*Applied Chemical Engineering (2025) Volume 8 Issue 1* ISSN: 2578-2010 (O)
doi: 10.59429/ace.v8i1.5611

RESEARCH ARTICLE

# Atmospheric monitoring network for engineering design data and quality of environment

**Ibrahim Altuwair***

*Engineering Faculty, Chemical Engineering and Material Science, Arar, 73211, Kingdom of Saudi Arabia*

***Corresponding author:** Ibrahim Altuwair, Ibrahim.altuwair@nbu.edu.sa

## ABSTRACT

Global warming has become a controversial topic world-wide. It is becoming even more important for researchers to define vital tools and environmental solutions to alleviate the industrial release effects. This paper highlights environmental issues in an industrial area in Saudi Arabia. For the sake of clarity, the industrial environmental issues specified into air and water. Additionally, the pollutants impact into the environment by industrial manufacturing activities around the Jubail Industrial City (JIC) is the main reason of growing pollution problem.

The data constitute the results of monitoring campaign of chemical concentration levels in JIC located. A daily averages atmospheric concentrations of gases were measured at different sites located around the city. The result showed that the measurement of gases concentrations consistently correlated to each other through the season (i.e. CO2). However, the research indicates that direct traffic emissions have an important contribution to increase the gas level such as Particulate Matters (PM's) and suspended material.

***Keywords:*** global warming; environment; pollution; monitoring; gas; emission

**ARTICLE INFO**

Received: 5 February 2025
Accepted: 14 April 2025
Available online: 29 April 2025



## 1. Introduction

The quality of air has become a controversial issue in our society, keeping the air quality clean is becoming a significant task for our environment and human health. The problem is complicated and needs joint efforts by governmental and private sectors, as well as entire society.

The article presents a prototype of an application that illustrates real-time air quality data and history for period of time.

The purpose of this research is to provide information to the public and organizations against air pollution in one of Jubail industrial city (JIC). It aggregates data from various sources, stations, and sensors. Data is collected by setting up a network monitoring stations and processed in a standardized manner. The application can be used to monitor the air levels and take precautions to protect the environment and human health. Functionalities to create long-term air pollution forecasts and approximate air quality with movement stations.

JIC is one of the largest industrial cities in the worldwide. The population of the city around five hundred thousand inhabitants. The geographic and topographic characteristics are very different to that of Model-East cities which are considered as paradigms of urban air pollution studies. In contrast to these cities, which are surrounded by hills or high mountain, Jubail surrounding lie on a vast plain area, within Arab Gulf line (which is here around 85 Km side).

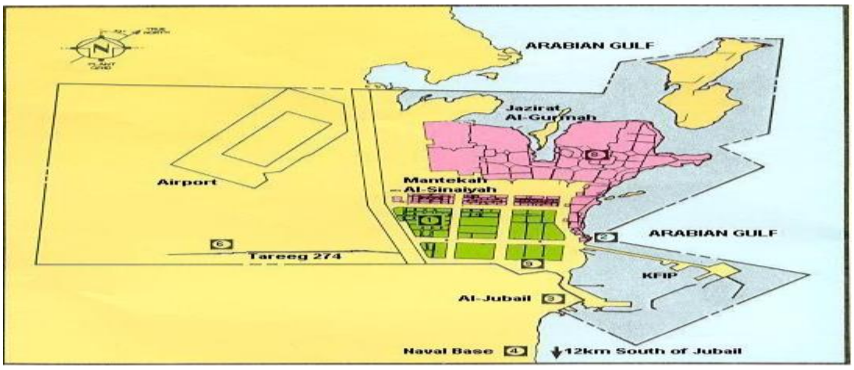



**Figure 1.** Atmospheric monitoring network map[12].

The authority has established an atmospheric monitoring network covering the area in and around Jubail Industrial City (JIC) to provide engineering design data and to monitor the quality of the environment. This network of monitoring stations has been operational since July 1977. As a basis for establishing meteorological and hydrological guidelines, data for monitoring Sites 1 and 2 are summarized herein.

Considering that atmospheric of JIC has not been characterized yet, and that there are no systematic controls of air quality in the city by local authorities, we have started few years ago a research project toward exploring its main characteristics. These series of studies are oriented to investigate some relevant aspects, such as the levels of atmospheric pollutants and its sources, on the basis of systematic measurements. There are different methods of air pollution monitoring system, a group of scientist has focused on the use of wireless sensors installed to complement fixed system and assess the quality of data transmission[3]. The first systematic method of gas pollutants performed in the JIC using continuous measurements with fully automated equipment were reported in a first work[12]. The results of modeling the dispersion of primary gas pollutants were reported. On the basis of these works, some very well-defined facts were established, that can be used as a reference frame valid for the densely populated area. In cases where the Jubail database is considered still inadequate to provide meaningful statistics, or as a supplement to the Jubail data, information from Ras Tanura and Dhahran with periods of record of up to 27 years is included. The

Meteorological and hydrological data are provided to aid the design of all facilities being constructed at JIC.

## 2. Climatology

The climatology of JIC is one of environmental extremes. Summers are characterized by intense heat and persistent, strong winds. In winter near freezing temperatures and occasional heavy rain showers, thunderstorms, and extended sandstorms can be expected.

Although four seasons are observed at JIC, the summer and winter seasons dominant. The length of the summer season is greater than in more temperate zones and can be considered to last from May until September. Rain is almost totally non-existent during this period and daytime temperatures in excess of 50°C are possible. Evaporation on land is greater during the summer, but is believed to be higher over the Gulf in fall, winter and spring. Relative humidity is generally low in summer but often high enough in fall and winter to cause persistent fogs.

Beginning in late May and June, an extensive low-pressure area develops over the Asian Continent due to excess summer heating of this large landmass. The counter-clockwise wind circulation, which is characteristic of a low-pressure area, persists for the entire summer. The eastern coast of Saudi Arabia lies on the northwest edge of this circulation resulting in northerly winds over the Jubail region. During June and July wind speeds are frequently strong enough to cause sandstorm conditions known locally as "Shammals" (from the Arabic word north). These strong winds may last for two (2) to three (3) days at a time with mean wind speeds of 15 $ms^{-1}$ or higher and gusts over 18 $ms^{-1}$. By mid-July, the pressure gradient between Asia and Saudi Arabia begins to diminish and the northwest winds weaken. September is the calmest month.

The fall months of October and November are transitional months during which temperatures lower and relative humidity begin to rise. By November, the first extra tropical cyclones begin to influence the area and may bring heavy but usually short duration rainfall.

The winter months of December through February are characterized by relatively mild weather interrupted by occasional stormy periods consisting of strong and variable winds; thunderstorms, sometimes-heavy rainfall and blowing dust. Winter winds are not a persistent as those of summer, but the strongest gusts of the year usually occur in association with the passage of frontal systems traversing the area from west to east. January is usually the coldest month and freezing temperatures, although rare, is possible.

During the spring months of March and April, strong thunderstorms may occur as surface heating increases and winter storms are still possible.

# 3. Meteorological data

The IPCC (IPCC 2021) has defined that human-induced climate change is affecting weather[18]

**Table 3-1** and **3-2** show climatological data summaries for Jubail Sites 1 and 2, respectively. As indicated in the tables, the data are based on period of time between 1988 to 1999.

