

# The Study on Datum Temperature of Concrete in Tropical Climate – Malaysia Case

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## Abstract

This study investigates the datum temperature for concrete maturity in Malaysia's tropical climate, aiming to enhance concrete strength prediction. Traditional methods are time-consuming, and the maturity method offers a viable alternative. The research establishes a customized datum temperature considering regional variability. Mortar samples of M25 and M35 were cured at 22°C, 27°C, and 32°C for 32 days, with compressive strength measured according to ASTM C1074 guidelines. Results indicated higher curing temperatures accelerated early strength development. For M25 mortar, compressive strength increased from 8.45 N/mm<sup>2</sup> at 22°C on day 1 to 28.07 N/mm<sup>2</sup> on day 32, and from 11.28 N/mm<sup>2</sup> to 28.76 N/mm<sup>2</sup> at 32°C. For M35 mortar, strength rose from 10.71 N/mm<sup>2</sup> at 22°C on day 1 to 37.20 N/mm<sup>2</sup> on day 32, and from 14.64 N/mm<sup>2</sup> to 38.08 N/mm<sup>2</sup> at 32°C. Despite variations in early strength gain, all samples achieved similar ultimate strength. The datum temperatures identified were 3.1°C for M25 and 3.5°C for M35, significantly higher than the ASTM C1074 range of -10°C to 0°C, underscoring the need for localized testing for accurate strength assessments. This study highlights the necessity of specific datum temperatures to improve the precision and effectiveness of concrete maturity methods in tropical climates.

## 1. Introduction

Datum temperature refers to the specific temperature at which the hydration of cement ceases, indicating the point at which concrete no longer gains strength due to the stoppage of the cement's chemical reaction. This datum temperature is crucial for maturity calibration, serving as a baseline for determining the maturity index, which correlates with concrete strength development. According to ASTM C1074, the recommended datum temperature for Type I cement, when used without admixtures, is 32°F (0°C), with the curing process typically conducted within a range of 32°F (0°C) to 104°F (40°C) [1] [2]

The concrete maturity method is a non-destructive technique for estimating the in-place strength of concrete structures. It monitors the temperature history of the concrete during curing to assess strength development, providing practical, real-time insights into strength values. Despite ASTM C1074's guidelines on datum temperature, local climate conditions can influence its applicability across different regions [3]

Malaysia, situated in Southeast Asia, has a tropical climate characterized by high temperatures and humidity year-round. The mean lowland temperatures typically range between 26°C and 28°C. Given these distinct climatic conditions, the ASTM C1074 recommended datum temperature may not be suitable for Malaysia [4].

The study aims to identify the appropriate datum temperature range for the maturity method in the context of Malaysia's climate. The findings will account for the unique environmental conditions of Malaysia, potentially establishing a datum temperature different from standard recommendations. This will facilitate the accurate

application of maturity methods in Malaysian construction projects, enhancing the sustainability and performance of construction materials in the region.

## 2. Literature Review

### 2.1 Concrete Maturity

The concept of concrete maturity has evolved over the past five decades, integrating temperature and time to predict concrete strength. This concept utilizes the multiplication of temperature and time factors to develop a maturity index, which is then correlated with the concrete's strength gain through a hyperbolic curve. Implementing this concept allows for more efficient and predictable scheduling of construction activities, such as formwork removal and load application. The significant milestone was reached in 1987 with the ASTM standard method C 1074-87, titled "Standard Practice for Estimating Concrete Strength by the Maturity Method." This standard solidified the maturity method as a recognized non-destructive testing approach applicable in the field for estimating concrete strength in situ. Since then, there has been increasing interest in exploring practical applications within the concrete industry [5].

The maturity method relies on tracking the temperature-time history of concrete and its related strength development to create an empirical correlation. This technique allows for the prediction of concrete strength during the curing phase by continuously monitoring in-place concrete temperatures in real-time. Such data is vital for making informed decisions on the best time to remove formwork, apply post-tensioning, or open pavements to traffic. These decisions can lead to considerable time and cost savings in construction projects. According to a 2007 survey by the West Virginia Division of Highways (WVDOT), twenty-five out of thirty-six states employed the maturity method, mainly as an alternative to early cylinder compressive strength tests, for determining the appropriate times to remove formwork or open roads to traffic [6]. Despite ongoing research into using this method to predict in-place concrete strength, there remain concerns about the accuracy of the maturity method in structural concrete applications, especially regarding the selection of the datum temperature.

