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ENDORSED STRATEGIES TO ALLEVIATE THE URBAN HEAT ISLAND: CASE STUDY ON ALAHSA GOVERNORATE, KSA

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ABSTRACT

This study endorses five strategies to alleviate the urban heat island (UHI) of Alahsa Governorate, Eastern Province, kingdom of Saudi Arabia. This study investigated and summarized the UHI studies done on the governorate concluding that, heat island intensity of 2.3º is evident. Previous studies expecting increase in the intensity of the urban heat island of the governorate because of high pace of urban development and increasing levels of urbanizations in terms of land use and population density. The study discusses factors contributing to the cause and effects of the urban heat island. Focus-ing on these factors, the study necessitates five strategies to be considered by strategic planners supported and enforced by decision makers, urban planner and relative authorized bodies to alleviate the UHI of the governorate. The main strategy for lessening the intensity of the UHI of the governorate is land Management. While, raising the awareness strategy is vital. That is because of its effect on the rest of strategies. Land, Building, Roof and Traffic strategies will not be acquired with-out good levels of awareness and understanding to the effects of the outdoor living environment on indoor environment and to what extent it might risk human comfort and health.

KEYWORDS: Strategies, Urban Heat Island, Alleviation, Alahsa Governorate, Saudi Arabia.

INTRODUCTION

Alahsa Governorate is located in the South-eastern corner of Saudi Arabia occupying the southern part of the eastern region between 17-26 latitudes and 48-55 longitudes. It covers a vast area of around 530 000 km2, representing 68% of the area of the eastern region and 24% of the area of Saudi Arabia. It is considered as the largest oasis in the Arabic Peninsula [1]. The Governorate consists of many cities and villages in addition to the most famous empty desert that is called Empty Quarter. Alahsa governorate is famous because of its recognized oil centres. The most famous field, Al-Ghawar, the largest oil filed that provides more than half of the cumulative oil production of Saudi Arabia is located within the premises of the governorate [1].

Level of urbanization in terms of population density and land use of the governorate is increasing [2]. Urban development of Alahsa Governorate passed over four recognized stages. The first stage was counted before 1963. This stage is considered as the origination phase of human settlement. It is characterized as the phase of looking for best position for stabilization and making use of the presence of wells and springs as a source of permanent water for drinking and agriculture activities. It is characterized by tribal groupings communities having their own lands and natural resources [1]. While the second stage extended to 1973. In this stage, Population grown as well as commercial activities increased on main streets in the heart of the conurbation. The expansion of development at that time was in southern and Western directions of the region and its commercial centres. The population density was less than 273045 which recorded for 1975 [2]. On the other hand, the third stage was counted until 1994. This stage is considered as the evolution phase. Reflecting the accumulation of wealth and escalating economic development, substantial urban growth rates were recorded in Alahsa. This phase was characterized by urban extension towards the West and South, resulting in the emergence of residential buildings on both sides of the new roads [1]. Population of this stage reached 759500 inhabitants. A considerable increase in urban growth in Alahsa Governorate took place in the Fourth Stage from 1994- 2012. This stage evident an increase in population density behind 1150000 that recorded for 2011. Moreover, the number of population recorded for 2016 is 1247000 inhabitants [14] with an expectation of 55% increase by 2029 counted for 2.28 million inhabitants [2].

Large urbanized regions have been shown to physically alter their climates in the form of elevated temperatures relative to rural areas at their periphery [sham]. Deterioration of the environment is always related to development and human activities. Human activities produce a significant amount of heat being a primary source of heat production from transportation systems, industrial plants, and heating ventilation and air conditioning systems. Studies show that the urbanization and human activity are major factors in increasing the intensity of the UHI and

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contribute significantly as one of the causes of the urban heat islands [3]. Brian [4] compared the elevation of temperature caused by global warming phenomenon and that caused by the urban heat island. He concluded that the global warming forecasts predict a rise in temperature of 3.5 to 6ºF, while large urbanized regions are measured to be 6 to 8 ºF warmer than surrounding rural regions. Considering the roughly 2.9 billion new residents projected to arrive in urban regions between 1990 and 2025, there is a pressing need to ascertain the implications of urban warming for urbanized regions and to identify potential strategies to counteract expected regional climate changes.