**Table 3.1.** Climatology data summary (1988-99).

| **Jubail Site 1** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Atmospheric Temperature (ºC )** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Years** |
| Absolute Max. | 28.6 | 34.6 | 37.9 | 43.2 | 45.2 | 47.3 | 49.7 | 48.6 | 46.2 | 45.4 | 37.6 | 31.8 | 12 |
| Mean Daily Max. | 19.2 | 20.9 | 24.8 | 33.2 | 36.7 | 40.3 | 41.6 | 41.2 | 38.3 | 34.0 | 27.2 | 22.0 | 12 |
| Monthly Mean | 14.9 | 16.4 | 19.9 | 25.4 | 30.8 | 33.1 | 35.5 | 34.9 | 31.7 | 27.7 | 21.9 | 17.4 | 12 |
| Mean Daily Min. | 10.7 | 12.2 | 15.5 | 20.4 | 25.3 | 27.8 | 29.8 | 29.2 | 25.8 | 22.0 | 17.0 | 13.1 | 12 |
| Absolute Min. | 5.6 | 2.9 | 7.6 | 10.6 | 19.3 | 20.5 | 25.8 | 25.7 | 20.3 | 16.8 | 7.8 | 6.4 | 12 |
| **Relative Humidity** | | | | | | | | | | | | | |
| Mean Relative Humidity (%) | 70.5 | 70.2 | 19.5 | 53.9 | 45.0 | 41.1 | 42.2 | 52.1 | 53.7 | 61.4 | 65.1 | 65.8 | 12 |
| **Rainfall** | | | | | | | | | | | | | |
| Mean (mm) | 23.3 | 3.8 | 6.8 | 1.8 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 24.1 | 10.0 | 12 |
| **Wind Speed (m/s)** | | | | | | | | | | | | | |
| Max. Gust | 19.0 | 19.2 | 21.4 | 20.2 | 29.9 | 22.1 | 17.5 | 16.4 | 16.0 | 24.6 | 42.7 | 38.3 | 12 |
| Max. 1 Hr Avg. | 12.7 | 12.3 | 15.8 | 12.5 | 13.5 | 13.9 | 12.2 | 11.2 | 11.5 | 11.9 | 17.2 | 11.4 | 12 |
| Monthly Mean | 4.3 | 4.3 | 4.4 | 4.3 | 4.5 | 4.6 | 4.1 | 3.8 | 3.7 | 3.8 | 3.9 | 4.2 | 12 |
| **Wind Direction** | | | | | | | | | | | | | |
| Prevailing | WNW | NW | N | NNW | N | NNW | NNW | N | NW | NW | NW | WNW | 12 |

## 3.1. Temperature

The main influence on JIC temperatures is the proximity to the Arabian Gulf.Daytime temperatures at inland locations can be substantially higher than temperatures along the coast. **Tables 3-1,3-2,3-3,** and **3-4** give temperature statistics and other nearby locations. Temperature data for Sites 1 and 2 are graphically displayed in **Figures 3-1** and **3-2**.

**Table 3.2.** Climatology data summary (1988-2001).

| Atmospheric Temperature (ºC) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Absolute Max.** | 28.6 | 36.2 | 37.3 | 44.7 | 41.5 | 46.4 | 45.5 | 46.8 | 42.4 | 45.5 | 36.5 | 31.3 | 14 |
| **Mean Daily Max.** | 18.5 | 19.45 | 26.11 | 28.05 | 35.06 | 35.46 | 36.69 | 36.59 | 34.56 | 29.02 | 25.92 | 21.22 | 14 |
| **Monthly Mean** | 15.41 | 16.84 | 19.94 | 24.95 | 31.66 | 32.41 | 33.68 | 33.45 | 31.19 | 27.8 | 22.42 | 17.99 | 14 |
| **Mean Daily Min.** | 11.84 | 13.67 | 17.01 | 22.03 | 26.46 | 29.15 | 30.64 | 30.1 | 27.12 | 23.63 | 18.36 | 14.34 | 14 |
| **Absolute Min.** | 6.1 | 8 | 10.5 | 14 | 19.3 | 23.7 | 27 | 26.5 | 21.6 | 18.3 | 9.5 | 7.5 | 14 |
| Relative Humidity | | | | | | | | | | | | | |
| **Mean Humidity (%)** | 71.15 | 71.78 | 65.21 | 58.34 | 50.22 | 45.89 | 47.31 | 56.09 | 56.69 | 63.09 | 65.17 | 65.49 | 14 |
| Rainfall | | | | | | | | | | | | | |
| **Mean (mm)** | 22.6 | 3.4 | 4.7 | 1.8 | 0.5 | 0.0 | 0.0 | 2.2 | 0.0 | 0.5 | 24.2 | 7.6 | 14 |
| Wind Speed (m/s) | | | | | | | | | | | | | |
| **Max. Gust** | 19.8 | 21.3 | 23.3 | 21.7 | 26.0 | 18.8 | 18.1 | 14.1 | 14.2 | 16.9 | 21.2 | 16.8 | 14 |
| **Max. 1 Hr Avg.** | 13.2 | 16.2 | 16.2 | 14.6 | 15.5 | 13.9 | 12.8 | 10.7 | 10.6 | 11.5 | 13.7 | 11.8 | 14 |
| **Monthly Mean** | 4.9 | 4.9 | 4.9 | 4.4 | 4.0 | 4.6 | 3.9 | 3.8 | 3.9 | 4.1 | 4.9 | 4.8 | 14 |
| Wind Direction | | | | | | | | | | | | | |
| **Prevailing** | NW | NW | N | NNE | NNW | NNW | NW | NE | W | N | WNW | WNW | 14 |

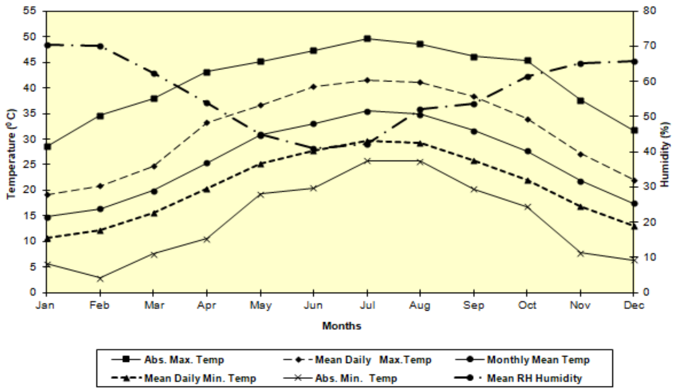



**Figure 3.1.** Temperature and humidity data for Sites 1.

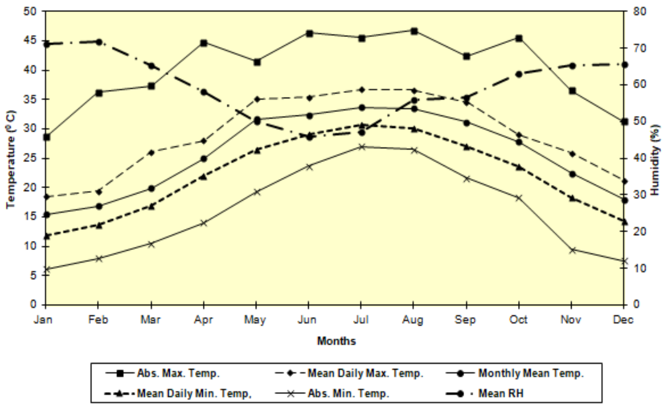



**Figure 3.2.** Temperature and humidity data for Site 2.

As indicated in the tables and the figures mentioned above the absolute maximum hourly temperatures recorded between 1988-2001 for Jubail Sites 1 and 2 were 49.7°C and 46.4°C, respectively. The long-term absolute maximum temperatures reported for Ras Tanura and Dhahran and 47°C and 51°C, respectively. The absolute minimum temperatures at Jubail during the 1988-2001 periods were 2.9 °C at Site 1 and 6.1°C at Site 2. Ras Tanura has recorded an absolute minimum temperature of 0 °C, while Dhahran reports an absolute minimum temperature of -1°C. It should be noted that all Jubail temperatures are measured at a height of 10m; temperatures at or near the surface can be expected to be slightly more extreme.

A comparison of mean monthly ambient air and sea surface temperatures at Ras Tanura is presented in **Figure 3-3**. It is based on records from 1945 through 1974.

As can be seen from the figure, mean coastal air temperatures are very close to Gulf water temperatures. In winter, Gulf water temperatures are about 0.5 °C above mean air temperature.