### 2.2 Nurse-Saul Maturity Function

The maturity concept was introduced by Nurse and Saul in 1950. They asserted that the strength of concrete depends on the accumulation of the temperature-time factor (TFT) during the curing process. Saul formulated the maturity rule principles, establishing that concrete of the same mix at the same maturity level has approximately the same strength. He suggested calculating maturity using a "datum temperature," the temperature at which strength development (cement hydration) stops, resulting in the Nurse-Saul maturity equation. The equation below shows the Nurse-Saul maturity equation.

$$M = \sum_0^t (T - T_0) \Delta t \quad (1)$$

Where M is the temperature-time factor at age t; degree-days or degree-hours;  $\Delta t$  is a time interval, days or hours; T the average concrete temperature during time interval,  $\Delta t$ , °C, and  $T_0$  is the datum temperature, °C. This equation indicates that the hydration rate corresponds linearly with the curing temperature. However, the temperature precision for estimating maturity is limited to a range of 0 to 40°C. Additionally, the selection of datum temperature is debated, with variations such as cement variety, water-cement ratio, and climate affecting the determination of  $T_0$ . These factors contribute to the TTF model's inadequate strength prediction effect [7].

The Nurse-Saul maturity equation has gained interest due to its simplicity and ease of application, becoming popular in civil engineering for calculating the maturity index. Its simplicity allows engineers to estimate concrete strength and aids decision-making processes related to concreting throughout construction projects. [8]

### 2.3 Datum Temperature

The datum temperature establishes the point at which strength development ceases. It is the temperature at which cement hydration halts, meaning concrete no longer progresses in strength development. For Portland cement concretes, the adopted datum temperature is often simplified to 0°C, though other industry-accepted temperatures such as -5°C and -10°C are also used [9]. To accurately determine the datum temperature, ASTM C1074 outlines procedures involving preparing mortar cubes representative of the concrete mix. These cubes are cured at different temperatures, and their strengths are tested at various intervals.

To compute the datum temperature, the reaction rate constant (k-value) for each curing condition is established. The k-value indicates the pace of the chemical reaction crucial for strength development in concrete. The k-values can be determined using the following equation:

$$S = S_u \frac{k(t - t_0)}{1 + k(t - t_0)} \quad (2)$$

Where S = average compressive strength of the cube at time t, t = test age,  $S_u$  = limiting strength,  $t_0$  = age when strength development is assumed to begin and k = rate constant. [12]

## 2.4 American Society for Testing Materials (ASTM)

In 1987, ASTM established a standard practice for using the maturity method to estimate in-place concrete strength (ASTM C 1074). This standard outline two methods for determining the maturity index: one based on the temperature-time relationship using the Nurse-Saul equation, and the other by calculating the equivalent age at a specified temperature using the Arrhenius equation [9]. According to ASTM C1074-98, the datum temperature should be experimentally determined for precise accuracy. For ASTM Type I cement without admixtures, the datum temperature is usually set at 0°C, with concrete curing expected to occur between 0°C and 40°C. However, the commonly used to value in most maturity instruments for many years has been -10°C, approximating the temperature at which cement hydration stops.

The ASTM standard provides procedures for establishing the relationship between strength and maturity and estimating in-place strength. It also offers methods to determine the datum temperature or activation energy if required. Despite the widespread use of ASTM C 1074 worldwide, challenges persist in implementing the maturity approach for estimating concrete strength. Variations in material properties, environmental conditions, and project-specific factors can influence the accuracy of the maturity index [10].

## 2.5 Effect of Concrete in Tropical Climate

Temperature significantly influences the rate of cement hydration and subsequent concrete strength development. In tropical climates, warmer ambient temperatures generally accelerate strength gain during moist curing. However, higher temperatures at the time of setting can negatively impact later-stage strength development. Although higher initial hydration rates lead to quicker early strength gain, they may result in lower strength over extended periods. Concrete set and cured at lower temperatures, despite initially slower hydration rates, can surpass the strength of concrete set and cured at higher temperatures, typically beyond a 90-day period [11].

