NARRATIVE REVIEW

Surface urban heat islands in the mega city of Karachi, their spatial distribution and health emergency response infrastructure

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Abstract

The 2015 heat wave resulted in an estimated over 1200 deaths during the month of June. However, there were no records on the spatial distribution of the effects of this heat wave. An analysis of Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperature (LST) daily data was conducted to identify regions that experienced above normal temperatures in 2015. An analysis of the monthly averages showed that in general April and May were the warmer months in Karachi, unlike the case in 2015. In addition, the general warm trends were common in the highly industrialised Sindh Industrial Trading Estate (SITE) and Liaquatabad towns, while Gadap, with its mostly barren land, and New Karachi also experience higher temperatures. Coastal towns were naturally cooler and more habitable in the given scenario. A count of the spatial presence of health facilities for the city was also extracted where Gadap and Korangi were poorly served while the more affluent towns of Defence Housing Authority (DHA) and Gulshan-e-Iqbal appeared to be better served.

Keywords: Heat wave, Karachi, Urban heat islands, MODIS-LST, Remote sensing.

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Introduction

The effects of climate change on quality of life and health of individuals and communities is a well understood prospect.[1] One of the major concerns with the current scenario, however, is heat stress and resulting deaths. Additionally, an increase in respiratory and heat-related illnesses is commonplace. In a normal situation, humans are acclimatised to the prevailing conditions where they plan for housing, power availability and cooling mechanisms as well as their working hours according to the prevalent heat index. It is, however, believed that people do not live comfortably outside the temperature range of 17-31ºC. If, however, the temperature range changes, so will the pattern of lives altogether, ranging from adaptability measures in terms of clothing to water and power consumption. One adaptability feature, the urban land-use and land-cover, nevertheless remains critical. In case of Karachi, this is a worst-case scenario where urban growth has shown to be tremendous. For instance, the recorded population of the city is 16,051,521 inhabitants.[2]

The effects of excess surface heating have been broad and wide, like, for instance, the number of deaths in the 2015 heat wave, which were unprecedented.[3,4] The event coincided with the holy month of Ramadan which meant no food/water consumption for more than 90% of adult population during the day, along with power shortages and the usual difficulty to access health services. Also, as high temperatures are considered a common occurrence in the city, people tend to try and adjust to it. But the situation went somehow out of control and blame-game between various stakeholders continued well into the crisis on improper provisioning and management of resources.[5]

In this context, the current analysis was conducted related to temperature from March, 2000, to August, 2016, for the entire city, based on Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperature (LST) data. MODIS was chosen as it provides a good approximation[6] of the day and night surface temperature (ST). The overpass time for MODIS Terra satellite is 10:30AM in descending mode while its ascending overpass time is 10:30PM.[7] These maps were then used to demarcate the dominant high temperature zones for the city. This was then examined in terms of the presence and geographic accessibility of health facilities in each heat island.

Literature Review

One of the key methods for studying geographic phenomena of large spatial and temporal stretch is the use of Remote Sensing (RS) data and Geographic Information System GIS.[8] It has been widely employed for urban land-use and land-cover characterisation, classification, surface run-off modelling, disaster mitigation, sustainability planning, urban LST mapping, quality of life analysis and public health management.[1]

Surface heat islands can be mapped using either data gathered from meteorological stations or from a field

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surface with the help of a mobile sensor. While the former limits us to available records from only a few stations across an entire city, particularly in the case of Third World countries, the latter is bound to be limited to roads or commutable segments of a neighbourhood. Surface urban heat islands (SUHI) mapped using satellite images have a different character in comparison. These tend to work well for inaccessible areas or in resource-deficient scenarios. The maps of ST derived from satellite remote sensing (SRS) can then be further classified as the urban canopy layer (UCL) heat islands, situated between the roughness elements like trees and buildings but lower than the neighbouring rooftops, and as the urban boundary layer (UBL), situated above the first and subjected to the effects of the urban surface.[9] It must be noted that with the help of GIS there is further possibilities of segregating regions close to large water bodies and industrial units etc.