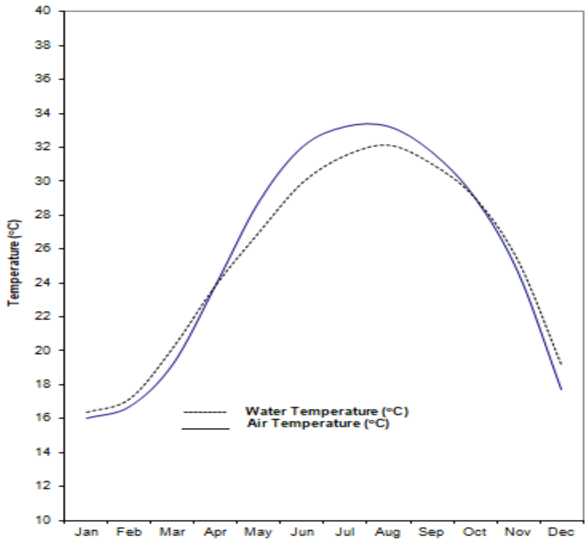



**Figure 3.3.** Mean monthly water surface and air temperatures[10].

## 3.2. Relative humidity

Proximity to the coast also influences relative humidity (see **Tables 3-1** through **3.4 and Figures 3.1** and **3.2**), larger differences between coastal and inland locations occur mostly in summer. Summer mean relative humidity is about 20 to 30 percent lower a few kilometers inland as compared to the coast. Daily relative humidity sometimes ranges from 10 to 100 percent at all locations. During the autumn and winter months, high relative humidity and a rapid drop in overnight temperature may cause early morning fog.

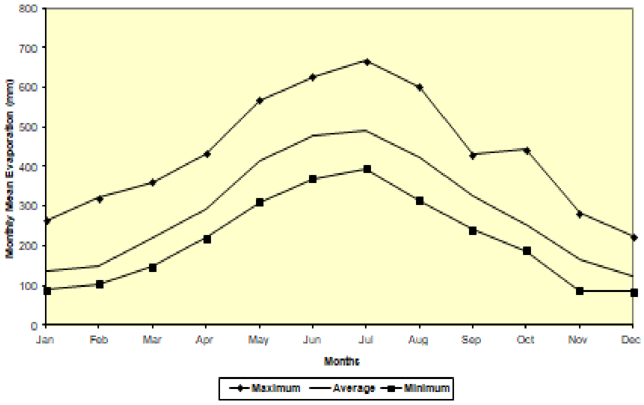



**Figure 3.4.** Monthly evaporation rate.

**Table 3.3.** Ras tanura climatology data summary.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Atmospheric Temperature (ºC)** | | | | | | | | | | | | | |
| Absolute Max. | 27 | 35 | 40 | 41 | 47 | 46 | 45 | 44 | 44 | 40 | 35 | 29 | 17 |
| Mean Daily Max. | 20 | 21 | 24 | 28 | 33 | 37 | 39 | 40 | 36 | 33 | 27 | 21 | 17 |
| Daily Mean | 16 | 17 | 20 | 24 | 29 | 32 | 33 | 33 | 31 | 28 | 23 | 18 | 17 |
| Mean Daily Min. | 12 | 13 | 17 | 21 | 24 | 27 | 29 | 27 | 26 | 23 | 19 | 14 | 17 |
| Absolute Min. | 0 | 5 | 6 | 12 | 16 | 21 | 22 | 24 | 21 | 16 | 8 | 4 | 17 |
| **Humidity** | | | | | | | | | | | | | |
| Mean Relative Humidity (%) | 76 | 75 | 72 | 68 | 63 | 60 | 62 | 67 | 68 | 70 | 71 | 73 | 17 |
| **Rainfall** | | | | | | | | | | | | | |
| Mean (mm) | 24 | 15 | 1 | 14 | 3 | 0 | 0 | 0 | 0 | 4 | 8 | 21 | 27 |
| **Wind Speed (mps)** | | | | | | | | | | | | | |
| Max. Gust | 22 | 21 | 23 | 26 | 21 | 21 | 18 | 18 | 17 | 24 | 20 | 17 | 17 |
| Mean Daily Max. | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 9 | 8 | 8 | 9 | 9 | 17 |
| Daily Mean | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 17 |
| **Wind Direction** | | | | | | | | | | | | | |
| Prevailing | NW | N | N | N | NNW | NNW | N | NNW | NNW | NNW | WNW | WNW | 17 |

## 3.3. Precipitation

The rainfall season at Madinat Al-Jubail Al-Sinaiyah extends from November to April, but precipitation has occurred in October and May(**Tables 3-1 to 3-4** and **Figure 3-4**). Older rainfall data from between 1940 and 1973 for Ras Tanura and Dhahran are shown in **Figure 3-5**. Mean annual precipitation at Ras Tanura for more than 25 years of records in 90mm while the mean annual precipitation at Dhahran is 88mm.

**Table 3.4.** Dhahran climatological data summary.

| **Atmospheric Temperature (ºC )** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Years** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Absolute Max. | 30 | 36 | 38 | 45 | 48 | 49 | 49 | 51 | 48 | 44 | 37 | 32 | 27 |
| Mean Daily Max. | 21 | 22 | 26 | 31 | 37 | 42 | 42 | 42 | 40 | 35 | 28 | 23 | 27 |
| Monthly Mean | 16 | 17 | 21 | 26 | 31 | 34 | 36 | 36 | 33 | 29 | 23 | 27 | 27 |
| Mean Daily Min. | 12 | 13 | 15 | 21 | 25 | 28 | 29 | 27 | 23 | 18 | 13 | 27 | 17 |
| Absolute Min. | -1 | 3 | 5 | 10 | 17 | 19 | 21 | 22 | 21 | 12 | 8 | 3 | 27 |
| **Humidity** | | | | | | | | | | | | | |
| Relative Humidity (%) | 68 | 65 | 60 | 50 | 41 | 33 | 39 | 49 | 51 | 59 | 64 | 69 | 27 |
| Mean Wet Bulb | 12 | 13 | 16 | 20 | 22 | 24 | 26 | 26 | 24 | 23 | 19 | 14 | 27 |
| **Rainfall** | | | | | | | | | | | | | |
| **Mean (**mm**)** | 22 | 12 | 12 | 10 | 2 | 0 | 0 | 0 | 0 | 0 | 9 | 21 | 27 |
| **Wind Speed (m/s)** | | | | | | | | | | | | | |
| Max. Gust | 29 | 34 | 28 | 26 | 24 | 25 | 24 | 22 | 21 | 19 | 21 | 24 | 24 |
| Mean Daily Max. | 10 | 12 | 11 | 11 | 13 | 13 | 13 | 9 | 10 | 11 | 10 | 11 | 24 |
| Daily Mean | 5 | 5 | 5 | 5 | 6 | 5 | 4 | 4 | 4 | 4 | 4 | 24 | 17 |
| **Wind Direction** | | | | | | | | | | | | | |
| Prevailing | NW | NNW | N | N | N | NNW | N | NNW | N | N | NW | NW | 24 |

Fourteen years of records (1988-2001) for Jubail show the mean annual rainfall is 86 mm. It is also important is note that most of the annual rainfall often occurs over relatively short periods in only a few storms (see Section 4.1).Hail storms are unusual but have been known to occur. The latest hailstorm occurred on 12 March, 1996. Hailstones over 1.0 cm in diameter were observed.

