

Temperature, Precipitation and Relative Humidity Fluctuation of Makkah Al Mukarramah, Kingdom of Saudi Arabia (1985-2016)

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ABSTRACT

The study presents the temperature, rainfall and relative humidity fluctuation of Makkah Al Mukarramah, Saudi Arabia for a time period of 1985-2016 in terms of general climatology, climate change, seasonal pattern and extreme weather condition. This is a city in the Tihamah plain of western Saudi Arabia, the capital of Makkah Province, birth place of Prophet Muhammad (PBUH) and holistic place in Islam. The factors that control the climate are surface water, coastal management, overgrazing, forestry, livestock, drought, desertification, industrialization, landuse change, tourism, altitude, location and marine influence etc. The mean monthly temperature of the city is 32°C having mean maximum of 38°C and mean minimum of 25 degree Celsius. The mean monthly temperature of the city shows an increase of one degree Celsius having -0.1°C decrease in maximum and -1.1°C in minimum temperature. Generally, there is a rise and fall in the temperature condition and shows periodic pattern after each ten years throughout the period. The total precipitation of the city is 189 millimeters (7.4inches); having an increase of 36millimeters (1.4inches) and shows an increasing trend. The relative humidity of the area is 46percent with an increase of 0.7percent. January and February are the wettest, while June and July are the hottest months of the city. The area shows an arid continental climate having two main seasons that is winter (5 months) and summer (7 months), which can further be sub-divided into four rainy seasons namely winter, post-winter, summer, and post-summer seasons. Annually, the temperature condition of the area rises from January to June, remains stable till September and slackens upto December. The heaviest rainfall of Makkah Al Mukarramah recorded in January, February and September and constitutes as wettest months of the year. The lowest rainfall of the city seems in June and July (driest months). To overcome the issue of climate change at Makkah Al Mukarramah, it is recommended to control wars, air pollution, improve forests, and to establish well canal system in the area.

Keywords: Climatology, Climate Change, Seasonal Change, Hajj and Ummrah, Summer Season, Winter Season

1 Introduction

The current study explains the general climatology, climate change and variation of different weather elements comprises of temperature, precipitation, and relative humidity of Makkah Al Mukarramah, Saudi Arabia. As climate change particularly the global warming, cooling and its impacts on the environmental

condition have attracted a great deal of interest to their theoretical and applied value. However, recently the change in weather elements in Saudi Arabia particularly at Makkah Al Mukarramah shows sweeping shifts as compared to the historical observations.

The climate of Makka Al Mukarramah province is marked by desert climate at the east and maritime climate at the west having hot long summers and moderate short winters. The distribution of weather elements in Makkah Al Mukarramah generally is due to the altitudinal and latitudinal zones of horizontal atmospheric convergence and divergence, the maritime or continental origin of prevailing air masses and the seasonal shifting of the zonal pressure and wind system. The local convectional system, which results from diurnal surface heating, also causes variation in the annual distribution of the weather elements.

The issues and changes of climate and weather is not a new phenomenon at Makkah Al Mukarramah but a number of workers discussed it in the past and recently. In which the utmost are summarized as; Alghafari and Khan (2016) has discussed the temperature and precipitation of Madinah Al Munawarah, Kingdom of Saudi Arabia for a time period of 1959 to 2011. Abdou (2014) has analyzed the temperature trends on Makkah Al Mukarramah, Saudi Arabia. Alharbi (2015) has described his views about the native settlements in Makkah Al Mukarramah area and factors affecting its distribution. Alrowaily *etal* (2016) have described the impact analysis of flooding area in Saudi Arabia. Determann (2012) has submitted a thesis on globalization, the state, and narrative plurality; Historiography in Saudi Arabia. Hussein, Bassam, and Zaidi (2014) have presented a book on extreme natural hazards, disaster risks and societal implications, a natural hazard in Saudi Arabia.

Makkah Al Mukarramah is one of the holiest places of Islam, situated at the eastern bank of Red sea in Kingdom of Saudi Arabia. It is the capital of Makkah Province and a birth place of Prophet Muhammad (Peace Be upon Him), the last prophet of God, the almighty. The city is located 70 kilometers (43 miles) inland from Jeddah in a narrow valley at an altitude of 277 meters (909 ft) above mean sea level. Its resident population is roughly two million, (2012), although visitors more than triple this number every year during Hajj period held in the twelfth Muslim lunar month of Zul Hijjah. The Makkah Al Mukarramah province located from 18⁰-14` to 23⁰-23` North latitudes and 21⁰-14` to 22⁰-23` East longitudes. The Holy city of Makkah Al Mukarramah situated at 39⁰-25` East longitude and 21⁰-24` North latitude. The Major settlements that cover the entire Makkah Al Mukarramah province comprises of Rabigh, Tuwwal, Jiddah, Taif, Zalim, and Kiyat (Figure-1).

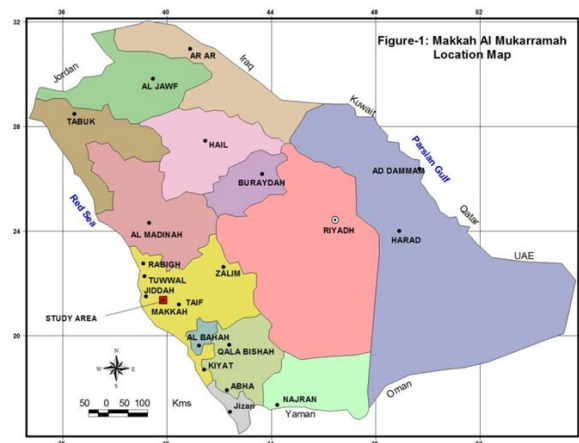


Figure 1

Historically, Makkah has also been known as Bakkah. In ancient times, Makkah was chiefly notable as a staging post on the trade route linking the spice producers of the east with Mesopotamia and the Mediterranean. Makkah lay about midway between Marib, one of the main cities, perhaps the capital, of the kingdom of Sheba (Yemen) and Petra (in Jordan), a city founded by Nabatean Arabs around the 6th century CE and which became a thriving center with commercial interests spreading into Syria. The religious significance of Makkah was established long before Islamic times. It was in Makkah that Allah commanded Ibrahim to leave Haajar and his young son Ishmael; it was in Makkah that Allah brought forth water from the Well of Zamzam which saved the life of Ismael and his mother and then allowed Makkah to develop as a habitable place. It was in Makkah that Allah instructed Ibrahim to build "the House of God" (the Holy Kaaba). As a result, from earliest times, Makkah became a place of pilgrimage and, although as centuries passed the pure faith of the Prophet Ibrahim became corrupted by idolatry and paganism, Makkah retained its hold on the minds of men as a place where men should worship. When Makkah came under the control of the Quraysh tribe, it was a noted trading center, a place for pilgrimage and the site of festivals chiefly remarkable for intensely fought poetry competitions and the excessive behavior of the idolaters.

