International Journal of Engineering Research and Development

DOI: 10.29137/ijerad.1500003

Volume:17 Issue:02 Pages:257-271 July/2025

Research Article

Climate Change and Its Effects on Concrete Pouring Activity: The Case of Kırıkkale

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Received: *10/12/2024* ***Accepted***: *15/04/2025* ***Published Online:*** *15/07/2025*
Final Version: *01/07/2025*

Abstract
Environmental factors, such as extreme temperatures-both high and low-, significantly impact the strength, durability, and fresh properties of conventional concrete. These conditions not only affect the strength and durability performance of concrete but also its transportation, placement, and curing conditions. Concrete, when properly designed, cured, and placed, can be a highly durable construction material. However, certain physical and chemical influences can hinder concrete from achieving its expected strength and durability. This study examines how climate parameters, specifically maximum temperature, minimum temperature, and precipitation, and their threshold values, will affect concrete pouring activities in Kırıkkale, Türkiye, in the future. The findings suggest that as rising air temperatures can improve concrete pouring performance during winter months, making placement more feasible in conditions that were previously challenging or impractical. However, in summer months, rising maximum temperatures could lead to decreased performance in concrete pouring activities unless appropriate measures are taken.

Keywords
Concrete, Climate change, Temperature, Precipitation, Fresh concrete, Hardened concrete

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1. Introduction

As a result of global warming extreme weather events are expected to occur more frequently and intensely in future climates (IPCC, 2014a; IPCC, 2014b; IPCC, 2013; IPCC, 2012). Although it is not easy to define the processes behind extreme weather events, studies agree that climate change determines and continues to determine the intensity and frequency of events such as extreme temperature and precipitation (Myhre et al., 2019; Keggenhoff et al., 2014). Moreover, climate change is expected to change not only the average variability but also the distribution of precipitation and temperature (Nordling et al., 2024). In this context, it is thought that climate change will probably have significant regional effects and that certain regions will experience more severe and intense climate events, which will affect construction processes.

Changes in production and consumption habits and unsustainable energy use have caused an increase in greenhouse gas emissions in the last century, contributing to anthropogenic climate change (IPCC, 2022). The negative effects of climate change have already been experienced as increase in both the frequency and intensity of weather events across various regions around the globe (Kay et al., 2021). It is anticipated that concrete, which is the most widely used construction material in the world, may cause changes in both fresh concrete properties and hardened concrete properties due to the impacts of climate change (Huang et al., 2020).

Unlike other sectors, each project in the construction sector has distinctive features arising from its unique structure. The type, scope, location, and resources used in the project are examples of these features (Fashina et al., 2021; Johnson & Babu, 2020; Loch et al., 2006; Cooper et al., 2005). The construction sector, which includes many activities that are sensitive to weather conditions, especially concrete casting, weather, and climate conditions, is often listed as one of the most common and harmful causes of delays (Oruc et al., 2024). Weather and climate conditions can have various impacts on construction projects. Those impacts can be reduced productivity, interrupted production, damaged exposed and unprotected components or prevented access to construction sites (Rogalska et al., 2006; Alarcón et al., 2005; El-Rayes & Moselhi, 2001). Weather-related situations are often a matter of dispute between contractors and project owners (Nguyen et al., 2010; Moselhi & El-Rayes, 2002).

Temperature changes have physical effects on structures, which cannot be ignored. These changes can cause thermal stresses and contractions that create cracks in structural elements. These cracks, together with wind and humidity, can facilitate the penetration of aggressive substances into concrete. In most chemical processes, temperature increases the reaction kinetics. This explains why certain structures in hot regions deteriorate faster than those in cold and temperate regions. But at the same time, precipitation is also a determining condition for such behavior. In addition to these effects, temperature changes also affect corrosion parameters. Relative humidity (RH) is very important for the deterioration of concrete structures. Most deterioration processes do not occur in the absence of moisture in concrete. This variable can be considered the most important parameter in terms of the durability of concrete. Rainfall falling on concrete provides higher humidity than a simple increase in relative humidity. Therefore, the amount and duration of rainfall should be considered. In addition to being dependent on RH, rainfall can be linked to wetting and drying cycles. These cycles may contribute to the development of aggressive processes such as chloride intrusion in reinforced concrete structures (Medeiros-Junior & Reichert, 2024).

Hot climates are prevalent in several parts of the world. The average summer temperature of hot arid areas is in the range of 40-50 °C and generally exceeds these values under direct solar radiation. In these regions, problems may occur in concrete owing to the limited water available for curing and/or the rapid loss of curing water by evaporation (Rizzuto et al., 2020). It has been observed that curing concrete at higher temperatures tends to significantly increase the early age hydration rate and reduce long-term compressive strength (Elkhadırı et al., 2009). Adverse weather conditions, including high and low temperatures, directly impact the mixing, transportation, casting, and curing performance of concrete, ultimately affecting its physical and mechanical properties. This situation concerns both concrete manufacturers and end-users because it creates a series of technical and economic situations (Ortiz et al., 2005).

Extreme temperatures in hot and cold climates do not pose a threat to concrete because dry concrete has an acceptably low coefficient of thermal expansion, and moderate movements can be considered in the design. However, when wet concrete in cold climates is subjected to repeated temperature cycles that cause pore water to freeze and thaw, a durability threat arises. The number of cycles was more important than the absolute minimum temperature. The expansion of wet concrete can be significant, and the stress generated in concrete can reach unacceptable levels. This is one of the most important issues affecting the durability of concrete (Richardson, 2007). The best mechanical performance of concrete is obtained when the concrete is poured at times when there is the least difference between the ambient temperature and concrete temperature (i.e., later in the day under hot weather conditions and early in the day under cold weather conditions) (Ortiz et al., 2005).It has been observed that the porosity of concrete under standard curing conditions is lower than that of concrete cured under hot weather conditions, and the permeability level of standard cured pozzolan-substituted concrete is lower than that of concrete cured in hot weather. As the fly ash content increased, the permeability of concrete became less sensitive to hot weather conditions. The permeability of concrete containing silica fume was less affected by hot-weather curing, but this situation increased as the curing age decreased (Khan & Abbas, 2017). It has been stated that the optimum pouring temperature is 32 °C for conventional Portland cement concrete and concrete containing silica fume, while 38 °C for mixtures containing very fine fly ash, ground granulated blast furnace slag, and natural pozzolan (Nasir et al., 2016). Based on this, it is understood that climatic conditions affect the concrete pouring process and the performance of the poured concrete to a non-negligible extent.

Changes in climate affect land, ocean, air, and ice mass, especially on land; differences begin to emerge in precipitation and temperature patterns and the length of seasons. Therefore, obtaining up-to-date weather and climate data and taking correct precautions against these risks is possible by considering not only historical but also predicted changes and analyzing the degree of predictability. This situation is not different for the concrete pouring activity, which is a fundamental activity in the construction sector and concrete serves as the primary building material for achieving and sustaining desired engineering applications. Differences that will arise as a result of climate change in the future may cause a series of problems in concrete pouring. Therefore, it is of great importance to reveal the possible problems that will be encountered in this activity by considering the climate forecasts made in advance to enable the production of solutions.

