Egyptian Journal of Archaeological and Restoration Studies (*EJARS*)
An international peer-reviewed journal published bi-annually
www.ejars.sohag-univ.edu.eg

Original article

CLIMATE CHANGES AND EGYPTIAN HERITAGE: VULNERABILITY AND ADAPTATION STRATEGIES (*A CASE STUDY ON THE CATACOMBS OF KOM EL-SHOUQAFA, ALEXANDRIA, EGYPT*)

Khater, M.[1,2,4(*)], Zoair, N.[3,4] & Faik, M.[4]

[1]*History and Islamic Civilization dept., College of Arts, Humanities & Social Sciences, Sharjah Univ., Sharjah, UAE.*
[2]*History and Islamic Civilization dept., College of Art, Sciences, Information Technology & Communication, Kalba Univ., Kalba, UAE.*
[3]*History dept., College of Art, Science, & IT, Khorfakkan Univ., Khorfakkan, UAE.*
[4]*Tourist Guidance dept., Faculty of Tourism and Hotels, Fayoum Univ., Fayoum, Egypt.*
**E-mail address: mha15@fayoum.edu.eg*

Article info.
EJARS – Vol. 14 (2) – Dec. 2024: 207-216

Article history:
Received: 18-1-2023
Accepted: 1-5-2024
Doi: 10.21608/ejars.2024.396687

Keywords:
Climate change
Egyptian heritage
Mitigation
Adaptation
Kom El-Shouqafa

Abstract:
Heritages provide tangible evidence of human development and civilization. However, most unique heritages are in danger due to climate change. The driving force behind the escalating rate of ecological change is human activity. Egypt is particularly vulnerable to the impact of climate change. This study aims to analyze possible adaptation measures for present climate change effects in Egypt, with a focus on the archaeological heritage site, the tombs of Kom El-Shouqafa in Alexandria, as a case study. It will also discuss the efforts of the Egyptian government to mitigate climate change effects by taking a holistic approach. This study will determine the local and regional priorities and barriers to adaptation to climate change. The study proposed some measures that facilitate the transition from conflict to cooperation considering diverse perspectives.

1. Introduction

The repercussions of global climate change are already being experienced both locally and globally. Naturally occurring climate change only has a minor impact on the environment as it is relatively slow. Human activity has considerably disturbed the natural equilibrium of the environment since the end of the 18th century. In addition to exploiting and destroying the planet's natural resources, humans have also made essential interventions and contributed to increasing the rate of climate change. The typical percentage of emitted greenhouse gases has increased drastically due to the excessive use of fossil fuels and deforestation, resulting in global warming. The corresponding increase in Earth's average temperature has triggered a series of climatic events. These new dynamics are crucial factors in altering the world's water map. This is expected to have high economic and environmental costs. All governments face severe challenges related to climate change because it seriously jeopardizes the national economy and food security [1]. Climate change has been a recurring theme throughout Earth's history. The average global temperature increased by 0.6 °C throughout the 20th century, which was the largest temperature increase over any century in the last 1,000 years. The IPCC (*Intergovernmental Panel on Climate Change*) asserts that 'there is new and more reliable evidence' linking human activity to the bulk of the warming recorded over the last 50 years. The rise in carbon dioxide concentrations is occurring at the fastest rate in at least 20,000 years. The increasing temperature is only one of many signs of ongoing climate change, which is already being felt and is predicted to have a greater future influence on people and the broader environments, such as other species, ecological systems, and conservation areas worldwide [2]. The main objectives of the study are to investigate the vulnerability of Egyptian heritage to the effect of climate change. It aims to clarify the responses of national and local management. Furthermore, the study proposes preventative and remedial measures that must be taken to protect the heritage. It Discusses local management plans, national policies, and global strategies to develop a set of policies to mitigate the effects of climate change.

1.1. *Impact of climate change on Egypt*

Egypt is a country that is mostly covered by desert and has a hot climate. It has a warm winter, with some coastal regions receiving rain, and a dry scorching summer (May to Sep.).

The dominant winds influence seasonal differences in daytime temperatures. In the coastal districts, temperatures range from an average summer maximum of 30 °C (May to Oct.) to an average winter minimum of 14°C (Nov. to April). Inland desert regions see substantial temperature variations, especially during the summer, where lows of 7 °C at night and highs of 43°C during the day are typical. Although the desert temperatures change less noticeably in the winter, they may drop below 0 °C at night and rise to 18 °C during the day. The scorching windstorms known as 'khamsin' also occur in Egypt (March to May) [3]. Egypt is extremely vulnerable to the consequences of climate change, and future projections show that erosion, saltwater intrusion, and flooding will significantly impact the Nile Delta's infrastructure, beaches, and productive land. As a result, Egypt's economy, ecosystems, human health, and food security are all in jeopardy [4]. ND-GAIN Index (The Notre Dame Global Adaptation Index) assigns a score to 181 nations based on their vulnerability to climate change and other global as well as their readiness to increase their resilience. This helps companies and the public sector to prioritize investments for more effective global crises. According to the 2019 ND-GAIN Index, Egypt is ranked 107 out of 181 countries, which denotes that it is vulnerable to the impact of climate change due to political, geographic, and social factors. The country's score on the index rises based on its level of preparedness and falls based on its vulnerability. Figure (1-a) depicts Egypt's score development from 1995 till 2020, while fig. (1-b) indicates that due to its high vulnerability and poor preparation, Egypt is positioned in the upper-left quadrant of the ND-GAIN matrix; it occupies 29th in readiness and 83rd in terms of vulnerability among countries. Thus, urgent investment, ideas, and action are needed to increase preparedness. [5].

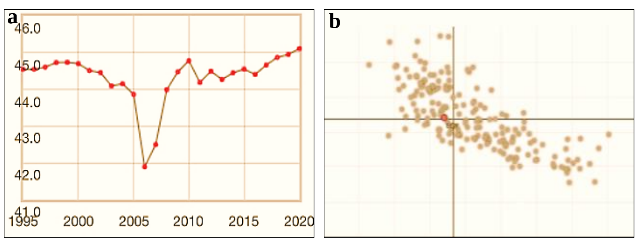


Figure (1) **a.** Egypt's ND-GAIN index score over time, **b.** Egypt's position in the ND-GAIN Matrix (*After: Notre Dame Univ., 2022*)

Figure (2-a, b & c) display essential data on Egypt's climatic zones and seasonal mean temperature and precipitation cycle. These charts were created using the latest climatology data from the Köppen–Geiger climate classification obtained from 1991 to 2020 [3]. based on the study of 32 global climate models (GCMs) by the German Climate Service Centre (GERICS, Egypt's annual mean temperature is predicted to increase by 35.24 - 41.36 °C before 2080,). All emission scenarios predict temperatures to rise until the end of the century. This increase in heat will significantly impact agriculture, water supplies, ecosystems, historic sites, and human and animal health. Egypt's rainfall patterns are very inconsistent with a decrease in precipitation observed over the past thirty years. According to GERICS GCMs analysis, this trend is expected to continue throughout this century), with projections showing even longer dry spells, up to an additional 75 days by the 2080s [6]. The Nile is a vital source of life in Egypt as it is the source of water for various activities such as farming, manufacturing, fish farming, energy production, inland river traffic, and electricity production. The country is heavily reliant on the Nile and as a result, it is vulnerable to changes in temperature, and reduced rainfall in the higher Nile Basins and on the eastern Mediterranean coast [6].

