Company Name
Your Slogan

2024

UAE CLIMATE VARIABILITY AND IMPACT REPORT

Union Street Eureka
707-445-6600

example@gmail.com

123-456-789

CONTENTS

1 GLOBAL IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES

Climate change is the cause of the global variations in the hydrological cycle. Shifts in precipitation patterns, increased evaporation rates, and frequency of extreme weather events create challenges. These changes are not uniform, with some parts of world experiencing increased rainfall while others parts face severe drought. Water scarcity is now a global issue. It is projected to intensify further due to climate change. Current estimates indicate that by 2025, nearly 5 billion people (over 60% of the projected global population of 8 billion) could live in water-stressed regions (Warszawski et al., 2014). This scarcity is driven by a combination of factors, including population growth, increased demand from agriculture and industry, and the effects of climate change on the hydrological cycle. On the other hand, the greenhouse effect is also leading to more intense precipitation. However, the distribution of this increased rainfall is highly uneven, with some areas experiencing significant reductions. In contrast, others face shifts in the seasonality of wet and dry seasons, disrupting established water systems and agricultural practices.

Coupled Model Intercomparison Project Phase 6 (CMIP6) is the latest product on climate change modelling, organized under the World Climate Research Program (WCRP) (Chai et al., 2024; Song, Chung and Shahid, 2024). It is widely used in major climate evaluations including The Intergovernmental Panel on Climate Change (IPCC). IPCC has consistently highlighted the likelihood of more frequent and intense floods and droughts due to global warming (Githeko and Woodward, 2003; Solecki, Roberts and Seto, 2024). These impacts are a result of physical changes in the climate, with many attributed to human activities (Lee et al., 2024). A rise in global temperatures has been recorded, 2011-2020 decade was approximately 1.1°C warmer than 1850-1900 (Lee et al., 2024). Projections suggest a stressed future, with potentially hundreds of millions more people facing increased water shortages by mid-century and beyond. Specifically, estimates indicate that an additional 335 million, 524 million, and 862 million people may experience heightened water scarcity by 2025, 2050, and 2085, respectively (Arnell et al., 2010). The IPCC reports also emphasize the growing concern of drought globally, predicting more severe and prolonged droughts in many regions (Arnell, 1999). These droughts threaten agriculture significantly, impacting crop yields and food security. Overall climate change will affect more on the Northern Hemisphere as compared to the Southern Hemisphere (Song, Chung and Shahid, 2024). Most of the projections have shown a high increase in precipitation for the low latitude of the Northern Hemisphere (Song, Chung and Shahid, 2024). The extent of future climate effects depends significantly on present decisions making.

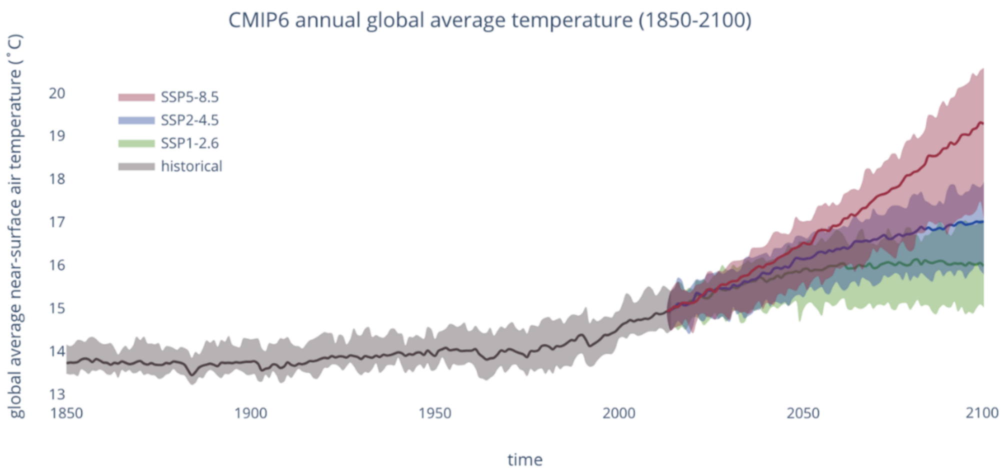

Figure 1: 001 Global temperature change from 1850 to 2100 using CMIP6 model. Credit: NOAA

1.1 THE WATER CYCLE

The water cycle (hydrological cycle), is a fundamental process driven by the Sun energy and Earth's gravity. It governs the continuous movement and transformation of water through various states of liquid, vapour, and ice and different locations of atmosphere, land surface, and subsurface (Allan et al., 2020). This natural cycle is essential for replenishing and distributing freshwater resources across the globe, sustaining ecosystems, supporting agriculture, and enabling human life.

1.1.1 THE NATURAL WATER CYCLE

At its core, the natural water cycle is a continuous loop powered by solar radiation mainly through vaporization (Kundzewicz, 2008). Solar energy heats the Earth's surface causing water to evaporate from water bodies such as; oceans, lakes, rivers, and even the soil. This evaporated water rises into the atmosphere. As it ascends, the water vapour cools and condenses, forming clouds of tiny water droplets or ice crystals. Eventually, these droplets grow large enough to fall back to Earth as precipitation. Upon reaching the Earth's surface, precipitation follows several pathways. Some water is intercepted by vegetation, which may evaporate directly into the atmosphere. The remaining water either flows over the land surface as runoff, eventually feeding rivers, streams, and lakes or infiltrates the ground, replenishing soil moisture and groundwater aquifers. Groundwater can also contribute to surface runoff through springs and seeps. Ultimately, much of this water returns to the oceans, completing the cycle and setting the stage for renewed evaporation.

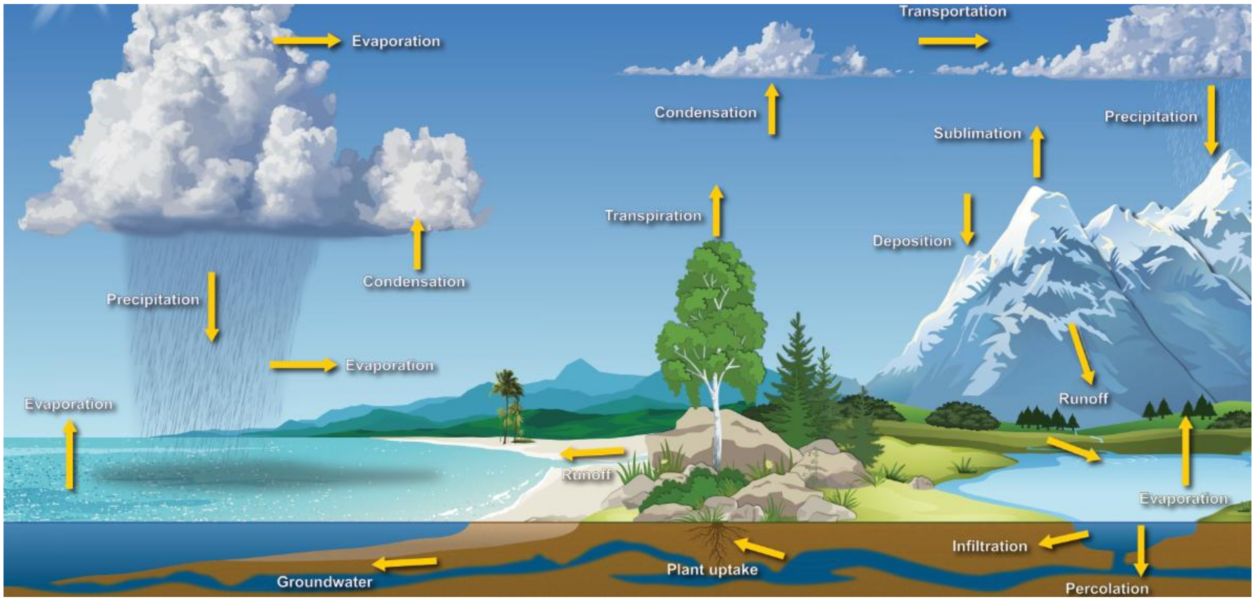

Figure 2: 002 Complex path of Water cycle from atmosphere to surface to underground, transitioning from different phases. Credit: Dennis Cain/NWS (Cain, 2024)

1.1.2 THE BINARY WATER CYCLE: INTEGRATING HUMAN INFLUENCE

While the natural water cycle continues to operate, human activities have significantly altered its dynamics, creating what can be described as a "binary" water cycle system (Nan, Bao-hui and Chun-Kun, 2011). This binary system reflects the relation between natural processes and human interventions, often driven by economic development, land-use changes, and water resource management practices (fig 003).

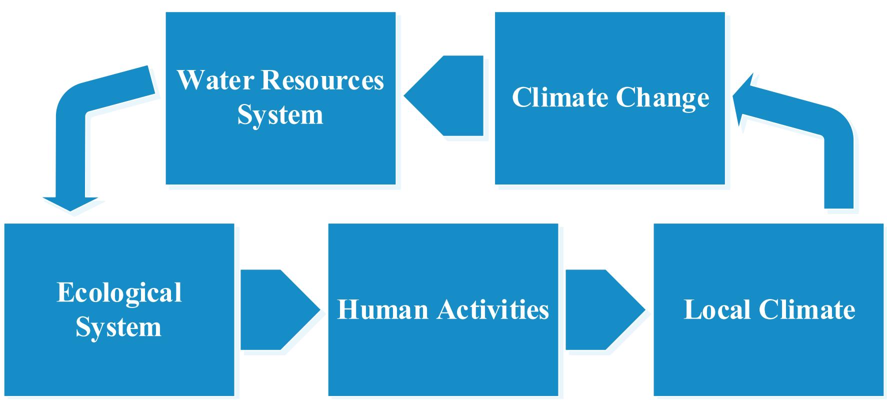

Figure 3: 003 Illustration of interactions between various systems in a binary water cycle.

Climate change is one of the most significant human influences on the water cycle. The enhanced greenhouse effect, caused by human activities is increasing evaporation and changing precipitation patterns, leading to more extreme weather events and impacting runoff and water availability (Nan, Bao-hui and Chun-Kun, 2011). In addition to climate change, direct human interventions, such as dam construction, large-scale irrigation, urbanization, and industrial processes, further change the natural flow of water (Allan et al., 2020). For example;

- Greenhouse gas emissions from human activity can affect the water cycle by altering the atmospheric energy budget. This can affect the frequency and intensity of flooding, droughts, and precipitation extremes (Allan et al., 2020).
- Urbanization and activities such as soil compaction and sealing can also alter the water cycle by reducing infiltration and recharge rates of groundwater, increasing runoff and flash floods (Allan et al., 2020).

The binary nature of the modern water cycle presents significant challenges for water resource management. Understanding the interactions between natural processes and human interventions is crucial for developing sustainable strategies that balance environmental preservation with human needs in a changing world.

1.2 PROJECTIONS FOR GLOBAL WATER DEMAND

By 2025, approximately 5 billion individuals of a world population (8 billion) are projected to reside in nations facing water stress (Arnell, 1999). Global water demand across all sectors is currently estimated at 4,600 km³ per year and is projected to increase by 20% to 30%, reaching between 5,500 and 6,000 km³ annually by 2050 (Boretti and Rosa, 2019). Further, it is also suggested a 55% increase in global water demand by 2050 (fig 004). While agriculture will remain the largest water-consuming sector, industrial and domestic demands are expected to grow at a faster pace. The anticipated population growth by 2050, from the current 8 billion to between 9.4 and 10.2 billion, will place a further strain on water resources (Piao et al., 2010). It will put a huge pressure on water availability in the Arab peninsula, might increases water scarcity to 80 to 100 percent with projected population growth and increasing climate temperature (fig 004). Projects a global population exceeding 9 billion by 2050, with nearly all growth occurring in less-developed states. Africa and Asia will contribute significantly to this growth, with Africa's population expected to double and Asia adding 750 million people (Boretti and Rosa, 2019). This will have significant impact of the water withdrawal (fig 004). This growth and urbanization trends will drive increased demand for water supply services, especially in developing regions.

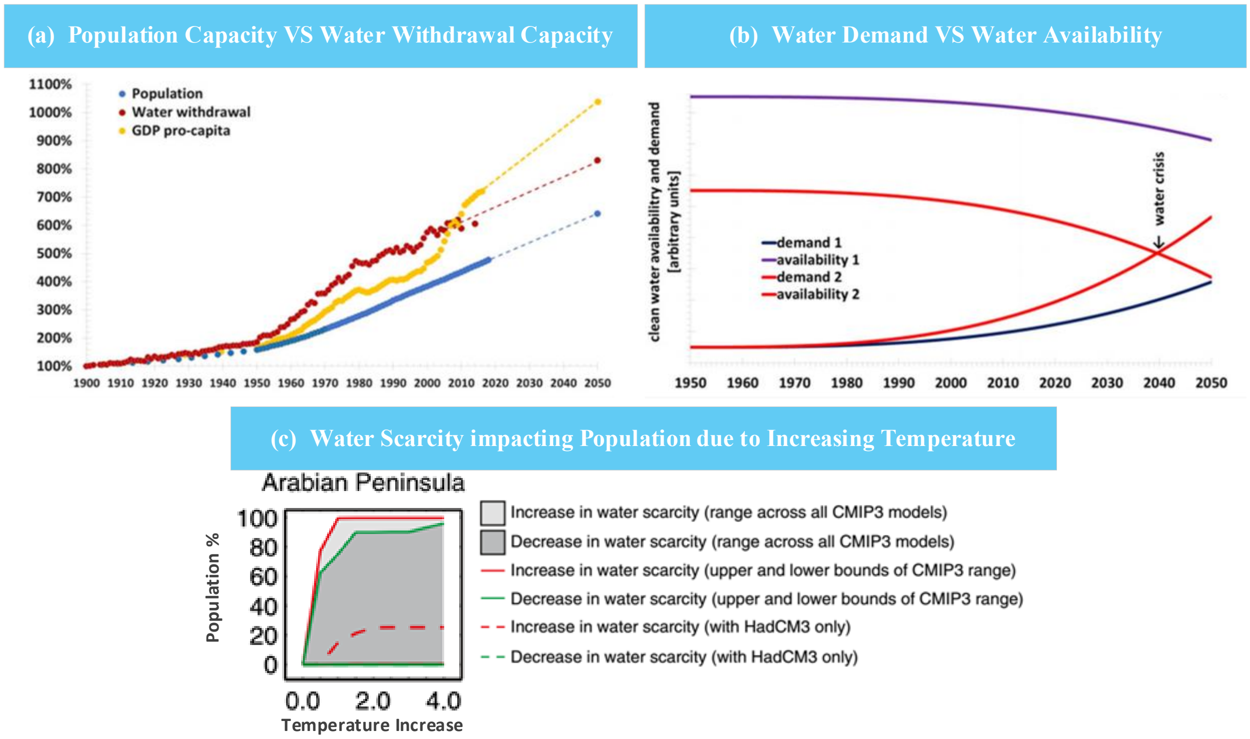

Figure 4: 004 (a) Trends in population growth, GDP per capita, and water withdrawal (1900–2050). Dashed lines indicate projected trajectories beyond 2020. (b) Projected clean water availability and demand (1950–2050). The intersection of demand and availability indicates a potential water crisis by 2040 under different scenarios. (c) Relationship between global temperature increase (above 1961–1990 levels) and exposure to water scarcity due to climate change, using the Water Crowding Index (WCI). The graphs show the percentage of regional and global populations experiencing increased or decreased water scarcity under an A1B socio-economic scenario for 2050. Results are based on ranges from CMIP3 models and HadCM3 projections. (Gosling and Arnell, 2016)

1.2.1 WATER DEMAND: A 2050 PERSPECTIVE

Global water demand has risen dramatically over the past century, driven by population growth, economic development, and evolving consumption patterns. Over the last 100 years, water use has surged by 600%, corresponding to an annual growth rate of 1.8% (Boretti and Rosa, 2019). While the current growth rate is lower, at approximately 1%, this may still be an optimistic estimate. Looking ahead, water demand is expected to rise unevenly across various regions, with the high increases occurring in urban areas. While access to improved water sources is expected to increase, primarily in the BRICS nations, over 240 million people globally are projected to lack such access by 2050 (OECD Environmental Outlook to 2050, 2012). This disparity highlights the uneven distribution of water resources and the challenges in ensuring equitable access.