This study endorsed five strategies that will contribute to the alleviation of the intensity of urban heat island of Alahsa governorate.

URBAN HEAT ISLAND OF ALAHSA GOVERNORATE

Latest studies on urban heat island of Alahsa Governorate [5] ascertained that, there is an increase of temperature counted for 2.3OC for one-decade period from 2004 to 2014. The urban heat island of the governorate is directly affected by level of urbanization. Increasing level of urbanization of the governorate in term of land use is evident [6]. As urban areas are swelling rural areas, a temperature increase is recorded. As the urban land increases, the intensity of the urban heat island increases. Alahsa governorate is experience similar scenarios the mega cities went through. The land use of the governorate increased from 15706.9 in 2004 to 24649.1 Acres in 2014, with an increase of almost 9000 Acres. While, the approved urban growth is going to be 38000 Acres by 2029 with addition of around 19000 Acres of lands. The figure 1 below depicts approved urban growth in Acres until 2029.

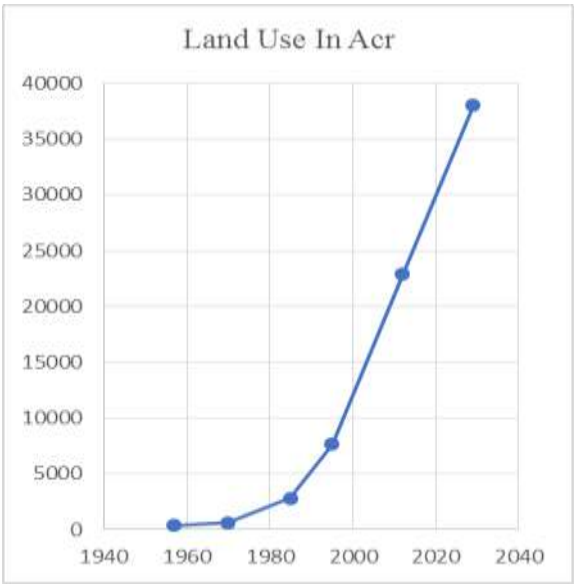

Fig. 1: Approved urban growth in Acres until 2029

On the other hand, increasing level of urbanization in term of population density, Figure 2 below, is evident too. Figure 2 below depicts population density of the Governorate between 1975and 2030 [2]. The population growth of the governorate is counted for 73% from 2004 to 2014. While the expected growth in 2029 is 55% of that recorded for 2016. On the other hand, the intensity of the urban heat island of the governorate is counted for 2.3 degree in 2014. That indicates an obvious direct effect of population density on the intensity of the urban heat island of the governorate.

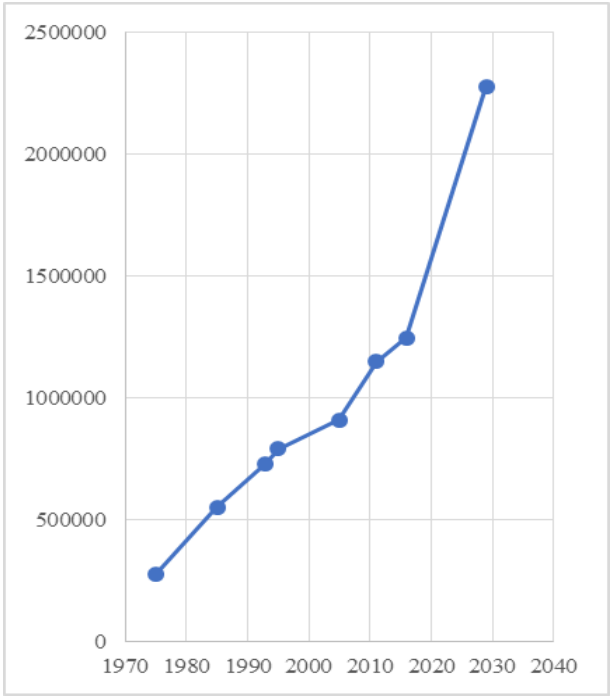

Figure 2: Population density of Alahsa Governorate from 1975 to expected 2029 [2]

As level of urbanization in terms of population density and land use of the governorate is increasing, the intensity of the urban heat island is increasing.