In this study, we attempted to reveal how concrete pouring activity in the future in Kırıkkale Province will change with the selected climate parameters and their threshold values. The threshold values determining the workability for the maximum temperature, minimum temperature, and precipitation were determined to influence concrete pouring, and the performance of the concrete pouring activity was determined for each variable and considering their joint effects. The performances in question were analyzed both for the reference (observation) period and for the distant future (2071-2100) periods within the scope of the SSP5.85 scenario. The high-resolution ERA5-Land reanalysis data was used as the reference (observation) dataset, both in the observation period calculations, while making the bias correction for both precipitation and temperature of the global climate models (GCM) required to obtain the future period data. Using the obtained data, the performances mentioned above were calculated separately for each day of the year for the selected analysis period, and the annual cycle of the activity performance was obtained.

Symbols and Abbreviations

°C	Degree Celsius
CMIP	Coupled Model Intercomparison Project
CO2	Carbon Dioxide
GCM	Global Circulation Model
kg	Kilograms
IPCC	Intergovernmental Panel on Climate Change
km	Kilometers
m	Meter
mm	Millimeter
MMEA	Multi Model Ensemble Average
P10	Rainfall ≥ 10 mm
QDM	Quantile Delta Mapping
RH	Relative Humidity
SSP	Shared Socioeconomical Pathways
Tmax40	Maximum temperature ≥ 40 C°
Tmin0	Minimum temperature ≤0 °C
TS	Turkish Standard

2. Materials and Methods

2.1. Study Area and Data

Kırıkkale Province is located between the 33°20'–34°25' east meridians and 39°20'-40°20' north parallels in the Central Kızılırmak section of the Central Anatolian region, and the region is dominated by semi-arid climate characteristics. The Kırıkkale province, which has an area of approximately 4694 km^2, has an altitude varies between 565-1746 m (Aktürk et al., 2022). The Kırıkkale Province is located in a temperate climate zone. However, because of reasons such as the area being far from the sea and the daily temperature difference being subject to changes due to being a steppe, the climate is becoming continental. According to the observations, the average temperature for many years is 12.5 ºC. In terms of average temperature, the hottest month is July (24.5 ºC) and the coldest month is January (0.6 ºC). During the same observation period, the maximum temperature was determined as 41.6 ºC and the minimum temperature as -22.4 ºC. The Kırıkkale Province is located in one of the semi-arid regions of the country. The average annual total precipitation in this province for many years was 366.2 kg/m². The highest daily precipitation recorded during the observation period was 100.6 kg/m² on 11.06.1997. The highest snow height was 48 cm on 05.01.2002 (TOBB, 2021).

The ERA5-Land dataset, of European Centre for Medium-Range Weather Forecasts (ECMWF), a global climate and historical weather reanalysis dataset, was used in this study. The ERA5-Land dataset provides open-source data for the period from 1950 to 5 days before the current date. ERA5-Land provides hourly high-resolution information on surface variables. The data had a grid spacing of 0.1 °× 0.1 ° (~ 9 km), which was obtained by replaying the land component of the ERA5 climate reanalysis with a finer spatial resolution. The reanalysis integrates model data with worldwide observations through the applications of laws of physics, creating a globally comprehensive and consistent dataset. ERA5-Land is a variant of the ERA5 dataset that is specialized for landmasses. The largest difference between this set and the original is that the horizontal resolution is 0.10° × 0.10° instead of 0.25° × 0.25° (J. Muñoz-Sabater et al., 2021). This difference makes it possible to operate on a finer scale. The temporal resolution is hourly, as in ERA5. This dataset was used to correct the bias in the estimates from the Coupled Model Intercomparison Project (CMIP)6 global climate models and to determine the performance of the bias-corrected data.

Furthermore, in this study, future projections were derived by analyzing the most up-to-date CMIP6 GCMs (Table 1). CMIP6 (O'Neill et al., 2016; Eyring et al., 2016), the 6th phase of the Coupled Model Intercomparison Project (CMIP), is better than its predecessor CMIP5. The reasons behind these developments can be attributed to the determination of the amount of natural or anthropogenic radiative forcing, inclusion of aerosols, and land use effects (Bayar et al., 2023; Bağçaci et al., 2021; Lie et al., 2020; Wyser et al., 2020; Stouffer et al., 2017; O'Neill et al., 2016). Although CMIP6 data are relatively new, there is an increasing interest in the application of the latest projections (Oruc, 2022; Fu et al., 2020; Checa-Garcia et al., 2018). While these studies showed different results between CMIP6 and CMIP5 results over the study regions, Bağçacı et al. (2021) investigated the novelties CMIP6 brings into the representation of hydro climatological variables of Türkiye and stated that CMIP6 products performed better than CMIP5 for precipitation and temperature in Türkiye. This finding, therefore, urged the need for updating the climate change impact studies based on the latest data. In this regard, CMIP6 models that are not only provide the most up-to-date climate data but also outperform the previous version of CMIP5 over Türkiye. The criteria for selecting the specific climate models were based on their performance in representing precipitation and temperature patterns separately in Türkiye, as well as their consistency with observed historical data. In this study, the two best models were selected separately for both precipitation and temperature based on the findings of Bağçaci et al. (2021) and the analyses were performed according to the averages of these models.

Table 1. Selected CMIP6 models

CMIP6 GCMs - Precipitation	**CMIP6 GCMs - Temperature**
HadGEM3-GC31-MM	MPI-ESM1–2-HR
GFDL-ESM4	CNRM-ESM2–1

2.2. Methods

2.2.1. Bias correction and multiple model averaging

The quantile delta mapping (QDM) approach was established to eliminate systematic biases while maintaining the relative change in the modeled quantiles of the variable being examined (Cannon et al., 2015). The basic equation of the quantile delta mapping method consists of the bias-corrected value obtained from the observation data and relative change term derived from the model data. This method not only consider the modeled mean but also all modeled quantiles are considered. Calculations of the QDM can be followed in equation 1, equation 2 and equation 3, respectively.

$$\hat{x}_{m,p}(t) = \hat{x}_{o:m,h:p}(t) * \Delta_m(t) \tag{1}$$

$$\hat{x}_{o:m,h:p}(t) = F_{o,h}^{-1}\{F_{m,p}[x_{m,p}(t)]\} \tag{2}$$

$$\Delta_m(t) = \frac{x_{m,p}(t)}{F_{m,h}^{-1}\left[F_{m,p}^{(t)}\{x_{m,p}(t)\}\right]} \tag{3}$$

In these equations, $\bar{x}_{(o:m,h:p)}$ (t) represents the bias-corrected historical period data and Δ_m(t) represents the relative change in the model data between the historical and forecast periods.

In addition to considering model biases and performance, multi-model ensemble averaging (MMEA) is a widely used approach to address uncertainties and biases originating from GCMs in climate modeling studies (Oruc et al., 2024; Gumus et al., 2023). Although there is no scientific consensus to determine the number of GCMs included in the analyses, studies show that the first three to ten GCMs are widely used in multi-model ensemble averaging (MMEA) (Ahmed et al., 2019). However, some studies prefer to include all available GCMs without ranking (Grose et al., 2020), which may lead to a decrease in performance.

2.2.2. Climate/weather variables affecting concrete pouring activities, influence factors and activity performance indices

The first step is to determine which combinations of certain climate variables and intensity levels are responsible for whether certain construction activities can be conducted (Ballesteros-Pérez et al., 2018). For this research, the threshold values for the climate factors summarized in Table 2 were considered as factors that prevent the realization of concrete pouring operations/activities (Oruc et al., 2024; Ballesteros-Pérez et al., 2018; American Concrete Institute, 1985). Precipitation- and temperature-based variables were selected, and then related threshold values were aligned. To decide those threshold values, cited literature, national and international standards, and expert opinions were utilized.

