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Estimation of spatial distribution and temporal variability of land surface temperature over Casablanca and the surroundings of the city using different Landat satellite sensor type (TM, ETM$^+$ and OLI)

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ABSTRACT: Over the last few decades, Casablanca city became the biggest industrial, commercial center in Morocco with rapid urbanization and explosive population growth, more than 4 million people. Urban expansion has reached to suburban areas due to population growth and socio economic development, not to mention the rapid increase of transportation. Result of these changes causes a change of microclimate in urban areas. The most evident phenomenon is the increase of urban surface temperature as compared with suburban areas, "heat island" is formed in the atmospheric boundary above urban area. It could make serious environmental problems for its inhabitants (e.g., urban waterlogged and thermal pollution). Thermal infrared remote sensing bands, proved its capability in monitoring temperature field. The purpose of this study is to evaluate the use of Landsat TM, ETM$^+$, OLI and TIRS data for indicating temperature differences in urban areas, in order to achieve a spatiotemporal study, using data between 1984 and 2014, and showing the relationship between urban expansion and the heat island effect during time, producing maps that shows the distribution of urban temperature. Results can be combined with land use/ land cover maps or thermal-land cover and operated as reference for urban planning and future solutions to reduce heat island effect.

KEYWORDS: Landsat series, OLI, TM, ETM+, Heat Island, NDVI, urbanization.

1 INTRODUCTION

Along with the latest technologies for spatial data acquisition, especially with the advent of satellites and high resolution sensors, it is possible to estimate land surface temperature (LST) spatially. Thermal infrared bands provided by satellite, can be used to estimate LST for a region. Urban areas suffer more from this phenomenon, and LST is one of the most important and commonly studied effects of urban climate, the air temperature increase in the city opposition to the surrounding areas, provoke among other factors by the emission of anthropogenic heat, and the higher heat capacity of urban surfaces, this called urban heat island (UHI) effect.

According to the report (UN-HABITAT Report 2010, 2012), the UHI effect continues to grow with ongoing, rapid urbanization. By 2050, about 70 % of the global population will most likely live in cities. This rapid migration to urban areas, causes modification of air and surface temperature fields significantly, which alters living standards for populations around the world [1]. It causes overheating of urban areas, especially in summer, but it may also have positive consequences, e.g. reducing energy use in cold climates during winter.

It was hard to estimate the LST of an area. Generally, it was calculated for a particular set of sample points and interpolated into isotherms to generalize the point data into area data Now significant progress has been made in satellite remote sensing technology, this revolution comes with the invention of Earth Observation Satellites (EOS) [2]. Data acquired from satellites like Landsat, Modis or Aster, can provide thermal satellite data, and some of this data are freely available, Landsat 4, 5 and 7, and their sensors. Thematic Mapper (TM), Enhanced Thermatic Mapper (ETM+) comes with thermal infrared band successively with 120 m^2 and 60 m^2, resampled to 30 m^2, and finally Landsat 8, Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), comes with two thermal infrared bands ($30m^2$). This data can be largely used to estimate LST over urban areas.

The objective of this study is to estimate Land surface temperature from thermal bands using different sensor type, of Landsat series with different acquired dates, in order to study the spatial distribution and temporal variability of LST over urban and sub-urban areas in Casablanca city.

2 LITERATURE REVIEWED

If we discuss the scientific objective and the application of this process, we can find that the measurement of Land Surface Temperature (LST) from thermal infrared images, has a considerable importance for many applications such as oceanography, global climate studies, geology, hydrology, meteorology and vegetation monitoring, [3] [4]. Most of the fluxes at the surface-atmosphere interface can only be parameterized through the use of LST. In comparison with sea surface, land surface has the additional difficulty of the high heterogeneity, mainly due to vegetation, topography and soil physical properties, not to mention the complex relationship between atmosphere and surface.

It is difficult to extend the temperature measurements to a larger scales, because they are very isolated in time and space. And this is due to the heterogeneity of the surface. We can use satellite images instead of in situ values [5], if the measurement techniques give good enough LST values with sufficient accuracy. So the satellite measured radiance must be corrected duo to atmospheric perturbation and emissivity value different from unity because natural surfaces are not blackbodies.