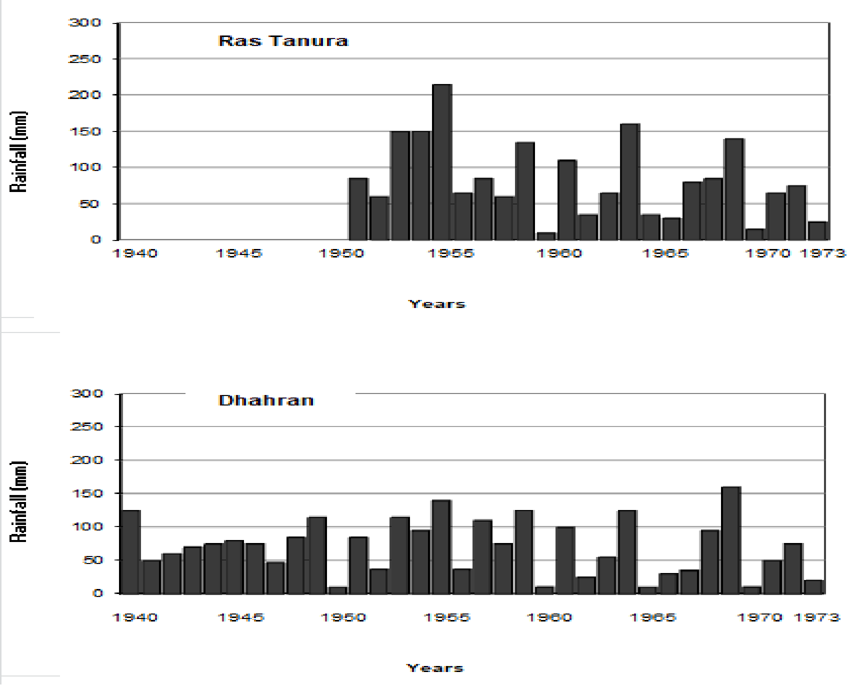



**Figure 3.5.** Annual rainfall records for dhahran and ras tanura.

## 3.4. Winds

Unless otherwise noted, all discussion in this section is based on wind speed and direction measurements obtained at a height of 10 m above ground. Prevailing wind directions at Madinat al-Jubail Al-Sinaiyah and nearby locations are nearly always in the north and North West quadrant as shown in **Tables 3-1** and **3.2**. Quarterly and annual wind roses for Jubail Sites 1 and 2 are presented in **Figures 3.6** through **3.9**. Winds are from the north and North West quadrant approximately 50% of the time. Strong winds frequently occur at Madinat Al-Jubail Al-Sinaiyah during winter through or frontal passages (known as winter Shammals) and during summer Shammals.

Although winter Shammals usually have higher wind speeds, summer Shammals have longer duration. Wind speed data for Jubail, Ras Tanura and Dhahran are shown in **Tables 3-1** through **3-4**. The maximum wind gust for Jubail is 42.7 m/s which occurred in November. Dhahran has recorded a maximum wind gust of 34 $ms^{-1}$ in the month of February, based on 24 years period of records.

As indicated in **Tables 3-1** and **3-2**, monthly mean wind speeds at Jubail are between 3.7 and 5.3 m/s throughout the year. **Figures 3.10A** and **B** show Jubail wind speed monthly frequency distribution maximum, mean, and minimum for the year 2001. Annual frequency distribution for five years (1997-2001) is shown in Figure 3-10C.

Winds equal to or greater than 13 m/s can be expected to persist for about 3 hours twice per year. Very long-duration, high-speed winds have been reported at nearby locations. In June 1956 at Mina Al-Ahmadi, Kuwait, it was reported that winds in excess of 18ms-1 persisted for 18 consecutive hours from the northwest.

**Figure 3-11** shows the 10 m (above ground) maximum one-hour mean wind speed, the maximum three-minute mean, and the maximum gust that can be expected for return periods of 2 to 100 years. To estimate maximum wind speeds at heights other than 10 m, it is recommended that the values from the figure be corrected using a power law relationship[1],

$$U/U_{10} = (Z/10)^{P} \quad (1)$$

Where U is the desired wind speed at height Z (m), $U_{10}$ is the estimated maximum wind speed at 10 m (taken from the figure), and P is an exponent that has a value between 0 and 1 (most often P is less than 0.5). For dry adiabatic lapse rate and fairly level terrain with low surface cover, for design winds P is approximately 1/7.

A high winds 1/7 is a reasonable value to use. If a structure is vulnerable to unusual wind effects due to height, size or shape, a specialist on wind forces on structures should be consulted. As an example of some of the severe winds that have been known to occur in the Gulf area, in November 1958 at Halul Island off the coast of Qatar in the Arabian Gulf, a maximum gust of 43 m/s was recorded. This gust was followed by another gust to 38m/s a few minutes later with the wind remaining over 22 m/s for about 20 minutes. The wind was from the southeast at about 9 m/s for about 6 hours period after the occurrence of these violent gusts from the Northeast. Two hours after the gusts occurred the wind subsided to almost calm conditions.

### 3.5. Sandstorms and dust storms

If surface winds exceed 13 m/s, sand particles can be lifted a meter or more above the ground. Blowing sand can reduce the visibility to less than 50 m. Sustained winds for two to four day periods at speeds of 11 to 13 m/s create blowing dusts which also reduce the visibility. Light wind conditions and visibility of 1 km or less in heavy hanging dust often follow periods of sustained high winds. These dust storms may be hundreds of meters in depth, last for several days (especially during summer months), cover a wide area, and extend for several kilometers offshore.

The monthly frequency of occurrence of sandstorms at Dhahran for an eight-year period is presented in **Table 3-5**. Dhahran experiences about 12 sandstorms per year, which occur most frequently during spring and summer months but can occur at any time.

**Table 3.4.** Dhahran sandstorm frequency of occurrence.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1966 | 0 | 0 | 5 | 0 | 0 | 5 | 4 | 0 | 0 | 2 | 0 | 0 | 16 |
| 1967 | 1 | 0 | 2 | 0 | 3 | 6 | 3 | 1 | 0 | 0 | 0 | 2 | 18 |
| 1968 | 1 | 0 | 2 | 0 | 1 | 5 | 3 | 4 | 0 | 0 | 0 | 0 | 18 |
| 1969 | 0 | 1 | 0 | 2 | 1 | 5 | 3 | 4 | 0 | 0 | 0 | 0 | 4 |
| 1970 | 0 | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 6 |
| 1971 | 0 | 1 | 2 | 1 | 2 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 18 |
| 1972 | 0 | 0 | 0 | 0 | 2 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 6 |
| 1973 | 1 | 1 | 1 | 2 | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| Total | 3 | 5 | 12 | 8 | 10 | 27 | 19 | 9 | 1 | 2 | 0 | 2 | 98 |
| % of Total | 3 | 5 | 12 | 8 | 10 | 28 | 19 | 9 | 1 | 2 | 0 | 2 | 100 |

The monthly frequency of occurrence of sand storms and dust storms at Madinat Jubail for the period of 1988 to 2001 is presented in Table 3-6. For the purposes of this procedure, Jubail sandstorms are defined as periods of reduced visibility of 1 km or less in blowing sand with sustained wind speeds of 13 m/s or more. During the fourteen years, the Jubail area experienced an average of 12 sandstorms or dust storms per year which occurred primarily in the spring and summer months.

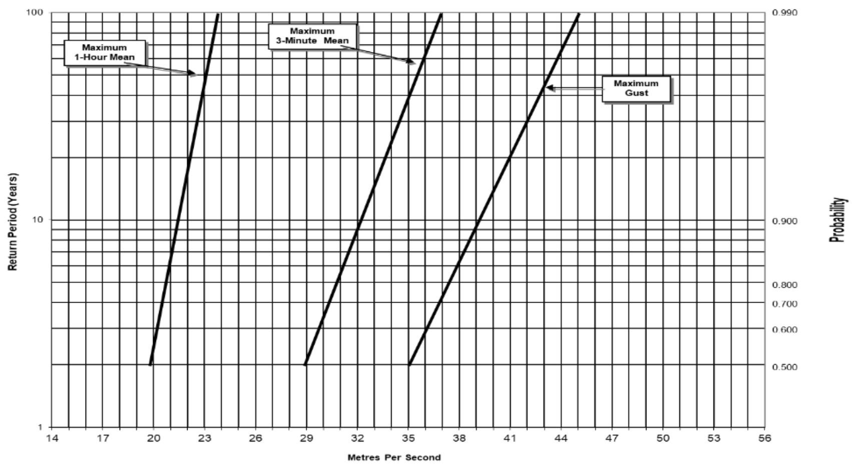



**Figure 3.11.** Maxiuml wind speed mean.

# 4. Hydrological data

## 4.1. Rainfall Intensity - duration - frequency

**Figure 4-1** compares actual rainfall data collected at JIC between 1978 and 1984 to intensity - duration - frequency curves developed by a Royal Commission consultant using 31 years of rainfall data (1951-1982) from Abqaiq, Dhahran, and Ras Tanura. The curves are also based on the heavy rainfall received at Jubail in October and November 1982. Each X shown in the figure indicates a datum point. Based on only five years of data, a few rainfall events approached or exceeded the 25-year curve. Many of the larger intensity values were recorded during the storms of 27 October to 3 November 1982. On one occasion during this period, the observed rainfall intensity-duration was about 95 percent of the probable 100-year storm.

