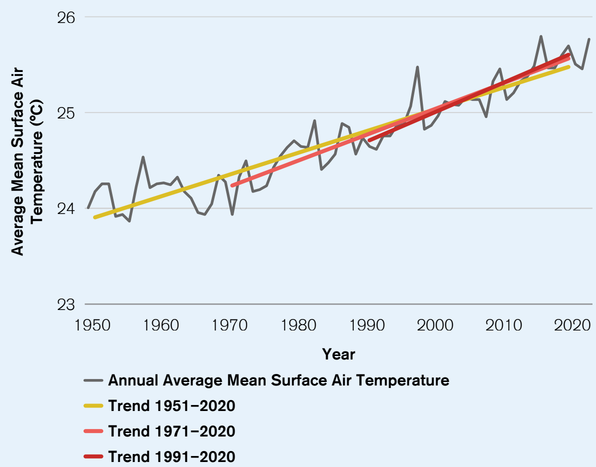
Data overview: Historical observed data is derived from the ERA5 reanalysis collection from ECMWF (1950–2023). Modeled climate data is derived from CMIP6, the Coupled Model Intercomparison Project, Phase 6. This risk profile focuses primarily on SSP3-7.0[11], which projects a doubling of CO_2 emissions by 2100, a global temperature change of approximately 2.1°C by mid-century (2040–2059) and 2.7°C (likely 2.1°C to 3.5°C) by the end of the century (2080–2099), with respect to pre-industrial conditions (1850–1900).

[11] Climate scientists may prioritize SSP4.5 and SSP8.5 to cover a range of potential futures, but SSP8.5 is frequently avoided in policy discussions due to its extreme nature. SSP3-7.0 is understood as a balanced compromise—sufficiently pessimistic yet in line with current policies. Note that patterns of change are generally consistent across scenarios, differing only in timing and impact intensity. For example, impacts projected under SSP3-7.0 by 2070 (2.8°C warming) are projected to occur by 2060 under SSP5-8.5, given the same level of warming. This approach allows scenarios to be translated by focusing on the warming signal rather than specific timelines. Please see the attached tables, which illustrate the relationship between warming levels and future periods for different scenarios. For more information see: IPCC AR6 https://data.ceda.ac.uk/badc/ar6_wg1/data/spm/spm_08/v20210809/panel_a

Historical Temperature Changes

Over the past few decades, mean surface air temperatures have risen significantly, with a trend of 0.23°C per decade from 1951 to 2020 (the last 70 years), 0.28°C per decade from 1971 to 2020 (the last 50 years), and 0.32°C per decade from 1991 to 2020 (the last 30 years) (ERA5, **Fig. 5**). The temperature increase has been most pronounced in Kalimantan, Sulawesi, and Papua, likely due to their large land masses and extensive areas far from the sea (**Table A1**).

FIGURE 5. Indonesia's Annual Mean Surface Air Temperature Time Series and Decadal Linear Trends for Different Periods Between 1951 and 2020 as Indicated, ERA5 Data

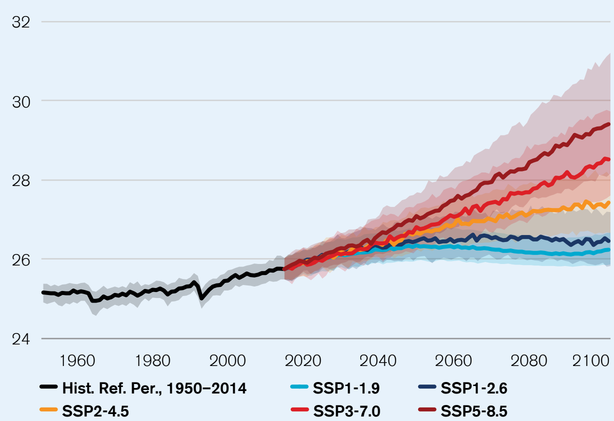


Projected Temperature Changes

Indonesia's temperatures are projected to increase further into the future for all the scenarios (**Fig. 6**). Under SSP3-7.0, the mean air surface temperature nationwide increases from 25.57°C during the historical reference period of 1995–2014 to 26.73°C (26.32°C, 27.39°C) for the period 2040–2059. The median temperature anomaly from the historical period to mid-century (2040–2059) is 1.18°C, which is below the global average. The projected temperature increase from 2000 to 2050 is 0.25°C per decade under SSP3-7.0, matching the warming rate observed in the past 50 years (**Table A3**).

This warming is expected to occur at similar rates for both minimum and maximum temperatures across provinces, although it may be slightly higher in eastern Java, with up to 0.28°C per decade in Jawa Tengah. From 2050 to 2100, the warming rate is expected to increase to 0.35°C per decade under SSP3-7.0, with the highest warming of 0.38°C per decade projected for Riau (in Sumatra).

FIGURE 6. Projected Average Mean Surface Air Temperature for Different Climate Change Scenarios as Labeled, Along with the 10th–90th Percentile Dispersion Across Models

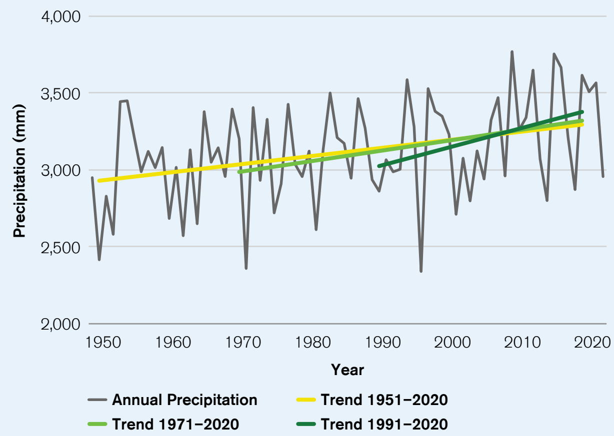


The minimum temperature nationwide increases from 22.19°C during the historical reference period to 23.4°C (22.99°C, 24.02°C) for 2040–2059. Maximum temperature increases from 28.94°C to 30.04°C (29.6°C, 30.77°C) for 2040–2059. Projected warming under SSP2-4.5 and SSP1-2.6 is lower, and under SSP5-8.5, higher.

Historical Precipitation Changes

Historical annual precipitation oscillates between 2250 and 3750 mm (ERA5), exhibiting high variability, with a significant but small increase in precipitation during the last 70 years: 51 mm/decade (from 1951 to 2020), 66.95 mm/decade (1971–2020), and 125 mm/decade (1991–2020), which represent a 1.6% increase (with respect to 1991–2020 average), a 2% increase, and a 3.9% increase (**Fig. 7, Table A2**).

FIGURE 7. Indonesia's Annual Precipitation Time Series and Decadal Trends for Different Periods Between 1951 and 2020 as Indicated, ERA5 Data



Precipitation has increased significantly in the northern provinces of Sumatra, with a maximum of 4.8% increase per decade (128 mm per decade) in Riau (1971–2020 with respect to 1991–2020). It has also increased significantly in the northern Kepulauan-Riau, Kalimantan Barat, Sulawesi Tengah and Papua. Meanwhile, the southern Sumatran Lampung, the full island of Java, Bali, and Nusa Tenggara provinces experienced a decrease in precipitation, driven by decreases from June to November (drier season), although this decrease is not significant there, as it gives a clue to how the climate is changing, but is not yet well distinguished from the natural variability in the region.

In the southern provinces, decreased rainfall during the dry season raises the need for irrigation during the third rice cropping cycle (June to October, with June and July as the planting months). This can also lead to delays and disruption in planting and harvesting for subsistence crops like corn, peanuts, soybeans, and the main rice cycle, which typically begins at the start of the wet season[12].

Projected Precipitation Changes

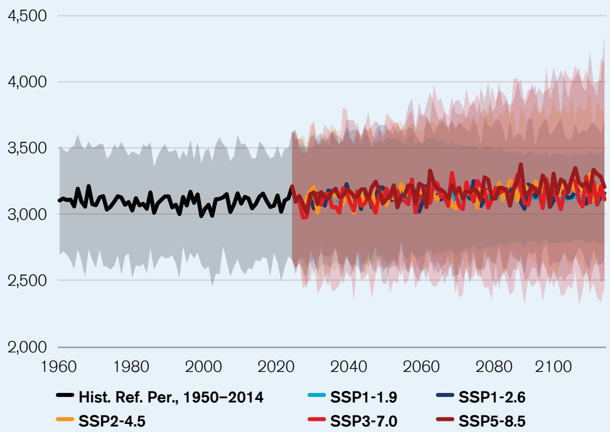
Under SSP3-7.0, Indonesia's average annual precipitation is predicted to change nationwide from 3091 mm (2884 mm, 10th percentile, 3286 mm, 90th percentile) during the historical period (1995–2014, historical scenario) to 3151 mm (2744 mm, 3583 mm) for 2040–2059, which represents a median anomaly of 66 mm or 2.1%, similar to what was observed during the historical period (**Fig. 8**). However, regional differences exist (**Table A5**).

Total yearly precipitation is projected to increase in the northern regions of Sumatra (northern provinces), Kalimantan, Sulawesi, Maluku, and Papua, consistent with historical trends. The highest increase is expected in eastern Maluku and Papua, with Papua showing a 5.6% rise by 2040–2059 compared to 1995–2014. In contrast,

[12] Foreign Agricultural Service, US Department of Agriculture (USDA). Indonesia profile, https://ipad.fas.usda.gov/countrysummary/default.aspx?id=ID

precipitation is expected to decline slightly (less than a 2% decrease by 2050) in the southwestern islands of Sumatra (except for the districts northern Nangroe Aceh Darussalam and Sumatera Utara), Java, Bali, and Nusa Tenggara, as observed historically. These areas typically experience lower precipitation. The decrease is mainly expected between September and November, during the transition to the rainy season, which suggests a delay in rainfall and a shorter rainy season, similarly affecting rice and subsistence crops as during the historical period. The Sumatran provinces of Sumatera Utara, Riau, Jambi, Sumatera Selatan, and Bangka Belitung, along with Kepulauan Riau, will also see a decline around March (end of the rainy season), in addition to the decrease in October, signaling a shortening of the rainy season at both ends. The northern Sumatra regions of Nangroe Aceh Darussalam and Sumatera are projected to experience a slight decrease in precipitation around March but an overall increase in annual precipitation.

FIGURE 8. Projected Annual Precipitation for Different Climate Change Scenarios as Labeled, Along with the 10th–90th Percentile Dispersion Across Models



IMPACTS OF A CHANGING CLIMATE

Hot Days

Hot days lead to higher energy demand for cooling, putting pressure on power grids and increasing costs. In agriculture, extreme heat can lower crop yields, damage plants, and disrupt crop cycles, particularly for rice, corn, and soybeans. It also raises water demand due to increased evaporation and stresses livestock[13], impacting food production and supply. Elevated temperatures create favorable conditions for the proliferation and spread of pests, particularly damaging palm oil plantations.

In the future, the number of hot days (Tmax > 30°C) is projected to increase significantly, throughout all year in northern regions and more so during the rainy season in the southern islands, driven by rising temperatures. During the historical period (1995–2014), there were 133 (118, 147) hot days per year (CMIP6 models). Under the SSP3-7.0 scenario, this number is expected to rise to 203 (172, 244) days per year during 2040–2059, and by the end of the century (2080–2099), it could reach 278 (232, 321) days per year. The number of days with hot temperatures is historically highest in the eastern regions of Sumatra - Riau, Jambi, and Sumatera Selatan, and also

[13] See for example Thornton et al. (2021). Increases in extreme heat stress in domesticated livestock species during the twenty-first century. Global Change Biology, Volume 27, 22, Volume27, Issue22, 5762–5772, DOI: https://doi.org/10.1111/gcb.15825

in southern Lampung, where this number is around or more than 200 days per year. Also, in the southern regions of Kalimantan, Kalimantan Barat, Kalimantan Tegah and Kalimantan Selatan, they suffer 200 hot days per year. These are regions at low level but that go inland far from the moist coast that protects from high temperatures. By 2050, Riau, Sumatera Selatara, Dki Jakarta and Kalimantan Tengah are projected to experience 300 hot days or above per year. The highest increases will be in Banka Belitung and Daerah Istimewa Yogyakarta, which will more than double the number of hot days, adding around 125 days more hot days by 2040–2059 compared to the approximately 100 days during the historical period (1995–2014). This represents around one more month per decade (**Table A4**).