CAUSE AND EFFECT OF THE URBAN HEAT ISLAND

Cause of the Urban Heat Island

There are many factors combine to warm urban regions generally and Alahsa Governorate specifically. There are at least four causes and factors control the urban climate and hence the urban heat island formation:

Urban Fabric

Urban areas are generally drier, denser, less pervious and have more rigid surfaces compared to the rural area. Vegetation, crops and soil of the countryside are replaced in the urban environment by bricks, concrete, steel, asphalt and glass. Thus, the thermal properties for the two surface areas are significantly different. Particularly, urban fabric possesses much higher conductive capacity and hence a greater ability to absorb and store daytime solar radiation, resulting in a time lag in the diurnal temperature and a subsequent release of the stored heat during the nighttime. Primary constituents of urban construction, such as asphalt cement, and roofing tile, have a much greater heat capacity than the forest vegetation and other natural features that have been increasingly displace in urban regions. Streutker [7] discussed the thermal properties of materials used to build urban structures and cover urban land surfaces, describing its substantial variation from materials found naturally in rural areas. He recognized that, the specific heat capacity of moist soil is approximately 50% greater than that of asphalt and concrete. Moreover, the radiative properties also differ, such as the very low albedo of asphalt relative to that of natural surfaces. Hufof and Mubarraz are the oldest and most developed urban cities in the governorate [1]. Both Hufof and Mubarraz are undergoing high levels of urbanization [population and land use papers] showing high records of temperature compare to that recorded at the premises of the governorate [5]. As cities grow, buildings and paved surfaces replace the natural landscape. Hard inert surfaces absorb heat, causing their temperature to rise steadily with increasing exposure. Dark colored surfaces like roofs, roads and parking lots absorb the greatest amount of heat. Large masses of tarmac, concrete and steel buildings absorb and store large amounts of heat, which in turn is radiated into the surroundings.

Artificial Heat Production

Alahsa governorate with its developing big cities, Hufof and Mubarraz, is experiencing similar scenarios mega cities went through. In urban regions, the amount of artificial heat produced to cool down homes and offices, to

operate industrial plants, and to propel automobiles is one of the recognized factors that share in the increase of temperatures in urban areas. To produce the cooling effect by air-conditioning buildings, a considerable amount of hot air must be pumped out to the atmosphere Oke [8].

There is a recognized amount of artificial heat production within the premises of the governorate in form of small and big industrial activities. The governorate has small industrial activity such as cement factories and big as Al-Ahsa First Industrial City, that was established in 1981 on Dammam expressway north of Alahsa province. It occupies a strategic area of approximately 1.5 million m². [9]

The Unique Property of the Urban Environment

The atmosphere of urban areas typically has higher pollution levels than that of surrounding rural areas [7]. The unique property of the urban environment is its envelope of air pollution. The anthropogenic heat sources and aerosols from pollutants is one of many factors contribute to the formation of the urban heat island [10]. Climatically, air pollution plays its most effective role in modifying the component fluxes of the radiation balance [11].

Urbanization and Human Activities

Increased associated population-level travel and workforce mobility demands impose risks and burdens in the environment [12]:

"Although today's rapid urbanization and economic development around the world bring many economic, health, and ecological benefits, this trend of rapid migration into the cities, most prominent in the developing nations, seems not to translate into any significant improvements in human life expectation (Eckert and Kohler, 2014)"

Level of urbanization of the governorate in terms of population density and land use is increasing. Which confirms increase in human activities levels. Atmospheric modifications through urbanization have been noted. Climatically, one obvious consequence of urbanization is the creation of the heat island [11]. Urban man has altered the roughness of the earth's surface changing small features, such as trees, bushes, houses, the spaces between them…etc. Through his urban constructions, he affected the exchange of energy and moisture within the system by altering the physical qualities and materials of the earth's surface. Moreover, he has become a primary source of heat production within the system of the city. There are other factors related to human activity that contribute to the formation of the urban heat island like the anthropogenic heat sources. These anthropogenic heat sources are coming indirectly from transportation systems hot air exhaust, industrial manufacturing processes and, HVAC systems for commercial and residential buildings [13]. Moreover, the absence of vegetation and greenery that were replaced by homes, offices and buildings.

