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# Assessing the Environmental Impact of Climate Change on Desert Ecosystems: A Review

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**Abstract:** Human population is interrelated with the demand of fuel, water and food. This is consequently leading to increasing rates of energy use and therefore greenhouse gas (GHG) emissions. Globally, the atmospheric concentrations of GHG have increased by approximately 35% for carbon dioxide, 148% for methane, and 14% for nitrous oxide. Desert ecosystems, in particular, are highly variable and unpredictable, where organisms and humans have utilized arid environments regardless of their naturally uncertain availability of resources. The fast spread of desertification has led to environmental degradation, unstable local political situations and economic losses. The extreme weather events in the past two decades caused many loses in terms of ecosystem alteration, economic impacts as well as social influences. Dryland communities adapt to dynamic climatic and environmental conditions due to rainfall variability. Unfortunately, climate change impact is not fully understood. The effects of climate change on species diversity is generally slow, but these effects are expected to show rapid progress over the next 50 years and beyond. Remote sensing and GIS based models allow simulating the change in particular landscape elements over time and space, and investigating different types of future scenarios. The information represented in this paper aims to give a review and discussion of the impact of climate change on arid and semi-arid regions to the researchers, ecologists and decision makers. There is a lack of resources about the impact of climate change on the Arabian Gulf region in particular. Therefore, we hope that this review will simulate researchers in the region and worldwide to conduct their research and focus their studies on this region.

**Key words:** Carbon dioxide, Climate change, Deserts, Ecosystems, Soil

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# 1. Introduction

## Climate Change Physical Settings

### Changes in Climate with Time

Climate change is a systematic change in the long-term progression describing the climate system that is continual over a number of decades or longer (Tabari and Talaee, 2014). Over the recent 100-year period (1906 to 2005), the global surface warming rate was estimated to be 0.74 ± 0.18 ˚C and the warming rate over the last 50 years of this period is almost twice that of the 100-year period (Solomon, 2007). According to Nemani et al. (2003), the 1980s and 1990s were two of the warmest decades ever recorded. It is mostly agreeable that what they claim is true. The root cause of the recent global changes is the great acceleration of population since the 1950s (P´aez-Osuna et al., 2016). Increasing numbers of human population caused by high birth rate, led to an increase in the demand of fuel, water and food which consequently led to an increase in GHG and other climate change related issues. Climate change will significantly influence all life sectors in the Arabian Gulf region. The current main problem is the uncertainty in determining its impact, alleviating it and dealing with it (Al-Maamary et al., 2017).

Climate and weather have a direct control on the distribution and productivity of species, ecosystems processes and landscapes (Leemans and Eickhout, 2004). For this reason, climatic changes will make considerable impact in many desert species' distributions and ecosystem processes. Emanuel et al. (1985) showed that climate change would have large impacts on the distribution of ecosystems. They concluded that more than 40% of the world's ecosystems would vary under a doubled carbon dioxide content in the atmosphere. This is noticeable in many parts of the world, where numbers of extinct species are getting higher and the alteration of ecosystems are clear examples. The linkage between climate change, temperature rise, rainfall fluctuation and agriculture has been well established scientifically (Ahmed et al., 2011; Rowhani et al., 2011). Due to climate change, food security challenges are being ultimately serious in the developing world and require an insistent reaction (AlAmin and Ahmed, 2016). This made the importance of introducing mitigation policies very high and governments all over the world should embrace this. Many sectors and systems, such as the desalination of seawater, public health, and food security are considerably threatened by climate change (Lattemann and H¨opner, 2008). It is feared that climate change will cause a huge impact on the water of the Arabian Gulf countries and its levels of salinity and as a consequence, the sustainability of the distillation of water in the region (Parry, 2004). These impacts are directly linked to the GHG emissions.

## Changes in Atmospheric GHGs

Presently, we annually release over 29 billion metric tons of carbon dioxide into our atmosphere (Boden et al., 2009; Williams et al., 2012). According to Rustad (2008), the atmospheric greenhouse gas concentrations have increased by approximately 35% for carbon dioxide, 148% for methane, and 14% for nitrous oxide. The changes to the Earth's climate system have risen from the accumulation of greenhouse gases in the atmosphere, which is leading to an increase in air temperature (Aragon-Gastelum et al., 2014). Based on Pachauri et al. (2014), total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger increases between 2000 and 2010. Moreover in 2010, the GHG emissions have reached $49 \pm 4.5 GtCO2 - eq/yr$.

Three forcing factors control the future of deserts; plate tectonics, global climate and humans (Warren et al., 1996). The first factor cannot be controlled, while global climate and humans are two interrelated factors. If humans changed their behaviors toward the globe, climate will be much controllable (Zhen-Feng et al., 2013). Future concentrations of tropospheric ozone and methane will be influenced by both emissions and climate. Natural emissions, such as lightning nitrous oxide and hydrocarbons from vegetation, are also expected to increase in a warmer, more carbon dioxide rich atmosphere (Stevenson et al., 2000). Dry land communities adapt to dynamic climatic and environmental conditions due to rainfall variability (Adger and Vincent, 2005). This is experienced in deserts and many arid and semi-arid ecosystems where species adapted to the situation through decades. However, the climate changes are feared to occur in a speed higher than the limits of adaptation in many parts of the world (Stringer et al., 2009).