Indonesia is also expected to experience extreme hot days (Tmax > 35°C) throughout the 21st century. At the national level, extreme hot days are projected to occur by mid-century, with an average of 2.5 (0.4, 8.5) days, peaking at 11 days in Sumatera Selatan. By the end of the century, this number could rise to 20 (3, 72) days per year. Next, we examine the percentage of the population at high health risk due to extremely hot days (**Table A6**). For the calculation of population exposure, high-risk areas are locations where the 50-year return level[14] of the annual number of days with maximum temperatures exceeding 35°C is greater than 30[15]. The population exposure in the historical period (1975–2024, centered on 2000) is minimal throughout the country (1.8%), but it rises to 11% by 2035 (2010–2059) and 38% by 2075 (2050–2099). By 2035, 64% of the population in Sumatera Selatan (southeast Sumatra) will be exposed to extreme heat, up from just 6% during the historical period. In Jawa Timur, exposure is projected to reach 21%, while in Kalimantan Tengah and Kalimantan Selatan, it will be 27% and 22%, respectively. By 2075, all provinces in Kalimantan are expected to experience severe exposure, with more than 60% of the population affected. The low-lying provinces of eastern Sumatra will also face high exposure by 2075, with Riau reaching 92%. In Java, the exposure will reach more than 50% in Banten and Dki Jakarta.

Hot (Tropical) Nights

Night temperatures in Indonesia are projected to rise rapidly, impacting both human health and agriculture. Hot nights are typically experienced in low-lying, humid areas, especially along the coast, on small islands, and regions far from the mountains. Key Indonesian crops most affected by high night temperatures, particularly those above 26°C, include rice, corn, and soybeans.

Historically (1995–2014), the country experienced only 10 (7, 13) tropical nights per year (CMIP6 models, Tmin > 26°C). By 2040–2059, this is projected to increase to 43 (26, 76) nights annually. This is a median anomaly of 33 more nights by mid-century (an additional month) compared to the historical period. Tropical nights at a low threshold (Tmin > 23°C) are also projected to rise, from 170 (150, 186) days in the historical period (over 5.5 months) to 246 (219, 271) days by mid-century (over 8 months). All regions are affected by an increase in night temperatures (**Table A4**).

[14] A 50-year return level refers to an event that is expected to occur, on average, once every 50 years.

[15] Population dataset: Gridded Population of the World, Version 4: GPWv4; Revision 11, Dec 2018. For each pixel (at approximately 25 km resolution), the return level for a given return period is calculated by fitting a Generalized Extreme Value (GEV) distribution to the time series. A pixel is classified as "too risky" (1) if the return level exceeds the specified threshold, and "not too risky" (0) otherwise. The reported population exposure represents the percentage of the total population in each region that is exposed to risk (1).

Historically, low-lying small islands Banka Belitung and Kepulauan Riau experience hot nights with Tmin > 23°C almost every day of the year, and 65 and 188 days annually with Tmin > 26°C, respectively. By 2050, these numbers are projected to rise to 225 and 326 days, with anomalies of 159 days and 137 days, respectively, the highest in Indonesia.

In Sumatra, the eastern low-lying regions of Riau, Jambi, Sumatera Selatan, and southern Lampung currently experience around 200 days per year with Tmin > 23°C. By 2050, this number is expected to increase, with Riau and Jambi seeing a maximum rise of over 90 nights more. Additionally, these provinces, Riau and Jambi, are projected to experience around 40 nights annually with Tmin > 26°C by 2050.

The western part of Java, including Banten, currently experiences 257 hot nights per year (Tmin > 23°C). By 2050, this will rise to 330 hot nights, an increase of 71 days. Nights with temperatures above 26°C (Tmin > 26°C) will grow from around half a month historically to 102 nights by 2050, an anomaly of 85 more days. The southeastern regions of Jawa Timur, Bali, and Nusa Tenggara will experience over two months of very hot nights (Tmin > 26°C) by 2050.

Maluku Utara and Maluku are projected to experience over four months each year with minimum temperatures above 26°C by 2050—125 and 142 days, respectively—representing some of the largest increases, with anomalies of about three months compared to the 1995–2014 period.

Next, we examine the percentage of the population at high health risk due to hot nights (**Table A6**). For the calculation of population exposure, high-risk areas are locations where the 50-year return level of the annual number of days with night temperatures > 26°C is greater than 30. At the national level, exposure to dangerous levels of tropical nights (Tmin > 26°C) is projected to rise, from 8.5% of the population during the historical period to 26.4% by 2035, and 64.2% by 2075. Historically (2000), 100% of the population in Kepulauan Riau was already exposed to hot nights, with 64% in Bangka Belitung and 48.5% in Maluku. These low-lying, coastal provinces, accustomed to high night temperatures, will face even hotter nights. By 2035, most provinces will see significant exposure, with Sumatera Selatan reaching 62% (up from 0.2% historically), Nusa Tenggara Barat at 60.7% (up from 11.7%), and Kalimantan Tengah at 67.4% (up from 0.4%). By the end of the century, Riau, Bangka Belitung, Dki Jakarta, and Kepulauan Riau will experience over 95% exposure, facing increased risks to both health and agriculture.

Humid Heat

The Heat Index is a measure of perceived temperature that combines both air temperature and humidity in the shade[16]. When both temperature and humidity are high, the Heat Index rises, significantly increasing the risk to human health. In these conditions, the body's ability to cool itself through sweating becomes impaired, which can lead to heat-related illnesses or even fatalities. For agriculture, the combination of heat and humidity can also cause crops to spoil more rapidly.

[16] Heat Index as defined by US-National Weather Service - Steadman R.G., 1979: The assessment of sultriness, Part I: A temperature-humidity index based on human physiology and clothing science. J. Appl. Meteorol., 18, 861–873, doi: http://dx.doi.org/10.1175/1520-0450

The number of days with a Heat Index of 35°C or higher is expected to become significantly more prominent by the end of the 21st century, particularly during the rainy season. This increase will be most noticeable in March to May (towards the end of the rainy season) and in October–November (at the start of the rainy season). In southern regions, the increase will be primarily confined to the rainy season, while in Sumatra, the highest increase is expected to occur in May.

During the historical period (1995–2014), there were only a few days with a Heat Index > 35°C (approximately 2.5 days). However, by 2040–2059, this number is projected to rise to 31.5 (9, 86) days (about a month). From 2051 to 2100, the number of days with a Heat Index > 35°C is expected to increase by an average of 28.1 days (a month) per decade (**Table A4**).

By mid-century (2040–2059), regions like Riau, Sumatera Selatan, Bangka Belitung, and Kepulauan Riau will experience over two months of high Heat Index (Heat Index > 35°C), with the following number of days compared to the historical period: 93 days (up from 4 days) in Riau, 65 days (up from 11 days) in Sumatera Selatan, 63 days (up from none) in Bangka Belitung, and 65 days (up from none) in Kepulauan Riau. The risk is projected to intensify further in the latter half of the 21st century. For example, from 2050 to 2100, areas such as Riau, Jambi, Sumatera Selatan, Bangka Belitung, Dki Jakarta, Kepulauan Riau, and Kalimantan Tengah are expected to see an increase of 40 or more additional days with a Heat Index above 35°C per decade under the SSP3-7.0 scenario.

Next, we examine the percentage of the population at high health risk due to increased humid heat (**Table A6**). High-risk areas are locations where the 50-year return level of the annual number of days with heat index exceeding 35°C is greater than 20—a threshold considered particularly dangerous for health. During the historical period (centered at 2000), population exposure to extreme heat was minimal, with only significant exposure in Sumatera Utara (26%) and Riau (36%). However, this exposure is projected to increase rapidly, reaching 45% by 2035 and 77.5% by 2075. By 2035, the regions most affected will include Sumatra (with up to 95% exposure in Riau), western Java (over 75%), Kepulauan Riau (100%), Kalimantan (more than 90%), and Sulawesi Selatan and Sulawesi Tengah (52% and 62%, respectively). By the end of the 21st century (2075), most areas will be affected, with the lowest exposure in Sulawesi Utara, which will experience 37% exposure.

Additionally, Indonesia's population is expected to face dangerous wet-bulb temperatures—another measure of extreme heat and humid conditions, which are particularly hazardous for outdoor workers[17]. By 2035, 17% of the population will be exposed to hazardous heat conditions, with the highest exposure in eastern and southern Sumatra and Kalimantan (**Table A6**). By 2075, nearly the entire population in these areas will be affected. Overall, 71% of Indonesia will experience exposure, with most regions seeing at least 50% of their population affected. Risk areas associated to high wet bulb temperatures are defined as locations where, the 50-year return level of the annual number of days with wet-bulb temperature exceeding 27°C is greater than 15.

[17] Wet Bulb Temperature formulation by Stull (2011) - Stull R., 2011: Wet-bulb temperature from relative humidity and air temperature. J. Appl. Meteorol. Climatol., 50(11), 2267–2269, doi: 10.1175/JAMC-D-11-0143-1

Drought

Drought conditions can severely disrupt the growth cycle of crops, leading to crop collapse and reduced yields, especially in places with poor irrigation systems. This not only affects agricultural productivity but also the livelihoods of small farmers, particularly those who rely on their crops for access to nutritious food. As a water-intensive crop, rice is highly susceptible to drought, especially during the critical flowering and grain-filling stages. Corn is particularly sensitive to drought during the pollination stage. Soybeans are very sensitive to water stress, particularly during the flowering and pod-setting stages. Drought conditions can cause reduced pod formation, fewer seeds, and lower overall yields.

The historical ERA5 data shows no significant changes in the yearly maximum number of consecutive dry days (CDD) (<1 mm of daily rain) on average at the national level (**Fig. 9a**). CDD historical variability ranges between 5 and 25 days. The driest provinces, with the longest droughts, are the eastern regions of Java (Yogyakarta and Jawa Timur), which experience almost 40 days of continuous drought per year on average, and Nusa Tenggara Barat and Timur, with around 50 days of CDD. Most other regions have fewer than 20 days of CDD on average (**Table A2**).

However, in the driest regions of Indonesia, the southern provinces, the maximum number of consecutive dry days has significantly increased over time. This trend corresponds with the decrease in precipitation, exacerbating the challenges faced by local communities and farmers. These areas are particularly vulnerable due to a high concentration of small-scale, intensive farms that depend on consistent rainfall but often lack resources for advanced irrigation or drought-resistant crops. Extended dry periods reduce water availability for irrigation, directly affecting the cultivation of staples like rice, corn, and legumes.

Daerah Istimewa Yogyakarta in Java has experienced the largest increase, with 5.63 more CDD per decade, reaching 40 dry days on average from 1991 to 2020. Jawa Timur has seen an increase of 4 CDD per decade, totaling 38 dry days during the same period. In Nusa Tenggara Barat and Timur, the increase is also above 4 days per decade, with an average of 46 and 51 CDD, respectively, from 1991 to 2020. In Sumatra, Sumatera Selatan has seen a significant increase in dry days, rising by 1 day per decade from 1971 to 2020, reaching an average of 13 dry days between 1991 and 2020. In Lampung, the increase is 0.9 days per decade, with an average of 11 dry days from 1991 to 2020. In the future, the CMIP6 models project a slight increase in the length of consecutive dry days (CDD), although this trend is not robust. However, the increase is expected to be more significant in the southern regions, like the historical period, with a median anomaly exceeding 2 days between 2040–2059 compared to 1995–2014 in Daerah Istimewa Yogyakarta, Jawa Timur, and Nusa Tenggara Barat. It's important to note that CMIP6 models consistently estimate lower historical values of Consecutive Dry Days (CDD) compared to ERA5, with a median difference of 34% across provinces. Since CMIP6 starts from a lower historical baseline, the absolute future values of CDD may also appear lower. This discrepancy should be considered when interpreting future projections.