2 Methodology

The work discusses the weather condition and climate change of Makkah-Al-Mukarramah taking into account the mean monthly and mean annual temperature, precipitation, relative humidity, and extreme events from 1985 to 2016 (31 years). The weather data obtained from the Meteorological Department, Makkah-Al-Mukarramah, Saudi Arabia. The monthly and annual averages and deviation from the mean have calculated for each weather element and tabulated for the analysis. The monthly and annual data have been further processed into seasonal means and deviation that led to the fluctuation of hot/dry or moderate/wet period.

For seasonal variation, the year has been divided into two main seasons that is summer and winter, so that months of the year having positive deviation from the mean considered as summer months and otherwise winter (Figure-2). Based on total annual precipitation, these two main seasons are further subdivided into four sub-rainy seasons that is winter season (November to February), post winter season (March to April), summer season (May to July), and post summer season (August to October). For all variables, the data has been subjected to various statistical techniques like deviation from the mean, averages; sum, time series etc. and the results are shown on tables, charts, and graphs.

3 Findings and Discussions

As Makkah Al Mukarramah is the Holy place of the Muslims Ummah and majority of them are travelling in this city to perform the Holly Huj and Ummrah every year. It is therefore, the work is of a prime importance for the guidance of Muslim Ummah so, they are able to know about the climate of the Makkah Al Mukarrama, Kingdom of Saudi Arabia.

3.1.1 Climatology of Makkah-Al-Mukarramah:

The temperature, rainfall and relative humidity are generally, the utmost weather elements that represent climate of a particular area. No narrative of the weather and climate can be inclusive devoid of a notation of the prevailing temperature, rainfall and relative humidity inclination more than ever of its

distribution in place and time. The temperature, rainfall and relative humidity stipulation of a location endow with a working condition for all physical, physiological and ecological phenomenons. Resultantly, majority of the bio-climate indices are based on temperature, rainfall and relative humidity.

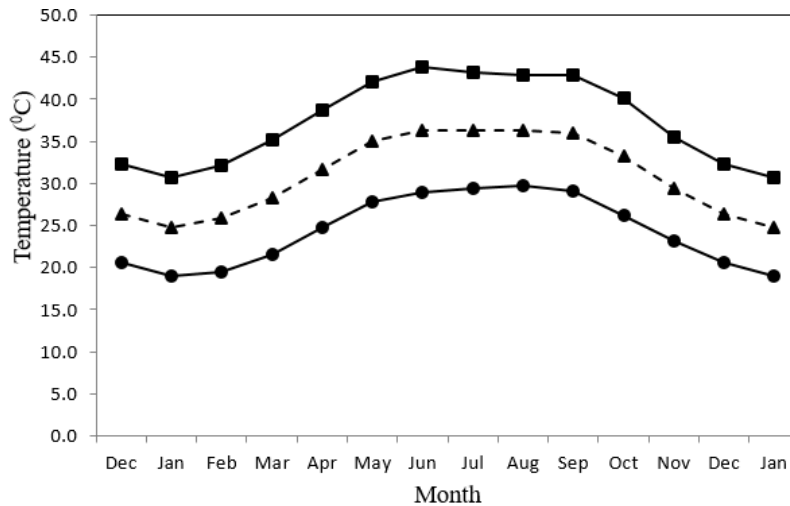


Figure-2: Makkah Al Mukarramah Mean Monthly, Mean Monthly Maximum and Minimum Temperature (1985-2016)

3.1.2 Temperature Distribution

The temperature of Makkah-Al-Mukarramah is fairly representative of the plain strip of land at the eastern coast of Red Sea with continental plain at the observatory and marine climates at Jeddah having hot long summers and warm short winters (Figure-2). The mean monthly temperature of Makkah-Al-Mukarramah is 31.6°C having maximum temperature of about 38.3°C and minimum of 25 degree Celsius. The area has moderate temperature in winters, when the mean monthly temperature drops to 26.9°C (December to March) and hot in summers, when it rises up to or above 35 degree Celsius (April to October). The highest mean monthly temperature of the area is above 36°C from June to September with a maximum of 43°C in July and minimum of 29°C in July to September, respectively and being hottest months of the Observatory. The lowest mean monthly temperature of 24.8°C with 30.7°C maximum and 19°C minimum temperature recorded in January and constitutes as a coldest month of the area (Table-1). However, the temperature condition at Makkah-Al-Mukarramah is more severe as compared to Madinah Al Munawarah.

The annual cycle of temperature reveals that the temperature condition of the area rises up from January to June and slackens till December (Figure-3). This variation in the annual temperature of the area is a result of revolution of the earth, angle of the sunrays, precipitation and topography of Makkah-Al-Mukarramah. The deviation of mean monthly maximum and minimum temperature reveals that it is below the mean condition from November to March and placed in winter months, whereas it is above the average line from April to October and considered as summer months of the area. This shows that there are two main seasons in the area that is summer, which lasts from April to October (7 months), and winter that lasts from November to March (5 months) and fall in continental climates. The extreme average maximum temperature of the city is 45.42°C recorded in June 2009 and 2012 as well as in July 2002 thrice times with a lowest maximum of 27.2°C recorded in 1992 during the period of 1985-2016 and being the hottest and warmest years of the area. The lowest mean monthly temperature is 21.8°C (1992) with mean

monthly highest temperature of 38.2°C (1990 and 2012) and mean monthly minimum of 16°C recorded in 1992 and highest mean monthly minimum temperature of 31.5°C in July 2012, and August 2015 respectively and being coldest and hottest years of the series (Table-2).