3 RELATED WORKS

Land surface temperature (LST) is the key variable to be retrieved from the TIR data. In the last years, several researches who are interested in Landsat TIR data, which has encouraged the emergence of different publications related to this issue.

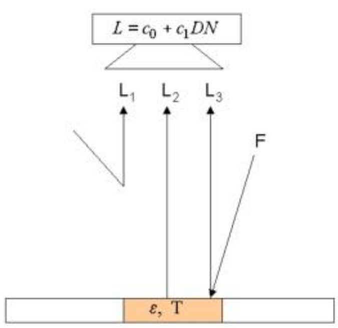
Several researches have been done on estimation of land surface temperature from thermal satellite bands. [6] suggested that the areal measure of vegetation abundance by unmixed vegetation fraction has a more direct correspondence with the radiative, thermal, and moisture properties of the earth's surface that determine LST. [7] have presented a comparison study between two algorithms used to estimate the LST, mono-window algorithm developed by [8], and the single-channel algorithm developed by [9]. [10], found there is a strong correlation is observed between surface temperatures with NDMI over different LULC classes. And other works that present more techniques and describe the risk of heat island.

4 THEORETICAL BASIS

The objective of any radiometric correction of airborne and spaceborne imagery of optical sensors, is the extraction of physical earth surface parameters such as spectral albedo, directional reactance quantities, emissivity, and temperature. To achieve this goal, the influence of the atmosphere, solar illumination, sensor viewing geometry, and terrain information have to be taken into account. Although a lot of information from airborne and satellite imagery can be extracted without radiometric correction, [11].

In the case of thermal regions, there are three radiation components: thermal path radiance (L1), i.e., photons emitted by the atmospheric layers, emitted surface radiance (L2), and reected radiance (L3) [12]. In the thermal spectral region from 8 - 14 nm the radiance signal can be written as:

$$L = L_{path} + \tau \epsilon L_{BB}(T) + \tau(1 - \epsilon)F/\pi \qquad (1)$$



$$L_1 = L_p$$
$$L_2 = \tau \epsilon L_{BB}$$
$$L_3 = \tau (1 - \epsilon) F / \pi$$

Fig 1. Radiation component in the thermal region

4.1 SINGLE CHANNEL ALGORITHM

The most appropriate procedure to retrieve LST from a single channel (SC) located in the TIR region, as is the case of Landsat series, is by inversion of the radiative transfer equation (RTE), [13] according to the following expression applied to a certain sensor channel:

$$B\,(T_S) = \frac{L_{sen} - L^{\uparrow} - \tau(1-\epsilon)L^{\downarrow}}{\tau\varepsilon} \quad (2)$$

Where:

B: Planck's law, expressed as:

$$B_\lambda\,(T) = \frac{c_1}{\lambda^5 \left(\exp\left(\frac{c_2}{\lambda T}\right) - 1\right)} \quad (3)$$

With c_1 and c_2 being the Planck's radiation constants, with values of (each sensor type has a value in)

λ : Wavelength;

T_S : Land surface temperature (LST);

L_{sen} : At-sensor registered radiance;

$L^{\uparrow}$: Upwelling atmospheric radiance (path radiance);

τ : Atmospheric transmissivity;

ε : Surface emissivity;

$L^{\downarrow}$: Downwelling atmospheric radiance.

Examples of this procedure can be found in [14] and [15] . The main problem when using (equation 2) is that atmospheric parameters τ, $L^{\uparrow}$ and $L^{\downarrow}$ must be known. This indicate the availability of atmospheric soundings launched near the study area and near the acquisition time of the satellite image. Currently, this problem is solved by using National Centers for Environmental Prediction (NCEP) modeled atmospheric profiles in online site (http://atmcorr.gsfc.nasa.gov/).