For the calculation of population exposure, risk areas for extended droughts are defined as regions where, the 50-year return level of the annual maximum number of consecutive dry days (with less than 1 mm of rainfall daily) exceeds 90. Due to Indonesia's generally high humidity, long droughts are not expected to amount to a considerable level at the national level. However, the population exposed to this threshold, which is currently 10% at the national level, is projected to double by 2075, reaching 20% under SSP3-7.0 (**Table A7**).

Only a few regions are and will be affected by these conditions. In Java, the exposure in Jawa Barat is expected to rise from less than 1% in 2000 to 7% by 2035 and 14% by 2075. Jawa Tengah will increase from less than 1% in 2000 to 5% in 2035, and 32% by 2075. Daerah Istimewa Yogyakarta will experience an increase from 13% in 2000 to 21% in 2035, reaching 26.5% by 2075. Jawa Timur, which already has high population exposure, will see an increase from 51.5% to 59% by 2075. In Nusa Tenggara, both Nusa Tenggara Barat and Nusa Tenggara Timur are expected to rise from 28.5% to 43% by 2035 (and remain at that level by 2075), and from 49% to 52% by 2035 and 56% by 2075, respectively.

The historical yearly maximum number of consecutive wet days (>1 mm per day) — CWD, indicating the length of the most robust part of the rainy season — is lowest in Nusa Tenggara and Sumatra's Riau, with around 55 days of continuous rain. Kepulauan Riau also experiences around 52 CWD, likely due to the lack of mountainous terrain in these areas. In contrast, the number of CWD increases significantly in other parts of the country, with up to 80 days or more in Sulawesi and up to 98 days in Papua.

On average, across Indonesia, there has been a significant decrease in CWD, with a reduction of –2.23 days per decade from 1971 to the present (**Fig. 9b, Table A2**). A decrease in CWD in absence of large precipitation changes generally indicates greater unpredictability. This trend of decreasing wet days is observed across most regions, but it is particularly significant in southern Sumatra. In Bengkulu, for example, there has been a maximum decrease of 5.8 days per decade, reaching an average of 67 CWD. In Kalimantan, significant decreases are also observed, with more than a 3-day reduction per decade in Kalimantan Tengah and Kalimantan Selatan. Lastly, Sulawesi Barat has experienced a decrease of nearly 4 days per decade in its CWD. Looking ahead, the CMIP6 models project a decrease in consecutive wet days (CWD) across all regions, although this trend is not consistent across models. The largest reductions are expected in Kalimantan, aligning with historical trends, with a maximum anomaly of −7.9 CWD by mid-century in Kalimantan Timur. It is important to note that the CMIP6 estimate of historical CWD is consistently higher than the ERA5 estimate.

FIGURE 9A. Indonesia's Historical Annual Maximum Number of Consecutive Dry Days, Along with Decadal Trends for Various Periods Between 1951 and 2020, Based on ERA5 Data

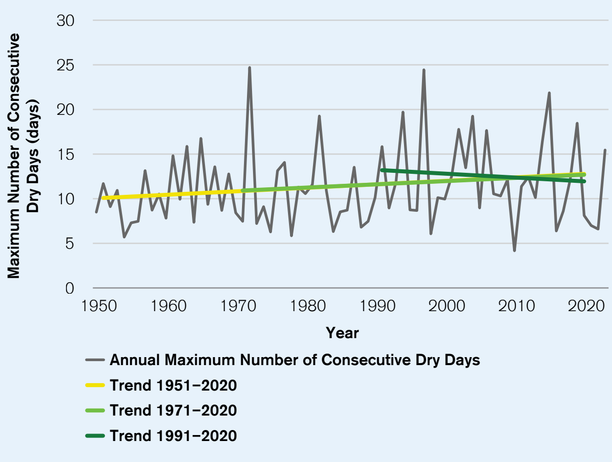
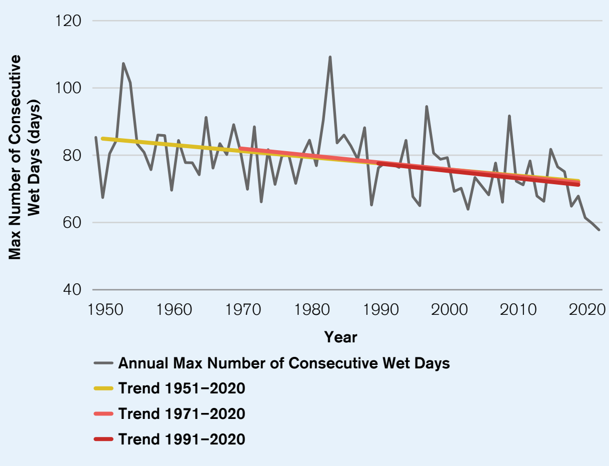


FIGURE 9B. Indonesia's Historical Annual Maximum Number of Consecutive Wet Days, Along with Decadal Trends for Various Periods Between 1951 and 2020, Based on ERA5 Data



Extreme Precipitation

Intense precipitation events are expected to become more frequent, with their return periods decreasing. In a warmer world, the potential of air to carry moisture goes up, and thus the potential for heavier precipitation goes up. Intense precipitation events, characterized by the largest single-day event during the historical period, will likely recur more frequently (e.g. the return period will decrease, **Table 1**), which can negatively affect the flooding risk, and be dangerous for infrastructure, human safety, or agriculture. In Indonesia, flash floods and landslides will become more frequent due to intense rain events especially when combined with anomalously dry conditions.

TABLE 1. Future (2035–2064) and (2070–2099) Return Period (years) for Extreme Precipitation Events that Correspond to the Return Levels for the Largest Single-day Event During the Historical Period (1985–2014) for SSP3-7.0. Change in Future Exceedance Probability Expressed as Change Factor for Extreme Precipitation Events that Correspond to the Return Levels for the Largest Single-day Event During the Historical Period (1985–2014) for Future (2035–2064) and (2070–2099) SSP3-7.0.

Time Period	Historical Return Period (1985–2014, center 2000)					
1985–2014 center 2000	5-yr	10-yr	20-yr	25-yr	50-yr	100-yr
	Return Level (mm) - Median (10th, 90th)					
1985–2014 center 2000	76.44 (44.53–137.21)	87.00 (49.83–161.40)	97.87 (55.05–188.53)	101.39 (56.72–197.87)	112.19 (61.90–231.53)	123.05 (67.09–270.40)
	Future Return Period (years) - Median (10th, 90th)					
2035–2064 center 2050	3.30 (1.94–5.42)	6.19 (3.26–11.38)	11.69 (5.48–24.04)	14.37 (6.47–30.56)	27.18 (10.85–65.12)	51.40 (18.14–135.60)
2070–2099 center 2085	2.22 (1.17–4.26)	3.86 (1.77–8.44)	6.76 (2.65–17.00)	8.09 (3.01–21.40)	14.17 (4.47–44.30)	25.05 (6.57–87.52)
	Change in Future Annual Exceedance Probability (change factor) - Median (10th, 90th)					
2035–2064 center 2050	1.54 (0.86–2.42)	1.65 (0.81–2.87)	1.76 (0.77–3.42)	1.79 (0.76–3.63)	1.91 (0.71–4.35)	2.04 (0.67–5.23)
2070–2099 center 2085	2.35 (1.07–4.25)	2.72 (1.07–5.52)	3.14 (1.06–7.24)	3.29 (1.06–7.93)	3.80 (1.05–10.54)	4.36 (1.07–14.12)

Fractional change above 1 indicates increased probability and decreased return period. for example, a fractional change of 1.76 indicates a 76% increase in the probability of suffering 20-year extreme precipitation events in the future, or 1.76 more likely.

Extreme precipitation events with return periods of 100 years are projected to occur 2 times more frequently by mid-century (2035–2064) under the SSP3-7.0 scenario, compared to historical data from 1985–2014. This means that what was historically a 100-year event will occur approximately every 51 years in the future. In Indonesia, a historical 100-year precipitation event corresponds to 123 mm of rain falling in a single day—an amount that, historically, has been observed over an average of around 12 days during the rainiest season (Dec–Feb). Similarly, 50-year return events are projected to increase 1.91 times, 25-year events 1.79 times, and 10-year events 1.65 times, 65% more often, by mid-century. However, there is significant uncertainty in these projections (**Table 1**). By the end of the 21st century, 100-year rare events are projected to occur 4.36 times more frequently, happening every 25 years (median value) instead of every 100 years. Similarly, 20-year, 25-year, and 50-year events are expected to occur at least three times as often—3.14, 3.29, and 3.80 times more frequently, respectively.

As a result, almost the entire population (97%) will be exposed to dangerous levels of extreme rainfall by 2075, compared to 88.5% during the historical period. Risk areas as defined as locations where the 25-year return level of the annual largest 5-day precipitation exceeds 130 mm. Exposure is high in most places already historically. There are few exceptions. Lampung, Riau, Jami, and Sumatera Selatan are projected to experience to experience a population exposure rise from 2000 to 2075 of 52% to 82%, 62% to 96%, 66% to 90%, and 35% to 85%, respectively. In Kalimantan, Kalimantan Tengah goes from 39% to 88%, Kalimantan Selatan goes from 30% to 72%, and Kalimantan Timur goes from 15% to 61% (**Table A7**).

Risk areas can also be defined as locations where, the 50-year return level of the annual number of days with precipitation greater than 50mm exceeds 5. Historically (central year, 2000), the population exposed to these conditions is higher than 30% in areas such as Bali (67%), Sumatera Barat (49%), Sulawesi Barat (43%), Papua (33%), Jawa Barat (32%), Nusatenggara Barat (32%), and Sulawesi Selatan (32%). By 2075, exposure is projected to increase and be highest in Bali (79%), Sumatera Barat (75.5%), and Sulawesi Barat (64%). Papua's exposure will increase to 44%, while there will be no increase in Jawa Barat. In Nusatenggara Barat, exposure will rise to 56%, and in Sulawesi Selatan, it will increase to 42%. Additionally, by 2075, at least one-third of the population in Nangroe Aceh Darussalam, Bengkulu, Jawa Tengah, Sulawesi Tengah, Sulawesi Utara, Maluku Utara, and Papua Barat will be exposed.

Sea Surface Temperatures

The oceanic Southeast Asia region, with Indonesia located in its center, has historically experienced an average sea surface temperature ranging from 27.9°C to 29.5°C between 1995 and 2014 (p10, p90, CMIP6 models[18]), with a median of 28.6°C. With climate change, the region is already experiencing more frequent marine heatwaves. Under the SSP3-7.0 scenario, sea surface temperatures are projected to increase by 0.5°C (with a range of 0.3°C at the 10th percentile to 0.7°C at the 90th percentile) in the near term (2021–2040), 1.0°C (0.8°C to 1.3°C) by mid-century (2041–2060), and 2.2°C (1.7°C to 2.8°C) by the end of the century (2081–2100), relative to recent historical averages (1995–2014), which are already higher than sea temperatures during pre-industrial conditions. This temperature increase is expected to be similar throughout the year.

Due to the inertia of the oceans, these temperature increases are unlikely to reverse anytime soon. A rise of more than 1°C is expected to have catastrophic consequences for fisheries, biodiversity, and coral reefs, which are especially vulnerable to even small increases in sea temperature.