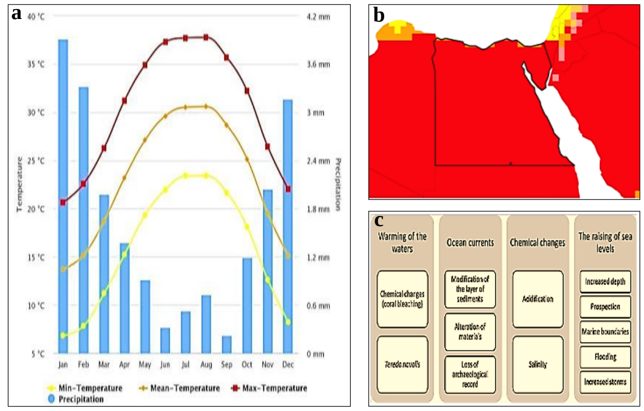


Figure (2) **a.** monthly climatology data for Egypt over the period of 1991-2020, **b.** Köppen-Geiger climate classification, 1991-2020 (*After: WB climate change knowledge portal, 2020*), **c.** four main climate-related changes and possible effects on tangible heritage (*After: Mishra, 2019*)

1.2. *Impacts of climate change on Egyptian heritage sites and tourism*

Egypt is a country with a wealth of cultural and natural heritage sites. It has 34 sites that are tentatively listed and 7 sites that are part of the UNESCO Heritage Sites. Additionally, Egypt has hundreds of archaeological and natural sites that are of great importance, although they are not listed by UNESCO, but of great importance. Considering the dramatic changes in the climate that will continue affecting the temperatures, rainfall rates, wind speed, and erosion rates, Egypt's historic sites are anticipated to be significantly impacted by climate change and may eventually be destroyed, fig. (6) [7].

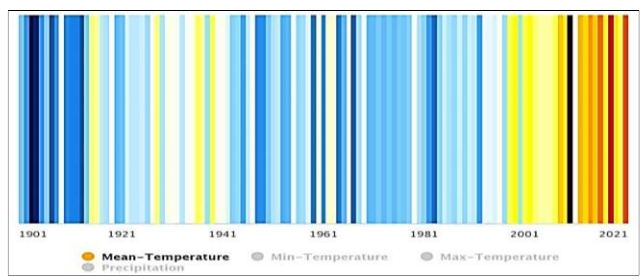


Figure (3) the observed annual mean temperature in Egypt from 1901-2021 (*After: WB Climate Change Knowledge Portal, 2020*)

Changes in most climatological indicators could harm natural World Heritage sites. For instance, coral reefs are bleaching, particularly in the Red Sea, and the planting season is getting longer. Flora and fauna ranges are shifting poleward and increasing in elevation, particularly in Egypt since there are large bodies of water, such as the Red and the Mediterranean Seas, Nile River, ice caps, glaciers, ice cover, and snow cover. Climate change affects ecosystems by disturbing plant and animal species and atmospheric CO_2 concentrations [8]. Because of the range changes and species extinctions caused by climate change, the composition and arrangement of ecological communities are changing. These many biological and physical modifications profoundly influence human lifestyles by affecting how ecosystems function, such as nutrient cycling and the supply of ecosystem products and services. As a result, socioeconomic activities, such as agriculture, fisheries, and tourism, can be negatively affected, especially by changes in the freshwater supply. Finally, interactions with other change factors, such as socioeconomic growth and changes in land use, may intensify the environmental and human health effects of climate change [9]. Climate change has many physical, social, and cultural impacts on cultural heritage. For example, pH variations in buried archaeological artifacts, and loss of stratigraphic integrity because of heaving and cracking due to variations in sediment moisture. Furthermore, physical alteration of porous materials can occur due to increasing humidity that brings dissolved salts that crystallize in archaeological artifacts, building materials and finishes, murals, frescoes, and other decorative surfaces and damage them during wetting and drying cycles [10]. In addition, inorganic and organic compounds can be eroded by flood, subsidence, ground heave, and soil instability, and materials and surfaces can split, fracture, flake, and dust due to humidity cycles, trauma, and metal corrosion [11]. Additional effects, such as an increase in air moisture when fertilizers and insecticides are used; facade deterioration brought on by thermal stress, frost, and freeze-thaw damage to masonry, stone, and ceramics, and modifications to the fitness for a specific structure. As another example, installing engineering solutions to address interior building overheating may result in unwanted changes to the building's historic fabric. In some regions, coastal loss/erosion results in permanent encroachment on low-lying regions, migration and disruption of communities, breakdown in social connections, and the loss of traditions [12]. Inadequate adaptation to maintain the usage of buildings, damage to and collapse of them, surface deterioration by erosion and the corresponding effect on the health of the population, and cultural memory loss [13]. Regarding Tourism in Egypt, global warming has a significant impact on tourism as affirmed by the USAID report. Millions of visitors visit Egypt yearly to see its historical sites, beaches, and coral reefs [14]. However, rising temperatures and shifting rainfall patterns are putting the country's top tourism draw such as ancient Egyptian palaces, temples, monuments, and treasures, which are in jeopardy [6]. For example, Luxor has a dry and consistent environment, which is perfect for the preservation of antiquities, and thus it becomes home to many of Egypt's antiques as the Pharaonic tombs. However, a rising population, temperatures, and humidity may harm structures that have stood for ages [15]. Rainstorms are happening more frequently in Egypt's arid heartland, causing mud-brick buildings to disintegrate, and putting ancient sites at risk of flooding. Moreover, the heat has caused granite structures in Aswan to crack, ruining old inscriptions and delaying official archaeological work. After the Aswan dam was built and year-round cultivation was enabled, the frequency of temple degradation accelerated. Temple sandstone is eventually degraded by salt crystallization caused by rising groundwater levels and increased humidity from evaporation [16]. To illustrate how climate change is affecting Egyptian heritage, here we explore some recent examples. For example, on Aug. 14, 2021, the Ministry of Tourism and Antiquities reported that a fire had started in the Giza Governorate, behind the ancient site of Mit Rahina. According to the director of the Egyptian Antiquities Sector of the Supreme Council of Antiquities, the fire was eventually extinguished, intense heat, had dried out the surrounding flora, increasing tits [17] at Karnak temple, the old stone works in Luxor suffer from rising temperatures related to global warming, wilder weather, and notably severe rains and flooding. According to El-badry, a heritage conservation expert working at Karnak temple, the effects of climate change are becoming increasingly visible in Luxor's archaeological site. The several tombs are corroding, and cracking and the hue of the archaeological stones is changing [18]. Over the past fifteen years, granite that was previously rose-coloured has faded to pale pink or even light grey. He notes that the problem is not limited to one site but "You can observe the changes in every archaeological site here in Luxor". The nation's historical landmarks are increasingly in danger from harsher weather and rising seas, including the pyramids, Sphinx, Qaitbay Citadel [19], and an old Roman amphitheatre close to the Mediterranean Sea. In Alexandria, one of the Mediterranean UNESCO Sites, coastal flooding and erosion are the main threats. The city is particularly vulnerable to increasing sea levels because of its location on the Mediterranean coast. According to reports, all of Egypt's ancient monuments along its northern shore are in danger owing to coastal erosion. [4]. The potential impacts of global warming on the maritime and coastal environment have also been considered by regional monitoring programs. In national scientific research plans, related subjects such as sea-level rise, coral bleaching, and coastal environment degradation are a focus. The most pessimistic predictions state that by 2100, 74% of Egypt's coral reef ecosystems will be gone; as a result, the government will lose a significant source of tourism-related revenue [20]. This study emphasizes authenticity and addresses gaps in existing research. By employing a multidisciplinary approach that integrates archaeological, architectural, and environmental perspectives, this study ensures a comprehensive understanding of the site's significance and challenges. Through meticulous historical research, including analysis of primary sources and archaeological reports, the study establishes the authenticity and cultural value of the catacombs. Furthermore, the methodology incorporates direct field observation and engagement with local stakeholders, ensuring a firsthand assessment of the site's current condition and challenges. Despite the wealth of historical and archaeological literature on the site, there remains a gap in understanding the specific impacts of climate change and environmental factors on its preservation. This study aims to bridge this gap by providing empirical data and analysis to inform adaptation and mitigation strategies tailored to the unique challenges faced by the Catacombs of Kom El-Shouqafa. By addressing these gaps and emphasizing authenticity, this study contributes to the ongoing efforts to safeguard this invaluable cultural heritage site for future generations.

