Analysis of correlation between urban heat islands (UHI) with land-use using sentinel 2 time-series image in Makassar city

To cite this article: S Rauf et al 2020 IOP Conf. Ser.: Earth Environ. Sci. 419 012088

View the article online for updates and enhancements.
Analysis of correlation between urban heat islands (UHI) with land-use using sentinel 2 time-series image in Makassar city

S Rauf¹, M M Pasra¹, M A Abdurrahman¹, and Yuliani¹
¹Civil Engineering Department, Universitas Hasanuddin, Makassar Indonesia

E-mail: syafrauf@yahoo.co.id

Abstract. In this study, to analyze the value of the correlation between Urban Heat Island and land-use variables. Y variable used is temperature and some variables X in the form of land use variants, namely road network area (km²), population density / ha, building area (km²), and image index data from sentinel2 and Landsat 8 time-series images in the form of satellite image index namely the normalized difference vegetation index (NDVI), the Normalized Difference Water Index (NDWI) and Moisture Indices (MI) in Makassar City. The method used in this study is the Pearson correlation coefficient to determine the variables that influence the increase in Urban Heat Island in Makassar City. Based on the results of the correlation analysis obtained, variables that influence Urban Heat Island are Moisture Indices (MI), which have a significant correlation in increasing Urban Heat Island, where the correlation value between temperature and Moisture Indices (MI) is R = -0.766. Another variable is the road area, where the correlation value R is -0.655.

1. Introduction
Urbanization and climate change are teaming up, turning up the heat in cities faster than rural areas. These hotter urban temperatures raise the risk of dangerous ozone air pollution. Urban heat islands have hotter days, far hotter nights, and more extremely hot days each summer than adjacent rural areas. Without greenhouse-gas reductions, cities will continue to get hotter, with potentially serious consequences. As a result of changes in land use and increasing population activity, changes in land functions in urban areas cause an increase in temperatures in urban areas compared to suburban temperatures, the difference in temperature distribution is called "Urban hot island."

Cities are responsive to urban climate instability and inconstancy and able to change their climates. The urban climate is a critical factor that affects regional and global climates and urban livability [1]. The microclimate of urban open spaces is influenced by several parameters such as the urban form and geometry, urban density, the vegetation, the water levels and the properties of surfaces. The inappropriate implementation of the parameters mentioned above contributes to the harshness of the environment and, therefore, makes the temperature in the urban areas higher than in the suburbs. This phenomenon called the urban heat island [2]. The main reasons for forming UHI include heat-trapping by urban geometry, properties of urban surfaces, replacement of vegetation by expansively built surfaces cover and the anthropogenic heat sources [3].

In addition to urban geometry and surface thermal properties, the following factors also contribute to urban microclimate modifications: (1) anthropogenic heat (heat waste from combustion and metabolism);(2) urban ‘greenhouse’ effect (increased incoming long-wave
radiation from polluted urban atmosphere); (3) evapotranspiration loss (reduction of green areas in cities lead to more sensible than latent heat transfer); and (4) wind shelter, i.e. reduced ability of wind to carry heat either as sensible or latent turbulent heat flux.

1.1. Reasons for urban heat island
Various causes add to the arrangement of Urban Heat Island. The causes which assume the critical part in the formation of UHI are described below:

- Low albedo materials
  Albedo is assessed by the proportion of the reflected sun powered vitality to the occurrence of sunlight based vitality. On the off chance that the albedo of the urban surface is low, it will store more sun based vitality and the expanding of urban temperature.

- Human gathering
  As the human get-together is noticeable in the downtown areas inferable from the accessibility of different offices, discharge of CO$_2$ is more in these zones. CO$_2$ stores warm, upgraded climatic temperatures. A definitive impact is that it aids the arrangement of Warmth Island as it were.

- Destruction of trees
  Trees capture the sun oriented warmth and assimilate CO$_2$ for their photosynthesis, making the earth cool. With the annihilation of vegetation, the productivity of the chilling framework goes drastically off causing the formation of the procedure.

![Figure 1. Summer in the city: seeking relief from urban heat islands](image)

1.2. Measuring and localizing UHIs
Two methods can measure UHI effects: (1) direct measurement of surface and air temperatures using sensors at fixed or mobile observation sites; and (2) indirect, remote measurement using satellite and aerial sensors that detect radiation emitted by surfaces. The surface urban heat island effect is observed as a temperature difference between surfaces such as roofs and tree canopies or open fields and parking lots. Satellite thermal images can be used to determine the location of “hot spots” in the urban environment (as illustrated in figure 1 above). This information could be used as a basis for the strategic implementation of UHI mitigation measures. However, the localization of these “hot spots” should be combined with information related to building characteristics and socio-economic factors and infrastructure to better protect at-risk populations by increasing their resiliency to heat.