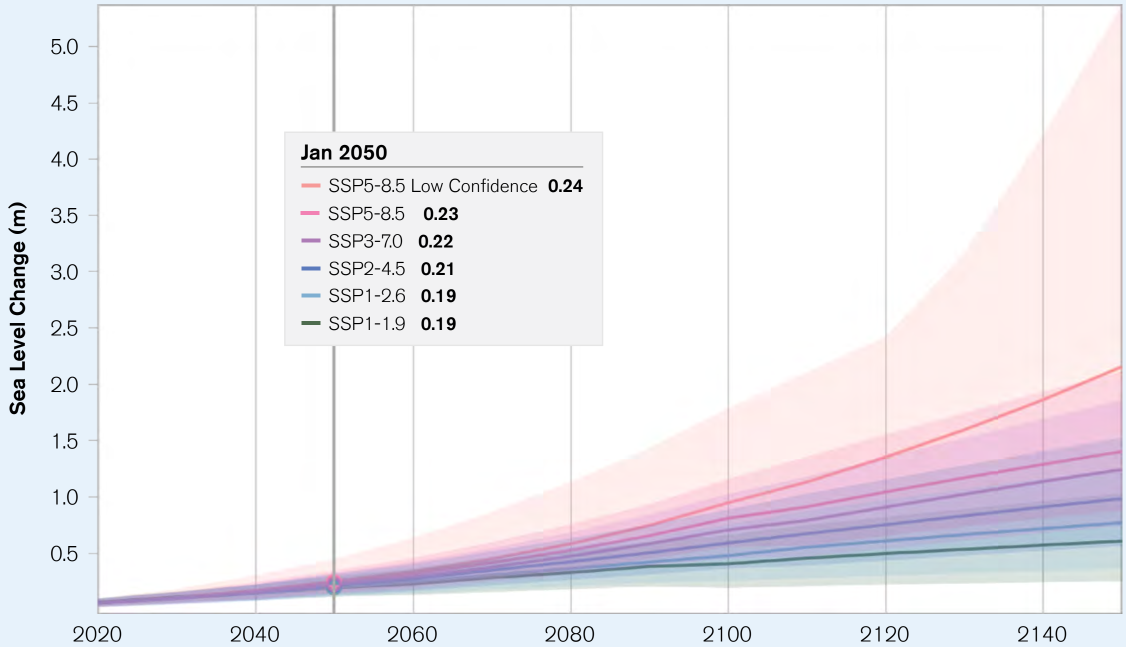
Sea Level Rise

According to altimetry (satellite) data, sea level rose 13 centimeters total from 1993 to present in Indonesia[19]. Under the SSP3-7.0 scenario, sea level is expected to rise 17 centimeters from 2020 to 2050, with a likely range from 12 to 24 centimeters, and 65 centimeters from 2020 to 2100, with a likely range from 44 to 94 centimeters.

[18] IPCC AR6 WGI Interactive Atlas https://interactive-atlas.ipcc.ch/.
[19] NASA https://earth.gov/sealevel/sea-level-explorer/

This means that sea level rise is projected to increase by 0.22 meters by 2050 and 0.90 meters by 2100 under the SSP3-7.0 scenario, relative to 2005[20] (**Fig. 10**).

FIGURE 10. Projected Total Sea Level Change Under Different SSP Scenarios Relative to the Historical Baseline (1994–2014). The Shaded Ranges Show Uncertainties at 17th–83rd Percentile Ranges. Data Reflects the Grid at 9°S, 127°E (along Timor-Leste's Southeast coast). Data from NASA Sea Level Tool[21].



Over the next two decades, sea level rise is expected to occur at a similar rate regardless of emissions, scenarios, or warming levels. However, beyond this period, high-emission scenarios project significantly greater increases in sea level. Despite uncertainties, it is certain that sea levels will continue to rise across all scenarios for centuries, underscoring the need for long-term planning. Sea level rise could reach 0.3 m above historical conditions starting before 2050 in all scenarios, and 0.5 m during the second half of the 21st century with respect to 1995–2014 baseline[22]. "Under the SSP3-7.0 scenario, there is a 92% chance of exceeding half meter of global sea level rise 9% chance of exceeding 1 meter of global sea level rise by 2100"[23].

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20 NASA https://earth.gov/sealevel/sea-level-explorer/

21 NASA https://earth.gov/sealevel/sea-level-explorer/
What are low confidence scenarios? https://earth.gov/sealevel/about-sea-level-change/future-sea-level/the-basics/#otp_what_are_low_confidence_projections_vs._medium_con

22 NASA Sea Level Projection tool at 5°S, 109°E https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?lat=-5&lon=%20109&data_layer=scenario

23 NASA https://earth.gov/sealevel

Concerning inundation, “on average across the coastlines of Indonesia there were 217 days in total exceeding the minor high-water level between 1980 and 1990, and 413 between 2005 and 2015”[24]. The minor high-water level is defined as 40 cm above the average high tide (mean higher high-water, MHHW) and serves as an indicator of potential flooding impacts.

Extreme sea level surge events are projected to become significantly more frequent across much of the tropics. In Indonesia, a sea level event with a 100-year return period, is expected to occur as often as once every 1 to 40 years (depending on the region) by 2050 under the RCP4.5 scenario, with approximately 2°C of warming[25]. Tebaldi et al. (2021)[26] project that 100-year sea level events will become annual occurrences with just 1.5°C of global warming (in Indonesia).

Cyclones

Although Indonesia is mostly located outside the primary cyclone zone (outside of the tropical belt), the southern islands are still impacted by tropical cyclones originating south of Indonesia, and northern Sumatra can be impacted by cyclones originating to the north (**Fig. 11**). These tropical cyclones can cause coastal damage, infrastructure destruction, biodiversity loss, and the displacement of communities. Additionally, landslides become more frequent due to intensified storms, and coastal flooding becomes more frequent due to cyclone coastal storm surge combined with sea level rise. Northern-influenced cyclones peak in northern late summer (September), while southern-influenced cyclones peak in southern late summer (February and March).

Data overview: The occurrence of tropical cyclones in any specific location remains a rare event, making historical records too limited to reliably estimate recurrence intervals for these storms. This historical uncertainty can be partially addressed using models that simulate large ensembles of tropical cyclones. One such tool is the Columbia HAZard Model (CHAZ[27]), which generates an extensive synthetic catalog of potential cyclone tracks by simulating tropical cyclones across the oceans and their impacts upon landfall. This approach provides a more comprehensive perspective compared to observational data alone. The findings presented here rely exclusively on the CHAZ model, utilizing the column relative humidity (CRH) configuration to represent moisture. These simulations are informed by 12 different Global Circulation Models from the CMIP6 ensemble and project tropical cyclone activity during the historical period (1951–2014) and into the future under the SSP2-4.5 scenario, focusing on the period 2035–2064 (centered around 2050). We apply a footprint to the CHAZ tracks to capture the full extent of the cyclones. This is especially important for small islands to ensure that the cyclone's impact is not underestimated. The footprint is based on modeled horizontal wind profiles and latitude, using a dual-exponential decay function derived from 380 observed storms, as detailed by Willoughby et al. (2006)[28].

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[24] NASA https://earth.gov/sealevel

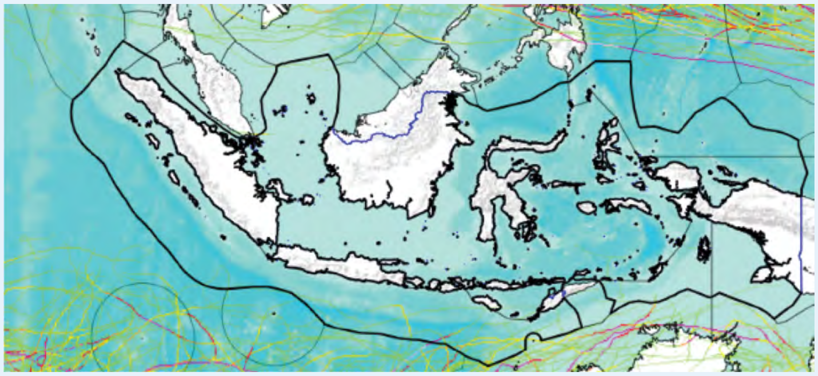
[25] Vousdoukas, M.I., Mentaschi, L., Voukouvalas, E. et al. Global probabilistic projections of extreme sea levels show intensification of coastal flood hazard. Nat Commun 9, 2360 (2018). https://doi.org/10.1038/s41467-018-04692-w

[26] Tebaldi, C., Ranasinghe, R., Vousdoukas, M. et al. Extreme sea levels at different global warming levels. Nat. Clim. Chang. 11, 746–751 (2021). https://doi.org/10.1038/s41558-021-01127-1

[27] Lee, C.-Y., Tippett, M. K., Sobel, A. H., & Camargo, S. J. (2018). An environmentally forced tropical cyclone hazard model. *Journal of Advances in Modeling Earth Systems*, 10, 223–241. https://doi.org/10.1002/2017MS001186

[28] Willoughby, H. E., R. W. R. Darling, and M. E. Rahn, 2006: Parametric Representation of the Primary Hurricane Vortex. Part II: A New Family of Sectionally Continuous Profiles. *Mon. Wea. Rev.*, 134, 1102–1120, https://doi.org/10.1175/MWR3106.1.

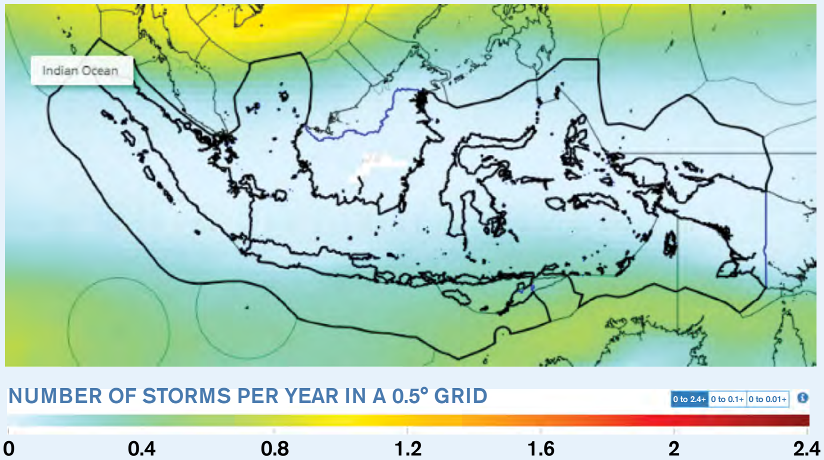
FIGURE 11A. Observed Historical Cyclones from IBTrACS[29]. All Recorded Cyclones have been Classified According to the Saffir-Simpson Scale Using the Variable "USA_wind", Which Records Sustained Maximum Winds Every 3 Hours (see label in knots). The IBTrACS Historical Data Covers Cyclones Recorded from 1840 to 2023, with the Caveat That Records Prior to 1980 May Be Incomplete.



CYCLONE CATEGORIES

- Tropical Storm
- Category 1
- Category 2
- Category 3
- Category 4
- Category 5

FIGURE 11B. Simulated Number of Storms Per Year in a 0.5° Grid for Category Tropical Storms and Above (CHAZ, Historical, 1950–2014, Median across CMIP6 models)



[29] International Best Track Archive for Climate Stewardship (IBTrACS) https://www.ncei.noaa.gov/products/international-best-track-archive

Tropical Cyclones are classified using the Saffir-Simpson Hurricane Scale, which is based on maximum sustained wind speeds (see **Fig. 11**). Historically, the frequency of tropical cyclones (maximum wind speeds above 34 knots) in the entire Indonesian EEZ is 7.1 cyclones per year (**Table 2**), corresponding to a return period of 0.14 years. Of these, 3 cyclones per year make landfall, equivalent to a return period of about 0.33 years. More than half of the tropical cyclones that intersect with the EEZ are tropical storms (58.3%), 18.1% are Category 1 cyclones, 8.4% are Cat 2, 7.0% are Cat 3, 6.0 are Cat 4, and only 2.2% reach Category 5 intensity. At landfall, the proportion of lower-intensity cyclones increases, with tropical storms accounting for 65.1%, while the proportion of Cat 1 and higher decreases to 17.1% (Cat 1), 7.1% (Cat 2), 5.1% (Cat 3), 4.1% (Cat 4), and 1.4% (Cat 5).

TABLE 2. Median Value (with 10th and 90th percentiles) of Counts of Cyclones per Year for Historical (1951–2014) for the Full EEZ Area and for Landfall for the Different Wind Strength Categories as Shown in Fig. 11. Values are Rounded to One Thousandths.