1.2.1.1 SECTORAL CONTRIBUTIONS TO WATER DEMAND

- **Agriculture:** Currently, agriculture accounts for 70% of global water usage, primarily for irrigation. To meet increasing food demands, this usage is projected to rise by 60% by 2050 (Fao, 2018). This will require expanded agricultural land and intensified production, significantly boosting water usage in this sector. Estimates global water withdrawals at about 5000 km^3 in 2000, with total water depletion at about 2900 km^3. By 2050, 53% of cereal production growth is expected to come from irrigation.

- **Industry:** Industrial water use represents 20% of the total, with energy production accounting for 75% of industrial consumption and manufacturing making up the remaining 25% (Water, 2012). By 2050, industrial water demand is expected to increase by 250% in Asia and 800% in Africa, where current usage is minimal (Wada et al., 2016). Global manufacturing water demand is projected to grow by 400%, with energy-related water use increasing by 20% between 2010 and 2035 and 85% by 2050 (Wada et al., 2016).

- **Domestic Use:** Domestic water consumption accounts for 10% of the global total and is expected to grow substantially by 2050. It highlights that as economies grow, water consumption becomes more intensive, indirectly through increased consumption of water-intensive foods and goods.

1.2.1.2 THE GLOBAL WATER CRISIS

Water scarcity is already a pressing issue for many countries, and the situation is expected to worsen by 2050. As of the mid-2010s, **1.9 billion people (27% of the global population) lived in areas with potential severe water scarcity** (UN, 2018) By 2050, this number is projected to rise to between 2.7 and 3.2 billion, a 42-95% increase (Veldkamp et al., 2017; UN, 2018). If monthly variations are considered, nearly 50% of the global population experiences water scarcity for at least one month each year, a figure expected to increase to 58% (4.8-5.7 billion people) by 2050. Currently, 73% of those affected by water scarcity live in Asia.

1.2.1.3 COASTAL ZONES UNDER PRESSURE

Coastal areas are home to large and growing populations. These areas are especially vulnerable to climate change impacts. Excessive pumping of groundwater, a critical resource for these communities, causes the land to sink. This combined with rising sea levels, creates a dangerous cycle: saltwater seeps into freshwater sources, polluting them and making land unsuitable for farming (Ranjan *et al.*, 2009). Studies have shown that groundwater extraction affects coastal aquifers as it leads to saltwater buildup in the cavities left by freshwater (Ferguson and Gleeson, 2012). As compared to groundwater extraction, the sea level rise (SLR) will have a much higher impact on groundwater as it leads to much more saline water intrusion into fresh groundwater (fig 005) (Ferguson and Gleeson, 2012). Managing water resources in these areas is a complex issue.

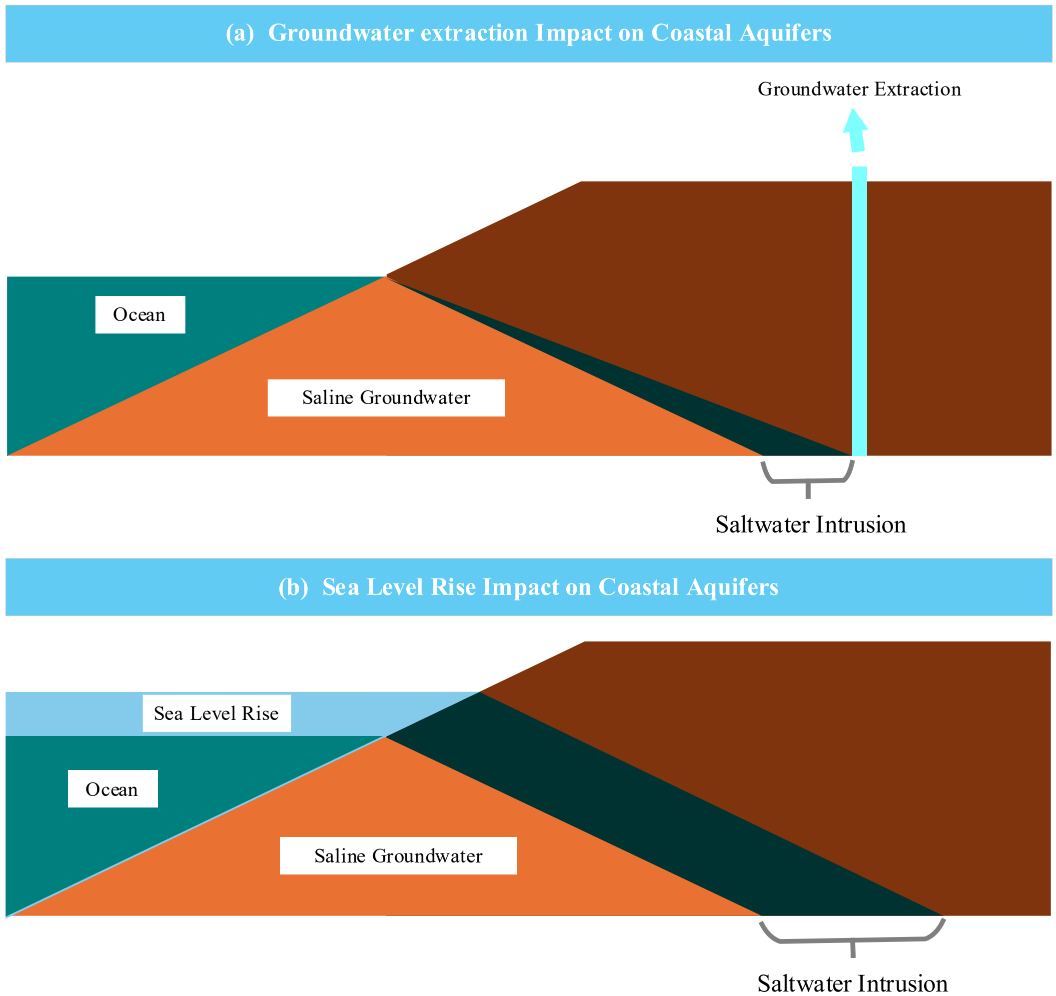

Figure 5: 005 Groundwater extraction and Seal Level Rise impact on coastal aquifers due to the intrusion of salt water from sea (Ferguson and Gleeson, 2012)

1.2.1.4 GROUNDWATER: A RESOURCE AT RISK

Groundwater, essential for both agriculture and drinking water, is being used up faster than it can be replenished. In the 2010s, global groundwater use was approximately 800 $km^3 year^{-1}$. In which few number of countries United States, India, Iran, China, and Pakistan, were responsible for 67% of this consumption (Nan, Bao-hui and Chun-Kun, 2011). By 2050, global groundwater demand is projected to reach 1,100 cubic kilometres annually, a 39% increase (Wada *et al.*, 2016). Alarmingly, over 30% of the world's major groundwater systems are already stressed, and the lack of accurate information about remaining reserves makes continued pumping a dangerous practice, potentially leading to permanent depletion.

1.2.1.5 DESALINATION: A SOLUTION WITH MORE CHALLENGES

Coastal zones face unique water-related challenges due to their dense populations and higher rates of urbanization. Over-extraction of groundwater in these areas leads to land subsidence, which, combined with sea level rise, exacerbates salinization and reduces arable land (Hu *et al.*, 2009; Hoogland, Van den Akker and Brus, 2012; Wang *et al.*, 2012; Shirzaei *et al.*, 2021). These issues threaten water availability and agricultural productivity in many coastal regions worldwide, changing their environmental and socio-economic landscapes. To address water scarcity, desalination has emerged as a potential solution, especially for coastal populations. However, it remains energy-intensive and expensive, limiting its adoption to around 1% of the global population. With the depletion of groundwater and rising global temperatures, salinization of water resources is expected to intensify. This will lead to an increased salt content in water causing higher reliance and more complexity of the desalination process.

1.2.2 IMPACTS ON WATER QUALITY: A 2050 PERSPECTIVE

Water quality faces a precarious future. By 2050, rising temperatures, altered precipitation patterns, and shifting wind regimes are projected to damage water resources globally. IPCC predicts a global average temperature increase of 1.5–2.5°C by 2050, leading to gushing effects on aquatic ecosystems (Pielke Jr, Burgess and Ritchie, 2022). This warming trend, coupled with changes in nutrient loading and other factors, will aggregate existing challenges and create new ones. Understanding these impacts is crucial for developing effective mitigation and adaptation strategies.

1.2.2.1 TEMPERATURE'S RIPPLE EFFECT

Temperature acts as a master control in aquatic environments, influencing fundamental chemical and physical processes. A projected increase of 1.5–2.5°C by 2050 will have profound implications for water quality. The solubility of oxygen in water decreases by approximately 10% per degree Celsius increase, such temperature change can lead to blooms in cyanobacteria, microbial activity in sediments causing high phosphorus content, limiting nutrients mixing conditions which are harmful to aquatic life specially in small lakes and dams (Peperzak, 2003; Hudnell, 2008; Joehnk *et al.*, 2008).

1.2.2.2 PRECIPITATION EFFECTS ON WATER QUALITY

In addition to temperature effects, alterations in the hydrological cycle are a major consequence of climate change. Significantly impacting water quality and nutrient dynamics. Climate projections under IPCC scenarios suggest that precipitation patterns will become more variable, with a decrease expected around the equatorial Pacific and high-latitude regions, while certain mid-latitude and subtropical areas may experience an increase in precipitation (Song, Chung and Shahid, 2024). In regions with higher projected precipitation, extreme precipitation events are likely to become more frequent and intense (fig 006).

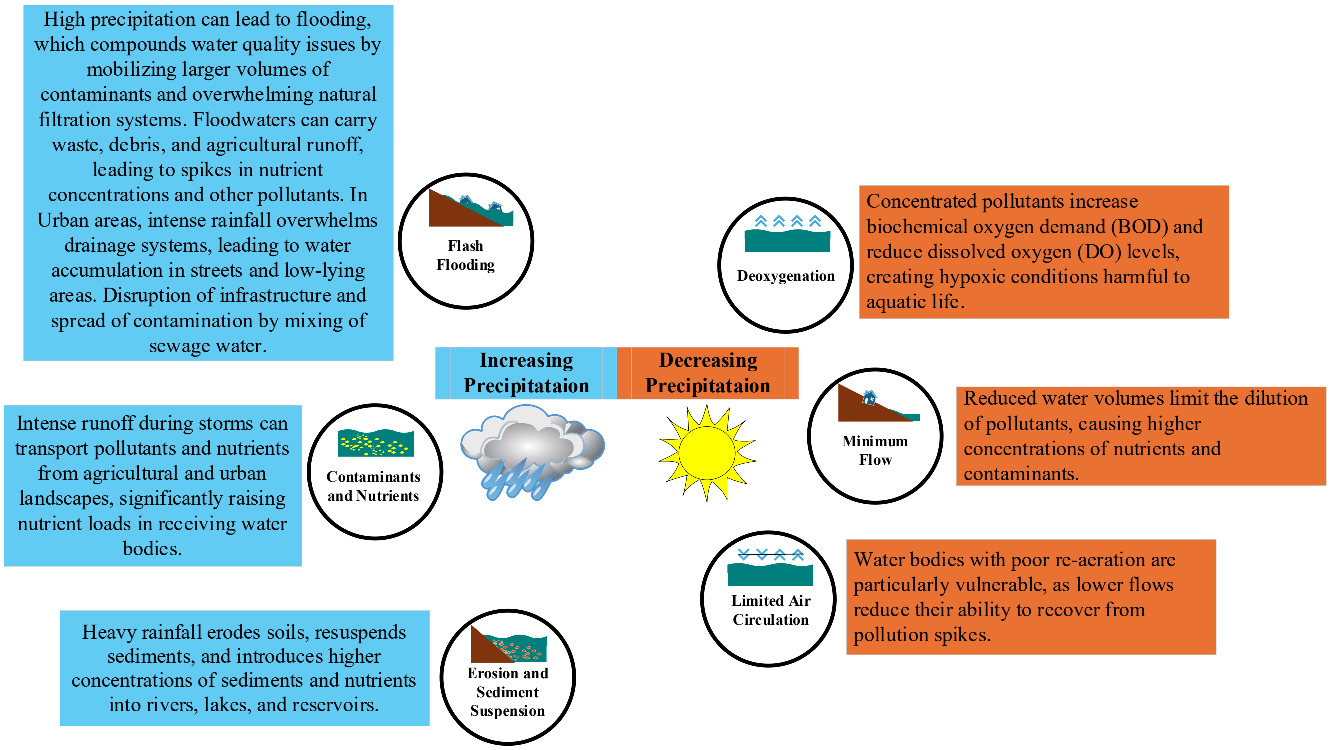

Figure 6: 006 Depiction of the impacts of increasing and decreasing precipitation in the UAE

1.3 CLIMATE CHANGE AND ITS EFFECTS ON THE ARAB REGION

The Arab region and the broader Middle East are facing climate change challenges impacting water, agriculture, urban infrastructure, and public health. These challenges are particularly noticeable in this Arab peninsula, where there is a heavy dependence on fossil fuels. The burning of these fuels releases large quantities of greenhouse gases which contribute to a global rise in temperature. It has been estimated that greenhouse gasses can increase by about 2-3% temperature in the Arab region (Al-Mebayedh, 2013). One of the impacts of climate change in the Arab world is water scarcity and the uneven distribution of water resources across the region makes it worse. Countries like Iraq, Syria, and Lebanon may have relatively more water availability compared to others, but much of the rest of the Middle East is experiencing acute shortages, with many countries already facing water stress (Al-Mebayedh, 2013). This situation is concerning, as water scarcity is expected to intensify under future climate scenarios, putting additional strain on already fragile ecosystems and communities. Agricultural livelihoods are especially at risk. Reduced agricultural productivity due to changing weather patterns, prolonged droughts, and increased temperatures will mostly affect poorer populations who rely on agriculture for their livelihoods. This creates a cycle of vulnerability, where most poor communities are hit hardest by climate impacts, making them even more vulnerable to food insecurity and economic instability (Al-Mebayedh, 2013). The Arabian Gulf, in particular, has already experienced a warming trend of about 0.2°C per decade, which is accelerating faster than the global average in certain areas, with some parts of the Gulf warming three times more (Ksiksi and Al-Blooshi, 2019). Rapid warming exacerbates existing environmental issues and threatens the region's economic and social stability. The combined effects of these climate stressors are making it increasingly difficult for the region to adapt and sustain its way of life.

