New Design Ideas
Special Issue | ICCAUA2022, pp.87-97

URBAN HEAT ISLAND EFFECT OF URBAN SPACES: THE CASE OF THE PEARLING PATH IN BAHRAIN

Fatema Mohamed[1*], Islam Hamdi Elghonaimy[1], Wisam Mohammed [2]

[1]University of Bahrain, College of Engineering, Department of Architecture and Interior Design, Isa Town, Bahrain
[2]Imam Abdulrahman Bin Faisal University, Collage of Architecture and Planning, Department of Landscape Architecture, Dammam, Saudi Arabia

Abstract. Bahrain has many touristic projects that care about historical areas, which contribute positively to the country. "Pearling Path" is one of these projects is located in the old part of Al-Muharraq city in Bahrain. This project faces an environmental challenge, the Urban Heat Island (UHI). Planners & developers in Bahrain recommended controlling the reasons of the UHI in such an area to improve this touristic project. This study investigates the effects of UHI in Pearling Path, which goes across different locations with different urban fabrics. The study methodology used the theoretical approach by the literature review on urban heat islands and assumptions regarding the causes and remedies to this problem, followed by the analytical stage by doing the mapping urban heat islands using remote sensing data which are conducted at the "Pearling Path" locations in Muharraq Island, in Bahrain. Moreover, the study is concluded using remote sensing data which is used to identify the spots showing significant symptoms of UHI. At the end of the study, the final analyses of results reveal that there are several spots of UHI, which have varying in intensity impacts.

Keywords: *Urban Heat Island, built environment, pearling path, Bahrain.*

Corresponding Author: *Fatema, Mohamed, University of Bahrain, College of Engineering, Department of Architecture and Interior Design, Isa Town, Bahrain, e-mail: 20100381@stu.uob.edu.bh*

Received: *18 June 2022;* ***Accepted:*** *19 September 2022;* ***Published:*** *29 September 2022.*

1. Introduction

Kingdom of Bahrain consists of thirty-three natural islands and an increasing amount of artificial reclaimed islands in the archipelago, located in the Arabian Gulf close to the Arabian Peninsula (Al-Khalifa, 2015). Chithambaran (2016) illustrated that the land is mainly an arid desert with few sources of fresh water. Due to its location and topography, the climate of Bahrain is extremely hot most of the year. Thus, historically, Bahrain supported a tiny population that was dependent mainly on fishing. On the other hand, the urban fabric and the finishing materials of the open spaces of the old parts of Bahraini areas are characterized by the organic pattern, which gave the residents of such area's comfortability. Moreover, Elghonaimy (2020) explained that this organic pattern affected the intimate feelings of the residents positively to their neighborhood and encouraged them to stay and develop these areas a long time ago. Hamouche (2004) mentioned that after discovering crude oil in the last century, Bahrain's economy diversified from fishing to several petroleum and petrochemical projects resulting in a significant increase in population. Especially in the last two decades, there has been a notable development in the tourism sector, which has further contributed to a dramatic increase in the population (Mansfeld & Winckler, 2008). This development has led to the

construction of numerous townships and urban centers and changed the Land cover in general, consequently raising the temperature of the country's urban spaces. In this regard, The Bahrain Culture Authority has different plans to develop the heritage areas in Bahrain. Most of these projects connect the heritage areas with the tourist activates. The strategic master plan for Bahrain 20230 shows the significance of such tourists' activities as source of income to enhance the economy of Bahrain (Information & eGovernment Authority, 2022). Tourists tours are using the outdoor spaces, which are the main areas of practicing different activities to attract tourists in such heritage areas (Bahrain Authority for Culture & Antiquities, 2022). The unique climate conditions may decrease such activities specially with the UHI phenomena. Although not many studies have been conducted till date on UHI and its effects on the chosen location however, this study tries to find out and identify if there are considerable effects of UHI within this area. Therefore, the objective of this study is to investigate the presence of UHI and its causes in the Pearling Path area of Muharraq in Bahrain.