	Indonesia EEZ	Indonesia (landfall)
Category 5	0.161 (0.140, 0.202)	0.043 (0.029, 0.054)
Category 4	0.424 (0.362, 0.456)	0.124 (0.092, 0.136)
Category 3	0.494 (0.428, 0.521)	0.153 (0.116, 0.179)
Category 2	0.598 (0.522, 0.632)	0.214 (0.169, 0.239)
Category 1	1.284 (1.184, 1.361)	0.514 (0.426, 0.569)
Tropical Storm	4.143 (3.848, 4.286)	1.952 (1.775, 2.131)
Total	7.104 (6.484, 7.459)	3.000 (2.607, 3.308)

In this region, the CHAZ model does not project any significant changes in the frequency of tropical cyclones in the future for the scenario SSP2-4.5.

Natural Hazards

Climate change is now recognized to have a significant impact on disaster management efforts and poses a significant threat to the efforts to meet the growing needs of the most vulnerable populations. EM-DAT[30] (1980–2020) shows flood as the most relevant natural hazard (43% of events), followed by earthquake (20%), landslides (12%), volcanic activity (9%), epidemic (6%), wildfires (2%), droughts and storms (<2% each) (**Fig. 12**). Think Hazard[31] identifies river floods, urban floods, coastal floods, earthquakes, landslides, tsunamis, volcanoes, cyclones, and wildfires as the highest natural risks, followed by water scarcity and extreme heat, categorized as medium risk—most of which are closely linked to the climate crisis. The risks of Water scarcity (droughts) and cyclones are most prevalent in the southern islands (**Fig. 13**).

[30] The International Disaster Database https://www.emdat.be/
[31] Think Hazard, GFDRR, https://thinkhazard.org/en/report/242-timor-leste

FIGURE 12. Percentage Distribution of Each Type of Natural Hazard. EM-DAT Dataset

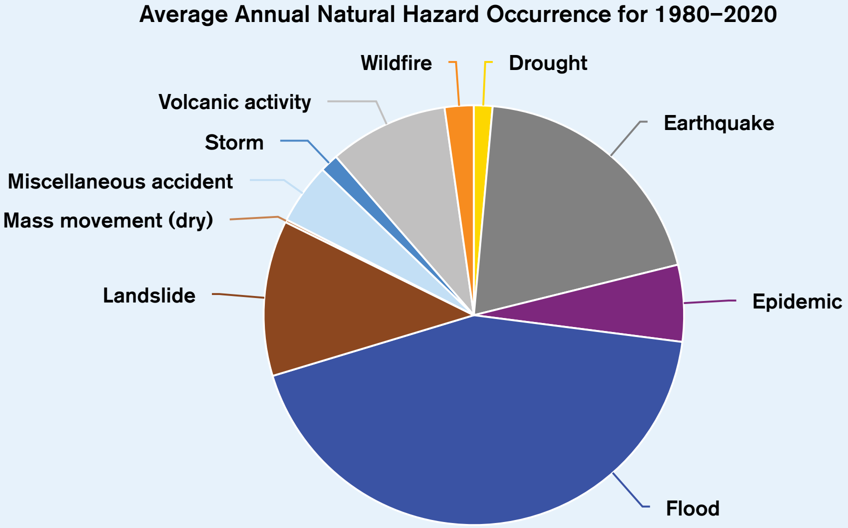
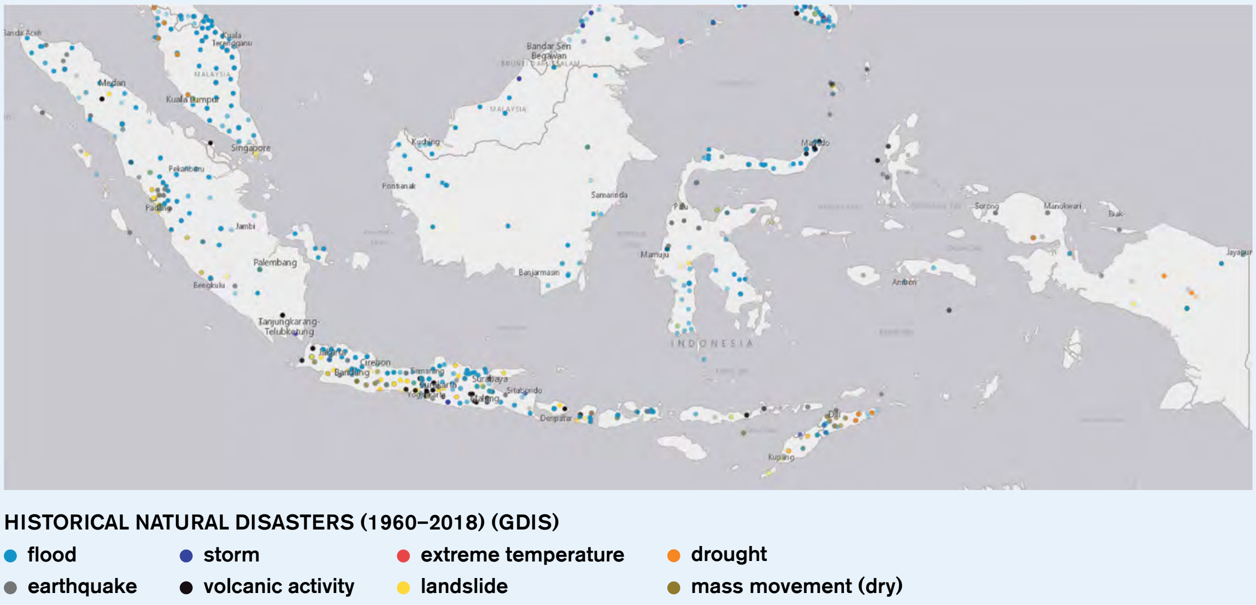


FIGURE 13. Distribution of Historical Natural Disasters (1960–2018) based on GDIS Data[32]



[31] Rosvold, E.L., Buhaug, H. GDIS, a global dataset of geocoded disaster locations. *Sci Data* 8, 61 (2021). https://doi.org/10.1038/s41597-021-00846-6

Blue Economy Impacts

Indonesia is home to one of the highest marine biodiversity levels in the world, hosting a rich variety of species and ecosystems. Its diverse marine environments, including coral reefs, mangroves, and seagrass beds, provide critical habitats for countless marine organisms, making it a global hotspot for marine life.

These ecosystems are under threat from overfishing, coastal development, climate change, and pollution, which highlight the need for sustainable management and conservation efforts.

The IPCC AR6 WGII Chapter 15 on Small Islands[33] states that coral reefs are most at risk. "Scientific evidence has confirmed that globally and in small islands tropical corals are presently at high risk (high confidence). Severe coral bleaching, together with declines in coral abundance, has been observed in many small islands, especially those in the Pacific and Indian oceans (high confidence)."

By the period 2090–2099 and under the high-emissions scenario RCP8.5 (+4.4°C), marine animal biomass along Indonesia's coast is expected to decline up to 60% north of Papua, and less so when moving to the western side of Indonesia (Tittensor et al., 2021[34]), relative to levels observed during 1990–1999.

The historical maximum sustainable yield from 2012 to 2021 is 2526 metric tons for Indonesia's entire Exclusive Economic Zone. By 2100, under the RCP8.5 scenario (with a projected warming of +4.5°C), the maximum sustainable yield is expected to decrease substantially by 75% compared to historical levels (Free et al., 2020[35]).

Temperate tuna species such as albacore, Atlantic bluefin, and southern bluefin are anticipated to decline in tropical regions (where Indonesia is part of) and migrate poleward. Conversely, skipjack and yellowfin tunas are expected to increase in abundance within tropical areas (Erauskin-Extramiana et al., 2019)[36].

Trisos et al. (2020)[37] project that as climate change advances, the risks to biodiversity will intensify, potentially leading to a catastrophic loss of global biodiversity. Using temperature and precipitation projections from 1850 to 2100, they assess the exposure of over 30,000 marine and terrestrial species to hazardous climate conditions. The study predicts that climate change will abruptly disrupt ecological assemblages, as most species within any given assemblage will simultaneously face conditions beyond their niche limits. Under a high-emissions scenario (RCP 8.5), these abrupt exposure events are expected to begin before 2030, with tropical oceans, including Timor-Leste, being particularly affected.

Tropical islands, and especially Indonesia, have particularly rich ecosystems. Protecting biodiversity is essential for adapting to climate change, among other reasons (e.g. Sala et al., 2021[38] or Zhao et al., 2020[39]).

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32 Chapter 15 - Small Islands, IPCCWG2, https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Chapter15.pdf

33 Tittensor, D.P., Novaglio, C., Harrison, C.S. et al. Next-generation ensemble projections reveal higher climate risks for marine ecosystems. Nat. Clim. Chang. 11, 973–981 (2021). https://doi.org/10.1038/s41558-021-01173-9

34 Free CM, Mangin T, Molinos JG, Ojea E, Burden M, Costello C, et al. (2020) Realistic fisheries management reforms could mitigate the impacts of climate change in most countries. PLoS ONE 15(3): e0224347. https://doi.org/10.1371/journal.pone.0224347

35 Erauskin-Extramiana M, Arrizabalaga H, Hobday AJ, et al. Large-scale distribution of tuna species in a warming ocean. Glob Change Biol. 2019; 25: 2043–2060. https://doi.org/10.1111/gcb.14630

36 Trisos, C.H., Merow, C. & Pigot, A.L. The projected timing of abrupt ecological disruption from climate change. *Nature* 580, 496–501 (2020). https://doi.org/10.1038/s41586-020-2189-9

37 Sala, E., Mayorga, J., Bradley, D. *et al.* Protecting the global ocean for biodiversity, food and climate. *Nature* 592, 397–402 (2021). https://doi.org/10.1038/s41586-021-03371-z

38 Zhao et al. (2020). Where Marine Protected Areas would best represent 30% of ocean biodiversity. Biological Conservation, Volume 244, 108536, https://doi.org/10.1016/j.biocon.2020.108536

ANNEX – TABLES: HISTORICAL AND PROJECTED CHANGES ACROSS REGIONS

In the following tables, the regions are organized starting from northern Sumatra, moving southeast to Nusa Tenggara, and then continuing through the islands in the northwest and finally the northeast. The regions are colored based on the large islands or island groups to which they belong.

Historical Climate Across Regions

Table A1 and A2 show the variations in historical temperature and precipitation across Indonesia's provinces.

TABLE A1. Historical a) Air Surface Temperature Averages (1991–2020) in degrees Celsius, CRU Dataset, and b) Trends per Decade (1971–2020), ERA5 Dataset. All Columns Colored According to Intensity. Significant Trends are Bolded.