2. Methodology

The methodology of this study combines historical and descriptive methods to comprehensively assess the value and condition of the Kom El-Shouqafa site in Alexandria, Egypt, and to develop appropriate adaptation and mitigation strategies. The historical method is applied to illustrate the significance of the site, its historical background, and its unique layout. Through extensive archival research and analysis of historical records, the study establishes the cultural and historical importance of the catacombs. The descriptive methods, on the other hand, rely on direct observation of the site through field visits to assess its current condition. These visits allow for the identification of deterioration, structural damage, and environmental impacts affecting the archaeological site. Furthermore, the study involves collaboration with the local community, site crew, inspectors, and other stakeholders through brainstorming sessions. This collaborative approach enables the understanding of the site's status from various perspectives and the identification of its strengths and weaknesses. By integrating historical research, field observations, and stakeholder engagement, this methodology provides a holistic understanding of the Kom El-Shouqafa site and informs the development of effective preservation strategies.

3. Results

3.1. *The catacombs of Kom El-Shouqafa*

3.1.1. Physical Environment

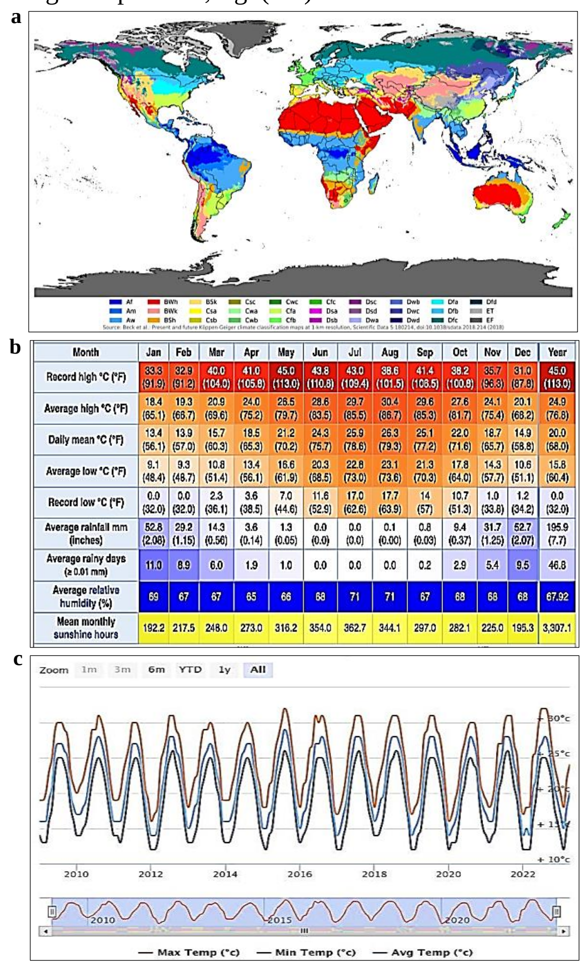
3.1.1.1. *Location*

East of Alexandria, in the Karmouz region, is where Kom El-Shouqafa is located. This catacomb is 2.2-2.5 kilometers from the coastline, figs. (4-a)

Figure (4) the location and the site of Kom El-Shouqafa (*After: Google Earth, 2023*)

3.1.1.2. *Climate*

The Köppen climate classification for Alexandria is BWh, it has a hot desert climate with hot steppe climatic influences nearby, fig. (5-a). The city experiences a less arid environment than the desert hinterland, like the remainder of Egypt's northern coast, thanks to the prevalent north wind that blows over the Mediterranean. One of the wettest regions in Egypt is Alexandria. The city's climate is influenced by the Mediterranean Sea, which moderates temperatures, and causes varied wet winters and generally hot, somewhat longer summers that occasionally can be highly humid. Jan. and Feb. are the coldest months [21]. The weather in Alexandria is arid. In Alexandria. The predominant climate in this area is designated as BWh by the Köppen-Geiger classification system. In Alexandria, the average annual temperature is 20.8 °C. Annual precipitation totals 181 mm, fig. (5-b). In the northern hemisphere, Alexandria is situated. With an average temperature of 30.4 °C, Aug. is the hottest month of the year. The typical Jan. temperature is 18.4 °C. It is the year's coldest average temperature, fig. (5-c).



Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	33.3 (91.9)	32.9 (91.2)	40.0 (104.0)	41.0 (105.8)	45.0 (113.0)	43.8 (110.8)	43.0 (109.4)	38.6 (101.5)	41.4 (106.5)	38.2 (100.8)	35.7 (96.3)	31.0 (87.8)	45.0 (113.0)
Average high °C (°F)	18.4 (65.1)	19.3 (66.7)	20.9 (69.6)	24.0 (75.2)	26.5 (79.7)	28.6 (83.5)	29.7 (85.5)	30.4 (86.7)	29.6 (85.3)	27.6 (81.7)	24.1 (75.4)	20.1 (68.2)	24.9 (76.8)
Daily mean °C (°F)	13.4 (56.1)	13.9 (57.0)	15.7 (60.3)	18.5 (65.3)	21.2 (70.2)	24.3 (75.7)	25.9 (78.6)	26.3 (79.3)	25.1 (77.2)	22.0 (71.6)	18.7 (65.7)	14.9 (58.8)	20.0 (68.0)
Average low °C (°F)	9.1 (48.4)	9.3 (48.7)	10.8 (51.4)	13.4 (56.1)	16.6 (61.9)	20.3 (68.5)	22.8 (73.0)	23.1 (73.6)	21.3 (70.3)	17.8 (64.0)	14.3 (57.7)	10.6 (51.1)	15.8 (60.4)
Record low °C (°F)	0.0 (32.0)	0.0 (32.0)	2.3 (36.1)	3.6 (38.5)	7.0 (44.6)	11.6 (52.9)	17.0 (62.6)	17.7 (63.9)	14 (57)	10.7 (51.3)	1.0 (33.8)	1.2 (34.2)	0.0 (32.0)
Average rainfall mm (inches)	52.8 (2.08)	29.2 (1.15)	14.3 (0.56)	3.6 (0.14)	1.3 (0.05)	0.0 (0.0)	0.0 (0.0)	0.1 (0.00)	0.8 (0.03)	9.4 (0.37)	31.7 (1.25)	52.7 (2.07)	195.9 (7.7)
Average rainy days (≥ 0.01 mm)	11.0	8.9	6.0	1.9	1.0	0.0	0.0	0.0	0.2	2.9	5.4	9.5	46.8
Average relative humidity (%)	69	67	67	65	66	68	71	71	67	68	68	68	67.92
Mean monthly sunshine hours	192.2	217.5	248.0	273.0	316.2	354.0	362.7	344.1	297.0	282.1	225.0	195.3	3,307.1

Figure (5) **a.** Köppen-Geiger climate classification map (2016-1980) (*After: Beck et al., 2018*), **b.** climate data for Alexandria (After*: World Meteorological Organization*), **c.** Alexandria yearly max, min, and average temperature (*After: World Weather Online, 2023,*)

The wettest month and the driest month differ in precipitation by 52.8 mm. July and Aug. have the greatest RH (71%). April (65%) has the lowest relative humidity of any month. With 11 days of rain, Jan. is the wettest month, figs. (6-a & b). The Mediterranean Sea is the nearest body of water to Alexandria; the sea temperatures reach an annual average of 22.50 °C. The annual maximum for the average monthly water temperature, which is 28.20 °C, occurs in August. The lowest temperature is recorded in Feb. at roughly 17.10 °C. Around Aug. 22, the water temperature hits its highest point of the year, 28.20°C. The lowest temperature occurs around Feb. 22 and is about 17.10 °C, fig. (6-c). The addition of water from melting ice sheets and glaciers and the expansion of warm saltwater are the two main contributors to sea level rise that are connected to global warming. The first graph, fig. (6-d) using satellite and coastal tide gauge data displays the amount of sea level change between about 1900 and 2018. Items with plus signs **(+)** raise global sea levels, whereas those with negative signs **(-)** lower them. These things are shown as they were at the time; they had an impact on sea level. The second graph, fig. (6-e) shows the satellite-observed change in the world's sea level from 1993 to the present, reaching 98.5 mm [22]. As a result, in Alexandria's coastal urban areas, sea-level rise (SLR) will cause coastal groundwater to increase. Groundwater rise (GWR) will inundate polluted soils, changing the physical, biological, and geochemical conditions that impact the fate and transport of existing toxins. Elevation changes can cause soil pollutants to be mobilized, change flow directions in a diverse urban environment with subterranean pipelines and utility trenches, and provide new exposure paths. Pumping for flood control raises the saltwater interface, altering groundwater salinity and mobilizing metals in the soil. This will greatly impact the facilities that are exposed to that groundwater, especially the archaeological buildings of a special nature and the extreme sensitivity to those climatic changes [23].

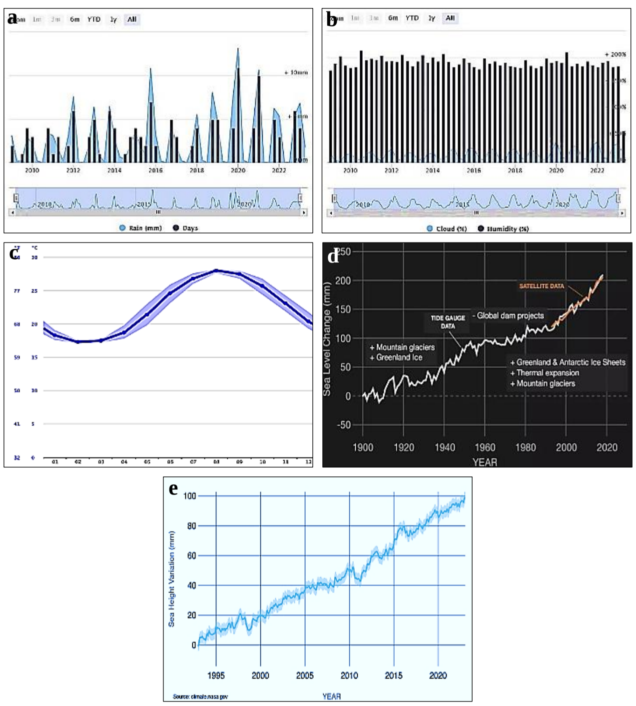


Figure (6) **a.** Alexandria yearly rainfall and rain day's average, **b.** Alexandria's annual cloud and humidity averages (*After: World Weather Online, 2023*), **c.** water temperature Alexandria (*After: Climate Alexandria*). **d.** sea level change from 1900 to 2018, **e. s**ea level change from 1993 till now (*After: NASA's Goddard Space Flight Centre, 2023*)

3.1.1.3. *Geology*

The Kom El-Shouqafa archaeological site is situated on the Delta's northern border, north of Lake Maryout, and 1.42 km south of the Mediterranean Sea shoreline. The Egyptian plateau's basement rock unit has Miocene and earlier carbonate deposits. Pilo-Pleistocene deposits consist of alternating strata of shale, limestone, sandstone, silt, and calcareous sand over the Miocene sedimentary rocks near the site of Kom El-Shouqafa, the pilot-Pleistocene sediments form a sequence of ridges and troughs that run roughly parallel to the Mediterranean shoreline [24].

3.1.2. Conservation status of the site

When the Catacombs were found, the region was immediately safeguarded from further urban expansion, and a red brick barrier wall was built around the site and the site building (which is now the Antiquities Inspectorate office). Alan Rowe photographed this wall, which still stands today. Alan Rowe, General Director of the Graeco-Roman Museum, began excavations of the catacombs and other archaeological sites within the site borders, including the third catacomb on the site, between 1941 and 1942. In 1941, Rowe was the first to clear the water from the first/lowest level. To do this, the Alexandria Municipal Technical Service erected a 35 HP electric pump at the bottom of the central shaft. As a result, Rowe was the first to fully reveal the catacombs' bottom level [25]. The SCA's engineering department initiated a dewatering program in 1985. The faculty of engineering at Alexandria Univ. was also participating. There were wells built. Pumping started, and water levels were checked twice daily. These wells are still in operation today. The water levels in the catacombs were extremely high in 1992, with water reaching the knee height of the sculptures in the antechamber on the second level, fig. (7). During a construction project in the region in 1996, a new fence wall was built, and the buffer zone was expanded to the northeast and northwest [26].

