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Potential of Hail, Rain and Gust/Wind Duration as Additional Variables for Windstorm Producing-Thunderstorms Damage Intensity Rating Scale

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ABSTRACT

Severe thunderstorms can cause damage to property and vegetations, injuries and claim the lives of humans and animals. This isdue to the heavy rain, hail, downburst and even tornadoes are severe thunderstorm by-products. Therefore, various measures have been taken to minimize the impacts. One of these measures is by developing a scale that relates to the tornado or straight-line wind intensity with potential damages such as Fujita scale, TORRO scale and Enhanced Fujita or EF-scale. However, existing scales are still controversial and have been criticized until now although many improvements have been made because some believed that they are inadequate under certain circumstances and difficult to rate consistently. Theaim of thisarticle is to justify that rain, hail and wind/gust duration should be considered as part of the variables in thewindstorm-producing thunderstorms damage intensity rating scale. The related reasons are the natural conditions of thunderstorm by-products, hail which has been proven to cause damage, different types and severity of damages, effects of wind/gust duration on certain damagesand inconsistency in damage intensity rating. The reasons cited are based on the evidencesgathered from the articles reviewed. More research needs to be carried out to ensure that the extent of the potential new variables in overcoming the shortcomings of the existing scales.

KEYWORDS: damage, gust/wind duration, hail, rain, rating, scale, windstorm producing-thunderstorms

1. INTRODUCTION

Natural disasters associated with a thunderstorm such as tornadoes and downbursts are capable of causing damage to property and losses oflife. These localized, short-lived and extreme meteorological disasters are also known as global phenomena as they can occur at any locations and time in the world. A tornado is a violently rotating column of air that is in contact with both the surface of the earth and the base of a cloudeither cumulonimbus or cumulus cloud. It can last from a few minutes to more than an hour. Mean while downburstis a strong ground-level wind system that emanates from a single source, blowing in a straight line in all directions from source which can last for periods of twenty minutes or longer. Eventhough, these thunderstorm by-products often producesimilar damage, the way a downburst produces damagesactually different from a tornado. Downburst produces damages by radiate from a central point as the descending column spreads out when impacting the ground, whereas tornado damage tends towards convergent damage consistent with rotating winds.

Thus, a scale which are classified between the intensity of the events with potential damages have been developedin order to mitigate the impacts of these disasters. In particular, the scale is a tool that can be used in risk assessment process by forecasters. The assessment can later be used to warn the local authorities and public. The local authorities and public upon receiving the warning, they can plan early preparation to minimise the impacts of the events.This is due to beneficial information on the scale which provides summarized impacts from the climatological perspective which may enhance societal response and increased preparedness [1,2].The well-known scales that relate with these two thunderstorm by-productsare Beaufort Scale [3], Fujita Scale [4], TORRO Tornado Intensity Scale [5]and Enhanced Fujita orEF-Scale[6]. The descriptive scales distinguish various levels of damages according to wind speed. A scale could provide beneficial information to the general public in evaluating the impacts from meteorological events of a particular magnitude that may have or had potential damages on the life and property of the humans [1]. The scale will describe and summarise the event's characteristics, so that it becomes much easier to assess since an event may often be complex in its their formation and behavior.

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Besidesas a supporting tool for forecasting and early warning system, the understanding of the wind speeds which caused the damage can also be used as an input in assessing design practice, construction methods and building codes[7]. Therefore, a minimum set of design specifications and/or regulations for resistance building and construction quality can be set up accordingly wherethe existing structures have to be modernised or upgraded in order to comply the safety of structures[8]. Moreover, the creation of building codes for constructing structurally sound housing and shelters can be justified [6]. The damage to structures caused by tornado or straight-line wind events, actually depends on wind hazard (i.e., risk) and the resistance (i.e., vulnerability) of structures [9].

Information on the damage caused by the tornado or straight-line wind needs to be highly precise because it will influence the decisions and preparations of the local authorities and public. At the locations where thetype of construction survived extreme winds, some believed that the building code neednot to be strengthened [10]. In the case of evacuation plans, public may not leave the building which they believe can survive the tornado or straight-line wind. If the information is false, then it is most likelythat the public will adversely be impacted because early preparations have not been plannedto confront with the disaster. This, consequently, can cause worse damage than expected.

