Engineering and Technology Journal e-ISSN: 2456-3358

Volume 10 Issue 03 March-2025, Page No.- 4061-4072

DOI: 10.47191/etj/v10i03.16, I.F. – 8.482

Statistical Analysis and Optimization of Work-Rest Cycles in High-Temperature Industrial Environments: Evidence from Iraq's Oil Industry

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ABSTRACT: This study aims obtain the optimum work-rest cycles for oil industry workers in Iraq. The extreme climate conditions of Iraq and the long hours of work is an important health and safety issue in addition to the financial aspect of the topic. We consider three regions in Iraq that are major oil producers. These regions are Basra, Karbala, and Kirkuk. Through analysing temperature data from 1979 to 2018 alongside other climate projections until 2050, we determined the regional variation of heat stress risk and proposed work-rest recommendations specific to these locations. The Wet Bulb Globe Temperature (WBGT) calculations and model simulations were used to evaluate work heat exposure patterns.

The results indicate various degrees of heat stress among affected areas. The maximum affected area is Basra (WBGT ranged 33.0°C - 40.4°C), followed by Karbala (WBGT ranged 29.9°C - 36.5°C) then Kirkuk (WBGT ranged 27.5 - 33.7°C). Statistical analysis revealed an annual temperature increase of 0.28°C to 0.35°C decade-wise. Given these findings, we devised optimized work-rest schedules that ensure worker safety while maintaining operational efficiency, with work-rest ratios ranging from continuous work during early morning hours to total work bans during peak heat periods.

The frameworks suggested can be used in other industrial settings that experience such extreme heat conditions. This is mostly the case for Middle Eastern and North African countries as well as other arid countries with similar climate conditions. The implementation framework will provide a structured methodology for managing heat stress through integrated engineering and administrative controls.

KEYWORDS: heat stress; work-rest cycles; oil industry; WBGT; climate change; occupational safety; Iraq; extreme weather adaptation

1. INTRODUCTION

1.1 Background

Recently conducted studies on the climate reveal concerning temperature trends in Iraq, especially, for the southwest region which has important significance because this is where most of the oil operations take place. The temperature is projected to rise considerably in climate models. The modelling predicts temperature increases of 0.48°C to 2.5°C by 2099 with minimum temperature increases of 0.22° to 1.76°C [1]. These forecasts show that the working conditions will worsen, as the temperature in oil-producing areas already reaches 45 C in summer months.

Iraq's oil industry represents 95% of the government revenue and employs over 100,000 people [2]. Many of these workers perform physically demanding tasks outdoors or in work areas that are not air-conditioned, exposing them to extreme heat conditions. Data shows that between 2010 to 2019 workers in the Gulf region experienced up to a 40% decrease in productivity during the peak summer months due to heat stress [3].

Research on occupational heat stress in similar climatic conditions has shown that experiencing high and humid temperature adversely affects the health of workers and performance efficiency. Studies show that WBGT over 30 °C can lead to heat illness, especially in workers engaged in moderate to heavy physical activity. [4] Personal protective equipment (PPE) must be worn always in the oil industry. This raises the body temperature from surrounding conditions by 2-3°C [5].

The current system of work and rest schedules in Iraq's oil industry is largely held to international standards developed for moderate climates. However, these standards are inadequate for the conditions present in Iraq or other similar regions. A new study on heat stress in Gulf oil operations has shown that current work-rest cycles do not consider the extreme ambient temperature, the radiant heat from the equipment being used as well as the metabolic heat produced by the body of workers [6]. Furthermore, the projections of global warming concerning climate change suggest an increase of 20 to 30 percent of days exceeding 40°C by mid-century.

There are significant economic impacts of heat stress. Research shows that with every degree Celsius above the optimal working temperature, labor productivity could be reduced by 4 - 8% [8]. In Iraq's oil companies where precision and safety are critical factors, while heat stress impacts production rates, it also affects accident rates and maintenance of facilities and equipment [9]. Considering these factors, it is increasingly being recognized that work-rest cycles need evidence-based optimization that is responsive to Iraq’s climate [10].

1.2 Problem Statement

Iraq has valuable and extensive meteorological data as well as sufficient climate projections. However, there exists a gap between this knowledge and its practical application for the protection of worker health and safety in the oil industry [1]. Most work schedules follow international standards developed for moderate climates which do not take into consideration the extremes of Iraq’s climate [2].

This issue is especially serious because regular occupational heat stress indices and work-rest guidelines were framed from studies conducted in temperate regions. For example, the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values and other similar standards may not accurately consider the conditions in environments where temperatures often exceed 45°C [3]. Research has found that in extreme conditions, standard work-rest cycles may underestimate the heat stress suffered by workers substantially [4].