The Eastern Mediterranean and Middle East are warming at an alarming rate of 0.45°C per decade, a pace 1.66 times faster than the global average of 0.27°C per decade (Zittis et al., 2022). This increase in temperature is slightly more pronounced than the rise in land areas at ±40° latitude, where temperatures are growing 1.5 times faster than the global average (Sutton, Dong and Gregory, 2007). According to projections by the IPCC, this warming trend is expected to persist throughout the century, with the extent of warming dependent on future emissions scenarios. In a more optimistic scenario (SSP1-2.6), temperatures in the Gulf region could rise by 1.3°C, while a more pessimistic scenario (SSP5-8.5) predicts an increase of 4.7°C. However, real-world outcomes are likely to fall somewhere between these two projections (Hausfather and Peters, 2020).This underscores the importance of considering a range of future outcomes when planning for climate adaptation.

The Key observations of Gulf region challenges related to water availability and drought as a result of climate change are as follows:

1. **Divergent Expectations on Water Stress**

   Projections regarding changes in water stress due to climate change vary significantly at both national and global levels for the Gulf region. This inconsistency reflects differing methodologies and assumptions in climate and water resource studies (Nelson *et al.*, 2009).

2. **Increased Water Pressure Without Comprehensive Estimates**

   Advanced simulations indicate that water stress is likely to intensify in the Gulf region under climate change. However, these simulations lack consistent estimates of how individual countries are specifically impacted. Additionally, they do not account for crucial factors such as desalinated seawater and withdrawals from older groundwater reserves (Tatsumi *et al.*, 2011).

3. **Importance of Desalination and Groundwater**

   Desalinated seawater and ancient groundwater reserves are critical components of the Gulf's water balance. A complete understanding of water needs in the region must also consider the water demands embedded in imported goods and the role of these non-conventional water sources in offsetting climate-induced pressures (Lobell *et al.*, 2008).

4. **Limited Flood Impact Assessments**

   Except for one global study, there is minimal detailed analysis of climate change's impact on flooding in the Gulf region. Climate models provide only preliminary evidence linking changes in flooding patterns to climate change within the region (Fischer, 2009).

5. **Sea Level Rise Impacts on Coastal Populations**

   While sea level rise poses a global threat, its impact on coastal populations in the Gulf region is relatively minor compared to many other nations. This suggests that while the Gulf faces acute water stress, other climate risks may not yet be as pronounced (Arnell *et al.*, 2010).

2 CLIMATE CHANGE IMPACT ON WATER RESOURCES IN UAE

The United Arab Emirates (UAE) is positioned in the Middle East, occupying the southeastern corner of the Arabian Peninsula. It shares borders with Saudi Arabia to the South and West, Oman to the Southeast, and the Persian Gulf to the North. It's proximity to the **strategic Strait of Hormuz a vital global shipping route** bolsters its geopolitical and economic significance, serving as a critical link for trade between Asia, Africa, and Europe (Akhavan and Akhavan, 2020). UAE contain diverse topology with topography, ranging from sea level along its extensive coastlines to rugged mountainous regions in the northeast (fig 007).

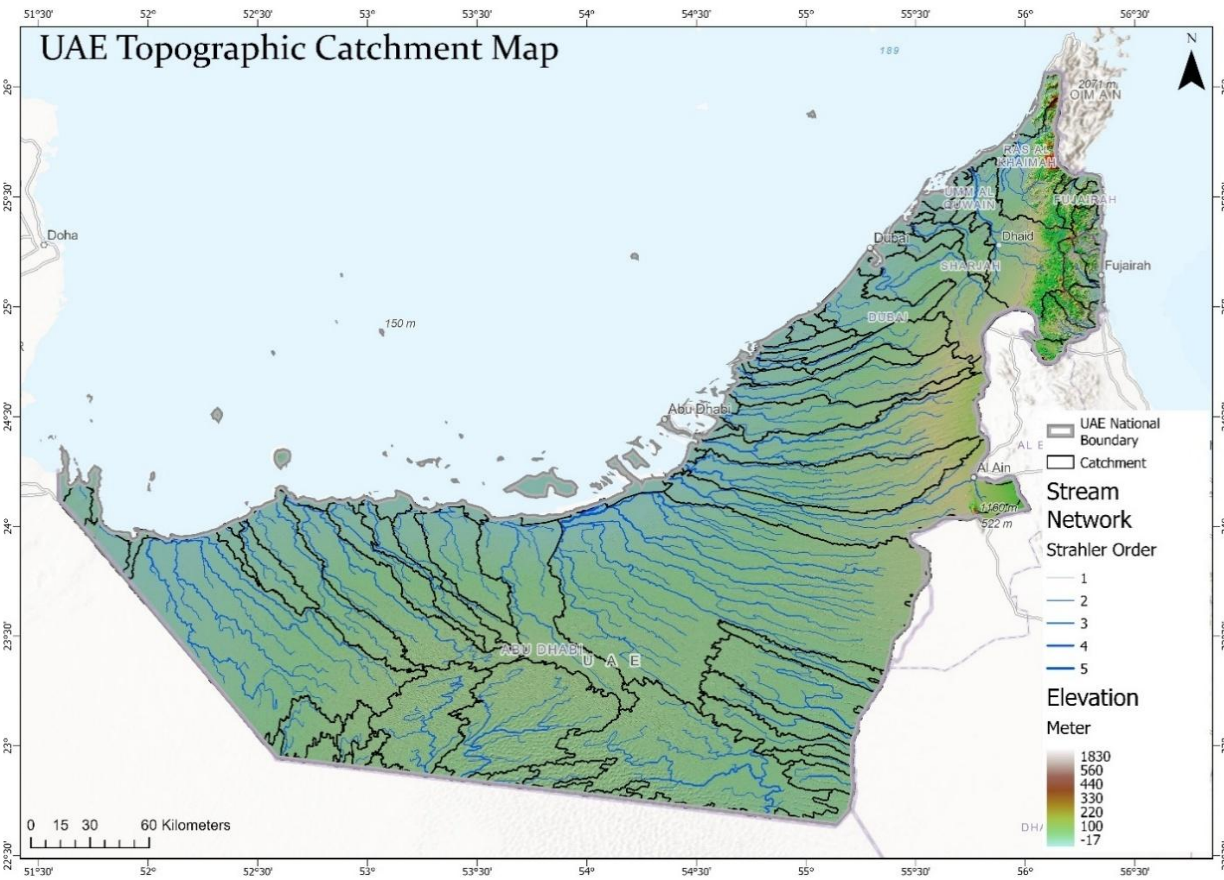

Figure 7: Topographical map of UAE representing elevation (from light blue to brown color), and Watershed with representation of blue lines for stream network and black polygons for basins. 007

Though a small country, the UAE is characterized by a remarkable variety of geographical features. It is divided into four main regions (Feulner, 2023);

1. **Coastal Plains**: These regions span the Arabian Gulf and Gulf of Oman, showcasing white sand beaches, sheltered lagoons, and prominent coastal sabkhas, especially west of Abu Dhabi Island. The area is rich in biodiversity, with mangrove forests, salt marshes, and eroded coastal dunes contributing to its ecological and geological significance.

2. **Sand Deserts**: Covering the west, south, and central parts of the country, the sand deserts are characterized by vast dune fields and extreme heat, with summer temperatures often exceeding 40°C. Rainfall in these regions is rare, highly localized, and unpredictable.

3. **Mountain Regions**: Located in the eastern UAE, the rugged Hajar Mountains stand in stark contrast to the arid deserts. These mountains are geologically significant and serve as vital freshwater sources, with rainfall flowing through wadis to replenish aquifers.

4. **Alluvial Plains**: Found alongside the mountains in the east and west, these plains are formed by sediment deposits from water flows. They play a critical role in groundwater recharge and support diverse vegetation and human activity.

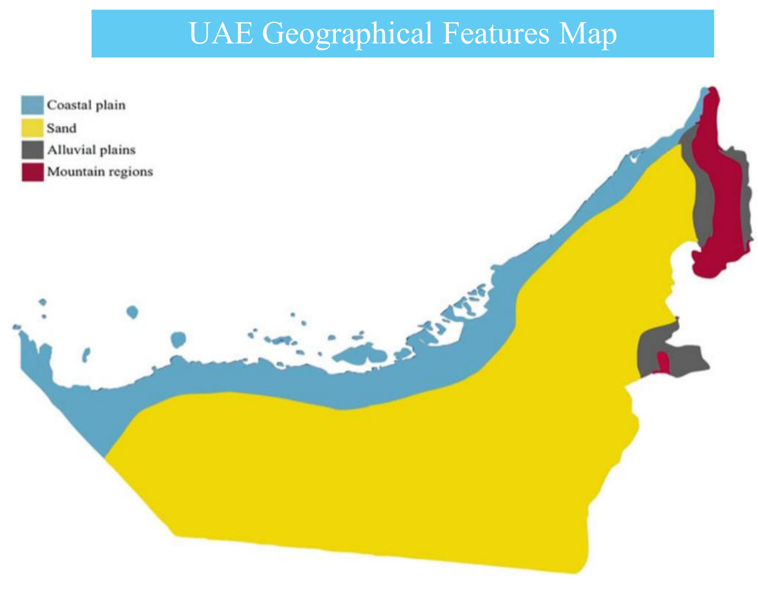

Figure 8: 008 Spatial representation of UAE four main geographical features (Feulner, 2023)

The United Arab Emirates experiences a hyper-arid desert climate classified as BWh (Köppen climate classification) (Paparella and Burt, 2023). This climate is characterized by extremely hot summers, mild winters, and minimal annual rainfall, with the majority of precipitation occurring sporadically during the winter months. Summers are intensely hot, with maximum temperatures often surpassing 40°C, while winters are moderate, with temperatures ranging between 10°C and 30°C (Elmahdy and Mohamed, 2015). Annual rainfall is scarce and unevenly distributed, varying from 40 mm in arid desert regions to 160 mm in mountainous areas, typically occurring during brief winter storms (Al-Rashed and Sherif, 2000). Typically the annual rainfall is less than 120mm (Terry et al., 2023). Coastal areas experience high humidity, especially in the summer, influencing both the natural habitat and urban development patterns.

With significant changes in Climate over the Arab region UAE falls under 4 major challenges of increasing temperature, water scarcity, irregular precipitation patterns, flash floods, drought and sea level rise (AlRustamani, 2014). These factors are discussed in detail in further components.

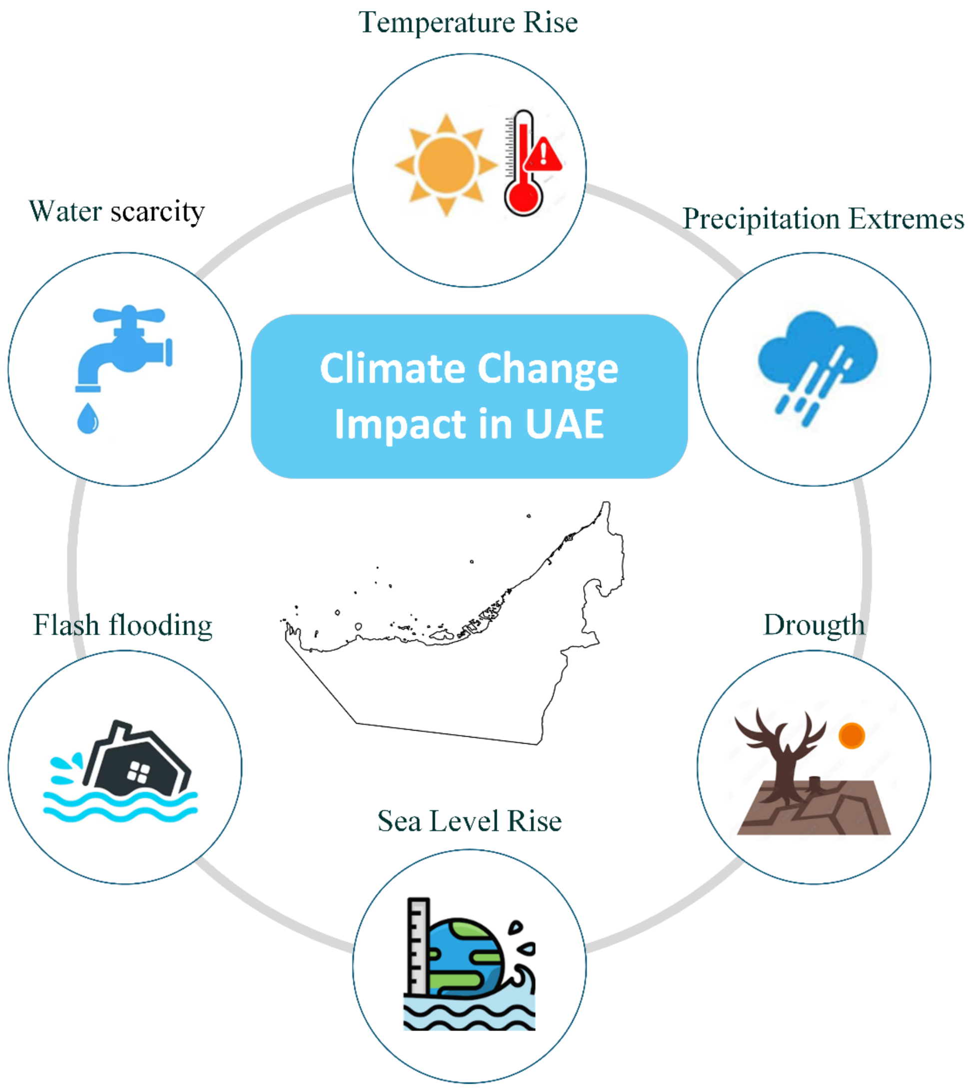

Figure 9: Factors impacting UAE due to Climate Change 0091

2.1 PRECIPITATION PATTERN AND ITS IMPACT

Precipitation plays a crucial role in replenishing groundwater resources and supporting ecosystems in the UAE. However, the region's limited rainfall is often unevenly distributed, leading to challenges in water resource management, particularly increasing water demand and climate variability. Understanding precipitation trends and variability is important for sustainable development in the UAE. The UAE experiences low and erratic rainfall, averaging around 78 to 120 mm annually showing significant variability from year to year (AlRustamani, 2014; Terry et al., 2023).