EventhoughFujita Scale, TORRO Scale and even EF-Scale were developed years ago and have been widely used around the world, somehow, the consistency of the rating in the scale is still being debated especially in categorizing tornadoes based on the post-storm characteristics of the damages from climatological perspectives. For example, there are inaccuracies in the existing scales (e.g Fujita Scale) because the scale development does not consider variations in construction quality and analytical basis on the movement of large objects and pieces of debris [11].

Scale for tornado or straight-line wind that relates to intensity and potential damages providesmany benefits. Unfortunately, difficultiesin making consistent assessment and inaccuracies in the information have caused limitations in the use of the existing scales. However, various measures been introduced and taken have made information of the scale more precise and, thus canbe used widely. Taking into considerationthat debris during tornado or straight-line wind can cause damage, this article is written to propose a slightchange to the existing concept of scales. Besides wind parameters, precipitation parameters should also need to be considered, particularly hail since hail canact as a debris. This is based on facts by the evidences gathered from the articles reviewed. The main aim of this article isto propose both precipitation and wind duration to be emphasizedin assessment the damage by tornado or straight-line wind.

2. REASONS

Empirical evidence from the articles reviewed has prompted the five (5) reasons thatprecipitation (rainfall and hail) and wind/gust duration factors need to be considered in the windstorm-producing thunderstorms damage intensity rating scale. Theseare:

a. natural conditions of thunderstorm by-products;
b. hail has been proven to cause damages;
c. different types and severity of damages;
d. effects of wind/gust duration on certain damages;
e. inconsistency in damages intensity rating.

a. Natural Conditions of Thunderstorm By-products

Figure 1 shows statistical analyses which indicated the thunderstorm by-products can possible be associated with each otherat the ground whereby whether downburst or tornado associated with rainfall and/or hail or even between rainfall and hail only without the presence of downburst or tornado according to severe thunderstorms study cases such as [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30].

The presence and action of precipitation during severe thunderstorm shows that association between thunderstorm by-products may occur at the ground. The main factor which triggers the mechanism for downburst initiation is the melting of small hailstones inside the cloud, while the secondary factor is the evaporation of rain or hydrometeor drag by large hailstones [31]. The operational polarimetric surveillance radar generation in the future, should be to function as automatic detection of layers with melting small hail [26]. Thus, it gives an indication of potential downburst initiation or detection of developing intense downdrafts, hence can be used as early warning. It implies that there is a relationship between the role of percipitation with production of thunderstorm by-products.

The classification of accompanying phenomena associated with convective storms is not new and has been created to be used for specific purposes such as the accompanying phenomena from historical–climatological database of the Institute of Geography, Faculty of Science, Masaryk University of Brno [32]. The type of event involved of squall (i. e. gusty wind during a thunderstorm), tornado – proved occurrence, tornado – probable occurrence, strong wind and blizzard, stormy wind or gales and violent stormto understand convective storms and their impacts within the Czech Republic, so that further studies could be carried out based on these phenomena. A separate category has been created for easy identification of accompanying phenomena according to its characteristics and the damages caused. The radar-based severe weather algorithms in determining hydrometeor species like drizzle, rain, rain–hail mixture, small hail (< 2 cm), large hail (> 2 cm), dry graupel, wet graupel, dry high-density snow, dry low-density snow and wet snow is an important aspect of the severe weather systems [20]. The hydrometeor species of a specific storm may be potentially hazardous and can be used as an alert for the forecaster and issue warning to the public. On the other hand, the National Climatic Data Center (NCDC) uses seven different codes which include thunderstorm, precipitation (rain, hail and snow), duststorm and sandstorm to indicate thunderstorm in progress. Moreover, in the TorDach database, additional meteorological information (e.g. air temperature, precipitation amount or hail sizes) also be remarked beside type of the event (tornado, waterspout, downburst etc.)[33].