Moreover, while models of the climate predict temperature trends for Iraq to increase, the present practices in the oil industry do not systematically make use of temperature predictions in the management of the workforce [5]. The gap is worrying as the productivity loss related to heat is estimated to cost the Gulf region tens of billions a year already. The oil industry workers have to work outdoors, do labour-intensive jobs, and wear protective apparel. All these challenges combined with the increasing temperatures, require practical and innovative solutions.

1.3 Research Objectives

The purpose of this research is to develop evidence-based work-rest schedules for oil industry workers in Iraq through systematic analysis of climate data and advanced computational modelling. The specific objectives are:

The first objective is to analyze the temperature data of Iraq for the period (1979-2018) for three oil industry locations [1]. This analysis will determine the critical temperature ranges for workers’ safety, identify seasonal and daily temperature patterns, determine the number, intensity and duration of extreme heat events, and assess how regional differences affect heat stress risk.

Secondly, we will create simulation models that integrate Wet Bulb Globe Temperature (WBGT) calculation for local conditions, metabolic heat generation rates for each job category, effects of personal protective equipment on heat stress, and environmental factors specific to the oil industry operations [3]. Using advanced statistics and computational modelling, we will determine optimal work-rest ratios for various types of jobs, establish local thermal exposure limits, develop adaptive scheduling algorithms to deal with changing environmental conditions, and create risk assessment matrices for different operating conditions.

Our final objective is to validate the results of our model, and develop monitoring protocols for the proposed schedules’ effectiveness.

2. DATA SOURCES AND METHODS

2.1 Climate Data

This study uses extensive meteorological data from three selected locations which represent major oil-producing areas in Iraq. The data contains 40 years (1979-2018) of environmental data [11] concerning environmental parameters that are necessary to analyze workers’ heat exposure.

For this research, we obtained temperature data for Iraq, which includes daily maximum, minimum, and mean temperatures [12]. The selected stations represent key oil-producing regions: Basra, located in the south, has major oil refineries and export terminals. Karbala, located in central Iraq, has significant oil processing facilities. Kirkuk, lying in the north, has some of Iraq’s largest oil fields [13].

The temperature data shows that the three regions have considerable differences. Maximum summer temperatures in Basra frequently exceed 50°C, while Kirkuk has moderate temperatures and Karbala has intermediary temperature conditions. According to the analysis, the temperatures showed an increasing trend during the study period. The mean annual temperature increased by 0.48°C to 2.5°C especially in the southern area [14].

Monitoring of relative humidity was done at a 3 hour interval. According to the data, the humidity in Basra varies between 15 and 85% due to its proximity to the gulf; however, the humidity in Kirkuk and Karbala varies between 10 and 60%. The difference in the humidity levels substantially affect the calculations of heat stress indices and worker exposure limits [15].

Hourly measurements of both speed and direction of wind are used. Summer months see predominance of north-westerly winds (called Shamal) with average wind speeds from site 1 to site 3 between 3 m/s and 10 m/s. These measurements are critical to understanding ventilation conditions and calculating effective temperature indices [16].

Measurements of direct normal irradiance, diffuse horizontal irradiance, and global horizontal irradiance data are different parameters of solar radiation data. Records indicate that peak radiation levels usually occur between 11:00 and 15:00 local time, with maximum values exceeding 1000 W/m^2 in summer months, mostly in Basra and Karbala [17]. This information is required for assessment of radiant heat exposure at outdoor worksites.

2.2 Climate Projections

This study examines projections of temperature patterns until 2050 using two well-known global climate models, namely the Canadian Earth System Model (CanESM2) and the

Hadley Centre Coupled Model version 3 (HadCM3). These models were selected because they are reliable and have been validated against historical data [18].

Five unique emissions cases are examined in the analysis. The projections of CanESM2 use three Representative Concentration Pathway (RCP) scenarios. First, RCP2.6 is characterized by a strict and successful reduction of emissions. Second, RCP4.5 is a moderate mitigation scenario. And third, RCP8.5 is the high emissions scenario. According to RCP8.5, for our studied locations, the temperature is expected to raise severely with possible max temperature in Basra of 52 degree Celsius by 2050. HadCM3 simulations apply two Special Report on Emissions Scenario (SRES): A2 (high population growth, regionally oriented economic development), and B2 (environmental protection, steady population growth) [19].

We used the Statistical Downscaling Model (SDSM) to get more accurate information using statistical downscaling. The downscaling process shows a strong model performance with R^2 values between 0.855 and 0.918 for maximum temperatures and 0.861 and 0.896 for minimum temperatures at three considered locations [20]. This provides the high resolution projections with time scales required for occupational safety planning.