5 STUDY AREA

Casablanca is located at latitude 33.577767, and longitude -7.614148 with a population of 4 million and total area of more than 387 km^2, [16]. Casablanca has a very mild Mediterranean climate with an average annual temperature of 21.8° C. The lowest temperature is normally found in January, averaging 17.1 °C and the highest temperature in July, averaging 25.9° C. The annual average precipitation ranges from 1600 to 2600 mm. Casablanca has taken great changes during the past 20 years and undergone a quick urbanization since the eighties. For the quick progress of the economic, lots of the agriculture lands have been converted into the built-up area and the development sites [17]. The population and the urban area also had a big growth and the effect of urban heat island in this area has become very obvious [18].

6 MATERIAL AND METHODS

The methodology adopted for this paper is made of three main parts, first we applied a preprocessing step, by taking into account the radiometric correction of input data. Applying the top of atmospheric (TOA) correction to multi spectral bands by the fallowing equation:

$$\rho\sigma = \frac{\pi L\sigma d2}{ESUN\rho SIN\theta}$$

Where:

Lσ = the radiance in unit of W/ (m²*sr*Um)
d = distance m the sun and earth in astronomic unit
ESUNσ = solar radiance in unit of W/ (m²*Um)
Θ = sun elevation in degree

Calculate NDVI using the standard formula: **NIR – Red / NIR + Red**. Recalculate infrared thermal bands data to the at-sensor spectral radiance (**Ls**) and then converts the radiance values to the at-sensor brightness temperature (**Ts**).

The second part allow us to convert the NDVI result to Land Surface Emissivity (**LSE**) values, using NDVI thresholds method to compute (**LSE**) [19]. In the final part, we insert values of upwelling, downwelling and transmission (equation 1) (from NCEP model for atmospheric profiles), in the single channel algorithm, in order to compute the correct LST for every sensor type.

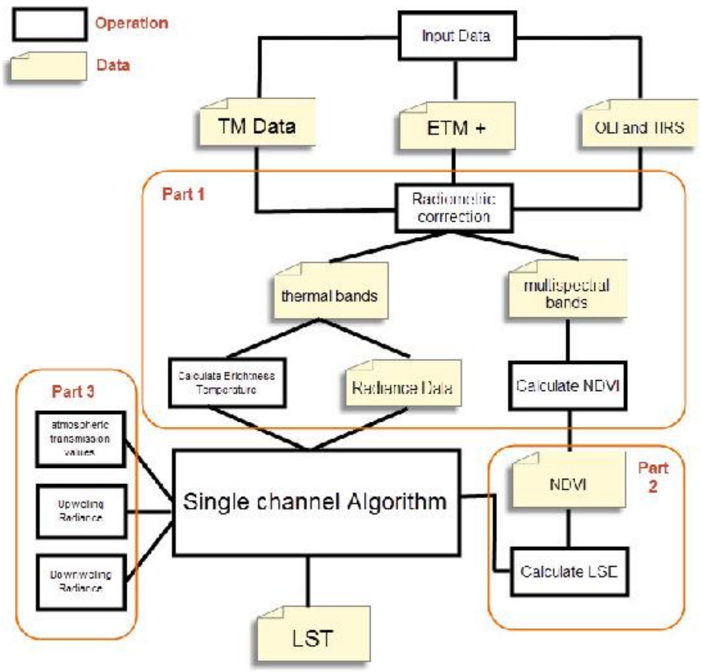


Fig 2. Processing chain

6.1 INPUT DATA

The data used in this study are from three different sensors of Landsat series, the main reason we decided to take 3 different sensors, is because they describe old dates with large intervals (section 5) for spatial variety of UHI effect. Table (1) shows characteristics for each sensor.

Table 1: Characteristics of Landsat series for each sensor

Sensor	Acquisition date	Multi spectral resolution	Thermal infrared bands resolution
OLI and TIRS	2014-04-06	30 m^2	60 m^2 resampled to 30 m^2
ETM +	2002-02-08	30 m^2	120 m^2 resampled to 30 m^2
TM	1987-02-07	30m^2	120 m^2 resampled to 30 m^2

For amenity, a single channel algorithm for retrieving LST from thermal band of Landsat TM ETM+ and TIRS data was designed by Jimenez-Munoz and Sobrino (2003), and only three parameters were required for the algorithm. The formula used dependent on atmospheric transmissivity, upwelling and downwelling atmospheric radiances. The single channel algorithm was expressed in section (**4.1**).