On the El Nino timescales (3 to 7 years), major changes of climate might lead to incidents of rigorous droughts or floods (Eddy, 1977; Warren et al., 1996). What we see nowadays is a proof to what was predicted. The extreme weather events in the past two decades caused many loses in terms of ecosystem alteration, economic impacts as well as social influences on communities. Changes in land cover can have a deep influence on the Earth's climate. Agricultural and pastoral activities increased the stress on plant cover that might be a factor in the increase of surface albedo, consequently leading to droughts (Sivakumar, 2007).

Climate has noticeably changed in the Arabian Gulf countries, where temperatures rose during the period from 1960 to 2010, as the cold days and nights over this period decreased, and the area faced warmer nights (Al-Maamary et al., 2017). By 2080, the value of declination in the agricultural production of the developing countries is expected to be between 10 to 25% in case that no effort was initiated to diminish carbon emission to a subordinate level, and no implementation of assured adaptation decisions for climate change (Al-Amin and Ahmed, 2016). Some countries has implemented adaptation plans while many still are under great risk unless they start to consider the climate issue as a serious problem that requires an urgent move.

Based on DeNicola et al. (2015), Saudi Arabia will continue to face challenges in coping with climate change and declining water resources. There are some doubts about the adaptation methods being applied and their sustainability and their potential to worsen climate change impacts and water scarcity in other parts of the globe (Lattemann and H¨opner, 2008). This is the reason why mitigation plans and water management methods should be well studied and addressed taking into consideration past, current and future scenarios of the local region, neighboring countries and other concerned parts of the globe. As water use efficiency depends on specific ecosystems. Sand dunes for instance cover areas of between a quarter and a third of the surface of most arid and semi-arid lands (Bowden et al., 1974). It is believed that these areas are very resilient to disturbance, but the vast areas covered by desert pavement are very exposed to disturbance by off-road vehicles, recreational or industrial, which can mobilize large quantities of dust. In summers where temperatures are higher, this is frequently experienced specially in hot areas such as Arabian Gulf countries. Warren et al. (1996), found that the most threatened areas are semi-arid soils, where the drier of these soils are predisposed to wind erosion when exposed to overgrazing or cultivation, while wetter areas are open to water erosion when exposed in similar conditions. Soil is highly influenced by climate. Its characteristics are dependent on temperature and rainfall. Yang et al. (2007), found that precipitation variability affects many sides of ecosystems. It influences the soil moisture content, the consolidation degree of surface soil particles and plant growth and the density of the vegetation coverage.

## Fluctuations in Temperature and Rainfall

Based on the IPCC AR5, the global average combined land and ocean surface temperature data show a warming of 0.85, ranging between 0.65 to 1.06 ˚C over the period 1880 to 2012 (Pachauri et al., 2014). From 1961 to 2010, the annual mean temperature increased by about 0.35 ˚C per decade in Northeast China (Chun-Yu et al., 2013). It was found that the seasonal mean temperature had significantly increased. The highest increase was in winter (0.55 ˚C per decade), followed by spring, summer and autumn. In the same study, they found that the number of precipitation days showed a significant downward trend causing a notable decline in the annual precipitation where the rate of precipitation became -2.4 days per decade. Regions like Middle East and Arabian Gulf countries specifically, have two seasons per year; summers and winters and the increase in temperatures is experienced by people, where precipitation rates are lower than the past decades. According to Tolba and Saab (2009), temperatures in the Arabian Peninsula are expected to be higher than the existing by 2 to 2.75 ˚C, while near to the coast; the temperature rise will be lower by 1.5 ˚C. They also mentioned that winter rainfall events that occur on October to March, would be lower by 10 to 15% but would increase by 25% over the Sahara.

Temperature and rainfall definitely influence the growing season of plants. Xiao-Ying et al. (2013) reported that climate changes has influenced the growing seasons of the plants in forests, by delaying the start date of the growing season for mixed coniferous and broad-leaved forests in Northeast China at an average rate of 2.1 days per decade. According to Fasona et al. (2013), fluctuation in rainfall and temperature rates would strongly influence the existence and distribution of specific ecosystems, plant species and patterns of natural resource systems. The length of growing season is a significant measure in forestry, agriculture and horticulture. It was found that a 1˚C increase in Europe leads to a progressive beginning of growing season by 6.7 days (Chmielewski and R¨otzer, 2001). Growing season has been affected by climate change in Arabian Gulf region and UAE as an example, which is one of the biggest producers of dates. Because of the increasing temperatures in cooler months, the start date of growing season is now earlier.