Table 2. Climatic Parameters Affecting the Performance of the Concrete Activity (Assumed to Cause Non-Working Days) and Selected Threshold Values (Oruc et al., 2024; Ballesteros-Pérez et al., 2018)

Variable	**Type**	**Threshold Value**
Temperature	Minimum Temperature	≤0 °C
Temperature	Maximum Temperature	≥40 °C
Precipitation	Rainfall Intensity	≥10 mm/day

After threshold value selection is completed, activity combination was integrated to the analyses by using daily historical data and bias-corrected CMIP6 data. In the analysis, if any of the daily calculated value exceeded the predetermined threshold value, it was considered unworkable, and the percentage of workable and unworkable days for each day in the year was calculated. For a day to be considered workable, no parameter should exceed the threshold value; otherwise, project execution is impossible for that day. Calculations were performed for each day of the year, from day 1 to day 365. For each day of the selected period/analysis interval (past, future, etc.), workable and unworkable days were calculated by considering all climate/weather variables listed in Table 2 and expressed as a percentage. However, it should be noted that the combination of weather variables and construction activities in Table 2 may vary depending on many countries, contexts, or projects; therefore, adaptation may be required.

The calculation of the climate impact factors for the determined threshold values of the selected variables is as follows in equation 4, equation 5, equation 6, respectively:

Minimum temperature ≤0 °C

$$Tmin0 = 1 - \frac{\text{Number of days when the minimum temperature is below 0°C}}{\text{Years of analysis (× Number of days per month when calculating monthly values)}} \quad (4)$$

Maximum temperature ≥ 40 C°

$$Tmax40 = 1 - \frac{\text{Number of days with average temperatures above 40°C}}{\text{Years of analysis (× Number of days per month when calculating monthly values)}} \quad (5)$$

Rainfall ≥ 10 mm

$$P10 = 1 - \frac{\text{Number of days with rainfall over 10 mm}}{\text{Years of analysis (× number of days per month when monthly values are calculated)}} \quad (6)$$

A coefficient value between 0.00-1.00 indicates the probability of the same weather event occurring on average. Consequently, a coefficient close to 1 indicates that the construction activity that is sensitive to weather conditions may not be subject to delays.

However, the common situation of dependence on more than one climate parameter is also valid for concrete pouring activity, in which case, when more than one coefficient exceeds the threshold, the effects of the variables exceeding the threshold value must be combined. As mentioned above, the climate impact factors (Tmin0, Tmax40, and P10) can be calculated separately. However, as is known, construction activities carried out in outdoor conditions are sometimes affected by a single variable, while sometimes they are affected by several variables together. At this stage, performance indices are calculated, which are produced with joint probability from climate impact factors and consist of different combinations of each activity. For example, the performance index for concrete (C) does not depend on a single climatic parameter. When concrete activities are considered, both temperature and precipitation affect them. During concrete pouring, both very hot and very cold weather conditions are avoided, and weather conditions that allow concrete pouring are limited by regulations, or concrete pouring is allowed by taking the necessary precautions. In addition, precipitation above a certain intensity is undesirable during concrete casting. In Table 2, these conditions are determined as a combination of three cases, where the daily minimum temperature is less than 0 °C, the daily maximum temperature is greater than 40 °C, and the daily precipitation exceeds 10 mm. This is possible by calculating the joint probability, as follows in equation 7:

$$\text{Concrete Pouring Activity Performance} = P_{(\text{Minimum temperature} \leq 0\ °C)} \times P_{(\text{Maximum temperature} \geq 40\ C°)} \times P_{(\text{Precipitation} \geq 10\ mm)} \quad (7)$$

However, it should be noted that these values may vary depending on regulations, location of work, criticality of work, and so on.

3. Results

A performance index methodology was used in this study to analyze the multivariate structure of the effects of climate impact factors (Tmin0, Tmax40, and P10) on construction activities. After calculating the individual impact factors listed in Table 2, a combined performance index was created for the concrete pouring activity. This index reflects the cumulative effect on activity performance more comprehensively by considering the simultaneous interactions of relevant climate variables.

The performance index for concrete activities was obtained using multivariate analysis, including both temperature and precipitation variables. Concrete pouring can be negatively affected by both extremely hot and cold weather conditions and require certain limitations. Similarly, the intensity of precipitation is an important factor affecting concrete pouring activities. Therefore, the concrete performance index evaluates the joint (dependent) probabilities of these climate variables and provides a more realistic representation of the suitable working conditions for concrete pouring. This approach provides a more comprehensive analysis by revealing the possible synergistic or combined effects of multiple climate variables on construction activities rather than evaluating the effect of a single climate factor in isolation. Figure 1 shows the components that make up the concrete pouring activity performance index for the grid covering the Kırıkkale city center during the observation period, and Figure 2 shows the annual change in the concrete pouring index. Because the probability of the temperature being above 40 °C in the selected coordinate is almost negligible (Figure 1, Tmax40), the minimum temperature parameter (Figure 1, Tmin0) has a greater weight in the activity performance for the selected coordinate. Again, when the effect of precipitation was examined, an effect was observed, particularly in the spring months, and this effect was almost zero in the summer months (Figure 1, P10).

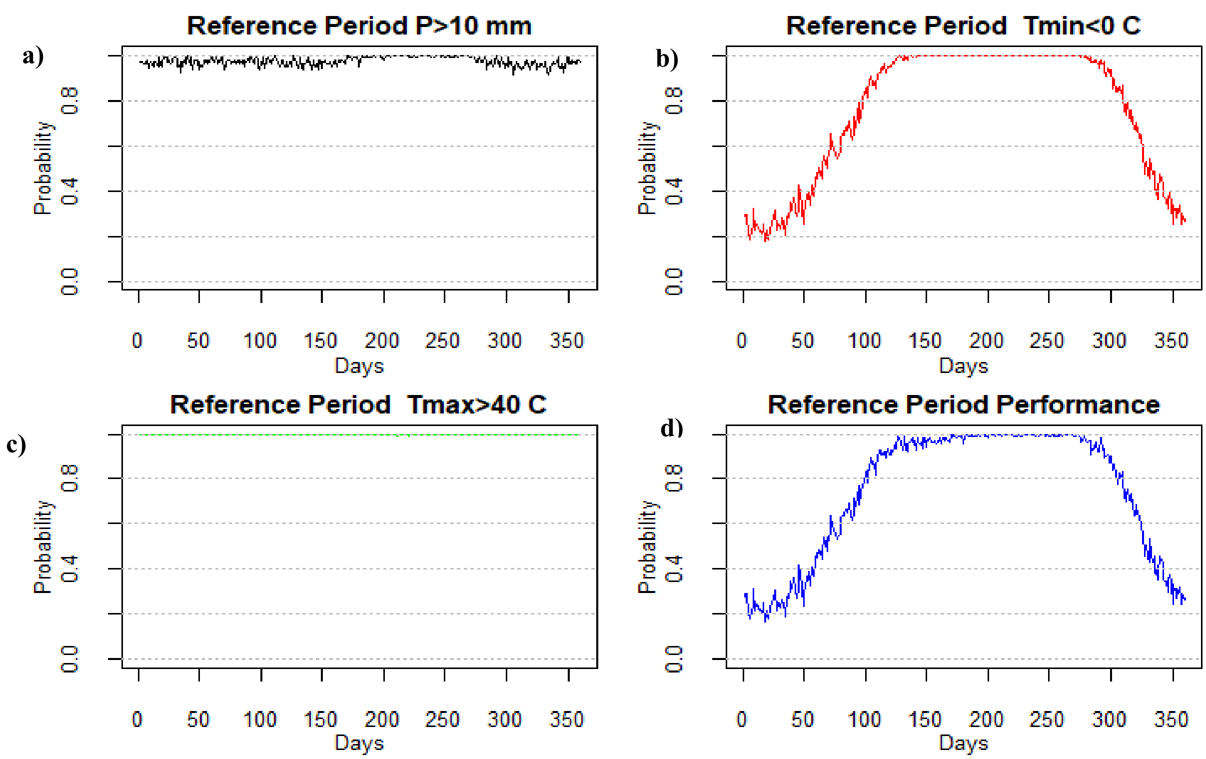

Figure 1. Annual Workability of the Components Affecting the Concrete Pouring Activity and the Activity Performance Under the Given Conditions During the Reference Period (1961–2014) a) P10, b) Tmin0, c) Tmax40 d) Concrete Pouring Performance

