



Impact of Dust Events on Vitamin D Effective UV-B Availability in Bahrain and Association with Population Serum 25-Hydroxyvitamin D

Thesis submitted in partial fulfilment of the requirement for the
degree of Master in Environment and Sustainable Development

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June 2023

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University of Bahrain
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6 | Approved at the University Council 6th meeting 2013
In accordance with Decision No.736/2013 dated 14/3/2013
Modified by University Council Decision No. 2043/2013 dated 20/11/2013.

Abstract

The aim of this study is to examine the relationship between dust and UV-B, and its effect on vitamin D synthesis in the body by analysing the trend of ground level solar UV-B irradiance measurements over the period from 2017-2022. In addition, the effect of dust events on UV-B irradiance over the period from 2017-2022 will also be investigated. Measurements of UV, temperature and humidity were obtained from the Meteorological Directorate. Manual UV-B calculation was done where 5% of the UV index was considered as UV-B. Dust particles at 1000m or less, 3000m or less and 5000m or less were obtained from the Meteorological Directorate, while vitamin D records of patients from 2017 to June 2022 were obtained from King Hamad University Hospital. The study included an investigation on healthy patients and patients with chronic diseases to identify whether a relationship exists between chronic diseases and vitamin D deficiency. A random sample of patients (10%) were selected out of the total of 16,239 to represent the patients with chronic diseases related to vitamin D deficiency. The data was analysed using Statistical Package for Social Science (SPSS version 28). The method used was Pearson correlation to correlate numeric variables such as UV-B, number of vitamin D tests, deficient patients and dust levels at 1000m or less, 3000m or less, and 5000m or less. A comparison of dust levels at 1000m or less, 3000m or less, and 5000m or less for the years 2017 to 2022 revealed that as the altitude increases, the dust levels also increase. A medium positive correlation was found between dust levels at 1000m or less and dust levels at 5000m or less ($r = 0.534$, $p < 0.001$), and a strong positive correlation between dust levels at 3000m or less and dust levels at 5000m or less ($r = 0.874$, $p < 0.001$). Both of these indicate that when dust levels increase at one altitude, an associated increase occurred at the other altitude. This suggests a relationship between the dust levels at these specific altitudes. Moreover, dusty days are strongly positively correlated with both dust levels at 1000m or less ($r = 0.534$, $p < 0.001$) and 3000m or less ($r = 0.874$, $p < 0.001$). In addition, the correlations between UV-B radiation and dust levels at 5000m or less ($r = 0.038$, $p = 0.784$) are weak and not statistically significant, indicating that UV-B radiation might not have an influence on dust levels at this altitude. Although the correlation found between them were very weak and not statistically significant, a slight increase in Pearson correlation was still observed as the altitude increased. Dust at 1000m or less ($r = -0.135$), dust at 3000m or less ($r = 0.023$) and dust at 5000m or less ($r = 0.038$). Finally, only 1.22% of the total

16,239 patients have vitamin D deficiency due to their chronic diseases which justifies that chronic diseases have a minor impact on vitamin D deficiency. The study resulted in a weak correlation between dust, UV-B rays, and vitamin D synthesis which could be due to several factors such as 5% estimation of UV-B from the UV index rather than accurate UV-B readings from a device and the dust readings at 5000m level which was inadequate for investigating the correlation between them. Much higher altitude of dust readings was required; however, the data was not available.

Acknowledgment

I would like to thank my supervisor Prof. Afnan Freije for all the efforts, expert advices and encouragement throughout this study and Dr. Mariam Al-Mannai for supporting me through the data analysis.

I would also like to thank my father and sister for always believing in me and helping me become the person I am today. Also, my dearest husband, there are no words that could express the tremendous support and motivation I get from you. Thank you for always being here. I would sincerely thank my dearest friends Fatima Rasool, Sara Al Ansari, and Walaa Radhi for the assistance that they have given me throughout this project.

Lastly, I would not have done this if it wasn't for you mother. For all the hard work that you have done, I am extremely proud to be your daughter. This master study is completely dedicated to you. I love you.

Thank you for helping me complete this chapter of my life. I surely would not have done it without you all.

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List of Abbreviations

25(OH)D	25-hydroxyvitamin D
25-OHase	Vitamin D-25-hydroxylase
AEST	Australian Eastern Standard Time
CKD	Chronic Kidney Disease
EPA	Environmental Protection Authority
GHI	Global Horizontal Irradiance
HDL	High Density Lipoprotein
HPLC	High-Performance Liquid Chromatography
KHUH	King Hamad University Hospital
LDL	Low Density Lipoprotein
MENA	Middle East and North Africa
NASA	National Aeronautics and Space Administration
NO	Nitric Oxide
OMI	Ozone Monitoring Instrument
PM	Particulate Matter
Serum 25(OH)D	Serum 25-hydroxyvitamin D
SO ₂	Sulphur Dioxide
T2DM	Type 2 Diabetes Mellitus
UAE	United Arab Emirates
UV	Ultraviolet
UV-A	Ultraviolet A
UV-B	Ultraviolet B
UVI	Ultraviolet Index
VDD	Vitamin D Deficiency
VDI	Vitamin D Insufficiency
WHO	World Health Organisation

Chapter One

Introduction to the Study

1.1 Introduction

1.2 Research Problem

1.3 Research Questions

1.4 Research Objectives

1.5 Research Significance

1.6 The Study Setting

1.7 Terminologies

1.1 Introduction

Vitamin D is a crucial element for the mineral metabolism and the bones, which help in the prevention of developing weak bones and rickets (Pilz et al., 2019). Majority of the world's population are diagnosed with either vitamin D insufficiency (VDI) or vitamin D deficiency (VDD). This is mainly narrowed down to the environmental factors and the lifestyle that limits the people from sun exposure which is needed for vitamin D synthesis (Nair & Maseeh, 2012). The most natural form of vitamin D synthesis in the body is the ultraviolet B rays (UV-B) that comes from direct exposure of sunlight, whereas the other form is through dietary intake (Al-Mohaimeed et al., 2012; Pilz et al., 2019).

Humans synthesize vitamin D after UV-B rays from sunlight strikes the skin. Vitamin D that comes from the skin or diet is biologically inert and requires its first hydroxylation in the liver by the vitamin D-25-hydroxylase (25-OHase) to 25(OH)D (Nair & Maseeh, 2012). Further hydroxylation of 25(OH)D is done in the kidneys by the 25(OH)D-1-OHase to form the biologically active form of vitamin D 1,25(OH)₂D (Figure 1). Then, vitamin D 1,25(OH)₂D stimulates intestinal calcium absorption (Nair & Maseeh, 2012). Without vitamin D, only 10–15% of dietary calcium and about 60% of phosphorus are absorbed. As a result, vitamin D sufficiency enhances calcium absorption by 30–40% and phosphorus absorption by 80%, to develop stronger bones (Al-Mohaimeed et al., 2012; Nair & Maseeh, 2012; AlShaibani et al., 2021).

People with darker skin have slight difficulty in absorbing the ultraviolet B rays (UV-B) than people with fair skin due to the high amount of melanin in their skin, thus, reducing the skins' ability to produce vitamin D from sunlight (Nair & Maseeh, 2012). Moreover, studies have shown that people with low sun exposure, will have low serum 25-hydroxyvitamin D (serum 25(OH)D) produced, which is required for the production of vitamin D in the body (Pilz et al., 2019; AlShaibani et al., 2021).

In addition to sun exposure, vitamin D can be absorbed from food sources such as eggs, fatty fish, cod liver oil, and fortified milk. There are two types of vitamin D, D₂ and D₃ (Figure 1) (Pilz et al., 2019). Figure 1 shows the synthesis of vitamin D in the body from the exposure of skin to the UV-B rays. It undergoes a complex process from the liver to the kidney, until the vitamin D is formed (Pilz et al., 2019).

Vitamin D₂ is a synthetic form and is derived from plants and mostly fortified food. Whereas vitamin D₃ can be obtained from animal sources and can be synthesized by the skin after sun exposure (Pilz et al., 2019). Recently, it was seen that a low level of serum 25(OH)D has been defined as VDD (Basit, 2013). There are many consequences of VDD. A range of disorders have been associated with low vitamin D levels. The most known bone diseases are osteoporosis and rickets (Al-Mohaimed et al., 2012; AlShaibani et al., 2021). Low vitamin D in the body can also weaken the immune system resulting in increased risks of heart diseases, bowel diseases, fractures, muscle weakness and falls, breast cancer, colon cancer and prostate cancer (Basit, 2013; Pilz et al., 2019). Table 1 shows the classification of vitamin D in relation to the levels of serum 25(OH)D

obtained from King Hamad University Hospital. The desirable concentration of serum 25(OH)D required for the body is 75 nmol/L. If the concentration is below 50 nmol/L it is considered as vitamin D deficient (Pilz et al., 2019).

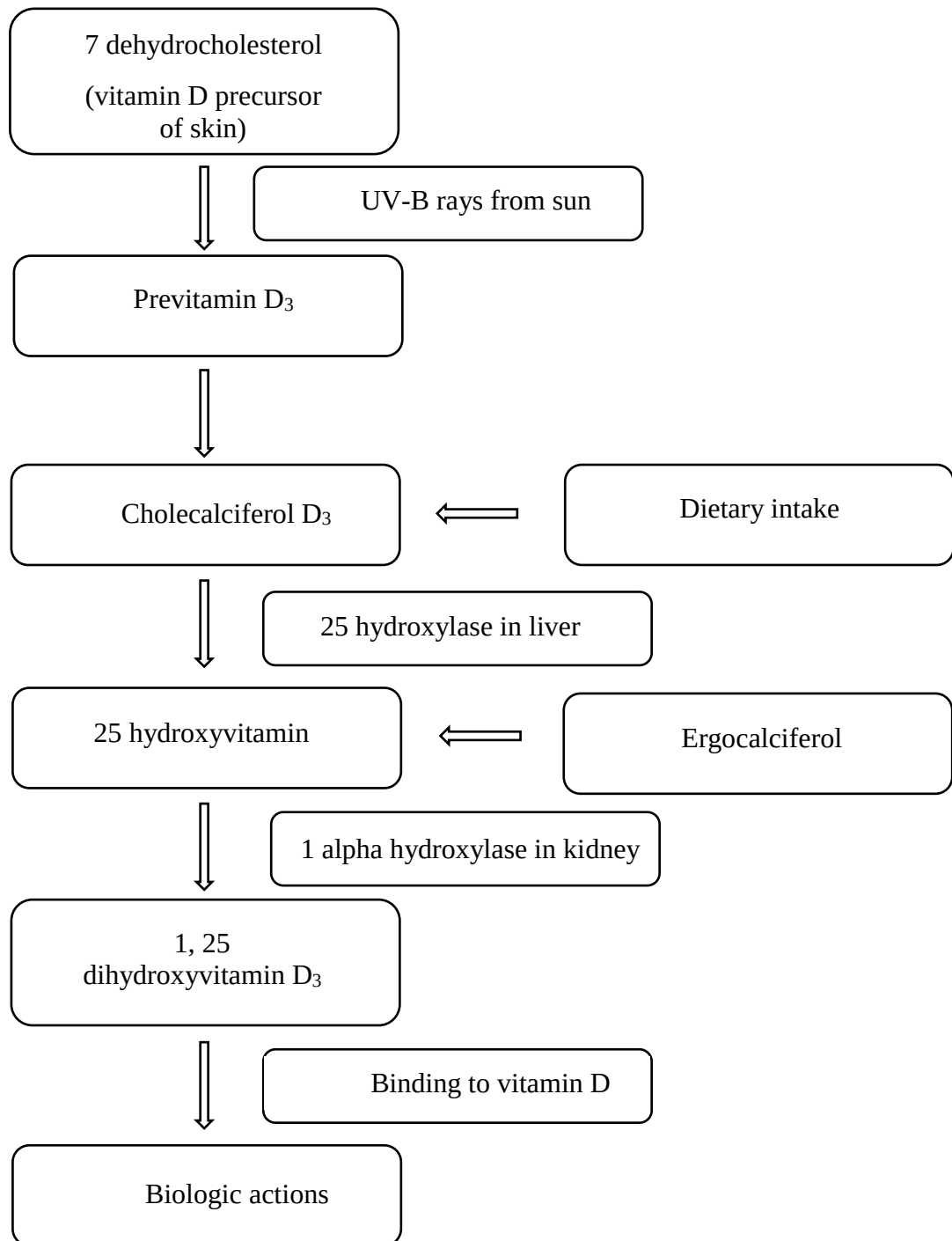


Figure 1: Vitamin D synthesis (Pilz et al., 2019).

Table (1): Serum 25(OH)D and its interpretations.

Classification	Serum 25(OH)D
Severe vitamin D deficiency	<25 nmol/L (<10 ng/mL)
Vitamin D deficiency	<50 nmol/L (<25 ng/mL)
Vitamin D insufficiency	<25-49 nmol/L (<10-19 ng/mL)
Adequate vitamin D threshold concentration	>50 nmol/L (>20 ng/mL)
Desirable vitamin D threshold concentration for reduction of falls and fractures	>75 nmol/L (>30 ng/mL)

1.2 Research Problem

Vitamin D plays an important role in maintaining human health. Its deficiency has been associated with increased risk of several chronic diseases. Sun exposure, particularly the UV-B radiation accounts for greater than 90% of vitamin D production in humans (Barrea et al., 2016). A study conducted in Bahrain showed no significant difference in vitamin D levels in Bahrainis and expatriates, considering both genders (AlShaibani et al., 2021). However, a high percentage of children in Bahrain have been found to be deficient in vitamin D, specifically girls (Isa et al., 2020). Therefore, the penetration of UV-B rays into the skin is mainly influenced by environmental factors and possibly cultural factors. On the other hand, dust and environmental pollutants also reduce the effectiveness of sun exposure and absorption into the skin due to the scattering of solar UV-B radiation, thus, decreasing the production of vitamin D in the skin (Hoseinzadeh et al., 2018). Although GCC countries are known to have high intensity of sunlight and UV-B radiation, employees prefer working indoors due to the extremely high temperatures, especially during the months of June to September, resulting in limited exposure of sun (AlShaibani et al., 2021). This may play a significant independent role on the development of VDD (Hoseinzadeh et al., 2018).

1.3 Research Questions

This study aims to answer the following questions:

1. What is the trend of ground-level solar UV-B irradiance measurements over the period from 2017-2022?

2. What is the effect of dust events on the ground level solar UV-B irradiance?
3. How much UV-B radiation is available across the Kingdom of Bahrain for the synthesis of sufficient vitamin D in the skin?
4. Should vitamin D oral intake enhancement be considered for the population of Bahrain?

1.4 Research Objectives

This study aims to fulfill the following objectives:

1. To analyse the trend of ground level solar UV-B irradiance measurements over the period from 2017-2022.
2. To study the effect of dust events on UV-B irradiance over the period from 2017-2022.
3. To assess UV-B availability all year round.
4. To compare these UV-B data with representative population serum 25-hydroxyvitamin D (25(OH)D) data from Bahrain.

