

Article

Cosmogenic Radionuclide-Beryllium 7 (^7Be) for Monsoon Rainfall Forecasting in Malaysia: A Systematic Literature Review

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Abstract— Within the region of India, monsoon prediction was reported to use the concentration of ^7Be cosmogenic radionuclide that contains crucial information such as atmospheric behaviour change. This review aims to identify and analyse the existing research on the usage of ^7Be Cosmogenic radionuclide in assisting weather forecasts, especially rain onset and withdrawal in the monsoon season and the correlations of rainfall and monsoonal variation in Malaysia. A comprehensive search of major scientific databases was conducted, and relevant studies were selected based on inclusion and exclusion criteria between January 2017 and August 2022. The review found that the method of utilising ^7Be as a parameter in monsoon forecasting for India is newly developed and only be assessed using the trans-equatorial method. The review also highlighted the expectation that the ^7Be concentration analysis throughout the years could provide new insight into understanding monsoon behaviour and can be further utilised in forecasting the rainfall intensity during a wet season in Malaysia.

Keywords— Cosmogenic Radionuclide, Beryllium-7, atmospheric tracer, rainfall, northeast monsoon

I. INTRODUCTION

Monsoon prediction within the Indian region based on the concentration of ^7Be cosmogenic radionuclide within the northern and southern parts of the hemisphere has been reported [1]. The ^7Be was used as it is an important tracer of cosmogenic radionuclides resulting from the spallation of nitrogen and oxygen after interaction with energetic free neutrons at high altitudes. Therefore, cosmogenic radionuclides will follow the path according to the wind which is determined by pressure and temperature differences from a high to a lower altitude until reaches the ground and are

deposited in the soil or ocean. Then, some cosmogenic radionuclides could reach and detect on the ground depending on the half-life. The existence of ^7Be at high altitudes makes a cosmogenic radionuclide widely used as an atmospheric tracer, whose evaluation and forecasting can provide valuable information on changes in atmospheric behavior [2]. Several other cosmogenic radionuclides reached the ground and became important traces for soil erosion and dating of ancient rocks or other objects as reported by [3][4][5] and [6]. In this regard, the concentration of cosmogenic radionuclides provides crucial information so that it should be detected and recorded immediately and continuously.

This systematic review examines the important aspects of the use of cosmogenic radionuclides-7Be as a climate change atmospheric tracer indicating that it is also can be used in the Malaysian environment. It was reported that the volume of rainfall has a negative correlation with the 7Be concentration of radionuclide [7]. It has been also demonstrated in [8], where the removal of 7Be increases with increasing air humidity and increasing precipitation. However, most past studies were conducted at higher meridians where the pressure and temperature are largely different compared to locations along or near the equator. It is well known that the air pressure, temperature, and wind direction within the equator region have strongly influenced by the climate condition in the northern and southern parts. Therefore, it is interesting to study the possibility and how cosmogenic radionuclides play the role in forecasting monsoons for the region within the equator where this region consists of wet and dry season only.

On the other hand, one example of how nuclear science and technology are employed for civilian purposes is in an environmental study. Furthermore, 7Be is one of the naturally occurring radionuclides being monitored under the Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO) because its behavior and distribution are closely sensitive to atmospheric conditions [9].

In this regard, 7Be, as an atmospheric tracer, has been studied extensively by many researchers and organizations around the world concerning its relationship with the weather [9][10][11][12][13][14][15] and could provide new insight in the study of rainfall intensity in Malaysia. Furthermore, as described by [16], this study can fill the gap in the use of a new parameter, 7Be, for the forecasting of rain events during the Meridional Surge (MS) and Easterly surge (ES) during Northeast Monsoon (NEM) in Malaysia.

In the reported studies, raw data on cosmogenic radionuclides detected and recorded at the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) Radionuclide stations has been analyzed to study the applicability of 7Be to forecast rainfall for the regions located close to the equator at the south and one of the countries in the maritime continent. Areas close to the equator have a variety of weather conditions [17]. There has been research conducted on cosmogenic radionuclides and the weather in Kerala, India which is an area that is quite different geographically from Malaysia. According to [18], different locales have different factors affecting their meteorological characteristics. Therefore, this technique has the potential to be used to estimate the monsoon phenomena in Malaysia.