2. Possibilities for UHI mitigation in old cities based on urban design

Urban Morphology and Urban geometry are two critical aspects of urban fabric that significantly impact the creation of Urban Heat Island (UHI). Urban morphology is the analysis of urban forms that considers the formation & transformation of the building in a city over time. Essentially, it is the study of physical characteristics and spatial patterns at various scales, in order to make appropriate urban interventions (Mohamed *et al*., 2021).

The effects of urban morphology and urban geometry could be proven using examples from two districts in Saudi Arabia's famous Makkah City, namely the Al-Eskan and Al-Sharshaf districts. In Al-Sharshaf district, there is an old organic fabric and traditional cul-de-sac pattern. The twisted iron-grid fabric with a curvilinear loop design, on the other hand, can be found in the AlEskan district. The impact of urban morphology and urban geometry has been studied on both sites. This study yielded several significant conclusions, including the following:

a) The mean temperature difference between these two sides was 1-1.5 degrees Celsius, with Al-Eskan being the higher of the two.
b) The urban fabric has a significant impact on UHI distribution. Narrow alleys and streets, for example, provide more shade than wide open streets, reducing the impact of UHI (Mohamed *et al.*, 2021).

Furthermore, the shade of the building in the old cities play an important role. Consider the study of Masoud et al. (2016), which explains the character of the streets in Jeddah's old city, the streets are narrower and curved, which offers shadow areas and reduces direct sunlight exposure.

There are several examples of having UHI inside the old fabrics in cities, for example, one of the essential criteria is the aspect ratio of canyon geometry in terms of urban architecture because it affects heat dissipation and wind access closer to the ground level. The aspect ratio is the proportion of the canyon walls' average height (H) to their width (W) (Aghamohammadi *et al*., 2021). The aspect ratio of a canyon is called uniform if it is nearly equal to one; if it is less than 0.5, it is considered shallow; and if it is around 2, it is considered deep. The magnitude of the aspect ratio has been found to be inversely proportional to the night-time air temperature, implying that a higher aspect ratio equals a higher night-time air temperature. Deep canyons reduce wind penetration and radiative

losses. Shade has been credited as the primary reason for cities' lower levels of heat discomfort (Aghamohammadi *et al*., 2021).

Another example is Malacca's historical district, officially classified as a 'UNESCO, World Heritage Site'. The heating emitted from the structures nearby and roads contribute significantly to the urban heat environment because of the great building ratio with narrow roads. As a result, expecting a significant improvement in thermal comfort for pedestrians from small-scale greening is unrealistic. On the other hand, Saito and Shinozaki suggest that community greening through street planting can help improve thermal conditions by filtering direct sunlight. Furthermore, pedestrians visibility of historic structures and the urban landscape, that is an essential aspect of the city's legacy and character, should be considered in the planting strategy (Saito *et al*., 2017).

In the old part of Manama, Bahrain, a study about the pockets of the heat island within the old fabric indicates that precedence must be given to resolving the conflicts among the strategic plans and the policy being developed through the following actions: At the outset, on the level of country, the matter of limiting and reducing UHI must be included in the yearly review of Bahrain National Strategy 2030 along with a close cooperation and keeping synergy between urban activities and infrastructure development. Next comes the role of different governorates and municipal units who should work to enhance the usage of open spaces and develop more spaces and landscapes. The city units must work towards removing the causes that create thermal pockets in the districts. The governorates can look at the master plans and take a lead in moving away central markets or scattered industrial workshops and micro industries in an appropriate area if required (Elghonaimy, 2019).

The smaller administrative units within the governorates can monitor thermal pockets within the residential blocks. They should prepare an all including plan that focuses on development of vacant land plots and the open spaces which are under planning, in relation to the urban fabric of Manama. They must work to increase the green places within the scope of the area under the study which can be done in several methods like preparing a green envelope design for buildings e.g., green roofs and facades. Equipping the roofs and facades with greenery is quite crucial as greenery acts as an insulation from heat and helps to keep the indoors away from high outdoor temperatures. Replacing the use of asphalt for paving streets with an alternate material also helps in reducing UHI (Elghonaimy, 2021).

