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Spatial - temporal analysis and potential health effects of air temperature - a case study in Makkah, Saudi Arabia.

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Abstract: High air temperature can adversely affect human health in various ways, including heat exhaustion and heat stroke. This paper analyses the spatial and temporal variability of air temperature within Makkah using data from 8 monitoring stations from 2002 to 2014. It was observed that air temperature varied both in space and time within Makkah and annual average temperature ranged from about 27°C to 32°C, however hourly temperature was much higher and reached as high as 55°C, which is above the comfortable temperature range for most people, especially for elderly, women, children and those with chronic health problems. Spatial analysis showed that northeast region of Makkah experienced lower temperature, probably due to higher altitude. During the Study period, temperature demonstrated positive non-significant trends at most of the monitoring stations, except at Arafat and Abidiah where the trend was negative. Only Leeth monitoring station, representing Waly Al-Ahd area had positive significant trend. The positive trend is expected due to global warming and increasing urbanisation in this region, however the negative trend in Arafat and adjacent areas is most probably due to mass plantations of neem trees. Analysis shows that Hajj is moving towards hotter months (June, July and August) of the year, which might be a challenge for organisers of the Hajj as well as for the Pilgrims. Therefore, there might be a need for better planning during the coming years, including better housing, scheduling, transportation and ensuring the availability of better quality food and drinks.

Key words: Temperature; temporal trends; spatial variability; health effect; Makkah.

Introduction

In recent years, the effect of air temperature on human health have been investigated by numerous scientists in different countries around the globe [1,2, 3, 4]. Human exposure to extremely high temperature may result in physical injuries, disease, reduced productivity, and even death [5]. It is reported that elderly, women, and individuals with chronic health problems, such as those with diabetes or cardiovascular disease are more vulnerable when exposed to high temperature [6,7]. Furthermore, Bobb *et al.,* (2014) and Gronlund *et al.,* (2014) [8,9] have reported that elderly people when exposed to heat waves are at an increased risk of morbidity and mortality. In addition to extremely high temperature, extremely low temperature can also have adverse health impacts. Temperature in the range between 15°C and 30°C are related with low health effects, however this might be different in different geographical regions [7].

The Holy City of Makkah is about 70 km inland from Red Sea situated in a narrow valley at about 277 m above sea level. Makkah is a densely-populated city and according to the general authority for statistics of the Kingdom of Saudi Arabia [10] its population is over 8 million. Makkah is considered the Holiest City in the Muslim World, and therefore million of Muslims visit the city every year to perform Umrah and Hajj (Pilgrimage). Makkah is situated in a hot arid region, where maximum temperature reaches over 50°C during the summer months. Research shows that exposure to such a high temperature can results in serious health consequences, including heat edema (swelling, especially in the ankles), heat rashes (tiny red spots on the skin causing a prickling sensation), heat cramps (sharp pains in the muscles), heat exhaustion (heavy sweating, weakness, dizziness etc.), heat syncope (dizziness and fainting, induced by temporarily insufficient flow of blood to the brain while a person is standing) and heat stroke (body temperature often rises than 41°C, and complete or partial loss of consciousness) [5]. Heat stroke is the most serious effect and requires immediate first aid and medical attention, otherwise the patient may die.

Recently several authors have analysed air quality in Makkah [11-16], however little is done about the spatial - temporal variations of temperature and its health effects. Almazroui *et al.,* (2012) [17] used annual averaged air temperature and reported a warming rate of 0.60 °C/decade across Saudi Arabia during 1978 to 2009. Furthermore, Almazroui *et al.,* (2012) [17] reported that the temperature rise was different from season-to-season and region-to-region

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in Saudi Arabia. Rehman and Al-Hadhrami (2011) [18] reported significant increase in summer time temperatures between 1970 and 2006 in Jeddah. Also, they reported that monthly and annual maximum temperature had increased more than the mean and minimum temperature. This paper intends to focus on analysing the spatial and temporal trends of air temperature and its potential impacts on the health of residents and visitors of the Makkah.