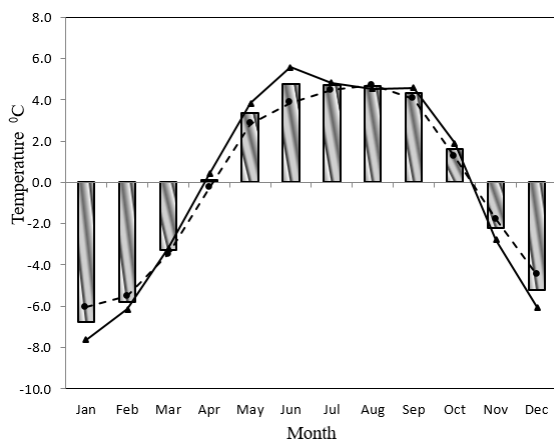


Figure-3: Makka Al Mukarramah Deviation of Mean Monthly, Maximum, Minimum Temperature (1985-2015)

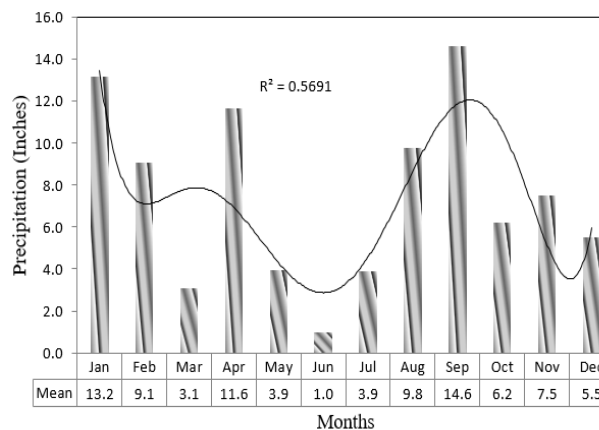


Figure-4: Makkah-Al-Mukkaramah Mean Monthly Precipitation (1981-2015)

Table-1: Makkah Al Mukarramah Temperature, Rainfall, Relative Humidity and Wind Speed (1985-2016)

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean_T	24.8	25.8	28.3	31.7	35.0	36.4	36.3	36.3	36.0	33.2	29.4	26.4
Maxi_T	30.7	32.1	35.1	38.7	42.1	43.9	43.1	42.8	42.9	40.2	35.5	32.3
Mini_T	19.0	19.5	21.5	24.7	27.8	28.9	29.5	29.7	29.0	26.2	23.2	20.5
Rainfall	13.2	9.1	3.1	11.6	3.9	1.0	3.9	9.8	14.6	6.2	7.5	5.5
R_Humidity	57.9	54.3	48.0	42.7	36.4	32.4	33.7	39.4	44.8	49.9	57.3	59.0

Source: Meteorological Department, Kingdom of Saudi Arabia

3.1.3 Rainfall Distribution

Succeeding to temperature, rainfall is the basic climate and weather factor. The agriculture activities on the terrain are the only real and lasting source of wealth, and it is in a large measure dependent on rainfall. The crop production fluctuates with the rainfall in such a way as to leave no doubt that the rainfall has been the real component, and the carrying capacity of grazing land in head of stock per square kilometer emphasis the same truth. It also influences the rate of evapotranspiration from vegetation and soil, which not only, affects the production of crops but also increases the ratio of moisture in atmosphere. The size and growth of vegetation is also closely related to the amount of rainfall. Sometimes, it also plays vital role in the industrial location and diseases controlling of an area.

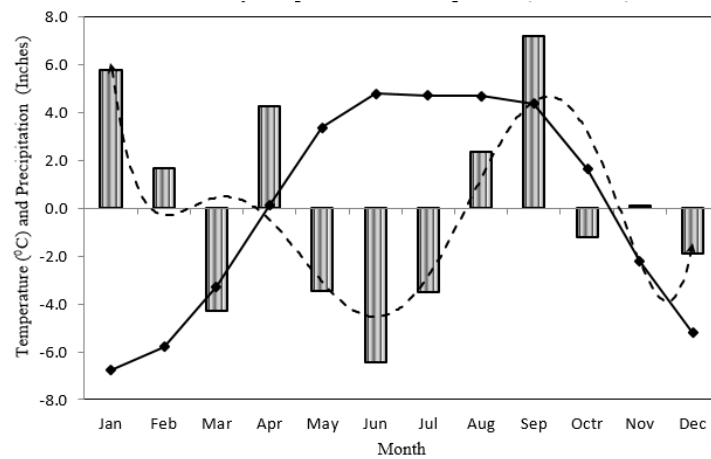


Figure-5: Makka Al Mukaramah Mean Monthly Temperature and Precipitation (1985-2015)

Annual rainfall is probably the most important climate indicator of productivity. The annual rainfall of the city is 189.1mm (7.4 inches), which is insufficient for plants growth and the city fall in the arid continental climate. However, during some years, the rainfall of the area rose to above 10 inches (254 mm) and showing semi-arid climates. The heaviest rainfall of 370.9 mm (14.6 inches) recorded in September (moistest) and lowest of 24.3 mm (One inches) in March (driest). The total rainfall of the area is 38.3 inches (972.8 mm) in winters that rose to 51 inches (1295.4 mm) in summers (Table-1). The heaviest rainfall of the area ever been recorded is 2362.2 mm (93 inches) in September 1999 (Table-3). In general, the higher rainfall occurred in the months of January, February, April, August and September and constitutes as the wettest months of the year and more suitable for the Holly Umrah.

The mean monthly rainfall indicates that it increases with decrease in temperature from November to February, while it decreases from April to October excluding April, August and September with the rise in temperature (Figure-4, Figure-5 and Table-1).

3.1.4 Relative Humidity

The relative humidity is defined as the amount of water vapor in the air relative to what the air can hold (Critchfield, 1978). An air should be called saturated, when its relative humidity reaches to 100 percent. It is also specific determinant of the amount and rate of evapotranspiration and critical climate factor in the rate of moisture loss by plants and animals, including human beings. It also expresses the average condition of water vapors in atmosphere. Relative humidity has also a physiological significance, as it determines the efficiency of the water-evaporating phase of our body cooling mechanism. It is also an important source of all forms of condensation and precipitation, where there is little moisture in the air; the precipitation will be low as compared to high atmospheric moisture. As the air is a principal absorber of solar energy and earth radiant energy as well, water vapor operates as a heat regulator and so have great effects on air temperature.