Effects of Urban Heat Island

Human Health and Comfort

In many developing countries, towns are expanding, and an increasing proportion of the land is being taken up for urban land use, replacing fields, farms, forests and open spaces resulting in distinctive unpleasant climatic conditions, which are experienced by many urban inhabitants in the world today [14]. The excess warmth within the urban layer causes an increase in human heat stress leading to greater cooling demands and a concomitant increase in energy utilization. Outdoor temperatures play a significant role in influencing the indoor environment. Unless the outdoor temperature is suitable, human could not experience nice indoor environment and feel thermal comfort. High temperatures are deleterious to health and comfort and prolonged exposure can be instrumental to the incidence of stroke, heart diseases and pulmonary disorders. Streutker [7] described a devastating heat wave that killed over 500 people in Chicago in 1995. The urban heat island intensity of 1.5 oC has a negative effect in human health and comfort [15]. As Alahsa governorate is experiencing an HUI of 2.3 oC, human health and comfort have to be considered.

Pollution

Increase in temperature in urban areas could accelerate certain atmospheric chemistry cycles leading to an increase in ground-level ozone [30]. Moreover, it increases the amount of energy used for air conditioning energy use. Thus, power plants burn more fossil fuels and more pollution. Higher air temperatures can also cause an increase in the emissions of biogenic hydrocarbons as well as higher evaporation rates of synthetic volatile organic compounds, both of which are linked to the production of tropospheric ozone. Urban heat islands are smoggier [16]. Smog is created by photochemical reactions of pollutants in the air. Pollution is one of the recognized effects

of UHI and it bears negative reflection on human health, comfort, and economy [14]. The higher the intensity of UHI, the higher the levels of pollution.

Meteorological and Climatologically Effects

The urban heat island effect can also be studied as a small-scale version of global warming. The urban heat island magnitude is typically approximately a few degrees Celsius [15], like the amount of global warming predicted to occur over the next century. Urban heat islands can thus be used to study how warming affects such things as vegetation growth, atmospheric dynamics and chemistry, and energy exchange between the land and atmosphere [7]. The climatologically changes result from urban heat island effects appear in form of increasing air turbulence and a reduction in the relative humidity. Furthermore, chemical composition of the air changes; receipts and losses of radiation are both reduced; temperatures are raised and rainfall in some cases increases. Buildings and structures in the urban area further complicate the airflow pattern and hence air pollution dispersion [17]. The urban heat island effect is believed to play a role in altering other meteorological phenomena in and around urban areas including the development of clouds, haze, fog, lightning strikes, thunderstorm, precipitation rates and heat waves.

Economics

Higher temperatures in urban regions reflects on high demand of energy due to a greater demand of air conditioning. As power plants burn more fossil fuels, they increase both the pollution level and energy costs. The effect of the urban heat island in some regions has been estimated to cost millions of dollars annually. Mostly due to the greater need to cool buildings, Houston city could save $82M annually implementing techniques used to reduce the urban heat island, such as urban reforestation and the use of high albedo roofing materials [30]. On warm afternoons in Los Angeles, the demand for electric power rises nearly 2% for every degree Fahrenheit the daily maximum temperature raises. It is estimated that about 1-1.5 Giga-watts of power are used to compensate the impact of the heat island. This increased power costs about $100,000 per hour, about $100 million per year [18]. Urban heat island influencing air pollution dispersion and energy demand for cooling [7]. The effect of UHI obviously has many implications. It could affect human thermal comfort, health, energy demand and hence national economy.