Regions	Temp	Temp Max	Temp Min	Temp Trend
Indonesia	26.0	30.6	21.4	**0.28**
Nangroe Aceh Darussalam	25.6	31.5	19.7	**0.22**
Sumatera Utara	26.4	32.1	20.7	**0.26**
Sumatera Barat	26.6	32.0	21.2	**0.24**
Bengkulu	26.3	31.6	21.0	**0.23**
Lampung	26.5	30.9	22.2	**0.23**
Riau	27.9	32.6	23.2	**0.28**
Jambi	27.7	32.3	23.2	**0.26**
Sumatera Selatan	27.4	32.0	22.8	**0.24**
Bangka Belitung	27.6	31.6	23.5	**0.18**
Banten	27.0	31.6	22.5	**0.21**
Dki Jakarta	28.0	32.4	23.7	**0.25**
Jawa Barat	25.8	30.8	20.9	**0.22**
Jawa Tengah	26.3	31.1	21.6	**0.23**
Daerah Istimewa Yogyakarta	26.5	31.2	21.9	**0.18**
Jawa Timur	26.6	31.4	22.0	**0.21**
Bali	25.5	30.0	21.1	**0.19**
Nusatenggara Barat	25.4	30.9	19.9	**0.2**
Nusatenggara Timur	25.0	30.4	19.8	**0.15**
Kepulauan-riau	27.7	31.6	23.9	**0.14**
Kalimantan Barat	26.8	31.3	22.3	**0.22**
Kalimantan Tengah	26.6	30.3	22.8	**0.29**
Kalimantan Selatan	26.6	30.5	22.7	**0.29**
Kalimantan Timur	26.3	30.6	22.1	**0.33**

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TABLE A1. Historical a) Air Surface Temperature Averages (1991–2020), CRU Dataset, and b) Trends per Decade (1971–2020), ERA5 Dataset. All Columns Colored According to Intensity. Significant Trends are Bolded. (*Continued*)

Regions	Temp	Temp Max	Temp Min	Temp Trend
Sulawesi Tengah	24.3	29.0	19.6	**0.3**
Gorontalo	24.5	28.4	20.5	**0.28**
Sulawesi Utara	24.5	28.4	20.6	**0.24**
Sulawesi Barat	24.0	29.1	19.1	**0.32**
Sulawesi Selatan	24.6	29.6	19.7	**0.28**
Sulawesi Tenggara	25.5	30.1	20.9	**0.28**
Maluku Utara	25.3	30.4	20.3	**0.16**
Maluku	25.8	30.0	21.6	**0.15**
Papua Barat	25.8	29.6	22.1	**0.23**
Papua	24.4	29.0	19.9	**0.36**

TABLE A2. Historical Averages and Trends per Decade for a) Precipitation (in mm), b) Yearly Maximum Number of Consecutive Dry Days (CDD), and c) Yearly Maximum Number of Consecutive Wet Days (CWD). Columns are Colored According to Intensity. Significant Trends are Bolded. Based on CRU and ERA5 Datasets, as Indicated. Historical period refers to 1991 to 2020. Percent variability refers to interannual standard deviation with respect to the total. Max and min month refer to the months during which the maximum and minimum rain is reported on average. Trends refer to the period 1971 to 2020.

	Historical Precipitation Totals (1991–2020) (mm), Variability, and Precipitation Trend (or % change) per Decade (1971–2020), CRU and ERA5									CDD (days) ERA5		CWD (days) ERA5	
Regions	Year Total CRU	Year Total ERA5	% Var ERA5	Max CRU	Max Month	Min CRU	Min Month	Trend ERA5	% Change ERA5	Hist	Trend	Hist	Trend
Indonesia	2767	3198	5.3	295	12	162	8	**67**	**2.1**	12.5	0.52	74.2	**–2.23**
Nangroe Aceh Darussalam	2498	3305	3.4	290	12	140	7	**112**	**3.4**	8.8	**0.4**	70.2	**–2.65**
Sumatera Utara	2756	3193	3.7	305	12	164	7	**151**	**4.7**	8.3	0.07	67.2	–1.95
Sumatera Barat	2742	3691	4.6	302	4	132	6	**132**	**3.6**	7.9	0.06	68.8	–2.52
Bengkulu	2718	3520	6.2	308	11	135	6	30	0.8	7.5	0.24	67.4	**–5.8**
Lampung	2494	2610	8.4	297	3	115	8	–45	–1.7	11.4	**0.93**	62.0	**–3.93**
Riau	2515	2672	4.1	274	11	147	7	**128**	**4.8**	8.1	–0.01	55.6	–0.89
Jambi	2698	2970	5.8	321	4	119	6	**66**	**2.2**	8.3	0.33	65.5	**–3.06**
Sumatera Selatan	2651	2696	7.2	337	3	103	8	18	0.7	13.3	**0.98**	61.6	**–4.1**
Bangka Belitung	2587	2690	9.0	379	12	89	8	3	0.1	15.2	1.01	66.2	**–3.7**

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TABLE A2. Historical Averages and Trends per Decade for a) Precipitation, b) Yearly Maximum Number of Consecutive Dry Days (CDD), and c) Yearly Maximum Number of Consecutive Wet Days (CWD). Columns are Colored According to Intensity. Significant Trends are Bolded. Based on CRU and ERA5 Datasets, as Indicated. (*Continued*)

Regions	Historical Precipitation Totals (1991–2020) (mm), Variability, and Precipitation Trend (or % change) per Decade (1971–2020), CRU and ERA5									CDD (days) ERA5		CWD (days) ERA5	
	Year Total CRU	Year Total ERA5	% Var ERA5	Max CRU	Max Month	Min CRU	Min Month	Trend ERA5	% Change ERA5	Hist	Trend	Hist	Trend
Banten	3188	2631	10.3	405	1	114	8	–35	–1.3	16.5	**1.46**	64.2	–1.62
Dki Jakarta	2444	2139	9.4	398	1	68	8	–51	–2.4	17.6	**1.82**	65.1	–1.04
Jawa Barat	2888	2896	9.8	362	1	67	8	–54	–1.9	20.4	**1.72**	77.9	–0.03
Jawa Tengah	2777	2770	9.5	430	1	42	8	–37	–1.3	26.6	**2.68**	76.9	–0.86
Daerah Istimewa Yogyakarta	2324	2277	11.0	379	2	22	8	–12	–0.5	39.3	**5.63**	60.7	–1.29
Jawa Timur	2163	2247	9.5	342	1	25	8	–15	–0.7	37.8	**4.16**	68.0	–1.7
Bali	2129	2430	8.7	345	1	39	8	–29	–1.2	24.2	1.57	62.1	–1.35
Nusatenggara Barat	1807	1769	8.6	322	1	18	8	–24	–1.4	46.3	**4.42**	55.8	–1.9
Nusatenggara Timur	1824	1661	7.9	329	1	13	8	–20	–1.2	50.8	**4.2**	55.3	–1.88
Kepulauan-riau	2670	2577	5.9	350	12	163	2	**116**	**4.5**	10.4	–0.01	52.3	0.29
Kalimantan Barat	3354	3275	5.1	389	12	170	7	**93**	**2.8**	10.1	0.06	61.8	**–2.1**
Kalimantan Tengah	2876	2989	6.3	346	12	124	7	51	1.7	11.3	0.26	58.3	**–3.12**
Kalimantan Selatan	2566	2561	7.8	375	12	88	8	24	0.9	15.0	0.43	69.1	**–3.15**
Kalimantan Timur	2688	3001	5.7	287	12	157	8	70	2.3	6.9	–0.08	71.5	–2.28
Sulawesi Tengah	1828	3210	6.8	181	7	95	9	**88**	**2.7**	8.2	0	95.7	0.9
Gorontalo	2154	3173	8.1	242	1	100	9	73	2.3	13.1	–0.03	83.5	–0.48
Sulawesi Utara	2543	3039	9.3	337	1	100	9	41	1.3	12.6	0.15	79.4	–1.59
Sulawesi Barat	2713	3785	7.5	330	1	119	8	12	0.3	7.2	0.15	89.2	**–3.94**
Sulawesi Selatan	2684	3089	8.0	318	12	95	9	14	0.5	16.9	0.49	84.1	0.3
Sulawesi Tenggara	2159	2704	8.9	260	4	78	9	10	0.4	20.8	0.86	85.2	–0.3
Maluku Utara	2204	3020	10.3	282	6	124	10	35	1.1	11.4	0.18	81.1	–0.96
Maluku	2394	2540	9.7	248	1	115	10	41	1.6	17.5	0.22	74.1	0.71
Papua Barat	3068	3488	6.8	309	3	200	8	65	1.8	6.9	–0.03	87.0	–2.12
Papua	3312	4434	5.6	357	3	220	10	**107**	**2.4**	7.9	–0.13	98.0	–1.65

Projected Climate Across Regions

Table A3 to A5 show the variations in CMIP6 historical and projected temperature and precipitation related variables across Indonesia's provinces.

TABLE A3. CMIP6 Simulated Historical Averages (1995–2014), Mid-Century SSP3-7.0 Projections (2040–2059, central year 2050), Median Anomalies by 2050 (with respect to historical reference period 1994–2015), and Decadal Trends for Average, Minimum and Maximum Surface Air Temperature. Columns are Colored According to Intensity.

	Average Surface Air Temperature (degrees C)					Minimum Surface Air Temperature (degrees C)		Maximum Surface Air Temperature (degrees C)	
Regions	**Hist**	**2050**	**Anomaly**	**Trend (2000–2050)**	**Trend (2050–2100)**	**Hist**	**Anomaly**	**Hist**	**Anomaly**
Indonesia	25.6	26.7	1.18	0.25	0.35	22.4	1.24	28.9	1.12
Nangroe Aceh Darussalam	23.9	25.1	1.19	0.25	0.35	20.4	1.21	27.6	1.14
Sumatera Utara	25.1	26.3	1.15	0.24	0.37	23.0	1.18	27.5	1.17
Sumatera Barat	24.6	25.7	1.15	0.24	0.35	21.3	1.18	27.7	1.11
Bengkulu	24.4	25.6	1.16	0.24	0.34	22.9	1.26	29.1	1.22
Lampung	26.5	27.8	1.22	0.26	0.36	24.0	1.24	30.5	1.23
Riau	27.2	28.4	1.17	0.24	0.38	22.4	1.26	29.9	1.10
Jambi	26.1	27.3	1.18	0.25	0.36	22.5	1.28	29.3	1.25
Sumatera Selatan	26.8	28.0	1.21	0.25	0.37	22.7	1.28	29.0	1.25
Bangka Belitung	27.2	28.3	1.16	0.24	0.34	23.0	1.29	30.2	1.07
Banten	26.5	27.7	1.19	0.26	0.32	23.5	1.20	30.0	1.10
Dki Jakarta	27.2	28.4	1.23	0.26	0.34	23.2	1.25	30.6	1.10
Jawa Barat	25.1	26.3	1.24	0.27	0.34	21.9	1.27	29.2	1.09
Jawa Tengah	25.9	27.1	1.26	0.28	0.35	23.2	1.27	29.9	1.15
Daerah Istimewa Yogyakarta	25.9	27.1	1.23	0.27	0.34	23.7	1.18	28.6	1.22
Jawa Timur	25.8	27.0	1.26	0.27	0.33	22.9	1.18	28.8	1.17
Bali	25.2	26.3	1.16	0.25	0.31	21.4	1.26	27.1	1.19
Nusatenggara Barat	26.0	27.2	1.17	0.25	0.32	22.7	1.20	28.6	1.16
Nusatenggara Timur	25.8	27.0	1.15	0.24	0.32	21.2	1.20	28.1	1.07
Kepulauan-riau	27.1	28.2	1.11	0.23	0.33	21.4	1.24	29.0	1.10

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TABLE A3. CMIP6 Simulated Historical Averages (1995–2014), Mid-Century SSP3-7.0 Projections (2040–2059, central year 2050), Median Anomalies by 2050 (with respect to historical reference period 1994–2015), and Decadal Trends for Average, Minimum and Maximum Surface Air Temperature. Columns are Colored According to Intensity. (*Continued*)

	Average Surface Air Temperature (degrees C)					Minimum Surface Air Temperature (degrees C)		Maximum Surface Air Temperature (degrees C)	
Regions	**Hist**	**2050**	**Anomaly**	**Trend (2000–2050)**	**Trend (2050–2100)**	**Hist**	**Anomaly**	**Hist**	**Anomaly**
Kalimantan Barat	26.5	27.7	1.17	0.25	0.36	25.2	1.17	29.2	1.15
Kalimantan Tengah	26.8	27.9	1.16	0.24	0.37	23.9	1.21	29.1	1.21
Kalimantan Selatan	26.7	27.8	1.15	0.24	0.36	22.8	1.26	28.5	1.18
Kalimantan Timur	25.5	26.6	1.18	0.24	0.37	22.4	1.21	28.0	1.15
Sulawesi Tengah	24.2	25.4	1.23	0.26	0.34	21.9	1.25	28.5	1.25
Gorontalo	25.6	26.8	1.23	0.27	0.32	26.1	1.10	28.2	1.11
Sulawesi Utara	25.3	26.5	1.17	0.25	0.31	24.1	1.11	27.7	1.13
Sulawesi Barat	23.2	24.5	1.26	0.26	0.36	23.7	1.18	27.6	1.15
Sulawesi Selatan	24.5	25.7	1.22	0.25	0.35	21.4	1.22	27.9	1.07
Sulawesi Tenggara	25.6	26.7	1.18	0.25	0.34	23.6	1.26	31.0	1.09
Maluku Utara	25.6	26.8	1.18	0.25	0.31	20.1	1.26	26.6	1.24
Maluku	25.8	26.9	1.10	0.23	0.30	21.3	1.23	27.7	1.19
Papua Barat	25.2	26.3	1.19	0.25	0.33	23.0	1.22	27.8	1.11
Papua	24.5	25.6	1.16	0.23	0.35	23.1	1.29	30.5	1.14

TABLE A4. CMIP6 Simulated Historical Averages (1995–2014), Mid-Century SSP3-7.0 Projections (2040–2059, central year 2050), Median Anomalies by 2050 (with respect to historical reference period 1994–2015), and/or Decadal Trends for a) Number of Hot Days per Year with Tmax > 30°C or 35°C, b) Number of Days per Year with Heat Index > 35°C, c) Number of Tropical Nights per Year with Tmin > 23°C and Tmin > 26°C. Columns are Colored According to Intensity.