1.1 THE NEED FOR SYSTEMATIC REVIEW

Compared to traditional literature reviews, the systematic review has several advantages and be as a way to come up with a solid and sensible response to a specific research question. In contrast to traditional narrative reviews, systematic literature reviews (SLR) use a reproducible, scientific, and transparent production process [19]. A well-designed SLR process is crucial because it guarantees that the work is thoroughly planned before the review activity itself begins. On the other hand, systematic reviews are made specifically to uncover scientific breakthroughs and trends more speedily and correctly as well as to reduce or minimize

the biases that are frequently present in expert reviews [20][21].

Meanwhile, a study related to monsoon rainfall prediction as reviewed by [22] showed it has been studied actively by many researchers globally and India is the most active country that published articles related to monsoon rainfall forecasting. Due to its complicated mix of islands and seas, as well as its mountainous geography, weather forecasting and climate over the Maritime Continent (MC) continues to be challenging [23]. Quite an extensive amount of study has been done related to monsoon and rainfall forecast, however, only a limited number of studies were performed within the maritime continent[24]. Furthermore, none of those work use cosmogenic radionuclide or specifically 7Be as one of the parameters in the prediction process.

However, there were a significant number of articles, especially from the Journal of Environmental Radioactivity that study about 7Be and their correlation with local meteorological parameters such as humidity, wind speed, temperature, and pressure. Their research leads to the assumption that 7Be has the potential and need for studying rainfall intensity during NEM in Malaysia. Thus, the goal of the current work is to fill this gap by thoroughly reviewing all the pertinent literature and determining how the findings regarding 7Be may be used in the study of forecasting rainfall intensity during Malaysia's NEM.

This review will adopt a method to look for in-depth information in terms of the use of keyword identification, article screening, article eligibility, and database use. Such a study can reduce the time of other researchers who are interested in doing the same study in the future. Furthermore, this work is significant because it sheds light on the amount of the peer-reviewed literature's focus, enabling researchers to give a perspective for comprehending future attention connected to rainfall intensity during Northeast Monsoon that demands scholarly attention. Table 1 below describes a set of research questions included in this study:

Table 1. Research questions used in this study

No.	Questions
RQ1	How many studies focus on 7Be in the study area near or in the maritime continent territories?
RQ2	Is the study based on previous studies?
RQ3	Is the paper describing the study on 7Be from the air surface in terms of rainfall or is related to monsoon?
RQ4	Does the paper detail the method for data and its processing?

The necessity for a comprehensive review of rainfall intensity forecasting during NEM is discussed in this section, and the methodology used to find the answer to the research question posed by the current study is presented in the section that follows. The third section then does a thorough assessment and synthesis of the scientific literature to separate, choose, and assess significant research on the viability of using 7Be as a useful metric for predicting rainfall intensity during NEM. Finally, the last section discusses the findings.

II. METHODOLOGY

2.1 Preferred Reporting Items For Systematic Reviews And Meta-Analyses (Prisma)

In general, publication standards are crucial to providing authors with the pertinent and important knowledge they need to assess and look into the fineness and depth of a review. This paper conducts a systematic review of the literature on the use of cosmogenic radionuclides, specifically ^{7}Be , in weather-related application areas using SLR tools called the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). It is available at www.prisma-statement.org. The literature review combines four phases which are identification, screening, eligibility, and inclusion [25] [26]. The method of the PRISMA used in this study is shown in Figure 1. SLR is a technique for evaluating, assessing, and analyzing the published article related to a research topic or problem of interest. As claimed by [27], and [28], PRISMA is suitable for the environmental management field because it clearly defines the research questions towards the need for a systematic review even though PRISMA is often utilized within medical studies. Additionally, PRISMA examines a sizable collection of scientific literature at a predetermined time, enabling precise or accurate term searches concerning the study of ^{7}Be in weather-related applications with a focus on rainfall and monsoon.