Materials and Methods

In this paper, meteorological data (2002 - 2014) from several monitoring stations were used, including Abidiah, Arafat, Aziziah, Leeths, Nawariah, Al-Sharaia, Takhassosi and Zahret Kudai. All the stations are situated within the Holy City of Makkah, Saudi Arabia (Figure 1). Due to missing data of year 2002 to 2011, Zahret Kudai was not included in temporal trend analysis, however it is included in spatial analysis during 2012 to 2014. A summary of temperature, relative humidity, wind speed, solar radiation and rainfall for the last three years (2012 - 2014) is shown in Table 1 to present an idea of the other meteorological parameters in Makkah. The Meteorological monitoring stations and their locations in Makkah are shown in Figure 1. Time plots of hourly average temperature (°C) from 2002 to 2014 at various monitoring sites are shown in Figure 2.

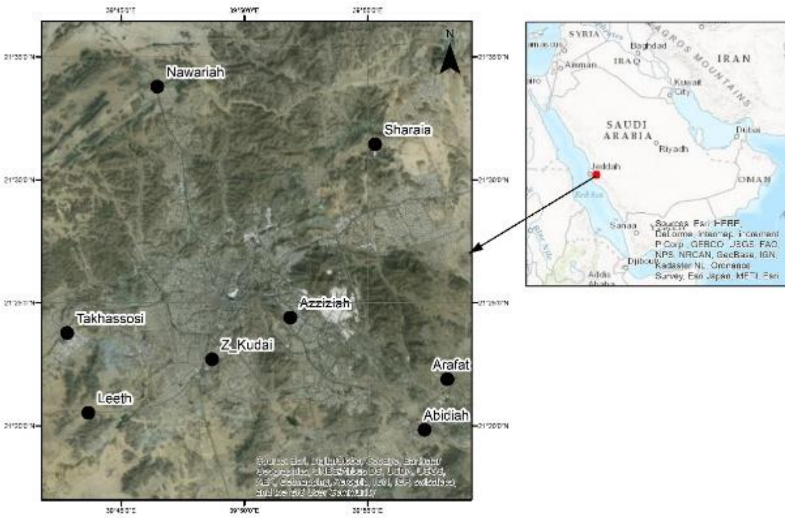


Figure 1: Map of the meteorological monitoring sites in Makkah, Saudi Arabia.

Table 1: Mean meteorological data at several monitoring stations in Makkah from 2012 to 2015.

Year	Station	Temperature (°C)	R. humidity (%)	Wind speed (m/s)	Solar Radiation (W/m²)	Rainfall (mm)
2012	Sharaia	29.19	42.44	2.34	169.99	34.04
	Leeth	30.86	45.19	2.82	224.93	118.36
	Azziziah	31.37	43.44	1.44	217.48	78.22
	Abidiah	30.96	33.09	2.33	238.47	55.88
	Takhassosi	32.24	32.06	2.27	240.38	68.07
	Nawariah	31.03	36.32	2.03	220.47	25.91
	Arafat	27.70	40.90	1.24	230.42	---
	Z_Kudai	31.69	35.69	1.52	248.08	119.63
2013	Sharaia	30.14	37.22	2.41	247.19	---
	Leeth	31.29	39.19	2.39	222.88	43.95
	Azziziah	31.32	47.03	1.43	215.96	55.88
	Abidiah	30.32	36.50	2.27	240.16	31.75
	Takhassosi	31.54	39.75	2.41	233.55	55.37
	Nawariah	30.57	38.18	1.94	222.66	17.27
	Arafat	30.91	39.61	0.95	228.45	---
	Z_Kudai	31.58	38.24	1.52	250.06	41.91
2014	Sharaia	30.28	36.04	2.4	245.63	73.142
	Leeth	31.85	36.8	2.85	220.06	94.74
	Azziziah	31.91	36.35	1.49	246.58	91.69
	Abidiah	30.89	39.13	2.2	238.11	141.974
	Takhassosi	31.75	37.88	2.4	231.8	138.18
	Nawariah	31.92	35.18	1.82	232.63	71.882
	Arafat	31.00	41.12	0.67	213.32	---
	Z_Kudai	31.72	36.8	1.51	246.84	84.576
2015	Sharaia	30.41	35.84	2.44	236.04	78.75
	Leeth	31.54	35.79	2.87	189.60	48.51
	Azziziah	31.67	37.86	1.44	225.24	79.50
	Abidiah	31.48	34.53	2.24	230.42	109.48
	Takhassosi	31.79	37.989	3.04	235.14	103.12
	Nawariah	30.75	36.47	1.91	215.77	41.91
	Arafat	31.31	39.19	0.68	213.19	82.82
	Z_Kudai	31.91	37.58	1.54	242.99	92.21
Mean		31.09	38.11	1.96	228.58	74.24