Generally, the average relative humidity of Makkah Al Mukkaramah recorded during 1981-2015 is 46.3% and represents a dry climate. The highest relative humidity of about 59% observed in December, whereas the lowest of 32.4% in June. The relative humidity is remaining high (above 50%) from November to February and constitutes as the pleasant months of the year. During March, April, September and October, it is between 40-50% and represents moderate atmospheric condition and 30 to 40% in the

excluding months and declared as a driest months of the area (Figure-6). The lowest ever recorded relative humidity of Makkah Al Mukarramah is 24.6% (2013) with chill and calm condition. The highest of 67.2% relative humidity has recorded in 1997 and constitutes as the most humid year of the series. The trend of relative humidity shows that it decreases from December to June and increases onward till November (Table-1).

3.2 The Characteristics Seasons

For the seasonal characteristics of weather element of Makkah Al Mukarramah, the year has divided into summer and winter season. The inter-relation of factors affecting climate of Makkah Al Mukarramah reveals that the summer month in coastal areas may not be the summer month inland, and a summer month in plain may not be that of the mountains. Therefore, months of the year having positive deviation from the mean temperature condition are considered as summer months, otherwise winter (Figure-3). Generally, in Makkah-Al-Mukarramah, the summer lasts from April to October (7 months) and winters from November to March (5 months).

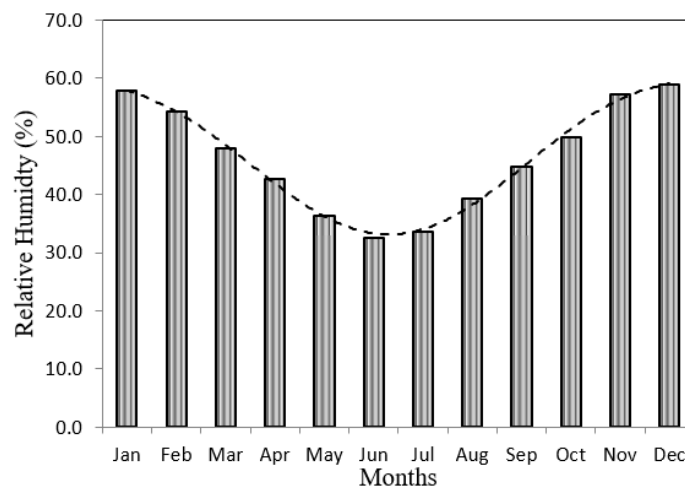


Figure-6: Makkah Al Mukarramah Mean Monthly Relative Humidity (1981-2015)

On the basis of precipitation, these two main seasons of the city are further divided into four sub-rainy seasons (Figure-4). The winter season that lasts from November to February (Moist), post winter season from March to April (Moderate), Summer season from May to July (Hottest), and Post Summer season from August to October (Warmer). The summary of each season are presented as follow.

3.2.1 Winter Season

Obviously, the winter season of Makkah Al Mukarramah varies from November to February (Four months). During this season, the climate of Makkah Al Mukarramah is controlled by the interaction of Siberian high pressure, the Mediterranean lows (Western Depressions) and the Sudan trough (Jet Stream). The Mediterranean cyclones, which travel from west to east in association with upper troughs and active phases of subtropical and polar jets, are the main sources, which cause rainfall during these months in the area. Their potential generally decreases from north to south except for the mountainous areas, where uplift motion acts as a trigger factor for the uplifting of winds into the condensation level. During winter season, the ridge of the Siberian high extends into the northeastern regions of Saudi Arabia. The trough

of the Sudan low brings warm humid air in the lower atmospheric layer to the southwestern parts of the country. When the cold air, which is associated with the Siberian ridge, extends especially far into the southern region and the humid air from the Sudan trough is concentrated along the Red Sea, the rainfall that occurs in this case is due to both instability and orography.

The rainfall generated by these western disturbances of the cooler season is usually fairly widespread and light to moderate. These disturbances provide a total of 35.2 inches (895.1mm) rainfall in the city and count as the moist season of the area with moderate temperature and maximum relative humidity. The heaviest fall is observed in the month of January 13.2 inches (334.5 mm), while the lowest is 140mm or 5.5 inches in December. The general pattern of the rainfall during these months shows an increasing trend from November to January and decreases in February. In winter, the mean monthly temperature of the city is dropped to 26.8°C, mean maximum temperature of 32.7°C, mean minimum temperature of 20.6°C, and relative humidity of 57.1 percent with clear skies (Table-2). During winter, the deviation of maximum temperature is -0.2°C (Decrease), whereas the minimum temperature reveals an increase of 1.4°C. There is no change in the rainfall condition; however the relative humidity shows an increase of 0.1 percent.

Table-2: Makkah Al Mukarramah: Mean Monthly Seasonal Temperature (°C), Rainfall (Inches) and Relative Humidity (%)

Season	Maximum Temperature		Minimum Temperature	
	Average/Sum	Deviation	Average/Sum	Deviation
Winter	32.7	-0.2	20.6	1.4
Post Winter	36.9	0.1	23.1	0.0
Summer	43.1	-0.1	28.7	0.0
Post Summer	42.0	-0.1	28.3	0.1
Season	Rainfall		Relative Humidity	
	Average/Sum	Deviation	Average/Sum	Deviation
Winter	35.2	0.0	57.1	0.1
Post Winter	14.7	-0.1	45.3	0.0
Summer	8.8	0.1	34.2	0.0
Post Summer	30.6	0.0	44.7	0.0

Source: Meteorological Department, Kingdom of Saudi Arabia

3.2.2 Post Winter Season

The season varies from March to April (Two months) and is characterized by moderate temperature and rainfall. It is some time called as the cool moderate season of post winter and the summer season. From March to April, the anticyclones subsidence and clear skies, characteristic of the winter months still prevails and this in combination with a much stronger solar radiation sets the weather pattern for the season. Temperatures are high and a heavy, dry haze envelops in the interior, but drought still grips most of the city. The post winter season, in general, is characterized by violent weather, in the form of thunderstorms and squalls. The rainfall accompanying this vigorous convective system is low, but occasionally well-developed cumulonimbus clouds, are generated with strong squall wind, and violent dust storms.

In post winter season, the mean monthly temperature exceeds 30°C, mean maximum temperature of 26.9°C, mean minimum temperature of 23.1°C with moderate rains of about 14.7 inches (374.6mm) and relative humidity of 57.1 percent (Table-2). These are the specific determinants, which caused parching

of leaves in plants and evaporation of sweats from human bodies. In post winter season, the area of Makkah Al Mukarramah is still under the influence of western depression associated with convection caused by the local heating that causes thunderstorms and rains. During post winter season, the deviation of mean temperature shows an increase of 1.7°C, mean maximum temperature 0.1°C and minimum temperature of 0.01°C. The mean monthly rainfall reveals a decrease of -0.1inches (2.54mm), while the relative humidity remains stable.