2.2. Resources

In any review process, the selection of the databases such as the ProQuest Central, Scopus and ScienceDirect were selected. ProQuest Central offers more than 12k scholarly journals while Scopus offers more than 87+ million scholarly articles while ScienceDirect offers more than 1199 journals with open access. Both Scopus and ScienceDirect belong to the same publisher Elsevier. However, these two databases function in two different manners. Scopus is working as an indexing/citation database that covers a great number of journals without full-text articles from those journals. Further, it acts as a multidisciplinary database. The full-text articles published in those indexed journals by the Scopus database are located in the ScienceDirect database. Each of these databases offer particular benefits as well as a unique search method. It is preferable to use as many databases as possible to prevent missing any articles that might be important to the investigation. Some search techniques limit the number of Boolean operators and disallow the usage of the asterisk (*) as a wildcard search method.

2.3. The Systematic Review Process for Selecting the Articles

2.3.1. Identification

The use of search terms or keywords is crucial when choosing and identifying articles that are truly relevant. Excluded terms are just as crucial as the search strings to avoid getting search results that are less relevant to the current study. As a result of preliminary observations from the articles obtained, final search strings and terms to be excluded were developed. This is shown in Table 2. Most importantly, the current review successfully retrieved a total of 218 articles from three main databases, and an additional 30 articles were found through manual searches based on related terms in other databases. All articles must be written in English and the selection is only for research articles.

2.3.2. Screening

The first step of the systematic review procedure yielded a total of 248 articles. The first step of screening cleared the duplicate articles. In this case, 206 papers were screened using inclusion and exclusion criteria decided upon by the researchers in the second stage, whereas a total of 42 articles were excluded during the first stage. Inclusion and exclusion criteria were used to exclude papers not applicable for evaluation. It is also possible to specify the inclusion and exclusion requirements before and during the review process. The first criterion concerned the type of literature, and the researchers decided to limit the attention to journal papers because they serve as the key sources for ^{7}Be empirical data. This further means that the current research did not include publications in the form of systematic reviews, reviews, meta-analyses, meta-synthesis, book series, books, chapters in books, or conference proceedings. It should be mentioned as well that the review was limited to English-language articles. Moreover, it is crucial to note that a timeline period from 2017-2020 was chosen for this study. Other than that, only studies conducted in the maritime continent and nearby territories were selected because they are in line with the objective of the review. Overall, a total of 150 articles were excluded based on these criteria as shown in Table 3.

2.3.3. Eligibility

A total of 98 articles were prepared for the third stage known as eligibility. The titles, abstracts, and main body of each article were carefully inspected at this point to make sure they met the inclusion criteria and were appropriate for use in the current study to meet the research objectives. As a result, 87 articles in total were eliminated because they either did not focus on the use of ^{7}Be in weather-related studies but instead used other radionuclides, such as ^{24}Na , ^{10}Be , or ^{210}Pb , or the discussions do not have enough detail about monsoons and rainfall on maritime continents or nearby countries and territories. Finally, a total of 11 remaining articles shown in Figure 2 are ready to be analyzed.