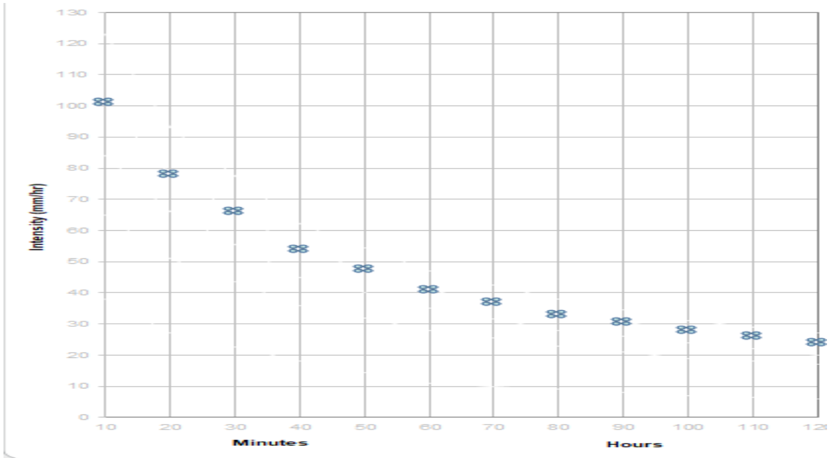



**Figure 4.1.** Observed rainfall intensity duration versus frequency.

**Figure 4-1A** shows calculated rainfall intensity – duration – frequency curves developed for Aramco using data from 1950 to 1990 recorded at locations in Dhahran. The frequency curves cover events for periods from 2 years up to 50 years.

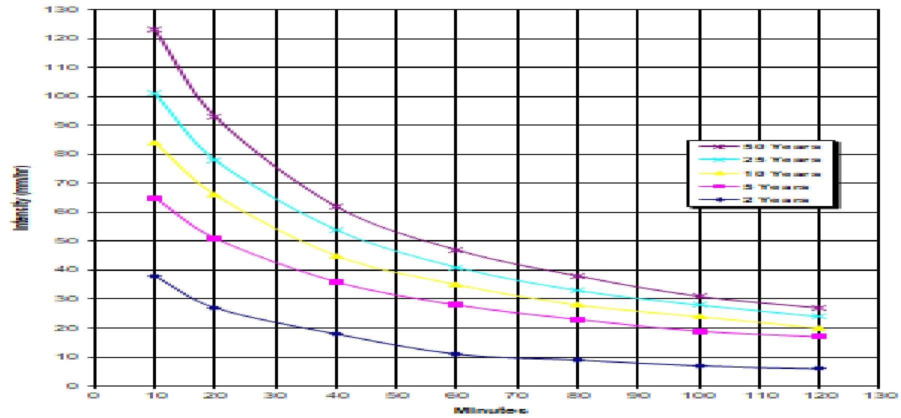



**Figure 4.1A.** Calculated frequency for rainfall intensity and duration.

**Figure 4-2** is a logarithmic chart showing the frequency of occurrence of rainfall intensities for twelve years (1991-2001) hourly precipitation data. The minimum detectable intensity using values measured over a 5 minute period is 2.4 mm/hr (0.2 mm/5-minutes) because the tipping-bucket rain gauges employed in Jubail have a detection threshold of 0.2 mm. The graph data shows that rainfall intensities of less than 4.0 mm/hr account for 90% of the time. The maximum 1-hour intensity recorded was 46.2 mm/hr at less than 1% of the time.

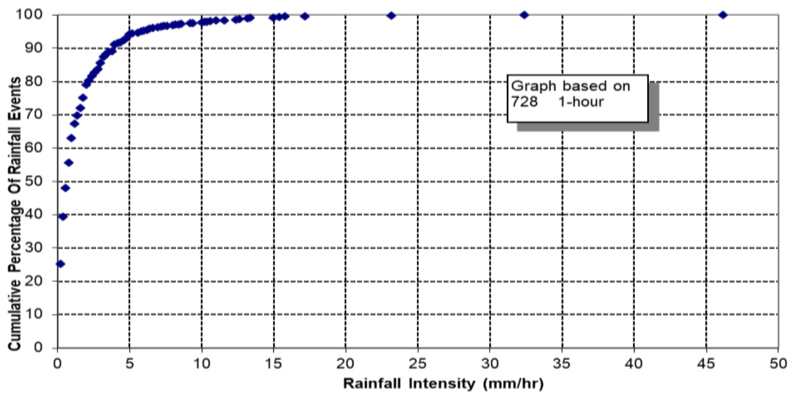



**Figure 4.2.** Hourly rainfall frequency of occurrence.

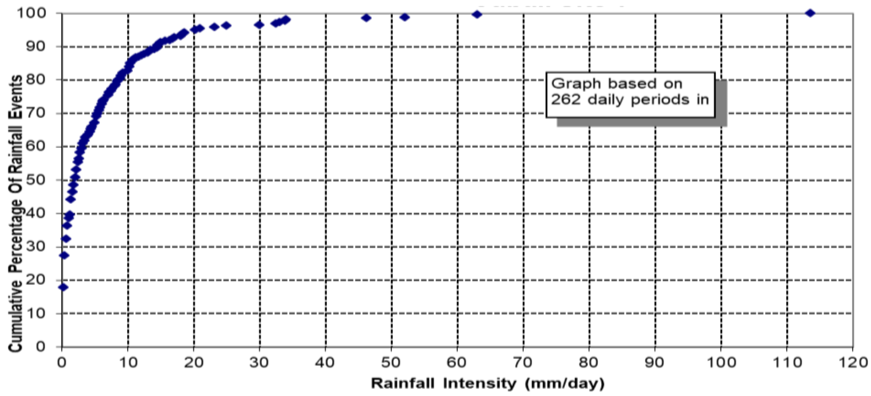



**Figure 4.2A.** Daily rainfall frequency of occurrence.

**Figure 4-2A** is a logarithmic chart showing the frequency of occurrence of rainfall intensities for twelve years (1991-2001) daily precipitation data. The graph data shows that daily rainfall intensity of greater than 9.0 mm is only exceeded 20% of the time. The maximum daily rainfall recorded was 114 mm.

## 4.2. Vertical control data

Vertical control data for Madinat Al-Jubail Al-Sinaiyah are shown in **Figure 4-3**. All elevations given in the figure are with respect to the Port of Jubail.

The level of the probable 100-year flood (combination of the mean high tide plus a maximum storm) is 3.53 m at the Community Harbour and 2.43 m near the Eastern Shore. The estimation of water level (combination of the highest astronomical tide plus a maximum storm) is 4.07 m at the Community Harbour and 3.07 m near the Eastern Shore.