RESULTS AND DISCUSSION

Developed countries like Canada, Australia, USA and Japan issued comprehensive guidelines to all their big regions to encounter the effects of UHI, even though the phenomena are only a problem in summer. In the hot regions as Alahsa Governorate, such excess heat could be unbearable especially in the afternoon time [19]. Nevertheless, comprehensive guidelines to encounter the effects of UHI or even control its intensity is not yet issued. The four causes associated with four effects of the urban heat island of the governorate discussed previously that is typical and valid. Therefore, five strategies is endorsed to alleviate the reign urban heat island intensity as follows:

Land Management and Plant Cover

Large cities have often been an unstable form of development and less desirable than smaller cities, bringing with them both an intensification of existing urban problems and new problems [8]. Generally, commercial centres are usually several degrees warmer than the surrounding countryside [mitigation paper]. In Alahsa Governorate, and use illustrated in Figure 2 above shows an expected urban growth of 38000 Acres by 2029 adding about 19000 Acres of rural lands. Land use in Alahsa Governorate changed from period to period to cope with the gradual development of Alahsa. The change is on either location or function. For example, transferal of Alahsa airport from southern Hufof to southwest of the city and customize its old location to accommodate King Faisal University expansions. The governorate experience tremendous land use changes specifically with in its central area. The land used for small and local industrial activities are turned into commercial land. Moreover, the governorate is experiencing change in the commercial land that were concentrated in the central area between Hufof and Mubarraz cities. Urban growth for the governorate led to emergence of secondary commercial centers on main roads of the cities. The lack land associated with declining trend to horizontal expansion of the market within the centre reflect on high rents of shops that led to suburban expansion. On the other hand, the residential land has grown dramatically on the outskirts of the city through the approved plans and switched from the centre of the regions to give way to commercial use and management services. As long as human are shifting from rural to urban areas, land cover is affected. To reduce these negative effects green areas should be increased with recommended specification from previous researches [20], Gardens and parks]:

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- Large green areas have positive effect on the temperature of the city. Areas with fewer plants always have higher temperature. On the other hand, the Central Business District area has the highest temperature due to high density and high-rise development. Previous studies [3, 11, 16, 21, 22, and 23] proved that green areas moderate urban temperatures where green areas are relatively low in temperature than non-green areas. Therefore, tree-planting programs should be reinforced, and incentives and subsidies should be part of the long-term planning for the governorate. Therefore, a well-planned tree-planting program is the main strategy to ameliorate excess heat. The use of sufficient and properly spaced parks would also help to ameliorate conditions there. Within the region, many open areas are covered with blocks of marble, granite or tiles. Although these are better than black tarmac, these areas still absorb a lot of heat in direct sunlight and release the heat at late afternoons, evenings and early nights. Such open areas should be turned into green areas and indigenous parks. The creation of as many cities parks as possible will improve the situation and help significantly in reducing the intensity of the UHI.
- The continuous massive tree-planting programs should encourage in either vertical landscape form or rooftop gardens form.
- Furthermore, trees should be planted to shade the hot tarmac of inner big city roads like Hufof and Mubarraz. Roads and highways, which take up an ever-increasing proportion of the urban area, should also be creatively designed to include green shade, at the very least along the medians. Such as overhanging creepers which can shield or block absorption of the heat and reduce the air temperature.
- Moreover, Car parks areas would comply with a minimum of 50% shade requirement. Previous studies [3, 11, 16, 21, 22, and 23] show that shade trees contribute significantly to reduction on the intensity of the UHI. Car parks comply with a minimum of 50% shade of trees or/and at least low-level bushes will reflect positively in intensity of the urban heat b island.
- Reduce solar radiation by managing lands that covered by critical surfaces such as pedestrian walks, waiting areas, and busy streets. Reduce the abundance of concrete and asphalt and increase the amount of vegetation and open water parks. This will increase higher volumetric heat capacities and greater rates of latent heat influx, thereby lowering air temperatures and reduce UHI intensity.

Roof Cover and New Materials

Almost most commercial and noncommercial buildings in Alahsa are having flat roofs [1] either to accommodate air-conditioning equipment or water tanks.

- Such buildings should green their roofs and planted them with shrubs or low-level bushes. This means cultivating greenery on the flat roof surfaces to absorb the heat. This will not only help the city to counter UHI but building owners will also benefit in terms of savings in air-conditioning power consumption.
- Moreover, roof tiles should comply with high albedo, reflectivity, values. So as the tiles will reflect most of the sunlight instead of absorbing it. It is also recommended to have them in light color, as dark tiles have the characteristic of high heat absorption rates [mitigation]. Urban Planner and engineers should recommend and use new materials that comply with high albedo, reflectivity coefficients.