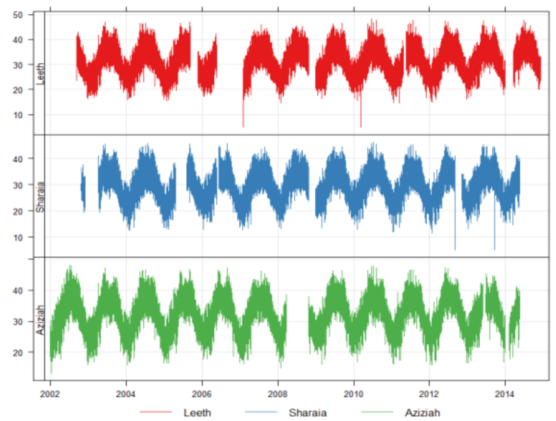


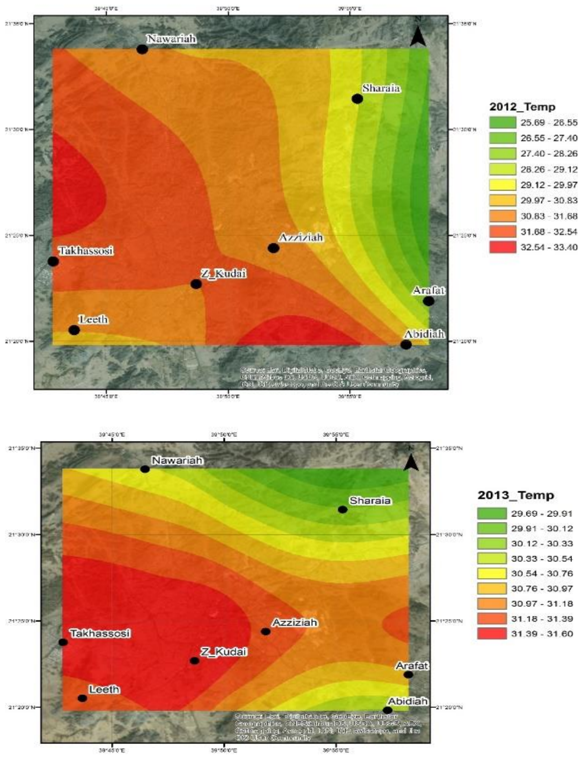
Figure 2: Time plots of average hourly temperature (°C) during 2002 to 2014 at Leeth, Sharaia and Aziziah monitoring stations in Makkah.

Statistical analysis was performed in R programming language version 3.2.2 [19], applying time variation plots, time plots and TheilSen function of 'openair' [20]. Spatial analysis was perform in ArcGIS version 10.3.1. To study the long-term temperature trend during the last 12 years (2002 - 2014), this study employed TheilSen function [20]. TheilSen approach is based on median and is robust (non-sensitive) to outliers and to non-normal probability distribution. Trends in temperature are determine not only for mean temperature but also for median and several percentiles like 5th percentile, 25th percentile, 75th percentile and 95 percentiles.