**Figure 4.3.** Vertical control data.

| Elevation (Metres) | | | |
|---|---|---|---|
| | 5.0 | | |
| | 4.0 | EL 4.07 | Extreme Water Level (Community Harbour) |
| | | EL 3.53 | 100 Year Flood Level (Community Harbour) |
| | 3.0 | EL 3.07 | Extreme Water Level (Eastern Shore) |
| | | EL 2.44 | Highest Astronomical Tide |
| | | EL 2.43 | 100 Year Flood Level (Eastern Shore) |
| | 2.0 | EL 1.38 | Mean Sea Level |
| | 1.0 | EL 0.44 | U.S.G.S. & British Chart |
| | | EL 0.34 | Lowest Astronomical Tide |
| | | EL 0.31 | Indian Spring Low Tide |
| | 0 | EL 0.00 | Royal Commission Jubail Complex Data |
| | | | Port of Jubail (Port Authority) Data<br>Sir William Halcrow Data |

*Notes:*

***1. All elevations on project topographic maps prepared by Maps (Saudi Arabia) Ltd are shown in metres, referred to the Port of Jubail (Port Authority) Data.***

***2. 100-Year flood level = combination of high tide plus a maximum storm.***

***3. Extreme water level = combination of highest astronomical tide plus a maximum storm.***

# 5. Heating, ventilation and air conditioning data

**Table 5-1** presents heating, ventilation, and conditioning design data for Dhahran and for two locations at JIC (an inland location, Site 1, and coastal location, Site 2). The data sources used in compiling Table 5-1 included at least ten years of Dhahran surface data preceding 1967 and three years (1981-1983) of Jubail Site 1 and Site 2 data measured at 10 meters above the surface.

The columns in **Table 5-1** labeled "Heating Design Data" display the dry-bulb temperatures that are surpassed during 99% and 97.5% of an average year. This shows, for example, that 97.5% of all hourly dry-bulb temperatures (about 8,541 hours/years) on the average are greater than 9$^{o}$C (49$^{o}$F) at Jubail Site 1. Conversely, the hourly Site 1 dry-bulb temperature is equal to or less than 9$^{o}$C (49$^{o}$F) during 2.5% of the year (about 219 hours/year). Comparing the three stations, the 99% and 97.55% dry-bulb temperatures at Jubail Site 1 appear to be about the same as Dhahran; whereas Jubail Site 2 99% and 97.5% dry-bulb temperatures are about 1 to 2$^{o}$C higher than Jubail Site 1.

**Table 5-1** columns labeled "Air Conditioning Criteria Data" present the dry-bulb and wet-bulb temperatures that are exceeded during 1%, 2.5%, 5% and 10% of the year. As the Table indicates, the criteria dry-bulb temperatures for Jubail Site 1 are about 4$^{o}$C lower than those for Dhahran, and the Jubail Site 2 values are about 4$^{o}$C lower than those for Site 1. Jubail Site 1 criteria wet-bulb temperatures are about 2 to 5$^{o}$C lower as compared to Dhahran or about 1 to 3$^{o}$C lower as compared to Jubail Site 2.

**Table 5.1.** Heating, ventilation and air conditioning data.

| Station | Location | | | | | Heating Design Data | | Air Conditioning Criteria Data | | | | | | | | Air Conditioning Design Data | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ***Dry Bulb*** | | ***Dry Bulb*** | | | | ***Wet Bulb*** | | | | ***Dry Bulb*** | | ***Wet Bulb*** | |
| | Lat. | | Long | | Elev | 99% | 97.5% | 1% | 2.5% | 5% | 10% | 1% | 2.5% | 5% | 10% | 93ºF | 80ºF | 78ºF | 67ºF |
| | | | | | | | | | | | | | | | | 34ºC | 27ºC | 26ºC | 19ºC |
| | ºN | ºN | ºW | ºW | (m) | ºF | ºF | ºF | ºF | ºF | ºF | ºF | ºF | ºF | ºF | hrs | hrs | hrs | hrs |
| | | | | | | (ºC) | (ºC) | (ºC) | (ºC) | (ºC) | (ºC) | (ºC) | (ºC) | (ºC) | (ºC) | | | | |
| Dhahran | 26 | 16 | 0 | 10 | 17 | 45 | 48 | 111 | 110 | 108 | 106 | 86 | 85 | 84 | 83 | 1811 | 3956 | 2219 | 3783 |
| | | | | | | (7) | (9) | (44) | (43) | (42) | (41) | (30) | (29) | (29) | (28) | | | | |
| Jubail | | | | | | | | | | | | | | | | | | | |
| Site 1 : | | | | | | | | | | | | | | | | | | | |
| 8 km | 27 | 2 | 49 | 32 | 5 | 46 | 49 | 104 | 102 | 100 | 96 | 82 | 79 | 75 | 73 | 1517 | 4098 | 262 | 3280 |
| inland | | | | | | (8) | (9) | (40) | (39) | (38) | (36) | (28) | (26) | (24) | (23) | | | | |
| Jubail | | | | | | | | | | | | | | | | | | | |
| Site 2 : | | | | | | | | | | | | | | | | | | | |
| Coast | 27 | 4 | 49 | 37 | 2 | 48 | 51 | 96 | 94 | 92 | 90 | 84 | 82 | 81 | 79 | 506 | 3816 | 943 | 4171 |
| | | | | | | (9) | (11) | (36) | (35) | (34) | (32) | (29) | (28) | (27) | (26) | | | | |

***Note:***

*Dhahran data obtained from Engineering Weather data, USAF, Army, Navy Joint Technical Publication, 1967.*

*Period of record is unknown but believed to be at least 10 years. Measurements obtained near surface.*

*Period of record for Jubail data is 3 years (1981-1983). Measurements obtained 10m above surface.*

**Table 5-1** columns labeled "Air Conditioning Design Data" gives the average numbers of hours per year that the dry-bulb temperature is greater than 34ºC (93ºF) and 27ºC (80ºF). Also shown are the average number of hours per year that the wet-bulb temperature is greater than 26ºC (78ºF) and 19ºC (67ºF). Insofar as dry-bulb hours are concerned, the three locations are quite similar except that Jubail Site 2 has significantly fewer hours above 34ºC. Comparing the wet-bulb hours, Jubail Site 1 has far fewer hours above 26ºC.

**Tables 5-2** and **5-3** present the coincident dry-bulb and wet-bulb frequency distributions for Jubail Site 1 and Site 2, respectively.

Three years of hourly data (1981-1983), measured at 10 m above the surface, were utilized in preparing these tables. The data are given in the tables in terms of four-degree class intervals with upper class limit indicated (e.g., an upper class limit of 30ºC means the class includes all temperatures greater than 26ºC but less than or equal to 30ºC

**Table 5.2.** Coincident dry bulb / wet bulb frequency distribution (%).

| **Wet Bulb (Upper Class** | **( Dry Bulb Upper Class Limits, Deg. C )** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Limits Deg.C ) | -2 | 2 | 6 | 10 | 14 | 18 | 22 | 26 | 30 | 34 | 38 | 42 | 46 | 50 | 54 | 60 | Totals |
| -2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 |
| 6 | 0 | 0 | 0.1 | 2.5 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.1 |
| 10 | 0 | 0 | 0 | 0.7 | 7.5 | 3.1 | 0.1 | 0.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11.5 |
| 14 | 0 | 0 | 0 | 0 | 0.7 | 8.9 | 5.4 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15.7 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0.9 | 6.8 | 3.8 | 5.1 | 6.1 | 0 | 0 | 0 | 0 | 0 | 0 | 22.4 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3 | 0.1 | 9.8 | 8.8 | 5.4 | 1.7 | 0 | 0 | 0 | 0 | 29.9 |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.6 | 4.8 | 4.7 | 3.2 | 0.4 | 0 | 0 | 0 | 14.7 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.7 | 0.9 | 0.6 | 0 | 0 | 0 | 0 | 2.3 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0.2 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Totals | 0.1 | 0 | 0.2 | 3.3 | 8.9 | 12.8 | 12.6 | 12.5 | 16.6 | 15.9 | 11.2 | 5.6 | 0.4 | 0 | 0 | 0 | 100 |

**Table 5.3.** Coincident dry bulb / wet bulb frequency distribution (%)

| **Wet Bulb (Upper Class** | **( Dry Bulb Upper Class Limits, Deg. C )** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Limits Deg.C ) | -2 | 2 | 6 | 10 | 14 | 18 | 22 | 26 | 30 | 34 | 38 | 42 | 46 | 50 | 54 | 60 | Totals |
| -2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0.1 | 1.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.4 |
| 10 | 0 | 0 | 0 | 0.9 | 6 | 1.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8.4 |

| Wet Bulb (Upper Class | ( Dry Bulb Upper Class Limits, Deg. C ) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 0 | 0 | 0 | 0 | 1.9 | 10.8 | 3.2 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| 18 | 0 | 0 | 0 | 0 | 0 | 2.2 | 9.7 | 4.8 | 1.8 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 18.9 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 7.4 | 3.5 | 0.8 | 0.1 | 0 | 0 | 0 | 0 | 21.5 |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.4 | 7.6 | 13.9 | 2.4 | 0.1 | 0 | 0 | 0 | 0 | 25.4 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 | 5.7 | 1.7 | 0 | 0 | 0 | 0 | 0 | 8.1 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0.2 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Totals | 0 | 0 | 0.1 | 2.1 | 8 | 14.4 | 14.7 | 14.4 | 17.5 | 23.5 | 5 | 3 | 0 | 0 | 0 | 0 | 100 |

**Table 5.3.** (*Continued*)

## 6. Evaporation data

**Figure 6-1** is a graphical representation of the average monthly evaporation rates at Dhahran, Ras Tanura and Madinat Al-Jubail Al-Sinaiyah Site 1. The curves for Dhahran and Ras Tanura were obtained from ARAMCO Engineering Report[10].