1.5 Research Significance

The study is significant and has practical benefits as it may provide a concise overview of why VDD is high in the GCC countries despite the sunny climate throughout the year. The availability of UV-B radiation during dust events will be explored to find out if there is any association between it and the serum vitamin D levels in Bahrain. This might be a beginning of a new approach towards environmental sustainability for the GCC countries by improving the landscape or introducing different environmental strategies in reducing dust events. The effects of seasonal changes, air pollutants, temperature,

and skin type on vitamin D-effective UV-B availability has been documented in several studies, however, as far as we know the association of dust events and serum vitamin D levels was not investigated in Bahrain or any of the GCC countries.

1.6 The Study Setting

The data for the study was collected from the medical records of King Hamad University Hospital (KHUH), where all samples of various age groups of patients' blood were collected from the years 2017 – 2022. The purpose of the blood samples was to identify the levels of serum 25(OH)D in the patient's body. In addition, daily measurements of UV-B, humidity, temperature and dust particles were collected from the Ministry of Transportation and Telecommunications, Head Climatology Studies Climate Section. This was a self-conducted study where a multivariate statistical analysis was conducted on these data to identify whether the environmental factors affect the vitamin D level in the body.

1.7 Terminologies

- **Vitamin D:** Vitamin D is a fat-soluble vitamin in a family of compounds that includes vitamins D1, D2, and D3 and is important for typical growth and development of bones and teeth (Alshahrani et al., 2013).
- **Ultraviolet B:** Ultraviolet radiation with wavelengths between 290-320 nm, comprising less than 1% of the ultraviolet radiation that reaches the earth (Alshahrani et al., 2013).
- **Melanin:** A dark brown to black pigment occurring in the hair, skin, and iris of the eye in people and animals. It is responsible for tanning of skin exposed to sunlight (Golbahar et al., 2013).

- **Osteoporosis:** A condition when bone strength weakens and is susceptible to fracture. It usually affects hip, wrist or spine (Al shaikh et al., 2016).
- **Rickets:** The softening and weakening of bones in children, usually because of an extreme and prolonged vitamin D deficiency (Al shaikh et al., 2016).

Chapter Two

Theoretical Framework and Literature Review

2.1 Ground-level solar UV-B irradiance measurements over the past 15 years

2.2 Effect of dust events on the ground-level solar UV-B irradiance

2.3 Relation between the ground-level solar UV-B irradiance, number of dust events and the prevalence of vitamin D deficiency

2.4 Vitamin D status in the Gulf region

2.1 Global Ground-level solar UV-B irradiance measurements over the past 15 years

The long-term trends at 307.5 nm between the period of 1992 and 2016 for Spectral Ultraviolet (UV) records of solar irradiance of Japan, Canada, and Europe stations have been used for the purpose of the study that was conducted by Fountoulakis et al. (2018). In addition to that, satellite measurements of the aerosol index, ground-based total ozone data, surface reflectivity, and cloud coverage have also been utilised to describe the predicted changes in UV to the correlation changes in these components (Bais et al., 1993; Bernhard et al., 2007). Ground-based instruments provided data on total ozone, while satellite instruments provided data on aerosols, cloudiness, and surface. The study aimed to investigate the trends and impact due to the changes in clouds, aerosols, surface reflectivity, and ozone over the past 25 years of spectral ultraviolet B (UV-B) measurements through Japan, Europe, and Canada (Kazadzis et al., 2009).

The above study showed a significant variation in the long-term changes in UV-B radiation arriving at the earth's surface in different regions of the Northern Hemisphere, which is attributed to total ozone and aerosol changes. Surface reflectivity changes could be a cause of the observed changes at high latitudes. There was a dramatic increase observed $\sim 3\%$ /decade in Japan over the past 25 years at 307.5 nm UV-B irradiance because of a notable absorption decrease via aerosols. It was discovered that most of this significant increase occurred before the mid-2000s. Thessaloniki, Greece is the only European station where UV radiation increases considerably. Analysis of the clear-sky irradiance for the specific station showed

that irradiance at 307.5 nm increased by 3.5%/decade during the entire research period, with a rising rate of change over the last decade, which probably attributed to a decreased absorption by aerosols (Fountoulakis et al., 2018).

2.2 Effect of dust events on the ground-level solar UV-B irradiance

UV radiation accounts for just 3% of the incoming solar energy reaching the Earth's surface, yet it possesses a variety of biological influences when absorbed by human skin, which could be beneficial or harmful. When the human body overexposes to UV radiation, it leads to skin cancer as well as inhibits the immune system's natural function. However, receiving an insufficient amount of UV radiation causes a deficiency in vitamin D in which the skin is not capable to synthesize it, which is a very essential vitamin to maintain good health. Numerous factors have been reported as being a core reason for increasing or reducing the UV-B radiation reaching the Earth's surface, such as clouds, dust aerosols, and chemicals present in the atmosphere (Kalashnikova et al., 2005).

An Australian study by Kalashnikova et al. (2005), investigated the impact of smoke and dust aerosols on UV-B radiation from ground-based and satellite measurements, and how the presence of these factors could reduce the UV irradiance. The analysis focused on the impacts of smoke on specific days at the Darwin location. The study discovered numerous instances with quite strong aerosol activity. A comparison has been carried out between irradiances, simulated using the software libRadtran radiative, and measured UV irradiances at Darwin and found that the UV-B irradiance was reduced

by 15% downwind and 50% close to the fire sources. Likewise, the influence of smoke particles is 5 -10% more in the UV-B than in the UV-A. Changes in aerosol loading caused higher fluctuations in surface UV irradiances at Darwin throughout the chosen timeframe than previously observed changes in the ozone column (Kalashnikova et al., 2005).

Another study presented by Roman et al. (2013) aimed to assess the influence of desert dust on global, direct, and diffuse spectral ultraviolet irradiance. The proposed paper targeted the outbreak of desert dust across the Iberian Peninsula, and how it would have an impact on the spectral UV irradiance in Spain and Granada. The ratio of measurements that was compared in the desert to the ones taken in cleaner sky conditions is a straightforward technique to examine the aerosol effect on the spectrum of solar irradiance. About up to 55% of the direct UV irradiance was attenuated due to the desert dust, whereas there was a considerable increase in the diffuse UV irradiance at 400 nm (up to 40%). Aerosol absorption characteristics examination revealed a significant reduction in UV spectrum irradiance with a weak spectral dependency (Román et al., 2013).

In 2020, a research examined the correlation between solar UV-B and different weather parameters in Kuwait's climate. An outdoor unit was designed at the College of Technological Studies, Kuwait, to observe the UV-B radiation, solar global radiation, and the surrounding temperature in Kuwait throughout the period 2014 – 2019. On a clear daytime, the results showed that the global radiation and solar UV-B throughout the entire day recorded the same behaviour. Some statistical analysis was made to find out if there are any correlation between global solar radiation, UV-B radiation, and

the surrounding temperature. Likewise, there was an assessment of the UV Index (UVI) for several months. From May-August, and through the midday hours, the UVI recorded the maximum values, which were greater than 9 through the time of the study. The lowest UV radiation was recorded to occur in the winter months (December-February). Dust particles were one of the causes of the difference between the maximum and minimum UV-B radiation. This would result in minimum UV-B data, which could result in an increase in UV-B radiation's peak values. As observed for several months, the UVI was evaluated and concluded that the risky sun exposure hours are during the day when UVI is greater than 6 (Kadad et al., 2020).

An investigation was carried out and reported by Rahman and Elmi (2021) to find out if there were any correlation between some air pollutants and UV-B intensity on the ground. Pollutants in the atmosphere could minimize UV-B intensity reaching the ground, which eventually causes a reduction in the synthesis of vitamin D. Data was gathered out of four weather stations for four years over Kuwait and they were examined via median regression. The Kuwait Environmental Protection Authority (EPA) monitoring stations provided data on environmental issues. Data were gathered for five time periods (7 am, 9 am, 12 pm, 3 pm, and 5 pm), which are the times when most people are exposed to sunlight through summer and winter. There are some pollutants that are negatively correlated with UV-B, which are listed as follow: Benzene, Particulate Matter PM₁₀, (β (95% CI), Ozone, Ethyl-Benzene, Nitric Oxide (NO), and Sulphur Dioxide (SO₂). While pollutants shown to be adversely related to the UV-B/UV-A ratio are Benzene, β (95% CI), total Hydrocarbon, Ozone, and Nitric Oxide (Rahman & Elmi, 2021). Particularly short-

wavelength solar radiation can be absorbed or scattered by these pollutants in the troposphere. Unfortunately, case studies that show how air pollution affects the UV radiation in exact and the resulting vitamin D level in the body are rare (Hoseinzadeh et al., 2018).

Through the study, it was found that in the evening and morning, the levels of NO and benzene were high. Those are the periods when this region receives the maximum sun exposure because of high temperatures throughout the day. Additionally, these pollutants could reduce the levels of vitamin D via UV-B attenuation due to the presence of those pollutants. The prevalence of vitamin D Deficiency (VDD) could be because of those pollutants. The investigation concluded that ethyl-benzene, ozone, SO₂, NO, and PM10 are negatively correlated with UV-B intensity reaching the ground. The significant prevalence of VDD in Kuwait is mainly contributed to the presence of a high concentration of these negatively associated pollutants in the atmosphere, especially at a time when the exposure to the UV-B is high (Rahman & Elmi, 2021).

UV irradiance is very essential for human health to maintain the level of vitamin D that is important to bone growth. However, when the UV irradiance exceeds the required dose, it becomes harmful. Excessive doses of UV irradiance could cause skin cancer or premature wrinkles. Desert dust is a factor that causes to obtain an inaccurate prediction of UV irradiance measurements in those spots under the global dust belt (Roshan et al., 2020). A study conducted in Doha, Qatar was designed to predict the UVI under desert dust exposure to find out whether there is an influence by the dust on the UV measurement. The broadband irradiances of ground-based measurements UV-A (320–400 nm) along with National Aeronautics

and Space Administration (NASA)'s Ozone Monitoring Instrument (OMI) on its Aura satellite-retrieved data, UV-B (280–315 nm), and the meteorology-chemistry mesoscale model WRF-Chem were used as a combination for a UV Index forecasting, particularly for heavy dust regions. The UV model was constructed through Doha using ground-based measurements of UV-A and UV-B between 2013 and 2018 for clear-sky days. State-of-the-art pollution and numerical weather prediction model was utilised to forecast the UVI and then compare it with the UV in clear sky obtained by NASA OMI Aura satellite from 1 January to 31 August 2019 (Roshan et al., 2020).

Consequently, correlation factors of 0.9 were obtained. The model's predicting abilities was examined on clear sky days and when dust storms were present in Doha. UV light contributes between 5% and 7% of total incoming Global Horizontal Irradiance (GHI), whereas UV-B contributes between 0.1 and 0.22%. The UVI forecasting was successful in its capability to predict the UV irradiance received, which showed an average error (6%) and 0.93 correlation coefficient. In the Arabian Peninsula, the model used expected that the noontime UV Index in clear sky falls between 10–11 whereas falls 6–7 through dusty sky. The outcomes were approximately similar to those obtained under heavy cloud cover (Roshan et al., 2020).

2.3 Relation between the ground-level solar UV-B irradiance, number of dust events and the prevalence of vitamin D deficiency

A huge dust occurrence (September 23, 2009) in Australia, was considered the most significant one. The recorded hourly average

particle concentrations surpassed $15,000 \text{ g m}^{-3}$ at their peak. Dramatically surpassing the Standard of Australian National Air Quality, which is $50 \mu\text{g m}^{-3}$, and averages of $20\text{--}25 \mu\text{g m}^{-3}$ on daily September. Spectral surface ultraviolet irradiance examinations were conducted before and after, as well as through the event of September 2009 to focus on the effect of severe dust load on the ultraviolet irradiance, as well as outperforming earlier reported UV attenuation measurements in Saharan and Chinese dust occurrences. On the morning of September 23 2009, spectral attenuation of over 99.5 % in UV-B and 97.6 % in UV-A were correlated with the advent of low altitude accumulate clouds and the dust plume before reaching the cold front (Kalashnikova et al., 2005; Downs et al., 2016).

The conducted study by Downs et al. (2016) examined the effect of frontal desert dust storm UV irradiance surface in subtropical Australia's naturally high ambient ultraviolet environment. The afternoon of September 23rd was cloudless. As a result, the afternoon UV attenuated of more than 50% at 1430 Australian Eastern Standard Time (AEST) was entirely attributable to dust. These UV attenuations are the greatest ever measured in Australia, exceeding previously reported UV-B attenuation of 40%–50% in smoky tropical Australian circumstances. The dust possesses a direct and significant impact on surface UV irradiance. UV wavelengths that are impacted contribute to physiologically effective radiation, global surface energy budgets, and the UV index (Downs et al., 2016).

Over Europe, VDD is a major health problem due to less UV-B received. As it is well known that the essential source of vitamin D is UV-B and the food sources come second (O'Neill et al., 2016). An evaluation conducted by O'Neill et al. (2016), aimed to examine the availability of UV-B over numerous European regions that ranged

from 35° N to 69° N. Additionally, those UV-B data obtained would be contrasted with data of serum 25-hydroxyvitamin D (serum 25(OH)D) from Norway (69° N) and Ireland (51–54° N). Using a validated UV irradiance model, vitamin D-effective UV-B availability was estimated for nine European regions. A project, which was supported by the European Commission, provided standardised serum 25(OH)D data. The obtained results stated that there was a significant reduction in UV-B availability as latitude increased from 35° N to 69° N, although all targeted regions showed considerable seasonal fluctuation in UV-B. Despite far lower UV-B availability at the northern latitudes, the considerable seasonal changes in serum 25(OH)D in Irish people were greatly reduced in Norwegian and Icelandic individuals, which showed much greater vitamin D intakes. The study suggests that increasing vitamin D intake could overcome the lack of UV availability on serum 25(OH)D (O'Neill et al., 2016).

The previtamin D3 photosynthesis in the skin is achieved by solar radiation within the UV-B range. UV-B transmission in the atmosphere is highly impacted by air conditions and the solar zenith angle. A study in 2017 was carried out in the United Arab Emirates (UAE) which aimed to investigate the impact of seasonal and daily variation on the availability of adequate UV-B light for appropriate previtamin D3, using an established in vitro model. The reagent 7-dehydrocholesterol borosilicate ampoules in 50 µg/mL ethanol were directly exposed to sunlight in Abu Dhabi between 0800-1700 hours yearly, once a month and an hour a day. Using High-Performance Liquid Chromatography (HPLC), an analysis was conducted on the transformation of metabolically inactive photo isomers, previtamin

D3, and vitamin D3. The conversion efficiency of 7-dehydrocholesterol to previtamin D3 varied with predicted UV-B intensity. Previtamin D3 can be synthesized over the year at the latitude of Abu Dhabi (24.2 °N). In contrast, a very small amount of previtamin D3 was generated before 0900 hours and after 1600 hours. The domestic condition in Abu Dhabi, and constant exposure to the sun provided a good environment to maintain vitamin D levels over the year (Buckley et al., 2017).