The mutual effects of climate change and water reduction is expected to have deep impacts on biotic communities (Maestre et al., 2015). A very important possible driver of future wind erosion and dust storm occurrence is climate change, which is via the episodes of intense wind events, larger drought frequency and greater aridity in some areas (Middleton, 2017). Hall et al. (2016) studied the North Western America, they found that there is a recent loss of 63 trillion gallons of surface water due to enduring drought.

As a semi-arid and arid region, Central Asia is at high risk due to changes in climate (Lioubimtseva and Henebry, 2009). According to Deng and Chen (2017), climate change has magnified water resources stress in Central Asia over the past few decades and temperatures became higher. While precipitation inconsistency and river runoff variability have increased, and more drought events were driven. Rate, concentration and period of rainfall would affect the vegetation and land cover in general, which has a direct impact on different types of ecosystems as well as the existing species. Temperature and precipitation are the major aspects that affect the expansion and ranges of ecosystems (Schellnhuber, 2010).

## Climate Change Effect on Desert Ecosystems

### The Influence on The Existence and Distribution of Ecosystems: Impactson desert life-forms

One of the major issues in global change research is the interaction between climate change and terrestrial ecosystems (Fasona et al., 2013). Long-term climate patterns could control vegetation type and canopy structure and the land-use type in an ecosystem (Schellnhuber, 2010). Climate can be affected by changes in vegetation distribution and growth can in turn be affected through biogeophysical and biogeochemical processes. Desert ecosystems are highly variable and unpredictable, where organisms and humans have utilized arid environments regardless of their naturally uncertain availability of resources (Stahlschmidt et al., 2011). Many ecosystems are particularly vulnerable to climate change as their adaptation depend largely on particular water regime including temperature, precipitation and evaporation (Dawson et al., 2003). Freudenberger et al. (2012) found that species with high functional richness present a diversity of plant growth strategies. They should be better placed to overcome the challenges of future climate change by interacting with ecosystem functionality and enhancing the adaptive capacity of ecosystems.

Dry lands cover about 40% of the worlds land surface and are home to more than two billion people (Middleton, 2017). Dune fields found in India, China, sub- Saharan Africa, the Middle East, and the southwestern United States are common within and on the margins of many dry lands (Ellwein et al., 2015). Climate models showed that dry lands and dune fields are expected to spread out in a warming world (Meehl et al., 2007). Deserts cover over 19 million $Km^2$ equivalent to 15% of the global land, and are home to some 144 million people (Ezcurra, 2006). More than one sixth of the world’s population of humans are affected by desertification (Badger et al., 2000). The fast spread of desertification has led to environmental degradation, unstable local political situations and economic losses (Xu et al., 2010). Two decades ago, it was believed that neither climate nor people have much effect on the ecology of hyper-arid deserts, because of the nature of deserts and their lack of biological material where there is nothing much to be damaged (Warren et al., 1996). Desertification can vary greatly in different regions with different climate characteristics and social economic conditions, which avoid their precise recognition (Collado et al., 2002). People including scientists used to believe that the main problem for desert soils is grazing by domestic animals. Nowadays this belief is no longer valid (Warren et al., 1996). Despite this evidence, many would deny or disagree.

Continuing climatic change is projected to lessen water supply in arid and semiarid areas and badly influence the water quality (Wang et al., 2016). They also reported that, the constant changes in productivity and vegetation growth zones has a direct impact on ecosystem services, through impacts on fresh water supply, food and organic matter production. Generally, plant biomass per unit area of the temperate desert is low, but the large surface area of some deserts in the world for example, the Central Asia dryland gives it a global importance in carbon cycle research (Zhang et al., 2016). In Central Asia, the desert vegetation not only has a significant role in supporting the wild and domestic animals in the dryland ecosystems, but also grants essential ecological services such as soil protection (Lioubimtseva and Henebry, 2009). The distribution of rainfall and temperature decides the global climate zones and the spatial allocation of terrestrial ecosystems; with direct effect on the emergence, distribution and ecological processes of water-influenced biotopes (Barron et al., 2012). Hence, the climatic changes outside the natural variability of the recent climate regime can extremely influence the habitats and the species communities inside of them (Solomon, 2007). The uncertainty regarding the future impacts of climate change on terrestrial biodiversity in Arabian Peninsula is extremely high. Consequently, this uncertainty makes prediction very difficult, despite the availability of high quality data (Agedi, 2016).