For the study of UHI, images from several SRS sources have been used at various times. For large-scale studies, National Oceanic and Atmospheric Administration (NOAA) satellite Advanced Very High-Resolution Radiometer (AVHRR) (~1000m), MODIS-LST (~250m-1000m) and Landsat temperature bands (~60-120m) have been widely used.[10-12]

MODIS, however, remains a preferable choice as it can be used to get daily coverage for day and night, and for large areas. One downside, however, is the excessive cloud cover that hinders recording good quality surface emissivity from space. But for that, spatial masking and subsequent gap-filling proves sufficient and has been employed where necessary. It is by far its temporal consistency and continued availability that MODIS LST for ST mapping remains an important choice.[6]

Studies[13] have successfully been able to scale the spatial resolution of LST maps and to render it a better consistency using Regularized Splines with Tension (RST) interpolation, preparing temperature maps of good quality for epidemiological research.

Studies[14] have mentioned climate change as one of the most significant urban health hazards. In an urban environment, its structure, surface types, population, road network density, traffic density and priority fuel types used as well as the coherence and sustainability of public transport networks contribute to this change at large. In the case of Karachi, urban expansion is at a large scale, with its urban built-up area increasing from ~500 sq.km in 1991 to ~1500 sq.km in 2013.[15] Similarly, its population size and lack of coherent and large-scale public transport network together mean that most people will prefer using private vehicles, hence, contributing to the pollutant concentration. A study[16] done in Bogota, Mexico City and Santiago suggested that temperature and air pollution are class-independent in terms of their effects on mortality.

Karachi in 2015 experienced its worst heat wave since 1979. While some other cities of Pakistan, like Larkana, Turbat and Sibi, recorded 49ºC, Karachi was not behind with 45ºC recorded on June 20. Weng et. al.[17] reported high temperatures, dehydration and very high humidity as major causes of deaths in the city. Romero et.al[16], however, called these causes as irrelevant and suggested that urban segregation had a bigger role to play. Climate Change and Development Knowledge Network,[18] an independent climate activism organisation, estimated that more than 1200 people died during the episode. However, some independent estimates put this death toll at multiple times higher as there are no substantial records of such incidents published.[19]

There is a general tendency of urban bias and class-oriented distribution of health facilities in Pakistan. It is believed that the far flung regions of Karachi are devoid of basic facilities, like water, power and healthcare.[19] Currently, however, it is hard to find research on the emergency caused by UHI distribution, spatial variability of temperature across the city and the presence of reliable healthcare in case of emergency. The current study, therefore, focussed on addressing these spatial inequalities.

Study Site

Karachi is located in the south of Pakistan and is the only commercial port city in the region since the British era. On its east, it is bound by the fertile plains of the Indus while on its west, it has the desert province of Baluchistan towards which its coastline continues. To its northwest, however, are the dry and moderately high (~300-600 m) Kirthar ranges.[20]

The total area covered by the city is ~3,527km. It boasts of ~163km coastline of which ~48km is dedicated to the port activities, while the rest is being used for recreational purposes.[21] Also, major parts of the city have grown along this coastline.

Citimertic[22] puts Karachi as the 7th largest city in the world in terms of population. According to the Globalisation and World Cities Research Network (GaWC),[23] Karachi is classified as an instrumental social and economic hub for Pakistan well above the league of its other cities such as Islamabad and Lahore.

Administratively, Karachi is divided into six districts: Karachi South, Karachi East, Karachi Central, Karachi West, Malir and