Practically, for equal 28-day strength values in design, concrete in tropical climates is expected to exhibit lower long-term quality compared to concrete in temperate climates. This affects the durability of concrete structures, especially in severe exposure conditions with higher tropical temperatures. The faster deterioration rate in tropical climates, coupled with observed lower long-term strength, implies that concrete designed based on temperate climate recommendations may show distress earlier in tropical regions [11].

Examples illustrating the impact of higher ambient temperatures on concrete durability include increased carbonation coefficients at higher temperatures and significantly shorter service life due to chloride-induced corrosion in reinforced concrete. These findings highlight the necessity of adapting construction practices in tropical climates to ensure long-term durability and performance of structures under varying exposure conditions [12].

## 2.6 Case Study

An experimental study was carried out in Punta Arenas to evaluate the datum temperature and activation energy of concrete exposed to very cold weather conditions. The research revealed that the traditional datum temperature of 0°C might underestimate early strength development. The study recommended -5°C for later strength determinations and -10°C for early strength predictions to improve accuracy. These findings highlight the necessity for context-specific adjustments in the maturity method to account for extreme cold conditions, ensuring more reliable strength estimations and optimizing construction practices in such environments [13].

The effectiveness of the maturity method was measured in Alberta's extremely cold weather. The study confirmed the reliability of this method in predicting in-place concrete strength, facilitating better decision-making in construction processes. By accurately estimating strength gain, significant time and cost savings were achieved. The study emphasized the importance of real-time strength predictions in cold weather conditions, which can enhance construction efficiency and ensure structural integrity [14].

Another study measured the variability in datum temperatures across different concrete mixes and environmental conditions. That research demonstrated that datum temperatures often exceed the ASTM C 1074 recommended 0°C, influenced by factors such as cement composition, admixtures, and curing environments. The study recommended that accurate datum temperature determination should be tailored to specific project conditions, rather than relying solely on standardized values. This approach ensures more precise strength predictions and enhances the reliability of the maturity method in diverse construction scenarios [15].

### 3. Methodology

#### 3.1 Sample Preparing

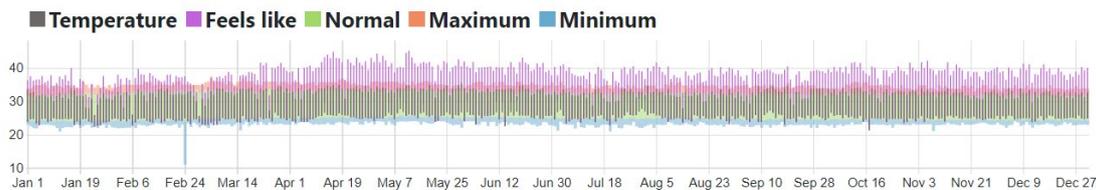
According to ASTM C1074 guidelines, it is recommended that mortar mixtures be formulated with sand-to-cement ratios equivalent to the coarse aggregate-cement ratio found in the corresponding concrete mixtures [1]. Table 1 showcases the mortar composition used in this study. Two different mortars were used. 50x50x50 mm steel moulds were used for mortar mixes. A total of 54 mortar cubes were prepared for each type of mortar.

**Table 1** The mortar mixture proportion

Types of Mortar	Cement (kg/m3)	Fine aggregate (kg/m3)	Water (kg/m3)	F.Agg Cement Ratio
M25	397	1495	324	3.76
M35	443	1492	310	3.38

#### 3.2 Curing of Sample

The concrete was cured at three different temperatures using thermostat, representing the climate of Malaysia. The temperatures were selected based on the highest and lowest temperature history of Malaysia in 2022. The data was obtained from the Malaysian Meteorological Department's open data. Daily temperatures were recorded by 42 manned weather stations in Malaysia. After reviewing the data from each weather station, the selected curing temperatures were the maximum temperature (32°C), minimum temperature (22°C), and average temperature (27°C). Figure 1 shows the daily temperature of Malaysia. Data from the Cameron Highlands, Pahang station was excluded because it is considered a highland, and the temperature is lower than in normal areas.