In an isothermal map, the UHI is represented by closed contours on the urban area, which contrasts with the wider contours of the rural areas. Meanwhile, in a thermal profile, the UHI is represented by the isothermic curve rise throughout the urban area, which contrasts with the characteristic low, flattened curve of the rural areas. According to the typical thermal profile of the UHI (figure 1), the rural thermal field is interrupted by a steep temperature gradient at the rural/urban boundaries (i.e.,
cliff), and thereafter a steady but weaker horizontal gradient of increasing temperature (i.e., plateau) is prolonged until reaching the highest temperature point at the urban core or city center (i.e., peak). The uniformity of this “island” shaped pattern generally indicates a few depressions due to the presence of particularly hot points (i.e. micro-urban heat islands) associated with features such as parking lots, malls, industrial facilities, etc, and minor rises due to the presence of particularly cold points (i.e. heat sinks) associated with features such as parks, fields, water bodies, etc. The difference between the warmest urban zone and the rural base temperature defines the intensity or magnitude of the UHI.

The highlights mentioned above the important role that the land use/land cover types have on the thermal pattern of the UHI. Usually, a close relationship is expected between the temperature radiated by the land surface (i.e., land surface temperature, LST) and the temperature of the atmosphere situated immediately above it (i.e., near-surface air temperature), due to the transfer of energy emitted from the former to the latter. Thereby, over the last decades, remotely sensed thermal infrared data have contributed to addressing the UHI through the estimation of LST, thus originating the study of the surface UHI. Nevertheless, it has been found that atmospheric and surface UHI are coarsely related, and they can exhibit quite different spatial and temporal patterns. Moreover, within the urban atmosphere, the heat island may present significant variations between the canopy and boundary layers. The former comprises the space below the general rooftop level, while the latter extends above that level to the point where the presence of the city modifies climatic conditions. The purpose of this study is to analyze the correlation of variable land use (road network, buildings, and sentinel image index with variable temperature, so we get a clear picture of what factors influence the occurrence of the Urban Heat Islands in Makassar City.

2. Literature review

Sentinel-2 is an Earth observation mission from the EU Copernicus Programme that systematically acquires optical imagery at high spatial resolution (10 m to 60 m) over land and coastal waters. The mission is a constellation with two twin satellites (Sentinel-2A and Sentinel-2B). The Sentinel-2 mission has the following key characteristics:

- Multi-spectral data with 13 bands in the visible, near-infrared, and short wave infrared part of the spectrum
- Systematic global coverage of land surfaces from 56° S to 84° N, coastal waters, and all of the Mediterranean Sea
- Revisiting every five days under the same viewing angles. At high latitudes, Sentinel-2 swath overlap and some regions will be observed twice or more every 5 days, but with different viewing angles. The spatial resolution of 10 m, 20 m, and 60 m, 290 km field of view. Free and open data policy

To achieve frequent revisits and high mission availability, two identical Sentinel-2 satellites (Sentinel-2A and Sentinel-2B) operate together [4]. The Sentinel-2 satellites will each carry a single multi-spectral instrument (MSI) with 13 spectral channels in the visible/near-infrared (VNIR) and short wave infrared spectral range (SWIR). Designed and built by Airbus Defense and Space in France; this MSI imager uses a push-broom concept and its design has been driven by the large 290 km (180 mi) swath requirements, together with the high geometrical and spectral performance required of the measurements has a 150 mm (6 in) aperture and a three-mirror anastigmat design with a focal length of about 600 mm (24 in); the instantaneous field of view is about 21 degrees by 3.5 degrees]. The mirrors are rectangular and made of silicon carbide, a similar technology to those on the Gaia mission [5]. The system also employs a shutter mechanism preventing direct illumination of the instrument by the sun. This mechanism is also used in the calibration of the instrument.
The planned orbit is Sun-synchronous at 786 km (488 mi) altitude, 14.3 revolutions per day, with a 10:30 a.m. descending node. This local time was selected as a compromise between minimizing cloud cover and ensuring suitable Sun illumination. It is close to the Landsat local time and matches SPOT’s, allowing the combination of Sentinel-2 data with historical images to build long-term time series [6].