3. Material and Methods

This research intends analyze the existing UHI in the area and identify the location of it on the "Pearling Path" Muharraq Island, in Bahrain. In addition to investigate the changes in air temperature within the Pearling Path area in various urban spaces. This research aims to use a case study to analyze the effect of UHI on the project using data from the metrology stations of Bahrain International Airport and Bahrain International Circuit and utilizing remote sensing data. This research will be guided by mapping urban heat islands using remote sensing data in the study area.

4. Overview of the study area: "Pearling Path" project, Muharraq Island in Bahrain

Bahrain's Pearling Path is one of the most important tourist destinations in the country Figure. 1. This site contains seventeen heritage buildings that highlight Bahrain's cultural heritage. The site is in Muharraq, Bahrain's former capital and center of economic activity. The historical, societal, and economical aspects of civilizations are expressed through architectural elements in city (Job & Elghonaimy, 2022). There are three large oyster beds on the island. It is also on the 2012 UNESCO World Heritage List as a cultural heritage site. People involved in the pearling industry used to launch their boats to search for pearls in the oyster beds (Shubbar & Furlan, 2019). Pearling was the backbone of the local economy before the discovery of oil in Bahrain and before Japan began cultivating pearls. After the 1930s, this trade declined slowly but surely, and most of the pearling locations in Bahrain vanished. As a result, this is the only surviving site that contains a complete sample of the pearling cultural traditions that aided the country's prosperity. It also includes a significant portion of the fortress of Qal'at Bu Mahir, which served to protect the area (Motisi et al., 2019). The Pearling Path, a project that displays a historical route comprises several heritage buildings conserved for sightseeing for locals as well as the tourists Figure 2.

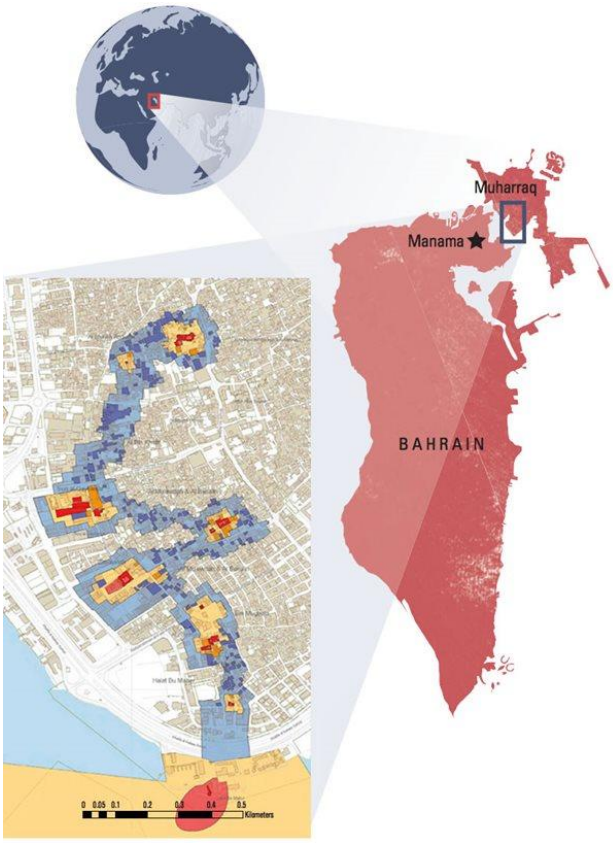


Figure 1. The Pealing Path map. Source: (Smith, 2017)

Figure 2. The Pealing Path links heritage buildings. Source: Authors

Therefore, because this is one of the last remaining cultural sites, the Bahrain Authority for Culture and Antiquities (BACA) has restored the majority of the cultural buildings in this area in order to preserve the structural characteristics of the buildings, and prevent them from being modified. The path will be a significant tourist attraction in the future, so studying the effects of urbanization and UHI on it is critical. The fact that these sites are in the middle of a densely populated area exacerbates the problem of UHI (Motisi *et al*., 2019). The effect of UHI is highly likely to increase in the future due to expected tourist traffic and increased commercial activities. Moreover, Bahrain 2030 vision has climate action as one of the major actionable goals. It emphasizes on the contribution of urban development on the phenomenon of global warming (Bahrain SDGs, 2021). It is in this pursuit that we need to study the effects of urban developments in terms of the dramatic increase in the number of concrete buildings as well as the enormous increase in the number of residents and density of population in some areas Figure. 3.