Figure (7) chamber G in the main catacombs with the high-water level (*After: ARCE, 1995*)

Six boreholes were dug on the archaeological site in 2004. Between Sep. 2014 and Aug. 2015, CDM Smith performed a survey both on-site and in the surrounding region. In tandem with the development of CDM Smith's engineering design, the American Research Centre in Egypt investigated the presence and potential for archaeological remains in the neighborhoods of Kom El-Shouqafa between Oct. 1, 2014, and Sep. 30, 2015 [27]. CDM Smith excavated eleven boreholes as part of their geotechnical data collection between Nov. 16 and Dec. 31, 2014. From Dec. 29, 2014, to Jan. 17, 2015, CDM Smith commissioned geophysical studies within the Kom El-Shouqafa site's catacombs and above ground [28]. Between Dec. 2017 and Sep. 2018, the Kom El-Shouqafa groundwater lowering project was part of a bilateral contract between the Government of the United States of America and the Egyptian government called the Sustainable Investment in Tourism in Egypt (SITE). CDM Smith managed the project, which was sponsored by USAID [27].

3.1.3. Cultural values

The Catacombs are in the Karmouz district, which is located east of Alexandria. The location was known as Kom El-Shouqafa." This cemetery was established in the early first century A.D. up to the fourth century A.D. and was still in use. In 1900, it was accidentally found when a donkey-drawn cart fell into a resulting in the finding. The Catacombs of Alexandria were so named because their architecture resembled the Christian Catacombs of Rome. The Alexandrian catacombs were almost certainly private burials that were eventually transformed into a public cemetery. It has three floors carved into the bedrock, a staircase, a rotunda, A burial room with three recesses on it, a vestibule, an antechamber, and a burial chamber—each containing a sarcophagus. Kom El-Shouqafa's tomb was submerged by subsurface water [29]. The Kom El-Shouqafa archaeological site in Alexandria consists of three underground passages carved from bedrock between the first and second century AD when Egypt was part of the Roman Empire. Only two of them are exposed to the public today: the 'Main Catacomb' and the 'Hall of Caracalla,' both accessed through a spiral staircase that runs around the tomb shaft of the Main Catacomb, figs. (8-a & b) [27].

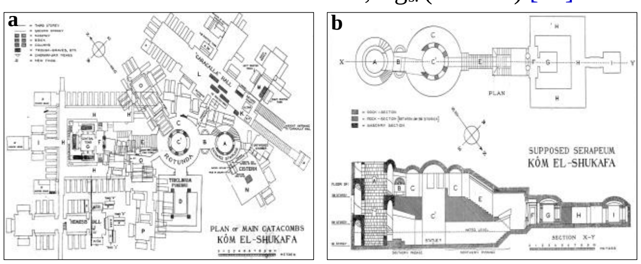


Figure (8) **a.** the main catacomb (three levels) and the 'Hall of Caracalla', **b.** profile through the Main Cata-combs main catacombs (lower) and plan of the lowest level (*After: Rowe, 1942*).

3.1.4. The catacombs threats and weaknesses points

According to the methodology used in this study, several threats and weaknesses in the study area represent a great danger to the heritage site. These problems are as follows:

3.1.4.1. *Geotechnical factors*

Protecting historical sites is crucial, especially in areas like the Mediterranean Region and Egypt's Alexandria, where underground water activity is a major factor, particularly in cases of underground Monuments. Environmental factors must also be considered when different protection measures are decided to be implemented. Seism tectonic and weathering regimes are active, and the complex geologic framework. Ancient structures are frequently destroyed by geological activity, earthquakes, settlement, and slope movements [30]. In some areas, the catacombs reveal unmistakable signs of partial collapse. Climate change, scaling on a stone surface, degradation of building material, intensive rock meal moist areas, particularly in semi-sheltered portions of the excavation, and salinity can all be found. degradation of the rock surface and ceiling cracks Structure-related deterioration includes partial collapse of some ceilings and walls, rock exfoliation, especially in the roof of the deepest, narrowest passageways, and mass wasting from the top and walls of passages. The bulk of structural defects is the result of the following elements: ***)** The gradual degrading of rock due to its intrinsic susceptibility to weathering processes, notably subsurface water and salt weathering. ***)** Earthquakes and different kinds of dynamic load induced by humans. ***)** The bulk of rocks is permanently deformed. ***)** The material's normal wear and tear. ***)** The history of local buildings. The earthquakes impacted a wide range of structural systems. The level of damage is determined by the structure type, craftsmanship quality, material, and the soil's state. Damaged regions around the epicenter of the 1992 earthquake were observed to be classified VII on the Modified Mercalli intensity scale [31].

3.1.4.2. *Environmental factors*

- ***)** *Lithology*: the catacombs are constructed from yellowish-white massive, fine- to medium-grained cross-bedded sandstone that has been cemented with calcareous cement. Extremely fine, water-soaked friable sand fills crossed conjugated joints in the lower sections. Calcareous sandstone surrounds this structure. It is a calcareous limestone with medium to fine grains that is brownish and has absorbed groundwater [32]. It irregularly sits on top of the Pliocene El Hagif formation or the older Miocene. Surface quaternary deposits mask the actual interaction.
- ***)** *Wind*: Because of wind-blown sand, monuments exposed to the wind may display severe deterioration. Corrosion's significance is influenced by the wind's force and how permanent it is. Because it comes into touch with the sand [33], the main cause of abrasion, the wind exerts its strongest thrust near the ground on the lowest portion of the monu-ments (1 to 2 m.), even more so. It should be emphasized that not all winds result in sandstorms, which require a threshold velocity of 6 to 8 m/s. As a result of the effects of air pressure, gradients, and deflection forces caused by the Earth's rotation around its axis, the wind velocity in the study area fluctuates from one month to the next. The highest wind speed ever recorded was 11.8 knots per hour in Feb., and the lowest was 9.7 knots per hour in Oct., fig. (9).