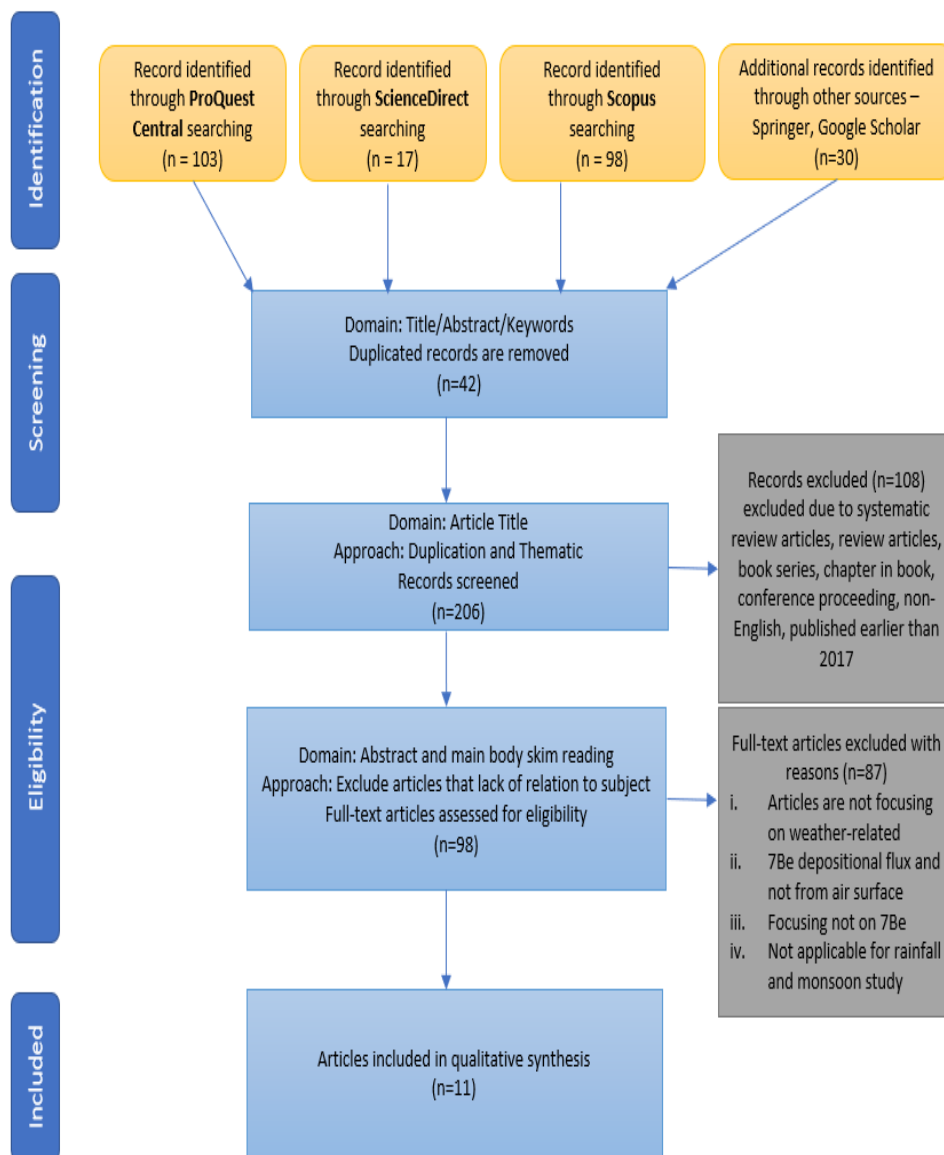


Figure 1: Flow Diagram of the study (adapted from Moher et.al, 2009)

Table 2. The total number of publications from each database, as well as the search and excluded words used

Databases	Search string and terms	No. of articles
Scopus	beryllium-7 AND weather AND NOT soil AND NOT sediment)	4
	(beryllium-7 AND rainfall AND NOT soil AND NOT sediment)	8
	(beryllium-7 AND meteorolog* AND NOT soil AND NOT sediment)	32
	(beryllium-7 AND weather AND meteorolog* AND NOT soil AND NOT sediment)	2
	(beryllium-7 AND atmospher* AND NOT soil AND NOT sediment)	69
	(beryllium-7 AND monsoon AND NOT soil AND NOT sediment)	5
	(beryllium-7 AND rainfall AND atmospher* AND weather AND monsoon AND meteorolog*)	0
	Total number of articles after duplication is removed	98
Science Direct	beryllium-7 AND weather AND NOT soil AND NOT sediment	3
	beryllium-7 AND rainfall AND NOT soil AND NOT sediment	2
	beryllium-7 AND meteorological AND NOT soil AND NOT sediment	13
	beryllium-7 AND weather AND meteorological AND NOT soil AND NOT sediment	3
	beryllium-7 AND atmosphere AND NOT soil AND NOT sediment	12
	beryllium-7 AND monsoon AND NOT soil AND NOT sediment	1
	Total number of articles after duplication is removed	17
ProQuest Central	(beryllium-7 AND weather) NOT soil NOT sediment	39
	(beryllium-7 AND rainfall) NOT soil NOT sediment	60
	(beryllium-7 AND meteorolog*) NOT soil NOT sediment	42
	(beryllium-7 AND weather AND meteorolog*) NOT soil NOT sediment	21
	(beryllium-7 AND atmospher*) NOT soil NOT sediment	89
	(beryllium-7 AND monsoon) NOT soil NOT sediment	20
	(beryllium-7 AND rainfall AND atmospher* AND weather AND monsoon AND meteorolog*) NOT soil NOT sediment	5
	The total number of articles after duplication is removed	103