7 RESULT AND DISCUSSION

In this study, we used 3 dates with tree different sensor type of landsat satellite series, to estimate LST from the TIR bands of each date, in order to make a spatio temporal study of UHI effect over Casablanca city.

We used a toolbox developed by [20] for automated mapping of LST with the use of Landsat data. The final result is a map that shows the spatial distribution of heat island effect during time (1987 2002 and 2014). A first visual interpretation shows that the hot areas (have an elevated temperature) are located in industrial areas such as Ain Sbaa and Sidi El Bernoussi , the old medina, with quite elevated population density produce also a remarkable temperature. Other municipalities closer to the center as Hay Mohammadi and Assokhour Assawda suffer from the heat island effect. In the other side, municipalities as ANFA and MAARIF characterized by haut standing buildings and vegetation cover showed a mean temperature variability.

Sub-urban areas as Bouskoura shows low temperature, first hypothesis allows us to presume that, diminution of temperature is due to the existence of vegetation cover surrounding the built-up areas.

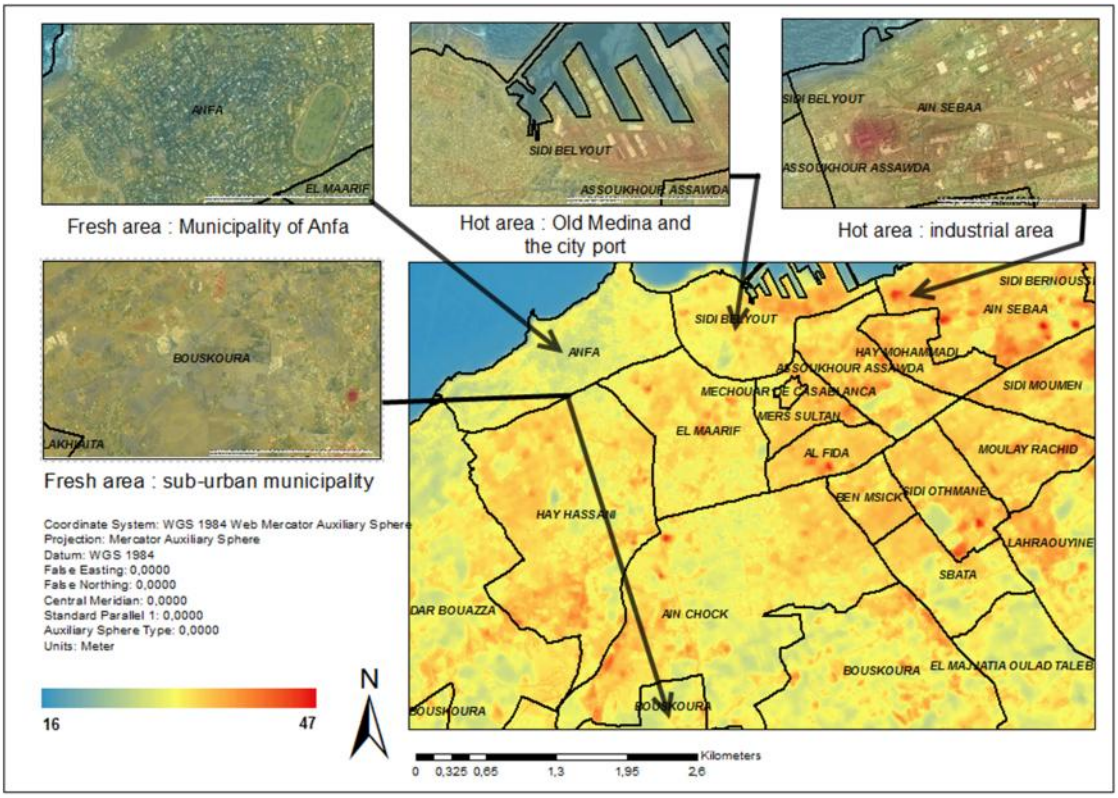


Fig 3. Land surface temperature map with fresh and cold areas – case of 2014

7.1 EXTRACTION OF FRESHNESS AND HEAT ISLAND AREA

The surface temperature at the urban areas, is a variable parameter in climatological and environmental studies, at this stage we have a result of LST images (continue raster), and we must produce segmented image that allow us to detect hot areas surfaces on each municipality compared to cold ones. The conventional segmentation method based on the arbitrary choice of the value of the threshold may not concretely extract the formations of the heat islands area (related to each municipality), we adopted a statistical method which gives more credibility in order to make a partition of the image.

We use a robust statistical method proposed by [21] to help quantify the urban surface temperature. Based on this method the ground surface temperature was divided into different scales by mean surface temperature and different times of standard deviation (Eq.3).

This method gives more credibility, is based on calculating the arithmetic mean and standard deviation. The equation developec by Zhang is:

$$T = a \pm X * S \qquad (3)$$

Where “a” represents the mean temperature, “S” is the standard deviation and “χ “statistical series:

χ = (–3, –2.5, –2, –1.5, –1, –0.5, 0, 0.5, 1, 1.5, 2, 2.5, 3)

Tests that have been made, have shown that with the statistical series of X, the variance of the standard deviation can give a representation of an object in the image [21]. According to the variance of the standard deviation following the series (X), it can detect a threshold value for partitioning hot areas from the cold ones.