Results and Discussion

Spatial analysis

Air temperature was monitored at several locations in Makkah. The four-year average (2012 - 2015) temperature was about 31°C in Makkah. Highest hourly average temperature was recorded at Takhassosi (55°C) and lowest at Sharaia (46°C). Temperature demonstrated both spatial and temporal variability in Makkah. Contour maps for each year 2012 to 2015 are shown in Figure 3, whereas the average (2012 - 2015) contour map is shown in Figure 4. There is slightly different spatial trend during different years, however generally the northeast side has observed lower temperature as compare to other areas. Sharaia (the monitoring sites situated in the northeast corner of Makkah) observed lowest annual average temperature in each year, except in 2012. In 2012 Sharaia experienced the second lowest temperature (about 29°C), whereas Arafat experienced the lowest temperature (about 28°C). Sharaia is situated about 13 km from the centre of Makkah City. The low temperature in this area could be due to the fact that Sharaia has the highest above sea level altitude (about 480 m) as compared to the other monitoring sites, where altitude above sea level ranges from 150 to 300 m. Furthermore, temperature in Sharaia is probably getting affected by the low temperature areas in the east, such as Al-Hadda and Taif, where altitude is about 1600 - 1800 m and experiences hourly temperature of about 15°C (in January) to about 28°C in (June), having an annual average of about 20°C. In contrast, the southern parts of Makkah, which include Takhassosi experienced the highest temperature (Figures 3 and 4) probably due to low above sea level altitude (< 200 m) and high rate of urbanisation in this area. Historical view on Google Earth shows that in 2002 there was hardly any house in Takhassosi and since then it has experienced rapid constructions activities and so this is probably one of the reasons why this area has shown higher temperature. It is reported by several authors [21] that the process of urbanization changes both surface and atmospheric characteristics at local-to-regional level largely due to fact that natural vegetation is removed and replaced by non-evaporating and non-transpiring surfaces such as highly reflective parking lots, concrete masses and asphalt roads. These materials can affect the thermal environment in cities. Large urban areas are normally warmer than surrounding rural areas. This temperature difference between rural and urban areas is generally referred to as 'urban heat island'. Furthermore, various land cover types such as natural vegetations, barren land, densely populated areas and water bodies can significantly contribute to changes in air temperature. Due to high temperature, low rainfall and lack of fertile land Makkah lacks natural vegetations, however with modern agricultural technology, including artificial irrigation systems, and heat and drought tolerant cultivars it is possible to grow various trees for landscaping in Makkah, which can play a role in moderating air temperature in Makkah.



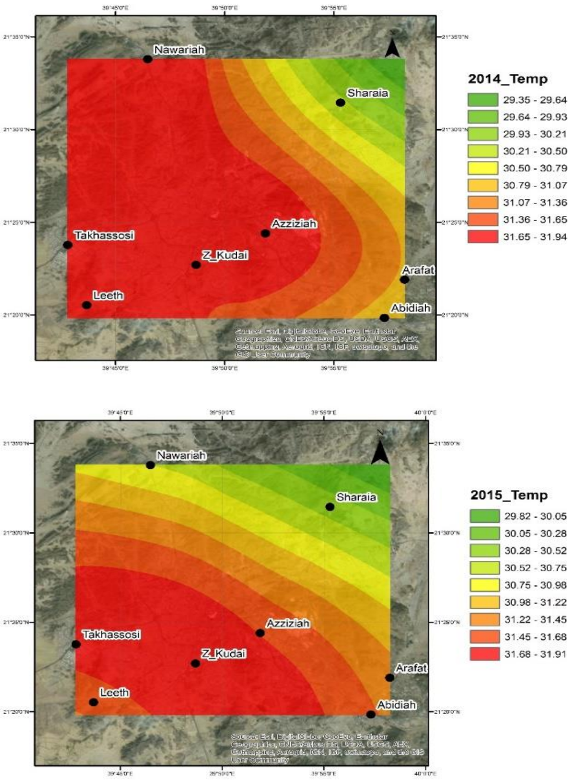


Figure 3: Spatial variability of mean annual temperature for year 2012 to 2015 in Makkah.

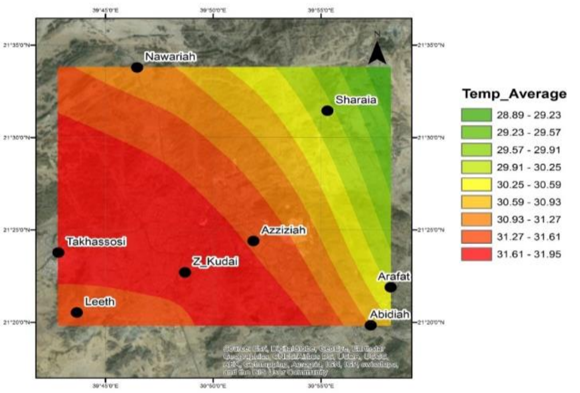


Figure 4: Spatial variability of mean annual temperature average of the 4 years (2012 – 2015) in Makkah.

