High-Resolution North Sulawesi Drought Hazzard Mapping Based on Consecutive Dry Days (CDD)

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Abstract. North Sulawesi is one of the Province in northern Indonesia with high spatial annual rainfall variations and influenced by global climate anomaly that can lead to extreme events and disaster occurrence, such as flood, landslide, drought, etc. The purpose of this study is to generate high-resolution meteorological hazard map based on long-term historical consecutive dry days (CDD) over the North Sulawesi region. CDD was calculated based on observed daily precipitation data from Indonesia Agency for Meteorology, Climatology, and Geophysics (BMKG) surface observation station network (CDD_{obs}) and the daily-improved Climate Hazards group Infrared Precipitation with Stations (CHIRPS) version 2.0 (CDD_{CHIRPS}) during 1981 – 2010 period. The Japanese 55-year Reanalysis (JRA-55) data obtained from iTacs (Interactive Tool for Analysis of the Climate System) with the same time scale period also used to explain physical – dynamical atmospheric properties related to drought hazard over this region. The Geostatistical approach using regression kriging method was applied as spatial interpolation technique to generate high resolution gridded (0.05° x 0.05°) drought hazard map. This method combines a regression of CDD_{obs} as dependent variable (target variable) on CDD_{CHIRPS} as predictors with kriging of the prediction residuals. The results show that most of the areas were categorized as medium drought hazard level with CDD values ranging from 80–100 days. Meanwhile, small islands around main Sulawesi island such as Sangihe and Karakelong island are dominated by low drought hazard levels with CDD values ranging from 50–60 days. The highest levels of drought hazard area are located in South Bolaang Mongondow Regency.

1. Introduction

Indonesia has experienced quite severe drought, especially in 1982-1983, 1997, and 2015 [1]. These unusual dry condition are related to El Niño occurrence [1–3]. One of the most intriguing impacts of this drought incident was the occurrence of quite severe forest fires in 1997 in several parts of Indonesia. The spread of smoke to neighboring countries (transboundary haze) as a consequence of this forest fire seize the attention of the international community. North Sulawesi is one of the Province in northern Indonesia that has high spatial annual rainfall variations [4]. This region is also influenced by another global climate anomaly that can lead to extreme events and disaster occurrences, such as floods, landslides, droughts, etc. Located near Philippine, Malaysia, and Brunei Darussalam make this region also relatively vulnerable to transboundary haze issue.

Consecutive Dry Days (CDD) is one of the extreme indices related to drought occurrence and recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI) [5]. This index
can be used for drought quantification and calculated based on observed daily precipitation. Unfortunately, North Sulawesi region is not yet covered by an evenly distributed meteorological station network. Several places which not covered by the weather observation network will not have any climatic information. In order to cover this condition, spatial interpolation method can be done for estimating meteorological parameter over those areas [6–8].

Remote sensing data from weather satellites or radar can be utilized and applied in order to provide climate-related information for non-covered surface observation networks [9–11]. However, further correction should be applied before using these products to dealing with bias between the remote sensing output and surface observations value [12,13]. Further step to blending observation and remote sensing data can be performed to dealing with this condition and obtain higher spatial resolution [10,14]. The purpose of this study is to generate high-resolution meteorological hazard map based on long term historical consecutive dry days (CDD) over North Sulawesi region.

2. Data and Methodology

2.1. Data

Daily precipitation data at four active observation stations in North Sulawesi from Indonesia Agency for Meteorology, Climatology, and Geophysics (BMKG) observation network station during 30 years period (1981 – 2010) are collected for this research. Those stations are Naha synoptic meteorological station (Non ZOM 52), Sam Ratulangi aviation meteorological station (ZOM 326), Bitung maritime meteorological station (ZOM 325), and Minahasa Utara climatological station (ZOM 324) (Figure 1). This daily precipitation data used to calculate CDD.

![Figure 1](source: BMKG [4]).
The daily-improved Climate Hazards group Infrared Precipitation with Stations (CHIRPS) version 2.0 (CDD\textsubscript{CHIRPS}) during the 1981 – 2010 period also used to calculate CDD for each grid covered on the study area with 0.05° x 0.05° spatial resolution. This gridded dataset is used as independent variable to create trend model prediction during regression kriging analysis in geostatistical approach.