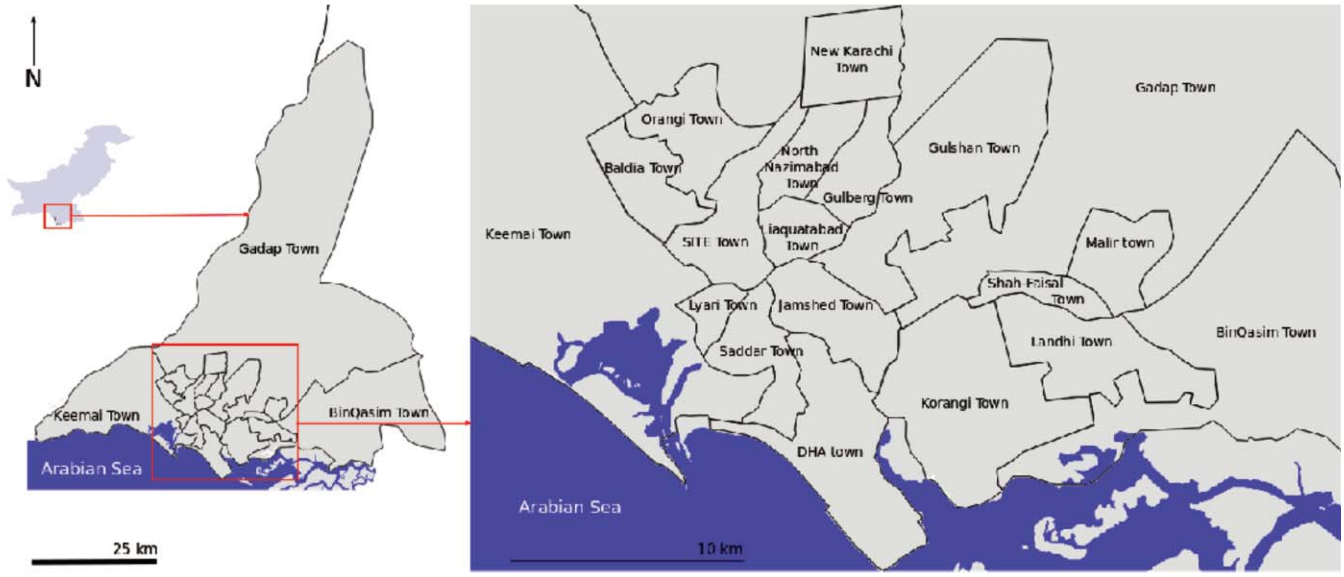

Figure-1: Map of Karachiand its 18 towns. Note that sub divisions are along major highways or roads and adjacent buffers in some cases. These towns are further subdivided into Union Councils (UCs).

Korangi. It is further divided into 18 towns (Figure-1), which are subsequently divided into Union Councils.[24] Health facilities in the city range from large government-owned hospitals to small private clinics owned by individual practitioners working under licensing from the government.

Methodology

The study used MODIS LST records version 5 data which is freely available from the National Aeronautics and Space Administration (NASA) Level-1 and Atmosphere Archive and Distribution System (LAADS) portal[25] for download. Records from March 5, 2000, to August 28, 2016, for Karachi were downloaded. MODIS data is distributed as tiled set of rasters in highly compressed hierarchical data format (HDF). For Karachi, h24v06 tiles were downloaded. Once downloaded, these files had to be made suitable for use with GIS and image analysis software and, hence, were processed using the MODIS re-projection tool (MRT) available online on the NASA Land Processes Distributed Active Archive Center (LP-DAAC) portal.[26]

The tiles were then processed to extract day and night ST layers for and the quality assurance (QA) files that came with the data. The selected projection parameters were universal transverse Mercator (UTM) projection zone 42N and the datum was WGS84. For better pixel consistency and artefacts removal, data was re-sampled to a higher resolution from its original 1000m coarse resolution.[13]