Table 3: Determination of Conditions for Inclusion and Exclusion Criteria

Criterion	Eligibility	Exclusion
Literature type	Journal (research articles	Book series, chapter in a book, conference proceeding
Language	English	Non-English
Timeline	Between 2017 and August 2022	< 2017
Countries and territories	Maritime continent and nearby	Far from the maritime continent
Subject area	7Be from surface air, rainfall, monsoon, seasonal weather	Other than 7Be, non-seasonal weather

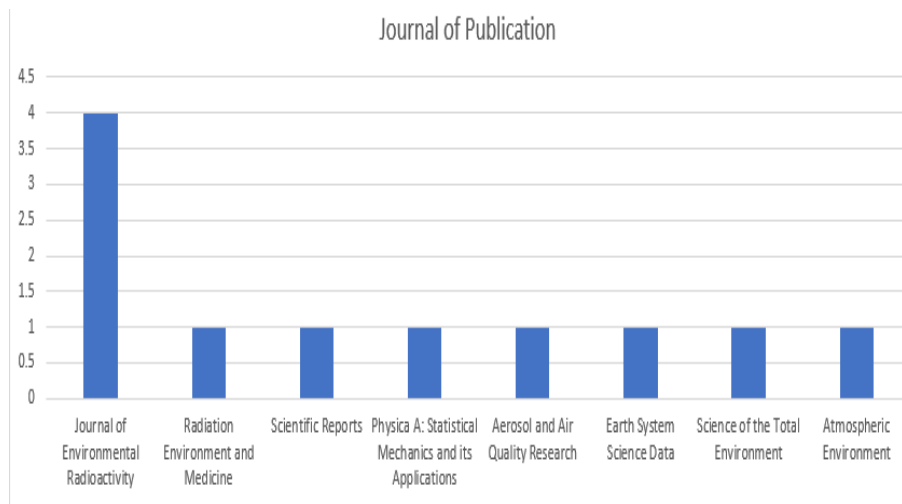


Figure 2: Title of journal selected in this study after screening process using PRISMA technique related with ^7Be and applications in weather technology.

III. RESULTS

3.1 General findings

The publication of particular articles is depicted in Figure 2 below. This data depicts that the Journal of Environmental Radioactivity published the majority of the study's articles. A summary of the selected articles based on journal publishing is shown in Figure 3. While Table 4 shows the author, title, publication year, journal, location under study, study period, and data sources. Note that data sources have been categorized into university and CTBTO only. The data by CTBTO are not publicly available. It is however accessible either by a principal or regular user as firstly granted by the CTBTO via a cost-free confidentiality agreement.

Data categorized as "university" indicates that it was presumably gathered on campus or by using its resources. Assuming that the collected data is kept under the university or the institutional own storage. On the other hand, one of the selected articles by [29] collects and sorts data from almost 495 other articles. Even though the majority of the location in the list is not located in the maritime continent (MC), some are located near the territory. Anyhow, it could be used as a good reference for future study as well. This study makes it quite clear that there has been very little research on the usage of ^7Be in the MC region and even lesser in Malaysia.