	Number of Hot Days per Year with Tmax > 30 or 35°C (days) - hd30 and hd35					Number of Days with Heat Index > 35°C - hi35		Number of Tropical Nights per Year with Tmin > 23°C (days) - tr23			Number of Tropical Nights per Year with Tmin > 26°C (days) - tr26		
Regions	**HD30 Hist**	**HD30 2050**	**HD30 Anomaly**	**hd30 Trend 2000–2050**	**HD35 2050**	**HI35 2050**	**HI35 Trend 2050–2100**	**tr23 Hist**	**tr23 2050**	**tr23 Anomaly**	**tr26 Hist**	**tr26 2050**	**tr26 Anomaly**
Indonesia	132.8	203.1	69.4	14.6	2.5	31.5	28.1	169.6	245.8	75.4	9.6	42.6	33.3
Nangroe Aceh Darussalam	48.4	113.3	62.6	12.7	0.2	13.6	13.0	91.2	126.2	34.7	10.2	33.8	23.7
Sumatera Utara	129.4	190.6	59.0	12.4	4.7	36.5	20.4	106.9	166.7	58.9	7.3	32.1	24.2
Sumatera Barat	58.0	124.7	64.4	13.1	0.0	7.3	14.7	83.7	134.5	50.2	9.1	31.2	21.3
Bengkulu	17.9	83.5	64.5	12.1	0.0	2.6	10.4	85.0	140.9	55.7	3.7	18.6	15.1
Lampung	201.5	262.3	58.7	11.8	5.4	51.5	35.2	225.0	301.2	73.7	4.9	40.7	36.2
Riau	279.2	332.8	52.2	11.5	4.3	92.9	41.8	244.1	343.2	97.0	5.4	39.7	34.8
Jambi	219.5	272.8	51.4	11.3	1.5	38.2	38.7	180.6	276.6	94.3	1.3	12.4	12.2
Sumatera Selatan	249.1	300.8	49.8	10.5	10.9	64.9	38.8	238.4	304.8	63.9	1.9	29.3	29.9
Bangka Belitung	98.3	225.3	125.2	27.1	0.0	63.4	52.4	358.1	364.2	5.4	65.1	225.2	158.5
Banten	98.6	209.5	109.9	23.4	0.1	25.4	35.4	257.5	330.7	71.0	15.7	101.7	84.9
Dki Jakarta	251.8	331.9	79.5	18.6	0.1	32.8	58.6	319.7	361.6	39.4	10.2	56.0	46.7
Jawa Barat	86.1	157.6	70.5	14.7	3.1	16.9	16.0	114.2	179.5	65.8	7.9	38.5	31.3
Jawa Tengah	121.4	212.8	90.6	19.4	8.7	18.2	25.3	152.6	244.8	91.3	3.7	31.9	29.2
Daerah Istimewa Yogyakarta	101.2	229.9	124.2	28.7	0.0	4.4	27.0	160.8	278.7	116.3	4.2	40.7	38.2
Jawa Timur	108.2	188.4	79.0	16.8	7.5	24.4	24.3	168.5	238.1	68.7	25.9	75.4	50.0

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TABLE A4. CMIP6 Simulated Historical Averages (1995–2014), Mid-Century SSP3-7.0 Projections (2040–2059, central year 2050), Median Anomalies by 2050 (with respect to historical reference period 1994–2015), and/or Decadal Trends for a) Number of Hot Days per Year with Tmax > 30°C or 35°C, b) Number of Days per Year with Heat Index > 35°C, c) Number of Tropical Nights per Year with Tmin > 23°C and Tmin > 26°C. Columns are Colored According to Intensity. (*Continued*)

Regions	Number of Hot Days per Year with Tmax > 30 or 35°C (days) - hd30 and hd35					Number of Days with Heat Index > 35°C - hi35		Number of Tropical Nights per Year with Tmin > 23°C (days) - tr23			Number of Tropical Nights per Year with Tmin > 26°C (days) - tr26		
	HD30 Hist	HD30 2050	HD30 Anomaly	hd30 Trend 2000–2050	HD35 2050	HI35 2050	HI35 Trend 2050–2100	tr23 Hist	tr23 2050	tr23 Anomaly	tr26 Hist	tr26 2050	tr26 Anomaly
Bali	7.0	50.7	44.3	8.2	0.0	1.6	13.2	187.4	255.3	68.9	15.7	61.7	47.0
Nusatenggara Barat	45.4	149.3	104.4	20.8	0.0	6.5	26.1	240.2	308.4	68.5	16.5	88.2	71.4
Nusatenggara Timur	75.2	165.6	89.4	18.2	0.5	12.0	20.8	186.4	247.4	61.6	26.9	78.8	51.2
Kepulauan-riau	18.0	91.0	72.9	11.0	0.0	64.9	48.1	363.6	364.8	1.1	188.2	326.3	136.6
Kalimantan Barat	206.4	285.1	78.4	17.3	1.7	42.4	37.1	169.3	294.3	123.0	3.9	24.8	21.4
Kalimantan Tengah	240.2	309.3	68.9	14.9	6.3	53.8	38.7	203.7	309.2	104.1	2.4	22.7	21.4
Kalimantan Selatan	174.8	277.8	102.8	22.4	4.7	40.3	41.1	213.8	322.2	105.9	12.3	53.8	42.1
Kalimantan Timur	139.4	218.3	79.1	16.6	0.8	23.8	27.4	123.0	211.3	87.8	2.6	19.2	16.6
Sulawesi Tengah	8.6	47.5	38.8	6.5	0.0	1.7	10.9	119.5	168.5	49.2	10.0	42.0	32.3
Gorontalo	31.9	131.8	99.8	18.9	0.0	0.4	16.5	148.7	232.7	85.2	2.7	56.6	53.2
Sulawesi Utara	2.6	50.3	48.8	7.3	0.0	3.5	14.8	157.8	232.0	74.0	29.3	71.4	42.1
Sulawesi Barat	3.6	34.5	31.4	4.9	0.0	2.8	9.8	71.3	99.5	27.8	13.7	41.5	27.4
Sulawesi Selatan	65.2	124.1	57.9	11.5	1.6	12.6	14.3	117.3	180.8	62.8	13.6	46.8	32.5
Sulawesi Tenggara	74.5	163.6	88.1	18.8	0.2	15.9	26.8	179.2	226.2	47.0	20.4	79.6	59.1
Maluku Utara	1.5	36.1	34.9	5.0	0.0	1.3	20.9	246.1	295.4	49.1	26.6	124.8	97.8
Maluku	7.5	54.5	46.5	8.0	0.0	14.1	26.9	249.9	300.3	50.3	53.6	141.8	88.1
Papua Barat	52.2	138.7	83.1	17.5	0.0	6.4	26.3	167.8	238.2	69.6	8.8	53.6	44.7
Papua	121.7	193.3	71.2	15.8	1.1	31.3	26.4	161.8	228.3	66.7	3.4	27.6	24.0

TABLE A5. CMIP6 Simulated Historical Averages (1995–2014), Mid-Century SSP3-7.0 Projections (2040–2059, central year 2050) and Median Anomalies by 2050 (with respect to historical reference period 1994–2015 for a) precipitation (mm) and b) Annual Maximum Number of Consecutive Dry (CDD) and Wet (CWD) Days. Columns are Colored According to Intensity. For Precipitation We Also Note the Anomaly as a Percentage Change. For CDD, We Only Show the Historical Value as There are No Significant Changes Projected in the Future.

	Precipitation Historical and Projected Annual Average Values (mm) and Median Anomaly to Mid-Century (mm and %)				Maximum Number of Consecutive Dry/Wet Days per Year (CDD, CWD) - Averages & Anomaly				
Regions	pr Hist	pr 2050	pr Anomaly	% Change	CDD Hist	CDD Anomaly 2050	CWD Hist	CWD 2050	CWD Anomaly 2050
Indonesia	3091	3151	66	2.1	8.4	0.44	136.2	131.6	–5.0
Nangroe Aceh Darussalam	3094	3130	59	1.9	5.3	0.3	119.6	115.7	–4.5
Sumatera Utara	2952	2967	20	0.7	5.2	0.27	120.6	114.5	–6.2
Sumatera Barat	3456	3446	–19	–0.6	4.8	0.29	123.7	116.9	–6.3
Bengkulu	3387	3316	–98	–2.9	4.6	0.5	130.4	123.9	–3.6
Lampung	2538	2478	–40	–1.6	8.9	0.71	113.4	108.2	–4.1
Riau	2450	2444	–4	–0.2	5.8	0.3	104.5	98.8	–5.5
Jambi	2815	2822	–8	–0.3	5.9	0.44	116.1	111.6	–4.9
Sumatera Selatan	2580	2559	–35	–1.4	8.8	0.86	113.8	108.7	–5.2
Bangka Belitung	2618	2606	–49	–1.9	10.4	0.8	91.5	89.5	–5.9
Banten	2514	2444	–29	–1.1	11.6	0.71	105.8	99.4	–6.3
Dki Jakarta	2088	2046	–21	–1.0	14.8	0.76	100.7	95.3	–5.5
Jawa Barat	2771	2692	–41	–1.5	14.0	1.04	116.8	111.9	–4.2
Jawa Tengah	2654	2644	–12	–0.5	18.8	1.74	111.6	107.9	–2.8
Daerah Istimewa Yogyakarta	2195	2185	–24	–1.1	26.5	2.55	102.7	97.5	–4.3
Jawa Timur	2179	2164	–23	–1.0	29.7	2.34	98.4	94.8	–3.6
Bali	2432	2392	–25	–1.0	19.4	1.05	90.8	88.0	–3.1
Nusatenggara Barat	1770	1756	–11	–0.6	39.9	2.45	71.2	68.1	–3.8
Nusatenggara Timur	1663	1646	–14	–0.9	43.3	1.8	65.5	62.8	–2.8
Kepulauan-riau	2397	2387	–27	–1.1	7.9	0.6	76.7	73.3	–2.6
Kalimantan Barat	3148	3207	62	2.0	6.8	0.2	101.4	96.4	–6.2
Kalimantan Tengah	2901	2941	47	1.6	7.1	0.53	106.8	103.7	–6.3
Kalimantan Selatan	2508	2518	23	0.9	9.2	0.58	111.7	107.2	–6.7
Kalimantan Timur	2954	3002	41	1.4	4.1	0.21	131.6	125.0	–7.9
Sulawesi Tengah	3070	3146	79	2.6	4.8	0.2	160.6	153.7	–5.1
Gorontalo	3050	3100	26	0.8	6.1	0.24	120.1	112.2	–2.7
Sulawesi Utara	2970	3002	35	1.2	7.3	0.16	105.5	101.0	–0.3
Sulawesi Barat	3797	3907	132	3.5	3.4	0.26	174.5	160.6	–8.7
Sulawesi Selatan	3024	3103	97	3.2	11.0	0.67	147.2	140.3	–5.4
Sulawesi Tenggara	2669	2718	72	2.7	12.5	0.64	131.5	128.7	–3.5
Maluku Utara	2971	3032	77	2.6	7.1	0.12	101.2	98.0	–1.1
Maluku	2485	2568	104	4.2	13.2	–0.38	93.1	92.1	–1.3
Papua Barat	3406	3523	114	3.3	3.7	0.08	164.5	161.7	–1.7
Papua	4322	4539	241	5.6	4.1	–0.03	228.4	224.6	–4.3

Population Exposure Across Regions

Tables A6 and A7 show the variations in CMIP6 historical and projected population exposure to temperature and precipitation related variables across Indonesia's provinces.