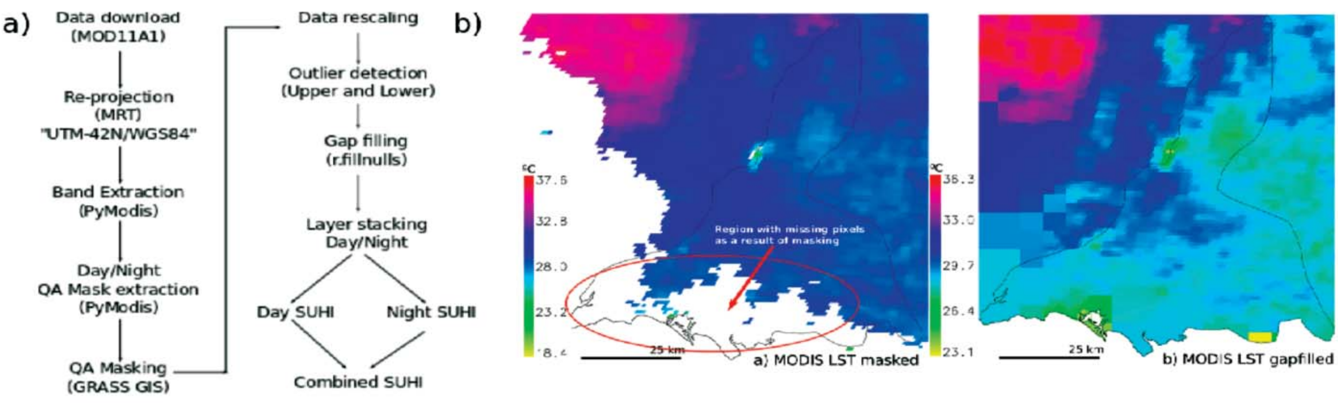

Figure-2: An overview of the approach used for data processing done for identifying the Surface Urban Heat Islands (SUHI) for Karachi. Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperature map for March 5,2000, with quality masking, note the missing pixels as a result of removal of bad quality pixels, b) MODIS LST map for March 5, 2000 with gap-filled pixels using the Geographic Resources Analysis Support System (GRASS) Geographic Information System GIS r.fillnulls module.[27] (Note the temperature was converted to °C and outliers have already been removed).