Table 1. Spectral bands for the sentinel-2 [7]

<table>
<thead>
<tr>
<th>Sentinel-2 bands</th>
<th>Sentinel-2-A</th>
<th>Sentinel-2B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central wavelength (nm)</td>
<td>Bandwidth (nm)</td>
<td>Central wavelength (nm)</td>
</tr>
<tr>
<td>Band 1 - Coastal aerosol</td>
<td>442.7</td>
<td>21</td>
</tr>
<tr>
<td>Band 2 - Blue</td>
<td>492.4</td>
<td>66</td>
</tr>
<tr>
<td>Band 3 - Green</td>
<td>559.8</td>
<td>36</td>
</tr>
<tr>
<td>Band 4 - Red</td>
<td>664.6</td>
<td>31</td>
</tr>
<tr>
<td>Band 5 - Vegetation red edge</td>
<td>704.1</td>
<td>15</td>
</tr>
<tr>
<td>Band 6 - Vegetation red edge</td>
<td>740.5</td>
<td>15</td>
</tr>
<tr>
<td>Band 7 - Vegetation red edge</td>
<td>782.8</td>
<td>20</td>
</tr>
<tr>
<td>Band 8 - NIR</td>
<td>832.8</td>
<td>106</td>
</tr>
<tr>
<td>Band 8A - Narrow NIR</td>
<td>864.7</td>
<td>21</td>
</tr>
<tr>
<td>Band 9 - Water vapour</td>
<td>945.1</td>
<td>20</td>
</tr>
<tr>
<td>Band 10 - SWIR - Cirrus</td>
<td>1373.5</td>
<td>31</td>
</tr>
<tr>
<td>Band 11 - SWIR</td>
<td>1613.7</td>
<td>91</td>
</tr>
<tr>
<td>Band 12 - SWIR</td>
<td>2202.4</td>
<td>175</td>
</tr>
</tbody>
</table>

The data used in this study, the Normalized Difference Vegetation Index (NDVI), Normalized Difference (NDWI), Moisture Indices (MI), and data at the study site were obtained from the results of the Sentinel2 image analysis and temperature from Landsat8 time series for two years. The most commonly used vegetation index is the Normalized Difference Vegetation Index (NDVI). NDVI is an index of ‘greenish’ vegetation or vegetation photosynthetic activity. NDVI can show parameters related to vegetation parameters, among others, the biomass of green leaves, green leaf areas, which are predictable values for the division of vegetation. This vegetation index value is based on the difference between the maximum absorption of radiation in the red channel (red) as a result of chlorophyll pigment and maximum reflectance in the near-infrared (NIR) channel as a result of the cellular structure of the leaf. The NDVI formulations are as follows:

\[
NDVI = \frac{NIR - RED}{NIR + RED}
\]

where:
- NDVI = The normalized difference vegetation index
- NDWI = Normalized Difference Water Index
- MI = Moisture Indices
Moisture Index (MI) is an index that is used to detect the humidity of a land surface. Humidity, in particular, the water content, plays an important role in the way vegetation functions. It is because the MI leaves have a positive relationship with NDVI, the higher the NDVI value, the higher the value of MI and vice versa if the value of MI is lower then the value of NDVI will be lower because dense vegetation causes higher moisture and moisture content in the environment. However, MI and NDVI have a negative relationship with the surface temperature when the value of MI and NDVI increases, the value of the surface temperature will decrease and vice versa if the value of MI and NDVI decreases, the value of the temperature will increase. Precisely where photosynthesis generally occurs, most of it is water. The Water Index formulations are as follows:

\[ WI = \frac{\text{NIR}}{\text{RED}} \] (2)

Where:
- NIR = Value of reflectance of the near-infrared channel (Band 5)
- RED = Red channel reflectance value (Band 4)
3. Research methodology

3.1. Pearson correlation coefficient

Pearson's correlation coefficient is the covariance of the two variables divided by the product of their standard deviations. The form of the definition involves a "product moment," that is, the mean (the first moment about the origin) of the product of the mean-adjusted random variables; hence, the modifier product-moment in the name.