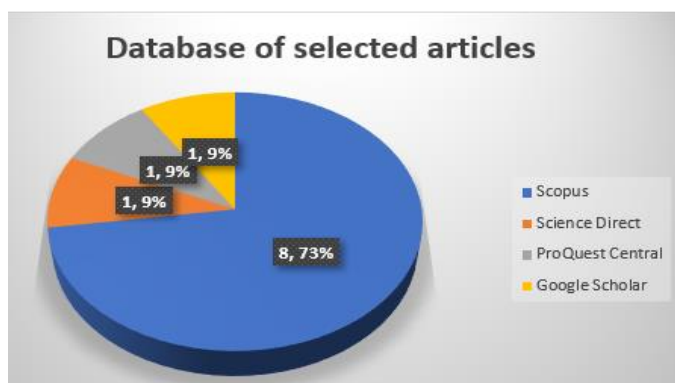


Figure 3: Database of selected articles

3.2 Main findings

The first study using a global network of ^7Be detection is reported in [30]. Using the pattern of ^7Be activity concentration profiles measured from 2001 to 2015, the global structure of the ITCZ, Hadley-Ferrel convergence zone (HFCZ), and Polar-Ferrel convergence zone (PFCZ) is rebuilt. Particularly for latitudes between 10 and 50 in both hemispheres, a similar pattern was seen. To observe the pattern change, the ^7Be concentration data were plotted in time series obtained at two stations located at different latitudes, and similar longitudes were compared. In 2019, [1] proved that ^7Be concentration can be used to predict monsoon onset and withdrawal in Kerala, India with an accuracy of ± 3 days, 2 months in advance compared to 1–3 weeks in advance by traditional methods whereas withdrawal prediction in a lead time of 42 ± 7.3 days.

On the contrary, articles selected in this review such as [30], introduced parameterization describing a decrease in the daily ^7Be activity concentration in the atmosphere due to precipitation and its recovery during the precipitation-free period. Although not close to the maritime continent, the paper discusses another important element, which is how to possibly calculate rainfall intensity using ^7Be as an indicator of prediction. Most research on ^7Be and weather-related only study on the relationship or correlation between rainfall and ^7Be . The study, on the other hand, takes a different approach and goes into greater detail about rainfall and ^7Be . On the first day of precipitation, daily values of ^7Be activity concentration decreased by 2% - 82% and averaged 37% - 21%. It is also discovered that an increase in precipitation length and intensity causes a significant decrease in daily ^7Be activity concentration. Within 1-2 days after a day of precipitation, the atmospheric ^7Be activity concentration returns to normal.

Results from earlier studies demonstrate a strong and consistent association between meridional surge (MS) and ES in increased precipitation during NEM in Malaysia[16]. MS can penetrate far into the tropical region, inducing convection and precipitation in Southeast Asian countries, especially around the South China Sea (SCS) and the Philippines Sea (PHS) [31].

Table 4. Shortlisted Related Studies in The Usage of 7Be for Monsoon Forecasting in Malaysia

Authors	Title	Year	Database	Publication	Location under study	Period	Data Source
Terzi L., Kalinowski M.	Worldwide seasonal variation of 7Be related to large-scale atmospheric circulation dynamics	2017	Scopus	Journal of Environmental Radioactivity	63 RN CTBTO stations	2001-2015	CTBTO
Mohan M.P., D'Souza R.S., Rashmi Nayak S., Kamath S.S., Shetty T., Sudeep Kumara K., Yashodhara I., Mayya Y.S., Karunakara N.	A study of temporal variations of 7Be and 210Pb concentrations and their correlations with rainfall and other parameters on the South West Coast of India	2018	Scopus	Journal of Environmental Radioactivity	Mangalore and Kaiga on the South West Coast of India	2014–2017	University
Akata, Naofumi; Shiroma, Yoshitaka; Ikemoto, Norihiro; Kato, Akemi; Hegedus, Miklos; Tanaka, Masahiro; Kakiuchi, Hideki; Kovacs, Tibor;	Atmospheric concentration and deposition flux of cosmogenic Beryllium-7 at Toki, Central Part of Japan	2018	Google Scholar	Radiation Environment and Medicine	Toki City, Gifu, JAPAN	Sep 2013 - March 2017	University
Cruz P.T.F., Bonga A.C., III, Dela Sada C.L., Olivares J.U., Dela Cruz F.M., Palad L.J.H., Jesuitas A.J., Cabatbat E.C., Omandam V.J., Garcia T.Y., Feliciano C.P.	Assessment of temporal variations of natural radionuclides Beryllium-7 and Lead-212 in surface air in Tanay, Philippines	2019	Scopus	Journal of Environmental Radioactivity	Tanay, Philippines	January 2012 to December 2017	CTBTO
Terzi L., Kalinowski M., Schoepfner M., Wotawa G.	How to predict seasonal weather and monsoons with radionuclide monitoring	2019	Scopus	Scientific Reports	Kerala, India	2003–2018	CTBTO
Longo, Alessandro; Bianchi, Stefano; Plastino, Wolfango;	tvf-EMD based time series analysis of 7Be sampled at the CTBTO-IMS network	2019	Science Direct	Physica A: Statistical Mechanics and its Applications	28 RN CTBTO stations	2003 to 2009, while all series end on March 2016	CTBTO
Liu G., Wu J., Li Y., Su L., Ding M.	Temporal variations of 7be and 210pb activity concentrations in the atmosphere and aerosol deposition velocity in Shenzhen, south China	2020	Scopus	Aerosol and Air Quality Research	Shenzhen, South China	January to December 2017	University
Zhang, Fule; Wang, Jinlong; Baskaran, Mark; Zhong, Qiangqiang; Wang, Yali; Paatero, Jussi; Du, Jinzhou	A global dataset of atmospheric 7Be and 210Pb measurements: annual air concentration and depositional flux	2021	ProQuest Central	Earth System Science Data	270 sites	1955 and early 2020	collect published papers between 1955 and early 2020
Dmitrii A. Kremenchutskii,	Influence of precipitation on the daily beryllium-7 (7Be) activity concentration in the atmospheric surface layer	2021	Scopus	Journal of Environmental Radioactivity	Sevastopol, Crimea	2011–2020	University
Huang S., Huang P.-R., Newman S., Li K.-F., Lin Y.-C., Huh C.-A., Lin N.-H., Hsu S.-C., Liang M.-C.	Enhanced stratospheric intrusion at Lulin Mountain, Taiwan inferred from beryllium-7 activity	2022	Scopus	Atmospheric Environment	Mt. Lulin, Taiwan	2010	University
Liu X., Fu Y., Wang Q., Bi Y., Zhang L., Zhao G., Xian F., Cheng P., Zhang L., Zhou J., Zhou W.	Unraveling the process of aerosols secondary formation and removal based on cosmogenic beryllium-7 and beryllium-10	2022	Scopus	Science of the Total Environment	Xi'an, Guanzhong Basin	September 2020 to February 2021	University