3.2.3 Summer Season

The summer season of Makkah Al Mukarramah varies from May to July (Figure-2) having extreme temperature, low rainfall and relative humidity with chill condition. The deflected monsoon currents, generally, travel northwards towards Saudi Arabia on the shores of the Arabian Sea. This branch of monsoon reaches to Saudi Arabia at mid-June and reaches to its climax in July. However, it is of low vertical extent and generally, produces stratus clouds in the coastal areas and cumulus clouds in plains and causes heavy rains in the month of July with low pressure and high temperature on the continental area. The monsoon currents remain steady till it begins retreating towards the beginning of August. The variation in precipitation intensity from monsoon is due to its long trajectory decreasing the moisture index of these depressions as they travel over continental areas. These winds are the only source of summer rains in Makkah Al Mukarramah, which keep temperature low in the month of July. These winds give torrential rains with showers and cause damage in different sectors of the human life.

As the sub-continent is heated intensively in April and May, the zonal westerly start to move northward and it changes its direction towards southwest. As a result, the jet stream, which had been at about 30°N during winter and post winter, tends to disappear. Disappearance becomes more frequent as the season advances and each disappearance is associated with a northward surge of the summer monsoon. Finally, in late May or early June, the jet disappears completely over Saudi Arabia and takes up a position at about 40°N. Simultaneously, there occurs a shift of the low latitude trough and ridge positions, and the upper trough which previously was located at about 85°E quickly moves westward some 10° and takes up a position over western Indo-Pakistan sub-continent at approximately 75°East. The heating of the Middle East and the development of a surface pressure trough are unable to produce a northward advance of the ITC until large scale dynamic features of the circulation aloft become favorable (Trewartha, 1961). When the jet stream reappears at Saudi Arabia, again in fall, the summer monsoon again retreat southward and is called reversible monsoon.

During this season, the total rainfall of Makkah Al Mukarramah is 8.8 inches (222.5mm) having heaviest of 3.9 inches (98.3mm) in July and lowest of one inch (24.3mm) in June and being the moist and driest months of the season. The mean monthly temperature of the city is raise to 35.9°C with mean monthly maximum temperature of 43.1°C and mean monthly minimum temperature of 28.7°C with hot gusts and sandy storms. The relative humidity of the area falls to 34.2 percent with chill condition. The area is extremely hot during these months due to sun burning overhead rays and low moisture (Table-2).

During summer season, the deviation of mean monthly temperature of the area shows a decreasing trend of about -0.1°C, while the mean monthly temperature remain stable with a minor increase. There is a rise of inches 0.1(2.54mm) in the rainfall and 0.01 percent in relative humidity (Table-2).

3.2.4 Post Summer Season:

The season varies from August to October and is characterized by pleasant weather with moderate temperature and low rainfall. During this season, the low pressure shifts to the Arabian Sea from continent and give way to high pressure on land areas. This change in the pressure system causes change in the direction of the monsoon from southeast towards southwest. Consequently, the monsoon winds start blow from land towards ocean and designated by the name reversible monsoon. By the late fall, the trough of low pressure, separating the easterly and westerly air currents establishes over the southern part of Saudi Arabia. Along the discontinuity between the equatorial westerly and the zonal easterly, various kinds of perturbations develop ranging all the way from weak monsoon depressions to hurricanes. The depressions follow less well definite tracks than in summer, but in general, their progress is westward, so that their rainfall effects are concentrated in coastal region of Saudi Arabia.

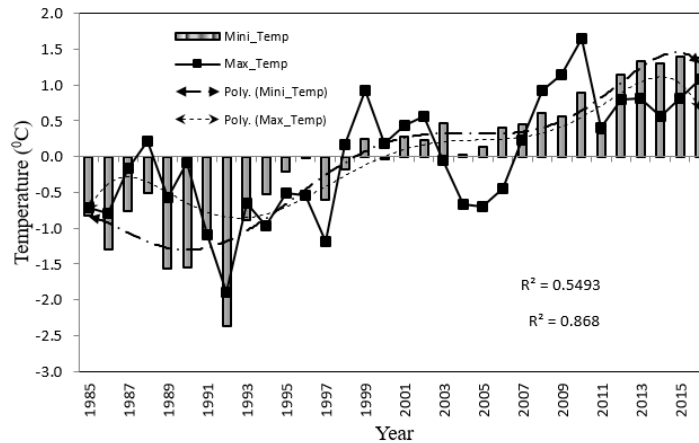


Figure-7: Makkah Al Mukarramah Deviation of Mean Monthly Maximum and Minimum Temperature (1985-2016)

During the fall months, the dynamic features of the circulation aloft, including jet stream and the orographically imposed troughs and ridges, begin to approach their cool season positions, with the reappearance at Saudi Arabia in September and October of the middle latitude westerly and the jet stream, and the re-establishment of the Polar front over the Mediterranean Sea/Europe. The western disturbances once more become an important control of weather in Saudi Arabia (Trewartha, 1961).

In post summer season, the mean monthly temperature of the Makkah Al Mukarramah falls to below 35.2°C with mean monthly maximum temperature of 42°C, and mean monthly minimum temperature of 28.3°C. The total rainfall of Makkah Al Mukarramah remains low that is 30.6 inches (796.9mm) during these three months having relative humidity of about 44.7 percent. The monsoon lows give way to those of winter currents (Western Depression) and most of the rains are caused by local thunderstorms or reversible monsoon winds, which develop due to local high pressure and heating on the inland areas. The retreat of monsoon from north Arabian Sea in marked by disappearance of the stratus clouds with a gradual increase in daytime temperature (Table-2). During post summer season, the mean monthly maximum temperature shows a decrease of -0.1°C, whereas there is an increase of 0.1°C in mean monthly minimum temperature. The mean monthly rainfall and relative humidity of the area remains stable throughout the season.

3.3 Climate Change

The climate is not a static phenomenon but its change from time to time and place to place in term of variation as well as fluctuation. Sometime, these changes are made on seasonal basis or daily basis and show linear or periodic trends. The climate change of Makkah Al Mukarramah in term of temperature, rainfall and relative humidity is presented as follow.