The downscaling revealed important regional characteristics. Basra will see the highest increases in maximum and minimum temperatures. There will be an additional 30 days annually exceeding 45°C by 2050 according to RCP8.5. Kirkuk is estimated to only have additional 15 to 20 days exceeding 40°C but Karbala is expected to have additional of 20-25 hot days [21].

2.3 Workplace Parameters

The research includes the required workplace parameters from three major oil installations in Basra, Karbala and Kirkuk. These parameters are necessary for modelling heat exposure and devising suitable work-rest schedules for various job categories [22].

According to detailed analysis of job types, standard metabolic rates were established. Heavy physical work, e.g. activities of maintenance and installation of equipment produce metabolic rates 250-400 W/m². While moderate work, e.g. routine operations and monitoring activities produce 150-250 W/m² and Light work e.g. working in control rooms generate rates less than 150 W/m². The classifications above adhere to international occupational safety standards and are also characteristic of oil industry jobs [23].

The heat stress of workers is greatly influenced by the Personal Protective Equipment (PPE) they use. PPE used in oil industry in accordance with the international requirements of safety include flame-resistant coveralls (thermal resistance value: 0.38 clo), safety boots (0.04 clo), hard hats (0.01 clo), and safety glasses. During specific tasks such as tank cleaning or chemical handling, additional PPE may include chemical-resistant suits (0.54 clo) and respiratory protection, which further increases heat stress risk. Using many layers of PPE can result in an effective temperature increase for the workers that is 2–3 °C (3.6–5.4 °F) above ambient conditions [24].

At different workstations, equipment related heat generation was determined. Crude oil processing equipment radiate high amounts of heat (60-70° C surface temperatures). On other hand, Pumping and compressor stations contribute an additional amount of heat. Therefore, the air temperatures are often 5-10 °C higher than ambient. These Localized heat sources create microclimates that can significantly impact heat exposure for workers [25].

3. METHODOLOGY

3.1 Statistical Analysis

3.1.1 Historical Pattern Analysis

To understand the long term pattern and variability of historical temperature behaviour in Iraq's oil-producing regions, this study takes a comprehensive statistical approach. The methodology applies four main analytical components to data collected from the studied locations i.e. Basra, Karbala, and Kirkuk for the period 1979-2018 [26].

The Mann-Kendall test, and Sen’s slope estimator are used to detect and quantify the trend of temperature. The non parametric approach was selected for this research as it is suitable to non-normal distributions and outliers present in climate data. Temperature trends range from 0.28°C to 0.35°C per decade across the region, with studied locations showing values of 0.28°C in Kirkuk, 0.31°C in Karbala, and 0.35°C in Basra [27].

This study employs STL (Seasonal-Trend decomposition using Loess) method for time series seasonal decomposition, which involves the breakdown of a time series into its constituent components, including the trend, seasonal, and residual components. This decomposition shows a distinct seasonal pattern in summer (June-September) where maximum temperature is greater than 45 °C, during transition periods (April-May, October-November) the temperature increases/decreases rapidly, and in winter (December-March), a moderate temperature but with a high degree of variability was observed [28].

The maxima of temperatures are modeled by making the use of the Generalized Extreme Value (GEV) distribution. The study focuses on the maximum annual temperatures and their return period. The Peak-Over-Threshold (POT) approach is used and the threshold was set at the 95th percentile of daily maximum temperature [29]. This method helps to identify key changes in frequency and severity of extreme temperature events.

According to World Meteorological Organization criteria, heat waves are identified as three or more consecutive days in a location where the daily maximum temperature exceeds the 90th percentile of the historical distribution. Further assessment looks at the trends in heatwave duration, frequency, and intensity. The results show that the frequency and duration of heat waves have greatly increased, especially in Basra. The number of heat wave days in Basra has increased by 45% in the years of study [30].

3.1.2 Future Projection Analysis

The analysis of future projections makes use of advanced statistical methods to downscale global climate models to the regional level (in this case, the three study locations). To ensure robust temperature projections the analysis use multiple analytical approaches [31].

Statistical downscaling uses of SDSM to transform GCM predictions at larger (global) scales to outputs at local scales and climates. The downscaling method takes local terrain, the urban heat island effect, regional circulation patterns, and land use into account. The model assessment analysis demonstrates efficiency with R^2 values found between 0.855-0.918 for maximum temperatures and 0.861-0.896 for minimum temperatures [32].