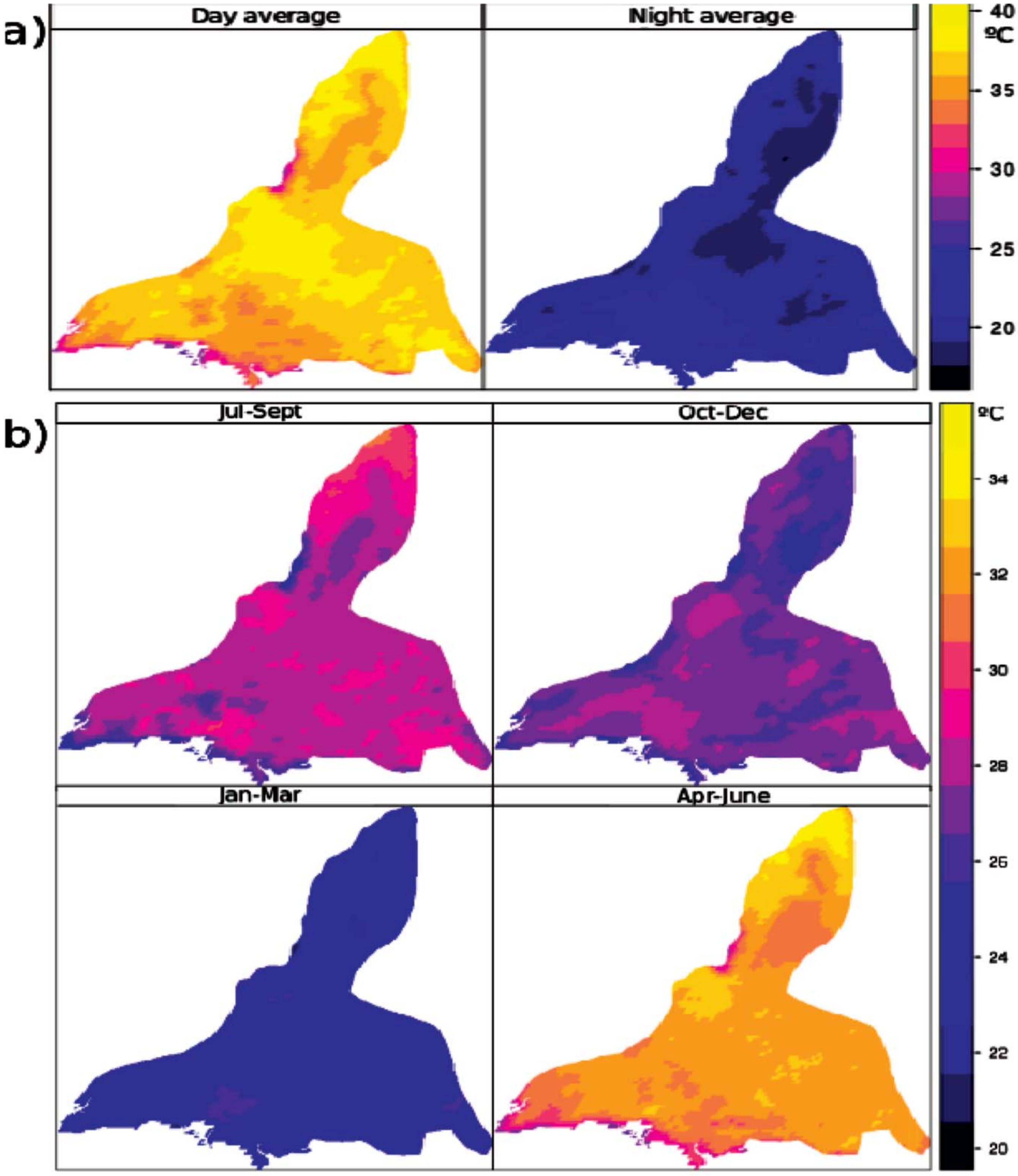

Figure-3: a) A comparison of day and night average temperature differences for Karachi. These maps were produced by averaging raster for day and night temperature values from March 5, 2000, to August 28, 2016, of Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperature (LST) b) Seasonal variability of temperature across Karachi. Above are the Averages of January-March, April-June, July-September and October-December for the city. These were created using both day and night surface temperature values. Note the lowering temperature trend between July-September as the monsoon arrives in South Asia.

Hence, the rasters were re-sampled to 200m resolution using nearest neighbours re-sampling. This latter method did not alter the adjacent pixel values and, hence, was suited for re-sampling such datasets. Once the initial processing was completed, the rasters were imported into Geographic Resources Analysis Support System (GRASS) Geographic Information System (GIS) and processed for removal of pixels with bad quality (Figure-2a).[27]

According to the MODIS LST v5 user manual,[28] the values in the original downloaded MODIS LST Spatial Data Sets (SDS) can alter up to a few degrees and, hence, it was necessary that pixels with >1°C of erroneous values be screened out. After masking out the bad pixels from the MODIS datasets, upper and lower outlier detection was done. This was necessary because MODIS data was prone to contain negative values due to the presence of cloud pixels representing cloud top temperatures. A simple exercise would be removing all values below 0°C as Karachi has never experienced such temperature. However, quartiles for all rasters were derived and used to mask out the unusual pixel values (Figure-3a).

After masking the MODIS data for highly error prone pixels, it is common to be left with null spaces in the output rasters (Figure-2b). Mostly in coastal areas where cloud cover is common in Karachi and after quality masking evidently, an open patch was left. Regularised Splines with Tension-based raster interpolation was used to fill the null areas. A total of 1,752 rasters did not have sufficient points available for reliable gap-filling and were left out. MODIS LST has a scaling factor applied and the data therefore needed rescaling and conversion of values to °C.

These were then interpolated for using harmonic analysis of time series. Once the rasters for the day and night LST temperatures were ready, they were averaged out to map high day and night temperature regions as SUHI. Subsequently, spatial distribution density maps for Karachi were produced highlighting the urban health inequalities.

The map of the health facilities included urban health centres/units, rural health centres (RHCs), conventional eastern medicine facilities, pharmacies, available records on general physicians, specialist doctors (not just those treating health stroke patients), children hospitals and general hospitals. These were then tabulated as count against the town-based population densities.

All health facility points were converted to heat maps. For these heat maps, the feature density for each town (polygon) was mapped.

Results

An ST analysis revealed that the night and daytime temperature differences were stark. Daytime rescaled time series range was calculated to be 7.17°C, while those for night-time was at 5.89°C.