## The Influence on the Existence and Distribution of Ecosystems: Impacts on Terrestrial Vegetation and Water Resources

Land degradation has been recently observed worldwide, influenced by human activities and global climate change, especially in arid regions, such as the grassland in Northwestern China (Li et al., 2016). Rangelands (including grasslands, shrublands, deserts and tundra) cover about 50% of the world’s land area, and contain about 35% of above- and below-ground carbon reserves (Schuman et al., 2002). The occurrence and development of terrestrial vegetation is affected by temperature and precipitation. Therefore, it is very important to learn and understand how the climate factors would vary during this century (Gang et al., 2017). Sivakumar (2007) reported that, rangelands in Sub-Sahara Africa are experiencing land degradation and desertification, which will lead to a permanent decline in productivity, as a harsh consequence of climate change in addition to other factors such as overgrazing, overstocking, and destructive soil management practices including nutrient mining. He also mentioned that, poorly managed soils are exposed to degradation and they are vulnerable to become infertile because of climate change. In Arabian Gulf region, climatic change is an additional stressor to worsen current degradation from the severe impacts of overgrazing and land use change in many areas (Talhouk and Abboud, 2009). Rangelands degrade in different ways; decline in bio-productivity, invasion of non-palatable species plus succulents and thorn-bushes, soil erosion, poorer livestock, and among many others (Hillel and Rosenzweig, 2005). Moreover, in desert zones, temperature increases would have harmful impacts on vegetation. As a result, plants with surface root systems, which depend on rainfall, will be at risk (Sivakumar, 2007). This can be expected to occur in other regions with similar conditions, such as farmlands.

Risks of severe vegetation loss leading to positive feedback in dry regions, between soil degradation and reduced vegetation and rainfall, as well as losses of pastoral areas and farmlands will occur (Zheng et al., 2002). Signs of desertification vary in different land-use forms. Based on Kassas (1995), deterioration in irrigated farmlands is often related to waterlogging, mainly because of unevenness of extreme irrigation and inefficient drainage. Nevertheless, degradation of rain-fed farmlands is often evident as soil erosion, loss of organic matter and diminution of nutrients, compaction and crust formation, and extensive attack of weeds (Hillel and Rosenzweig, 2005). The greater-than-average annual population growth rate of 2.5% together with an 8.8% annual increase in the demand for water and the changes resulting from climate change will have major effects on the future availability and quality of water resources in Saudi Arabia (DeNicola et al., 2015) and other similar terrestrial ecosystems in the region. Al-Maamary et al. (2017) reported that, climate change is affecting various sectors and systems such as; distilled water processing, food security, renewable energies and public health. Several areas of the Arabian Gulf countries depend heavily on groundwater. The future estimations have shown that all the countries will be suffering from a lack of water availability (Menzel and Matovelle, 2010). There is a high scientific implication in semi-arid and arid regions, where the demand for finite and stressed fresh water is increasing and influencing groundwater recharge (Viglizzo et al., 2016). Groundwater recharge usually engages a deep drainage function connected to the provision of two ecosystem services: water filtration/ water cleaning, and freshwater supply from underground aquifers (Costanza et al., 2007). This can be a serious issue in regions where underground aquifers are the main source of water; an example is old oases in Al-Ain City, UAE.

Biologists, sociologists, and policy makers are concerned about the possible influences of climate change on ecosystems. Researchers predict that the deserts of North America will become warmer and drier at a fast rate (Solomon, 2007). The unevenness of precipitation in the region has lately increased and this trend is expected to carry on. Moreover, recent indication shows that most of the hydrological and temperature-related climate trends of the western United States are human-induced (Barnett et al., 2008). As a result of these and other related factors such as shifts in the seasonal timing of reproduction, the deserts of North America have experienced several vegetation die-offs associated with extended drought (Stahlschmidt et al., 2011).

## The Influence on the Existence and Distribution of Ecosystems: Carbon Dioxide Emissions a Blessing or a Curse

Including carbon dioxide fertilization in the simulations, produced a decrease in desert area, as the higher carbon dioxide levels allow the plants to prevent the increased aridity in an effective way (Mahowald, 2007).

Ksiksi and Youssef (2010) reported that plants grown under the high carbon dioxide concentration had higher plant height than plants grown under the normal carbon dioxide concentration. Many experiments showed that increased carbon dioxide concentrations could increase photosynthesis and growth, and reduce stomatal conductance. However, the response is varied between different species and experimental conditions (Jarvis and Aitken, 1998). These studies were made under special conditions with controllable amounts of carbon dioxide and controlled temperatures. In reality, other factors might interfere and climate change has shown negative effects on almost all researched fields.