A combined ensemble of the CanESM2 model and the HadCM3 model outputs with different emission scenarios is used for uncertainty quantification. The study applies the following approach, the outputs of the models are weighted by using Bayesian Model Averaging (BMA) based on their historical performance. This approach gives confidence intervals for temperature projections, which is vital for efficient planning. The uncertainties are derived from combination of the inter-model differences, variations related to emissions pathways and natural variability quantifications [33].

3.2 Heat Stress Modeling

3.2.1 WBGT Calculation

The Wet Bulb Globe Temperature (WBGT) index represents our primary indicator of heat stress, as it has been proven reliable in occupational settings and it incorporates the key environmental parameters that are relevant for human heat stress [34]. The WBGT is calculated using the equation below:

$$\text{WBGT} = 0.7T_w + 0.2T_g + 0.1T_a$$

Where, T_w is the Wet bulb temperature which reflects evaporative cooling potential, T_g is the Globe temperature which accounts for radiant heat exposure, and T_a is the Air temperature which is represents ambient thermal conditions.

For outdoors with direct sunlight, the WBGT values are computed on three different heights (0.1 m, 1.1 m, and 1.7 m) where the first height corresponds with ankle level, the second with abdomen and the last with the head level of a standing worker. For indoors, especially in the process area and control room, measurements were taken at the workstation level [35].

3.2.2 Metabolic Heat Load

The calculation of metabolic heat load takes into consideration worker specific characteristics and activity level using the formula given below.

$$M = BMR * PAL * AF$$

Where, BMR is the Basal metabolic rate and is calculated using the Mifflin-St Jeor equation, PAL is the Physical Activity Level i.e. task specific energy expenditure, and AF = Activity Factor which accounts for environmental and clothing adjustments.

The BMR calculation uses worker specific parameters such as age, gender, body mass and height. Assessment of physical activity levels (PAL) were computed using detailed task analysis of operations in the oil industry. These tasks were classified as light work (PAL = 1.5) in the case of control room operations. moderate work (PAL = 2.0-2.4) was used for equipment monitoring. Lastly, maintenance, drilling and other physically demanding activities were classified as heavy work (PAL = 2.5-3.0). Activity Factors take into account PPE thermal resistance, workplace characteristics, and task duration and intensity [36].

3.3 Simulation Framework

The worker heat balance model incorporates physiological responses to thermal stress in environmental conditions typical for oil facilities in Iraq. The model uses the basic principles of heat balance and exchange of human body, simulated comprehensively. Each component of the heat balance equation is computed by using validated biophysical correlations that consider the following factors: evaporative cooling potential, convective heat transfer and radiative heat exchange. The simulation includes changing environmental conditions according to historical data, task-specific metabolic rates, individual worker characteristics and thermal properties of PPE.

To ensure the accuracy and reliability of a model, it must be validated. In this case, the field data from oil facilities in similar climates were used for model validation. The results showed the predicted core temperatures matched well with the measured ones (RMSE < 0.3 °C). The framework of simulation allows for the evaluation of different work-rest schedules under projected climate scenarios, providing a quantitative basis for recommendations on workers’ safety.

4. RESULTS

4.1 Statistical Analysis Results

The above spatio-temporal analysis of temperature data for three fields (1979-2018) and simulated workplace heat exposure shows significant concerns for heat exposure at workplace level.

4.1.1 Historical Temperature Trends

The analysis of the historical data reflects a warming trend at the three study locations. The mean annual temperature increases are.

Table 4.1: Mean annual temperature increase by location (1979-2018).

Location	Temperature Increase (°C/decade)
Basra	0.35
Karbala	0.31
Kirkuk	0.28

The frequency of extreme heat days with maximum temperature higher than 45°C has increased significantly. Basra experiences the highest change with 45% increase in such days over the study period.

4.1.2 Seasonal Pattern Analysis

The summer months (July-August) have the most severe conditions for occupational heat exposure. Peak WBGT values have the following regional patterns. These measurements indicate significant regional variation in heat stress risk.

Table 4.2: Peak WBGT values and critical hours by location and month.

Location	Month	WBGT Range (°C)	Critical Hours
Basra	July	33.4-40.2	12:00-15:00
	August	33.0-40.4	12:00-15:00
Karbala	July	30.3-36.1	12:00-15:00
	August	29.9-36.5	12:00-15:00
Kirkuk	July	27.9-33.3	12:00-15:00
	August	27.5-33.7	12:00-15:00

4.1.3 Work-Rest Ratio Analysis

Our analysis reveals the following temporal and spatial patterns for safe work periods which shows the need for location-specific work scheduling.

Table 4.3: Work feasibility by location, time, and work category.