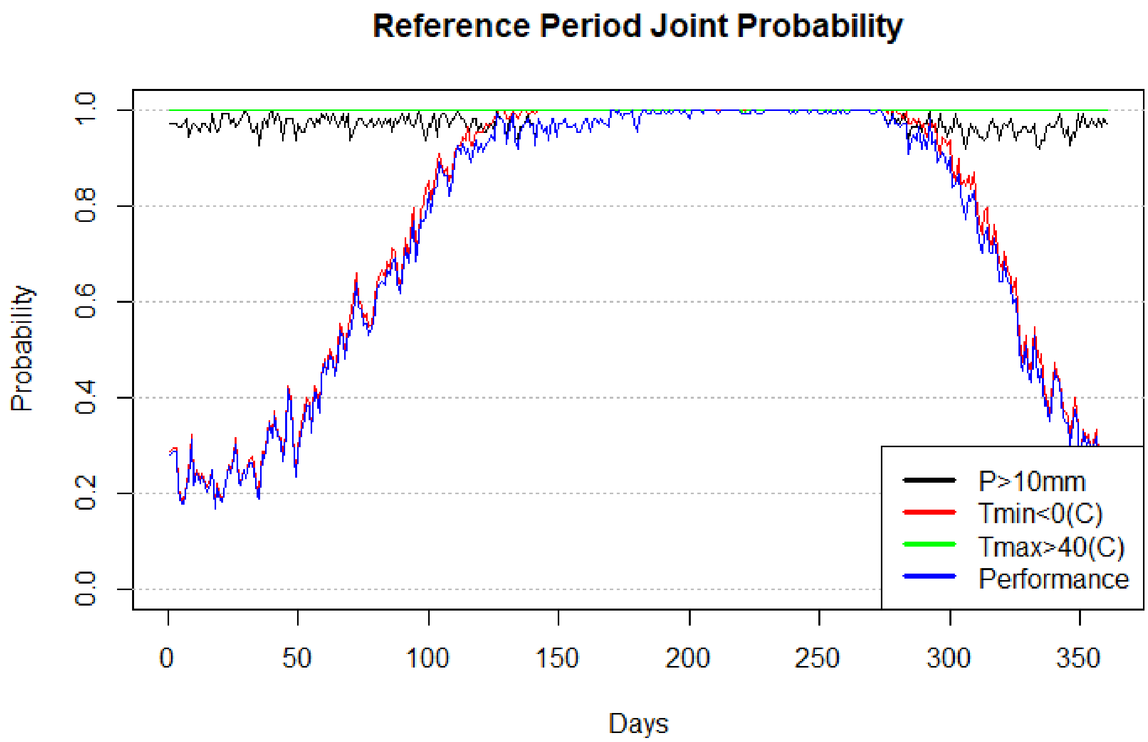

Figure 2. Annual Performance of Concreting Activity During the Reference Period (1961–2014)

When the components of the performance index of the same activity for the period 2071-2100 and the index itself (Figure 3 and 4) are compared with the observation period within the scope of the SSP5-8.5, it can be said that the performance of concrete works in the selected location will experience significant increases in the winter months. It can be predicted that the temporal negativities in reinforced concrete structures and concrete pouring works will decrease, especially in the first months of the year, but the negativities will increase during a certain period in the summer months. This reveals that the climate parameter most likely to affect concrete pouring activities in the future will be rising temperatures.

In this study, where the effects of climate change in the construction sector were observed, it was clear that the optimum time periods for concrete pouring activities were also affected. The data presented in the figures show that these optimum periods shifted throughout the year. This situation should be considered an important factor in the planning phase of a construction project.

Concrete pouring times determined by traditional methods may lose their validity under changing climatic conditions. For example, concrete pouring conditions that were ideal in a certain month in the past may no longer be achievable in the same month in the future due to changing climate conditions. In addition, precautions taken for concrete pouring under hot and cold weather conditions may not be sufficient. Therefore, it is vital to use up-to-date analyses based on climate change projections for construction planning. Considering these shifts in optimum periods for concrete pouring activities when determining project durations is critical for a timely and trouble-free construction process. The costs of precautions that need to be taken owing to the increase in temperature, especially in the summer months, may increase. Otherwise, delays, cost increases, and structural problems may occur. In summary, the planning of concrete pouring activities should be based not only on traditional calendars, but also on scientific data reflecting the future effects of climate change. This is an important step for the construction sector to adapt to changing climatic conditions and maintain sustainability.