Based on White et al. (1999), climate change that resulted in the loss or reversal of the supposed terrestrial carbon sink, would itself lead to a positive reaction to the climate system. This drew the attention to changes in the amount of carbon stored in global vegetation and soils. Terrestrial plants are a basic sink for anthropogenic carbon, as atmospheric carbon dioxide increases (Falkowski et al., 2000). Terrestrial plants fix carbon dioxide as organic compounds throughout photosynthesis (Beer et al., 2010). They also found that, terrestrial gross primary production (GPP) is the largest global carbon flux, and it controls several ecosystem functions, such as respiration and growth. The effect of climate change on the net primary production (NPP) of the world is expected to be high (Melillo et al., 1993). Terrestrial ecosystems sequester 20 to 30% of global anthropogenic carbon dioxide emissions and play a key role in global carbon cycling (Saleska et al., 2003). On the other hand, global terrestrial net primary productivity is a major driving force of the inter-annual carbon dioxide growth rate (Zhao and Running, 2010). Over the past several decades, climate change positively influenced the terrestrial ecosystems, through a phenomenon known as ”the green trend” (He et al., 2014). Yet, many studies have shown that reduction of (NPP) in the global terrestrial ecosystem, due to increasing temperature rates and drought has significantly weakened that positive effect. Severe drought affected the benefits of climate change for middle and high latitude terrestrial ecosystems (Ma et al., 2012; Zeng et al., 2005). Based on Booker et al. (2013), carbon sequestration would increase over time due to the increase in woody plants. While the bare land and loss in grasses may lead to a decrease in soil carbon stocks in desert from exposure and decay. (GPP), along with respiration, is one of the main processes that controls land-atmosphere carbon dioxide exchange, and provides the capacity of terrestrial ecosystems and to a certain extent counterbalance anthropogenic carbon dioxide emissions (Beer et al., 2010). On the other hand, changes in terrestrial ecosystems will result in a flux of carbon between the land and the atmosphere (Levy et al., 2004). Based on (Xu and Zhou, 2008), stomatal density responds to several environmental factors, such as elevated carbon dioxide concentration, drought, rainfall fluctuation, heat stress, salt stress, and plant density. (Jobb´agy and Jackson, 2000).

Lucht et al. (2006) reported that, changes in temperature, precipitation, light and nutrient availability, and in atmospheric carbon dioxide concentration affect plant biochemistry and physiology in addition to the distribution of carbon in plant parts such as leaves, stems and roots. Moreover, their results showed that plants have developed diverse functional strategies to handle unfavorable conditions such as drought, cold or floods, therefore changes in these conditions will lead to changes in the species composition of an ecosystem even after several decades. Land biosphere is a net sink of carbon (House et al., 2003). Future simulations of the land biosphere’s response to climate change show that there will be a decline in the sink and it will begin in middle of the 21st century, with some scenarios showing a net carbon loss by the end of the century (Woodward and Lomas, 2004). The degree of the terrestrial response on climate is expected to be an extra increase in atmospheric carbon dioxide concentration involving an additional increase in temperature (Berthelot et al., 2005). In global change analyses, predicting terrestrial carbon exchange is critical (Woodwell and Mackenzie, 1995). Nevertheless, if terrestrial carbon is lost to the atmosphere, climate change effects could be worse and improvement costs would increase. Braswell et al. (1997) reported that, models are used to project changes in the terrestrial carbon cycle, but their predictions vary in extent and sometimes in their response. Additionally, they found that atmospheric carbon dioxide record is examined along with global, satellite-derived temperature and vegetation index data to identify the mechanisms controlling the response of terrestrial carbon storage to climate changes.

Based on Yigini and Panagos (2016), researchers confirmed that doubling atmospheric carbon dioxide without the effects of climate change could improve NPP by 25% and lead to a significant expansion in carbon stocks in vegetation and soils. They also found that, climate change without a rise in carbon dioxide rates will reduce the global NPP and soil carbon stocks. However, this can lead to an increase in vegetation carbon in the areas where forests extended and NPP enhanced. Climate appropriateness is one way of looking at the metric standard across all countries in the Arabian Gulf region. It shows the level of assessment of the variables that impact crop production (Al-Maamary et al., 2017). Considering the potential of the Kingdom of Saudi Arabia, or Arabian Gulf region to reach optimal crop yield, Kang et al. (2009); Avnery et al. (2011) applied a quantitative evaluation of t the influences of carbon dioxide on crops production and studied the impact of modifications. Their results showed that yield losses increased with climate change for all emission scenarios and time horizons. Yet, some scientists believe that climate change may present opportunities, including growing food production through better water management, irrigation, rainwater harvesting, and possible increased crop productivity, due to increased aerial fertilization by carbon dioxide (Epule et al., 2017).

## Desert Species' Response to Climate Change

In the coming decades, species will need to modify their distribution patterns, change their behaviors and adjust their physiology. Which can be fulfilled by acclimation throughout phenotypic flexibility or by evolutionary shifts in their physiological phenotype by natural selection (Williams et al., 2012).

Warmer temperatures and seasonal distributions of precipitation had a large impact on the survival of populations, species and communities (El-Gabbas et al., 2016). Through the past 40 years, the main reason for distributional shifts and extinctions is climate change, with a particularly strong impact on butterflies, birds and species at high latitudes (Hannah, 2014; El-Gabbas et al., 2016). These changes are expected to force some ecosystems and their species to move poleward or up-slope, downslope, and cause heterogeneous range, or contractions in their ranges (Inman et al., 2016). The most affected species are those with narrow niche breadth as they may be highly threatened by changes in climates because of their limited geographic range, low dispersal capacity, low reproductive output, and limited physiological tolerances (Schloss et al., 2012). The effects of climate change on species diversity is generally slow, but these effects are expected to show high progress over the next 50 years and beyond (El-Gabbas et al., 2016). It is still not very clear how warming will affect the distribution and survival of many species of plants and animals and whether the effects will be positive or negative (Vieites et al., 2007). They found that in range shifts and demographic changes in short-lived species, effects might be observed easily in response to changes in climate. While measuring population responses of long-lived species requires data from long-term studies that are not always available (Lovich et al., 2014). Sometimes short-term studies of long-lived species can show extreme changes in demographic parameters. The estimates of these parameters over shorter time periods can cover the significance of severe climatic events in case those events were missed (Congdon et al., 1994). The lack of long-term studies for most species makes it harder to understand the impact of climate change, specifically on long-lived organisms (Lovich et al., 2014). Climate change model forecasts propose that from 15 to 37% of existing species will be extinct by 2050 (El-Gabbas et al., 2016). Fast changing climate is expected to change the selective pressures acting on species (Vale and Brito, 2015). Species vulnerability to climatic changes is dependent on their level of exposure, obviously linked to the extent of their geographical environment space would change their sensitivity (Foden et al., 2013). Various faunal and floral species showed different responses to climate change.