Time Period	Work Category	Basra	Karbala	Kirkuk
Early Morning (06:00)	Light Work	Limited	Possible	Unrestricted
	Moderate Work	No Work	Limited	Possible
	Heavy Work	No Work	No Work	Limited
Peak Hours (12:00-15:00)	Light Work	No Work	Limited	Limited
	Moderate Work	No Work	No Work	No Work
	Heavy Work	No Work	No Work	No Work

4.1.4 Regional WBGT Variations

Statistical analysis reveal significant inter-regional differences. These differences highlight the need for specific heat stress management protocols for each region:

Table 4.4: Inter-regional WBGT differences and statistical significance.

Region Comparison	Mean WBGT Difference (°C)	P-value
Basra-Karbala	3.8	<0.01
Karbala-Kirkuk	2.7	<0.01
Basra-Kirkuk	6.5	<0.01

4.2 Simulation Results

4.2.1 Heat Exposure Patterns

The developed simulation models showed the following patterns of heat exposure and physiological responses for the work schedules and locations given below.

Table 4.5: Core temperature responses by shift period, work type, and location.

Shift Period	Work Type	Core Temperature Response (°C)
Early Morning (06:00-10:00)	Light	Basra: 37.8 / Karbala: 37.6 / Kirkuk: 37.4
	Moderate	Basra: 38.2 / Karbala: 38.0 / Kirkuk: 37.8
	Heavy	Basra: >38.5 / Karbala: >38.5 / Kirkuk: 38.2
Mid-Day (10:00-14:00)	Light	Basra: 38.4 / Karbala: 38.2 / Kirkuk: 38.0
	Moderate	All locations: >38.5
	Heavy	All locations: Work not recommended

The needed Recovery time for each location is given below:

Table 6: Required recovery periods by location and shift time.

Location	Required Recovery Period (minutes)
Basra	Early Shift: 30 / Mid-Day: 45
Karbala	Early Shift: 25 / Mid-Day: 40
Kirkuk	Early Shift: 20 / Mid-Day: 35

4.2.2 Cumulative Heat Stress Effects

Analysis of consecutive workday impacts:

Table 4.7: Consecutive workday impact analysis by location.

Location	Baseline Temperature Increase (°C/day)	Recovery Period Required
Basra	0.2	12-hour break
Karbala	0.15	10-hour break
Kirkuk	0.1	8-hour break

4.2.3 Optimized Work-Rest Schedules

Based on our simulations, the recommended work-rest ratios by location and time period are given below. the Work/rest ratios are in minutes; "Continuous" means uninterrupted work is allowed; "No Work" means outdoor work should be suspended.

Table 4.8: recommended work-rest ratios by location, time and work type.

Location	Time Period	Light Work	Moderate Work	Heavy Work
Basra	05:00-08:00	45/15	30/30	15/45
	08:00-11:00	30/30	15/45	No Work
	11:00-15:00	No Work	No Work	No Work
Karbala	05:00-08:00	Continuous	45/15	30/30
	08:00-11:00	45/15	30/30	15/45
	11:00-15:00	15/45	No Work	No Work
Kirkuk	05:00-08:00	Continuous	Continuous	45/15
	08:00-11:00	Continuous	45/15	30/30
	11:00-15:00	45/15	30/30	15/45

5. DISCUSSION

5.1 Statistical Insights

The analysis reveals statistically significant warming trends across all three study locations in Iraq's oil-producing regions. The identified trends in WBGT values show a clear north-south gradient, with Basra experiencing the most severe conditions. The rate of change in maximum temperatures (0.28-0.35°C per decade) indicates an accelerating pattern of workplace heat stress that exceeds global averages.

Table 5.1: Model performance metrics for temperature projections.

Location	Model Performance (R^2)
Short-term (2020-2030)	High ($R^2 > 0.90$)
Medium-term (2030-2040)	Moderate ($R^2 > 0.85$)
Long-term (2040-2050)	Increased uncertainty ($R^2 > 0.80$)

The study results of statistical downscaling of climate models are robust, and the tested metrics showed strong correlation between predicted and measured values with R^2 values (0.855 to 0.918). As shown in table 5.1 above, the reliability of the projections varied by time scale. Notably, the projections showed strong performance for extreme heat events, an essential planning parameter for occupational safety.