In 2021, a study conducted by AlShaibani et al. (2021) focused on assessing the level of vitamin D and calcium for expatriate labourers and Bahrainis. Sun exposed and non-sun-exposed cases were considered. A Cross-sectional observational study was carried out at Arabian Gulf University and the Middle East Hospital in Bahrain to find out any differences in these levels among the selected cases. The study was conducted between October 2018 to September 2019, where four groups were chosen (N=24 non-exposed expatriates, N=31 exposed expatriates, N=25 non-exposed Bahrainis, and N=94 exposed Bahrainis) to evaluate the levels of calcium and vitamin D using 5 mL blood sample. The obtained results showed an elevation in vitamin D levels for sun-exposed Bahrainis in comparison to non-exposed Bahrainis. While vitamin D levels for expatriates have been recorded an opposed result. There was a low vitamin D for exposed expatriates compared to non-exposed expatriates. The study stated that there was a higher vitamin D level for Bahraini outdoor workers and a lower vitamin D level for expatriates. Whereas the exposed expatriates' workers have been recorded an elevated calcium level compared to the Bahraini outdoor workers, which was stated a lower calcium level.

2.4 Vitamin D status in the Gulf Region

The Gulf region is known for their abundant sunlight throughout the year and extremely hot weather during the summer. Despite this, the population in the Middle East and North Africa (MENA) is accounted to be the highest in VDD and Vitamin D Insufficiency (VDI) (Chakhtoura et al., 2018). Many studies have shown that the MENA region has the lowest concentration of serum 25(OH)D, which is an essential element for the production of vitamin D in the body. As a result, the number of individuals that are diagnosed with rickets are also one of highest, worldwide (Al-Mohaimeed et al., 2012; Al Mutair et al., 2012; Muhairi et al., 2013; Chakhtoura et al., 2018). The duration and frequency of exposure to UV-B is an important factor to determine the vitamin D status. People who mostly stay indoors and spend very few hours' outdoors; mostly women; have limited sun exposure. Furthermore, the sunlight that penetrates through glasses and enters the houses doesn't contain UV-B, therefore, its ineffective for the production of serum 25(OH)D (Al-Mohaimeed et al., 2012).

According to the studies conducted in the Middle East by Al-Mohaimeed et al. (2012) and Muhairi (2013), Arab women have been found to have higher VDD than men. This is mainly due to the conservative clothing style such as hijab, niqab, in which most of their body parts should be covered, thus, limiting the penetration of sunlight into their skin. Other reasons also include avoidance of sun exposure due to extremely hot weather, application of sunscreen, different skin pigmentation that reduces the penetration of UV light and inadequate diet that lacks vitamin D. As a consequence, the level of serum 25(OH)D found in their body is low. In addition, several studies were done to compare the concentration of serum 25(OH)D

between Arab women with conservative style living in Europe and normal European women. The results concluded that Arab women produce much lower serum 25(OH)D in their body (Al-Mohaimed et al., 2012; Muhairi et al., 2013). Similar results were also found in studies conducted in Kuwait, UAE and Oman for females with different age groups and styles of adolescents to old age. Almost all female participants had VDD. The few others were diagnosed with VDI, which were mostly unveiled women and had more sun exposure (el-Sonbaty, & Abdul-Ghaffar, 1996; Al-Kindi, 2011; Dawodu et al., 2011).

Moreover, a research in Doha, Qatar, was done to investigate the prevalence of VDD among health care professionals working at Hamad Medical Corporation. The result concluded a very high percentage of VDD in their healthy volunteers, in which females again were found to be dominant (Mahdy et al., 2010). In addition, a similar exploration was also done in Saudi Arabia among 2110 adolescents of age range between 6 to 15 years living in 8 different provinces. The study showed that 45.5% of the children had VDD and 49.9% of them had VDI. The rate of VDD and VDI combined, showed a higher percentage in females (97.8%) than in males (92.8%). Also, adolescents with dark skin were found to have lower levels of vitamin D (Al Shaikh et al., 2016).

As previously mentioned, the high temperatures and humidity in the Gulf significantly contribute to the high percentage of VDD and VDI (Golbahar et al., 2013; Al-Haddad et al., 2014; Saleh et al., 2018) which emphasises the need to determine ideal timings for sun exposure. Although focused in Saudi Arabia, Alamri (2015), identified the summer conversion of previtamin D3 per city, which is

the ideal timing for sun exposure for maximum synthesis of vitamin D in the skin. These are important since lower sun angles on the horizon allow the ozone, clouds, and particulate air pollution to absorb UV-B radiation, thus, limiting direct sun ray exposure (Alamri, 2015). On the other hand, maximum UV-B exposure leads to skin diseases and sunburn (Holick, 2014). Therefore, the optimum time calculated for Riyadh is between 8:30am-10:30am and 2:00pm to 4:00pm (Alamri, 2015). While another study reported it to be between 9:00 am – 10:30 am and 2:00pm – 3:00pm. Therefore, sun exposure during midday would be harming to the skin (Alshahrani et al., 2013).

In the case of Bahrain, an adequate variety of factors have been explored when studying both the prevalence of VDD and VDI across the nation. Studies have reported that 87.4% of the total population are either VDD or VDI (Golbahar et al., 2013). This is partly due to the excess heat and humidity which prevent direct sun exposure to the skin since people would prefer to stay indoors (Al-Haddad et al., 2014). Furthermore, it has also been reported that the overall national deficiency is higher between April to September than October to March due to limited outdoor activity in summers (Golbahar et al., 2013). Other factors such as current voluntary food fortification strategies and darker skin pigmentation also contribute to a high VDD (Golbahar et al., 2013; Al-Haddad et al., 2014).

Overall, it has been statistically concluded that VDD is more common in females rather than males with a drastic difference of 86% and 14% respectively, based on a study conducted in Al Kindi Hospital (Golbahar et al., 2013; Al-Haddad et al., 2014; Saleh et al., 2018). However, in regards to VDI, Golbahar et al. (2013) have found insufficiency to be more common in males than in females. Most

papers regard the drastic statistical difference to cultural attire and behaviour (Golbahar et al., 2013; Al-Haddad et al., 2014; Saleh et al., 2018). This was further supported by Al-Haddad et al. (2014) and el-Sonbaty & Abdul-Ghaffar (1996), reporting that 87% of veiled women from the participants had lower 25(OH)D levels. Moving on, one study conducted in 8 maternity hospitals showed 88.8% and 90.3% VDD in pregnant women and new-borns respectively, which is accelerated by prolonged breast-feeding without proper Vitamin D supplementation (Golbahar et al., 2013; Al-Haddad et al., 2014). As far as age is concerned, deficiency percentages were found to be higher in younger age groups (<30) while lower percentages exist in age groups above 30 (Golbahar et al., 2013). A similar conclusion was also drawn by Saleh et al. (2018) with higher deficiency levels found in age groups below 50.

Chapter Three

Methods and Procedures

3.1 Methodology

3.2 Study Population and Sample

3.3 Data Collection/Procedure

3.3.1 Data Collection

3.3.1.1 Environmental Factors

3.3.1.2 Medical Records

3.3.2 Procedure

3.3.2.1 Dusty & Non dusty days

3.3.2.2 Vitamin D tests

3.3.2.3 Deficient Patients

3.3.2.4 Patients with Chronic Diseases

3.4 Statistical Analysis

3.1 Methodology Used

This study is a cross sectional exploratory study from the period of January 2017 to June 2022. Quantitative research was approached since a statistical analysis will be conducted to examine the association between UV-B, vitamin D levels of patients, altitude level and the dust events. Measurements of UV, temperature and humidity were obtained from the Meteorological Directorate along with the number of dusty days at 1000m or less, 3000m or less and 5000m or less. In addition, dust particles (PM_{2.5} and PM₁₀) were also gathered from the Supreme Council of Environment. Vitamin D records of patients from 2017 to June 2022 were obtained from KHUH. The study was an investigation on healthy patients and patients with chronic diseases to identify whether a relationship exists between chronic diseases and VDD.

3.2 Study Population and Sample

The study population was considered as the residents of Bahrain, mainly Muharraq Island as KHUH is located there, and the study sample was focused on the records of patients in KHUH from the years 2017 to June 2022. The populations were divided into two categories, the first one were all individuals that have medical records at KHUH. The second category were individuals with any chronic diseases including digestive, renal, and liver disease, parathyroid gland dysfunction, and those who use any medications that affect bone metabolism and vitamin D status as well as obesity status. In addition, serum 25(OH)D data from all adult/older adult study populations and all childhood/adolescent study populations in

Bahrain during the period of 2017 to June 2022 were used in the present work.

3.3 Data Collection and Procedure

3.3.1 Data Collection

3.3.1.1 Environmental Factors

Hourly measurements of solar UV radiation, temperature and relative humidity were obtained from the Meteorological Directorate from the period of 2017 to June 2022. The process of how each parameter is measured along with the instrumentation used are explained below.

The Delta OHM radiometer named LPUVI02 measures the global sun irradiance (UV index) on a specific flat surface (Watt/m²). Table 2 shows the UV classification (Delta OHM, 1978).

Table (2): UV Classification

UV Classification	Necessary Action
Less than 2	No protection is required
From 3 to 7	Require protection from sunlight using UV blocking creams
8 and above	Require extra protection using UV blocking creams

Thermometers are usually required to measure the temperature of the surrounding air. To ensure that the surrounding air matches the thermometers own temperature, it requires specific shielding from sunlight, and should be exposed to ideal ventilation. These conditions are met by enclosing the thermometer inside a wooden box with

slanted sides, it is referred to as a Stevenson screen. To indicate the maximum and minimum temperatures reached over a period of day, special thermometers are used such as the U-shaped thermometers. These thermometers are known for their combination of minimum and maximum temperatures in them. In addition, the thermometers are also used to measure the ground temperature at night to calculate the falling temperature and air humidity (FisherBrand, 2006).

Furthermore, humidity can be calculated from readings taken by a hygrometer. Hygrometer has two thermometers, one wet bulb thermometer, and one dry bulb thermometer. The wet bulb thermometer is a typical thermometer with a bulb covered muslin bag in which an absorbent wick is dipped in water to keep it moist. When the water is evaporated from the muslin, the temperature of the thermometer lowers. The main distinct difference between wet and dry bulb is the calculation of various types of humidity. Relative humidity is measured by equating the mass of vapour in the air to the mass of saturated air at the same temperature reading, which is what have been used in the calculation (FisherBrand, 2006).

The above data were then arranged in an excel file by showing the daily records from 2017 to June 2022. With regards to the hourly measurements of UV, temperature and humidity, the average was calculated per day and recorded in the excel sheet to achieve uniformity in data arrangement.

Furthermore, about 5% of the UV rays reaching the earth is UV-B. This information was used to calculate the UV-B percentage since the data received from Meteorological Directorate contained only UV index. Therefore, manual calculation of UV-B percentage

was done. An example of UV-B percentage calculation is shown below:

$$UV\ index = 13.8$$

$$5\%\ of\ 13.8 = UV-B$$

$$0.05 \times 13.8 = UV-B$$

$$0.7 = UV-B$$

3.3.1.2 Medical Records

Representative population of vitamin D were also gathered from the medical records of KHUH from the period of 2017 to June 2022. The device used to measure the vitamin D was ADVIA Centaur IM assay. The device is an equimolar, fully automated vitamin D total assay that is traceable to LC-MS/MS (Liquid Chromatography-Mass Spectrometry). Additionally, the assay measures total 25-hydroxyvitamin to make sure that patients are tested for sufficiency, deficiency or toxicity (Siemens Healthineers, 2017). Vitamin D in Bahrain hospitals are categorised as follows;

- Less than 20 ng/ml is considered as deficient
- Between 20 - 30 ng/ml is insufficient
- Between 30 - 100 ng/ml is sufficient vitamin D measurement.

The data received from KHUH included a total number of 33,262 patients each containing details such as personal number, patient name, test date, vitamin D value and if the patient is categorised as deficient or normal. The age of patients from the date of test were also calculated to identify the different age groups that are included in the study. This was done by finding their year of birth from the personal number and subtracting it from their date of test. An example is shown below:

Date of Test	Patient Name	CPR	Age on Test Date
28 February 2017	M.G.Z.A	67xxxxxxx	50

$$2017 - 1967$$

$$= 50 \text{ years}$$

Out of the 33,262 patients, 16,239 patients (48.82%) were sorted out as vitamin D deficient patients in which the study mainly focused on. In addition, a random sample of 1694 (10%) patients were selected out of the total of 16,239 to represent the patients with chronic diseases related to VDD. The random sample was calculated on a 95% confidence interval and 5% margin of error where a random sampling size of minimum 376 are only needed to represent the population. Therefore, a random sample of 10% patients were more than enough to represent accurate results. The frequency of the diseases was calculated to show the most occurred chronic disease in Bahrain and its relationship with VDD.

3.3.2 Procedure

Bar charts were created to compare the number of dusty days, number of non-dusty days, number of vitamin D tests conducted and the total number of deficient patients in each month of that specific

year. This process will be done from the years 2017 to June 2022. In order to do this, the total number of dusty days, non-dusty days, vitamin D tests conducted and the deficient patients were calculated separately for each year in the excel sheet.

3.3.2.1 Dusty & Non dusty days

Using the records received from the Meteorological Directorate, the number of dusty and non-dusty days were specified daily in each year for three different altitudes, 1000m or less, 3000m or less and 5000m or less. These data are recorded for aviation purposes in Bahrain. However, higher altitudes are required for this study which are not available. As a result, the sum in each month for each altitude was calculated annually from the year 2017 to June 2022 and only dust readings at 5000m or less were used in the study to provide the closest predicted result.

3.3.2.2 Vitamin D tests

Similar process was performed to calculate the total number of vitamin D tests conducted yearly. The records from KHUH included the test dates which was used to calculate the sum of tests conducted in each month annually from the year 2017 to June 2022.

3.3.2.3 Deficient Patients

The data from KHUH showed the vitamin D results of each patient along with classifying it to be deficient or normal. Only the ones that were classified as deficient were taken to calculate the sum of deficient patients in each month annually from the year 2017 to June 2022.

Once all four parameters were found, a bar chart for each year including all 12 months showed the four parameters. In addition, one

bar chart that contained the summary of all the years showing the four parameters was also created.

3.4 Statistical Analysis

The data was analysed using Statistical Package for Social Science (SPSS version 28). The method used was Pearson correlation since it measures linear correlation between two sets of continuous data (Faizi & Alvi, 2023). Therefore, it was used to correlate numeric variables such as UV-B, number of vitamin D tests, deficient patients and dust levels at 1000m or less, 3000m or less, and 5000m or less. The main aim of the statistical analysis was to investigate the relationship between dust levels at different altitudes and whether these dust particles prevent the UV-B rays from reaching the earth's atmosphere leading to VDD.