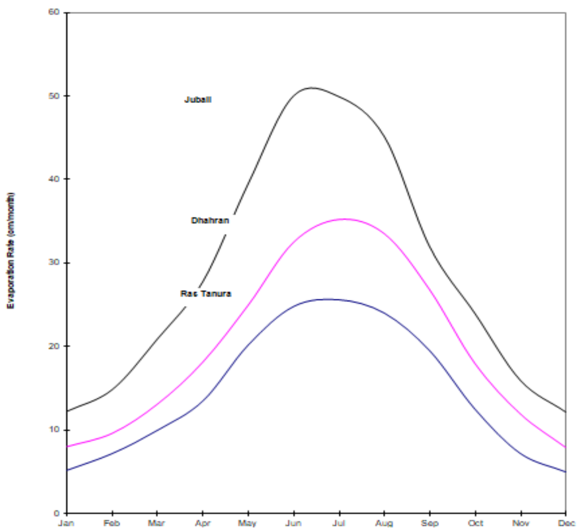



**Figure 6.1.** Mean value of evaporation rates.

Dhahran monthly evaporation rates are based on **class-A** evaporation pan data, and Ras Tanura monthly evaporation rates were calculated using the Hargreaves formula. Mean monthly evaporation rates for Jubail Site 1 are based on daily **Class-A** evaporation pan observations obtained during the period October 1980 to May 1984. **Figure 6-1A** shows evaporation observations obtained from January 1988 to December 2001.

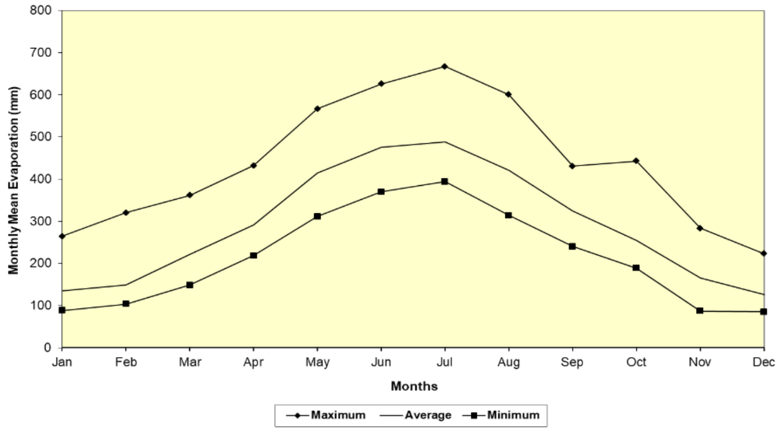



**Figure 6-1A.** Evaporation pan observations.

As the figure indicates, Site 1 has the highest mean monthly evaporation rates of the three locations shown. Site 1 mean evaporation rates are from 4 to 15cm/month greater than Dhahran and are as much as 25 cm/month greater than Ras Tanura. The marked difference in the evaporation rates is mainly due to the location of the three measurement sites relative to the Gulf. Jubail Site 1 is located about 8 km inland near the limit of sea breeze penetration, while the Dhahran pan is located within 2-3 km of the coast and is affected by the higher humidity and lower summer mean and maximum temperatures associated with the sea breeze. The meteorological data used in the Hargreaves calculation reflect the more marine conditions of the Ras Tanura peninsula. Thus, Ras Tanuara evaporation rates are less than Dhahran rates and much less than Site 1 evaporation rate. Hence, even within the boundaries of Madinat Al-Jubail Al-Sinaiyah, evaporation rates can be expected to differ substantially between the coast and inland locations. For locations a few kilometers inland, the Jubail Site 1 pan evaporation data should provide reliable evaporation estimates.

For coastal locations at Jubail, the Jubail Site1 values probably are not representative, but the Ras Tanura evaporation rates may provide a reasonable estimate (1988-2001 data show the same trend for Site 1 as the 1980-84 data).

The Jubail **Class-A** evaporation pan is mounted and operated in accordance with U.S. National Weather Service procedures. Applying a correction factor (pan factor) in the range of 0.6 to 0.7 to class-A pan evaporation data generally yields reasonable estimation of the evaporation rates of relatively small water bodies such as ponds or pools.

## 7. Airborne particulate data

Airborne particulate data are collected at all sites within the Jubail atmospheric monitoring network. Each site is equipped with a high-volume sampler fitted with an Andersen head to exclude large (non-inhalable) particles. Primarily, the samplers collect only particles less than 10 microns diameter. This size fraction is termed Inhalable Suspended Particulate (ISP). The samplers are operated every other day from midnight to midnight.

**Table 7-1** summarizes twelve years of ISP data (1988-2001) for Jubail Sites 1,2 and 6. Maximum, minimum and mean values for 24 hour sampling times are indicated in the table. Site 1 has probably been the most affected by construction activities and thus has experienced some of the highest measured concentrations.

**Table 7.1.** 24-Hours inhalable suspended particulate (µg/m$^3$).

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Site 1 | | | | | | |
| Max ISP | 920 | 1069 | 1108 | 1116 | 1061 | 3802 | 1696 | 838 | 1338 | 454 | 667 | 819 |
| Min ISP | 9 | 14 | 13 | 32 | 34 | 52 | 46 | 46 | 33 | 34 | 15 | 17 |
| Mean ISP | 85 | 118 | 152 | 163 | 205 | 246 | 276 | 175 | 154 | 109 | 95 | 84 |
| | | | | | | Site 2 | | | | | | |
| Max ISP | 1408 | 1072 | 4048 | 1281 | 1305 | 2377 | 902 | 646 | 1528 | 796 | 476 | 959 |
| Min ISP | 2 | 6 | 7 | 4 | 19 | 26 | 47 | 49 | 34 | 8 | 8 | 12 |
| Mean ISP | 77 | 101 | 124 | 135 | 169 | 181 | 229 | 139 | 132 | 94 | 74 | 81 |
| | | | | | | Site 6 | | | | | | |
| Max ISP | 1223 | 1319 | 4766 | 1289 | 1152 | 3552 | 1252 | 793 | 1016 | 675 | 654 | 876 |
| Min ISP | 2 | 6 | 4 | 15 | 21 | 20 | 27 | 8 | 15 | 14 | 6 | 7 |
| Mean ISP | 89 | 118 | 141 | 131 | 172 | 211 | 197 | 136 | 111 | 81 | 69 | 74 |

Site 2 data are reasonably representative of coastal locations at Madinat Al-Jubail Al-Sinaiyah. Site 6 data are representative of inland, undisturbed desert conditions.

## 8. Solar radiation

In regard to monthly maximum solar radiation, it is interesting to note that the period from April through August is relatively "flat". This is because the large amount of dust in the atmosphere during the summer months tends to diminish the peak that could otherwise be expected to occur in June. Daily cumulative solar radiation does peak in Jubail because of the relatively long time between sunrise and sunset, but the peak is not as high as less dusty locations at similar latitudes.