**Fig. 1** Daily temperature of Malaysia

#### 3.3 Compressive Strength Test

The compressive strength of concrete was assessed through the utilization of concrete cube specimens in a compressive strength test. All mortar specimens were crushed at different time intervals (1, 2, 4, 8, 16, and 32 days) as specified in ASTM C1074. Before conducting the strength test, the specimens were cleaned, and excess water was wiped away from the surface. The mortar was placed on the platform of the compression testing machine without any additional packing, and the cube was subjected to increasing compressive loads until it reached the point where it could no longer support them. The compressive strength test was performed on each cube for every curing temperature at the specified time intervals [1].

Two cubes were tested for each time interval and curing temperature. If the maximum load withstands for the first two cubes differed by more than 10%, a third cube was tested, and the average load value was calculated for the calculation of compressive strength mortar for the selective time interval and curing temperature.

#### 3.4 Data Analysis

The k-values and Su for each curing temperature of the cube samples were analyzed as in Equation 2. Best-fit values of Su, t<sub>0</sub> and k-value in Equation 2 were then determined. The data was analyzed using the solver function in Microsoft Excel to fit it into the equation.

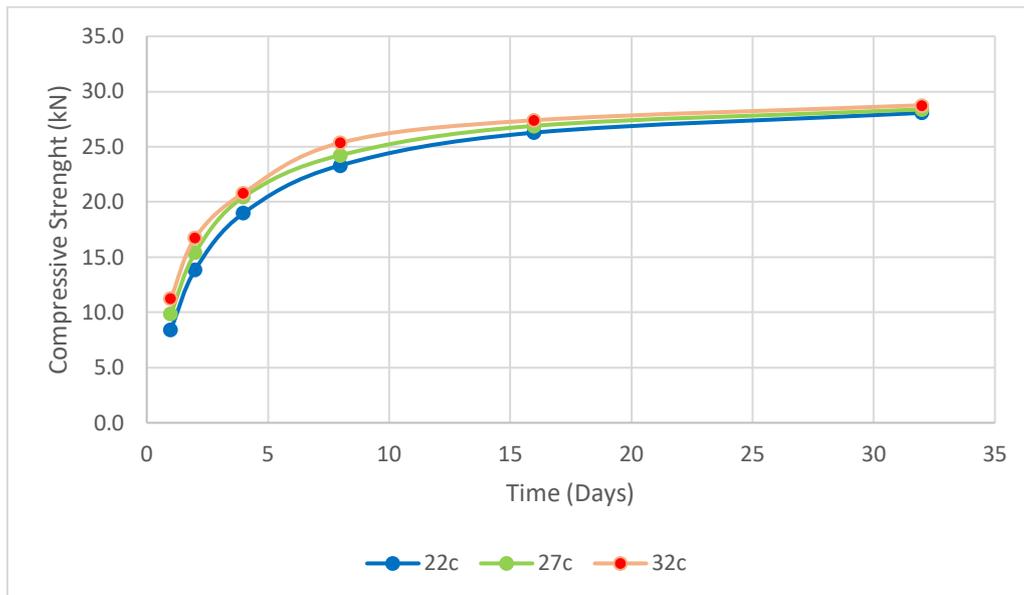
## 4. Data and Analysis

### 4.1 Compressive Strength

The mortar cubes were categorized into three groups, each cured at temperatures of 22°C, 27°C, and 32°C. The strength of the mortar samples was measured on days 1, 2, 4, 8, 16, and 32. Table 2 presents the results of the compressive strength tests for M25 samples while Figure 2 illustrates the strength gain of the mortar cube over the time.

**Table 2** Compressive strength of sample of M25

Curing Temperature (°C)	Compressive Strength (N/mm <sup>2</sup> )					
	Days					
	1	2	4	8	16	32
22	8.45	13.86	19.00	23.32	26.28	28.07
27	9.85	15.40	20.46	24.24	26.89	28.38
32	11.28	16.75	20.83	25.36	27.40	28.76