Time Variations in temperature

How temperature changes during every hour of the day, day of the week and month of the year can affect human health. Information about the time variations of temperature has considerable implications for impact studies, especially for a semi-arid and arid region, such as Saudi Arabia [17]. Therefore, here a brief analysis of temporal variations in temperature level is provided in Makkah. Figure 5 shows temperature variations of temperature in Makkah at three monitoring stations (Aziziah, Leeth and Sharaia), where data were available for the study period (2002 to 2014). Again, it can be observed that of the three monitoring sites, Sharaia experienced lowest averaged temperature during all hours, days and months of the study period. All three stations demonstrated the same pattern of variations. As expected, highest temperature was recorded in the afternoon (12:00 to 18:00 hours), reaching the peak level at about 15:00 hour and lowest early in the morning (about 06:00 hour). During different days of the week, there is not much change in temperature, but this is expected because temperature is dependent more on time of the day or season of the year rather than day of the week. Looking at the annual cycle, air temperature increases gradually from January to May, then stays at the highest level from May to September, and then gradually decreases. The highest temperature was recorded in June - July and lowest in December - January.

In June, all three sites had monthly average temperature 30 or over 30°C, whereas in January the monthly average temperature was less than 25°C. So, the difference was about 5°C. However, when hourly-averaged maximum temperature was considered, in the month of June maximum temperature was about 48°C (all three sites averaged), whereas in the month of January it was 34°C. Over all difference between the hot and cold month as 14°C and ratio was 1.4. Mean (average of all three sites) hourly temperature in the month of June was 36°C and in January 24°C, therefore had a difference of 12°C and ratio 1.5. Minimum (average of all three sites) hourly temperature in the month of June was 25°C and in January 13°C, therefore had a difference of 12°C and ratio 1.9. Rehman (2010) [22] investigated temperature variations in Dhahran, Saudi Arabia over a period of 37 years spanning from 1970 to 2006 and reported that monthly maximum of 41°C and minimum of 22.1°C of the daily average temperatures were observed in July and January, respectively and the ratio between the hottest and the coldest temperature was 1.855. This shows how temperature range and ratio change from one area to another within Saudi Arabia. How the temperature variations can affect the health of Makkah residents and visitors is discussed later in the paper (section 3.4).

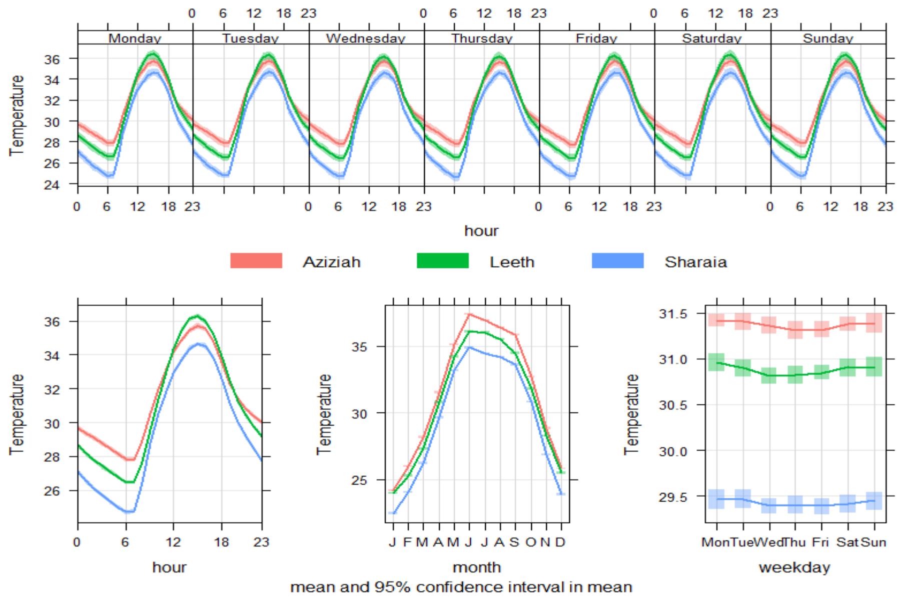


Figure 5: Time variations of temperature at three (Aziziah, Leeth, Sharia) monitoring stations averaged during 2002 to 2014 in Makkah.

