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Return period and Pareto analyses of 45 years of tropical cyclone data (1970–2014) in the Philippines

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ABSTRACT

The epiphenomena of tropical cyclones (TCs) such as landslides, storm surges, and floods cause the largest loss of life and property in the Philippines. In order to improve the disaster risk management efforts of the country, it is necessary to evaluate the return periods (RPs) or chance of occurrence (CoC) of TCs. Hence, this study generally aimed to investigate the relationship of the RPs/CoC, sea surface temperature (SST) anomaly associated with the Interdecadal Pacific Oscillation (IPO), and the cost of socio-economic damages and the number of deaths caused by TCs. The Weibull parametric models and the Pareto principle were utilised to achieve this overarching objective. Using the maximum sustained wind speed (v), forty-five (45) years of TC data (1970–2014) within the Philippines Area of Responsibility (PAR) were analysed by applying the stationary and non-stationary stochastic modelling techniques. The stationary Weibull probability density function revealed that TCs Rita (1978), Dot (1985) and Haiyan (2013) occupy the wind speed region of $61 \geq v \leq 64$ m/s with a probability of 0.4% for any given year. On the other hand, the analysis of the cumulative distribution function revealed a 60% probability of TCs for the cumulative years with a maximum sustained wind speed of at most 38 m/s. This indicates the central estimate of the wind speed from 1970 to 2014 with TCs Ruby (1988) and Vicki (1998) as the observed cases. Furthermore, the probability values on the annual CoC maps depict the indicative positions of TCs, either singly, co-shared or cross-shared, that made landfall (or not) in the Philippines. Results from the non-stationary stochastic modelling revealed that the low probability values on the decadal CoC maps indicate the locations where extreme TC events are likely to occur within PAR; hence, showing the areas in the country that are more at-risk. The relationship of SST anomaly and CoC values disclosed that the TCs are intensified in the northern Philippines and south of West Philippines Sea during the positive(+) phase and the negative(-) phase of the IPO, respectively. Finally, the Pareto analysis revealed that 80% of the TC-related damage cost and the number of deaths are shared by three (3) different stationary and non-stationary RPs with TCs Ike (1984), Nina (1987), Fengshen (2008), Mike (1990), Parma (2009), and Haiyan (2013) as the observed extreme events. In the absence of accurate or updated cyclone risk models, the communities that are highly vulnerable to TCs can use the stationary and non-stationary stochastic CoC models as an early warning tool for disaster preparedness. Ultimately, the results of this study can provide significant insights to support the Philippines in their pursuit of improving cyclone resilience programs.

1. Introduction

Tropical cyclones (TCs) are one of the most destructive natural disasters affecting many societies around the world. In a Western North Pacific (WNP) country like the Philippines, its climate and weather conditions are greatly influenced by TCs. Together with the Asian southwest monsoon, both events contributed to high rainfall in the northern Philippines (Bagtasa, 2017) and caused flash floods over the low lying areas and landslides along the mountain slopes (Cayanan, Chen, Argete, Yen, & Nilo, 2011).

While the rainfall associated to TCs is beneficial to the country's agricultural farming and water supply systems, it also causes devastation when it is coupled with massive flooding and landslides. When cyclones make a landfall, strong winds can destroy agricultural crops and residential houses while storm surges can cause death and significant damages to the country's coastal towns and cities. Of all the natural disasters, tropical cyclones with its epiphenomena such as landslides, storm surges, and floods cause the largest loss of life and property in the Philippines (Huigen & Jens, 2006).

As the global climate has warmed, the TC intensity has increased

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over the past 40 years (Emanuel, Sundararajan, & William, 2008). Several studies have also shown the increasing trends in TC frequencies in the WNP (Walsh et al., 2016). Results from the other studies argue, however, that the longer-term records do not show changes in the frequency or severity and the recent upward trend is within the natural climatic variability (Landsea, Harper, Hoarau, & Knaff, 2006). Aimed to provide a framework to combine atmospheric science and economics, it was found that the tropical cyclone damage from climate change tends to be concentrated in North America, East Asia and the Caribbean-Central American region (Mendelsohn, Emanuel, Chonabayashi, & Bakkensen, 2012). In Southeast Asia, a recent study was conducted to analyse the trend in the annual total number and intensity of TCs within the Philippines Area of Responsibility (PAR) (Cinco et al., 2016).

Previous studies mainly focused on the largescale weather events that correspond to macrometeorological fluctuations in wind and used wind speed data to estimate 50- or 100-year return levels (Steinkohl, Davis, & Klüppelberg, 2013). The primary interest of this study lies in the spatiotemporal mapping of return periods of most intense and extremely destructive cyclones and then use the result to apply the Pareto principle.

1.1. Mapping the return periods of tropical cyclones

Following the NHC-NOAA's (2018) definition, tropical cyclone is described as a rotating, organised system of clouds and thunderstorms that originates over tropical or subtropical waters and has a closed low-level circulation. In the Philippines, they are classified based upon their degree of intensity as follows (PAGASA, 2018):

- Tropical Depression (TD) - a tropical cyclone with maximum sustained winds of up to 61 kilometres per hour (kph) or less than 33 nautical miles per hour (knots).
- Tropical Storm (TS) - a tropical cyclone with maximum wind speed of 62–88 kph or 34–47 knots.
- Severe Tropical Storm (STS) - a tropical cyclone with maximum wind speed of 89–117 kph or 48–63 knots.
- Typhoon (TY) - a tropical cyclone with maximum wind speed of 118–220 kph or 64–120 knots.
- Super Typhoon (STY) - a tropical cyclone with maximum wind speed exceeding 220 kph or more than 120 knots.