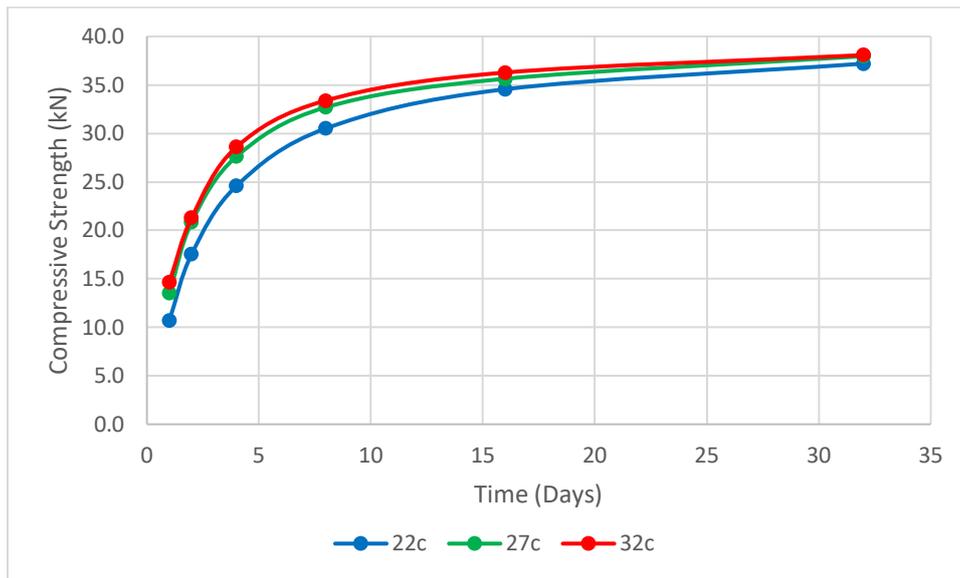
**Fig. 2** Compressive strength development of M25 cube

The compressive strength development of M25 mortar cubes over 32 days at different curing temperatures (22°C, 27°C, 32°C) is illustrated in Table 3 and Figure 3. Higher curing temperatures resulted in a faster initial gain in compressive strength. For instance, at 22°C, the strength increased from 8.45 N/mm<sup>2</sup> on day 1 to 28.07 N/mm<sup>2</sup> on day 32. At 27°C, the strength increased from 9.85 N/mm<sup>2</sup> to 28.38 N/mm<sup>2</sup>, and at 32°C, from 11.28 N/mm<sup>2</sup> to 28.76 N/mm<sup>2</sup> over the same period. By the end of 32 days, all samples converged towards a similar compressive strength value of approximately 28 N/mm<sup>2</sup>.

Table 3, and figure 3 showcase the compressive strength development of M35 mortar cubes cured at different temperatures over a 32-day period.

**Table 3** Compressive strength of sample of M35

Curing Temperature (°C)	Compressive Strength (N/mm <sup>2</sup> )					
	Days					
	1	2	4	8	16	32
22	10.71	17.56	24.59	30.52	34.56	37.20
27	13.51	20.84	27.62	32.70	35.64	37.96
32	14.64	21.31	28.6	33.40	36.28	38.08



**Fig. 3** Compressive strength development of M35 cube

At 22°C, the compressive strength of M35 mortar cubes increased from 10.71 N/mm<sup>2</sup> on day 1 to 37.20 N/mm<sup>2</sup> by day 32. At 27°C, the strength increased from 13.51 N/mm<sup>2</sup> to 37.96 N/mm<sup>2</sup>, and at 32°C, from 14.64 N/mm<sup>2</sup> to 38.08 N/mm<sup>2</sup> over the same period. Similar with M25, higher curing temperatures accelerated early strength development in M35 mortar cubes, with all samples reaching comparable ultimate strengths by the end of the curing period. This is due to the higher temperatures can accelerate the chemical hydration reactions of cement as the temperature enhance the mobility and interaction of water molecules with cement particles.

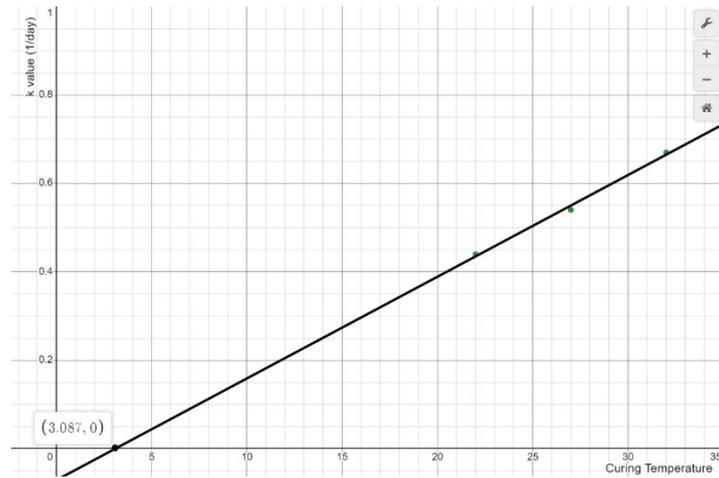
### 4.2 Datum Temperature

The compressive strength data collected for both M25 and M35 grades were further analyzed to determine the k-value using Equation 2. The data were processed in Excel, and best-fit curves were determined for each curing temperature to ascertain the k-value accurately (see Table 4).