3.3.1 Temperature Change

The natural, physical, religious and socio-economical ecosystems of Makkah Al Mukarramah are not only dependent on how much temperature rises or falls but also on how it varies from year to year and time to time. Generally, the mean monthly, mean maximum and minimum temperature of the area show an increasing trend during 1985-2016. The temperature of the city remains low during the period, where the concentration of rainfall remains high and converse condition during dry years. During 1985-98, the trend of mean maximum temperature is below the mean condition and turned to positive deviation onward till 2002. From 2003 to 2006, there is a decrease in the maximum temperature of the city, whereas it remained high from 2007 to 2016 (Figure-7). The deviation of mean monthly maximum and minimum temperature is almost same with little alter in few years of the series. The minimum temperature of the Makkah Al Mukarramah remained below the average condition from 1985 to 1998 and rise to positive deviation till 2016.

The mean monthly maximum temperature of the city shows an increase of one degree Celsius having -0.1°C in mean monthly maximum and -1.1°C in mean monthly minimum temperature during 1985-2016 (Table-3). The highest positive deviation of 1.3°C in mean monthly temperature is recorded in 2010 and 2016; 1.7°C in mean monthly maximum temperature (2010) and 1.4°C mean monthly minimum temperature in 2015 and 2016 respectively. The lowest of negative deviation of -2.1°C of mean monthly temperature has noted in 1992, -1.9°C mean monthly maximum (1992) and -2.4°C mean monthly minimum temperature in the same year and considered as hottest and coldest years of the series. Generally, the deviation from the mean temperature condition of the city shows an increase in mean monthly and mean monthly maximum temperature, while it indicates a decreasing trend in the mean monthly minimum temperature.

The work is further condensed into the deviation of five and ten years for the purpose to understand the time period of positive and negative deviation. The figure-9 shows that the mean monthly maximum temperature of the area was remain negative during the time period of 1985-90, 1991-95, 1996-2000 and 2001-2005 and turn to positive in the excluding years 2006-2016 and shows a periodic pattern of 20 years time interval.

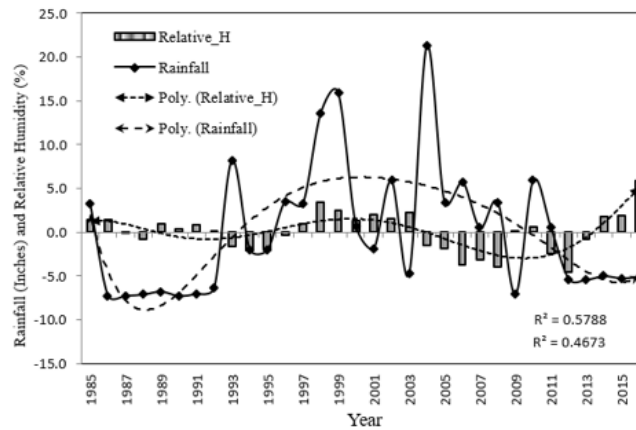


Figure-8: Makkah Al Mukarramah Deviation of Mean Monthly Rainfall and Relative Humidity (1985-2016)

But in general, the trend shows an increase throughout the time period of 1991-2016. As for as the mean monthly minimum temperature has concerned, it remained below the mean condition during the first fifteen years (1985-2000) and turned to positive deviation from 2001-2016. However, the increase in the minimum temperature of the area seems throughout the series. The mean monthly temperature of the area also shows the same pattern. It is concluded that the temperature condition at Makkah Al Mukarramah shows an increasing trend since 1985 till to date with little ups and downs in few years of the series having a linear trend (Figure-9).

As for as, the deviation from the mean of ten years has concerned, the mean monthly, mean monthly maximum and minimum temperature of the Makkah Al Mukarramah shows a negative deviation from 1985 to 2005 (20 years) and then change into positive deviation during the last decadal period of 2006-2016 and it is expected that it will further increase till 2025 (Figure-9).

3.3.2 Rainfall Change

After temperature, rainfall is the most important weather element that maintains stability in the water resources and agriculture activities in the area. Besides, it also plays a vital role as a controlling factor of temperature and other weather elements. The annual trend of rainfall shows that the area remains dry during 1985-95, wet during 1996-2011 and reversed during 2012-2016 having ups and downs for a short time interval (Figure-7). The area falls in arid continental climate and drought prevails in the city for most of the years. The longer and most severe drought of the city was observed during 1985-95, and moderate drought since 2012 till to date.

Generally, the sum of deviation from the mean condition of rainfall shows a total increase of 1.4 inches (36mm) 1985-2016. Overall, the trend of rainfall at Makkah-Al-Mukarramah shows an increasing trend throughout the series (Figure-8). The maximum of positive deviation of 21.3 inches (540.7mm) of the city was recorded in 2004, while the lowest of -7.3 inches (184.6mm) observed in 1986, 1987 and 1990 and constitutes as a wettest and driest years of the series with drought and chill condition (Table-3).

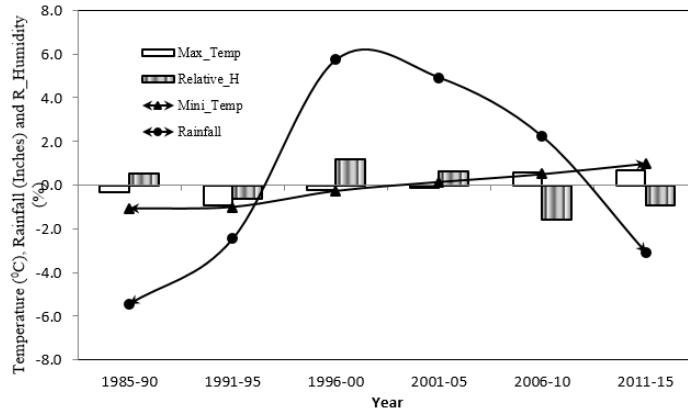


Figure-9: Makkah Al Mukarramah Five Years Deviation of Maximum and Minimum Temperature, Rainfall and Relative Humidity (1985-2015)

As for as the five years deviation of Makkah Al Mukarramah has concerned, during 1985-90 and 1991-95, the deviation from the mean shows a negative trend and the area remained under a long drought condition. From 1996-2010, the trend shows a positive deviation having heavy rains in some years and count as wet period of the Makkah Al Mukarramah. The trend in precipitation takes a negative deviation during 2011 to 2016 and expected that it will further decrease with passage of time. However, the overall trend of rainfall at Makkah Al Mukarramah reveals an increasing trend with passage of time (Figure-9 and Figure-10).