Historical temperature trend

Determining long-term temperature variability is of significance importance from the point view of its impact on human health and for predicting how the climate has been changed during a certain period. Long term variations in temperature can influence agriculture, energy use, transportation systems and more importantly human health [18]. In this section temperature data from 2002 to 2014 are used to analyse how temperature has increased / decreased during the study period. Mean temperature trends (°C/year) at three monitoring stations in Makkah are shown in Figure 6. Results for all the 7 sites are presented in Table 2, where in addition to mean trend, the trends of 5th percentile, 25th percentile, 50th percentile (median), 75th percentile and 95th percentile are also presented. The p.stars in the table relate as to how statistically significant the trend estimates are: $p < 0.001 = ***$, $p < 0.01 = **$, $p < 0.05 = *$ and $p < 0.1 = +$, ns = non-significant. It is clear from Figure 6 and Table 2 that all sites have demonstrated non-significant trends, except Leeth. Temperature showed positive significant trends at mean, median and various percentile at Leeth monitoring site, except 95th percentile. Most of the other sites have also shown non-significant positive trends, such as Nawariah and Takhassosi. It is interesting to see that Abidiah and Arafat have demonstrated negative trends (non-significant) at all metrics. This analysis shows that overall temperature has not changed significantly during the study period in Makkah. Furthermore, the trends vary from site to site, most probably due to micro - local characteristics and land use within Makkah. Arafat area is one of those holy areas that has been reserved only for the Hajj season. Pilgrims spend only one day here known as the day of Arafah on the 9th of Zulhijjah (the 12th month of Islamic Calendar) and during the rest of the year no one lives or works here. During the study period greenery of the area has increased significantly. The Arafat plantation project was started in 1986. Initially several neem trees were planted, however since then the number of neem trees has increased significantly and have covered the whole Arafat area. The trees are used for their shade on the day of Arafah, when temperature in summer gets as high as 50°C. The plantation project has probably played a vital role in the temperature negative trends in this area and the surrounding areas of Abidiah.

Positive temperature trends in urban areas is one of the major problems in large urban areas. However, in Saudi Arabia the increasing temperature could be more serious as maximum hourly temperature already gets as high as 50°C. Alghannam and Al-Qahtnai (2012) [23] have reported that heat waves emanating from concrete roads and tall buildings keep urban areas hotter long after the sun has set as compared to rural areas which cool down rapidly. Urbanization tends to channel the net solar gains into sensible heat by increasing the air temperature, whereas the presence of trees and other vegetations in rural areas tends to channel it to latent heat by evapo-transpiration, which is a desirable cooling effect and keep temperature moderate. Vegetation is considered to be one of the simplest and most effective ways to moderate climate and save energy used by running air conditions and fans. Alghannam and Al-Qahtnai (2012) [23] reported that the mean maximum hourly urban heat island for Al-Hofuf and Al-Qurain was a difference of 4°C between the highest urban and rural temperatures. Whereas a peak difference in minimum and mean temperatures was 9.8°C and 6.6°C, respectively which was believed to be mainly due to the presence of vegetations in rural areas. Therefore, tree plantation needs to be seriously considered in desert environments, such as Makkah Saudi Arabia to nullify the positive temperature trends due to local urbanization and regional and global warming due to climate change.