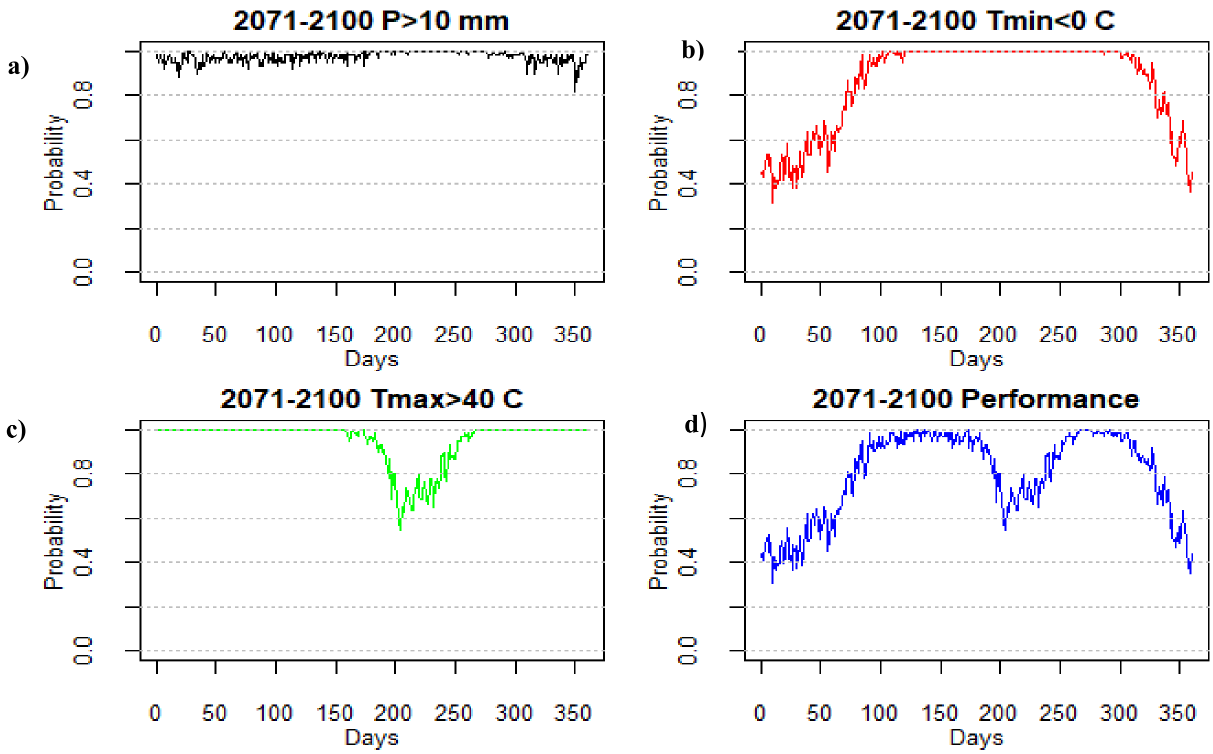

Figure 3. Annual Performances of Individual Components Affecting the Concrete Pouring Activity During the Future Period (2071-2100) a) P10, b) Tmin0, c) Tmax40, d) Concrete Pouring Performance

Figure 4 illustrates the annual performance of concrete pouring activity under projected future climate conditions. In addition to the duration of concrete pouring activity, climate change and external weather conditions, which can be seen in Figure 4, have significant effects on the physical and mechanical properties of concrete. Temperature changes can significantly affect the strength and durability of concrete. High temperatures can cause workability problems, sweating, cracking, and a decrease in the strength of fresh concrete or an increase in permeability due to these cracks, thus reducing the durability. Low temperatures can cause water to freeze in fresh concrete, and the resulting concrete loses its properties. The observed shifts highlight increased challenges in summer months due to rising temperatures, necessitating mitigation strategies such as altered pouring schedules and cooling measures.

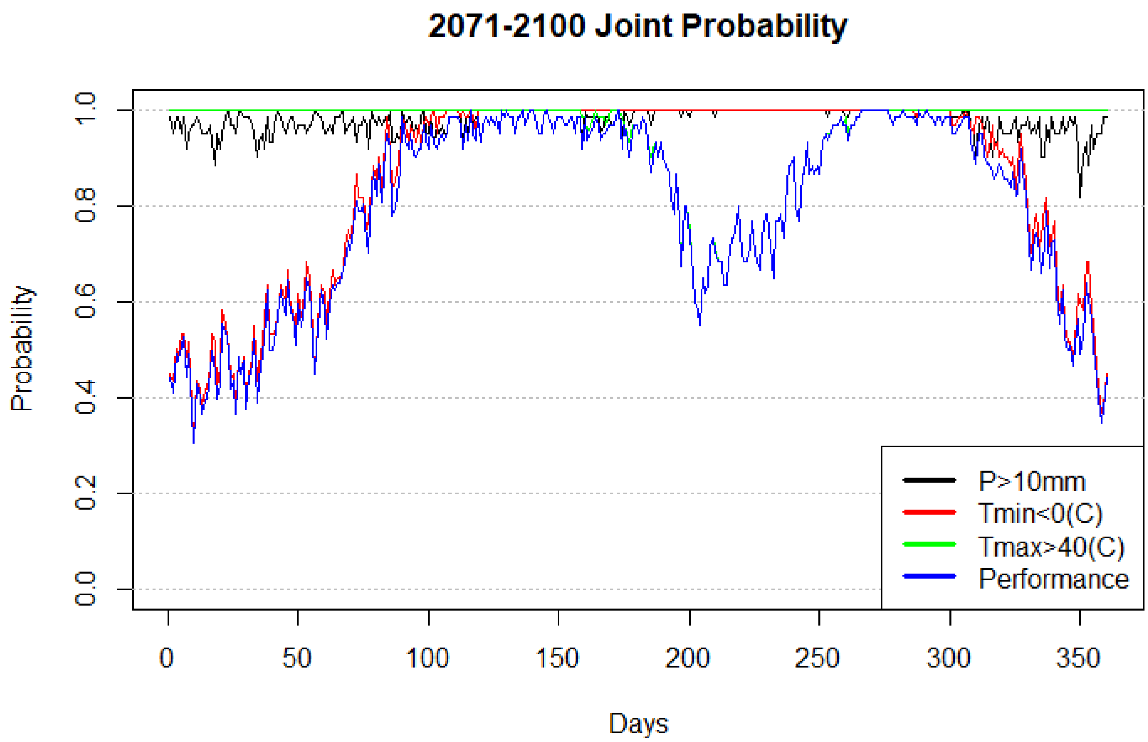

Figure 4. Annual Performance of Concrete Pouring Activity During the Future Period (2071-2100)

In addition, based on Figure 5 and 6, the probability distributions of the climate variables (precipitation, minimum temperature, maximum temperature, and general performance) affecting concrete pouring activities can be seen in both sets of graphs. The differences between the two periods made it possible to observe the effects of future climate change on these activities. Figure 5 shows the distributions of climate variables critical for concrete pouring during the reference period. Here, it is observed that the number of days when the probability of P>10 mm (precipitation) is close to 1 is higher than the other probabilities. There is a similar trend for Tmin<0°C (minimum temperature), it is seen that the number of days increases as the probability approaches 1, indicating that the probability of workability increases. For Tmax>40°C (maximum temperature), it is seen that the number of workable days reaches its peak, and it can be said that the reason for this is that the temperatures rarely exceed 40 °C in the reference period.

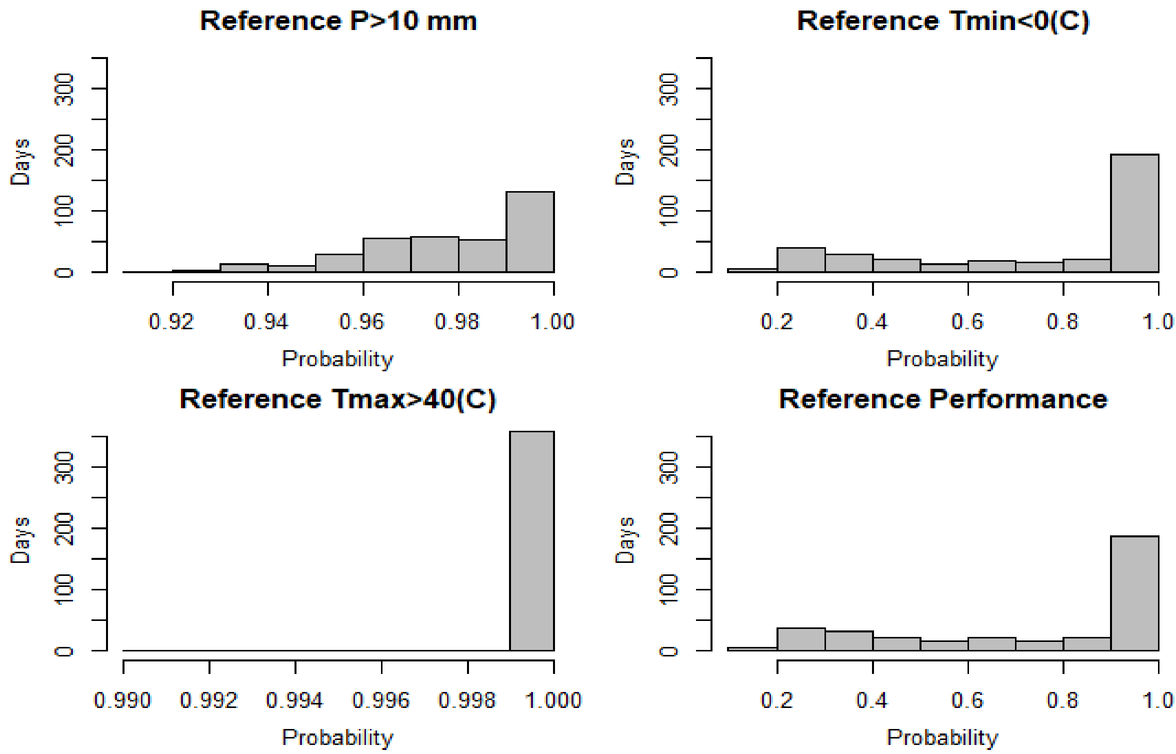

Figure 5. Workability Distribution of Components Affecting the Concrete Pouring Activity and Activity Performance During the Reference Period