Figure 3. The Pealing Path is quite densely populated. Source: Authors

According to Hamouche (2004), the density of the old city of Muharraq is 70% of the covered area. The canyon in the pearling includes uniform, shallow and deep canyons. Most canyons consider as deep with around two and uniform nearly equal to one aspect ratio, the proportion of the average height of walls to the width of the canyon Figure. 4. Furthermore, the flooring in the Pearling Path is paved with mother of pearl encrusted concrete flooring, interlocking concrete paver blocks, and asphalt.

Figure 4. The shading in the open space and allays at afternoon time

Pearling path is a historical site and the weather of the area changed as Bahrain weather has altered over the time. According to Elagib and Abdu (2010), a fresh perspective concentrates on examining the mean temperatures of Bahrain, observed at the International Airport since 1947 upto 2005, for almost 59 years. The worldly trends point towards a noticeable temperature increase during the dry season of 0.166 °C in decade. Specifically in summers from May to July and October show a trend, which is quite significant (0.172 to 0.247°C decade). In wet months, there is a tendency to demonstrate both a rise and a fall in their temperatures. Noticeable warmings were noted during the decade of 1991-2000 and also the incidences of unusual mean temperatures and count of months in the years showing more than usual temperature. Within a year or season, the variabilities in temperature were insignificant but the wet season displayed high variations of temperature in that season. Additional examinations conducted on the data available of temperature for 1981 to 2005 in a trial to find a probable origin of climatical and or non climatical factors, for example accelerated urbanization and intensified desertification. Noticeably higher levels of increase in maximum temperature in contrast to lower levels of rise in minimum temperature have resulted in a raise in the levels of daily temperature variations. As compared to the nighttime, the warming rate of the day time is seven times. However, night time temperature of the wet season has had a huge increase at a rate of more than three times than the night time temperature of the dry season. Enough evidence is available which points towards rapid urbanization as a significant contributor for the recorded levels of temperature increase. The effect of desertification on temperature changes has been neutralized by urbanization (Elagib & Abdu, 2010).

5. Existing environmental conditions:

Environmental information collected from the Meteorological Directorate, Kingdom of Bahrain for two locations (Bahrain International Airport and Bahrain International Circuit). The Pearling Path is located in Muharraq city as well as Bahrain International Airport. In comparison, Bahrain International Circuit is located in the Sakhir desert with different urban characteristics. Besides this, Sakhir is considered a rural area with more open spaces and fewer people and buildings than Muharraq area. Therefore, the air temperatures of both locations were compared during four sessions. The dates selected for the study represent the average temperature of the month. The air temperature, relative humidity and wind speed can affect outdoor human comfort in an urban climate (Stathopoulos, 2016).

The existing environmental condition shows the air temperature for the four sessions was lower at noontime at Bahrain International airport, Muharraq, while the temperatures were higher in the desert. However, the temperatures were higher at Bahrain International airport at night before sunrise and in the early morning Figure 5. Considering the rise in the temperature at night in Muharraq and developing the study using remote sensing is essential to identify the phenomena within the Pearling Path, Muharraq.