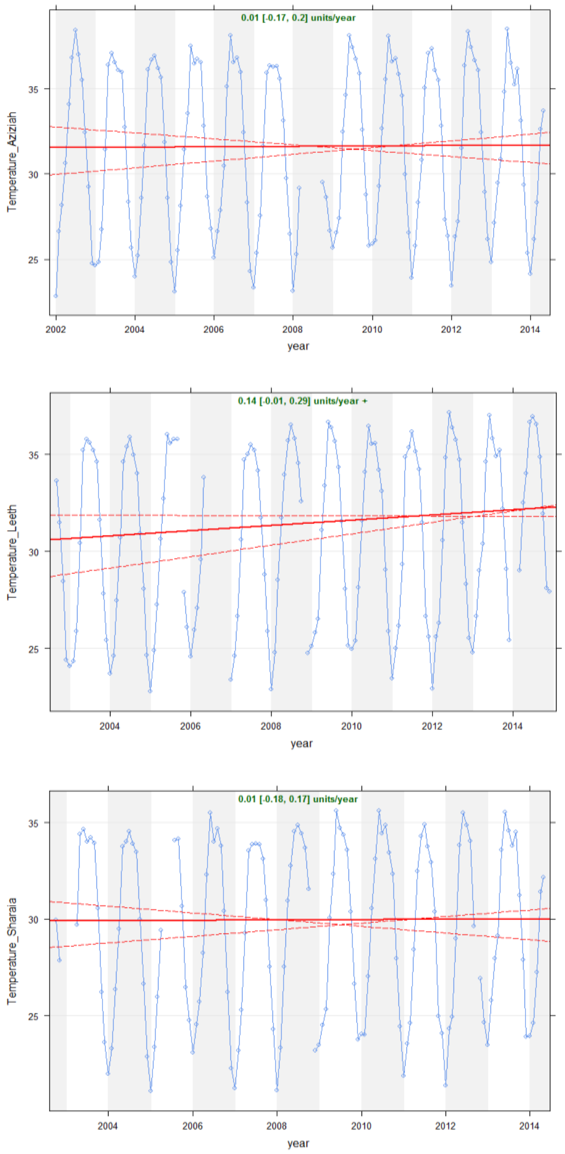


Figure 6: Mean trend (°C/year) in temperature from 2002 to 2014 at Aziziah, Leeth and Sharaia in Makkah.

Table 2: Temporal trends (°C/year) in temperature at various percentiles from 2002 to 2014 in Makkah.

Site	Metrics	Lower	Upper	Slope	p.stars
Aziziah	Mean	-0.258	0.136	-0.057	ns
	5th %ile	-0.135	0.260	0.055	ns
	25th %ile	-0.109	0.235	0.060	ns
	50th %ile	-0.146	0.192	0.023	ns
	75th %ile	-0.203	0.164	-0.019	ns
	95th %ile	-0.258	0.136	-0.057	ns
Leeth	Mean	-0.007	0.294	0.135	+
	5th %ile	0.000	0.343	0.160	+
	25th %ile	0.011	0.320	0.150	*
	50th %ile	-0.009	0.312	0.138	+
	75th %ile	-0.037	0.308	0.133	+
	95th %ile	-0.059	0.296	0.104	ns
Sharaia	Mean	-0.176	0.173	0.010	ns
	5th %ile	-0.183	0.202	0.011	ns
	25th %ile	-0.144	0.191	0.037	ns
	50th %ile	-0.184	0.211	0.026	ns
	75th %ile	-0.196	0.195	-0.007	ns
	95th %ile	-0.059	0.296	0.104	ns
Abidiah	Mean	-0.618	0.056	-0.224	ns
	5th %ile	-0.530	0.113	-0.159	ns
	25th %ile	-0.532	0.069	-0.185	ns
	50th %ile	-0.580	0.050	-0.224	ns
	75th %ile	-0.622	0.057	-0.214	ns
	95th %ile	-0.605	0.055	-0.220	ns
Nawariah	Mean	-0.217	0.431	0.076	ns
	5th %ile	-0.210	0.478	0.129	ns
	25th %ile	-0.156	0.432	0.101	ns
	50th %ile	-0.217	0.429	0.086	ns
	75th %ile	-0.270	0.427	0.063	ns
	95th %ile	-0.289	0.357	0.051	ns
Arafat	Mean	-0.308	0.120	-0.075	ns
	5th %ile	-0.286	0.155	-0.084	ns
	25th %ile	-0.265	0.120	-0.062	ns
	50th %ile	-0.315	0.143	-0.076	ns
	75th %ile	-0.337	0.140	-0.084	ns
	95th %ile	-0.351	0.145	-0.076	ns
Takhassosi	Mean	-0.145	0.365	0.102	ns
	5th %ile	-0.124	0.402	0.126	ns
	25th %ile	-0.133	0.369	0.112	ns
	50th %ile	-0.160	0.376	0.100	ns
	75th %ile	-0.155	0.381	0.100	ns
	95th %ile	-0.166	0.378	0.076	ns

Note: p.stars relate to how statistically significant the trend estimate is: $p < 0.001$ = * * *, $p < 0.01$ = **, $p < 0.05$ = * and $p < 0.1$ = +, ns = non-significant.