The mean ST was 28.35°C, with the lower average values

Table: Health facilities present in Karachi. Only the major ones have been marked here while there are other facilities such as pharmacies and traditional medicine stores too (included in the point count column here however). Population statistics were derived using Landscan data,[29] while hospital records were mapped from Alhasan[30] and Open Street Maps.[31]

No.	Town	General Hospitals	Children Hospitals	Physicians	Specialists	UHC	RHC	Dispensaries	Count (all included)	Pop 2010
1.	DHA	24	1	16	6	0	0	4	81	9,74,651
2.	Korangi	16	0	28	0	0	0	1	66	8,43,197
3.	Landhi	16	1	7	0	0	0	0	34	4,01,418
4.	Bin Qasim	5	0	0	1	0	0	0	11	2,94,592
5.	Shah Faisal	9	0	11	0	0	0	0	34	1,29,005
6.	Malir	15	0	21	1	0	0	1	50	2,19,600
7.	Jamshed Town	35	2	63	1	4	0	1	136	11,64,759
8.	Liaquatabad	14	0	16	0	0	0	0	49	6,69,569
9.	Saddar	30	1	25	5	0	0	5	79	9,65,300
10.	Lyari	7	0	22	0	0	0	0	39	4,27,492
11.	SITE	14	0	17	0	1	1	1	55	6,54,701
12.	North Nazimabad	18	2	13	1	0	0	0	53	9,20,845
13.	New Karachi	14	0	33	1	0	1	2	79	7,30,072
14.	Gulberg	16	0	16	2	0	0	0	49	7,47,260
15.	Baldia	8	0	11	0	1	0	0	24	3,48,625
16.	Orangi	10	0	17	0	2	0	1	60	6,48,369
17.	Gulshan	42	1	65	7	0	0	2	191	11,30,394
18.	Gadap	13	0	33	1	1	1	2	88	10,71,464
19.	Kemari	12	1	3	0	1	2	0	32	8,24,142

DHA: Defence Housing Authority. SITE: Sindh Industrial Trading Estate.