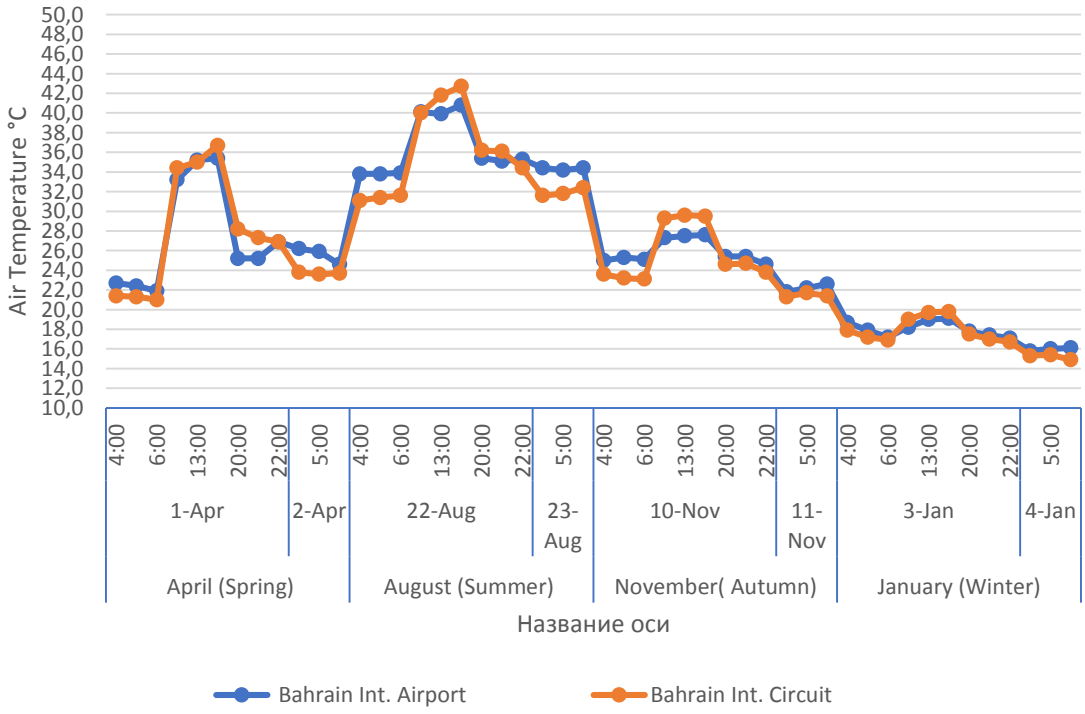


Figure 5. Air Temperature (Bahrain International Airport and Bahrain International Circuit)

6. Mapping urban heat islands using remote sensing data

Two Landsat 8 OLI/TIRS images were obtained from USGS EarthExplorer (USGS, 2012) data hub and dated September 12, 2020 and March 7, 2021. Hereinafter, we are going to point simply to these images as 2020 and 2021 respectively. Both images are cloud free and georeferenced to the WGS84\UTM Zone 39N coordinate system with

spatial resolution 30 m for pixel. Landsat 8 OLI/TIRS has eleven bands as shown in table 1. In this study, only reflectance in visible red and near infrared are required. Band 4 and band 5 represent red and near infrared reflectance respectively. Land thermal infrared emittance is required and it is provided by band 10 and band 11, due to uncertainty of band 11 calibration, only band 10 was used in this study (USGS 2019).

Required bands were cropped to match study area. The top atmosphere temperature is obtained from band 10 using the following conversion equation:

$$T_{TOA} = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}+1\right)}, \quad (1)$$

where T_{TOA} is the land surface temperature in Kalvin as measured top of atmosphere, L_λ is the land emittance as recorded by band 10, K1 and K2 are constants.

Land surface emissivity which is required for removing the effect of atmosphere was retrieved using the following equation:

$$\varepsilon = \varepsilon_v . P_v + \varepsilon_s (1 - P_v), \quad (2)$$

where ε_v and ε_s are vegetation emissivity and soil emissivity. For Landsat 8, these values are 0.98 and 0.96 respectively. P_v is vegetation fraction which was obtained by the following:

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2, \quad (3)$$

where NDVI is the normalized difference vegetation index that was retrieved using the following equation:

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4}, \quad (4)$$

$NDVI_{min}$ and $NDVI_{max}$ are the minimum and the maximum value of NDVI respectively.

Finally, the land surface temperature was obtained using the following equation:

$$LST = \frac{T_{TOA}}{1 + \left(\frac{\lambda \cdot \sigma \cdot T_{TOA}}{h \cdot c}\right) \ln \varepsilon}, \quad (5)$$

where λ is effective wavelength of band 10, σ is Boltzmann's constant, h is Blank's constant, and c is the light speed in the vacuum.