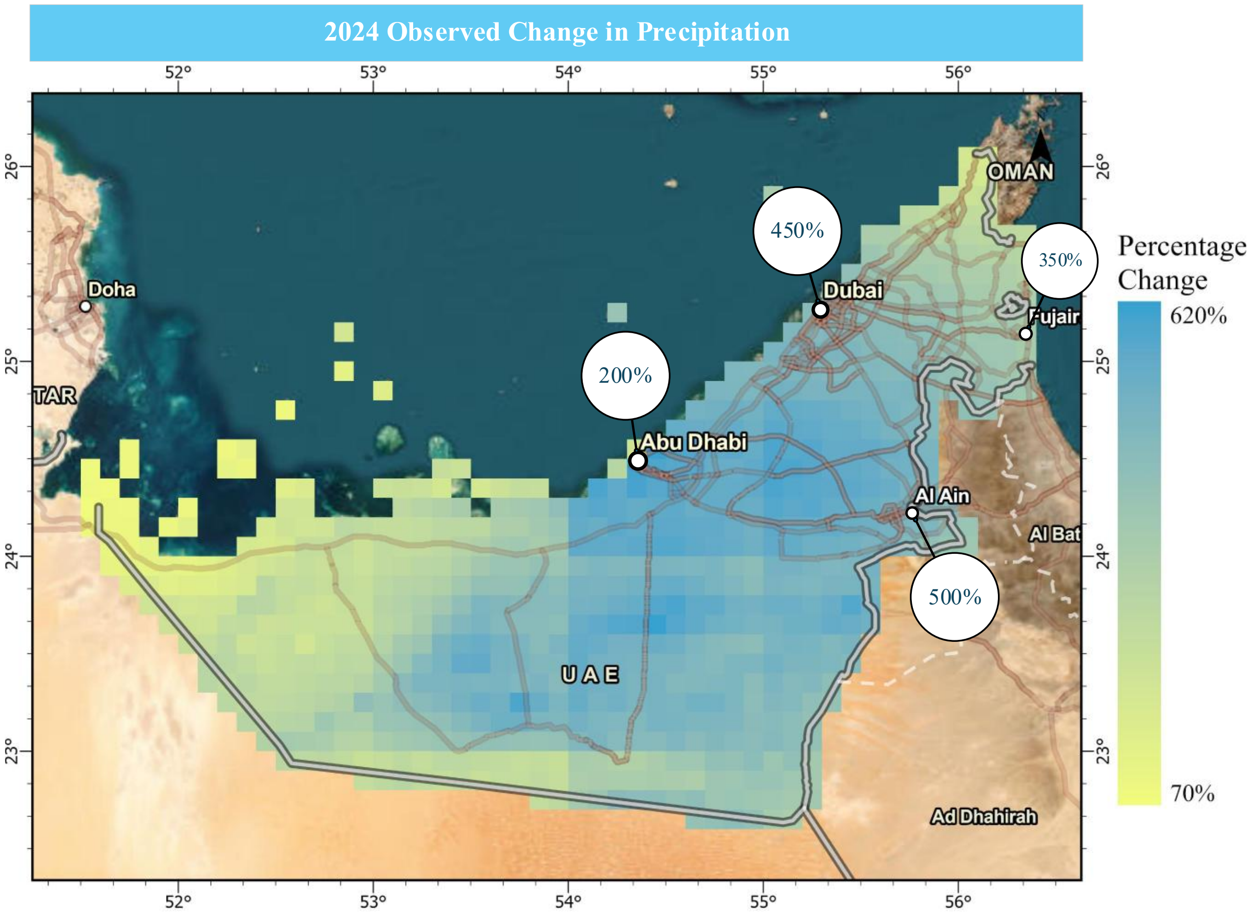

Figure 10: Percentage change in Precipitation in UAE using GPM dataset for average precipitation from 2000 to 2020 009

Precipitation patterns in the UAE during 2024 were highly unpredictable, marking it as a year of climate extremes that signal the crossing of a threshold associated with climate change is true (fig 009). Using the Global Precipitation Measurement (GPM) satellite on precipitation measures of 2024 in UAE. Revealed increasing changes in precipitation trends across the country. For instance, Al Ain experienced a 500% increase in precipitation compared to the past 20-year average (2000-2020), while Dubai, Fujairah, and Abu Dhabi recorded increases of 450%, 350%, and 200%, respectively (Figure 009). Arid regions precipitation is typically sparse. Over the last few years, it has become highly variable, both in terms of frequency and magnitude. Under the SSP5-8.5 scenario, model predictions indicate a wide range of potential changes in rainfall, from -21% to +196% (Paparella and Burt, 2023). This large variability underscores the increasing unpredictability of rainfall patterns in the region, with far-reaching implications for water resource management, agricultural practices, and flood risk mitigation.

The UAE experienced a precipitation event in February 2024, with high rainfall recorded at several locations. Rain gauges reported a maximum of **145.4 mm over two days (February 10–12)** at UAE University in Al Ain (National Center of Meteorology 2024). Other notable observations included 127.6

mm in Khatm Al Shaklah, 116.3 mm in Al Sarouj, 79.1 mm in Umm Ghafa, and 74.8 mm in Saa (National Center of Meteorology 2024). Ahu Dhabi and Dubai showed precipitation of around 50 mm. Satellite-derived precipitation datasets, including PERSIANN-CDR, CHIRPS, and GPM also showed similar findings, revealing rainfall of 102 mm for February (fig 0010). The most rainfall was concentrated in Al Ain, Fujairah, and coastal areas such as Dubai and Sharjah. Daily precipitation showed February 12 as the peak of the event, with rainfall rates of 7 mm/day by PERSIANN-CDR and 16 mm/day by CHIRPS (fig 002).

Table 1: 111 Top 5 observed precipitation sites in UAE from February 10th to 12th, 2024.

Precipitation from February 10th to 12th 2024 in UAE	
Location	**Precipitation (mm)**
UAE University	145.4
Khaam Al Shaklah	127.6
Al Sarouj	116.3
Umm Ghafa	79..1
Saa	74.8

Heavy rainfall was recorded in April, with a maximum of **234.4 mm over two days (April 14–16)** in Khatm Al Shiklah region (National Center of Meteorology 2024). This two-day event delivered rainfall equivalent to the UAE's 2 years of precipitation. The table (Table 112) provides a detailed account of other significant precipitation events recorded during this period with the majority of locations showing higher than 200 mm precipitation. Daily visualization through CHIPS precipitation shows majority of the precipitation occurs in just 2 days on 15 and 16 April with an average rate of 15 mm/day over UAE (fig 00101). GPM showed similar results with an average of 75 mm/month precipitation recorded through UAE. When visualized spatially, West part of UAE stayed dry while North and Eastern parts got heavy precipitation.

Table 2: 112 Top 5 observed precipitation sites in UAE from April 14th to 16th, 2024.

Precipitation from April 14th to 17th 2024 in UAE	
Location	**Precipitation (mm)**
Khatm Al Shiklah	259.5
Kalbah	239.5
Al Marmoom	219.4

Wadi Al Tuwa	205.6
Margham	200.6

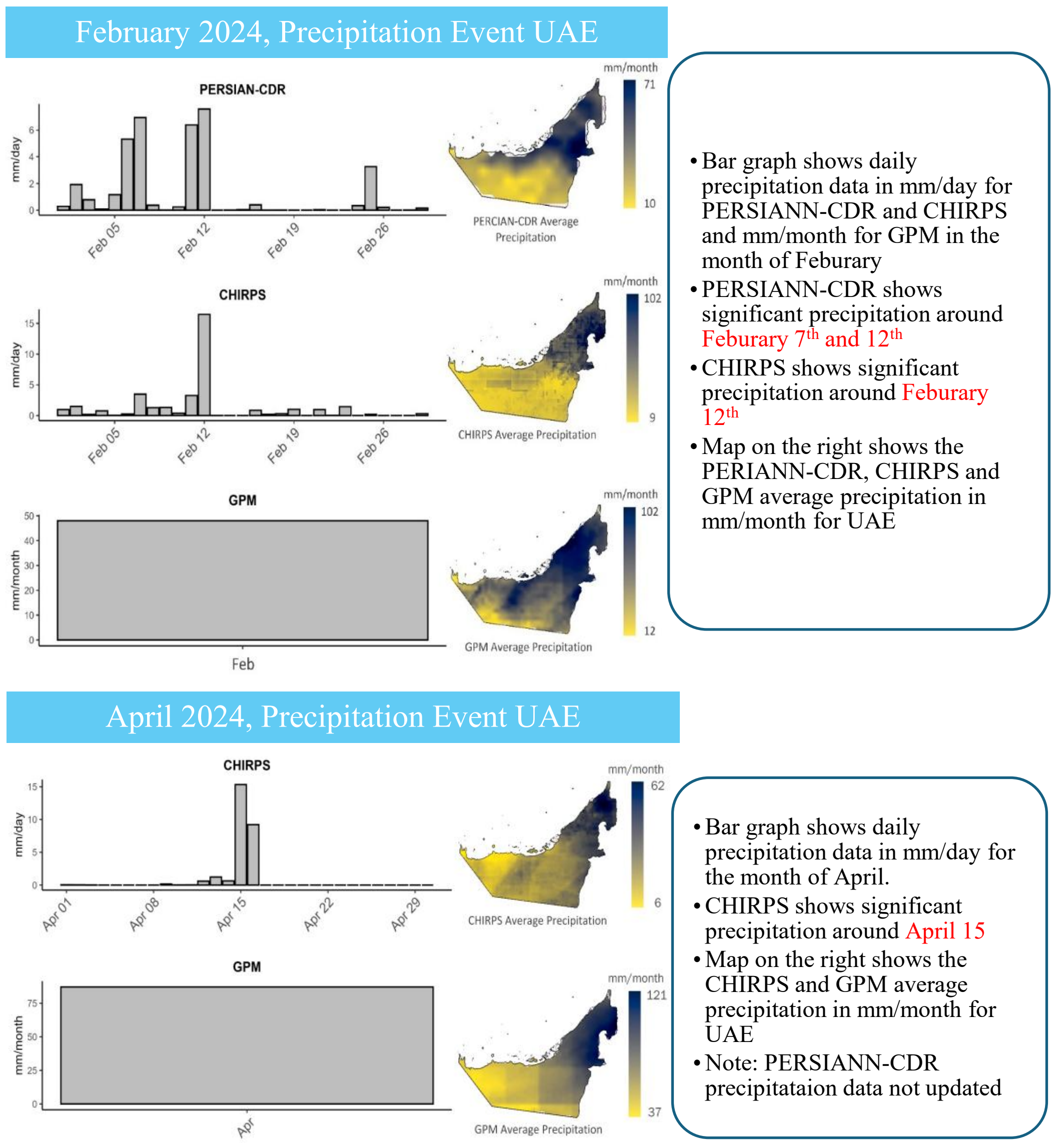

Figure 11: 0010 Maps and Bar charts showcasing precipitation data in the UAE for February and April 2024, derived from PERSIAN, CHIRPS, and GPM datasets.

These results presents historical precipitation across a UAE based on a set of 24 annual precipitation maps spanning the years 2000 to 2023 for each precipitation datasets of CHIRPS, PERSANN-CDR and GPM (fig 0011,0012,0013). Each map employs a uniform color scale ranging from dark blue (0 mm/year) to yellow (300 mm/year) to visualize the spatial distribution and intensity of rainfall. The bottom bar chart presents the annual precipitation from 2000 to 2024 averaged over UAE region (Different months accumulation for different centers in 2024, PERSIAN-CDR 1-3, CHIRPS 1-4 and GPM 1-6). These maps reveal temporal variations in precipitation patterns, which are critical for understanding climate trends, water resource management, and environmental changes in the region.

Summaries from three key datasets from annual precipitation 2000 to 2023;

- GPM Dataset:
  - **Mean Precipitation: 103.31 mm/year**
  - Median Precipitation: 95.63 mm/year
  - Standard Deviation: 39.20 mm/year, indicating moderate variability.
  - **Range: 47.45 mm/year (minimum) to 411.72 mm/year (maximum).**
  - Quartiles: 1st Quartile = 73.00 mm/year, 3rd Quartile = 129.21 mm/year.
- CHIRPS Dataset:
  - **Mean Precipitation: 50.61 mm/year**
  - Median Precipitation: 45.43 mm/year
  - Standard Deviation: 22.02 mm/year, reflecting less pronounced variability.
  - **Range: 9.64 mm/year (minimum) to 133.99 mm/year (maximum).**
  - Quartiles: 1st Quartile = 33.42 mm/year, 3rd Quartile = 62.30 mm/year.
- PERSIANN-CDR Dataset:
  - **Mean Precipitation: 99.63 mm/year**
  - Median Precipitation: 99.63 mm/year, suggesting a symmetrical distribution.
  - Standard Deviation: 34.90 mm/year, with moderate variability.
  - **Range: 33.20 mm/year (minimum) to 199.49 mm/year (maximum).**
  - Quartiles: 1st Quartile = 72.56 mm/year, 3rd Quartile = 123.24 mm/year.