Buildings

Proper urban design of cities in high temperature climates is effective whenever proper planning of buildings is maintained to weaken the heat island intensity. This could be done using:

- Sufficient and properly spaced parks.
- High-albedo, low thermal-capacity, low thermal-conductivity for building materials.
- Light colors paints for such urban buildings.
- High albedo tiles for the sides of the tall buildings, as the sides of the tall buildings are subject to long hours of exposure to sunlight.
- Combined alternative passive cooling and lighting techniques to reduce the amount of energy consumed for air-conditioning of buildings. These techniques will properly improve the thermal quality of the ambient urban environment.

Traffic activity

In addition to ecological impacts of using the private vehicle mode instead of public transportation mode, there are social and economic consequences [12]. Rising income levels and private vehicle ownership and decline in public transport keeps road transportation the major contributor to air pollution in the developing world. [24] An economic study revealed that the private vehicle rate in Saudi Arabia is one vehicle per 1.3 person, 78 cars per 100 inhabitants, for those over 15 years of age; three quarters of the population aged 15 years have private cars.

If the number of vehicles is compared to the full population, the rate will be one vehicle per 1.8 personnel, 54 vehicles per 100 inhabitants, about half of the population with vehicles, based on the latest official statistics for 2012. Putting in mind, that driving is allowed for male only and females are allowed to drive June 2018 [25]. Therefore, the number of vehicles is expected to increase dramatically. Studies shows that, as the traffic activity in the city increases, the intensity of the UHI of the city increases [Traffic activity by Sudanese Journal]. Therefore, to alleviate the UHI intensity:

- The use of private vehicles should be reduced and activation to the public transportation system within the region, as Elsayed [13] found that, the intensity UHI is directly proportional to the number of private vehicles and inversely proportional to public transport vehicles.
- With the soon engagement of females to private vehicles driving, new regulations and legislation are needed to cope with the increasing number of private vehicles.
- Air conditioners used for different means of transportations, make urban heat build-up worse as they continuously emit hot air out into the atmosphere [6]. Regulation used for such means should be reinforced and penalties should be applied perfectly.

Awareness

Awareness needs great deal of well-organized work supported by different authorities that in charge of the development of the governorate. All above strategies will not be effective unless the governorate inhabitant is well aware of the importance of having sustainable environment in the region. Intensive Programs for raising the awareness is needed in terms of using:

- The governorate land and controlling plant cover. These programs are suggested to be initiated by the municipality of Alahsa.
- New materials and techniques in buildings and utilization of power effectively. Support and strong legislations from the authorized bodies such as Alahsa Municipality, ministry of Environment and Economy are needed.
- Private vehicles with specific particulars and activation of public transportation systems. Such programs should be organized by General Adminstration of Traffic and Vehicles in Alahsa Governorate.

CONCLUSION

Guidelines and suggestions to mitigate the intensity of urban heat islands are many. Nevertheless, the situation varies from a region to another. The study recommends five strategies need to be applied by political leaders, policy makers or/and urban planners to mitigate the intensity of the UHI of the governorate.

The first strategy for lessening the intensity of the UHI of the governorate is Land Management and Plant Cover. The strategy focuses in well-planned tree-planting program including creation of small city parks and plantation of different types of vegetations. On the other hand, the fourth strategy, Raising Awareness affects all the endorsed strategies. Land Management and Plant Cover, Roof Cover and New Materials, Buildings, and Traffic Activity strategies will not be acquired without good levels of understanding to the effects of the outdoor living environment on indoor environment and to what extent it might put human comfort and health under risk.

More effort and reinforcement are needed from political leaders, decision maker and urban planners to mitigate the UHI and reduce its effects. Mitigation of the UHI of the city through planning and designing necessitates the formulation of a series of strategies and guidelines that ensure the governorate to remain lively and attractively developed as projected. The incorporation of climate responsive design strategies can help achieving 2030 Saudi Arabia vision for having a sustainable, livable, attractive and thriving governorate.

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