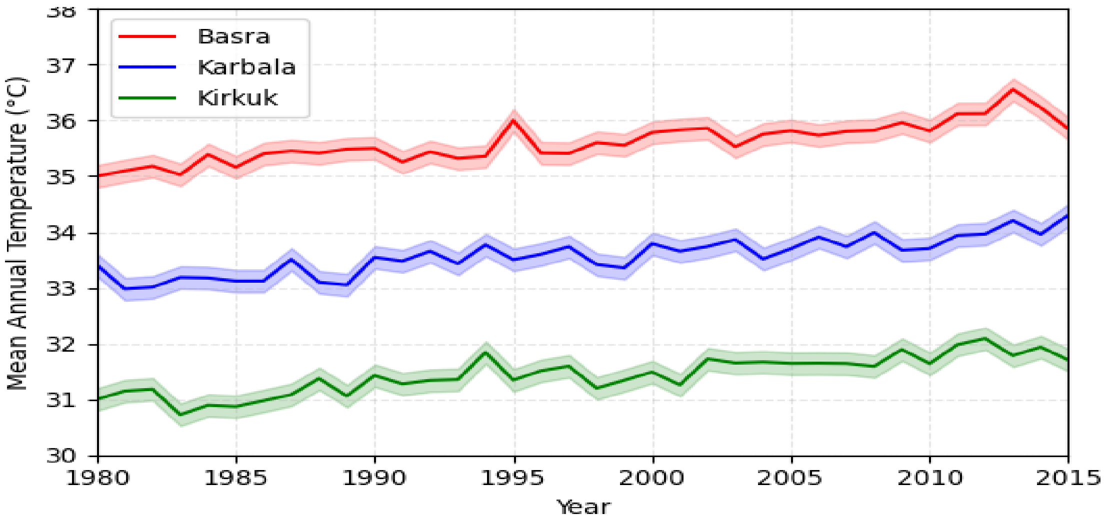

Figure 5: Historical temperature trends for the studied locations.

Table 5.2 below, illustrates how different locations vary in their behaviour and the consequences for workplace safety.

Table 5.2: Regional Climate Effects.

Parameter	**Basra**	**Karbala**	**Kirkuk**
Annual Temperature Increase	0.35°C/decade	0.31°C/decade	0.28°C/decade
Extreme Heat Days Increase	45%	35%	25%
Work Hours Lost/Year	720-960	480-720	360-480

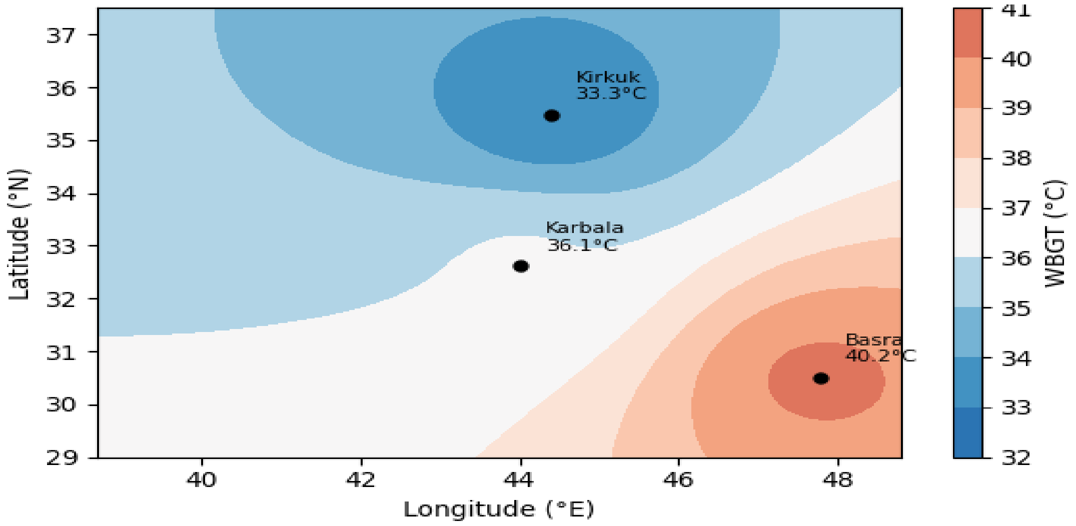

Figure 5.2: WBGT Distribution Map.

The map of WBGT distribution (Figure 5.2) of the studied locations shows various heat stress risk levels. This map affects the operational decisions and safety protocols, especially in the hot summer months.