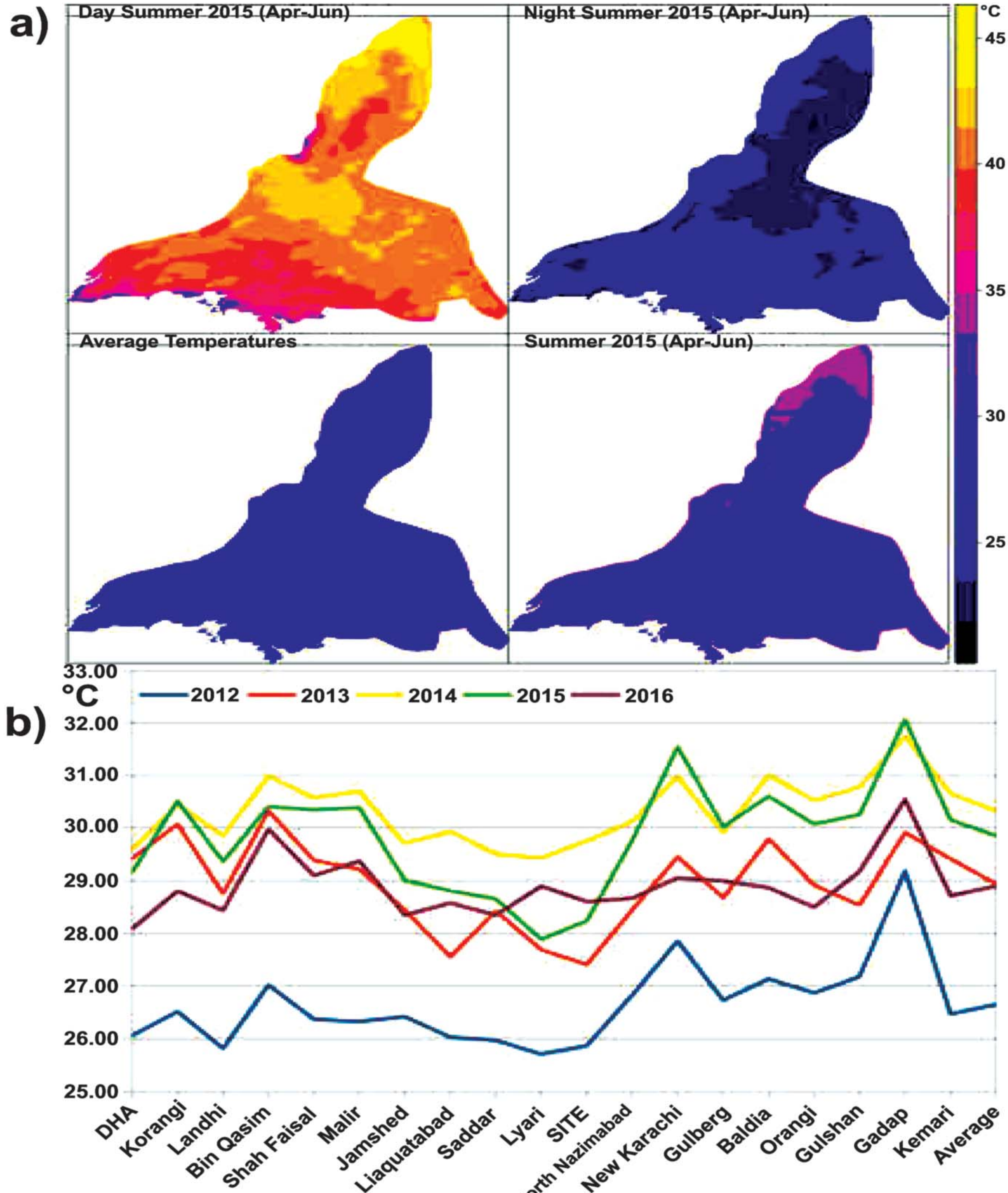

Figure-4: a) A comparison of the average temperature, average April-June temperatures, and the day and night temperatures. b) A comparison of the June, 2015, temperature daytime (10:40 am) temperature with that of 2012, 2013, 2014 and 2016. The districts of Defence Housing Authority (DHA), Korangi, Landhi, Bin Qasim, Shah Faisal and Malir recorded comparatively lower temperatures.

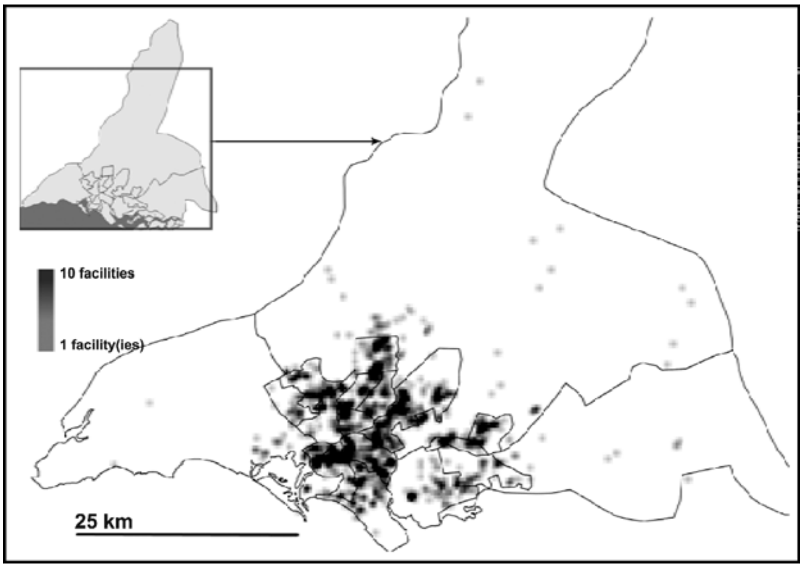

Figure-5: Map containing the point densities for all health facilities in Karachi. It can be seen that most of these facilities are centred towards the more affluent districts of Defence Housing Authority (DHA), Saddar and Gulshan-e-Iqbal. Data source.[29-31]

observed in Defence Housing Authority (DHA) (27.2°C), Kemari (27.8°C) and Korangi (27.7°C), which are coastal and benefit from cold sea breeze, particularly at night. Their night-time temperature mean was (27.6°C).