Chapter Four

Results, Discussion, and Recommendations

4.1 The Study's Results

4.1.1 Temperature & Relative Humidity

4.1.2 UV & UV-B

4.1.3 Dusty & Non-Dusty Days

4.1.4 Healthy Patients

4.1.4.1 Vitamin D Tests

4.1.4.2 Deficient Patients

4.1.5 Patients with Chronic Diseases

4.2 Discussion of Results

4.3 Study's Recommendations

4.1 The Study's Results

The demographic information of the patients received from KHUH consisted of personal number, number of vitamin D tests, the date of tests and year which showed a wide range of age groups. The data included patients from the birth year of 1910 to 2009. As per the data, patients started testing for vitamin D level since 7 years old to 112 years old (Appendix 1). The study analysis has been performed for the years 2017 to 2022.

4.1.1 Temperature & Relative Humidity

Table 3 shows the average temperature recorded from 2017 to June 2022. The highest temperatures are seen in July and August which fluctuates yearly between 33°C to 38°C. Similarly, the coolest months in Bahrain are January to March where the temperature drops to an average of 17°C.

Table (3): Monthly average Temperature for the years 2017 to June 2022.

Average Temperature (°C)						
Month	2017	2018	2019	2020	2021	2022
Jan	21.2	18.8	20.9	18.1	20.4	19.3
Feb	18.3	17.2	20.5	19.1	18.1	19.3
Mar	18.8	20.9	19.2	22.1	19.8	20.4
Apr	27.1	24.4	24.9	27.0	27.8	25.7
May	30.4	29.3	28.4	31.0	29.8	28.9
Jun	32.5	37.1	36.0	34.7	35.3	31.5
Jul	36.5	33.8	37.9	36.9	37.9	
Aug	36.2	35.9	38.4	36.1	37.3	
Sep	35.9	35.3	36.2	34.8	35.5	
Oct	32.8	33.6	34.3	30.1	33.4	
Nov	28.5	26.7	28.5	26.2	27.9	
Dec	23.9	23.3	23.6	21.0	23.5	
Average	28.5	28.0	25.7	28.0	28.9	24.2

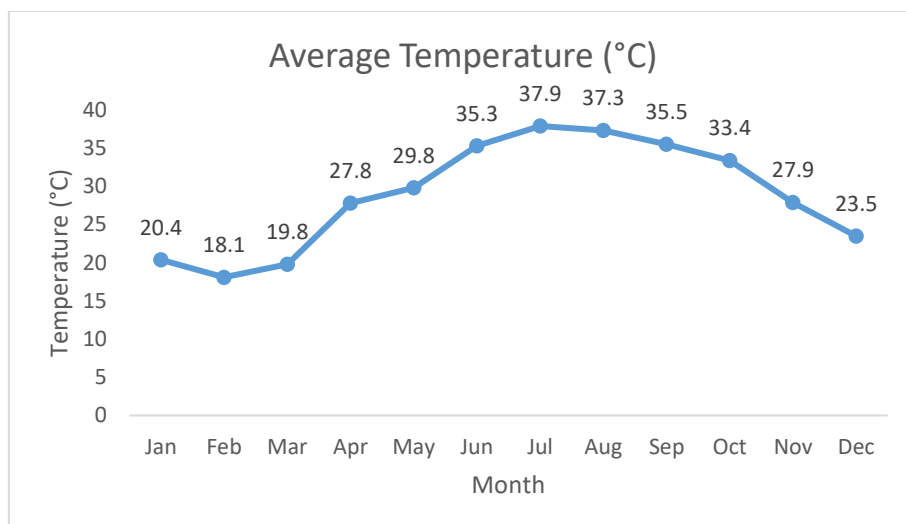


Figure 2: Average temperature variation for the year 2021.

Table 4 shows the average monthly relative humidity in Bahrain from 2017 to June 2022. The months with the lowest relative humidity are found in May and June and the highest humidity are from December to February. It can be interpreted that the humidity levels are higher in the cooler months of Bahrain rather than the hotter months. Overall, it can be seen that relative humidity in Bahrain is high throughout the year.

Table (4): Monthly average Relative Humidity for 2017 to June 2022.

Average Relative Humidity (%)						
Month	2017	2018	2019	2020	2021	2022
Jan	68	61	65	64	66	67
Feb	68	67	65	64	69	64
Mar	70	53	60	62	55	55
Apr	52	53	54	55	45	45
May	47	46	41	47	37	43
Jun	44	42	41	44	47	44
Jul	52	47	47	51	51	
Aug	59	52	52	50	51	
Sep	60	63	59	55	54	
Oct	61	59	61	56	61	
Nov	57	69	56	60	61	
Dec	65	67	67	66	66	
Average	58.6	56.6	55.7	56.2	55.2	53

4.1.2 UV & UV-B

Daily UV index readings were received and the average for each month was calculated and shown in Table 5. Less sunlight is received during the cooler months such as December - March due to lower temperature which will have lower UV index and this is what is observed in Table 3 and Table 5. The hottest months in Bahrain are July and August and it can be seen in Table 3 and Table 5 that the highest temperatures and UV index are recorded in these months. A higher UV index means more UV rays entered the earth's atmosphere. Therefore, looking at the values in Table 5, overall, much higher UV index throughout the year were received in Bahrain.

Table (5): Monthly average UV Index for the years 2017 to June 2022.

	UV Index (Watt/m ²)					
Month	2017	2018	2019	2020	2021	2022
Jan	15.0	16.6	15.2	16.5	15.9	14.5
Feb	17.1	17.8	18.9	20.4	19.4	17.5
Mar	18.6	24.7	22.3	20.5	21.7	17.8
Apr	25.2	20.5	22.1	21.8	26.3	16.6
May	25.9	22.5	24.1	25.4	26.4	17.8
Jun	26.0	27.3	27.4	27.4	26.5	21.1
Jul	24.5	24.7	26.6	26.2	26.4	
Aug	26.5	23.6	25.8	25.2	26.4	
Sep	24.3	23.8	23.7	23.0	26.1	
Oct	21.7	18.4	20.1	21.4	22.0	
Nov	17.7	16.3	17.5	16.8	17.3	
Dec	16.9	17.6	16.0	16.3	14.4	

However, since UV-B readings were required for this study, an approximate 5% of the UV is considered as UV-B which was calculated and shown in Table 6. The below UV-B readings were used throughout the study. Lower UV-B rays are found in the cooler

months and higher UV-B rays are recorded in the hottest months; both can be observed in Table 6. In addition, a similar trend of UV-B values can be seen throughout all the years which are constant, except for 2022 where the UV-B values are lower than the previous years.

Table (6): 5% estimation of UV-B calculated from the UV Index in Table 5 for the years 2017 to June 2022.

	UV-B					
Month	2017	2018	2019	2020	2021	2022
Jan	0.7	0.8	0.8	0.8	0.8	0.7
Feb	0.9	0.9	0.9	1.0	1.0	0.9
Mar	0.9	1.2	1.1	1.0	1.1	0.9
Apr	1.3	1.0	1.1	1.1	1.3	0.8
May	1.3	1.1	1.2	1.3	1.3	0.9
Jun	1.3	1.4	1.4	1.4	1.3	1.1
Jul	1.2	1.2	1.3	1.3	1.3	
Aug	1.3	1.2	1.3	1.3	1.3	
Sep	1.2	1.2	1.3	1.2	1.3	
Oct	1.1	1.1	1.0	1.1	1.1	
Nov	0.9	0.8	0.9	0.8	0.9	
Dec	0.8	0.9	0.8	0.8	0.7	

4.1.3 Dusty & Non-Dusty Days

Dust readings at 3 different altitudes (1000m or less, 3000m or less, and 5000m or less) for the years 2017 to 2022 have been compared and shown in Table 7. As the altitude increases, the dust levels also increase. The year with the highest dust was found to be in 2018, where it had a total of 4 dusty days at 1000m or less, a total of 30 days in 3000m or less, and a total of 57 days at 5000m or less. In 2022, the data were recorded only up to June, however it can still be predicted that it was one of the dustiest years since it had a total of 5 days at 1000m or less, 13 days at 3000m or less and 30 days at 5000m

or less being relatively high only halfway through the year when compared to the previous full years. Since no dust records for higher altitudes are available, dust readings at 5000m or less were used throughout the study.

Table (7): Comparison of dust levels from 2017 to 2022 between altitudes of 1000m or less, 3000m or less and 5000m or less.

	Total Dusty Days					
Altitude	2017	2018	2019	2020	2021	2022
1000m or less	2	4	2	1	2	5
3000m or less	12	30	9	11	12	13
5000m or less	23	57	25	25	19	30

Table 8 shows the breakdown of the total number of dusty days at 5000m or less from the year 2017 to 2022. It can be seen that 2018 had the highest dusty days (57) and 2021 had the lowest (19) with relevant to the rest of the years. Although only half of the data was provided for 2022, however, by looking at the total dusty days till June (30), it can be predicted that it had high number of dusty days totally until end of the year. The data also exhibited seasonality in the occurrence of dusty days. In particular, April, May, and June have had higher numbers of dusty days in most years, suggesting that these months were more prone to dust events that might affect VDD occurrence. The same trend was also found in 2022 where April, May and June had the highest number of dusty days compared to the same months in the previous years, thus supporting the prediction that 2022 could be considered as a year with a high number of dusty days. Finally, looking at the total number of dusty days across all the years, no significant trend can be observed, in which the total dusty days kept fluctuating across the years.

Table (8): Total number of dusty days for 5000m or less from 2017 to June 2022.

Month	Year					
	2017	2018	2019	2020	2021	2022
Jan	0	5	8	5	1	4
Feb	4	5	0	3	0	2
Mar	2	5	5	7	4	4
Apr	3	10	2	6	0	6
May	6	6	6	2	0	11
Jun	3	9	1	0	10	3
Jul	0	9	1	0	1	-
Aug	0	6	2	0	1	-
Sep	0	0	0	1	2	-
Oct	0	2	0	0	0	-
Nov	2	0	0	0	0	-
Dec	3	0	0	1	0	-
Total Dusty Days	23	57	25	25	19	30

Table 9 summarizes the total number of non-dusty days at 5000m or less from the year 2017 to 2022, in which 2021 since has the least year with dust, having a total number of 346 days. The combined data showed that the total number of non-dusty days tends to be higher than that of dusty days across all years. As a result, the weather was predominantly free of dust events. However, the difference in the number of non-dusty and dusty days varies from year to year, suggesting that certain years might have experienced more frequent dust events. The data from Tables 8 and 9 also demonstrated seasonality in the occurrence of dusty and non-dusty days. The months of April till June have higher numbers of dusty days and lower numbers of non-dusty days in most years. Conversely, the months of September to December consistently showed lower numbers of dusty days and higher numbers of non-dusty days, indicating that these

months have had more stable conditions that prevent the formation of dusty events.

Table (9): Total number of non-dusty days at 5000m or less from 2017 to June 2022.

	Year					
Month	2017	2018	2019	2020	2021	2022
Jan	31	26	23	26	30	27
Feb	24	23	28	26	28	26
Mar	29	26	26	24	27	27
Apr	27	20	28	24	30	24
May	25	25	25	29	31	20
Jun	27	21	29	30	20	27
Jul	31	22	30	31	30	-
Aug	31	25	29	31	30	-
Sep	30	30	30	29	28	-
Oct	31	29	31	31	31	-
Nov	28	30	30	30	30	-
Dec	28	31	31	30	31	-
Total Non-Dusty Days	342	308	340	340	346	151

Table 10 shows the readings of the dust particles $PM_{2.5}$ and PM_{10} from the years 2018 to June 2022. Unfortunately, many readings were not available, however, the PM_{10} in August 2018 was the highest (181.7) compared to the rest of the months. In 2019, $PM_{2.5}$ was highest in September (50.6) and PM_{10} was highest in May (161.9). In 2021, $PM_{2.5}$ and PM_{10} were both the highest in August, 80.3 and 295.7 consecutively. In 2022, $PM_{2.5}$ and PM_{10} were both the highest in May, 97.0 and 285.5. In addition, a trend can also be noticed that PM_{10} is much higher in Bahrain than $PM_{2.5}$.

Table (10): Monthly average PM_{2.5} and PM₁₀ (ug/m³) from 2018 to June 2022, excluding 2020.

Month	PM2.5 2018	PM10 2018	PM2.5 2019	PM10 2019	PM2.5 2021	PM10 2021	PM2.5 2022	PM10 2022
Jan	-	-	32.4	149.1	-	-	42.3	97.2
Feb	-	-	19.6	83.8	23.5	80.5	63.5	144.7
Mar	-	-	22.4	99.3	26.6	155.1	44.7	219.2
Apr	-	-	26.2	114.2	44.8	128.3	83.8	219.9
May	-	-	48.1	161.9	48.6	165.5	97.0	285.5
Jun	-	-	44.8	146.6	44.6	289.3	70.5	190.1
Jul	-	-	38.3	96.1	19.5	159.6	-	-
Aug	-	181.7	47.2	115.6	80.3	295.7	-	-
Sep	-	153.4	50.6	108.4	-	-	-	-
Oct	-	141.9	55.4	134.7	41.9	268.1	-	-
Nov	-	80.6	24.4	102.7	41.8	84.5	-	-
Dec	-	92.6	-	-	31.5	77.9	-	-

4.1.4 Normal Patients

The data of patients were gathered and compared with factors such as dusty days, non-dusty days, number of tests conducted, and number of deficient patients per specific year which are shown in Tables 8, 9, 11 and 12.

4.1.4.1 Vitamin D Tests

Table 11 presents the total number of vitamin D tests conducted from the year 2017 to June 2022. It is noticeable that the number of tests kept increasing yearly. In 2017, a total of 2,910 vitamin D tests were carried out. The number of tests per month ranged from its lowest (128 tests) in September to the highest of 304 in May. In 2018, 3,076 tests were conducted, with the lowest number of the performed tests in August (181) and the highest in May (313). By 2019, the total number of tests increased to 5,012, with the lowest number of tests in January (352) and the highest in September (522). On the other hand, the total number of test in 2020 decreased to 4406 tests and this could

be due to COVID-19 lockdown restrictions in Bahrain. Notably, a significant increase in the number of tests was observed in 2021, with a total of 7,237 tests conducted. The number of tests ranged from a low of 387 in February to a high of 816 in November. In 2022, up to June, a total of 8,414 tests were conducted. The number of tests per month was observed to increase considerably, with the lowest number of tests in January (906) and the highest in May (1,631).

Table (11): Total number of vitamin D tests from 2017 to June 2022.