Severe thunderstorms recorded events have shows the precipitation role in triggering downburst initiation and classification. This categorizes the accompanying phenomena into separate categories which proves that there is a possiblity that severe thunderstorm by-products could be associated with each other at the ground. In Germany, wet downbursts which characterised by heavy rain or hail are apparently more common events compared to the dry downbursts [26]. Meanwhile, there is a study considered analysis of rainfall patterns before, during and after a typical thunderstormas part of study on wind characteristics of tropical thunderstorms [34]. Insurance records of catastrophes further reinforced this fact whereby the causes of catastrophes not only caused by hail but also some were due to tornado and hail and from the events with hail, tornadoes and floods[35].

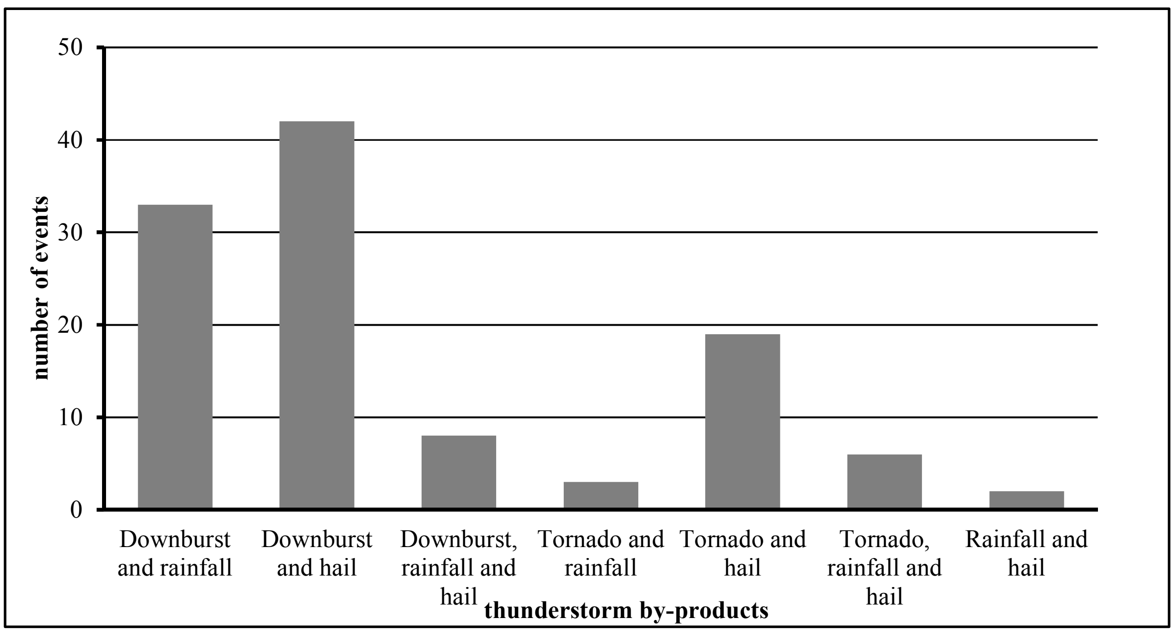

Fig. 1. Frequency of various types of association between thunderstorm by-products

b. Hail has been Proven to Cause Damages

Hail could cause a variety of damages. Besides damages to property and vegetation, it could also cause damages to humans and animals (Table 1). In Northeren Greece, crop damage is the main economic impact to farmers in the hail prone regions [36]. Potential damage caused by hail depends on the maximum diameter of hailstones, D_{MAX}[37]. This is the reason TORRO hailstorm intensity scale distinguish into several levels based on the maximum hailstone size and potential damages. The scale is intended as reference for analysis and forecasting. Since hail could potentially create the damages, several countries have set hail as one of the warning criteria to the public and the authorities. Further actions hadbeen taken to reduce the impacts of the hail. Fifteen (15) out of twenty-six (26) countries in Europe have declared that hail is used as a warning criterion [38].