The ten years deviation of the Makkah Al Mukarramah has calculated for the purpose to understand the regular or periodic trend of rainfall in the area (Figure-10). The figure shows that the rainfall condition of Makkah Al Mukarramah has remained below the mean condition in the first decadal period of 1985-1995, turned into positive deviation from 1996 to 2005 and taken negative trend again during 2006-2016 and reveals a periodic trend after each ten years. It is expected that during 2016-2025 the rainfall condition of the area will remain positive with gradual increase in floods.

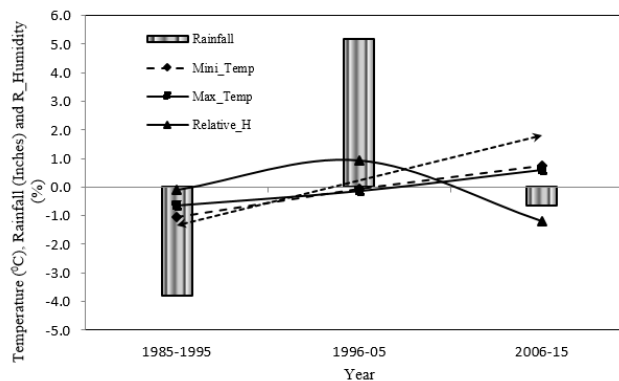


Figure-10: Makkah Al Mukarramah Ten Years Deviation of Maximum, Minimum Temperature, Rainfall and Relative Humidity (1985-2015)

3.3.3 Relative Humidity

After temperature and rainfall, the relative humidity is the utmost variable of weather and climate that control the percentage of moisture in atmosphere and save the area from chill condition. Besides, it also

plays a vital role in the temperature inversion of atmosphere, hydrological cycle, conduction and evapotranspiration.

Obviously, the sum of deviation of mean monthly relative humidity of Makkah Al Mukarramah is 0.7% and shows an increase during 1985-2016. The highest positive deviation of 5.9% has recorded during 2016 and the lowest negative deviation of -4.6% in 2012 and considered the years of maximum and minimum relative humidity throughout the series (Table-3). The annual trend of deviation of relative humidity from the mean condition shows ups and downs after each five years having an increasing trend throughout the series (Figure-8). The five years deviation of relative humidity indicates that it has above the mean condition during 1985-90 and took negative trend from 1991-95. Onward, 1996 to 2005, it remained above the mean condition and then slackens from 2006 to 2016 (Figure-9). The ten years deviation of the relative humidity from the mean reveals that it is below the mean condition during 1985-1995, positive trend from 1996-2005 and then inverse during 2006-2016 (Figure-10). Generally, the trend of the relative humidity of Makkah Al Mukarramah shows a periodic change after each ten years.

Table-3: Makkah Al Mukarramah Deviation of Mean Monthly Temperature, Rainfall and Relative Humidity (1985-2016)

Year	Mean Monthly				Deviation from the Mean			
	Mini_T	Maxi_T	Rainfall	R_H	Mini_T	Max_T	Rainfall	R_H
1985	24.2	37.6	10.6	47.8	-0.8	-0.7	3.2	1.5
1986	23.7	37.5	0.1	47.8	-1.3	-0.8	-7.3	1.5
1987	24.2	38.1	0.1	46.2	-0.8	-0.2	-7.3	-0.1
1988	24.5	38.5	0.2	45.5	-0.5	0.2	-7.2	-0.8
1989	23.4	37.7	0.6	47.2	-1.6	-0.6	-6.8	0.9
1990	23.5	38.2	0.1	46.6	-1.5	-0.1	-7.3	0.3
1991	24.0	37.2	0.3	47.1	-1.0	-1.1	-7.1	0.8
1992	22.6	36.4	1.0	46.5	-2.4	-1.9	-6.4	0.2
1993	24.1	37.6	15.6	44.7	-0.9	-0.7	8.2	-1.6
1994	24.5	37.3	5.4	44.3	-0.5	-1.0	-2.0	-2.0
1995	24.8	37.8	5.3	44.5	-0.2	-0.5	-2.1	-1.8
1996	25.0	37.8	10.9	45.9	0.0	-0.5	3.5	-0.4
1997	24.4	37.1	10.6	47.3	-0.6	-1.2	3.2	1.0
1998	24.8	38.5	20.9	49.8	-0.2	0.2	13.5	3.5
1999	25.2	39.2	23.3	48.8	0.2	0.9	15.9	2.5
2000	25.0	38.5	8.1	47.6	0.0	0.2	0.7	1.3
2001	25.3	38.7	5.5	48.3	0.3	0.4	-1.9	2.0
2002	25.2	38.9	13.3	47.9	0.2	0.6	5.9	1.6
2003	25.5	38.2	2.6	48.6	0.5	-0.1	-4.8	2.3
2004	25.0	37.6	28.7	44.8	0.0	-0.7	21.3	-1.5
2005	25.1	37.6	10.7	44.5	0.1	-0.7	3.3	-1.8
2006	25.4	37.9	13.2	42.6	0.4	-0.4	5.8	-3.7
2007	25.5	38.5	7.9	43.2	0.5	0.2	0.5	-3.1
2008	25.6	39.2	10.8	42.3	0.6	0.9	3.4	-4.0
2009	25.6	39.5	0.3	46.3	0.6	1.2	-7.1	0.0
2010	25.9	40.0	13.3	46.9	0.9	1.7	5.9	0.6
2011	25.3	38.7	7.9	43.9	0.3	0.4	0.5	-2.4
2012	26.1	39.1	2.0	41.7	1.1	0.8	-5.4	-4.6
2013	26.3	39.1	1.9	45.5	1.3	0.8	-5.5	-0.8
2014	26.3	38.9	2.3	48.1	1.3	0.6	-5.1	1.8
2015	26.4	39.1	2.1	48.2	1.4	0.8	-5.3	1.9
2016	26.4	39.4	2.3	52.2	1.4	1.1	-5.1	5.9
Annual	25.0	38.3	7.4	46.3	-1.1	-0.1	1.4	0.7