Number of Vitamin D Tests						
Month	2017	2018	2019	2020	2021	2022
Jan	287	250	352	393	494	906
Feb	233	246	476	346	387	966
Mar	264	253	488	307	602	1238
Apr	291	224	476	198	464	987
May	304	313	299	137	452	1631
Jun	211	242	377	309	585	1578
Jul	262	316	450	404	513	-
Aug	181	222	378	339	589	-
Sep	128	208	522	443	812	-
Oct	239	240	357	414	755	-
Nov	283	268	502	594	816	-
Dec	227	294	335	522	768	-
Total	2910	3076	5012	4406	7237	8414

4.1.4.2 Vitamin D Deficient Patients

Table 12 demonstrates the rapid increase of patients with VDD across the years 2017 to June 2022. The year with the highest deficient patients is 2021 which had a difference of more than 600 deficient patients compared to 2019. In 2017, a total of 691 vitamin D deficient patients were identified. The number of deficient patients per month ranged from 24 in September to 83 in May within the same year. In 2018, there were 826 identified deficient patients, with the lowest observed number in February (61) and the highest in December (94). In 2019, the total number of deficient patients increased to 1,186, with the lowest number in March (67) and the highest in November (135). In 2020, there were 1012 deficient patients with the lowest in May (25) and the highest in November (126). A significant increase in the number of deficient patients was observed in 2021, with a total of 1,834 patients identified. The number of deficient patients ranged from a low of 95 in February to a high of 227 in September. In 2022, up to June, a total of 1,555 vitamin D deficient patients were identified. The number of deficient patients per month increased notably, with the lowest number in January (148) and the highest in March (272). The observed pattern may indicate a growing prevalence of VDD and outline the importance of continued screening and intervention efforts.

Table (12): Total percentage of deficient patients from 2017 to June 2022.

Month	Number of Deficient Patients					
	2017	2018	2019	2020	2021	2022
Jan	68	63	78	109	116	148
Feb	61	61	95	92	95	259
Mar	54	55	67	93	130	272
Apr	67	70	118	34	127	182
May	83	87	70	25	106	254
Jun	52	64	83	65	153	249
Jul	56	71	97	74	134	-
Aug	43	52	126	71	163	-
Sep	24	66	143	101	227	-
Oct	69	66	76	100	176	-
Nov	50	77	135	126	202	-
Dec	64	94	98	122	205	-
Percentage of the total tests done	23.7%	26.9%	23.7%	23%	25.3%	18.5%

Figures 3-9 illustrate the total number of dusty and non-dusty days, vitamin D tests, and deficient patients from the years 2017 to June 2022. In 2017 (Figure 3), the highest number of tests were performed in May (10.4%) along with the highest number of deficient patients (12%) and dusty days (6). The number of dusty days was relatively low compared to other years, with April and May showing the highest dusty days. In the same year, the total number of vitamin D tests was 2910, and the number of deficient patients was 691. Moreover, the percentage of vitamin D deficient patients was approximately 23.7%. Also, the lower number of dusty days was not associated with a significant impact on VDD, given that the proportion of deficient patients was comparable to the following years.

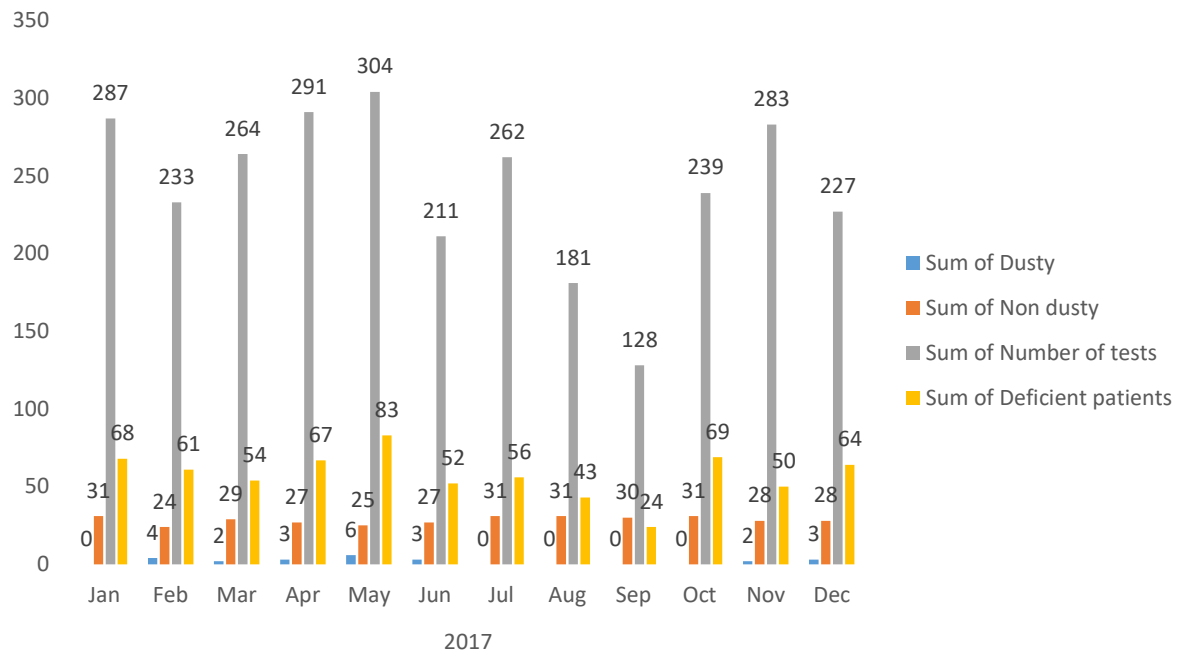


Figure 3: Total number of dusty days, non-dusty days, number of vitamin D tests and deficient patients in 2017.

In 2018 (Figure 4), July was the most month in which vitamin D tests were conducted (10.3%) and it had the dustiest days (9). However, the highest deficient patients were found to be in December (11.4%). It can be seen that there's a slight change compared to the trend found in 2017. Proceeding with the years, 2018 witnessed a higher number of dusty days, particularly in April, May, and June. The total number of vitamin D tests increased to 3076, and the number of deficient patients rose to 826, with a proportion of approximately 26.8%.

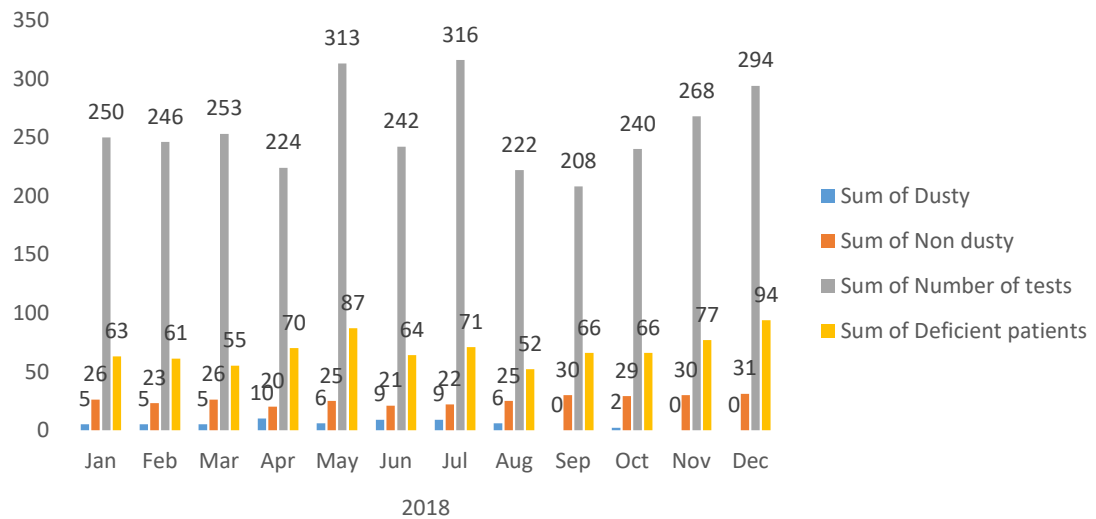


Figure 4: Total number of dusty days, non-dusty days, number of vitamin D tests and deficient patients in 2018.

Likewise, in Figure 5, September 2019 had the highest number of tests (10.4%) and deficient patients (12.1%) but the month with maximum dusty days was January (8). In 2019, the number of dusty days was relatively moderate compared to the years of investigation, with May experiencing the highest number of dusty days. The total number of vitamin D tests surged to 5012, and the number of deficient patients reached 1186. The proportion of deficient patients to tests conducted was approximately 23.7%.

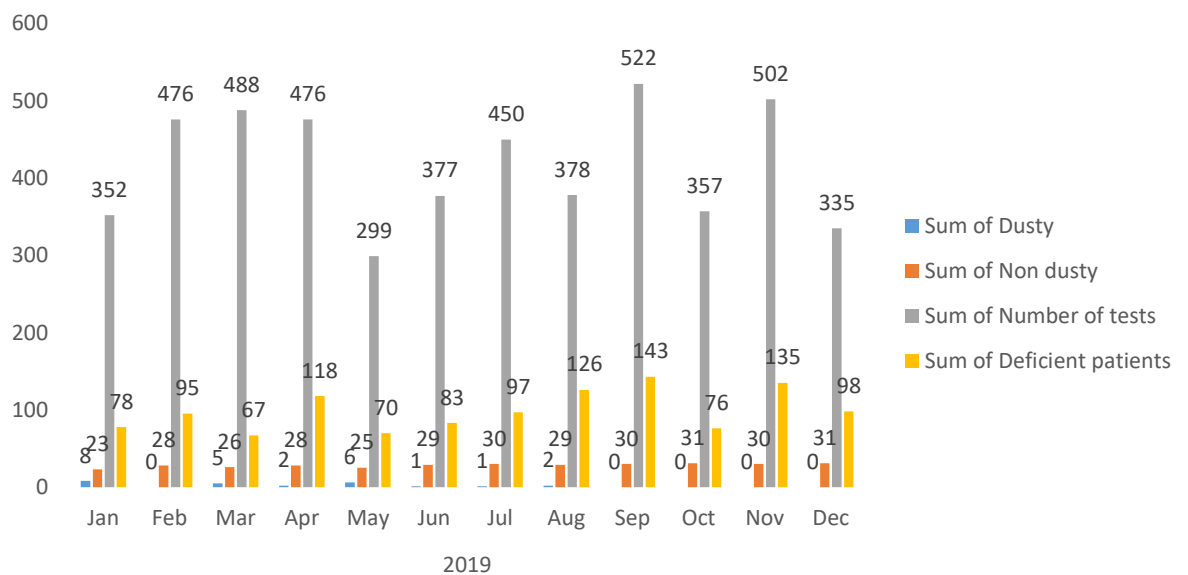


Figure 5: Total number of dusty days, non-dusty days, number of vitamin D tests and deficient patients in 2019.

In 2020, November had the highest number of tests (13.4%) and deficient patients (12.5%). The month with maximum dusty days was March (7). The total number of vitamin D tests conducted in this year reached up to 4406 test with a total of 1012 deficient patients. The proportion of deficient patients to tests conducted was approximately 23%.

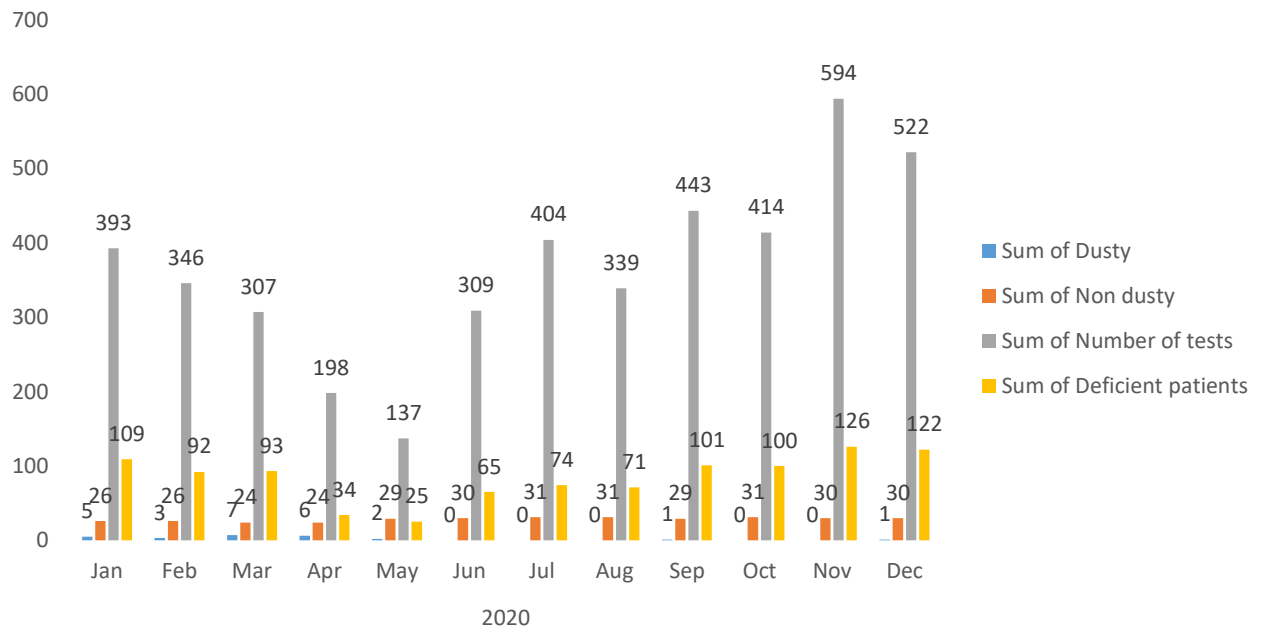


Figure 6: Total number of dusty days, non-dusty days, number of vitamin D tests and deficient patients in 2020.

In 2021 (Figure 7), a complete different trend was shown. November had the highest vitamin D tests performed (11.3%), September had the highest deficient patients (12.4%), and June was the dustiest month, adding up to a total of 10 days. The total number of vitamin D tests increased to 7237, and the number of deficient patients rose to 1834. The proportion of deficient patients to tests conducted was approximately 25.3%.

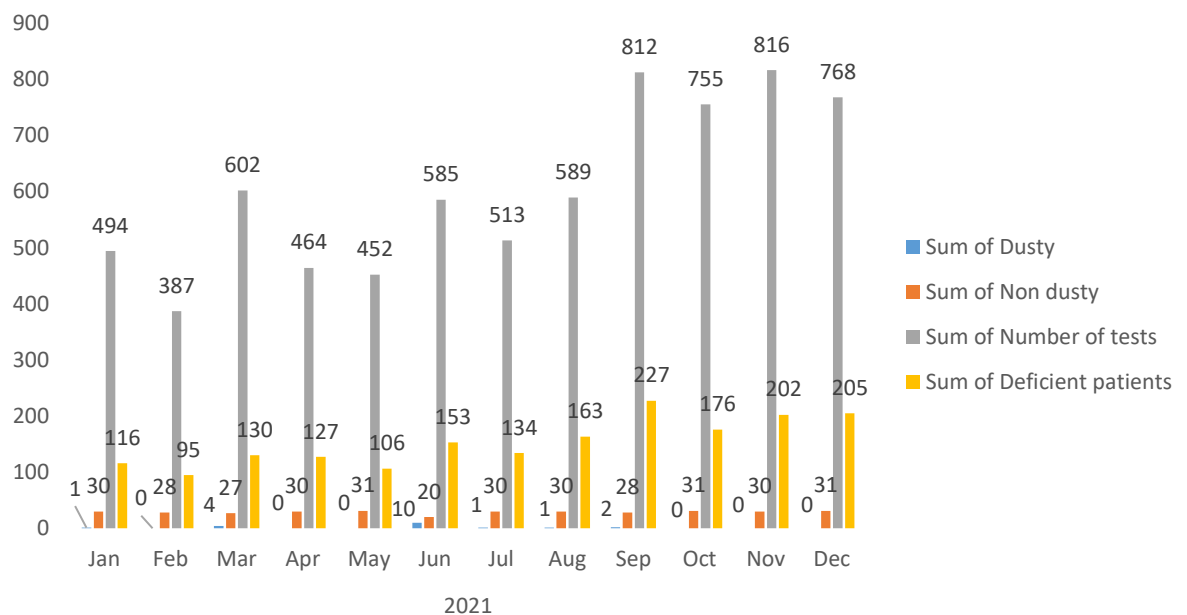


Figure 7: Total number of dusty days, non-dusty days, number of vitamin D tests and deficient patients in 2021.