This statement is further strengthened by a study from a group of researchers from the Malaysia Meteorological Department [16] where they claimed that one of the primary factors known to contribute to extreme Malaysian rainfall occurrences during the boreal winter or northeast monsoon is the cold surge or meridional surge. During this period, large pressure gradients develop between the Siberian High and the South China Sea (SCS). Whereas for the easterly surge, it was discovered that the easterly surge induced convergence

with the easterly winds coming from the western north Pacific Ocean (WNP) [32]. For that reason, the remaining selected papers were chosen as relevant as they might be a location where the wind flow brings along 7Be together with the particles to which they were attached. Each of these articles contains information about 7Be and its temporal variations at those places. Observing the variations and fluctuations of 7Be in this area hopefully could help us understand about 7Be and the monsoon characteristic in MC territories as shown in

Figure 5, and even further for Malaysia. Figure 4 shows International Monitoring Station (IMS) radionuclide network.

All of the research findings from the identified papers show that numerous studies using ^7Be and meteorological parameters have been conducted and assist a seasonal or monsoonal weather prediction in the desired location. Most studies rarely study the relationship between ^7Be and typical meteorological parameters in the MC area, which has more dynamic weather variability compared to other areas in the world. Due to the complex combination of islands and seas, as well as its mountainous geography, forecasting weather and climate over the MC continues to be difficult. The monsoon system has a significant impact on the MC. With two transitional times in between, its two primary monsoons are the summer and winter monsoons, which correlate to the boreal summer and winter, respectively. As also reported [23], Ramage's work in 1968 brought attention to the significance of the MC as the primary energy source for global atmospheric circulation. It was noted that the MC, which is

located in Southeast Asia, produces the most latent heat among the three tropical continental regions such as Latin America, the Afrotropics, and Southeast Asia that act as a convective centre. When water vapor is transformed into moisture during condensation in the process of convection, the latent heat of condensation is released. Thus, a tremendous quantity of energy is released into the atmosphere from this area, especially during the boreal winter.

Rainfall is among the most important climatic elements of the MC [33] as it is uniquely located in the world's most active convective area. However, the lack of a dense rain gauge network prevents us from knowing with certainty what the characteristics of the rainfall are in the MC [34][35][36][37], because most unpopulated land locations lack access to rain gauge data, and ocean areas do not have access to gauge observation [39].