The year with the lowest precipitation in the UAE, according to the image, is 2001. All three data sources (CHIRPS, GPM, and PersianCDR) show relatively low precipitation values for 2001 as compared to other years. Other than that 2000, 2007, 2011, 2012, 2015, 2018 and 2021 shows less than 40 mm of annual precipitation. 2008,2009, 2016, 2017 and 2020 showed higher than 120 mm precipitation.

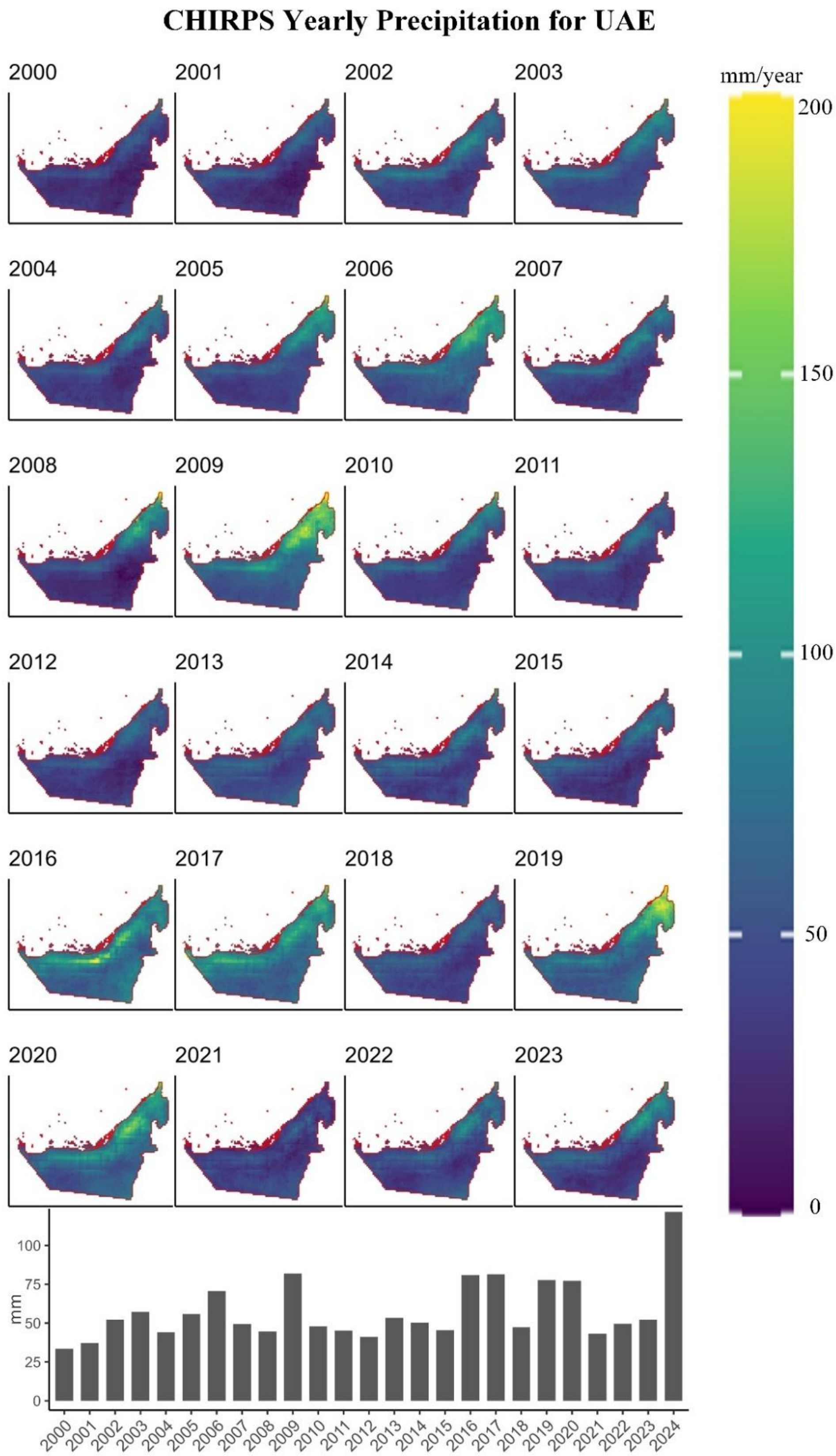

Figure 12: 0011 Annual CHIRPS precipitation distribution in the UAE from 2000 to 2023, presented through annual bar charts and spatial maps.

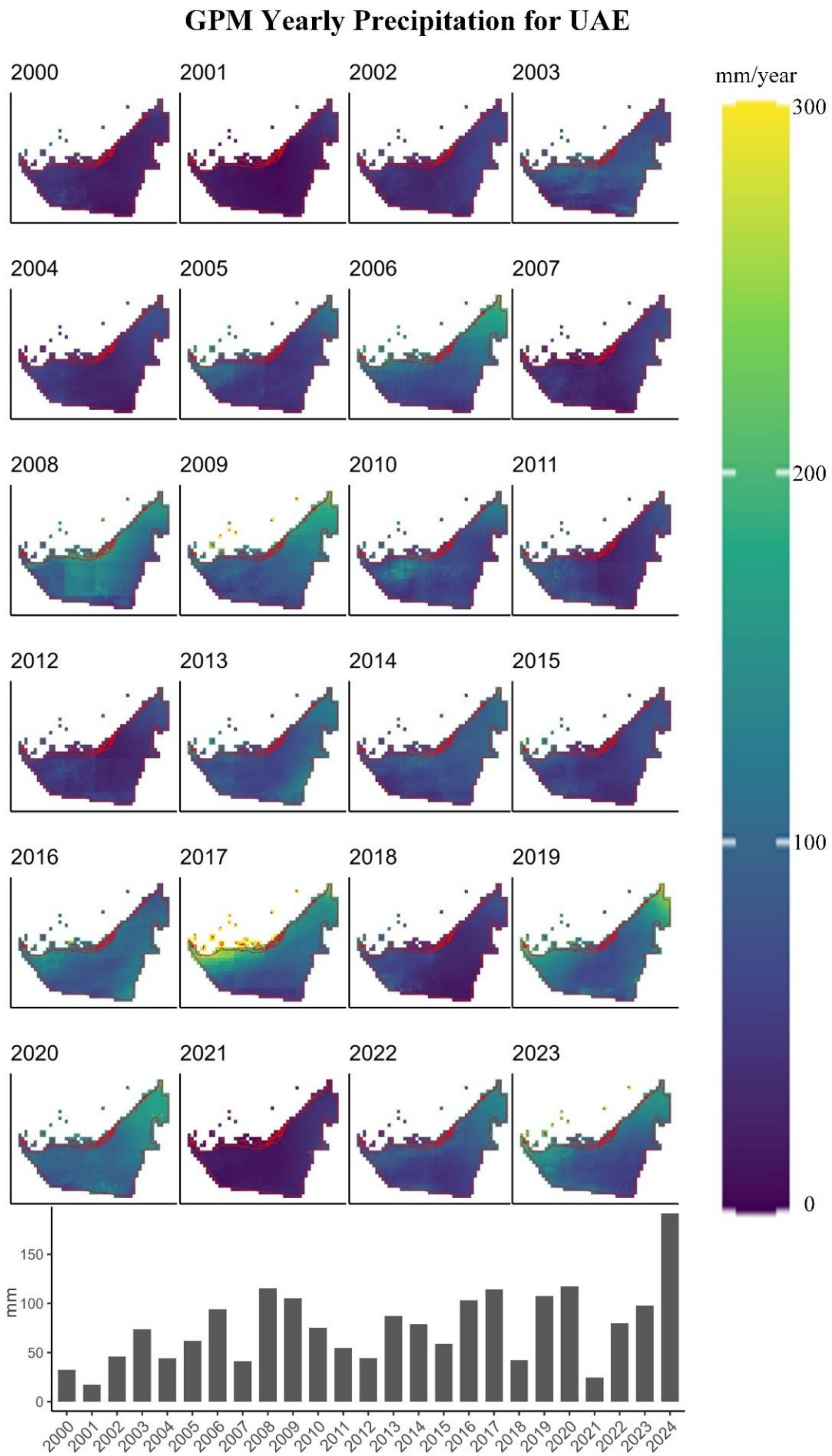

Figure 13:0012 Annual GPM precipitation distribution in the UAE from 2000 to 2023, presented through annual bar charts and spatial maps.

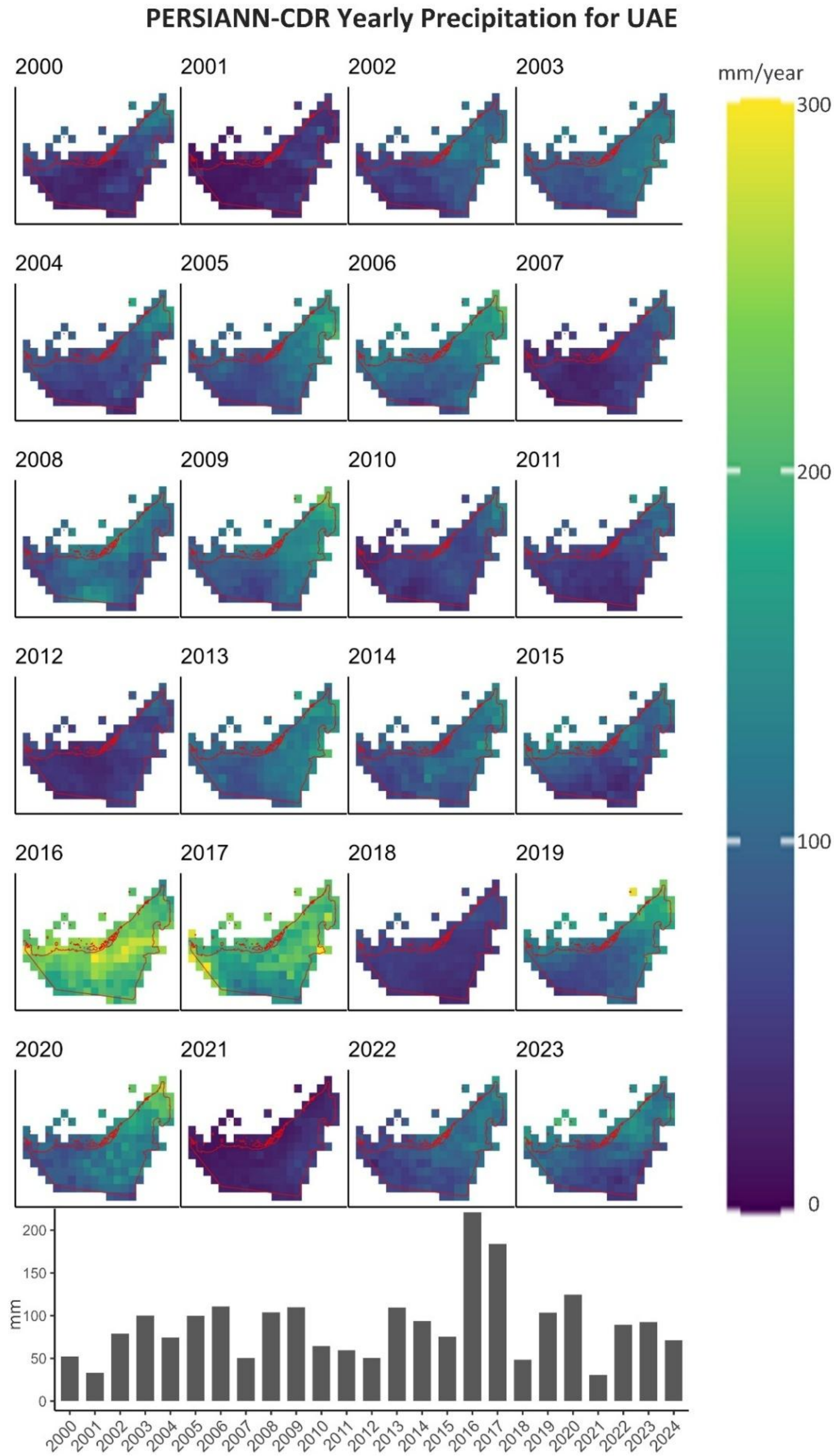

Figure 14:0013 Annual PERSIAN-CDR precipitation distribution in the UAE from 2000 to 2023, presented through annual bar charts and spatial maps.

2.2 FLOODING

UAE is known for its arid climate and desert landscapes. But it is increasingly experiencing cases of flooding. Though the nation receives minimal annual rainfall, rapid urbanization, changing weather patterns, and infrastructure contribute to the occurrence of flash floods (Almheiri et al., 2023, 2024). In some regions, short but intense rainfall events overwhelm drainage systems, causing water to accumulate in urban and low-lying areas. Flash floods in Wadis are common during heavy rainstorms, where water flows rapidly and unpredictably, posing significant risks to life and property (Khan *et al.*, 2024).

2.2.1 CAUSES OF FLOODING IN THE UAE

The primary causes of flooding in the UAE include extreme weather events, poorly managed urban infrastructure, and climatic influences such as global warming (Almheiri *et al.*, 2023).

- **Extreme Weather Events:** Sudden and intense rainfall, often exceeding annual averages within hours, triggers flash floods.
- **Climate Change:** Global warming has increased both frequency and magnitude of extreme precipitation events, increasing flood risks.
- **Urbanization:** Impervious surfaces like roads and buildings reduce natural water infiltration, leading to increased surface runoff.
- **Inadequate Drainage Systems:** Older urban areas often lack the infrastructure capacity to manage heavy rainfall effectively.
- **Geographical Features:** Dry riverbeds (wadis) and mountainous regions in the north and east accelerate water flow during rainstorms, resulting in flash floods.
- **Human Activities:** Construction and expansion into natural waterways or flood-prone regions further increase vulnerability to flooding.

2.2.2 FLOODING EVENTS OF 2024

Flooding events in the UAE are increasingly being monitored using advanced remote sensing techniques, including optical imagery composites, the Normalized Difference Water Index (NDWI), SAR thresholding, and Coherence Change Detection (CCD) combined with Principal Component Analysis (PCA). Optical imagery, while useful, is often limited by cloud cover, especially since flooding events are typically associated with precipitation clouds that obstruct visibility.

Although SAR thresholding can penetrate cloud cover, it is less effective in desert regions due to the high scattering of radar signals by sand, which can mimic water signatures and lead to inaccuracies. In contrast, CCD with PCA has proven to be more effective for flood detection in desert environments. CCD benefits from SAR's ability to penetrate clouds and relies on coherence measurements, which are unaffected by sand scattering (Normand and Heggy, 2024). The use of PCA further enhances the method by filtering out noise and delineating flood-affected areas, making it a reliable approach for flood monitoring in arid landscapes (Normand and Heggy, 2024).