We tried all the statistical series of (X), it turned out that the best interval which gives a good representation of threshold value, is the mean and one time of standard deviation. So the thresholding value (a + S) will be used to extract the heat islands area, while (a – S) will be used to identify urban fresh surfaces.

By the method described in section (7.1), the area whose temperature was higher than the mean and one time of standard deviation was called hot island area. The sum of average temperature and 1 time standard deviation was used as threshold to outline the hot island area. According to the statistics, the mean for each date temperature and the standard deviation is shown in (table2). We use equation 3 as threshold to draw the outline of the hot island area and the size of hot island for each municipality is shown in graph (fig 4).

Table 2: mean and standard deviation of each LST result

Sensor	*Mean temperature*	*Standard deviation*
OLI and TIRS	*26.98 ° C*	*6.26 ° C*
ETM +	*21.54 ° C*	*2.40 ° C*
TM	*16.14 ° C*	*1.43 ° C*

There is a strong correlation between the heat island and vegetation cover in urban areas, tests have been done by randomly taking 100 points dispersed in the LST image. In the other side we compared the hot areas with vegetation cover, result are showed in figure (4). Surrounding areas have a richer vegetation cover, even that heat island effect is developed during the last 10 years, municipalities as Bourkoura, Dar Bouazza shows an elevated temperature which indicates a progressive change of population and built up areas.

Municipalities close to the center shows a rapid increase of UHI effect. A comparison between old medina and the new built up shows that buildings constructed recently can produce temperature more than the old one [22].

Healthy vegetation can reduce the high temperature caused by building especially new built up. Absorbing and decreasing temperature for cities like Casablanca, which suffer from the phenomenon. Excessive heat events, or abrupt and dramatic temperature increases, are particularly dangerous and can result in above-average rates of mortality, and that can be a cause for next generations to suffer from diseases such as allergy of the lungs and cancer [23] . Not to mention the high pavement and rooftop surface temperatures can heat storm water runoff. Tests have shown that pavements that are 100ºF (38°C) can elevate initial rainwater temperature from roughly 70ºF (21ºC) to over 95ºF (35ºC). This heated stormwater generally becomes runoff, which drains into storm sewers and raises water temperatures as it is released into streams, rivers, ponds, and lakes. (Center for Disease Control and Prevention. 2006). Fig 4 shows the relationship between vegetation index and heat island, the vegetation index is a determining factor for increase or decrease of heat island effect in urban areas [24].