Finally, in Figure 8, May 2022 had the highest vitamin D tests (19.4%) and dusty days (11) whereas, February had the highest number of deficient patients (16.7%). The proportion of deficient patients to tests conducted was approximately 18.5%.

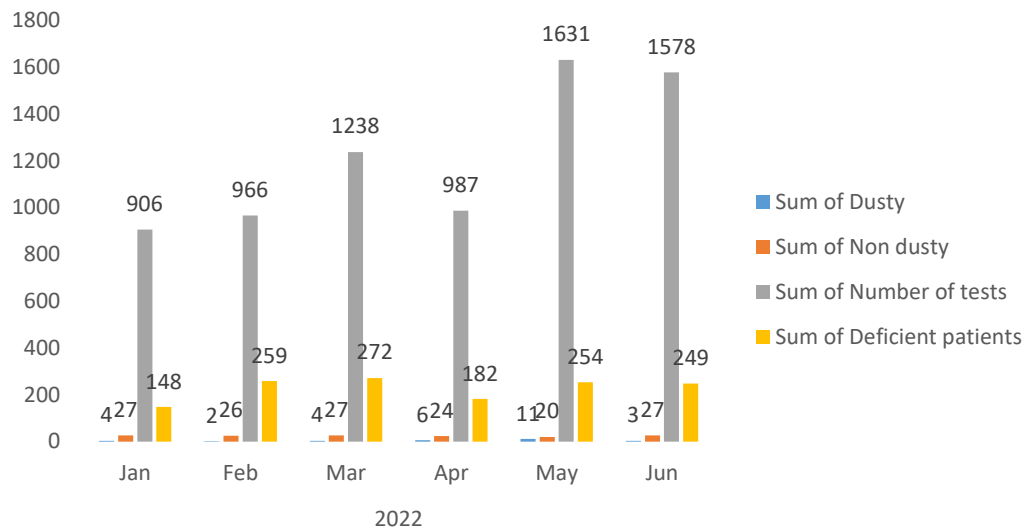


Figure 8: Total number of dusty days, non-dusty days, number of vitamin D tests and deficient patients in 2022.

Figure 9 summarizes the total number of dusty days, non-dusty days, number of vitamin D tests, and deficient patients from 2017 to June 2022 where it can be seen that the number of tests conducted along with the deficient patients kept increasing. However, the same trend was not found with the number of dusty days. The year with the highest dusty days was 2018 and the lowest was 2021. The data presents varying patterns across the five years (2017-2022). The total number of dusty days fluctuated across the years, with 2018 and 2021 showing relatively higher numbers of dusty days than other years. The percentage of vitamin D deficient patients to the total number of tests conducted also varied, with proportions of approximately 23.7% in 2017, 26.8% in 2018, 23.7% in 2019, 25.3% in 2021, and 18.5% in 2022 (until June). The data exhibited a seasonal pattern in both dusty days and vitamin D tests and the deficient patients, with higher numbers typically occurring between January and June.

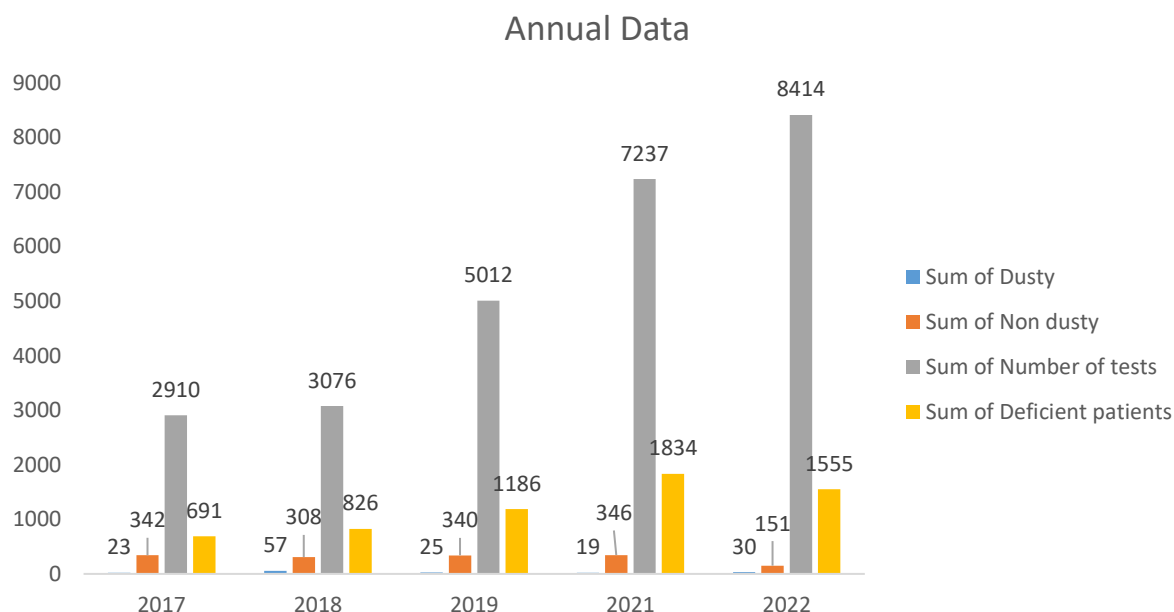


Figure 9: Summary of dusty days, non-dusty days, number of vitamin D tests and deficient patients from 2017 to June 2022.

Table 13 compares the total number of dusty days and the percentage of deficient patients from the years 2017 to June 2022. The total dusty days from 2017 to 2018 increased from 23 to 57 in which the percentage of deficient patients also increased from 23.7% to 26.8%. Proceeding further, there was a decrease of total dusty days from 2018 to 2019, and the same trend was also found in the deficient patients. The total dusty days remained the same from 2019 to 2020 and the deficient patients decreased slightly from 23.7% to 23%. However, there was a decrease in the total dusty days from 2020 to 2021 but the opposite was found in the deficient patients where it showed an increase from 23% to 25.3%. Except for 2021, the overall results show a direct relation between the dusty days and the deficient patients on a yearly average.

Table (13): Comparison between total dusty days and percentage of deficient patients in the years 2017 to June 2022.

	Year					
	2017	2018	2019	2020	2021	2022
Total number of dusty days	23	57	25	25	19	30
Percentage of deficient patients	23.7%	26.8%	23.7%	23%	25.3%	18.5%

4.1.5 Patients with Chronic Diseases

Another factor that might cause VDD is chronic diseases. In order to investigate whether chronic diseases are a major contributor to the deficiency in vitamin D, a random sample of 1694 (10%) patients were selected out of the total of 16,239 to represent the patients with chronic diseases related to VDD. The random sample was calculated on a 95% confidence interval and 5% margin of error where a random sampling size of minimum 376 are only needed to represent the population. Therefore, a random sample of 10% patients were more than enough to represent accurate results. On the other hand, only 199 patients from the 1694 (11.7 %) were found to have chronic diseases that directly affects their vitamin D synthesis in the body resulting in deficiency in vitamin D. This implies that only 1.22% of the total 16,239 patients have VDD due to their chronic diseases.

Table 14 shows the chronic diseases that causes VDD from the randomly selected patients. The most repeated one was found to be chronic kidney disease (CKD) followed by bariatric surgery.

Table (14): Most occurred chronic diseases resulting in VDD found in patients.

	Frequency	Percent	Valid percent	Cumulative percent
Valid	1494	88.2	88.2	88.2
Bariatric	35	2.1	2.1	90.3
Celiac disease	2	.1	.1	90.4
Cirrhosis	11	.6	.6	91.1
Chronic kidney disease	118	7.0	7.0	98.1
Chronic kidney disease, psoriasis	2	.1	.1	98.2
Hypoparathyroidism	3	.2	.2	98.3
Inflammatory bowel disease	11	.6	.6	99.0
Liver malignancy	3	.2	.2	99.2
Malnutrition (anorexia nervosa)	1	.1	.1	99.2
Medication	4	.2	.2	99.5
Nephrotic syndrome	1	.1	.1	99.5
Psoriasis	7	.4	.4	99.9
Psoriasis, chronic kidney disease	1	.1	.1	100.0
Total	1693	100.0	100.0	

Table 15 shows a strong positive correlation between year and number of tests ($r = 0.818$, $p < 0.001$), and year and deficient patients ($r = 0.855$, $p < 0.001$). This indicates that the number of tests and vitamin D deficient patients has increased over the years. Similarly, a strong positive correlation was demonstrated between month and number of tests ($r = 0.798$, $p < 0.001$), and month and deficient patients ($r = 0.853$, $p < 0.001$), highlighting the seasonal patterns previously observed. The correlation between the number of tests and dusty days was weakly positive but not statistically significant ($r = 0.149$, $p = 0.283$). Moreover, the relationship between deficient patients and dusty days was weakly positive and not statistically significant ($r = 0.023$, $p = 0.866$). The correlation between UV-B radiation and the other variables was generally weak and not statistically significant. Additionally, the correlation between dust levels at 3000m or less and dusty days ($r = 0.874$, $p < 0.001$). These findings suggest that dust levels at specific altitudes might have an influence on the occurrence of dusty days.

Table (15): Two Tailed Pearson Correlation between year, month, number of tests and number of dusty days.

	Year	Month	Number of tests	Dusty
Pearson Correlation	1	.965**	.818**	.027
Sig. (2-tailed)		.000	.000	.845
N	54	54	54	54
Pearson Correlation	.965*	1	.798**	-.037
Sig. (2-tailed)	.000		.000	.790
N	54	54	54	54
Pearson Correlation	.818*	.798**	1	.149
Sig. (2-tailed)	.000	.000		.283
N	54	54	54	54
Pearson Correlation	.027	-.037	.149	1
Sig. (2-tailed)	.845	.790	.283	
N	54	54	54	54
Pearson Correlation	-.041	.038	-.151	-.960**
Sig. (2-tailed)	.767	.787	.276	.000
N	54	54	54	54
Pearson Correlation	.855*	.853**	.922**	.023
Sig. (2-tailed)	.000	.000	.000	.866
N	54	54	54	54
Pearson Correlation	-.119	-.099	-.207	.038
Sig. (2-tailed)	.390	.476	.134	.784
N	54	54	54	54
Pearson Correlation	.154	.094	.380**	.534**
Sig. (2-tailed)	.267	.499	.005	.000
N	54	54	54	54
Pearson Correlation	.003	-.072	.139	.874**
Sig. (2-tailed)	.981	.605	.318	.000
N	54	54	54	54

Table 16 shows a strong positive correlation between year and deficient patients ($r = 0.855$, $p < 0.001$), and month and deficient patients ($r = 0.853$, $p < 0.001$), highlighting the increase in deficient patients over the years and the season patterns observed. The number of tests was also positively correlated with deficient patients ($r = 0.922$, $p < 0.001$), indicating that as the number of tests increases, the number of deficient patients also increases. The correlation between non-dusty days and deficient patients was not statistically significant ($r = -0.042$, $p = 0.765$), suggesting that there might not be a direct association between these two factors. The correlation between dust levels at 1000m or less and non-dusty days was moderate and statistically significant ($r = -0.485$, $p < 0.001$), while the correlation between dust levels at 3000m or less and non-dusty days was strongly negative and statistically significant ($r = -0.838$, $p < 0.001$). These findings suggest that dust levels at specific altitudes might have an influence on the occurrence of non-dusty days.

Table (16): Two Tailed Pearson Correlation between number of non-dusty days, deficient patients and UV-B.

	Non dusty	Deficient patients	UV-B
Pearson Correlation	-.041	.855**	-.119
Sig. (2-tailed)	.767	.000	.390
N	54	54	54
Pearson Correlation	.038	.853**	-.099
Sig. (2-tailed)	.787	.000	.476
N	54	54	54
Pearson Correlation	-.151	.922**	-.207
Sig. (2-tailed)	.276	.000	.134
N	54	54	54
Pearson Correlation	-.960**	.023	.038
Sig. (2-tailed)	.000	.866	.784
N	54	54	54
Pearson Correlation	1	-.042	-.014
Sig. (2-tailed)		.765	.922
N	54	54	54
Pearson Correlation	-.042	1	-.159
Sig. (2-tailed)	.765		.252
N	54	54	54
Pearson Correlation	-.014	-.159	1
Sig. (2-tailed)	.922	.252	
N	54	54	54
Pearson Correlation	-.485**	.246	-.135
Sig. (2-tailed)	.000	.072	.332
N	54	54	54
Pearson Correlation	-.838*	.046	.023
Sig. (2-tailed)	.000	.743	.867
N	54	54	54

Table 17 shows there was a strong positive correlation between dust levels at 1000m or less and dust levels at 3000m or less ($r = 0.714$, $p < 0.001$), indicating that when dust levels increase at one altitude, an associated increase occurred at the other altitude. This suggests a relationship between the dust levels at these two specific altitudes. Dusty days are strongly positively correlated with both dust levels at 1000m or less ($r = 0.534$, $p < 0.001$), and 3000m or less ($r = 0.874$, $p < 0.001$), suggesting that an increase in dust levels at these altitudes was associated with an increase in the number of dusty days. As a result, it could be said that dust level increases as we go higher up the altitude. Conversely, non-dusty days show a strong negative correlation with both dust levels at 1000m or less ($r = -0.485$, $p < 0.001$) and 3000m or less ($r = -0.838$, $p < 0.001$), indicating that higher dust levels at these altitudes are associated with fewer non-dusty days. The correlations between dust levels at 1000m or less and deficient patients ($r = 0.246$, $p = 0.072$) and dust levels at 3000m or less and deficient patients ($r = 0.046$, $p = 0.743$) are weak and not statistically significant. Finally, the correlations between UV-B radiation and dust levels at 1000m or less ($r = -0.135$, $p = 0.332$) and 3000m or less ($r = 0.023$, $p = 0.867$) are weak and not statistically significant, indicating that UV-B radiation might not have an influence on dust levels at these altitudes.