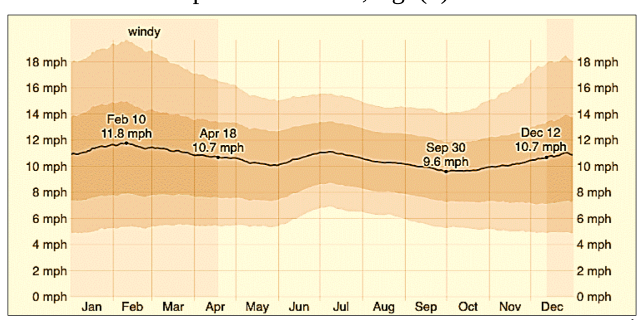


Figure (9) the average of mean hourly wind speeds (dark grey line), with 25th to 75th and 10th to 90th percentile bands. (*After: Weather Spark*)

3.1.5. Local scale monitoring and climate change adaptation

The monitoring of the archaeological site should be carried out using several survey methods including ground-based radar and 3D scanning lasers, as well as satellite images. Also, local monitoring of the site can be used in the future. The local observing approach entails monitoring and techniques for remote sensing to confirm the effects of natural dangers. Besides the topographic survey as well as aerial images of Unmanned Aerial Vehicles for documentation and comparison of three-dimensional models as well as the use of photographs to assess the deformation direction in the heritage site. As a result, areas prone to potential hazards can be recognized promptly, and as a result, information is given to decision-makers to safeguard the historic property from natural calamities. The primary objective is the long-term low-impact monitoring process on the site. The monitoring methodology begins with the use of satellite images, to determine the natural hazards on the archaeological site. When these images indicate the hazard from or near the study area, the second step begins with monitoring and field verification to record the change caused by the potential natural hazard and gauge its impact. Then the documentation process and field monitoring using laser scanning or remote sensing at low altitudes, using UAV and the method of the topographic survey GNSS and total station as a measuring tool, fig. (10). After determining the change in the site using the field mentioned above verification tools, satellite imagery is used again to verify and evaluate the damage to the archaeological site.

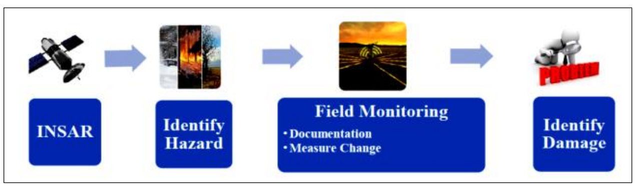


Figure (10) the local scale monitoring process

3.1.5.1. *UAVs documentation tool*

UAVs are now a common instrument utilized in many historical and archaeological research projects for their ability to provide high-resolution images compared to satellites and for their low cost [34]. They also provide more extensive information about the cultural site, particularly for difficult-to-access places in other systems. Remote sensors and cameras are positioned upon the UAVs to monitor the archaeological site and produce large quantities of high-resolution images of the site from the top [35]. The aircraft must possess a camera with a 20-megapixel to obtain high-resolution images of the site with fixed geo-point control spheres to produce 3-D models and compare them at different intervals [36].

3.1.5.2. *Laser scanners*

Laser scanners are tools used to monitor archaeological sites and are a handy tool in addition to the possibility of carrying and ease of use in addition to the not high cost [37]. This tool helps in the production of high-resolution digital reference data and allows easy distribution of these digital data. So, digital documents can, therefore, be prepared for the site of Kom El-Shouqafa and compared at different time intervals to determine the extent of the change in the archaeological site [38].

3.1.5.3. *Surveying techniques*

Scanning techniques are used to determine spot changes to any point on the surface, as geotechnical techniques measure the deformation ratio of the archaeological site on a relatively short measurement base [39]. The local changes of any spot on the surface are measured using the total station and the GNSS with millimeters precision and are used to measure distortions within the archaeological sites affected by the hazards [40].

3.1.6. Egyptian institutional framework for climate change

The UNFCCC, Kyoto Protocol, and United Nations Convention to Combat Desertification (UNCCD) were all ratified by Egypt in 1994, 2005, and 1995, respectively. Three national communications from Egypt have been produced for the UNFCCC (1990, 2010, 2016). The susceptibility and adaptation of several industries in Egypt that are affected by climate change were discussed in the Second National Communication. The Third National Communication updated the exposure and adaptability assessment, emphasizing health, tourism, and biodiversity. Egypt ratified the Paris Agreement on Climate Change in Sep. 2017 after signing it in April 2016 [41]. The Ministry of State for Environmental Affairs in Egypt gathers information from the relevant ministries required for the National Climate Change Communications. The National Adaptation Plan project in charge of the National Council on Climate Change, was founded in 2015. The National Committee on Climate Change, founded in 2007, has been replaced by this Council. The National Adaptation Strategy 2011 and high-level political institutions made up of line ministries with the responsibility for executing the plan are the foundation of Egypt's climate policy framework. The policy intends to provide Egypt with more flexibility to discuss the dangers and detrimental effects of climatic change across various industries while minimizing the negative effects of these changes [42]. Furthermore, Egypt has created its Vision 2030, which lays out a plan for accomplishing sustainable development objectives. The top priorities include promoting sustainable and decentralized development dynamics, broadening the scope of sustainable growth, and raising real per capita GDP in the middle-income country [43]. Sustainable agriculture, protection of coastal infrastructure, and effective water consumption are among the climate-change-related projects included in the Sustainable Development Strategy (SDS): Egypt Vision 2030. The possibility of incorporating climate change into national priorities is provided by the SDS 2030 update, which is now in progress. This will improve national budget allocation across crucial development sectors [44]. The impact of climate change on cultural heritage is unavoidable. The site of Kom el-Shouqafa faces numerous threats due to climate change. Many scenes and the lower parts of the walls have deteriorated because of the groundwater and the humidity that increased in Alexandria. The different stakeholders during brainstorming affirmed that the pace of deterioration has markedly increased during the last decade. They also affirm that Egyptian heritage and the tourism sector should be the focus of strategies and tactics to lessen the effects of climate change [45,46]. They should combine preventative and precautionary measures with other direct and effective active measures, such as:

- Developing a set of strategies to manage biodiversity areas commensurate with their vulnerability.

- Accurately identifying nature reserves and areas eligible for inclusion in relevant lists.
- Develop integrated management plans for heritage areas, based on a range of factors, strengths, weaknesses, opportunities, and threats.
- Develop risk management plans for heritage sites, both natural and cultural, by evaluating the condition of the sites and identifying the problems they face. This is considered an essential step in adapting to climate change.
- Implementing a continuous monitoring system for heritage areas, either local-scale or satellite monitoring, to track changes and natural hazards that may affect the site and its contents. It is essential to integrate climate monitoring into the national budget.
- Taking all precautionary measures (engineering, construction, and environmental) to confront rising ocean levels due to global climate change.
- Cultural heritage sites where soil movement causes severe damage to the archaeological structures are mostly located in areas with unstable sandy soils. This problem can be alleviated by expanding farming operations with specific types of trees following scientific bases of protection within the management plans, which will stabilize the soil and prevent further wind erosion.
- Designing training programs and awareness campaigns to raise environmental and archaeological awareness and promote the culture of mitigation and adaptation to climate change for target groups, such as management teams of heritage sites and natural reserves. It is important to identify the stakeholders directly related to heritage to clarify the sensitivity of these sites and the importance of managing them well. It is also necessary to raise environmental and archaeological awareness in the local community as a critical partner in preserving heritage because they deal with heritage sites directly and continuously.
- Developing school awareness campaigns is an essential adaptation policy to raise awareness among school and university students regarding the seriousness of the current situation of climate change and the need to follow specific measures in their daily lives to mitigate these effects and minimize how climate change affects all industries. The school curriculum and universities should be modified to add mandatory courses about global climate change for all disciplines to raise awareness of the global problem.
- Develop plans to manage visitors and tourists to natural and cultural heritage areas to relieve the pressure on the sites most sensitive to climate change.
- Encouraging scientific research to investigate the issues with climate change to create many solutions for mitigation and adaptation.
- Directing the spending process in the country to build capacity in the context of climate change. We do not need to issue new laws to protect the environment or heritage sites, as they already exist. However, it is necessary to apply these laws to protect the environment and archaeological holdings. The Egyptian government issued Environmental Diet Law No. 4 (1994) and the Law on the Protection of the River Nile and Waterways (1982), in addition to the international agreements to prevent marine pollution, to which Egypt acceded in 1978. Egypt also issued the Antiquities Protection Law No. 117 in 1983, to which several amendments were made in subsequent years.