Sentinel-1 is a part of the European Space Agency's Copernicus program. It is a radar imaging satellite equipped with Synthetic Aperture Radar (SAR) technology. SAR satellites can operate in all weather conditions, day or night and can provide high-resolution imagery for a wide range of applications (Risling, Lindersson and Brandimarte, 2024; Zhao and Zhu, 2024). One of its key uses is flood monitoring, where its ability to penetrate clouds and capture surface water dynamics proves invaluable (Colacicco et al., 2024). By detecting changes in land surface coherence and backscatter, Sentinel-1 enables precise mapping of flooded areas, aiding in disaster response, risk assessment, and long-term water resource management (Tarpanelli, Mondini and Camici, 2022).

In 2024, two major flooding incidents occurred, providing insights into the spatial extent and variability of flood-prone regions (fig 0014). On the February 12 flooding, fortunately, Sentinel-1 captured the flooding on the same date, revealing significant water inundation across key urban and rural areas. Dubai and Sharjah witnessed a combined flooded area of 36 km², while Fujairah experienced 47 km² of inundation (table 113). **The most wide impact was recorded in Al Ain, with a flooded area of 588 km²**, indicating the susceptibility of its large, low-lying landscape to flash floods (table 113). The observation on the same date captured the peak flood extent, accounting for the higher flooded areas in February.

Table 3: 113 Overview of flooded areas and impacted cities in the UAE during heavy rainfall of February and April 2024.

February 2024 Flood Areas captured through Sentinel 1		
Location Name	**2024 February Flooding (km^2)**	**2024 April Flooding (km^2)**
Dubai, Sharjah	36	60
Fujairah, Kalba	47	32
Al Ain	588	120

In contrast, the April 16 flooding, analyzed using Sentinel-1 imagery captured on April 24, showed a different pattern in flood extent due to the delayed observation date. Dubai and Sharjah saw an increased flooded area of 60 km², potentially linked to prolonged waterlogging in urban zones (table 113). Fujairah, on the other hand, experienced a reduced flooded area of 32 km², likely reflecting the efficient drainage facilitated by its rugged, mountainous terrain (table 113). Al Ain exhibited a dramatic decrease in flooded area to 120 km², indicating a natural decline in water levels over the observation gap. The delay in observation meant that some water had already receded, resulting in lower recorded flooding areas compared to February.

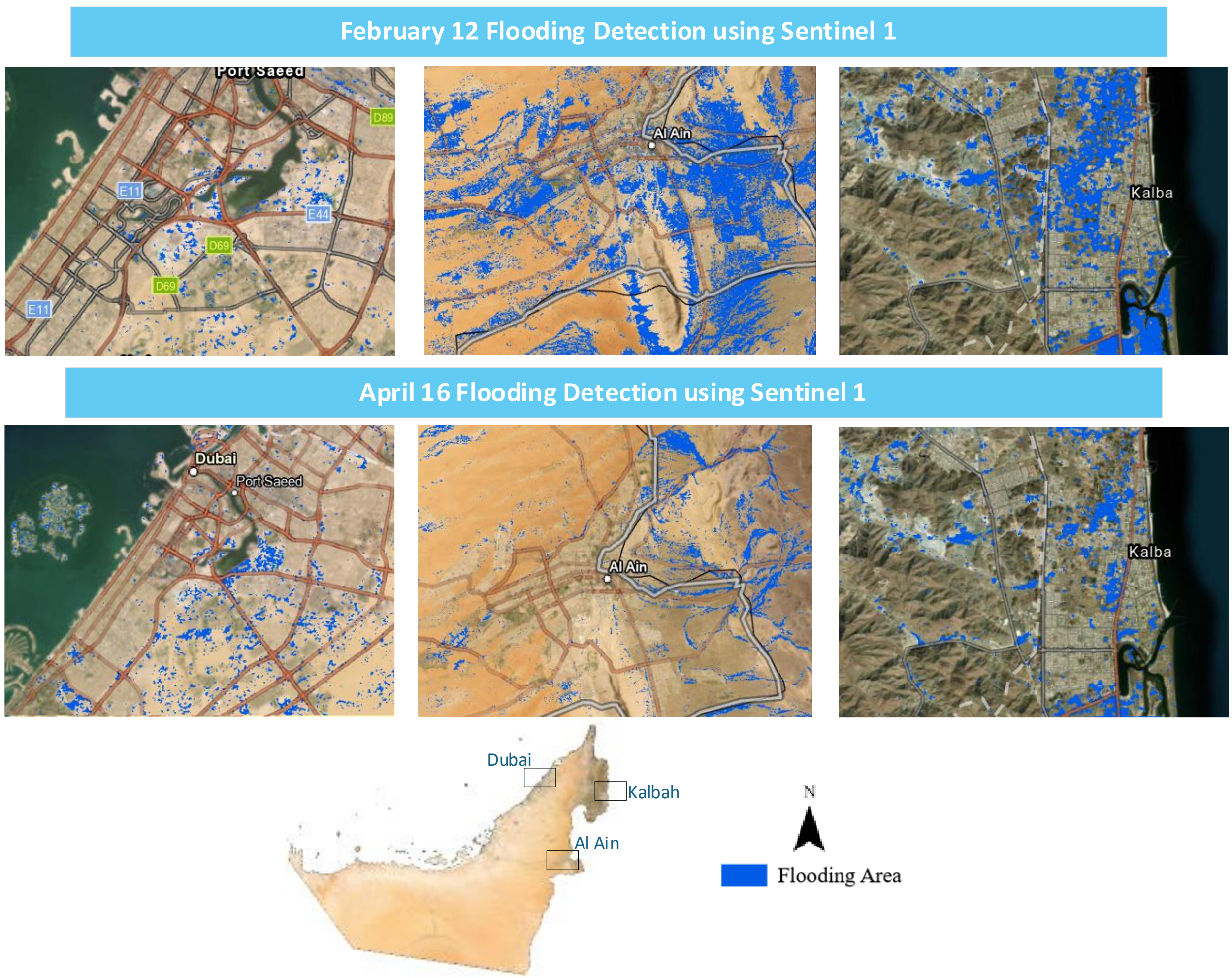

Figure 15: 0014 Maps illustrating flooded areas in the UAE during heavy rainfall events, highlighted in blue. Flood extent was calculated using Sentinel-1 data and the CCD-PCA technique

2.2.2.1 NECESSITY OF DAM

The development of dams in the UAE began in 1982, with the establishment of the Ham, Bih, and Gulfa dams by the Ministry of Environment and Water. Over time, the number of dams grew, with over 200 now distributed across the country, collectively holding a total capacity of over 114 million cubic meters. This infrastructure supports water storage for irrigation, enhances groundwater recharge, and prevents the loss of floodwater to the desert or sea. The variation in dam capacities from large reservoirs like Shuaib and Tawyyaiien to smaller dams such as Gulfa and Eden reflects the differing regional rainfall patterns and water needs.

The UAE's dams are categorized into earth and concrete types, with the majority being earth dams due to the availability of natural construction materials in plain regions. Notable exceptions include the Al Ghail and Gulfa dams, which are concrete structures designed to suit narrower stream channels in Ras Al Khaimah and Ajman, respectively

Table 4: 114 Top 10 capacity Dams of UAE

UAE High Capacity Dams	
Dam Name	**Capacity (Mm^3)**
Shuaib	20
Tawyyaiien	19.5
Bih	7.5
Ham	7
Warraiyaa	5.5
Hatta	4.5
Zikt	3.5
Shi	3
Siji	0.75
Sufini	0.46

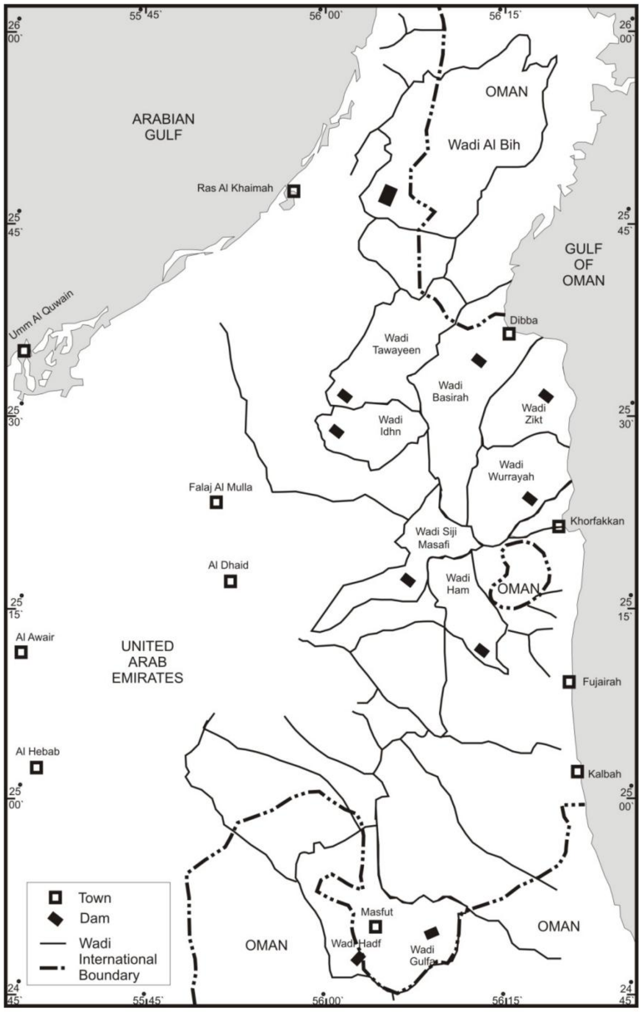

Fig. 2 Location map showing major dams and wadis in the eastern and the northern parts of the UAE (MEW, 2005).

Figure 16:0015

2.3 GROUNDWATER

The United Arab Emirates (UAE) hosts a variety of aquifers spread across diverse geological formations, operating under differing conditions. Four main aquifer types dominate the region: **limestone, gravel plain, ophiolite, and sand-dune aquifers** (Fig 0015).

Among these, the limestone aquifers are further categorized into two significant areas:

- **Wadi Al Bih aquifer in Ras Al Khaimah**
  - The Wadi Al Bih aquifer has an annual groundwater recharge of approximately 7.4 million cubic meters, with about 2.4 million cubic meters lost to the sea (Murad, Al Nuaimi and Al Hammadi, 2007).

- **Jabal Hafit aquifer south of Al Ain City**
    - The Jabal Hafit aquifer produces around 7.7 million cubic meters of brackish thermal water annually, extracted from 15 wells located at the northern end of Jabal Hafit. These wells, ranging from 6 to 61 meters in depth, contain high levels of radium-226 and radon-222 and currently supply water to a recreational spa (Murad, Al Nuaimi and Al Hammadi, 2007).

The ophiolite aquifer situated in the Northern Oman Mountains, fromed through the jointing, faulting, and weathering of the Semail-Hawasina formations, which increases its capacity to store and transmit water. This aquifer covers around 8% of the UAE's land area (Sherif, Ebraheem and Shetty, 2017). Nearby, the gravel plain aquifers, split into eastern and western zones, provide fresh groundwater from alluvial deposits of the Piedmont plains.

The sand-dune aquifer spans roughly 74% of the UAE. It is the largest aquifer in the country (Sherif, Al Mulla and Ebraheem, 2011). It supplies freshwater reserves stored within Quaternary sand dunes, particularly in the Liwa and Madinat Zayed regions of Abu Dhabi. Additionally, shallow alluvial aquifers shared between the UAE and Oman contribute to about 40% of the shared water resources (Kansoh, Muller and Klingbeil, 2003)

The Quaternary aquifer is a critical resource for the northern Emirates, and has been extensively utilized since the 1980s to meet growing water demands. However, its extraction rate exceeds its natural recharge rate by over 14 times (Sherif, Al Mulla and Ebraheem, 2011; Sherif, Ebraheem and Shetty, 2017). This aquifer rests above the low-permeable Juweiza aquifer, composed of clay and gravel, in northern UAE regions.

Historically, **falajes** ancient irrigation systems were essential for sustaining agricultural communities, supporting thriving palm oases and settlements like those in Al Hili near Al Ain. Over time, many of these systems have dried up due to over-extraction of groundwater, although a few continue to supply water to oases (Rizk, Alsharhan and Shindo, 1997).

Studies on groundwater quality have shown significant degradation in agricultural areas like Remah and Al Khatim in Abu Dhabi. Over-irrigation and fertilizer use have reduced groundwater quality, making it unsuitable for many local crops (Almheiri et al., 2023). Water resources in the UAE are under severe pressure due to climate change and population growth:

- Decline in Renewable Water Resources:
    - The availability of renewable water has plummeted, dropping from 50 to 400 m³ per capita in the 2000s to a critical low of 22 m³ per capita by 2009 (AlRustamani, 2014).

- Groundwater over-extraction has led to significant depletion and deterioration of water quality. In Abu Dhabi, groundwater serves as the primary source of water, meeting approximately 71% of the total demand, while desalinated water and treated wastewater account for 24% and 5%, respectively. The rising temperatures, driven by climate change, combined with the persistent challenge of water scarcity, contribute to worsening arid conditions in the region (AlRustamani, 2014).

- Reliance on Alternative Sources:
    - Desalination Plants: While vital for supplying potable water, desalination is energy-intensive and contributes to carbon emissions. The brine discharge also disrupts marine ecosystems (Mfarrej, 2019).
    - Treated Wastewater: The use of treated wastewater for non-potable purposes (e.g., irrigation) has grown but requires careful management to avoid public health risks.