Source: Meteorological Department, Kingdom of Saudi Arabia

4 Conclusion

- Makkah Al Mukarramah receives 7.4 inches (189.1 mm) rainfall annually and considered as arid continental climate. However, the coastal region of the province (Jeddah) is characterized by land and ocean breezes and shows a maritime climate. The average relative humidity of Makkah Al Mukarramah is 46.3 percent with an increase of 0.7percent.
- The annual march of temperature reveals that the temperature condition of the area rises up from January to June, remains stable till September and slackens upto December. The mean monthly temperature of the city recorded during 1985-2016 is 31.6°C having maximum temperature of about 38.3°C and minimum of 25°C. The area has moderate temperature in winters, when the mean monthly temperature is dropped to 27°C and hot in summers when it rises up to above 35 degree Celsius.
- The extreme average maximum temperature of the city is 45.4°C recorded in June 2009 and 2012 with a minimum of 31.5°C recorded in July 2012 having 38.2°C mean monthly temperature in June 2009 and 2012 and being the hottest months/years of the series. The lowest mean monthly temperature of 20.9°C (February, 1992) with mean monthly lowest maximum of 27.3°C (February, 1992), and mean monthly minimum of 14.6°C recorded in February 1992 and being a coldest months/years of the series.
- Makkah Al Mukarramah characterized by two main seasons that is summer season that lasts for seven months (April to October) and winter season for five months (November to March). The summers of the city are extremely hot, while the winters are warm. The city is extremely hot in July and August and cool from December to January. On the basis of rainfall and relative humidity, these two main seasons are further sub-divided into four seasons that is winter (November to February), post winter (March to April), summer (May to July) and post summer seasons (August to October). The area remains moist during winter seasons, moderate in post winter seasons, hot in summer season and warm in post summer seasons.
- The total precipitation of the city is 189.1mm (7.4 inches), which is insufficient for plants growth having arid continental climate with hot long dry summers and short warm winters. The heaviest precipitation of 3160.8mm (124.4inches) recorded in January and February 2004 and constitute as the moistest months/year of the series. In general, the heaviest rainfall occurred in the months of January, February and September. The average relative humidity of the area is 46.3% having highest of 67.2% in December 1997 and lowest of 24.6% in June 2013. During winter months the relative humidity remains high and more suitable for Holly Umrah, whereas there is a chill condition during summer months in the area that evaporates water from the human bodies and turns the skin dry. The mean monthly rainfall indicates that it increases with decrease in temperature from November to February, while it is decreases from April to October excluding April, August and September with the rise of temperature
- The mean monthly temperature of the city shows an increase of one degree Celsius having decrease of -0.1°C in mean monthly maximum and -1.1°C in mean monthly minimum temperature during 1985-2016. In general, the deviation from the mean shows that there is a periodic change in the temperature condition of the precipitation as well as temperature after each ten years.

- The area falls in arid climate, however during some years it rose up to above 10 inches (Semi-Arid) and drought prevails in the city for most of the years. The longer and most severe drought of the city observed during 1986-92 (7 years) and moderate drought in 2011-2016 (6 years). Generally, the sum of deviation from the mean condition of rainfall shows a total increase of 1.4 inches (36mm) during 1985-2016. The driest years of the series having precipitation 0.1inches (2.54mm) are 1986, 1987, and 1990 respectively, when the area passed through a severe drought and chill condition. Overall, the trend of rainfall at Makkah Al Mukarramah shows an increasing trend throughout the series and it is expected that the precipitation condition of the city will increase with passage of time. However, at Jeddah there is marine climate and completely different from Makkah Al Mukarramah.
- The heaviest rainfall of Makkah Al Mukarramah recorded in the month of January, February and September and constitutes wettest months of the year. The lowest rainfall of the city seems in June and July and marked as driest months of the year having high temperature and lowest relative humidity.
- The climate of Makkah Al Mukarramah is more severe as compared to Madina Al Munawwarrah in term of Temperature, rainfall, relative humidity, wind speed, atmospheric pressure and dust storms. So the Muslims who visited these cities for Holly Huj and Umrah should be aware about these environmental differences in both Holly cities of Hejaz.

RECOMMENDATIONS

- The explosive materials used in wars and burning of oil wells particularly in Gulf war, Syria, and Iraq are hazardous to the green house of the nature. Therefore, it is required to control wars in the Middle East and to resolve the issues with cooperation instead of using supremacy and to provide harmony to the physical environment in the study area. These wars not only caused climate change in the Middle East but also increased the rate of fog and smog in the Southwest Asia and affected the winter rains.
- Vehicles and Industrialization are the utmost factors that tire out green house gases into the ocean atmosphere. Therefore, it is indispensable to perk up automobile engines, industrial machineries with new trend and techniques, and to design policy for the controlling of chlorofluorocarbons, and awareness of people about the ongoing environmental issues in the area.
- The meager forests of Middle East are basic element that exposed earth surface to irradiant solar energy and enhancing the evapotranspiration and pollution. Therefore, legislation is required to put off deforestation and also to ensure the immediate replanting of trees particularly on the mountains slopes and barren lands round the city of Makkah AL Mukarramah, and to make a policy for its protection and preservation. The suitable tree for the plantation in desert area is Acacia having low water requirements.
- The famous conference about, “how to combat global warming” are: Vienna convention for the protection of the ozone layer (1985), Montreal Protocol (1987), UN Earth Summit (1992), Kyoto protocol (1997), Agenda-21 (2002), and IPCC (2007) etc, but the conditions recommended in the summary of these summits has not implemented properly on national as well as international level by the member countries. It is therefore, recommended that the countries of Middle East

must plan a criteria to collect funds and to fight for the green revolution in the entire region together particularly at Medina Al Munawarah and Makkah Al Mukarramah (The Holly Places of Muslim Ummah).

- For intensive forestation, it is substantial to make available facilities to the occupants of the area and to hearten the community reforestation. Also, to initiate programs for the awareness of the locals about the roles of forests in green revolution and climate change.
- The ozone layer can be protected by replacement of chlorofluorocarbons by hydro-fluorocarbons released to atmosphere from aerosol, refrigeration and air conditioning, and foam Industries. Besides, a forestation, which releases oxygen in abundance to the atmosphere in turn plays a significant role in increasing concentration of ozone in the stratosphere, is highly appreciable in this regard.
- Further research is required to study the causes and impacts of climate change and global warming at Saudi Arabia so, that by proper planning, the problem arising due to the increase in temperature and decrease in precipitation shall be control for the performing of Holly Huj and Umrah.

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