TABLE A6. For Each Admin1 Province, Percent of the Population[40] at High Health Risk for Three Periods: Retrospective (1975–2024, centered on 2000), Future (2010–2059, centered on 2035), and Distant Future (2050–2099, centered on 2075), Under SSP3-7.0. High-risk areas are defined as locations where the 50-year return level indicates, that, on average once every 50 years, a year occurs with a) more than 30 days with Tmax > 35°C, b) more than 20 days with Tmin > 26°C, c) more than 30 days characterized by heat index surpassing 35°C, d) more than 15 days characterized by wet bulb temperatures surpassing 27°C (not showing the retrospective values as it zero everywhere).

Regions	Hot Days (Tmax > 35°C)			Tropical Nights (Tmin > 26°C)			Heat Index > 35°C			Wet Bulb Temp > 27°C	
	hd35 - 2000	hd35 - 2035	hd35 - 2075	tr26 - 2000	tr26 - 2035	tr26 - 2075	hi35 - 2000	hi35 - 2035	hi35 - 2075	wb27 - 2035	wb27 - 2075
Indonesia	1.8	10.9	38.3	8.5	26.4	64.2	4.0	44.6	77.5	17.0	71.3
Nangroe Aceh Darussalam	0.0	0.0	8.7	9.2	28.3	49.5	4.2	27.3	68.7	17.0	57.6
Sumatera Utara	0.0	8.9	59.7	3.8	22.4	59.8	26.0	57.5	81.5	32.9	72.8
Sumatera Barat	0.0	0.0	5.2	0.9	3.1	16.8	0.0	6.3	46.1	1.6	23.6
Bengkulu	0.0	0.0	1.9	2.3	19.4	31.0	0.0	15.6	49.4	0.0	54.8
Lampung	0.0	12.4	59.8	4.2	32.4	82.4	0.0	63.3	92.9	26.2	95.0
Riau	0.0	6.7	91.7	4.5	16.7	95.1	35.8	94.9	98.6	88.5	98.2
Jambi	0.0	0.0	80.8	1.6	30.5	83.7	0.0	77.8	87.5	50.8	87.3
Sumatera Selatan	6.0	63.9	88.6	0.2	61.6	86.1	0.0	79.6	88.8	68.4	89.4
Bangka Belitung	0.0	0.0	4.4	67.2	100.0	100.0	0.0	100.0	100.0	88.5	100.0
Banten	0.0	0.0	57.8	11.2	14.7	93.6	0.0	78.1	99.5	4.9	91.8
Dki Jakarta	0.0	0.0	98.9	1.2	1.1	100.0	0.0	100.0	100.0	0.5	100.0
Jawa Barat	1.7	3.1	28.7	3.4	16.2	37.7	0.5	28.2	54.8	4.0	51.8
Jawa Tengah	5.1	15.3	25.0	3.3	11.8	65.9	0.0	30.2	86.0	5.0	74.3
Daerah Istimewa Yogyakarta	0.0	0.0	0.0	7.8	20.9	69.9	0.0	13.1	98.2	0.0	98.2
Jawa Timur	2.7	21.2	36.9	18.9	33.6	60.9	7.0	37.1	76.1	12.7	69.1
Bali	0.0	0.0	0.0	11.7	32.6	72.7	0.0	10.4	72.7	0.0	36.4
Nusatenggara Barat	0.0	0.0	0.0	11.3	60.7	81.0	0.0	37.0	84.2	0.0	80.1

(continues on next page)

[39] Population dataset: Gridded Population of the World, Version 4: GPWv4; Revision 11, Dec 2018. For each pixel (at approximately 25 km resolution), the return level for a given return period is calculated by fitting a Generalized Extreme Value (GEV) distribution. A pixel is classified as "too risky" (1) if the return level exceeds the specified threshold, and "not too risky" (0) otherwise. The reported population exposure represents the percentage of the total population in each region that is exposed to risk.

TABLE A6. For Each Admin1 Province, Percent of the Population at High Health Risk for Three Periods: Retrospective (1975–2024, centered on 2000), Future (2010–2059, centered on 2035), and Distant Future (2050–2099, centered on 2075), Under SSP3-7.0. High-risk areas are defined as locations where the 50-year return level indicates, that, on average once every 50 years, a year occurs with a) more than 30 days with Tmax > 35°C, b) more than 20 days with Tmin > 26°C, c) more than 30 days characterized by heat index surpassing 35°C, d) more than 15 days characterized by wet bulb temperatures surpassing 27°C (not showing the retrospective values as it zero everywhere). (*Continued*)

	Hot Days (Tmax > 35°C)			Tropical Nights (Tmin > 26°C)			Heat Index > 35°C			Wet Bulb Temp > 27°C	
Regions	**hd35 - 2000**	**hd35 - 2035**	**hd35 - 2075**	**tr26 - 2000**	**tr26 - 2035**	**tr26 - 2075**	**hi35 - 2000**	**hi35 - 2035**	**hi35 - 2075**	**wb27 - 2035**	**wb27 - 2075**
Nusatenggara Timur	0.0	3.9	9.2	18.5	34.4	63.4	5.3	22.6	66.6	2.1	53.1
Kepulauan-riau	0.0	0.0	0.0	100.0	100.0	100.0	3.4	100.0	100.0	33.7	100.0
Kalimantan Barat	0.0	0.0	66.0	9.6	37.8	97.8	4.2	90.2	99.6	64.7	99.3
Kalimantan Tengah	0.0	26.9	89.9	0.4	67.4	98.4	13.4	94.7	99.9	83.5	99.1
Kalimantan Selatan	1.3	22.2	81.5	6.6	43.7	99.6	0.1	93.4	100.0	61.5	99.8
Kalimantan Timur	0.0	0.0	61.3	18.2	50.0	95.6	4.0	90.0	97.5	71.6	96.9
Sulawesi Tengah	0.0	0.0	0.0	7.2	20.1	36.5	0.0	2.3	44.1	0.0	45.8
Gorontalo	0.0	0.0	0.0	3.7	13.8	74.9	0.0	0.0	93.3	0.0	79.7
Sulawesi Utara	0.0	0.0	0.0	18.0	33.8	49.9	0.0	4.5	36.6	0.0	46.7
Sulawesi Barat	0.0	0.0	0.0	25.9	27.4	35.5	0.0	1.4	57.2	0.0	44.4
Sulawesi Selatan	0.0	3.4	21.4	13.4	49.9	70.7	0.0	49.8	77.6	2.2	66.1
Sulawesi Tenggara	0.0	0.0	16.3	14.6	59.4	71.4	0.0	61.7	88.1	8.3	80.5
Maluku Utara	0.0	0.0	0.0	22.9	55.5	76.6	0.0	2.2	69.7	0.0	63.3
Maluku	0.0	0.0	0.0	48.5	57.6	71.8	0.0	35.1	74.1	4.0	72.8
Papua Barat	0.0	0.0	0.0	11.8	22.7	63.4	0.0	8.2	75.7	0.9	69.7
Papua	0.0	0.0	18.4	5.9	26.8	48.8	1.4	34.0	59.3	19.0	54.7

TABLE A7. For Each Admin1 Province, Percent of the Population at High Health Risk for Three Periods: Retrospective (1975–2024, centered on 2000), Future (2010–2059, centered on 2035), and Distant Future (2050–2099, centered on 2075), Under SSP3-7.0. High-risk areas are defined as locations where a) the 50-year return level of the annual number of consecutive days of drought (<1mm/day) (CDD) exceeds 90, b) the 50-year return level of the number of days with precipitation greater than 50 (r50) mm exceeds 5, c) the 25-return level of the annual largest 5-day precipitation (rx5) exceeds 130 mm.

	Maximum Number of Consecutive Dry Days - CDD			Precipitation Greater than 50 mm - r50			5-Day Cumulative Precipitation - rx5		
Regions	cdd - 2000	cdd - 2035	cdd - 2075	r50 - 2000	r50 - 2035	r50 - 2075	rx5 - 2000	rx5 - 2035	rx5 - 2075
Indonesia	10.5	13.2	20.1	16.7	18.6	23.7	88.5	92.4	96.8
Nangroe Aceh Darussalam	0.0	0.0	0.0	27.8	33.1	46.9	100.0	100.0	100.0
Sumatera Utara	0.0	0.0	0.0	10.2	12.6	13.3	91.3	98.2	99.4
Sumatera Barat	0.0	0.0	0.0	49.1	49.7	75.5	96.0	95.8	100.0
Bengkulu	0.0	0.0	0.0	17.6	18.5	45.5	99.8	100.0	100.0
Lampung	0.0	0.0	0.0	0.0	0.0	0.0	52.0	60.6	81.9
Riau	0.0	0.0	0.0	0.0	0.0	0.0	62.3	85.1	96.3
Jambi	0.0	0.0	0.0	3.1	2.6	4.8	66.4	68.1	90.4
Sumatera Selatan	0.0	0.0	0.0	0.3	0.3	1.2	34.7	48.7	84.9
Bangka Belitung	0.0	0.0	0.0	0.0	0.0	0.0	99.1	99.1	100.0
Banten	0.0	0.0	0.0	0.6	0.7	0.7	94.3	95.1	100.0
Dki Jakarta	0.0	0.0	0.0	0.0	0.0	0.0	99.3	100.0	100.0
Jawa Barat	0.9	6.7	14.2	31.9	32.5	29.6	95.9	98.8	99.4
Jawa Tengah	0.6	5.0	32.1	20.2	19.9	34.4	99.9	99.9	100.0
Daerah Istimewa Yogyakarta	12.7	20.9	26.5	0.1	0.1	30.1	100.0	100.0	100.0
Jawa Timur	51.5	53.8	58.7	10.0	14.0	18.8	96.9	100.0	100.0
Bali	0.6	4.0	3.8	67.2	67.4	78.8	99.9	100.0	100.0
Nusatenggara Barat	28.5	42.7	42.7	32.2	54.1	56.2	98.8	98.8	98.9
Nusatenggara Timur	48.6	51.9	56.1	17.0	19.9	25.7	96.4	96.6	96.8
Kepulauan-riau	0.0	0.0	0.0	3.4	3.4	3.9	100.0	100.0	100.0
Kalimantan Barat	0.0	0.0	0.0	0.6	4.0	15.6	91.0	98.9	99.8
Kalimantan Tengah	0.0	0.0	0.0	0.0	0.0	0.3	39.3	66.1	87.7
Kalimantan Selatan	0.0	0.0	0.0	0.0	0.0	0.0	29.6	41.6	72.4
Kalimantan Timur	0.0	0.0	0.0	0.1	0.1	0.2	15.4	39.4	60.9
Sulawesi Tengah	0.0	0.0	0.0	3.9	5.3	33.1	86.8	88.8	93.8
Gorontalo	0.0	0.0	0.0	7.5	9.8	8.1	78.5	77.1	93.6
Sulawesi Utara	0.0	0.0	0.0	23.2	38.5	49.7	99.7	99.7	99.7
Sulawesi Barat	0.0	0.0	0.0	42.9	54.7	64.1	76.4	76.9	76.6
Sulawesi Selatan	3.1	3.3	5.6	31.6	38.5	42.3	88.5	92.8	94.1
Sulawesi Tenggara	0.3	0.3	2.8	3.4	3.8	4.2	63.7	68.8	72.2
Maluku Utara	0.0	0.0	0.0	20.5	29.2	34.3	86.8	91.9	93.5
Maluku	0.6	0.6	0.6	1.1	8.8	22.8	91.9	93.2	97.9
Papua Barat	0.0	0.0	0.0	19.4	20.2	33.6	96.3	96.7	99.6
Papua	0.0	0.0	0.0	33.4	35.3	43.8	85.3	89.9	99.4

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