Table 1. Landsat 8 OLI/TIRS band designations. Source: (USGS, 2019)

Band	Wavelength (μm)
Band One –Coastal aerosol	(0.43-0.45)
Band Two –Blue	(0.45-0.51)
Band Three –Green	(0.53-0.59)
Band Four –Red	(0.64-0.67)
Band Five –Near Infrared (NIR)	(0.85-0.88)
Band Six –Shortwave Infrared (SWIR1)	(1.57-1.65)
Band Seven –Shortwave Infrared (SWIR2)	(2.11-2.29)
Band Eight –Panchromatic	(0.50 – 0.68)
Band Nine –Cirrus	(1.36-1.38)
Band Ten –Thermal Infrared (TIRS1)	(10.60 – 11.19)
Band Twelve –Thermal Infrared (TIRS2)	(11.50-12.51)

The following rule was used to delineate and classified urban heat islands in the study area:

if $LST_{min} \leq LST < \mu_{LST} + 2\delta_{LST}$ *then there is no heat island.*

If $\mu_{LST} + 2\delta_{LST} \leq LST < \mu_{LST} + 3\delta_{LST}$ *there is weak heat island.*
If $\mu_{LST} + 3\delta_{LST} \leq LST < \mu_{LST} + 4\delta_{LST}$ *there is middle heat island.*
If $\mu_{LST} + 4\delta_{LST} \leq LST < \mu_{LST} + 5\delta_{LST}$ *there is strong heat island.*
If $\mu_{LST} + 5\delta_{LST} \leq LST < \mu_{LST} + 6\delta_{LST}$ *there is extreme heat island.*

7. Results

The main results of the analysis were the allocating the UHI in the "Pearling Path" Muharraq Island, in Bahrain. Moreover, the results demonstrate that there are spots created throughout the area showing the effects of UHI. Findings of the study illustrate that in September 2020, most of the areas impacted by UHI were generally around the asphalted road and at the beginning point of the Muharraq Souq of Shaikh Abdulla Ave. The effects were also seen in several open spaces and unshaded spots used for car parking. They were further finding in March 2021 show similar trends of UHI being concentrated around the asphalted roads and in the Muharraq Souq area at the starting point of Shaikh Abdulla Avenue and in the open spaces and Parking areas too. However, the area of the spots showing effects of the UHI was significantly more in March 2021 than what was identified in September 2020. The UHI phenomena around the pearling path project contributed by factors such as construction material of the buildings, road and the design of the open unshaded car parking spaces effect the surfaces temperature (Figure 6).

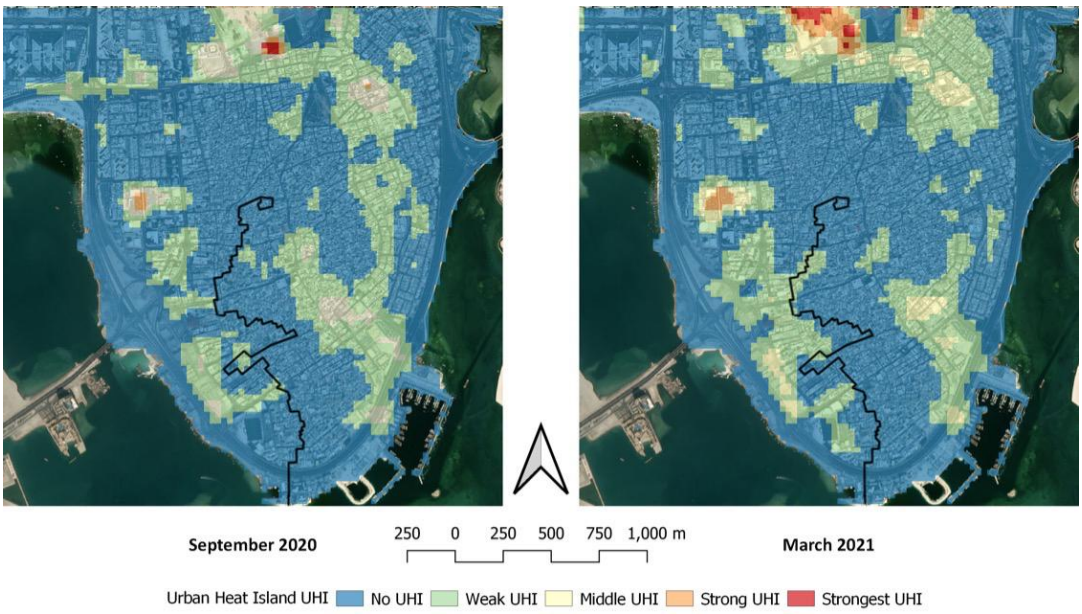
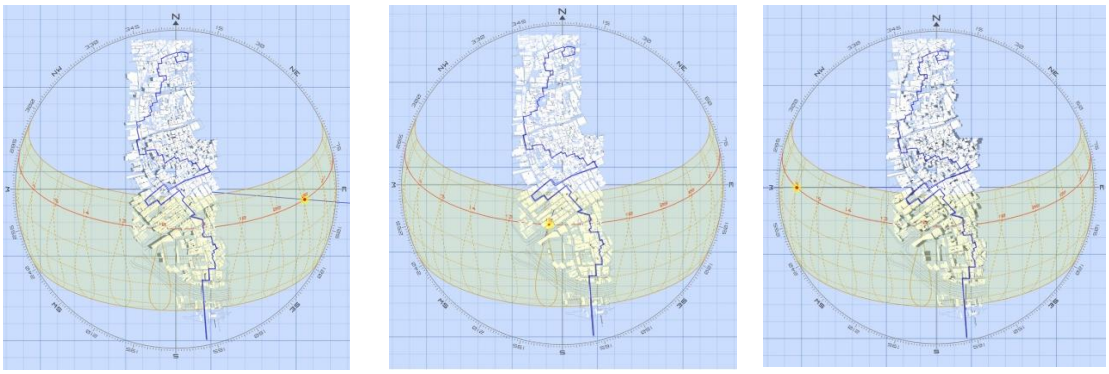