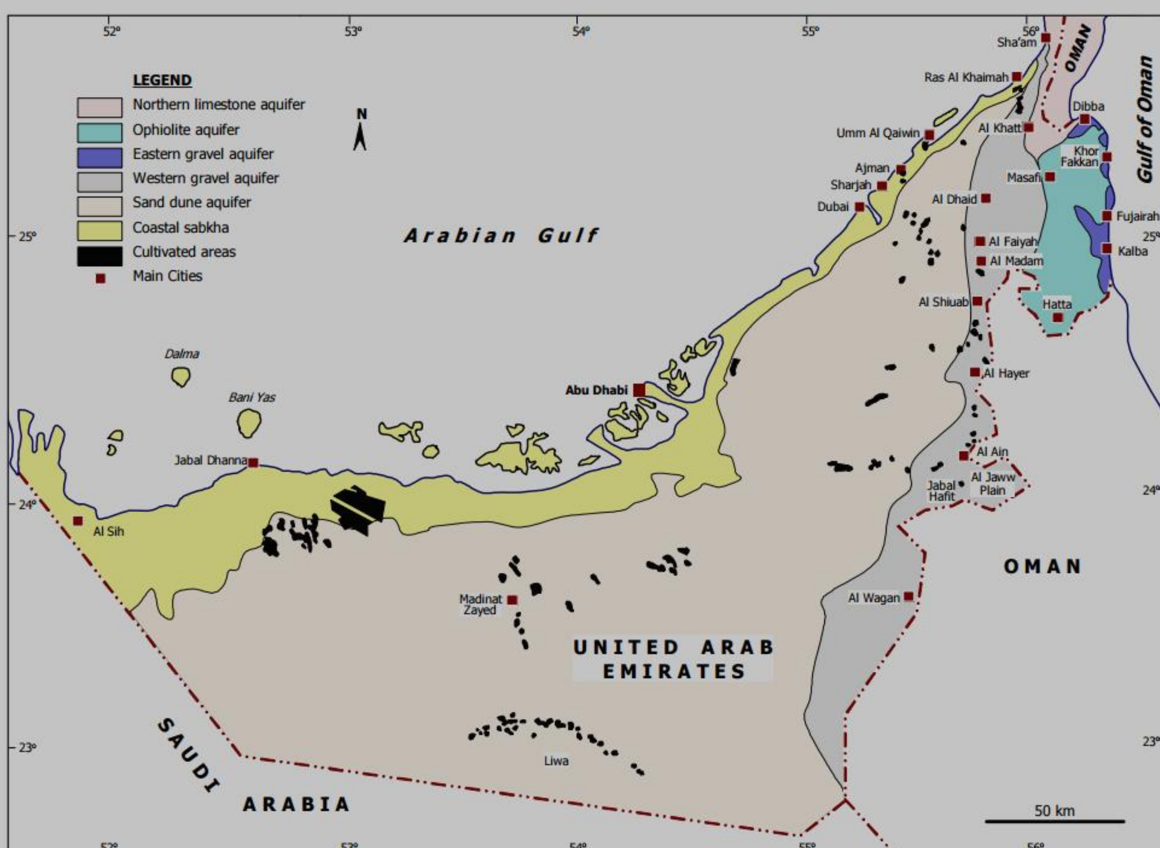

Figure 1. Main aquifers in the United Arab Emirates (Al Sharhan, 2000).

Figure 17: 0015

2.3.1 GROUNDWATER CHANGE USING REMOTE SENSING

GRACE/GRACE-FO and GLDAS Noah provide critical insights into hydrological processes. GRACE focuses on large-scale water storage changes, while GLDAS offers finer detail on soil moisture dynamics, supporting integrated studies of water resources (especially aquafer) and climate impacts.

GRACE and GRACE-FO are satellite missions launched to monitor Earth's gravity field and track changes in mass distribution. GRACE operated from 2002 to 2017, while GRACE-FO, launched in 2018, continues this legacy (Landerer, F.W. and Cooley, 2019; Fatolazadeh and Goïta, 2021). These missions are primarily used to study variations in Earth's water storage, such as groundwater, glaciers, and sea level, by measuring subtle changes in gravity (Groundwater | Applications – GRACE Tellus, 2024). JPL Mascon Product: is a widely used data set derived from GRACE and GRACE-FO observations (Wiese et al., 2023). It provides gridded estimates of terrestrial water storage anomalies (TWSA) at 0.5° × 0.5° spatial resolution and monthly temporal resolution with the unit of cm.

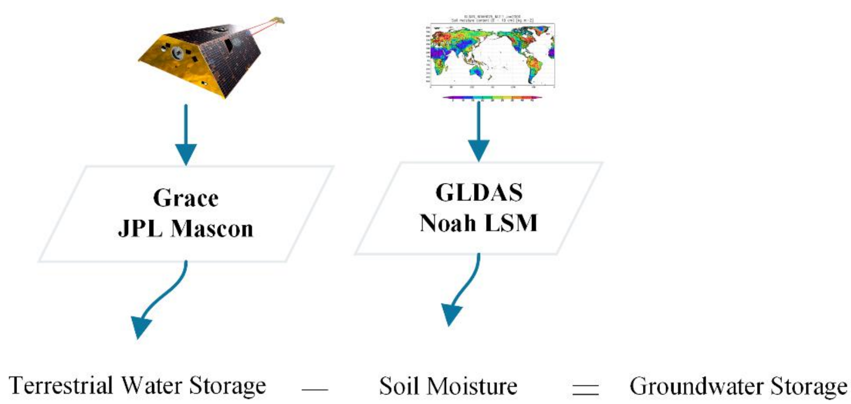

Figure 18: 0017 Showcasing GRACE and GLDAS data used for estimating groundwater storage anomalies, along with the equation:

GLDAS Noah (Global Land Data Assimilation System) is a land surface model that integrates satellite and ground-based observations to estimate various hydrological and energy fluxes (Beaudoing and Rodell, 2020). The Noah version of GLDAS offers detailed information about soil moisture, snowpack, surface runoff, and evapotranspiration. GLDAS provides soil moisture estimates in 4 layers from 0 to 200 cm: Soil moisture is reported in kg/m², which can also be interpreted as mm of water over a given area. For example, 1 kg/m² is equivalent to 1 mm of water (Landerer, F.W. and Cooley, 2019).

The derivation of groundwater storage anomalies typically combines data from GRACE/GRACE-FO and GLDAS Noah to isolate groundwater storage changes from terrestrial water storage (TWS) changes. TWS includes all water storage changes, but by subtracting other contributions from air, surface and soil moisture (from GLDAS Noah), the residual represents the groundwater anomaly. As for a desert region such as the

UAE, water change through air and surface is negligible. Therefor only SM is used for the derivation of GWS.

The analysis of GRACE JPL Mascon data, GLDAS Noah soil moisture, and the derived groundwater storage anomaly (GWSA) for the UAE from 2002 to 2024 shows water resource trends. The TWS Anomaly from GRACE indicates a significant and consistent decline over the study period, starting at around 2.5 cm in 2002 and dropping to approximately -5 cm by 2024. This downward trend, confirmed by a statistically significant negative trend (tau = -0.81) and a Sen's slope of -0.03 cm/year, underscores the depletion of water resources in the region. In contrast, the Soil Moisture Anomaly (SMA) derived from GLDAS Noah shows stable seasonal variability, with values fluctuating between -2.5 cm and 5 cm. The positive z-value of 7.63 and a small Sen's slope of 0.01 cm/year suggest no long-term decline in soil moisture storage.

Table 5: 115 Showing trend and slope of TWSA, SMA, and GWSA, calculated using Mann-Kendall trend analysis and Sen's slope estimation

Terrestrial Water storage, Soil Moisture and Groundwater storage Trend from 2003-2024					
Variable	z-value	p-value	Kendall's Tau (τ)	Sen's Slope (cm/year)	Confidence Interval (95%)
TWSA	-19.71	0	-0.81	-0.03	-0.03 to -0.02
SMA	7.63	0	0.31	0.01	0.01 to 0.01
GWSA	-17.84	0	-0.73	-0.03	-0.04 to -0.03

The Derived Groundwater Storage Anomaly (GWSA), highlights the decline in groundwater levels. GWSA starts at 5 cm in 2002 and drops to -9 cm by the end of 2024, showing a pronounced negative trend with a statistically significant negative trend and a Sen's slope of -0.03 cm/year. This substantial reduction points to groundwater as the primary contributor to the overall loss in water storage.

The results for 2024 highlight the impact of high precipitation events in the UAE. Both TWSA and SMA show a positive trend during this period, reflecting increased water inputs to the hydrological system. GWSA, however, reveals a distinct pattern. Groundwater storage shows high values in the first four months of 2024, peaking in February, likely due to the infiltration of excess rainfall into the subsurface. However, these gains decline rapidly during the peak summer months, with a steep drop of approximately 4 cm, indicating heavy groundwater extraction or insufficient recharge to maintain elevated levels.

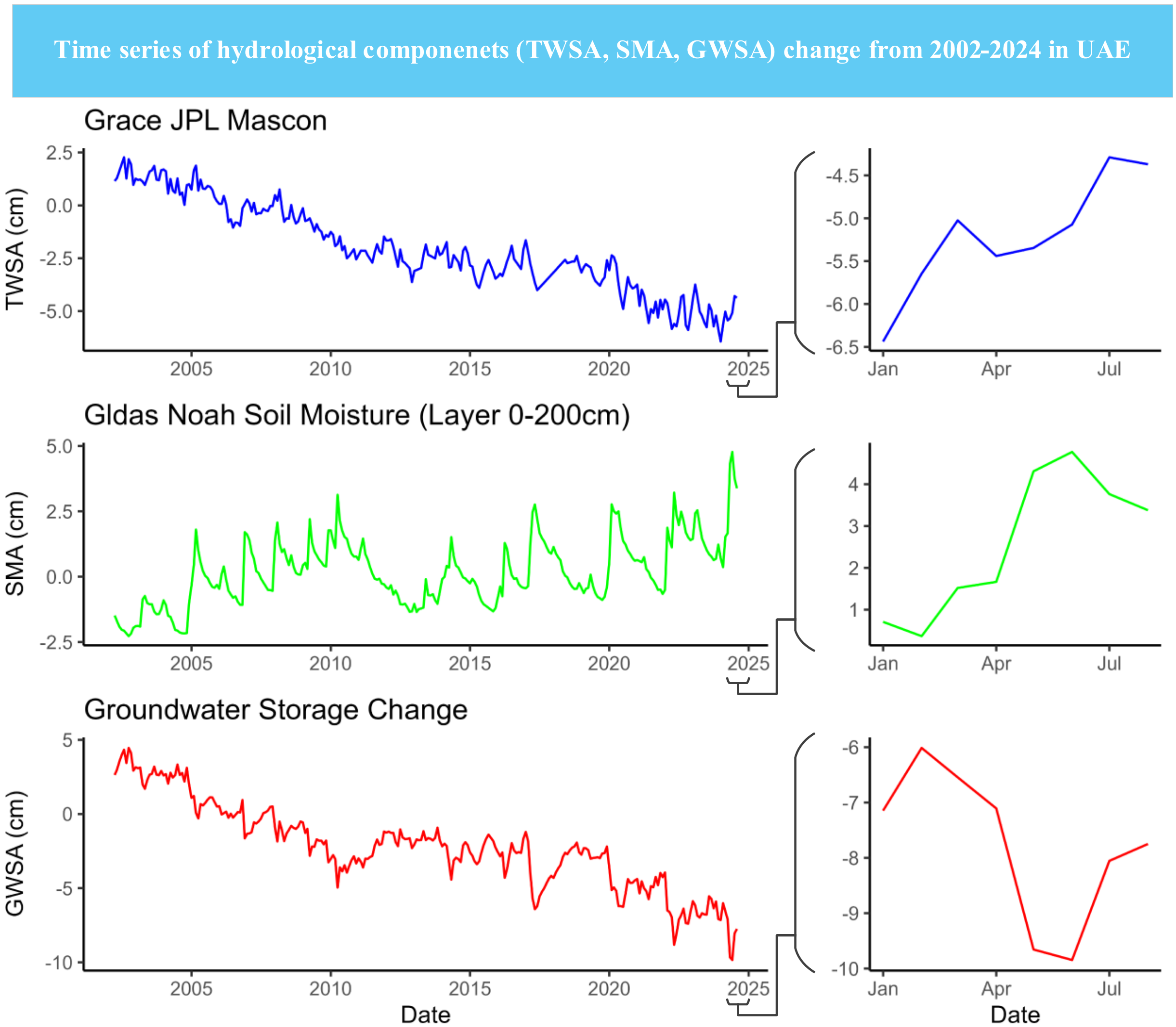

Figure 19: Time series showing the variation of TWSA, SMA, and GWSA from 2002 to 2024, with a zoomed-in view of the for 2024 year

2.3.2 GROUNDWATER CHANGE PREDICTION

The application of machine learning and deep learning techniques has opened new horizons in predicting hydrological phenomena, including groundwater dynamics. Machine learning (ML) encompasses algorithms that learn from data to identify patterns and make predictions, while deep learning (DL) extends ML through neural networks capable of modelling intricate relationships. Among the diverse ML and DL algorithms, Random Forest (RF) and Long Short-Term Memory (LSTM) networks stand out for their effectiveness in handling time-series data and nonlinear interactions, making them suitable for groundwater prediction.

Random Forest (RF) is an ensemble learning method that combines multiple decision trees to improve prediction accuracy and robustness. It is particularly adept at capturing nonlinear relationships and interactions between variables. LSTM, on the other hand, is a specialized type of recurrent neural network (RNN) designed to model sequential data by retaining long-term dependencies, making it well-suited for time-series forecasting of hydrological parameters.

RF and LSTM models were employed to predict groundwater levels using various hydrological and climatic factors. The models were trained using data from **GRACE Total Water Storage (TWS), GLDAS soil moisture, GLEAM evapotranspiration, ENSO indices, and GPM precipitation**, alongside observed in-situ **hydraulic head** data from 2003 to 2019. The trained models were subsequently used to predict groundwater levels for the period 2020–2023, with predictions validated against observed hydraulic head data. Both models demonstrated excellent predictive capabilities (table 116).

Table 6:116 Training and testing accuracy of machine learning models, LSTM (Long Short-Term Memory) and RF (Random Forest), used for predicting Hydraulic Head (groundwater level)

Accuracy of LSTM and RF models in predicting Groundwater change				
Stats	RF		LSTM	
	Training	Testing	Training	Testing
RMSE	1.35	0.46	1.61	0.42
NSE	0.39	0.67	0.21	0.71
Correlation Coefficient	0.71	0.91	0.51	0.86
Index of Agreement	0.25	0.21	-1.54	0.27

The results reveal that both RF and LSTM models are effective in predicting groundwater storage anomalies, with each model showcasing unique strengths. RF achieved a higher Correlation Coefficient (0.906) during testing, indicating strong alignment between observed and predicted data. It also demonstrated robustness with a low RMSE (0.455) and good generalization capability. LSTM, on the other hand, excelled in modelling temporal variability, as reflected by its higher NSE (0.714) in testing. While LSTM struggled with training performance, its testing accuracy with an RMSE (0.417) highlights its potential for time-series analysis.