Unless specified, this study used the term “tropical cyclones” (or TCs for short) referring to all these types of cyclones.

The return period (RP) of TCs' maximum wind speeds can be defined as the average period in which an event is expected to recur once (Chu & Wang, 1998a, b). The use of the term “return period”, however, has been criticised as it is confusing to decision-makers; hence, the National Oceanic and Atmospheric Administration (NOAA) used the term “average recurrence interval” (ARI) to describe the frequency of an event (Parzybok, Clarke, & Hultstrand, 2011). Often referred to as the Annual Exceedance Probability (AEP) (USGS, 2016), the ARI can also be expressed as the probability or percent chance of occurrence (CoC) of an event for any given year (Parzybok et al., 2011).

In applying the extreme value theory to wind speed data, one key objective is often the determination of the RPs (Steinkohl et al., 2013). The generated information can be used then for building designs and disaster preparedness (Chu & Wang, 1998a, b). The motivations of various studies have been founded on this principle. Using the 1987 HURISK Program, for example, NOAA generates spatial information on the RPs of major cyclones passing through various locations on the U.S. Coast (NOAA, 2017a, b). Malmstadt, Elsner, and Jagger (2010) and Trepanier and Scheitlin (2014) employed the spatial and temporal approaches to calculate the RPs of TCs. The combination of these approaches such as the works of Andrews (2004), Keim, Muller, and Stone (2007), Della-Marta et al. (2009), and Hoque, Phinn, Roelfsema, and Childs (2017) provides a unique picture when and where certain areas were mostly threatened by TCs (Keim et al., 2007). In a recent study conducted by Hong, Li, and Duan (2016), they estimated the RPs of the annual maximum typhoon wind speed for a set of grid points and then interpolated using ordinary kriging to develop the typhoon wind hazard contour maps.

Using the CoC in the present study, the generated spatial information shows the zones of cyclone tracks with corresponding probability values for a particular year during the cyclone season. While several cyclones can originate in different locations and travel much different paths from the average, mapping of the TCs' maximum wind speed gives a better picture of the average cyclone season (NOAA, 2017a, b). In the present study, this gives a better picture of the average recurrence interval or probability of occurrence of cyclones within PAR.

While the RP-based approach can be used to obtain an annual rate of return on the extreme winds with significant application and was proven useful for setting building codes (Rupp & Lander, 1996) including insurance and risk management (Elsner, Jagger, & Tsonis, 2006), the idea of this present study is to translate the annual rate of RP or percent CoC of extreme winds into spatially-explicit construct. This method does not only go beyond the empirical methods of storm counting by intensity category (Elsner et al., 2006), but also provides the annual or decadal spatial distribution of RPs or percent CoC of cyclone tracks within PAR over a forty-five-year time-period. This approach has never been substantially explored within PAR despite the fact that the WNP is the most active region on Earth for tropical cyclone occurrences (Rupp & Lander, 1996). Furthermore, the TC intensity is highly influenced by its genesis location and it is significant to investigate its spatial changes (Park, Ho, & Kim, 2014). Hence, this present study gives a better picture of cyclone occurrences within PAR with the aid of maps.

The temporal decrease in the year-to-year variability of the annual number of TCs in WNP was observed from 1959 to 1991 (Rupp & Lander, 1996) and the same trend was observed within PAR crossing the Philippines from 1951 to 2013 (Cinco et al., 2016). In a recent study conducted by Lee, Tippett, Sobel, and Camargo (2018), the Philippines has observed to experience 2–3 years return period of TCs. However, mapping the RP or percent CoC of TCs to depict the country's most active cyclone zones has never been explored. Through this approach, it is possible to identify and classify areas within PAR where tropical depressions (TD), tropical storms (TS), severe tropical storms (STS), typhoons (TY), or super typhoons (STY) are mostly and actively formed through the maximum sustained wind analysis.

1.2. Pareto Principle

In most developing countries such as the Philippines, lack of financial resources, few opportunities, and the politicisation of disaster risk management hindered the country from immediate rehabilitation, recovery and reconstruction (Alcayna, Bollettino, Dy, & Vinck, 2016) (Kure, Jibiki, Iuchi, & Udo, 2016). Some of the contributing issues include the poor implementation of vulnerability assessment to support survival funds (Blanco, 2015), lack of support to youth council participation for disaster risk reduction (Fernandez & Shaw, 2013), and the alleged funnelling of funds by corrupt politicians and political elites (Hodes, 2013; Webb, 2013). While the country is a leading regional actor in disaster risk management in South East Asia, the full picture of who is doing what, how, where and when the resilience and disaster preparedness should take place does not exist (Alcayna et al., 2016). Regardless of these issues, both the national government and local government must play an active and coordinated role in disaster governance on a limited resource (Blanco, 2015). The use of the Pareto principle can help direct this inadequate resource in order to make the maximum impact.

Pareto principle has been generalised to mean that approximately 80% of given effects (“trivial many”) can be attributed to the 20% of the possible causes (“vital few”) (Scott, 2017). Various studies were