4. Discussion

Sustainability must be included in all efforts and policies to effectively adapt to climate change. It is not useful to begin planning or implementing any development project or program without first considering the consequences of climate change. Additionally, all the necessary safeguards and steps must be taken to minimize the hazards associated with anticipated climate change [47]. By adding value to urban/rural sustainability and attaining the following sustainability features, heritage may be a solid basis for practical development plans and government policies worldwide. These plans should include environmental, economic, social, and cultural sustainability [48]. When adopting any regulations regarding the adaptation of heritage sites to climate change, it is essential to consider the following factors. ***)** The combination of coastal ecosystems, sea levels, beaches, and the probability of the occurrence and recurrence of hurricanes and storms. ***)** Conferences, adventures, safari tours, coral bleaching, and shifting tourist rates. ***)** Shifting dunes may increase erosion activity. ***)** The importance of including policies regarding climate change in planning for sustainable and economic development impacts the environment, the economy, and many facets of society [49].

5. Conclusion

Climate change poses a significant threat to the preservation of Egypt's cultural heritage, which is an essential part of the country's identity and history. Effective adaptation requires a multi-disciplinary approach involving collaboration between archaeologists, climate scientists, policymakers, and local communities. The integration of sustainable building materials, traditional knowledge, and community engagement can safeguard the preservation of Egypt's cultural legacy for future generations and assist in lessening climate change's consequences. The primary objective of this research was to determine the essential coping mechanisms for a changing climate to safeguard the overall natural and cultural heritage of Egypt. The results showed that one of the nations that is particularly vulnerable to climate change exposure is Egypt. It also showed the need to focus on all categories of adaptation, whether structural adaptation in terms of engineering, the environment, technological services, and the ecosystem, as well as social adaptation in terms of spreading education and media and the need to pay attention to changing and developing public behavior. Among the findings of the study was the necessity of institutional adaptation through activating the regulations, laws, policies, and programs of the government. The study also found, the necessity of social and economic development to be able to adapt to those climatic changes. Finally, some adaptation policies, such as enhancing public awareness, developing sustainable management plans for heritage areas, encouraging scientific research, and following up on international reports, were proposed; these policies can be adopted by the Egyptian government to achieve sustainable climate management.

References

[1] El Zein, A. & Chehayeb, N. (2015). The effect of greenhouse gases on earth's temperature. *Int. J. of Environmental Monitoring and Analysis*. 3 (2). 74-79.

[2] Kennedy, J., Thorne, W., Peterson, T., et al. (2010). State of the Climate in 2009” Special supplement: *Bulletin of the American Meteorological Society*. 91 (7): S1-S224.

[3] ADB. (2020). *Climate risk country profile: Sri Lanka.* World Bank Group.

[4] Kamal, I., Fekri, M., Abou El-Magd, I. (2021). Mapping the impacts of projected sea-level rise on cultural heritage sites in Egypt: Case study (Alexandria). *J. of Faculty of Tourism Univ. of Sadat City*. 5(1/2), doi:10.21608/mfth.2021.190350.

[5] Gates, B. (2022). How to avoid the climate disasters, *https://gain.nd.edu/our-work/country-index/* (5/10/2023)

[6] USAID., (2018). Climate links, *https://www.climatelinks.org/sites/default/files/asset/document/2018_USAID-ATLAS-Project_Climate-Risk-Profile-Egypt.pdf*. (13/9/2023)

[7] UNESCO: World Heritage Convention. (2022). https://whc.unesco.org/en/statesparties/eg/. (5/11/2023)

[8] Osipova, E., Shadie, P., Zwahlen, C., et al. (2017). *World heritage outlook 2: A conservation assessment of all natural world heritage sites*, IUCN, Gland, Switzerland.

[9] Turner, M., Calder, W., Cumming, G., et al. (2020). Climate change, ecosystems and abrupt change: science priorities. *Philosophical Transactions of the Royal Society B*. 375, doi: 10.1098/rstb.2019.0105.

[10] Climate Change and Heritage Working Group. (2019). The future of our pasts: Engaging of cultural heritage in climate action, ICOMOS, *https://indd.adobe.com/view/a9a551e3-3b23-4127-99fd-a7a80d91a29e*, (15/10/2023)

[11] Sabbioni, C., Brimblecombe, P., Cassar, M. (2010). The atlas of climate change impact on European cultural heritage. *Scientific analysis and management strategies*, 1st ed., Anthem Press, UK.

[12] Berenfeld, M. (2008). Climate change and cultural heritage: Local evidence, global responses. *George Wright Forum*. 25 (2): 66-82.

[13] Hollesen, J., Callanan, M., Dawson, T., et al. (2018). Climate change and the deteriorating archaeological and environmental archives of the Arctic. *Antiquity* 92 (363): 573-586.

[14] Chaidez, V., Dreano, D., Agusti, S., et al. (2017). Decadal trends in Red Sea maximum surface temperature. *Scientific Reports.* 7, doi:10.1038/s41598-017-08146-z

[15] El-Sayed, H. (2013). The future impacts of climate change on Egyptian population., *https://iussp.org/sites/default/files/event_call_for_papers/Extended%20abstract_Climate%20change%20in%20Egypt_Khaled%20Hassan_0.pdf.* (12/9/2023)

[16] UNEP. (2018). How climate change and population growth threaten Egypt’s ancient treasures, *https://www.unep.org/news-and-stories/story/how-climate-change-and-population-growth-threaten-egypts-ancient-treasures#:~:text=Increasingly%20erratic%20weather%20that%20many,growth%20is%20complicating%20preservation%20efforts*. (25/8/2023)

[17] State Information Service, (2021). *https://linksshortcut.com/ajKuQ*. (14/8/2021).

[18] Dave, V. (2023). monitoring temperature patterns at selected world heritage sites in Egypt using high resolution worldclim data. *Landscape & Environment*. 17 (2): 42-58

[19] El-Gohary, M.A.: The environmental factors affecting the archaeological buildings in Egypt, “IV deterioration by synergistic marine effects. *Heritage Science*. 11: 122, doi: 10.1186/s40494-023-00963-y

[20] Hilmi, N., Safa, A. & Reynaud, S. (2012). Coral reefs and tourism in Egypt's Red Sea. *Topics in Middle Eastern and North African Economies*. 14: 416-434.