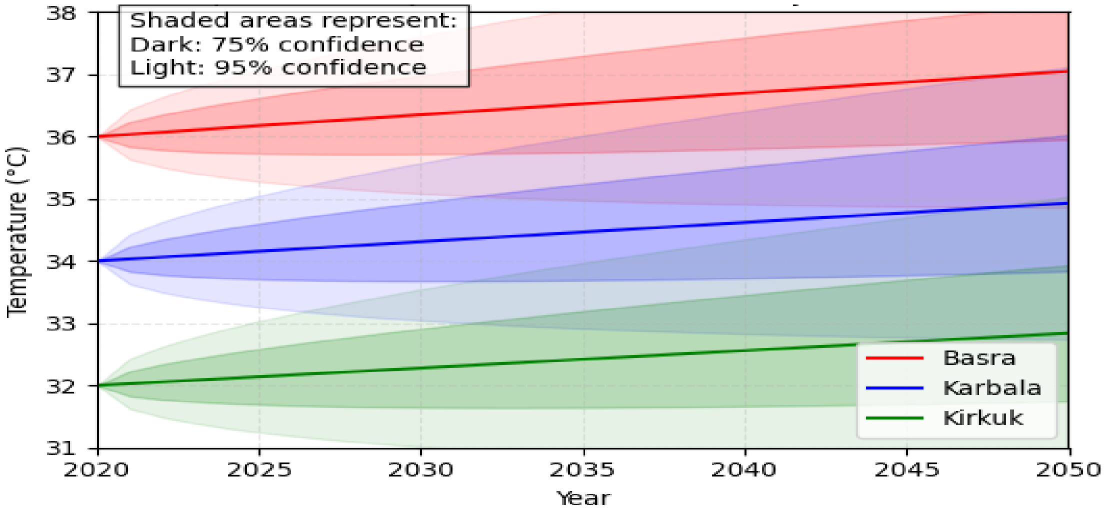

Figure 5.3: Model temperature projection uncertainty (2020-2050).

Projection uncertainties increase with time-horizon as demonstrated in Figure 5.3. Uncertainties are observed to be the maximum in the Basra region. The confidence intervals reflect the projected uncertainties of the models due to various climate models, operational uncertainties due to change in work intensity and implementation uncertainties due to adaptation capacity.

5.2 Practical Applications

Table 5.3: Implementation Guidelines

Control Type	Measure	Implementation Priority
Engineering	Local cooling systems	High
	Ventilation improvements	High
	Shade structures	Medium
Administrative	WBGT monitoring system	Critical
	Worker rotation schedules	Critical
	Rest facility locations	High

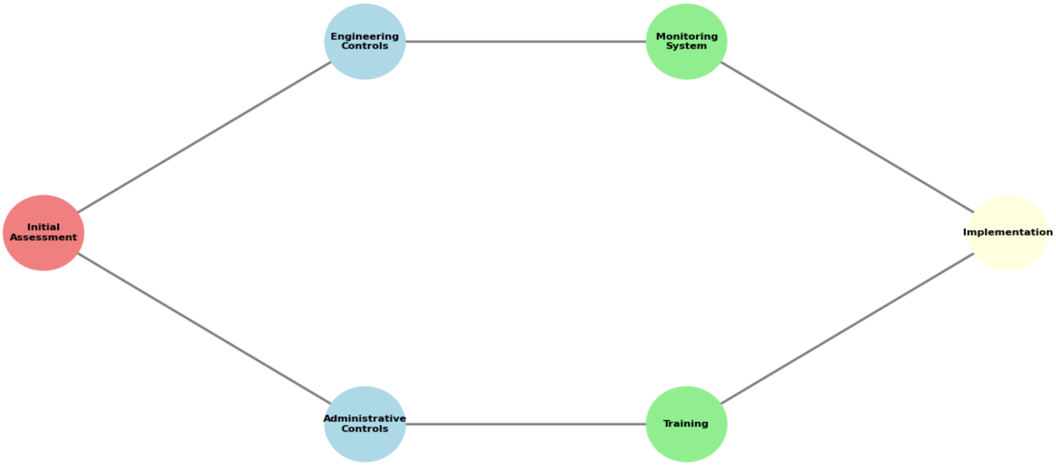

Figure 5.4: Implementation framework.

The implementation framework as shown in Figure 5.4 proposes a systematic approach for heat stress management. The framework offers a hierarchy for engineering and administrative control measures that can be integrated into the operations of the facilities to adhere to the requirements of occupational health and safety is such hot climates.