LSTM Training and Testing plots from 2003 to 2023, predicting Hydoulic Head

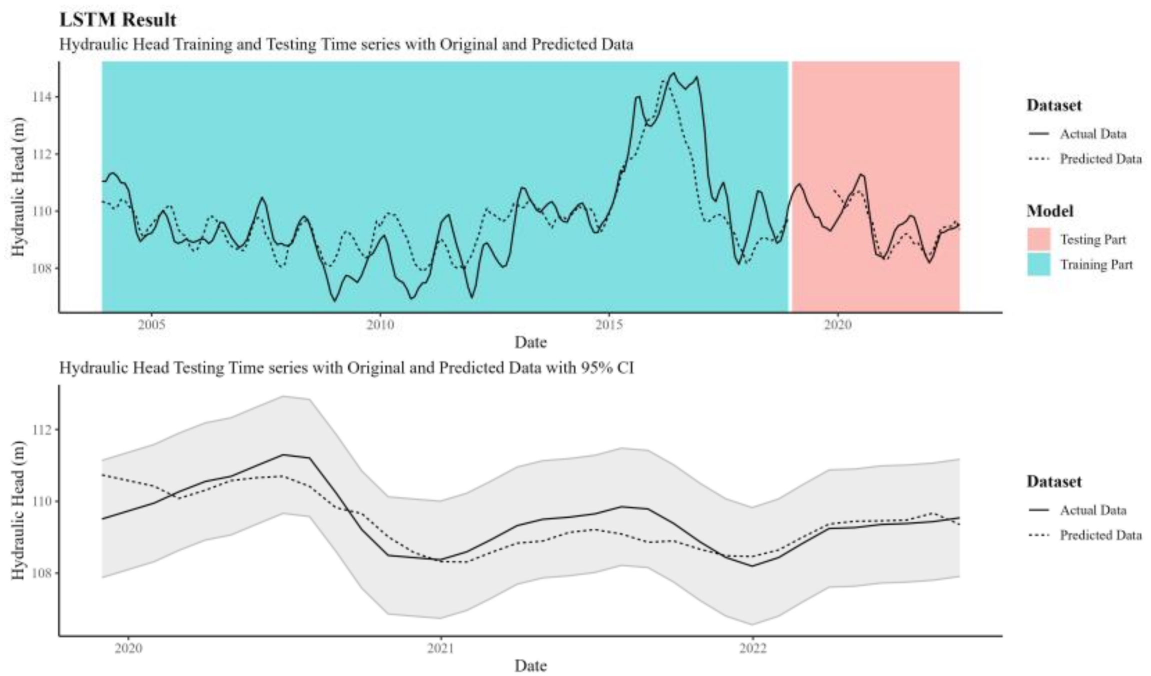

Figure 20: 0018 LSTM time series training (2003-2019) and testing (2020-2023) part of Original and predicted dataset.

Random Forest Training and Testing plots from 2003 to 2023, predicting Hydoulic Head

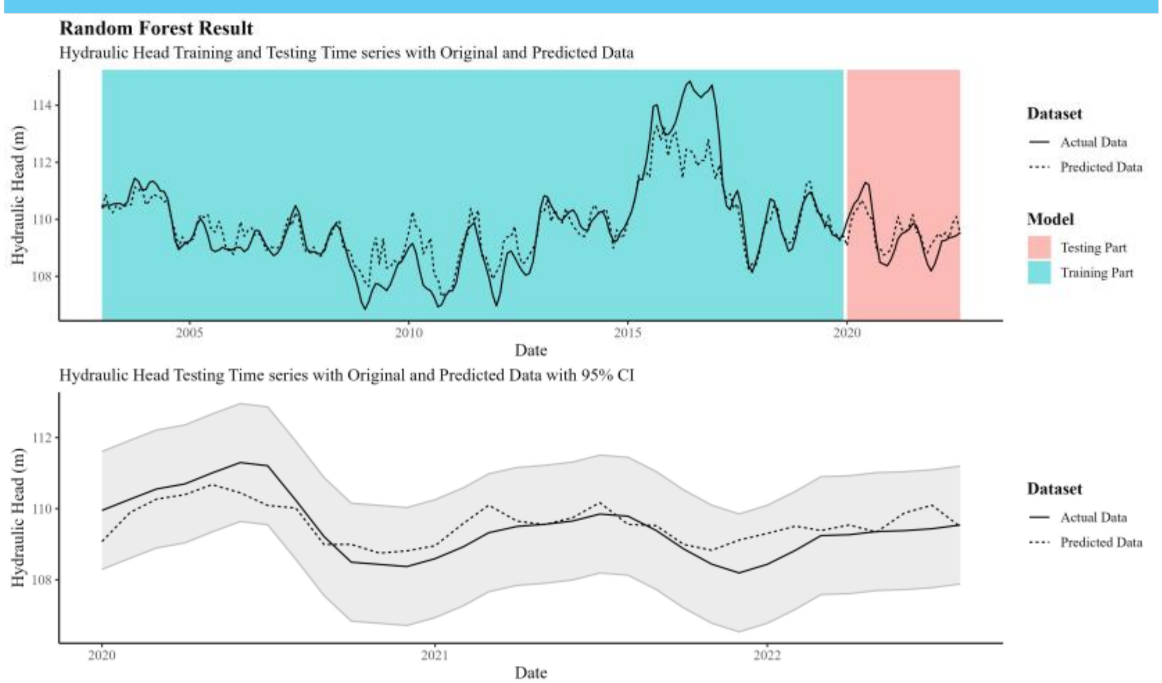

Figure 21: 0019 RF time series training (2003-2019) and testing (2020-2023) part of Original and predicted dataset.

The time series plots for both LSTM and RF models demonstrate their ability to replicate observed groundwater trends effectively across training and testing phases (figure 0018-19). The graphs highlight a strong alignment between actual and predicted data, with a clear division between training (2005–2015) and testing phases (2015–2020). For the testing period (2020–2022), both models provide accurate predictions, accompanied by a 95% confidence interval (CI) that measures uncertainty.

2.4 SEA LEVEL RISE

Many Arab countries are near the Mediterranean Sea, the Red Sea, the Arabian Gulf, and the Atlantic Ocean. Low-lying coastal areas in the UAE face severe risks from rising sea levels: These areas are home to large populations and growing tourism with a **total coastal line of 34000 km, out of which 18000 km is populated** (Massoud, Scrimshaw and Lester, 2003). These areas are at huge risk from Climate change.

UAE population grew exponentially from 1975 to 2005, it have been the most highest growth rate around the world (Albedwawi, 2021). More than **85% population of UAE live across the coastline** with most infrastructure, tourism center and major institutes. If the coast line increase just **0.5 meter it will affect 5 percent** of the infrastructure of UAE, with **3 meter increase around 40 percent** of the urban areas are going to be flooded (fig 0021).

Using GIS and RS techniques along with ground survey, these high risk areas can be identified. Further authorities can prioritize measurements to protect lives and infrastructure.

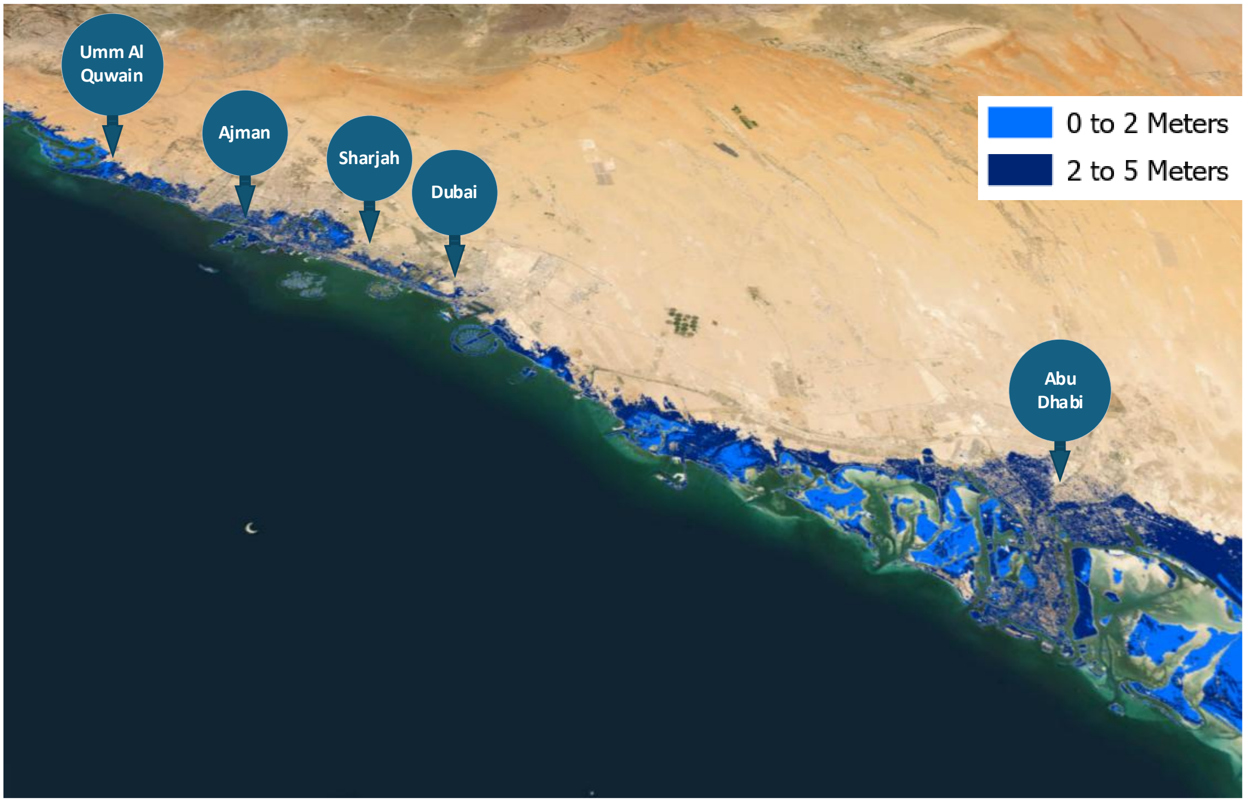

Figure 22: 0022 Map illustrating the vulnerable zones covered by water in the coastal regions of the UAE due to sea level rise.

3 TECHNOLOGICAL ADVANCEMENTS TO FACE CLIMATE CHNAGE

Climate model for UAE

Global Climate Models (GCMs) are useful for studying large-scale climate systems and identifying overall trends (Azmat et al., 2020). They help in understanding how the climate changes on a global scale. Regional Climate Models (RCMs), offer higher resolution data and are better for analyzing specific areas (Azmat et al., 2020). Both of these model results are further used for Hydrological Modeling, climate Projections, Climate Change Impacts, adaptions, and mitigations (Akhtar, Ahmad and Booij, 2009).

- To better understand the climate variability and extremes in UAE, RCM should be made for UAE.

Precipitation data

The accuracy and availability of precipitation data are crucial for arid regions, where rainfall is often scarce, highly variable, and difficult to predict. It helps to face challenges put by their environmental conditions.

- There is a major need for **better integration of satellite-derived precipitation data** with on-the-ground measurements. Such integration enhances the accuracy and reliability of early warning systems, and hydrological models, ensuring a more comprehensive understanding of rainfall patterns.
- **Availability of rain gauge data** for research purposes, hydrological and machine learning modelling should be made easier and free of charge. Increasing rain gauge stations will improve spatial coverage.

Flash Floods

Mitigation of flash floods in the UAE involves flood management strategy and infrastructure improvement as suited to the region's arid environment. Strategies, such as flood forecasting, risk mapping, and emergency response planning, are essential to decrease infrastructure vulnerability.

- There has not been much work on the effectiveness of **early warning systems on flooding** (Ringo, Sabai and Mahenge, 2024). By implementing early warning and preparedness by the institution a lot can be done for flash flood-prone areas.
- **High-resolution flood simulations using hydrologic models** have proven effective for arid regions, especially when integrated with satellite-based rainfall measurement products like GPM (Hamouda et al., 2023), CHIRPS (Alsumaiti et al., 2023), PERSANN-CDR (Baig et al., 2023) and combined with ground observations . It performed well in predicting runoff during major storm events (Abdouli et al., 2019; Terry et al., 2023; Khan et al., 2024).
- **Flood control measures**, such as detention basins (artificial depressions or ponds designed to temporarily hold excess stormwater) or dry dams (Dams that remain empty under normal conditions and only fill with water during flood events), could reduce peak discharge and limit downstream impacts, with studies showing up to 92% flood damage reduction in similar arid regions (Kantoush32 et al., 2010; Sumi, Saber and Kantoush, 2013; Sohn et al., 2020).
- Urban areas like Sharjah and Fujairah could also benefit from **alternative drainage solutions**, such as porous paving and vegetated swales, to promote infiltration and reduce runoff velocity (Shanableh et al., 2018).
- **Digital Elevation Model** (DEM) plays a crucial role in hydrological modelling. Either accurate evaluation of present DEMS or the creation of high-resolution DEMs is essential for generating reliable data.

Updating IDF curve

An intensity duration frequency (IDF) curve is a statistical tool used to estimate the likelihood of extreme rainfall events. It is based on long-term historical precipitation data (IDF curves estimate the return period of rainfall events or the intensity for a specific return period) and plays a critical role in engineering design IDF curves help illustrate the relationship between rainfall intensity, event duration, and the frequency of occurrence (Baig et al., 2023; Almheiri et al., 2024).

- **Developing reliable IDF curves** requires extensive historical data to capture the dynamic nature of climate systems, especially concerning extreme weather patterns. For that satellite (GPM, CHIRPS, PERSIANN-CDR) with rich and accurate data can be used.
- Regularly **updating IDF curves** is crucial to maintain their accuracy and relevance. Particularly as climate change continues to drive an increase in the frequency and severity of extreme weather events. Outdated IDF curves may fail to represent current conditions and associated risks effectively.
- Along with climate change, the study of **cloud seeding impact on the IDF curve** is needed. Insufficient data may introduce uncertainties.

Groundwater monitoring Data

The natural recharge to the surficial aquifer is estimated at 187 MCM per year, accounting for just 6.7% of the total annual groundwater abstraction of 2764 MCM (Sherif et al., 2021). For a sustainable management of aquafer with fresh water and overall water availability. There is a continuous need for groundwater monitoring, that is provided through easy and free access for research purposes.

- It is essential to address **data gaps in monitoring wells**, by increasing the number of well stations and ensuring broader spatial coverage and validation.
- Outdated equipment should be replaced with new machinery or reliable alternatives, with a particular focus on **upgrading battery systems** to improve functionality.

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