**Figure 8-1A** and **8-1B** summarize twelve years of data collected at Site 1. Figure 8-1A represents daily maximum, minimum and average solar radiation. Figure 8-1B represents total monthly maximum, minimum and average solar radiation.

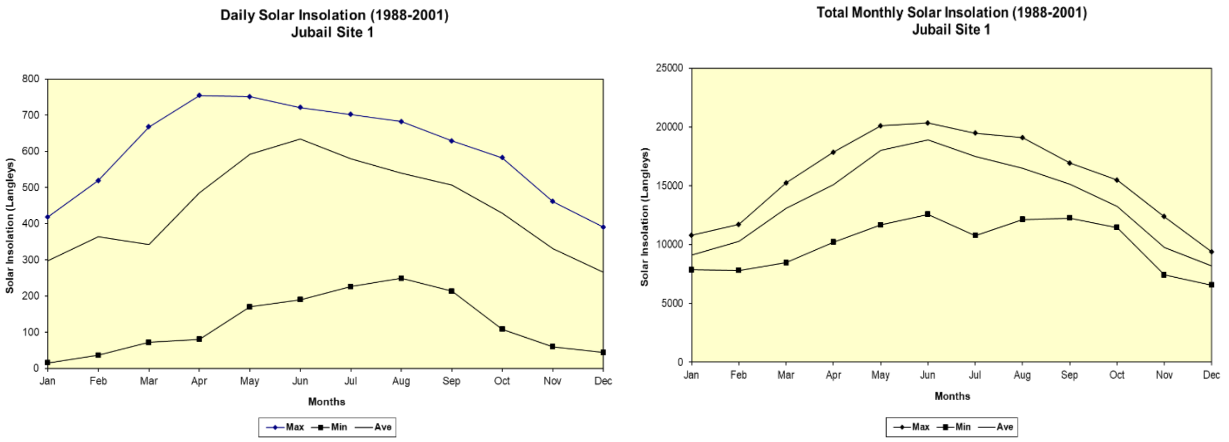
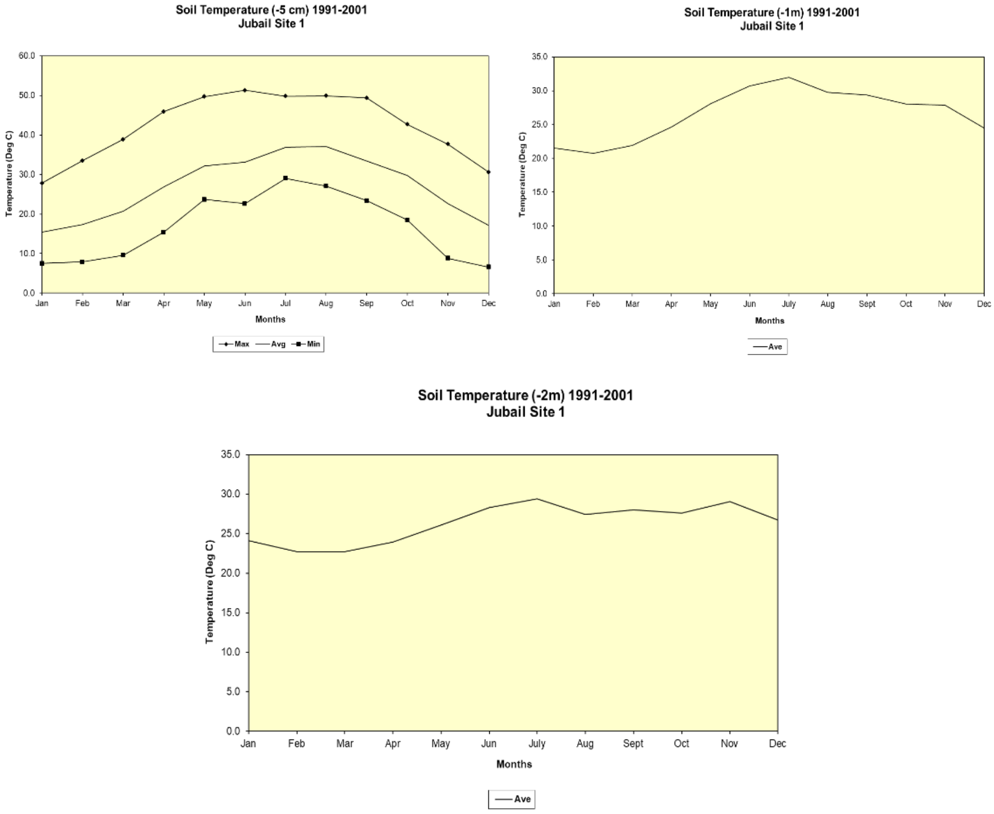



**Figure 8-1.** Solar radiation insolation.

## 9. Soil temperature data

Soil temperature is measured at Jubail Site 1 at three levels: 5 cm, 1 m, and 2 m. **Figures 9-1A, 9-1B** and **9-1C** summarize soil temperature data (1988-2001). For the 5 cm level, the mean daily maximum, mean daily average and the mean daily minimum are indicated on the figure. For the 1m and 2 m levels, only the mean daily averages are shown since the daily temperature ranges at these levels are relatively small. At the 5 cm level, the daily temperature range has a magnitude of about 6 ºC in winter and 10 ºC in summer.




**Figures 9-1.** Summary of soil temperature data for 5cm, 1m, and 2m.

All curves shown in the figures have been smoothened. Hence, the actual day-to-day variations at the 5cm level may not be as uniform as the figure indicates, but the daily changes at the 1 m and 2 m levels are relatively small and regular even without being smoothened and should therefore be close to the variation indicated.

On annual basis, the soil temperature curves become increasingly out of phase with increasing depth as should be expected. The annual maximum 5 cm soil temperature occurs in July, while the maximum for the 1 m and 2 m levels occur in August and September, respectively. The annual minimum occurs during December at the 5 cm level. It can also be observed that the double amplitude of the curves decreases from about 22ºC at the 5 cm level to about 12ºC at the 1 m level to approximately 9ºC at the 2 m level.

In addition, Author acknowledges that a change in climate condition such as wind direction, snow, rain and source terms may affect the outcome of an analysis. Dispersion of chemicals in to atmosphere is strongly dependent on the operating of parameters and one set of parameters may not represent all scenarios. Thus, a combination of strategies needs to be applied by considering prevalent operating conditions. For illustration purpose, only a specific case presented, as wind condition, rain, and other parameters changes, in this study. Accordingly, the response needs to be monitored considering different scenarios.

Despite having complex correlations among various parameters involved in gas emissions, the integrated risk profile can be effective for designing safety system to mitigate potential effect and risk associated with thermal radiation, wind condition and other parameters. Considering of effects among thermal radiation, wind, rain, humidity and temperature in transitional event makes the study unique and realistic in safety analysis of industrial processing facility.

## 10. Conclusion

Previous gas report data in JIC showed very limited measurements of TSP levels. However, the data reported here constitute the results of the first long-term monitoring campaign of daily gases concentration levels in Jubail Industrial City. The results of the first long-term monitoring campaign of daily chemicals concentration levels in Industrial area were analyzed. Twenty-four hours averages atmospheric concentrations of gases were measured at different sites located around the city. The values of gases concentrations correlate well with each other, indicating that direct traffic emissions have an important contribution to increase the gas level. Further studies on source of chemicals are necessary. The research is aimed to continue on defining the industrial chemicals that contribute to increase the global warming and affect human health. This guideline clarifies existing application requirements under the Environmental Protection Act (EPA act) and provides information about how to meet these requirements in relation to global warming. It does include developed method. The first systematic method of gas pollutants performed in the JIC using continuous measurements with fully automated equipment[12]. This guideline sets out the minimum expectations for chemical emissions information to be provided with applications for new environmental authorities and amend existing ones to mitigate greenhouse gases (GHG).

## Conflict of interest

The authors declare no conflict of interest.

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