When Figure 6 is examined, it can be said that the probability distributions of the factors affecting the concrete pouring activities for the future period show different distributions compared to the reference period. In general, much more days are reached with high probabilities for P>10 mm and Tmax>40°C. However, the fact that the probability of a temperature of 40°C and above in the future period has increased has had a negative effect on workability. An increase in the number of days with the probability of workability has also been observed owing to the Tmin<0°C constraint, which is directly related to the temperature increases expected to occur in the future period.

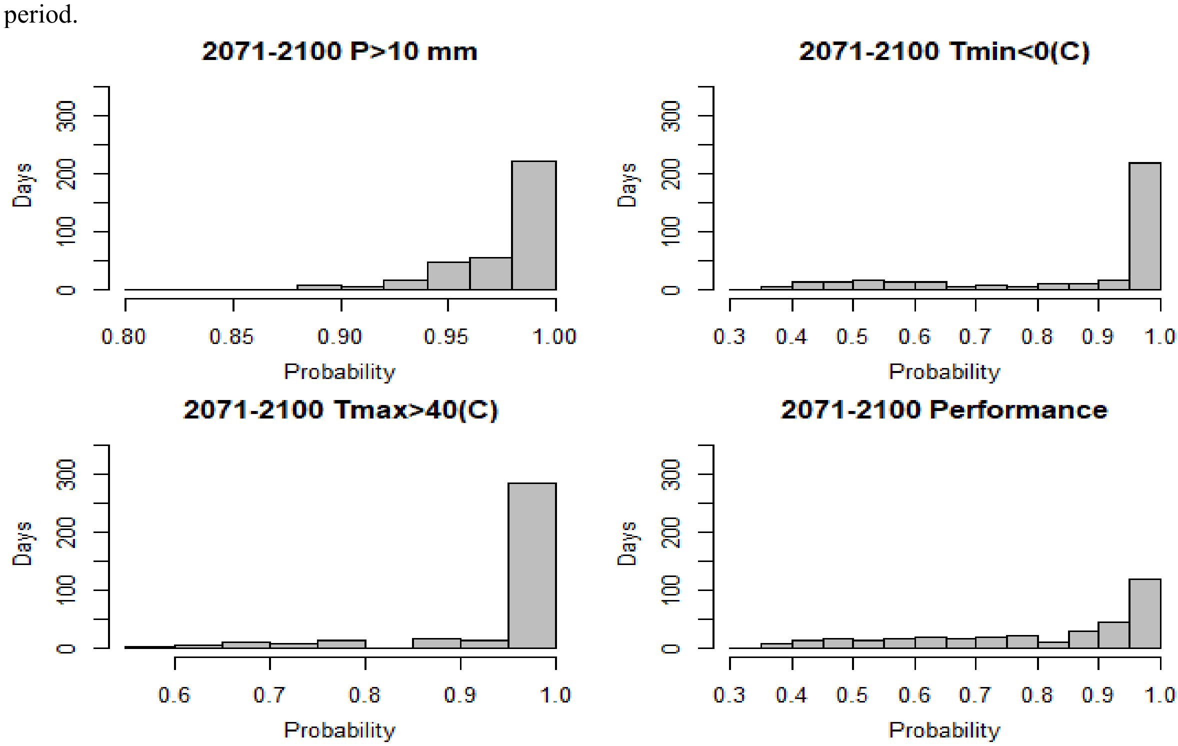

Figure 6. Workability Distribution of Components Affecting Concrete Pouring Activity and Activity Performance During the Future Period (2071-2100)

The increase in air temperature causes the hydration to accelerate too much, the need for mixing water in the concrete to increase, the strength to decrease, and the volume to increase by increasing evaporation. These events and their various harmful effects should be prevented by appropriate measures (TS 1248, 2012).

Humidity and precipitation can also have negative effects on concrete in terms of its resistance to external effects. The entry of unwanted substances into the concrete, together with moisture and water, is facilitated through the capillary cracks formed in the concrete owing to high and low temperatures. For example, the entry of sulfate, chloride, salt, and acid into concrete can increase, which can reduce the durability of concrete. Another important issue is that carbonation can occur together with the entry of CO_2 into the concrete, which can change the pH value of the concrete and cause rust in the reinforced concrete. In addition, carbonation shrinkage may be undesirable. Under cold weather conditions, it is possible that the water entering the capillary cracks will cause the concrete to lose its strength with repeated freezing and thawing.

4. Discussion and Conclusion

In this study, bias corrections were made for CMIP6 GCM precipitation and temperature data for Kırıkkale with the Quantile Delta Mapping method based on ERA5-Land as reference data. Daily data were obtained, and the probabilities of days that could not be calculated for both the reference and future periods were calculated for the selected scenarios and threshold values. Two separate models, whose performance was determined to be better than that of other models for both precipitation and temperature over Türkiye (Bağçaci et al., 2021), were averaged and used.

As a result, it was observed that the minimum temperature factor was dominant in the winter months, while the maximum temperature factor was dominant in the summer months. In this study, it was observed that precipitation had a relatively low effect. In addition, when the concrete pouring activity performances for the past and future periods were examined, it was not misleading to expect an increase in concrete pouring activity performance in winter months within the selected scenario and the future period. The reason for this is that with the increase in temperature, the distribution of the minimum temperature throughout the year will change and also increase; as a result, it is expected that the concrete pouring performance, especially in the cold months when concrete cannot be poured before or less, will increase. If the necessary precautions are not taken with the increase in maximum temperatures in the summer months, it would be natural to expect a decrease in concrete pouring activity.

Although this study shows that the effect of cold weather conditions will decrease, it is predicted that the effect of hot weather conditions will increase, and there will not be much change in precipitation. It is predicted that the effects on concrete caused by the increase in temperature may lead to rapid evaporation of water, loss of workability, shrinkage cracks, increase in internal temperature of concrete, and formation of voids in concrete, and accordingly, problems of strength, durability, and workability may increase. For these reasons, a suitable environment should be provided for the fresh and hardened concrete properties of the produced concrete to be in the desired state and that the necessary planning should be done both in concrete design, pouring and curing for possible weather events. It is important to take the necessary precautions in the concrete to be poured under these conditions to ensure the desired concrete properties and to minimize the effects of temperature and precipitation changes.

While this study focuses on SSP5-8.5 due to its relevance in assessing extreme climate impacts, future research could incorporate a broader range of possible climate outcomes (Mondal et al., 2024; Chen et al., 2021; Qin et al., 2021). Regarding the future scenarios, respectively investigating SSP1-2.6, SSP2-4.5 and SSP3-7.0 will surely offer insightful analysis of the effects of active mitigating measures and projected socioeconomic fragmentation respectively. Future research should thus incorporate a wider spectrum of SSP scenarios to also adequately cover the whole spectrum of uncertainty and possible results.