The Japanese 55-year Reanalysis (JRA-55) data [15] obtained from iTACS (Interactive Tool for Analysis of the Climate System) for physical – dynamical atmospheric explanation related to drought hazard in this region. The daily zonal (u) and meridional (v) wind at 850 mb level was selected to plot seasonal streamline over the study area. Furthermore, total precipitation rate then overlaid with this streamline plot.

2.2. Methodology

Daily precipitation from BMKG observation is used to calculate the maximum number of consecutive days with daily precipitation amount < 1 mm (CDD) for each year [5]. CDD values were also calculated from daily-improved CHIRPS precipitation data, for each grid in the study area with a 0.05 x 0.05° horizontal resolution.

Geostatistical approach (Regression Kriging) was applied to generate high resolution gridded (0.05° x 0.05°) drought hazard map. CDD\textsubscript{obs} as dependent variable (target variable) and CDD\textsubscript{chirps} as predictors with kriging of the prediction residuals. Detailed information and step-by-step calculation to generate this high-resolution CDD data then carry on following Setiawan (2018) [16]. The maximum number of CDD data distribution during all time period (1981 – 2010) and all location then used to generate drought hazard classification.

3. Result and Discussion

Meteorological drought hazard classification based on the maximum number of Consecutive Dry Days (CDD) data distribution over North Sulawesi can be found in Table 1. Maximum CDD for 1981 - 2010 in North Sulawesi was classified into four drought hazard categories as follows: 0 - 30 days (none); 30 - 60 days (low); 60 - 120 days (medium); and > 120 days (high).

| Number of Consecutive Dry Days | Meteorological Drought Hazard Level |
|-------------------------------|------------------------------------|
| 0 – 30                        | None                               |
| 30 – 60                       | Low                                |
| 60 – 120                      | Medium                             |
| > 120                         | High                               |

Most of North Sulawesi areas were categorized as medium drought hazard level with CDD values ranging from 80-100 days. Small islands around main Sulawesi island such as Sangihe and Karakelong island are dominated by low drought hazard levels with CDD values ranging from 50-60 days. Highest levels of drought hazard area are located in South Bolaang Mongondow Regency (Figure 2).

The dynamical interaction between atmospheric-sea conditions at various space and time scales is suspected as the driving factor of the medium hazard drought level in this region. Global scale climate variability such as ENSO [2,3], Indian Ocean Dipole [17], and monsoon[18] play important role for determining climate condition in Sulawesi, including North Sulawesi CDD characteristic.
Figure 2. Meteorological drought hazard category in North Sulawesi based on Maximum CDD during 30 years period (1981 – 2010).

Seasonal streamline of 850 mb wind climatology overlaid with seasonal precipitation was plotted in order to describe monsoon impact on precipitation induced drought (Figure 3). Asian monsoon period is represented by December – January – February (DJF) plot, while Australian monsoon season is represented by June – July – August (JJA) plot.

Figure 3. Streamline of 850 mb wind (line) and total precipitation rate (shaded) climatology (1981-2010) for DJF (left) and JJA (right) period of surface meteorological observation station data used in this research
During DJF, northwesterly to northerly 850 mb wind dominate on this region. Air mass contained with a lot of water vapor from Asia and Pacific Ocean region bring wetter condition in northern part of North Sulawesi. During JJA, southerly 850 mb wind generally occurred and dominated over this region. It brings sufficient water vapor from surrounding waters and can be followed by a wetter condition in southern and eastern part of North Sulawesi (Figure 3). The combination of these two monsoonal patterns and their interaction with local conditions are suspected as the main cause of relatively low drought hazard spatial variation.

4. Conclusion

High-resolution meteorological drought hazard map successfully generated based on historical observed CDD blended with CHIRSP based CDD over North Sulawesi region. In addition to other global climate anomalies, monsoon winds and their interaction with the local condition may play important role to meteorological drought hazard variability over this region.

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