TORRO tornado intensity scale and TORRO hailstorm intensity scale shows that these scales have similarities in causing damages for the building, vehicle, utilities and vegetation. However, the main difference between these two thunderstorm by-products is the type of the damages. As a result, strong hailstorm or the effect of wind is sometimes not stated as the primary cause of the damage in a certain territory [32]. The wind will cause the entire roofs removed but hail causes roof slates and broken tiles. While vehicles may be levitated by wind, hail does not do so. Instead, it can cause the bodywork of the vehicles visibly pitted. The wind makes objects (debris) becomes airborne causing secondary damags, but hail, otherwise acts as debris itself. In other words, an object which are damaged by the wind is pushed at longer distances compared to the hail. According to the scales, winds also would also be able to cause more diverse damage to the more resistant objects. The comparison only involves TORRO scales since these scales developed by the same agency.

Table 1. Sample of hail events and its associated damages

Date	Place	Hail size (mm)	Damage	Source
August 18th,1971	Brive (Corrèze), France	-	People killed	[37]
July 13rd, 1984	Munich, Germany	10	Building, good, and vegetation heavily damaged	[28]
May 5th, 1995	Fort Worth, TX, United States	> 11.5	People injured	[46]
March 28th, 2000	Fort Worth, TX, United States	> 11.5	People injured	[46]
May 7th, 2000	Bracknell, Berkshire, England	15 – 30	Garden were completely destroyed	[47]
August 16th, 2003	Alcaniz, Ebro Valley, Spain	12	Car and street furniture damaged	[48]
April 3rd, 2004	New Mexico, United States	30	Home damaged	[49]
September 11st, 2004	Toulouse, France	-	Animal killed	[37]
September 11st, 2004	Ebro Valley, Spain	34	Agriculture and property damaged	[50]
October 16th, 2006	Padstow, North Cornwall, England	20 – 22	Light structural, vegetation and crops damaged	[40]

c. Different Types and Severity of Damages

Table 2 shows severalsevere thunderstorms events and their by-products associated at the ground with its produced damages. The damagesare quite similar with the damages listed in the Fujita Scale, TORRO Scale, EF-Scale or TORRO Hailstorm Intensity Scale. This proven that the presence of rain and hail with strong winds will also affect the damages. The effect of rain and falling hail is the main reason the damages produced during tornado or straight-line wind events on May 9th, 2003 in Southwestern Slovakia. The event destroyed electric power line poles, agricultural plants, vegetables and fruit in fields and gardens. Such damages were not in the supposedly wind speed or even hail rating classification [24]. This is due to the reason thatdamaging potential of hail will increase if the hailstone velocity increases. Wind that is produced from downburst by the precipitation of hail and rain acts as horizontal component to increase hailstone velocity [37]. Hail and wind could cause enormous property damages during storm because the enormous size of the hailswath increases the likehood of damages [39]. Near-continuous production of hailstones is often associated with high winds and hail fell over the area. The presence of wind could enhance the damaging potential of the hail and produce visible damage. Moreover, surface wind speed is one of the factors that should be considered if available since its can reflect the increment in TORRO Hailstorm Intensity Scale rating [40].

Characteristics of hail, which are solid, hard and granular could cause damages since hail can act as flying debris during a tornado or straight-line wind. There are several factors affecting the relationship between damage and wind speed for any particular event. One of them is the impact of flying debris because it can change the response of a structure [41]. Similar damage also can be caused by hail if it involvesa vegetation. The wind speed is not only the factor influencing the degree of tree debarking but also the amount of flying debris and the strength of the thickness of the bark as well [42].

Although hail seems to give more impacts than rain, it does not mean strong wind accompanying rain is not noteworthy because rain can also enhance the effects of damages. For example, the rain causes the land to be wet and this makes trees much easier to be uprooted than just a break at a certain wind speed. TORRO scale at T0 states that trees will be broken at the wind speed 21.5 ± 3.5 m/s but on wet unstable soil, tree will be uprooted. Another example is the broken windows and sliding doors due to wind loads that cause water penetration into the buildings and damage to the interiors. This damage was experienced at Guam Reef Hotel on September 16th, 1997 [10].

Evaluation of the potential damages by winter storm may require the consideration of wind and precipitation. These are evidences indicating that the combination of these two factors can cause damages. In evaluating disparate impacts winter storm instead of societal susceptibility, wind and precipitation (snowfall accumulation, snow density, relative timing of the strongest winds and heaviest precipitation, occurrence of freezing rain, presence of snow mixed with rain and gust duration winds) are the other factors [2]. Precipitation together with strong winds could lead to a larger societal impact during winter storm [1, 2].