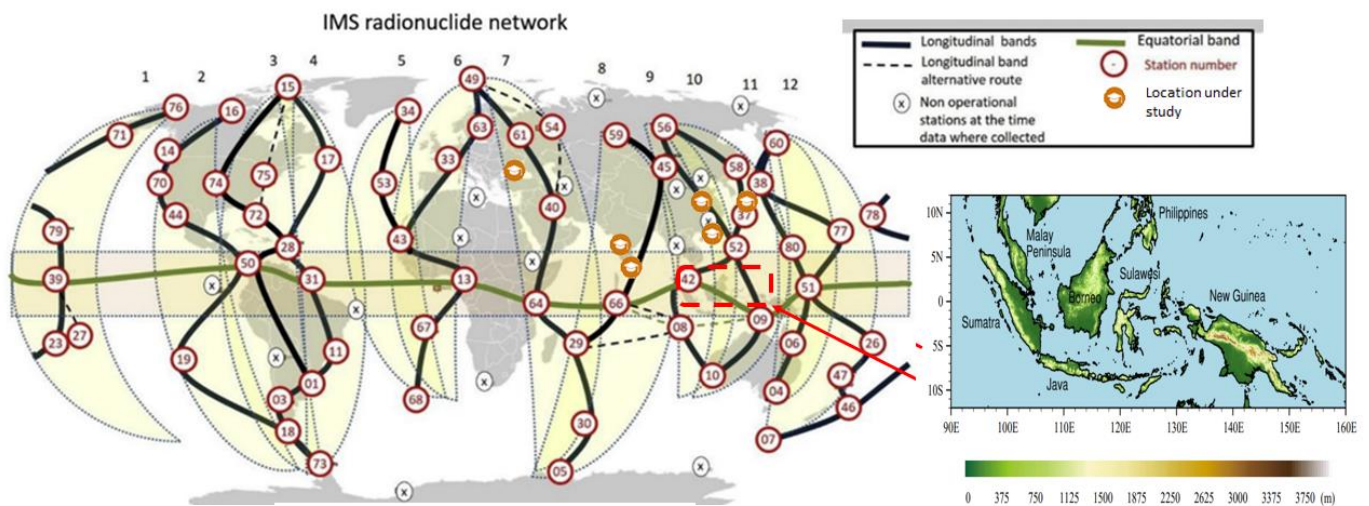


Figure 4: International Monitoring Station (IMS) radionuclide network divided into 12 longitudinal bands and 1 equatorial band by [38]. The red dashed line indicates the maritime continent.

Figure 5: Maritime Continent [33]

IV. CONCLUSION

This article demonstrates how recent research on cosmogenic radionuclides, notably ^7Be , is the most useful parameter for weather forecasting. Although cosmogenic radionuclides have been used for different purposes since the 1960s, particularly in terrestrial and space environments. Better prospects for weather study in the MC area now exist as a result of this newly introduced parameter, especially for those who appear to still be looking for ways to define the various and dynamic weather patterns in these territories specifically.

With the addition of a new parameter, ^7Be , also known as atmospheric tracers, the investigation of rainfall intensity in MC can be taken more seriously. Additionally, numerous researchers from all over the world have provided a lot of information or the most recent information regarding the usability of ^7Be . Data sources for ^7Be concentration intensity have been monitored continuously and shared among the respective researchers. It is recommended that research is based on locations or geographic features that are relatively comparable with previously done. Furthermore, the techniques for processing large amount of data to produce results are also discussed in the corresponding articles.

The complexity of the knowledge depicted from forecast of rainfall using ^7Be , as stated in the Quran "Indeed, Allah [alone] has knowledge of the Hour and sends down the rain and knows what is in the wombs. And no soul perceives what it will earn tomorrow, and no soul perceives in what land it will die. Indeed, Allah is Knowing and Acquainted" - The Qur'an Luqman 31:34 (translated by Saheeh International) [40] that we will never get 100% forecast accuracy as the knowledge of when and how many drops of rain will fall belongs only to God. At the same time, we were asked to observe the greatness of Allah and finally submit and obey God's command and leave what is forbidden.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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