## Migratory Birds

Climate change is challenging biodiversity conservation and has altered the distributions of many species over the past several decades (Freeman and Freeman, 2014). If an accurate projection of the effects of climate change on the distribution of species is needed, these changes should be detected and explained (Stone et al., 2013). Climatic changes put migratory birds at greater risk of extinction than permanent resident birds. These species depend on habitats and resources in a wide range of areas at different stages of their annual cycles and because of their nature of using various habitats or geographical areas at different time periods (Cox, 2010).

Based on Wu and Shi (2016), in recent years, changes in the distributions of certain migratory bird species have occurred. Consequently, detection and attribution of the effects of climate change on species changes are critical to anticipate future distribution changes and possible extinctions for migratory birds due to climate warming. Moreover, when comparing the total number of migratory bird species on the earth with the number of species that made changes in their distribution, it was found that the number is relatively small. Almost 6% of birds in the Arabian Gulf region are considered endemic (Mallon, 2011). More than 150 bird species in the Arabian Gulf region are considered threatened nowadays and more species are at high risk from climatic change (Talhouk and Abboud, 2009). Future predictions expect increases in heat waves.

Severe heat waves can lead to serious avian mortality in hot desert environments (Agedi, 2016). McKechnie and Wolf (2009) found that by the 2080s, desert birds could experience low survival times and high frequencies of catastrophic mortality events. Different studies on migratory birds showed influence of various climatic attributes on their distribution. Sekercio˘glu et al. (2012) studied the range shift of migratory birds due to climate and their consequences. A number of studies have highlighted the effects of summer conditions on the distributions of species (Zuckerberg et al., 2011). Additionally, other studies found that interactions between temperature, precipitation rate or other factors influence changes in the distributions of the migratory birds (Wu and Shi, 2016).

### Bats are Bio-indicators of Climate Change

Desert bats were studied to determine if reduced water availability, which is an expected outcome of climate change, would lead to species-specific responses based on morphological traits (Hall et al., 2016). Bats were specifically chosen because they are considered as bio-indicators of climate change due to their sensitivity to environmental conditions such as rising temperatures and droughts (Jones et al., 2009). According to Hall et al. (2016), during times of extended drought periods, bats have experienced a decline in reproduction and undersized young. Due to the high demand of water by lactating females, water loss due to climatic changes would highly affect reproduction (Adams and Hayes, 2008). The experimental findings discovered that smaller water surface areas affected drinking success and timing of use by less-maneuverable bats. Which means that less-maneuverable bats would experience lower drinking ratios upon reduction of water sources (Hall et al., 2016).

### Rodents

A study in California, USA, showed that the ranges of small mammals at high elevations have decreased within the last century most likely due to climate change (Inman et al., 2016). Scientists in Texas, USA have predicted that the distributions of many rodent species will decrease to 60% of their current distributions (Cameron and Scheel, 2001). Similar changes in climate have occurred historically, but wide landscape changes resulted from recent human development may considerably decrease some species’ abilities to adapt to and disband across a rapidly changing landscape (Schloss et al., 2012). This will with no doubt result in narrowing their ranges and causing declination in their population (Inman et al., 2016).

### Reptiles

Climate change has direct and indirect risks on lizard thermal niches by affecting thermal environments in changing the vegetation cover through time (Leavitt and Schalk, 2017). A study made on Egyptian reptiles by

El-Gabbas et al. (2016) showed that some of the species might lose up to 80% of their current habitats in some cases, and some areas will definitely lose or change a large numbers of their species due to climate change. Barrows et al. (2016) reported that, extended drought as one of the climatic changes, with its impacts to prey, activity periods, or hatching success could affect the sustainability of populations of reptiles. They found that climate change might have already caused an up-slope shift for Side Blotched Lizards in USA deserts, as well as Western Whiptails and Chuckwallas. Based on Vale and Brito (2015), Sahara-Sahel endemics are arid-adapted species. They could be sensitive to temperature and precipitation changes, or in some cases have a capacity to tolerate the predicted climatic changes. Experiments showed that reptiles could be sensitive to the future increasing temperatures, especially for species existing near the extremes of their thermal tolerance limits (Bestion et al., 2015). Lizards for instance, have low adaptive capacity, and particularly low dispersal ability that make them highly vulnerable to climatic changes (Vale and Brito, 2015).