The presence of other elements such as storm surges during strong winds, will increase the damaging effects. Some events have shown that damages occurred under the classified wind speed. The use of the EF-Scale to predict hurricane wind damage based on peak wind speeds is discouraged because wind from the hurricane is co-mingled with storm-surge action whereby storm-surge is another different element [43]. Hurricane storm surge constitutes a greater hazard to lives and coastal property than hurricane winds [44]. The combination between precipitation and wind factors can be taken into account to assess the damage by winter storm. Heavy rain may accompany a hurricane and causes similar damage [45]. Therefore, variety of damage as a consequence from the association need to be addressed.

Table 2. Sample of association between thunderstorm by-products events with its produced damages

Date	Place	Type of event	Damage	Source
July 12nd, 1984	Southern Bavaria, Germany	Downburst, hail and rainfall	People injured, buildings, goods, and vegetation heavy damaged	[28]
November 3rd, 2000	Sydney, Australia	Tornado, downburst, hail and rainfall	Property damaged	[21]
March 23rd, 2001	Southern Germany, Germany	Downburst and hail	Tree uprooted and snapped, roof damaged	[22]
May 22nd, 2001	Vitosha mountain and Jeleznitsa village, Bulgaria	Tornado, downburst and hail	Wood and houses damaged	[19]
July 9th, 2002	Munich, Germany	Downburst and hail	Tree uprooted and forest damaged	[26]
March 12nd, 2003	Gangetic West Bengal, India	Downburst, hail and rainfall	People injured, houses damaged and wall of the well-built structures collapsed	[53]
May 9th, 2003	Southwestern Slovakia, Slovakia	Downburst, hail and rainfall	Electric power line pole destroyed, roof and vehicle damage, agricultural plant, vegetable and fruit in field and garden were almost completely destroyed	[24]
October 4th, 2007	Palma, Spain	Tornado, downburst and rainfall	Tree, traffic sign and light tore down, people injured and killed	[29]

d. Effects of Wind/Gust Duration on Certain Damages

Several authors believed that the wind/gust duration during storm must be considered because these variables canaffect the damage. The rapid changes in wind direction will minimize the chance of a particular component of a building to receive maximum loading throughout the storm [43]. On the other hand, a component which experiences high wind pressures in shorter time duration most probably will not receive maximum loading that can lead to widespread fatigue failures. The failure and subsequent flight of small elements, like roof sheathing, depend not only on the local flow field above the roof and the wake downsteam of the structurebut also on the gust duration and characteristics of the debris elements as well [7, 51]. Wind duration is one of the factors that can influence the damage [2, 41]. In addition, randomness of the duration, intensity and time of occurrence is the stochasticfeatures of the storm [52]. The duration of the wind/gust can not be ignored because the combination of these three characteristics will produce a variety of action patterns that could produce various types of damages. This is due to the relationship between damages and wind speed for any particular event that involves the nonlinear interaction of a complex wind fields in space and time with a unique set of structures [41].

e. Inconsistency in Damages Intensity Rating

Inconsistency in rating is still a problem until to-date, eventhough several improvements have been made to overcome the deterrent reasons. There are certain damages of categories F3, F4 and F5 in F-Scale where overestimates its wind speeds, these being indicated by analytical calculations of wind speeds [54, 55]. As a result, this could lead to over- or under-rating of the existing scales. Differences in rating F-class between tornadoes in France and America where most tornadoes F2 and F3 in France have paths of greater width but shorter length [14]. A tornado that struck La Plata, Maryland in April, 2002 being over-rating at the first place by

National Weather Service (NWS) office, however after subsequent review, official rating eventually was downgraded[41]. Mean while, tornado struck province of Upper Austria in March, 2008 is otherwise, tornado is being classified as F0 which is under-rating, even though a few media report suggested tornado that been strucked supposed to be F1 or F2 according to photographic evidences[56].