It is important to acknowledge that, beyond the factors primarily discussed in this study, there are other significant environmental parameters such as wind speed, humidity, and solar radiation which also influence concrete pouring conditions (Wang, 2021; Liang et al., 2023; Niu et al., 2020). Future research studies should therefore aim to integrate these variables to develop a more comprehensive and accurate understanding of climate-related impacts on construction activities, thereby potentially leading to improved planning and mitigation strategies before and throughout the project.

Effectively mitigating the effects of extreme temperatures on fresh and hardened concrete necessitates the implementation of adaptive measures such as adjusting pouring times (e.g., early morning or late evening), using cooling admixtures, and employing shading or misting techniques (Savva et al., 2018; Güzelküçük and Demir, 2019; Shi et al., 2022; Liang et al., 2023). These strategies, when applied thoughtfully, can help maintaining concrete workability, controlling hydration temperatures and in this way ensuring long-term durability and performance even under changing climate conditions.

Acknowledgments

This article draws partially on methodological components developed in the first author's doctoral dissertation titled Climate and Weather Impacts on Construction Projects: Improving the Short-Term and Long-Term Predictability of Delays, completed at İstanbul Medipol University in 2025. The authors gratefully acknowledge the support and foundation provided by that prior work.

References

Ahmed, K., Sachindra, D. A., Shahid, S., Demirel, M. C., & Chung, E. S. (2019). Selection of multi-model ensemble of general circulation models for the simulation of precipitation and maximum and minimum temperature based on spatial assessment metrics. Hydrology and Earth System Sciences, *23*(10), 4803–4824.

Aktürk, G., Zeybekoğlu, U., & Yıldız, O. (2022). SPI ve SPEI Yöntemleri ile Kuraklık Araştırması: Kırıkkale Örneği. International Journal of Engineering Research and Development, *14*(2), 762–776. https://doi.org/10.29137/umagd.1100886

Alarcón, L. F., Diethelm, S., Rojo, O., & Calderón, R. (2005, July 25–27). Assessing the impacts of implementing lean construction. In Proceedings of the 13th International Group for Lean Construction Annual Conference (pp. 387–393). International Group on Lean Construction.

American Concrete Institute. (1985). Manual of concrete practice, Part 1. Detroit, MI: American Concrete Institute.

Bağçaci, S., Yucel, I., Duzenli, E., & Yilmaz, M. T. (2021). Intercomparison of the expected change in the temperature and the precipitation retrieved from CMIP6 and CMIP5 climate projections: A Mediterranean hot spot case, Turkey. Atmospheric Research, 256, 105576. https://doi.org/10.1016/j.atmosres.2021.105576

Ballesteros-Pérez, P., Smith, S. T., Lloyd-Papworth, J. G., & Cooke, P. (2018). Incorporating the effect of weather in construction scheduling and management with sine wave curves: Application in the United Kingdom. Construction Management and Economics, *36*(12), 666–682. https://doi.org/10.1080/01446193.2018.1478109

Bayar, A. S., Yılmaz, M. T., Yücel, I., & Dirmeyer, P. (2023). CMIP6 Earth System Models project greater acceleration of climate zone change due to stronger warming rates. Earth's Future, *11*, e2022EF002972. https://doi.org/10.1029/2022ef002972

Cannon, A. J., Sobie, S. R., & Murdock, T. Q. (2015). Bias correction of GCM precipitation by quantile mapping: How well do methods preserve changes in quantiles and extremes? Journal of Climate, *28*(17), 6938–6959.

Checa-Garcia, R., Hegglin, M. I., Kinnison, D., Plummer, D. A., & Shine, K. P. (2018). Historical tropospheric and stratospheric ozone radiative forcing using the CMIP6 database. Geophysical Research Letters, *45*(7), 3264–3273. https://doi.org/10.1002/2017GL076770

Chen, L., Wang, G., Miao, L., et al. (2021). Future drought in CMIP6 projections and the socioeconomic impacts in China. International Journal of Climatology, 41(7), 4151–4170. https://doi.org/10.1002/joc.7064

Cooper, D. F., Grey, S., Raymond, G., & Walker, P. (2005). Project risk management guidelines: Managing risk in large projects and complex procurements. John Wiley & Sons.

Elkhadırı, I., Palacios, M., & Puertas, F. (2009). Effect of curing temperature on cement hydration. Ceramics – Silikáty, 53(2), 65–75.

El-Rayes, K., & Moselhi, O. (2001). Impact of rainfall on the productivity of highway construction. Journal of Construction Engineering and Management, 127(2), 125–131.

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., & Taylor, K. E. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geoscientific Model Development, 9(5), 1937–1958. https://doi.org/10.5194/gmd-9-1937-2016

Fashina, A. A., Omar, M. A., Sheikh, A. A., & Fakunle, F. F. (2021). Exploring the significant factors that influence delays in construction projects in Hargeisa. Heliyon, 7, e06826. https://doi.org/10.1016/j.heliyon.2021.e06826

Fu, Y., Lin, Z., & Guo, D. (2020). Improvement of the simulation of the summer East Asian westerly jet from CMIP5 to CMIP6. Atmospheric and Oceanic Science Letters, 13, 550–558.

Grose, M. R., Narsey, S., Delage, F., Dowdy, A. J., Bador, M., Boschat, G., Chung, C. T., Kajtar, J. B., Rauniyar, S. P., & Freund, M. B., et al. (2020). Insights from CMIP6 for Australia's future climate. Earth's Future, 8, e2019EF001469.

Gumus, B., Oruc, S., Yucel, I., & Yilmaz, M. T. (2023). Impacts of climate change on extreme climate indices in Türkiye driven by high-resolution downscaled CMIP6 climate models. Sustainability, 15, 7202. https://doi.org/10.3390/su15097202

Güzelküçük, S., & Demir, İ. (2019). Perlit esaslı geopolimer kompozitlere kür süresi ve sıcaklığın etkisi. International Journal of Engineering Research and Development, 11(2), 730–737. https://doi.org/10.29137/umagd.558983

Huang, B., Gao, X., Xu, X., Song, J., Geng, Y., Sarkis, J., Fishman, T., Kua, H., & Nakatani, J. (2020). A life cycle thinking framework to mitigate the environmental impact of building materials. One Earth, 3.

IPCC (Intergovernmental Panel on Climate Change). (2012). Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of Working Groups I and II of the Intergovernmental Panel on Climate Change (Field, C. B., Barros, V., Stocker, T. F., Dahe, Q., Dokken, D. J., Ebi, K. L., Mastrandrea, M. D., Mach, K. J., Plattner, G.-K., Allen, S. K., Tignor, M., & Midgley, P. M., Eds.). Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change). (2013). Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M. M. B., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P. M., Eds.). Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change). (2014a). Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., Chatterjee, M., Ebi, K. L., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandrea, P. R., & White, L. L., Eds.). Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change). (2014b). Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, Pachauri, R. K., & Meyer, L., Eds.). IPCC.