In the Arabian Peninsula, reptiles are relatively well protected, (84%) of the species represented in protected areas. Only six species are listed as globally threatened, and only 10 are of regional concern (Talhouk and Abboud, 2009). Land use change and agriculture are considered the greatest threats (Cox et al., 2012) in addition to climate change.

### Plants

Plant-cover change has a global effect on carbon cycle, warming and climate. Vegetation is responsible for transferring heat and releasing water vapor that eventually makes rain. Direct measurements above Amazonia forests showed that evapotranspiration declined and temperature increased after converting forests to pasture (Gash and Nobre, 1997). Through satellite data, it was found that there was a continued release of water vapor into the atmosphere in forests but not in deforested areas, especially during dry periods (Viglizzo et al., 2016). According to Gray and Brady (2016), plants are currently experiencing climate change factors individually, but this will not be the case in the future where they will be exposed to multiple elements of environmental change concurrently. In most studies of plant developmental responses to climate change, plants are exposed to only one climate change factor at a time. This approach is experimentally tractable, but limits the capability to come with conclusions about plant responses to realistic climate change scenarios (Gray and Brady, 2016). The effects of climate warming on desert plants is not very well known. It is due to the general belief that desert vegetation will expand as consequence of climate change but the determination of what plant species will endure the expected increases in temperatures remains as an unanswered question (Arag’on Gast’elum et al., 2014). Compared to current atmospheric carbon dioxide concentrations, across several species and under unstressed conditions, it was found that, crop yields increase at 550 parts per million (ppm) carbon dioxide in the range of 10 to 20% for C3 crops and 0-10% for C4 crops (Ainsworth et al., 2004; Long et al., 2006).

Based on early projections on southwestern Africa Young et al. (2016), indicating that richly bio-diverse regions including the Succulent Karoo and Fynbos biomes would be mostly influenced by changes in the climate. Where some deserts will potentially expand and Fynbos will be reduced. The research papers and studies found on the response of desert species to climate change are limited and mainly on species in ecosystems outside the Arab Gulf region. The references that include studies on the region for example are part of international or local initiatives and lack monitoring and detailed analysis, as well as application of supporting tools.

## Using RS/GIS to Assess Climate Change Effect on Desert Ecosystems

The application of remote sensing (RS) in the research activity and land resource management has been fostered by the beginning of the first land sat launch in 1972. Dailey et al. (2015) adopted an integrated geophysics, remote sensing, and geographical information system (GIS) approach for investigating the role of structural elements, faults and basement uplifts, to control the groundwater flow in the Mojave Desert.

Another study on groundwater was done by (Abdalla, 2012) to determine the most important contributing parameters for indicating the groundwater potential such as slope, stream networks, lineaments, lithology and topography, where a thematic map of each parameter was produced using GIS and RS. GIS models and remote sensing data allows simulating the change in particular landscape elements over time and space, and investigating different types of future scenarios (Maeda et al., 2011). Gad (2015), developed a GIS based model for land capability classification to locate the geographical distribution of the studied soil profiles in the western desert Oases of Egypt. Zhang et al. (2008) developed techniques for assessing and studying land desertification in Yulin of Northern China using RS and GIS. They applied Normalized Difference Vegetation Index (NDVI) to study the change in land cover. They concluded that the integration of RS and GIS was critical for monitoring the environmental change in semi-arid regions. Ahmady-Birgani et al. (2017) used coupled techniques of GIS and RS, where the analysis of remote sensing images offers a successful tool for the monitoring and assessment of sand dune movement and sand sea change. Also in Iran, Masoudi et al. (2018) developed a new technique to evaluate the current state of land degradation in southwestern Iran using satellite images and GIS. Their results indicate that using FAO-UNEP view and NDVI index is a useful method to measure the degree of land degradation or desertification. Their results showed that the amount of degradation in the desert area is extremely higher than other ecosystems. Based on Buchanan et al. (2015), conservationists will always be in need of recent information on habitat extent and change in that extent. Using remote sensing data, Ghadiry et al. (2012) developed a new GIS-based model for automated extraction of sand dune encroachment and for assessing the rate of sand dune movement. Thakkar et al. (2016) improved the classification accuracy in the arid heterogeneous landscape of Arjuni watershed, India, using RS and GIS. In Dubai, GIS and RS were used to determine the dynamics and controls of Surface Urban Heat Sinks (SUHS) and Surface Urban Heat Islands (SUHI) in desert cities (Nassar et al., 2016). Another important application of remote sensing is on assessing drought, due to its massive impact of all the 20th century natural hazards (Obasi, 1994). Khosravi et al. (2017) tried in their study to express the effect of drought on vegetation cover in Yazd-Ardakan plain, central Iran using NDVI and GIS tools. Alshaikh (2015) conducted a study to monitor and assess the drought condition in Wadi-Dama, north KSA, in 1990 and 2013 using satellite remote sensing data analysis and GIS technology. Based on Smith et al. (2014), changes that are too small to be noticed at the local level may be major when reviewed at wider scales captured by remote sensing data. Recently, the spatiotemporal characteristics of the sensitive factors for climate change have experienced significant change (Guo et al., 2015). (Guan et al., 2017) used RS and GIS to collect desert distribution data from the southern region of the Tengger Desert, they analysed indices as well as climate data to explore the primary influencing factors in the desert dynamic changes. Changes in terrestrial vegetation as a reaction to climatic changes have been observed using remote sensing datasets, mostly in climatically extreme regions (Smith et al., 2014). Remote sensing is also used in monitoring the impacts of climate change on ecosystems, such as changes in tree lines with altitude or latitude, and phenology indicators of change during the growing season (Buchanan et al., 2015). Ghoneim (2009) conducted a study on the Arab region, using RS techniques to monitor the impact of climate change. Based on Guo et al. (2015), the use of a range of methods such as multi-satellite, multi-sensor, and long-term time series remote sensing data, helped to develop climate sensitivity factors and support the study of the spatial variability of terrestrial ecosystems to investigate how ecosystems respond to global climate change.