Figure 6. Urban Heat Island effect on the "Pealing Path", Muharraq. Source: Authors

Further investigation is done to demonstrate the shading pattern's performance for the area adjacent to the Pearling Path using the Andrewmarsh 3-D sun path software. The simulation takes in summer when the sun is directly above the equator. In order to illustrate the shading pattern's performance at different times of the day (morning-08:00, noon-12:30, and afternoon-16:00). Based on the material's conductivity, the building envelope surfaces absorb and store heat. At certain periods, heat is emitted into the building. The shading technique is used to protect the surface area exposed to solar radiation. Figure 7 illustrates the result of the shading within the pearling path. The open

spaces are mostly exposed to the sun during the day, which increases the temperature and UHI effects.



8:00 AM 12:00 PM 16:00 PM

Figure 7. Shadow performance on the Pearling Path area

8. Discussion and conclusion

To conclude, this study has allowed us to identify the exist of the UHI phenomena within the pearling path. It also allows us to find the locations of the UHI patches in different sessions along the area by using the remote sensing data. The research recommends that, on a national level, the issue of restricting and eliminating UHI must be addressed in the Bahrain National Strategy 2030's annual review. In addition to strong collaboration between urban activities and infrastructure development. In addition, it is the of different ministries to collaborate to improve open spaces usage and develop new landscapes. The Bahrain Authority for Culture and Antiquities (BACA) has preserved the culture of Bahrain and renovated the historical buildings, also created public spaces along the Pearling Pathway planted with trees. Although reducing the UHI phenomena in the Pearling Path needs to consider; to increase the number of people who can walk and visit these heritage buildings. As observed during the study, the increase in temperatures is due to lack of shade and high density of population. In addition, high traffic volumes increased business and commercial activity, and the lack of open and shaded spaces became a crucial cause of urban heat.

Therefore, this research helps to recognize the specific areas where we need to increase the green places. The mitigation of UHI could be accomplished in various ways, including tree planting and creating an environmental design for buildings, such as green roofs and facades. Moreover, the adoption of an alternative material for paving streets instead of asphalt also helps to reduce UHI. Furthermore, create shedding spaces within the scope of the area infected with UHI under the study. Thus, designing spaces and considering the environmental aspect can enhance the users and tourists experience. Future studies can use this research as preliminary evidence to support their research into this area in Bahrain and the Gulf region.