IPCC. (2022). Climate change 2022: Mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009157926

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H., Martens, B., Miralles, D. G., Piles, M., Rodríguez-Fernández, N. J., Zsoter, E., Buontempo, C., & Thépaut, J.-N. (2021). ERA5-Land: A state-of-the-art global reanalysis dataset for land applications. Earth System Science Data, 13(9), 4349–4383. https://doi.org/10.5194/essd-13-4349-2021

Johnson, R. M., & Babu, R. I. I. (2020). Time and cost overruns in the UAE construction industry: A critical analysis. International Journal of Construction Management, 20(5), 402–411. https://doi.org/10.1080/15623599.2018.1484864

Kay, A. L., Rudd, A. C., Fry, M., Nash, G., & Allen, S. (2021). Climate change impacts on peak river flows: Combining national-scale hydrological modelling and probabilistic projections. Climate Risk Management, 31, 100263. https://doi.org/10.1016/j.crm.2020.100263
Keggenhoff I, Elizbarashvili M, Amiri-Farahani A, King L (2014) Trends in daily temperature and precipitation extremes over Georgia, 1971–2010. Weather Clim Extrem 4:75–85. https://doi.org/10.1016/j.wace.2014.05.001

Khan, M. I., & Abbas, Y. M. (2017). Curing optimization for strength and durability of silica fume and fuel ash concretes under hot weather conditions. Construction and Building Materials, 157, 1092–1105.

Liang, Z., Zhou, H., Zhao, C., Wang, F., & Zhou, Y. (2023). Experimental and numerical study of the influence of solar radiation on the surface temperature field of low-heat concrete in a pouring block. Buildings, 13(6), 1519. https://doi.org/10.3390/buildings13061519

Liu, X., Li, C., Zhao, T., & Han, L. (2020). Future changes of global potential evapotranspiration simulated from CMIP5 to CMIP6 models. Atmospheric and Oceanic Science Letters, 13, 568–575. https://doi.org/10.1080/16742834.2020.1824983

Loch, C. H., DeMeyer, A., & Pich, M. T. (2006). Managing the unknown: A new approach to managing high uncertainty and risk in projects. John Wiley & Sons.

Mondal, S. K., Su, B., Huang, J., Zhai, J., Wang, G., Kundzewicz, Z. W., et al. (2024). Climate change will aggravate South Asian cropland exposure to drought by the middle of 21st century. Earth's Future, 12, e2023EF003872. https://doi.org/10.1029/2023EF003872

Medeiros-Junior, R. A., & Reichert, T. A. (2024). Impact of climate change on the service life of concrete structures. In Eco-efficient repair and rehabilitation of concrete infrastructures. Elsevier. https://doi.org/10.1016/B978-0-443-13470-8.00006-X

Moselhi, O., & El-Rayes, K. (2002). Analyzing weather-related construction claims. Cost Engineering, 44, 12–19.

Myhre, G., Alterskjær, K., Stjern, C. W., Hodnebrog, Ø., Marelle, L., Samset, B. H., & Stohl, A. (2019). Frequency of extreme precipitation increases extensively with event rareness under global warming. Scientific Reports, 9, 16063. https://doi.org/10.1038/s41598-019-52277-4

Nasir, M., Al-Amoudi, O. S. B., Al-Gahtani, H. J., & Maslehuddin, M. (2016). Effect of casting temperature on strength and density of plain and blended cement concretes prepared and cured under hot weather conditions. Construction and Building Materials, 112, 529–537.

Nguyen, L. D., Kneppers, J., García de Soto, B., & Ibbs, W. (2010). Analysis of adverse weather for excusable delays. Journal of Construction Engineering and Management, 136, 1258–1267.

Niu, X., Li, Q., Liu, W., & Hu, Y. (2020). Effects of ambient temperature, relative humidity and wind speed on interlayer properties of dam concrete. Construction and Building Materials. https://doi.org/10.1016/j.conbuildmat.2020.119791

Nordling, K., Fahrenbach, N., & Samset, B. (2024). Climate variability can outweigh the influence of climate mean changes for extreme precipitation under global warming. EGUsphere [preprint]. https://doi.org/10.5194/egusphere-2024-1068

O'Neill, B. C., Tebaldi, C., van Vuuren, D. P., Eyring, V., Friedlingstein, P., Hurtt, G., ... & Lowe, J. (2016). The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. Geoscientific Model Development, 9, 3461–3482. https://doi.org/10.5194/gmd-9-3461-2016

Ortiz, J., Aguado, A., Agullo, L., & García, T. (2005). Influence of environmental temperatures on the concrete compressive strength: Simulation of hot and cold weather conditions. Cement and Concrete Research, 35, 1970–1979.

Oruc, S. (2022). Performance of bias corrected monthly CMIP6 climate projections with different reference period data in Turkey. Acta Geophysica, 70, 777–789. https://doi.org/10.1007/s11600-022-00731-9

Oruc, S., Dikbas, H. A., Gumus, B., & Yucel, I. (2024). The impact of climate change on construction activity performance. Buildings, 14(2), 372. https://doi.org/10.3390/buildings14020372

Qin, J., Su, B., Tao, H., et al. (2021). Projection of temperature and precipitation under SSPs-RCPs scenarios over northwest China. Frontiers of Earth Science, 15, 23–37. https://doi.org/10.1007/s11707-020-0847-8

Richardson, M. (2007). Degradation of concrete in cold weather conditions. In Durability of Concrete and Cement Composites (pp. 282–315). Woodhead Publishing.

Rizzuto, P. J., Kamal, M., Elsayad, H., Bashandy, A., Etman, Z., Roos, M. N. A., & Shaaban, I. G. (2020). Effect of self-curing admixture on concrete properties in hot climate conditions. Construction and Building Materials, 261. https://doi.org/10.1016/j.conbuildmat.2020.119933

Rogalska, M., Czarnigowska, A., Hejducki, Z., & Nahurny, T. O. (2006). Methods of estimation of building processes duration including weather risk factors. Building Review, 1, 37–42. (In Polish)

Savva, P., Nicolaides, D., & Petrou, M. (2018). Internal curing for mitigating high temperature concreting effects. Construction and Building Materials. https://doi.org/10.1016/j.conbuildmat.2018.04.032

Shi, T., Deng, C., Zhao, J., Ding, P., & Fan, Z. (2022). Temperature field of concrete cured in winter conditions using thermal control measures. Advances in Materials Science and Engineering. https://doi.org/10.1155/2022/7255601

Stouffer, R. J., Eyring, V., Meehl, G. A., Bony, S., Senior, C. A., Stevens, B., & Taylor, K. E. (2017). CMIP5 scientific gaps and recommendations for CMIP6. Bulletin of the American Meteorological Society, 98, 95–105. https://doi.org/10.1175/bams-d-15-00013.1

TOBB Kırıkkale Ticaret ve Sanayi Odası. (2022). 2022–2025 Stratejik Plan. https://www.kirikkaletso.org.tr/ktso/dosyalar/STRATEJ%C4%B0K%20PLAN%202022-2025.pdf

Türk Standardları Enstitüsü. (2012). TS 1248 Betonun hazırlanması, dökümü ve bakım kuralları - Anormal hava şartlarında.

Wang, J. (2021). Test and simulation of concrete surface factor under different wind speeds. Construction and Building Materials, 300, 124019. https://doi.org/10.1016/j.conbuildmat.2021.124019

Wyser, K., Kjellström, E., Koenigk, T., Martins, H., & Doescher, R. (2020). Warmer climate projections in EC-Earth3-Veg: The role of changes in the greenhouse gas concentrations from CMIP5 to CMIP6. Environmental Research Letters, 15, 054020. https://doi.org/10.1088/1748-9326/ab81c2