Higher ranges of temperature were observed in Sindh Industrial and Trading Estate (SITE) (29.17°C) and Liaquatabad (29.2°C), where the former is highly industrialised and bears significant on the latter both in terms of temperature and economic effects. This also owes to their distance from the coast and central nature to the urban built-up area.

An analysis of the seasonal variability of temperature indicated that in general high temperatures were observed during the second quarter of the year from April to June. The mean for day was 38.32°C and 24.78°C for ST at night. The coastal localities of Kemari, DHA and Korangi, benefiting from the cold sea breeze, had a mean temperature of 30.7°C.

In case of monthly averages, the months of April and May were the warmest. Of the summer, the daytime mean for April was comparatively higher at 39.64°C compared to 38.85°C and 36.47°C in May and June. However, as a whole, May tended to remain warmer with higher temperatures recorded in the Gadap town and areas northwest of the urban built-up regions.

The rest of the years were almost at par with the exception of 2012 which was colder (Figure-4 a,b). It is pertinent to mention that these are the daily average, and not the daytime STs for the city.

A simple overview of the health facility count for each town of the city suggested that there was a serious imbalance in terms of the presence of these facilities (Table-1). It would have been interesting to map the computability in case of a heatstroke of the patients to these destinations, but no such records were available. However, the highest density of these facilities is in Saddar and Jamshed towns followed by DHA and Gulshan-e-Iqbal. It must be noted that these were the districts observed to bear comparatively lower temperatures in the wake of the 2015 heat wave and even in general (Figure-4b).

The hospital-to-population ratio for 2010 was really poor. For Gulshan-e-Iqbal, where the number of hospitals was the highest, for every ~27,000 individuals, there was one available hospital. Most of these hospitals were private and not readily reliable or accessible. However, for Jamshed town that followed in terms of hospital count, the ratio stood poor at ~33,728 people per hospital. The town boundaries were not clearly demarcated and connectivity within the city was appropriately good, which means the actual load during a health emergency might be difficult to handle.

In Gadap town the situation was grave, with most of the population being rural and located at places that did not have access to good healthcare facilities.

The total number of people that one hospital roughly had to cater to was 82,420. By virtue of both the land area covered and difficulties in commuting, the ratio was dangerously low. Other poorly-served towns included Lyari and Korangi with the population-to-hospital ratio being one to ~50,000.

Discussion

The problem with the 2015 heat wave that were cited in general were unbearably high temperatures, but an alternative set of perspectives have been found as interesting contributors to the state of affairs. While temperatures remained below historically recorded highs (Figure-4b), as found in the MODIS LST analysis, and at par in some cases, it was mostly the provision of utility services, and health service amenities that must have resulted in a large number of deaths as most of the districts had never experienced such temperature highs. It was also interesting to see that densely populated areas with a high proximity to the sea had better amenities, and probably better provisioning of power and water supplies, but regions like SITE and Gadap were neglected at both levels and were apparently suffering from lack of appropriate provisioning of these facilities (Figure-5). While it would be interesting to link the entire episode with power distribution patterns and availability, such information is not available. Another interesting perspective is that barren lands towards the north were highly affected, and one widely known reason for that is the lack of vegetation and exposed soil bed. The reason needs to be investigated by further studies.

Conclusion

The overall trend of temperature across the city was not exceedingly high on a long-term basis. However, some mismanagement on the part of the local authorities and power supply inconsistency during the season need to be analysed for other details. However, it is true that with an ever-growing population, the people-to-health facilities ratio is a cause for concern. Those in need of urgent attention were areas like Gadap, Kemari and Orangi. Also, Saddar, Jamshed town, SITE and Liaquatabad are areas that are under a constant threat from high temperature.

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