Potential health impacts

Extremely high temperature can affect human health in various ways. People reaction and sensitivity to air temperature differ from person to person depending on their individual health and local geographical and atmospheric characteristics. However, according to the National Institute for Occupational Safety and Health [5] most people feel comfortable at a temperature range 20°C - 27°C and relative humidity 35 % to 60 %. At air temperature and relative humidity higher than this range, people start feeling uncomfortable. At a very high temperature the body cannot adjust its internal temperature and the body temperature begins to rise, resulting in heat related illness. Air temperature above 30°C may interfere with the performance of mental tasks [5].

Overall, in Makkah air temperature has not increased significantly during the last decade according to Table 2 and Figure 6. However, there are 2 important factors which need to be considered to avoid any adverse health effects caused by high air temperature in Makkah. Firstly, annual average temperature in Makkah is greater than 30°C during most of the year, especially during summer. In summer air temperature reaches as high as 56°C [24], therefore residents and especially visitors to Makkah need great care to avoid exposure to such a high temperature. Figure 5 shows that temperature is particularly high during the months of May to September and during 12:00 hour to 18:00 hour, therefore special care should be taken during these months and hours of the day. Secondly, the Hajj event (Pilgrimage) - an annual religious event, which takes place in Makkah every year in the last month of the Islamic (Hijri) Calendar, is moving to the hotter months. During Hajj several million pilgrims gather in Makkah. The pilgrims stay in the open area and tents of Arafat for a day and in Mina for several days. This is the most crucial period, especially for the coming years as Hajj is moving to the hotter months, such as June, July and August (Table 3). The air temperature in these months in Makkah is above the comfortable range of all people and can be detrimental to their health, especially for those not acclimatised to Makkah climate and coming from colder climates, such as Europe. In Table 3, the time table for performing Hajj in the coming several years is presented, which shows that Hajj event will be performed during the hottest months of the year during the coming years, therefore there is a need for proper planning, efficient management and extra care for the Hajj authorities and Pilgrims to avoid any unpleasant happening.

Table 3: Showing how the Day of Arafah (9th of Zulhijjah) is moving towards hotter months in coming 10 years.

Greg. Year	Dec	Nov	Oct	Sept	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Hijri Year
2015				23 (9th Zulhijjah)									1436
2016				10(9th Zulhijjah)									1437
2017					31(9th Zulhijjah)								1438
2018					20(9th Zulhijjah)								1439
2019					10(9th Zulhijjah)								1440
2020						30(9th Zulhijjah)							1441
2021						19(9th Zulhijjah)							1442
2022						8(9th Zulhijjah)							1443
2023							27(9th Zulhijjah)						1444
2024							15(9th Zulhijjah)						1445
2025							5(9th Zulhijjah)						1446

Conclusions

In this study, spatial - temporal trends of air temperature is analysed using data from 8 meteorological monitoring stations during the last 12 years (2002 - 2014) in Makkah, Saudi Arabia. Diurnal cycle of air temperature shows that temperature is highest from 12:00 to 18:00 hour, and the annual cycle shows highest temperature during May to September. Spatially the northeast region of Makkah experienced lower temperature, probably due to relatively high altitude. During the study period, Leeth has shown positive significant temporal trends, whereas Arafat and adjacent areas have shown negative (non-significant) trend, most probably due to mass plantations in this area. Due to difference in Islamic and Gregorian calendars, the Hajj event is moving towards the hotter months, which might have serious health consequences for visitors and even for residents. Therefore, to avoid potential negative impacts of high temperature during the Hajj, there is a need for better planning and extra care for both hajj authority and individuals performing Hajj.

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