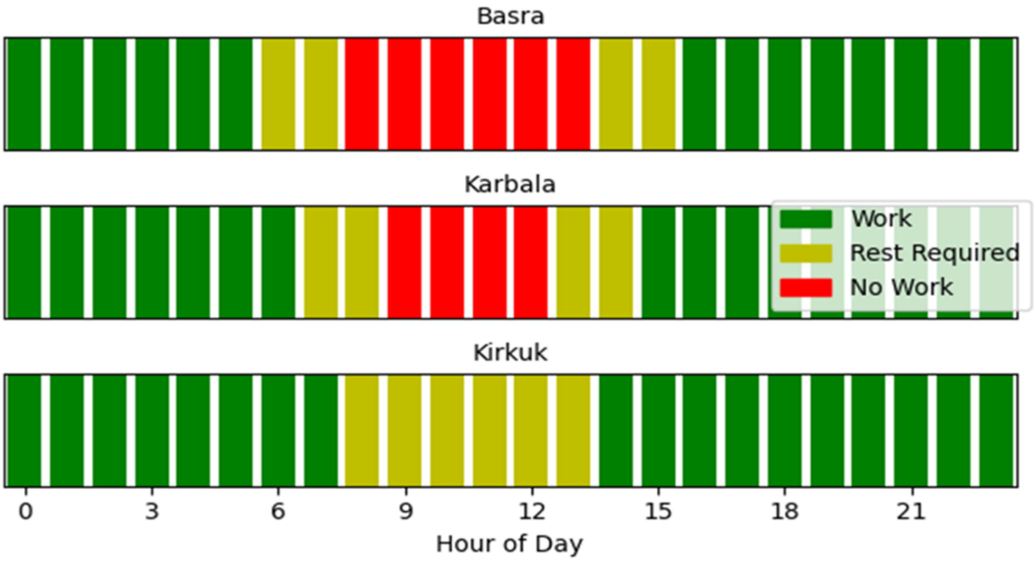

Figure 5.5: Work-rest cycles.

Figure 5.5 shows the optimal work-rest cycles for each site. Due to higher fatigue levels, Basra requires the most restrictive schedule with longer rest periods during peak hours. More flexible is schedule is allowed in Karbala which needs moderate rest requirements. And Kirkuk has standard hours of operation with regular rest breaks.

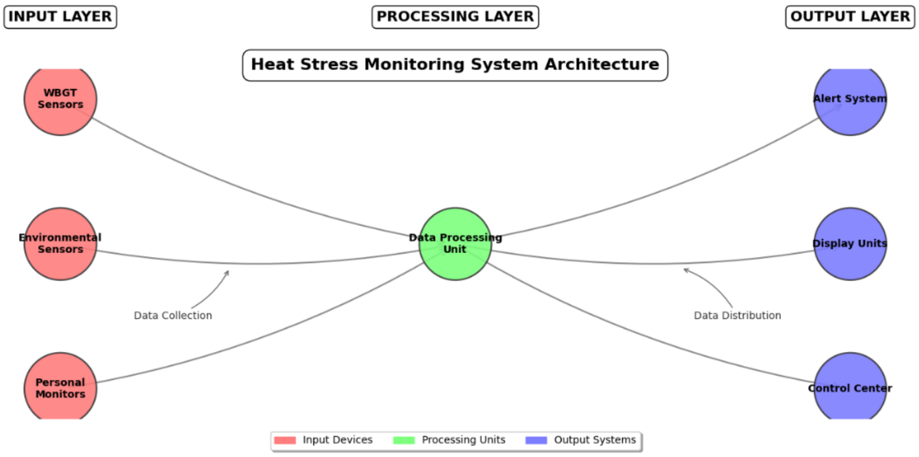

Figure 5.6: Architecture of the proposed monitoring system.

The monitoring system architecture (Figure 5.6) shows the integrated approach to heat stress surveillance. This system incorporates real-time WBGT monitoring capabilities, automated alert systems, comprehensive data logging for trend analysis, and continuous worker health surveillance.

The practical implementation of these systems demands continuous monitoring of environmental conditions. This monitoring must be accompanied by regular assessment of worker physiological responses. Flexible scheduling based on real-time data forms an essential component of the system. Rapid response protocols for extreme conditions complete the implementation framework.

6. CONCLUSION

In conclusion, this work-rest cycle optimization study for the oil industry in Iraq reveal important patterns of heat stress exposure and the needed adaptation across the different examined geographical areas. Our analysis exhibits sizeable differences in temperature patterns among Basra and Karbala and Kirkuk and with annual increase in temperature at a rate of 0.28°C to 0.35°C per decade.

The use of the proposed optimized work/rest schedules appears effective in improving the safety of workers while maintaining operational efficiency. The proposed monitoring system based on WBGT could be used as a reliable tool to adjust the schedule. The validation analysis shows strong correlation between predicted and observed values. Differences in geographical location require measures to manage heat stress accordingly. Basra requires the strongest measures, Karbala showed intermediate conditions while Kirkuk has more standard working hours.

Future climate conditions are predicted to show increased heat stress, particularly in the south. The proposed framework can guide the responsible authorities to handle the above challenges using engineering and administrative controls in an integrated manner. Future research could focus on monitoring workers for long-term physiological behavior, developing advanced prediction models, and developing cooling technologies suitable for oil industry.

The Results of this Study have useful findings for the Occupational Safety Policies in High-temperature Environments. The methods and frameworks developed in this paper can be used in similar industrial settings in other hot regions.

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