References

Al-Khalifa, F. (2015). *Urban Sustainability and Transforming Culture in the Arabian Gulf: The Case of Bahrain*. PhD thesis, University of Sheffield. URL: https://rb.gy/eipvi4

Aghamohammadi, N. Ramakreshnan, L. Fong, C.S.F. & Sulaiman, N.M. (2021). Urban Heat Island, Contributing Factors, Public Responses and Mitigation Approaches in the Tropical Context of Malaysia. *Urban Heat Island (UHI) Mitigation Hot and Humid Regions Advances in 21st Century Human Settlements*. DOI: 10.1007/978-981-33-4050-3_5.

Bahrain SDGs. (2021). Sustainable Development. https://www.sdgs.gov.bh/ [Date of access: 25.02.2021].

Bahrain Authority for Culture & Antiquities. (2022). Culture & Antiquities Strategy. https://culture.gov.bh/en/ [Date of access: 15.03.2022].

Chithambaran, S. (2016). Desert aquaculture & environmental sustainability. *Indian Journal of Geo-Marine Sciences*, *45*(12), 1733–1741.

El-Ghonaimy, I. H. (2020). Street furniture influence in revitalizing the Bahraini identity. *Journal of Contemporary Urban Affairs*, *4*(1), 11-20.

Elghonaimy, I., Mohammed, W.E. (2019). Urban heat islands in Bahrain: an urban perspective. *Buildings*, *9*(4), 96.

Elghonaimy, I., Albadal, N. (2021). Vertical Farming Projects and Reducing Urban Heat Islands Phenomenon in Cities. In R. Rahbarianyazd., (Ed.). *Contemporary Approaches in Urbanism and Heritage Studies* (pp.95-105).

Elagib, N., Abdu, A. (2010). Development of temperatures in the Kingdom of Bahrain from 1947 to 2005. *Theoretical and Applied Climatology*, *101*(3), 269–279.

Hamouche, M.B. (2004). The changing morphology of the gulf cities in the age of globalization: the case of Bahrain. *Habitat International*, 28, 521-540.

Information & eGovernment Authority. (2022). National strategies and alignment with SDGs. Available at: https://www.bahrain.bh/new/en/sdgs-strategies_en.html Date of access: 15.03.2022.

Job, S., Elghonaimy, I., (2022). Experiencing public parks through phenomenology: Case of Riffa Walk Park, Bahrain. *Civil Engineering and Architecture*, *10*(1), 224-235.

Mansfeld, Y., Winckler, O. (2008). The role of the tourism industry in transforming a rentier to a long-term viable economy: The case of Bahrain. *Current Issues in Tourism, 11*(3), 237-267.

Masoud, B., Beckers, B. & Coch, H. (2016). Sky Access versus Shading for Pedestrian Comfort in the Hot Tropical Climate of Jeddah. United Nations Development Programme.

Mohamed, M., Othman, A., Abotalib, A.Z., & Majrashi, A. (2021). Urban heat island effects on megacities in desert environments using spatial network analysis and remote sensing data: A case study from western Saudi Arabia. *Remote Sensing*, *13*(10).

Motisi, M., Casarin, F., Rizzi, G., Pianon, F., Zamara, A., & Gomez-Robles, L. (2019). The Bahrain Pearling Path: Urban Planning, Structural Investigation and Design of the Strengthening Interventions. In *RILEM Bookseries* (Vol. 18).

Saito, K., Said, I., & Shinozaki, M. (2017). Evidence-based neighborhood greening and concomitant improvement of urban heat environment in the context of a world heritage site-Malacca, Malaysia. *Computers, Environment and Urban Systems*, 64, 356-372.

Shubbar, F., Raffaello, F. (2019). Kanoo', a traditional urban neighborhood in Manama City: An approach to promote urban regeneration and enhance livability. *Saudi Journal of Civil Engineering*, *3*(5), 105-121.

Smith, S. (2017). *Bahrain's Pearling Path.* Aramco World.

Stathopoulos, T. (2006). Pedestrian level winds and outdoor human comfort. *Journal of Wind Engineering and Industrial Aerodynamics*, *94*(11), 769-780.

USGS. (2012). EarthExplorer. General Information Product. 136. Reston, VA: U.S. Geological Survey.

USGS. 2019. Landsat 8 (L8) Data Users Handbook. LSDS-1574 Version 5.0. Sioux Falls, South Dakota: U.S. Geological Survey (USGS).