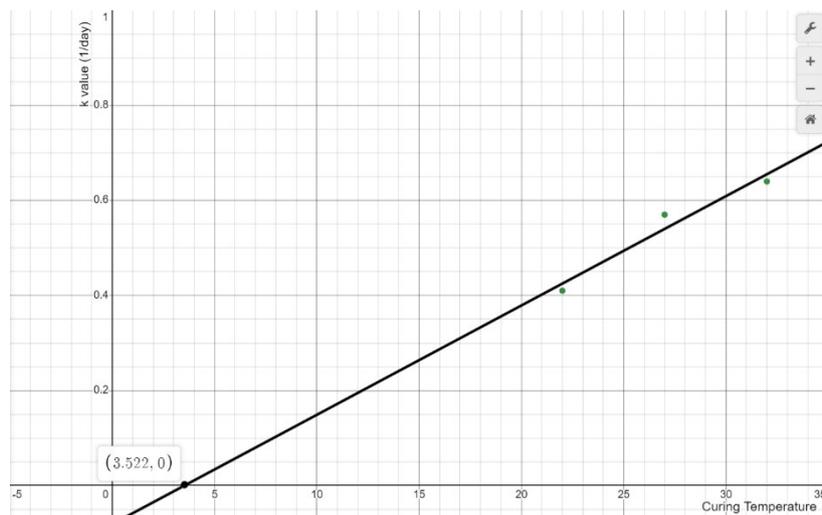
**Table 4** Result of k-value and datum temperature

Mortar type	M25			M35		
Curing Temperature(unit?)	22	27	32	22	27	32
k-value (1/day)	0.44	0.54	0.67	0.41	0.57	0.64
Datum Temperature	3.1			3.5		

The k-values represent the rate constant of strength gain for each mortar type at different curing temperatures. As shown in Table 4, Figure 4 and Figure 5, higher curing temperatures corresponded to higher k-values, indicating a faster rate of strength development due to accelerated hydration reactions. The relationship between k-values and curing temperatures was analyzed using the Desmos graphing calculator, showing a clear linear trend. The x-intercept of the best-fit line represents the datum temperature, which was determined to be 3.1°C for M25 and 3.5°C for M35. Figure 4 and Figure 5 illustrates the line of datum temperature for each mortar grade.



**Fig. 4** *k*-value against curing temperature of M25



**Fig. 5** *k*-value against curing temperature of M35

## 5. Conclusion of Research

The results clearly demonstrate that curing temperature significantly influences the rate of strength gain in mortar cubes. Higher curing temperatures accelerated early strength development due to increased cement hydration rates facilitated by elevated temperatures. However, after 32 days, all samples from the same grade converged towards similar ultimate values. This convergence indicates that while higher curing temperatures enhance early strength gain, they do not compromise the final strength of the mortar. These findings underscore the importance of considering surrounding temperatures for optimal early strength development in concrete.

The study determined a datum temperature of 3.1°C for M25 and 3.5°C for M35 mortar grades, which exceeded the commonly cited range in ASTM C1074 (-10°C to 0°C for general concrete mixes). This observation suggests that tropical climates like Malaysia require higher datum temperatures for accurate concrete maturity method calculations. The study highlights the critical need for localized testing and calibration of datum temperatures to ensure precise and accurate strength assessments. Applying generalized ASTM C1074 datum temperatures may lead to inaccuracies in strength assessments in tropical regions, potentially impacting construction processes. Therefore, the study emphasizes the importance of using experimentally determined datum temperatures tailored to specific environmental conditions to enhance the accuracy, precision, and effectiveness of concrete maturity methods.

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## Conflict of Interest

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

## Author Contribution

*The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.*

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