There are factors have beenimplicated as hindering factors of the rating consistency to the existing tornado or straight-line wind rating scale in terms of itsover- or under-rating. Differences in construction between countries, ability of individuals and workers, various quality of constructionand movement of large objects and pieces of debris during storm are the factors that could lead to over- or under-rating of the existing scales[11, 14, 40, 41]. However, if according to movement of objects and debris during storm, there is no exaggeration to say that the presence of rain or hail during storm and gust duration can also be the factors that should be given attention.

3. CONCLUSION

Scale has been widely used in evaluating the risk of natural disasterbecause the scale can simplify complex relationships between atmosphere and earth, thus making iteasy to be referredand utilized. The main scales for wind related disaster are Beaufort Scale, Fujita Scale, TORRO Scale and EF-scale. However, these tornado or straight-line wind intensities scalesare still being a subject of long debate and controversy, although Fujita Scale has gained the widest acceptance internationally over two decades. This includes the EF-Scale which has been enhanced in terms of itsconceptual improvements compared to Fujita Scale due to some believe that the scales are inadequate under certain circumstances.

Since existing scales still have their weaknesses, the existing scales is suggested need to be modified by adding new variables namely rain, hail and wind/gust duration. This is based on the evidences from the articles reviewed. Rain and hail are normally emphasized because they are oftennaturally accompanying tornadoes and downburst at the ground. There are evidences from recorded events which indicates the role of the rain and hail initiating downburst and tornadoes from convective storm and association classification that has existed.In addition, the presence of rain and hail during strong winds will increase and diversify the effects of damages. This causes thewind speed being lower than the classified speed. This is due to the different actions on objects by hail compared to wind and hailstone speed. In fact, there are recorded events showingthat the damagescan be caused by the association between wind and precipitation. Wind/gust durationis alsoproposed since there aredamages only produced if the concentration of intensity at that components beyond the period of time thecompenentsare able to withstand. It can be concluded that the concept of wind, precipitation and duration as part of variables in the scale that relates to potential damage is not a new concept of scale since the concept has been applied in the scale for winter storms/nor'easters in the Eastern and Central United States and Local winter storm scale. On the other hand, the evidences have indicatedthe need to propose new variables that influence the damagesand suggested reasons as part of the consideration. Difficulty in consistency rating of tornadoes or straight-line wind according to existing scales is still a problem as the deficiencies have yet to be fully resolved. This creates a possibility that the new variables should be taken into consideration and to be included in the future in order to improve the existing scales.

Evidences gathered from the articles reviewed show that rain, hail and wind/gust duration has a potential to be considered in the existing scales in order to rate tornadoes or straight-line wind. It is believed to be more accurate and can be widely used, eventhoughmore studies are needed prior to the improvements. If proven effective, the next step is to carry out further studies on how the proposed modified scale can be leveraged as aninput for tornado or straight-line windearly warning system or other uses. In getting a clearer picture, it is recommended that the scales which relates between wind, hail or rain with potential damage should be scrutinized to identify how far its suitability if combined together. Information in the scale needs to be precise because inaccuracies will cause adverse effects on the various parties.

Moreover, there are also established scales that have been modified or enhanced which are intended to make the scales more accurate, thus be used extensively. As examples of these are the Modified Mercalli Intensity (MMI) scale and Enhanced Fujita scale (EF-scale). Modified Mercalli Intensity (MMI) scale is a scale that began as a shorthand description of earthquake intensity in terms of levels of damage. However, it had been modified in the recent years by combining other new variables to provide damage curves. As a result, MMI scale converted from intensity scale to magnitudes scale and later used to calculate the magnitudes of pre-instrumental earthquakes that gave more comprehensive earthquake losses estimation. Quantities involved in magnitude scales are believed more measurable, scientific and/or rational compared to intensity scales. On the other hand, EF-scale has been enhanced from Fujita scale with aim to lead more consistent and more accurate estimates of tornado intensities by increasing the amount of detail that goes into determining the rating such as damage indicators, construction quality and variability and correlation between damage and wind speed. These two examples show that the existing rating scales are long lasting and not rigid. They can be modified or enhanced if the accuracy of the scales is questionable and their application is limited.

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