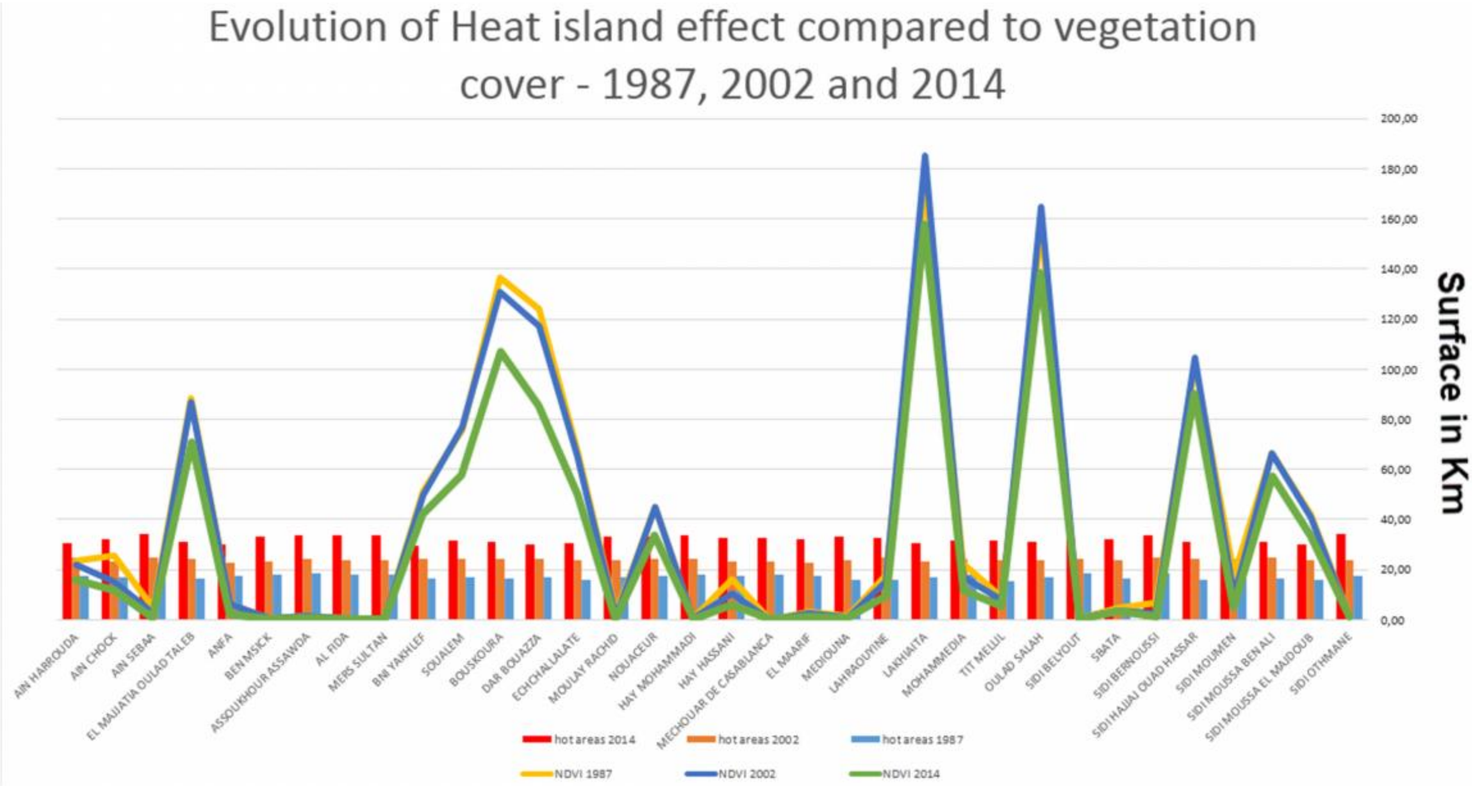


Fig 4. Estimated surface of heat island divided for each municipality

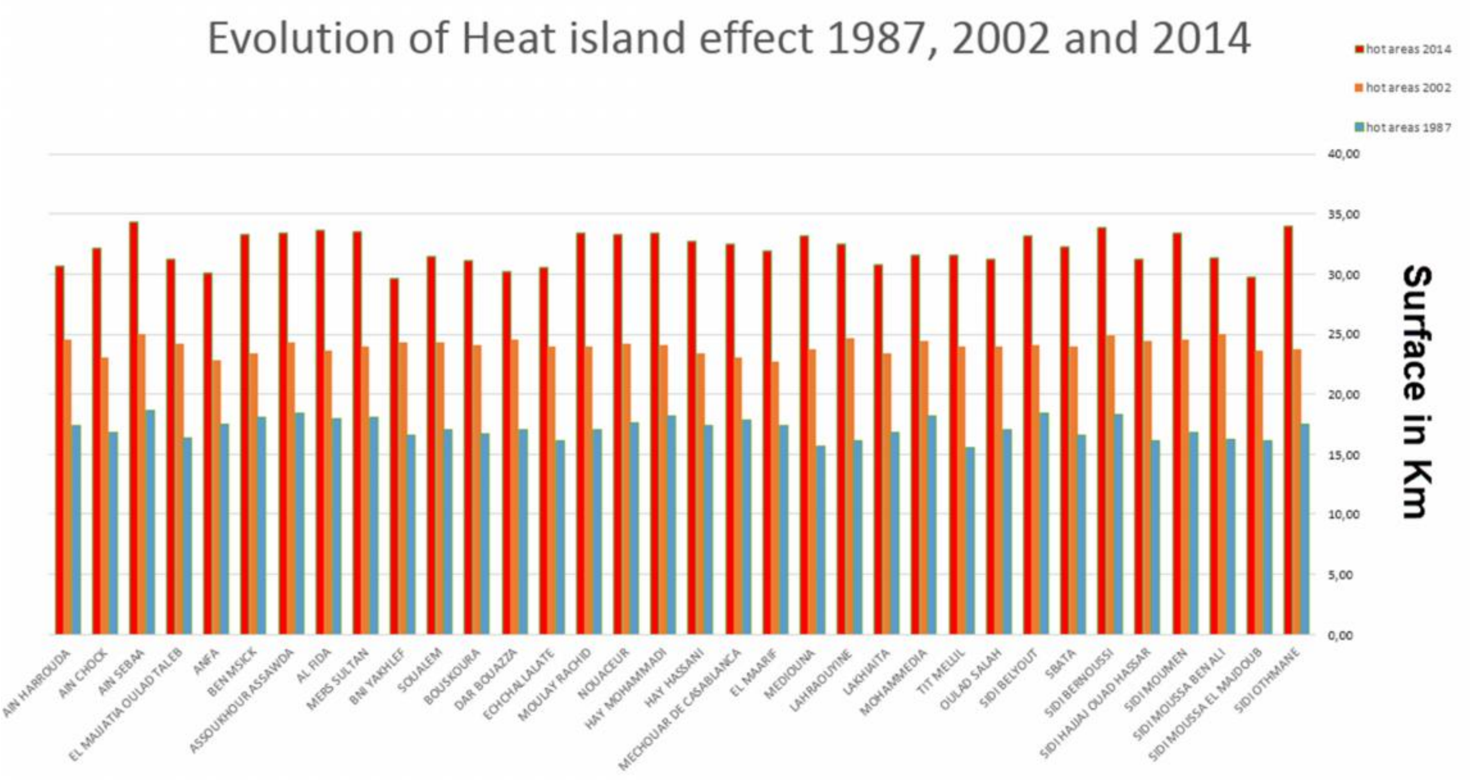


Fig 5. The ratio between heat island and NDVI for each municipality in grand Casablanca

8 CONCLUSION

The warmth rising off earth's landscapes influences our world's weather and climate patterns, scientists monitor land surface temperature and they want to know how increasing atmospheric greenhouse gases affect land surface temperature globally, and how rapid urbanization affect LST locally and produce UHI effect. Monitoring LST can help us to reduce UHI by taking smart decisions during the design of our urban planning face uncontrolled urbanization. Casablanca is one of the most affected regions in the world and which requires rapid intervention to reduce the danger in the future.

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