Table (17): Two Tailed Pearson Correlation between dust levels in 1000m or less and 3000m or less.

	Dust in 1000m or less	Dust in 3000m or less
Pearson Correlation	.154	.003
Sig. (2-tailed)	.267	.981
N	54	54
Pearson Correlation	.094	-.072
Sig. (2-tailed)	.499	.605
N	54	54
Pearson Correlation	.380**	.139
Sig. (2-tailed)	.005	.318
N	54	54
Pearson Correlation	.534**	.874**
Sig. (2-tailed)	.000	.000
N	54	54
Pearson Correlation	-.485**	-.838**
Sig. (2-tailed)	.000	.000
N	54	54
Pearson Correlation	.246	.046
Sig. (2-tailed)	.072	.743
N	54	54
Pearson Correlation	-.135	.023
Sig. (2-tailed)	.332	.867
N	54	54
Pearson Correlation	1	.714**
Sig. (2-tailed)		.000
N	54	54
Pearson Correlation	.714**	1
Sig. (2-tailed)	.000	
N	54	54

Table 18 shows a medium positive correlation between dust levels at 1000m or less, and dust levels at 5000m or less ($r = 0.534$, $p < 0.001$), and a strong positive correlation between dust levels at 3000m or less and dust levels at 5000m or less ($r = 0.874$, $p < 0.001$). Both of these indicate that when dust levels increase at one altitude, an associated increase occurred at the other altitude. This suggests a relationship between the dust levels at these specific altitudes. Not to mention that the $r = 0.874$ between the dust levels at 3000m or less, and dust levels at 5000m or less increased than the dust levels at 1000m or less, and dust levels at 5000m or less ($r = 0.534$). This justifies even more that there is a relationship between the dust levels and the increased in altitude. The correlations between dust levels at 5000m or less and deficient patients ($r = 0.023$, $p = 0.866$) are very weak and not statistically significant. This suggests that there might not be a direct association between dust level at 5000m or less and the number of deficient patients. Finally, the correlations between UV-B radiation and dust levels at 5000m or less ($r = 0.038$, $p = 0.784$) are weak and not statistically significant, indicating that UV-B radiation might not have an influence on dust levels at this altitude.

Table (18): Two Tailed Pearson Correlation between dust at 5000m or less.

	Dust in 5000m or less
Pearson Correlation	-.381**
Sig. (2-tailed)	.004
N	54
Pearson Correlation	.149
Sig. (2-tailed)	.283
N	54
Pearson Correlation	.023
Sig. (2-tailed)	.866
N	54
Pearson Correlation	.038
Sig. (2-tailed)	.784
N	54
Pearson Correlation	.534**
Sig. (2-tailed)	.000
N	54
Pearson Correlation	.874**
Sig. (2-tailed)	.000
N	54
Pearson Correlation	1
Sig. (2-tailed)	
N	54

Although the correlation between UV-B and the dust levels at 1000m or less, 3000m or less, and 5000m or less were very weak and not statistically significant, Table 19 shows the comparison of Pearson correlation values between each altitude and the UV-B. It can be clearly seen that the Pearson correlation value increased slightly with increase in altitude.

Table (19): Comparison of Pearson Correlation values between UV-B and the dust level at 1000m, 3000m and 5000m or less.

	Dust in 1000m or less	Dust in 3000m or less	Dust in 5000m or less
Pearson correlation	-.135	.023	.038
Sig. (2-tailed)	.332	.867	.784
N	54	54	54

Table 20 shows a medium positive correlation between dust particles of PM2.5 and dust particles of PM10 ($r = 0.534$, $p < 0.001$) indicating that there is a relation between the two sizes of dust particles. A weak correlation was found between the number of vitamin D tests and PM2.5 ($r = 0.380$, $p = 0.005$), and between the number of tests and PM10 ($r = 0.149$, $p = 0.283$), which means that there is no strong relation between the dust particles and the number of tests conducted. Similarly, a weak correlation was also found between the deficient patients and PM2.5 ($r = 0.246$, $p = 0.072$), and between the deficient patients and PM10 ($r = 0.023$, $p = 0.866$). This again indicates that there is almost no relation between the dust particles and the deficient patients. In addition, there is a very weak correlation between the UV-B with PM2.5 and PM10 ($r = -0.135$, $p = 0.332$) and ($r = 0.038$, $p = 0.784$) correspondingly. This suggests that the dust particles might not have an impact on the UV-B.

Table (20): Comparison of Pearson Correlation values between UV-B and the dust particles PM_{2.5} and PM₁₀.

	UV-B	PM_{2.5}	PM₁₀
Pearson Correlation	-.117	.145	.027
Sig. (2-tailed)	.387	.257	.845
N	54	54	54
Pearson Correlation	.124	-.303*	-.381**
Sig. (2-tailed)	.373	.026	.004
N	54	54	54
Pearson Correlation	-.207	.380**	.149
Sig. (2-tailed)	.134	.005	.283
N	54	54	54
Pearson Correlation	-.159	.246	.023
Sig. (2-tailed)	.252	.072	.866
N	54	54	54
Pearson Correlation	1	-.135	.038
Sig. (2-tailed)		.332	.784
N	54	54	54
Pearson Correlation	-.135	1	.534**
Sig. (2-tailed)	.332		<.001
N	54	54	54
Pearson Correlation	.038	.534**	1
Sig. (2-tailed)	.784	<.001	
N	54	54	54

4.2 Discussion of Results

Very limited studies have demonstrated a clear relationship between dusty weather and VDD. However, few studies have revealed that air pollutants are negatively associated with VDD (Hoseinzadeh et al., 2018; Rahman & Elmi, 2021; Song et al., 2021).

A four-year study in Kuwait was performed and obtained data from four different weather stations across the country which concluded that atmospheric levels of pollutants absorb the UV rays thus decreasing the UV-B intensity in the earth's surface, resulting in reduction in vitamin D synthesis in the body. This has resulted to a very high prevalence of VDD in Kuwait (Rahman & Elmi, 2021). In addition, a study was conducted in two different areas, polluted and unpolluted regions. In the areas where the pollutants were very low, no association was found between air pollution and VDD. On the other hand, many people were found to have VDD in the polluted area justifying a link between air pollution and VDD (Song et al., 2021). Intriguingly, no evident correlation between dusty weather and VDD were observed in the present study. The discrepancy between the study findings and the rest of literature that investigates the same relationship might be due to various factors that led to that disagreement (Rahman & Elmi, 2021; Song et al., 2021).

This discrepancy can be justified through multiple reasoning. Firstly, the study design and the employed methods to assess the relationship between dusty weather and VDD vary significantly from study to study. These variations could possibly be associated with subsequent impact on the study results. The study analysis relied principally on the correlation between UV-B, dusty days, and VDD values, while other previous studies have adopted more complex

models and controlled experiments (Al Othman et. al., 2012; Rivas et. al., 2015; Roshan et. al., 2020). A similar study in Qatar involved an experiment in which surface solar monitoring stations were spread all over the country to measure the global horizontal irradiance, UV-A, UV-B and relative humidity. These measurements were taken using a special solar radiation instrument that contains a sun tracker and sun sensor kit to accurately track the sun. In addition, two pyranometers, one for measuring global horizontal irradiance and the other for diffuse horizontal irradiance, and one pyrhelimeter to measure direct normal irradiance. Besides, daily cleaning, maintenance and quality control checks of the collected data and the sensors were also performed (Roshan et. al., 2020). Furthermore, a surface ozone monitoring instrument which was developed by NASA was used to calculate the clear sky surface UV irradiance and to correct that irradiance for aerosols and clouds by using measured backscattered and reflected lights at 331nm and 360nm. These analyses are all performed during local noon time for surface UV-A and UV-B data from the ground surface ozone monitoring instrument and the pyranometers (Roshan et. al., 2020). Moreover, the global horizontal irradiance is simulated using a three-dimensional atmospheric meteorology chemistry model which is configured specifically for Middle East countries with a focus on dust rich environments and hot desert climate. This helped in obtaining accurate results due to the concentration predictions of the atmospheric emissions (gases, dust, and aerosols) and its process of transportation in the surroundings. Evidently, such complex models can better account for confounding variables, which is unknown if the source of the data used for the purpose of this study takes into consideration such intricate measures.

Moreover, weak correlations were also found between the number of tests conducted, deficient patients, UV-B with PM_{2.5} and PM₁₀. Mainly, this discrepancy could be due to the unavailability of most of the dust particle readings which were directly received from the Supreme Council of Environment, causing weak statistical analysis. There are very rare studies regarding the relation between particulate matters and its effect on vitamin D in general, however few studies have proved its effect on serum 25(OH)D status among pregnant women. A study conducted in Shanghai, China, examined the effects of serum 25(OH)D levels among pregnant women after weekly exposure of PM_{2.5}. A direct significant incident of VDD was found. A 10 µg/m³ increase in PM_{2.5} exposure resulted in a 1.346 nmol/L drop in serum 25(OH)D. During the first 10 weeks of the study, a stronger correlation was found between average PM_{2.5} exposure and VDD in weather conditions with lower mean sunlight hours (Yang et al., 2022). In addition, Zhao et al. (2019) also observed the association between PM_{2.5} and PM₁₀, and circulating 25(OH)D concentration during the entire pregnancy period. The study resulted in elevated VDD in the pregnant women due to decreased circulating 25(OH)D levels which was mainly because of the reduction of the amount of solar UV-B radiation reaching the ground level.

Although weak correlations have been found as an output of the statistical analysis done on the dust levels, dust particles, UV-B, and percentage of deficient patients presented in the results, a direct relationship can be observed between the overall values of total number of dusty days and percentage of deficient patients when closely compared. As such, when there was an increase or decrease in the total number of dusty days, there was a corresponding increase or decrease in the percentage of vitamin D deficient patient in each year.

An exception is observed in the year 2021 where a decrease in dusty days showed a 2% increase in the percentage of vitamin D deficient patients. This phenomenon may be explained due to COVID-19 outbreaks and its corresponding lockdown measures in Bahrain which was at its peak in 2021 reaching 20,829 cases for the first time (WHO COVID-19, 2022). The lockdown measures could explain the increase in percentage of deficient patients due to a lack of sun exposure, while a reduction was observed in the total number of dusty days due to improved air quality during the COVID-19 epidemic (Nese, 2020; Wang et al., 2020). It is also important to consider the average time of vitamin D level changes in the human body. Vitamin D level does not instantly change with any environmental factor or oral supplements, rather, it gradually increases or decreases in the body. According to the hospitals and health centres in Bahrain, a vitamin D deficient patient is called for follow-up every 3 – 6 months, depending on the severity of the vitamin D level.

Regardless, discrepancy in the results could be justified by the unavailability of dust readings at higher altitudes. Proceeding with, Table 5 in the results showed an overall high UV index in Bahrain throughout the years 2017 to 2022 which supposedly means that direct vitamin D synthesis from the sunlight should be high in the body, irrelevant of the summer and winter seasons. A study in Africa was conducted to investigate the relationship between UV exposure, skin cancer and its association with altitudes, where it concluded that UV increases with increase in altitude (Rocholl et al., 2021; Wittlich et al., 2022). With every 1000m increase in altitude, the UV rays will also increase by approximately 10%. This is because there will be less atmosphere to absorb the UV radiation with increasing altitude (WHO, 2021). A study in the Alps was conducted where it measures

one of the highest UV levels in Europe. The study included broadband UV radiation measurements on three different heights for more than four years where it showed that as the height increases, the UV radiation also increased. The major causes of the increase in UV radiation with increase in altitude were due to snow-covered surfaces and a decrease in air molecules, aerosols, ozone and clouds in the atmosphere (Barnes et al., 2023). In addition, a study in Iran was also done to compare the UV with the increase in altitude and it resulted in an increase of UV radiation as the altitude increased (Roghayeh Jahdi & Arabi, 2023). On the other hand, specific regions such as the Middle East have dust rich environments where long ranged transportation of dust particles are much more often. UV irradiance is significantly impacted by desert dust intrusions, with variations greater than 30% in clear skies such as from the west coast of North Africa, through the Middle East and into Central Asia. Because of a thinner atmosphere that scatters and absorbs radiation and fewer anthropogenic particles, which are typically restricted to lower altitudes, UV irradiance rises with altitude. However, due to the dust conditions in these areas, most of the UV irradiance gets absorbed and scattered by the dust at higher altitudes before reaching the ground level (Roshan et al., 2020). A recent study over high mountain Asia showed dust being dominant at higher altitudes. The snow at the highest part of the mountain was much darker than the ones at the lower altitudes which also contributed to more snowmelt (Sarangi et al., 2020). According to Glover (2014), the ozone layer absorbs a significant amount of UV-B rays. At around 20-30 km above sea level, the lower stratosphere is where the ozone layer deteriorates the most. As a result, UV-B levels are significantly higher at altitudes more than 20-30 km. In actuality, UV-B levels at the top of the

atmosphere are up to 350 million times higher than they are at the earth's surface. The standard limit is that UV-B levels rise 4% for every 300m increase in altitude below 20–30 km. The main cause of this is a thinner atmosphere since there are less particles to absorb UV-B. At low altitudes, the amount of UV-B that reaches the ground is reduced by the presence of dust, smog and aerosols. Therefore, dust measurements at 20-30 km altitude is the ideal readings required to investigate the relationship between dust particles and UV-B. However, human accessibility at this level of altitude is rare and there has been no study conducted which clearly states the measurements of dust particles at 20-30 km (Glover, 2014). Although the dust readings at the preferred altitudes were not available, Table 18 showed an increase in the Pearson correlation values for the examined altitude levels (1000m, 3000m and 5000m) and UV-B readings, justifying a possible relation with higher altitudes. UV irradiance gets affected by other factors other than air pollution as it reaches ground level from higher altitudes. Ozone layer is considered as an effective absorber of the UV radiation. The atmosphere's ability to operate as a protective filter is gradually diminished as the ozone layer becomes thinner. Consequently, there is an increased exposure to UV radiation in the ground level, particularly UVB, for both the environment and the people. Moreover, there are many surfaces that reflect UV light in the ground level, which raises the overall UV exposure in an individual. Sand and sea foam absorb approximately 15% and 25% of UV light, respectively, but grass, soil, and water only reflect less than 10% of the radiation. Snow can also reflect as much as 80% of UV radiation (WHO, 2016).

Furthermore, external factors could also contribute to the discrepancy in the correlation between UV-B, dust, and VDD. While dust events can reduce UV-B radiation, other factors, such as cloud cover and air pollution can also significantly impact UV-B exposure, and subsequently vitamin D synthesis. Bahrain witnesses a rapid urbanization that is associated with an increased rates of pollution levels from a variety of land-based sources. Mainly the most contributing sectors are the industrial, power generation, and transportation sectors. An air quality analysis for main pollutants in Bahrain during the period 2006–2012 revealed significant increases in particulate matter $PM_{2.5}$ and PM_{10} that exceeded the World Health Organization (WHO) recommended levels (Jassim et al., 2018). Therefore, these factors were not accounted for in the present study, leading to an exacerbate problem.