[21] Bastin, J., Clark, E., Elliott, T., et al. (2019). Understanding climate change from a global analysis of city analogues. *Plos One*. 14 (7), doi: 10.1371/journal.pone.0217592.

[22] Lindsey, R. (2023). Climate change: Global sea level. *https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level.* (25/8/2023).

[23] Hill, K., Hirschfeld, D., Lindquist, C., et al. (2023). Rising coastal groundwater as a result of sea-level rise will influence contaminated coastal sites and underground infrastructure. *Earth's Future*. 11 (9), doi: 10.1029/2023EF003825.

[24] Shipley, L. (2018). A *phenomenological approach to the Kom El-Shuqafa catacombs*, MA., Cornell Institute of Archaeology and Material Studies (CIAMS), Faculty of the Graduate School, Cornell Univ., NY.

[25] Abdallah, I., Abd El-Tawab, N. (2013). Effects of the groundwater on deterioration of the catacombs of Kom El-Shoqafa, Alexandria, Egypt. *e Conserv*, doi: 10.13140/RG.2.1.2407.7520.

[26] Sorbets, G., Pelle, A., Seif el-Din, M. (2015). *Renaître avec Osiris et Perséphone, Alexandrie, les tombes de Kôm el-Chougafa*, Centre d’Études Alexandrines, Alexandrie, Egypt.

[27] Sadarangani, F., Shehab, E., Jones, M., et al. (2019). Kom El-Shuqafa groundwater lowering project: Archaeological assessment report (investigations and findings). Final Report: CDM Smith, USAID. *https://pdf.usaid.gov/pdf_docs/PA00W4SB.pdf* (22/8/2023).

[28] Sadaramangalam, F., Omar, A. S., Shehab, E. (2015). *Desk-based assessment for the catacomb site of Kom El-Shuqafa, Alexandria Governorate: Archaeological assistance to the groundwater lowering projects at Kom El-Shuqafa and Kom Ombo (Annex to final report)*. The American Research Center in Egypt (ARCE), Egypt. *https://pdf.usaid.gov/pdf_docs/PA00KX9W.pdf.* (2/6/2023).

[29] Amin, M. (2017). The effect of underground water on heritage sites: A case study on Graeco-Roman cemeteries in Alexandria. *J. of Association of Arab Universities for Tourism and Hospitality*. 14: 65-78.

[30] Hemeda, S., Pitilakis, K., Papayianni, I., et al. (2007). Underground monuments (Catacombs) in Alexandria, Egypt. In: Pitilakis, K. (ed.) *4th Int. Conf. on Earthquake Geotechnical Engineering*, Thessaloniki, Greece, pp. 25-28.

[31] Badawi, H. & Mourad, Sh. (1994). Observations from the 12 October 1992 Dahshour earthquake in Egypt. *Natural Hazards.* 10: 261-274.

[32] El-Gohary, M. (2016). A holistic approach to the assessment of the groundwater destructive effects on stone decay in Edfu temple using AAS, SEM-EDX and XRD. *Environ Earth Sci*. 75:13, doi: 10.1007/s12665-015-4849-x

[33] Girgis, G. P. (1956). *Geology of the Pleistocene sediments of the Mediterranean coast west of Abou Qir,* Ph.D., Geology dept, Faculty of Science, Cairo Univ., Egypt.

[34] Colomina, I., Molina, P., (2014). Unmanned aerial systems for photogrammetry and remote sensing: A review. *ISPRS J. of Photogrammetry and Remote Sensing*. 92: 79-97.

[35] Khater, M. (2020). Heritage site management plan of Tuna El-Gebel. Ph.D., Faculty of Letters, Komazawa Univ., Japan.

[36] Themistocleous, K. (2017). *The use of UAVs to monitor archaeological sites: The case study of Choirokoitia within the PROTHEGO project*. In: Kyriacos, Th (ed.) *Cyprus 5th Int. Conf. on Remote Sensing and Geo-information of Environment (RSCy2017)*, Paphos, Chypre, doi.org/10.1117/12.2292351.

[37] Fassi, F., Fregonese, L., Ackermann, S., et al. (2013). Comparison between laser scanning and automated 3d modelling techniques to reconstruct complex and extensive cultural heritage areas. *The Int. Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 40: 73-80.

[38] Vilceanu, C., Herban, S., Alionescu, A., et al. (2015). Processing of environmental data using digital terrain models for the western part of Romania. In: Bulgarian Academy of Sciences (ed.) *15th Int. Multidisciplinary Scientific Geo Conf. SGEM*. 2 (2): 1043-1050.

[39] Jiang, Y., Wdowinski, S., Dixon, T. H., et al. (2012). Slow slip events in Costa Rica detected by continuous GPS observations, 2002-2011. *Geochemistry, Geophysics, Geosystems*. 13 (4), doi: 10.1029/2012GC004058.

[40] Hassani, F. (2015). Documentation of cultural heritage; techniques, potentials, and constraints. *The Int. Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*. 40: 207-214.

[41] Jungudo, M. (2022). The impact of climate change in Egypt. *Int. J. of Research*. 9 (3): 286-287.

[42] Mostafa, A. 2023). An update on Egypt climate change policies post-coronavirus. *J. of Legal and Economic Research*, 13: 101-186.

[43] Aguilar, L., Rogers, F., Haddad, F., et al. (2011). Natio-nal strategy for mainstreaming gender in climate change in Egypt. (IUCN. *https://genderclimatetracker.org/sites/default/files/Resources/2011_IUCN_Climate-Change-Gender-Action-Plan-Egypt.pdf.* (25/3/2023)

[44] Egyptian Environmental Affairs Agency. (2016). *Egypt's third national communication under the United Nations Framework Convention on Climate Change (UNFCCC)*, EEAA, Cairo, Egypt.

[45] Hefny, H., Elmekkawe, M. & Ramadan, M. (2019). *Climate governance in Egypt*. The Public Policy HUB, School of Global Affairs and Public Policy, AUC. Cairo.

[46] Colette, A. & Rao, K. (2007). *Climate change and world heritage: Report on predicting and managing the impacts of climate change on world heritage and strategy to assist states parties to implement appropriate management responses*, UNESCO, Paris.

[47] Laurence B. (2008). Climate change: Impacts, vulnerabilities and adaptation in developing countries, UNFCCC, Bonn, Germany.

[48] Sedova, A. (2021). Cultural heritage adaptation is sustainable. IOP Conf. Series: Earth and Environmental Science. 822, doi: 10.1088/1755-1315/822/1/012006.

[49] El-Ramady, H., El-Marsafawy, S. & Lewis, L. (2013). Sustainable agriculture and climate changes in Egypt. In: Lichtfouse, E. (ed.) *Sustainable Agriculture Reviews*, Springer Netherlands, Dordrecht, pp. 41-95.