## 2. Methodology

Search engines such as google scholar and web of science were used to collect the available research papers about climate change and desert ecosystems. We also searched for the resources that include climate change and desert. The results are shown in figure 1. It was noticed that the number of research papers increased significantly in the period 1981-2000, because of the Intergovernmental Panel on Climate Change (IPCC) initiative in 1988 and the emphasis put on climate change studies. One hundred and forty (140) references were used. In this review paper, they were categorized according to the keywords in the research articles as shown in table 1. The objectives of this review paper is to; study the impacts of climate change on desert ecosystems in the Arabian Gulf region and to identify gaps and opportunities in related research fields of the region.

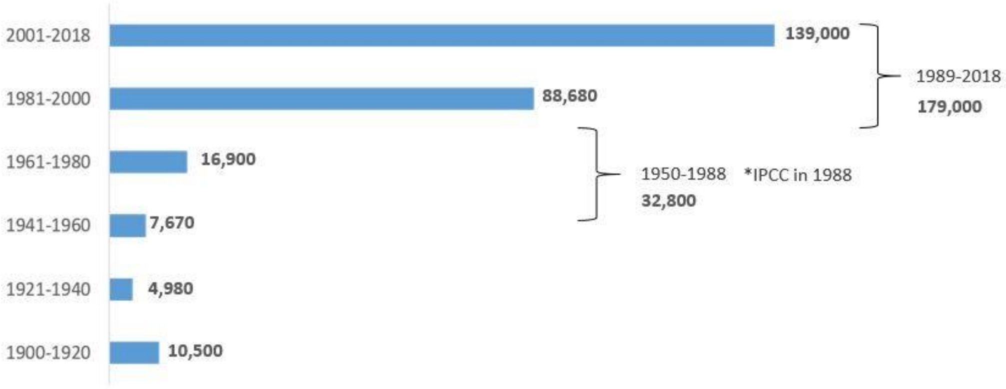

Figure 1: Number of Studies with Climate Change and Desert on Google Scholar in years 1900-2018

Table 1: Statistics of number of studies used in the review paper according to the research topic

| Topic of research | Number of studies in review paper |
|---|---|
| Climate change | 21 |
| Climate change and desert ecosystems | 76 |
| Climate change and desert species | 28 |
| Climate change and RS/GIS | 15 |

## 3. Conclusion

The changes to the Earth’s climate system have arisen from the accumulation of greenhouse gases in the atmosphere, which is leading to an increase in air temperature. Climate change will significantly influence all life sectors in the Arabian Gulf region. The current main problem is the uncertainty in determining its impact, alleviating it and dealing with it (Al-Maamary et al., 2017). Climate has noticeably changed in the Arabian Gulf countries, where temperatures rose during the period from 1960 to 2010, as the cold days and nights over this period decreased, and the area faced warmer nights. Climate and weather have a direct control on the distribution and productivity of species, ecosystems processes and landscapes (Leemans and Eickhout, 2004). Temperatures in the Arabian Peninsula are expected to be higher than the existing by 2 to 2.75 ◦C, while near to the coast; the temperature rise will be lower by 1.5 ◦C (Tolba and Saab, 2009). Fast changing climate is expected to change the selective pressures acting on species (Vale and Brito, 2015). Species vulnerability to climatic changes is dependent on their level of exposure, obviously linked to the extent of their geographical environment space would change their sensitivity (Foden et al., 2013). Conservationists will always be in need of recent information on habitat extent and change in that extent which can be fulfilled using remote sensing tools. From this review paper, we conclude that, there is an urgent need for studies and research on the terrestrial ecosystems and the effect of climate change on the deserts of the Arab Countries and specifically the Arabian Gulf region.

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