Dust particles obviously have significant implications on air quality, climate, and aviation safety. In the present study, dust measurements were primarily gathered for aviation purposes, with readings taken at altitudes of 1000m, 3000m, and 5000m. However, recent studies suggest that dust concentrations may increase with altitude, emphasizing the need for more comprehensive dust monitoring at higher altitudes. Studies have shown that dust particles can travel long distances to reach higher altitudes (20 – 30 km) above sea level, affecting atmospheric processes (Glover, 2014; Groot et. al., 2016; Sarangi et. al., 2020; Brunner et. al., 2021). Therefore, the current dust monitoring approach in Bahrain may not adequately capture the true extent and characteristics of dust events. For the mentioned potential implications, it would be beneficial to expand its dust monitoring capabilities to higher than 5000m or provide a simulated atmospheric meteorology chemistry model which is

configured specifically for Middle East countries with a focus on dust rich environments and hot desert climate. This would provide a more accurate representation of dust distribution in the region, enabling better understanding of the associated environmental and health impacts.

To address this, collaborations could be held with international organizations to develop and implement advanced monitoring techniques, such as satellite remote sensing and ground-based lidar systems. These techniques can provide more accurate and comprehensive dust measurements at various altitudes (Tian et. al., 2017). Consequently, a better understanding could be gained of the role of dust in atmospheric processes and to develop more effective strategies to protect public health, the environment, and aviation safety.

In the present study, direct measurements of UV-B radiation were not available. Consequently, the UV-B data was obtained from the UV index, with the assumption that 5% of the UV index represented UV-B radiation. This method of calculating UV-B radiation may introduce uncertainties in the analysis and could potentially contribute to the observed lack of correlation between dust and VDD. It was demonstrated that the UV index is not a direct measure of UV-B radiation but rather an indicator of the potential for skin damage due to UV radiation, which includes both UV-A and UV-B. The proportion of UV-B radiation in the UV index can vary depending on factors such as time of day, latitude, and atmospheric conditions (Gholamnia et. al., 2021). Therefore, using a fixed percentage of 5% to estimate UV-B radiation from the UV index may not accurately reflect the actual levels of UV-B radiation.

Direct measurements of UV-B radiation are typically carried out using broadband radiometers or spectro-radiometers. Broadband radiometers measure the total irradiance within a specific wavelength range, while spectro-radiometers provide higher resolution and can accurately measure irradiance at individual wavelengths, including those within the UV-B range. These instruments can provide more accurate and reliable measurements of UV-B radiation compared to estimations based on the UV index (Huang et. al., 2021). Given the potential implication in the used UV-B data, the lack of correlation between dust and VDD may be partially attributed to uncertainties in the UV-B measurements.

VDD is considered a global public health concern. It is highly associated with several chronic diseases including kidney diseases, bariatric surgeries and obesity, diabetes, and hyperlipidemia. It is essential to investigate the underlying mechanisms and potential impact of these chronic conditions on vitamin D status (Pannu et. al., 2016). According to Table 12, the most common chronic diseases found in the patients of Bahrain are chronic kidney disease (CKD) and bariatric surgeries that lead to VDD. CKD causes dysregulation of mineral metabolism and vitamin D which means there is a lack of proper nutrient intake that are essential for the body. The development of disturbances in mineral metabolism, which a majority of patients encounter as their disease advances and has been linked to bone loss and fractures, cardiovascular disease, immune system suppression, and increased mortality, is an important contributor of morbidity in CKD patients (Christodoulou et al., 2021).

For individuals that are severely obese, bariatric surgery is becoming a more frequently used procedure to help them lose weight permanently. Long-term morbidity following bariatric surgery might

result from vitamin and mineral shortages. According to Benito et al. (2023) and Mayana et al. (2023), people who are morbidly obese are likely vitamin D deficient before surgery due to inadequate sun exposure, the vitamin's reduced bioavailability when stored in fat cells, and hindered hepatic vitamin activation. Furthermore, due to poor compliance, loss of follow-up, reduced food consumption, and malabsorption, bariatric surgery may worsen vitamin D and calcium intake or production in the body leading to metabolic complications.

Diabetes mellitus, particularly type 2 diabetes, is one of the most prevalent chronic diseases in Bahrain and has been linked to VDD (Naser et. al., 2023). It was demonstrated that low levels of vitamin D is associated with an increased risk of developing type 2 diabetes. Moreover, vitamin D supplementation was observed to improve glycemic control in patients with type 2 diabetes. A relationship has been observed between a lack of vitamin D and metabolic syndromes including Type 2 Diabetes Mellitus (T2DM). The active compound $1\alpha,25$ -dihydroxyvitamin D₃ has an impact on insulin sensitivity through different pathways (Maddaloni et. al., 2018).

Hypertension is another common chronic condition in Bahrain that has been associated with VDD. It was elaborated that vitamin D may have a role in regulating blood pressure through its effects on the renin-angiotensin-aldosterone system. Dyslipidemia has also been linked to VDD. Studies have shown that low vitamin D levels are associated with unfavorable lipid profiles, including increased levels of low-density lipoprotein (LDL) cholesterol and decreased levels of high-density lipoprotein (HDL) cholesterol. Vitamin D supplementation has been suggested as a potential therapy for improving lipid profiles in patients with dyslipidemia and hypercholesterolemia. Obesity is another chronic disease that is

prevalent in Bahrain and has been associated with VDD. Vitamin D is a fat-soluble vitamin, and its storage in adipose tissue may lead to decreased bioavailability in obese individuals. Furthermore, obesity-related inflammation may impair the conversion of vitamin D to its active form, further exacerbating the deficiency (Mousa et. al., 2017). On the contrary, it is true that VDD are caused due to various chronic diseases, however, according to the present study, only 1.22% of the total 16,239 patients have VDD due to their chronic diseases. This justifies that chronic diseases have a minor impact on VDD and the environmental factors such as air pollutants and dust contribute more to VDD along with imbalanced diet.

4.3 Study's Conclusion and Recommendations

To conclude, vitamin D is a vital component in the human body which is responsible for strengthening the bones. The two main source of vitamin D are food intake and sunlight. UV-B rays from the sun contribute to the synthesis of vitamin D in the body. However, due to environmental factors such as dust, it can reduce the amount of UV-B rays entering the earth's atmosphere thus affecting the production of vitamin D in the body. Unfortunately, due to the high number of vitamin D deficient patients found recently in Bahrain which are representing an average of 23.5% from total patients, vitamin D oral intake enhancement must be considered for the population of Bahrain.

The study aimed at investigating whether the environmental factors such as dust actually affect the UV-B rays or not, and it resulted in a weak correlation between dust, UV-B rays, and vitamin D synthesis. The method used was Pearson correlation to correlate numeric variables such as UV-B, number of vitamin D tests, deficient patients and dust levels at 1000m or less, 3000m or less, and 5000m or less. In addition, the study also included an investigation on healthy patients and patients with chronic diseases to identify whether a relationship exists between chronic diseases and vitamin D deficiency. Although other studies have supported the hypothesis and concluded a strong relationship between dust and UV-B, the present study stated otherwise and this was due to numerous factors such as 5% estimation of UV-B from the UV index rather than accurate UV-B readings from a device and the dust readings at 5000m level which was inadequate for investigating the correlation between them. Dust readings at 20 to 30 km above sea level were required, however, the required data was not available.

Several main limitations and recommendations for future study purposes are addressed to the readers:

- Dust readings at 1000m, 3000m and 5000m are only available in Bahrain for aviation purposes. Therefore, dust readings should be measured at much higher altitude levels (20-30 km) to investigate whether the dust particles prevent and disturb the UV-B rays.
- UV-B (5%) was calculated from UV index since no direct UV-B reading is measured in Bahrain. Broadband radiometers or spectro-radiometers are recommended to accurately measure the UV-B rays. These instruments can provide more accurate and reliable measurements of UV-B radiation that could be used for research purposes.
- The study analysis completely depended on the Pearson correlation between UV-B, dusty days, and VDD. Other complex models can also be adopted such as controlled experiments for better reliability and comparison between the data.
- Consideration of air pollutants and how it affects the UV radiation.

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Appendices

Appendix 1



Full Vitamin D results
EDITED.xlsx



Statistical Analysis
Data.xlsx

ملخص

هدفت هذه الدراسة الى فحص العلاقة بين الغبار و الاشعة فوق البنفسجية - ب و قياس مدى تأثيرها على مستوى فيتامين (د) في جسم الانسان و ذلك من خلال تحليل اتجاه قياسات الاشعاع الشمسي فوق البنفسجي على مستوى الارض خلال الفترة من 2017-2022. بالاضافة الى ذلك، تم فحص تأثير حدوث الغبار على الاشعة فوق البنفسجية - ب خلال الفترة من 2017 الى 2022. هذه الدراسة عبارة عن دراسة استكشافية من الفترة من يناير 2017 إلى يونيو 2022. تم إجراء بحث كمي لإجراء تحليل إحصائي لفحص الارتباط بين الأشعة فوق البنفسجية - ب ومستويات فيتامين (د) للمرضى وارتباطه بحدوث الغبار. تم الحصول على قياسات الأشعة فوق البنفسجية ودرجة الحرارة والرطوبة من مديرية الأرصاد الجوية. تم إجراء حساب يدوي للأشعة فوق البنفسجية - ب حيث تم اعتبار 5٪ من مؤشر الأشعة فوق البنفسجية. تم الحصول على جزيئات الغبار عند 1000 متر أو أقل، 3000 متر أو أقل و 5000 متر أو أقل من مديرية الأرصاد الجوية ، بينما تم الحصول على سجلات فيتامين (د) للمرضى من 2017 إلى يونيو 2022 من مستشفى الملك حمد الجامعي. تضمنت الدراسة على الاشخاص الغير مصابين بأمراض مزمنة والمرضى المصابين بأمراض مزمنة قد تؤثر على نسبة فيتامين د وذلك لتحديد ما إذا كانت هناك علاقة بين الأمراض المزمنة ونقص فيتامين (د). تم اختيار عينة عشوائية من المرضى (10٪) من إجمالي العدد الكلي 16,239 لتمثيل المرضى المصابين بأمراض مزمنة مرتبطة بنقص فيتامين (د). تم تحليل البيانات باستخدام برنامج SPSS الإصدار (28). كانت الطريقة المستخدمة هي ارتباط بيرسون لربط المتغيرات الرقمية مثل الأشعة فوق البنفسجية - ب وعدد اختبارات فيتامين (د) والمرضى الذين يعانون من نقص ومستويات الغبار عند 1000 متر أو أقل و 3000 متر أو أقل و 5000 متر أو أقل. أثبتت نتائج الدراسة على وجود ارتباط إيجابي قوي بين السنة وعدد الاختبارات لمستوى فيتامين (د) ($r = 0.818, p < 0.001$) ، والسنة والمرضى الذين يعانون من نقص فيتامين (د) ($r = 0.855, p < 0.001$) ، مما أشار إلى أن عدد الاختبارات والمرضى الذين يعانون من نقص فيتامين (د) قد زاد على مر السنين. وقد بينت النتائج كذلك بوجود علاقة ضعيفة وليست ذات دلالة إحصائية بين مستويات الغبار عند 5000 متر أو أقل والمرضى الذين يعانون من نقص فيتامين (د) ($r = 0.023, p = 0.866$) ، مما يعني أنه قد لا يكون هناك ارتباط مباشر بين مستوى الغبار عند 5000 متر أو أقل وعدد المرضى الذين يعانون من نقص فيتامين (د). علاوة على ذلك ، أظهرت مقارنة مستويات الغبار عند 1000 م أو أقل ، و 3000 م أو أقل ، و 5000 م أو أقل للأعوام من 2017 إلى 2022 أنه مع زيادة الارتفاع في نسبة المرضى الذين يعانون من نقص في فيتامين (د)، تزداد مستويات الغبار أيضًا. تم العثور على ارتباط إيجابي متوسط بين مستويات الغبار عند 1000 متر أو أقل ومستويات الغبار عند 5000 متر أو أقل ($r = 0.534, p < 0.001$) ، وعلاقة موجبة قوية بين مستويات الغبار عند 3000 متر أو أقل ومستويات الغبار عند 5000 متر أو أقل ($r = 0.874, p < 0.001$). تشير كلا هاتان النتجتين إلى أنه عندما ازدادت مستويات الغبار على ارتفاع واحد، حدثت زيادة مصاحبة على ارتفاع آخر. يشير هذا إلى وجود علاقة بين مستويات الغبار عند هذه الارتفاعات المحددة. علاوة على ذلك ، ارتبطت الأيام المغيرة ارتباطًا إيجابيًا قويًا بكل من مستويي الغبار عند 1000 متر ($r = 0.534, p < 0.001$) و 3000 متر أو

أقل ($r = 0.874, p < 0.001$). بالإضافة إلى ذلك ، فإن الارتباطات بين الأشعة فوق البنفسجية - ب ومستويات الغبار عند 5000 متر أو أقل ($r = 0.038, p = 0.784$) ضعيفة وليست ذات دلالة إحصائية ، مما يشير إلى أن الأشعة فوق البنفسجية - ب قد لا يكون لها تأثير على مستويات الغبار عند هذا الارتفاع. ولكن على الرغم من أن الارتباط الموجود بينهما كان ضعيفاً جداً وليس ذا دلالة إحصائية ، إلا أنه لا تزال هناك زيادة طفيفة في ارتباط بيرسون مع زيادة الارتفاع في مستوى الغبار عند 1000 متر أو أقل- ($r = 0.135$) والغبار عند 3000 متر أو أقل ($r = 0.023$) والغبار عند 5000 متر أو أقل ($r = 0.038$). أخيراً ، يعاني 1.22% فقط من إجمالي 16،239 شخص من نقص فيتامين (د) بسبب أمراضهم المزمنة مما يبرر أن الأمراض المزمنة لها تأثير طفيف على نقص فيتامين (د). أسفرت هذه الدراسة عن ارتباط ضعيف بين الغبار والأشعة فوق البنفسجية - ب وفيتامين (د) والذي يمكن أن يكون بسبب عدة عوامل مثل تقدير 5% للأشعة فوق البنفسجية - ب من مؤشر الأشعة فوق البنفسجية بدلاً من قراءات دقيقة للأشعة فوق البنفسجية - ب من جهاز وقراءات الغبار على مستوى 5000 م والتي كانت غير كافية لفحص الارتباط بينهما. كانت هناك حاجة إلى ارتفاع كبير في قراءات الغبار حيث لم تكن هذه البيانات موجودة.

جامعة البحرين

كلية العلوم



تأثير حدوث الغبار على توافر الأشعة فوق البنفسجية -

ب في البحرين وارتباطه بنسبة فيتامين د (25

هيدروكسي فيتامين د) في الدم عند السكان

أطروحة مقدمة كجزء من متطلبات الحصول على درجة الماجستير في البيئة و التنمية

المستدامة

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