Pearson's correlation coefficient applied to a sample using the following equation:

\[
r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2} \sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}
\]

where:

- \( r_{xy} \) = coefficient correlation
- \( n \) = sample size

The validity will interpret; the correlation coefficient is categorized as follows:

<table>
<thead>
<tr>
<th>( r ) value</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.81 – 1.00</td>
<td>Very high</td>
</tr>
<tr>
<td>0.61 – 0.80</td>
<td>High</td>
</tr>
<tr>
<td>0.41 – 0.60</td>
<td>Middle</td>
</tr>
<tr>
<td>0.21 – 0.40</td>
<td>Low</td>
</tr>
<tr>
<td>0.00 – 0.20</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

4. Results and discussion

4.1. Population density

The largest population density in Makassar City is in Ujung Tanah Subdistrict with a value of 34,223.3 people / km², and the smallest density is in the District of Tamalanrea with a value of 2,883.28 inhabitants / km². With the help of the QGIS application, the ship file can be classified based on the population level so that it can be seen the difference in population density in each sub-district (figure 8). Based on the map of population density below, we can know the densest area or location occupied or occupied by residents. Ujung Tanah Subdistrict, which has the densest population, is marked by dark color on the map. While the smallest population density is in Tamalanrea District with bright colors marked on the map.

4.2. Road network

In mapping, the road network in Makassar City, road network data, is downloaded from the Open Street Map through the QGIS application in the form of an shp file. With the help of the QGIS application, it can be analyzed the length of the road per sub-district and then classified to find out the sub-district on the longest road. The longest road network in Makassar City is a road network in Birirngkanaya District with a total length of 567.73 Km or 19.7% of the total length of the road in
Makassar City. As for the shortest road network in Ujung Tanah Subdistrict with a road length of 38.88Km or only 1.3% of the total road length in Makassar City. This explanation is shown in figure 8, as stated that the urban heat island will be forecast in the future.

The Normalized Difference Vegetation Index (NDVI) is a 'greenish' vegetation index or vegetation photosynthetic activity. This vegetation index value is based on the difference between the maximum absorption of radiation in the red channel (red) as a result of chlorophyll pigment and maximum reflectance in the near-infrared (NIR) channel as a result of the cellular structure of the leaf. NDVI Index of Makassar City based on Sentinel2 image data obtained based on spatial analysis in QGIS shown in figure 10 below.

4.3. Normalized difference water index (NDWI)
NDWI shows the dominance of water areas because the use of the Green wave spectrum in the range (1.55-1.75 µm) maximizes water reflectance by the recorded object. Making NDWI index maps is not different from WI, which is processing. Making NDWI index maps is no different from WI, which is processing NDWI formulations with the Raster Calculator tool to produce new raster data that analyze the presence of watery areas. The blue color on the map signifies the presence of a watery area. The aqueous area that intended is inundation or water flow areas such as lakes, watery fields, swamps, rivers, and beaches. NDWI can read watery areas and distinguish between dry areas around them compared to WI maps. Based on the NDWI map in figure 12 below, it can be analyzed that most watery areas are in Tallo Subdistrict, Wajo Subdistrict, and Bontoala Subdistrict, Mariso Subdistrict, and Tamalate Subdistrict, watery areas consist of swamp areas or other puddles. The following is presented an NDWI magnification map in Makassar City. Temperature maps are obtained based on Landsat8 satellite images from the corrected band ten results (RT), which depict areas with temperature values that differ from region to region in Makassar City. Figure 13 describes the distribution of temperature levels in Makassar City.

4.4. Correlation analysis
Urban Heat Island is a temperature change that is increasing in urban areas compared to suburban areas. The phenomenon of Heat Island is characterized by the existence of an area that has a much higher temperature compared to the surrounding temperature. Y variable is the temperature, and it will be correlated with 8 X variables, namely Area (km²), Road network area, Population density, NDVI index value, NDWI, MI, and road network length. As presented in table 2 below. From the analysis based on the data, the correlation results obtained using the Pearson correlation coefficient method that influences the occurrence of the Urban Heat Island phenomenon in Makassar City. Based on the results of the correlation analysis, the variables that influence the occurrence of Urban Heat Island are variable Moisture Index (MI) with a correlation value of $R = -0.766$, and other variables that significantly influence the occurrence of Urban Heat Islands respectively are population density variables with $R$ correlation values = 0.721, and the width of the road network with a correlation value of $R = 0.65$. 
5. Conclusion

Urban Heat Islands in Makassar City can be eliminated by increasing the development of areas of water bodies such as lakes, rivers, and reservoirs, where areas of water bodies have a significant correlation reducing Urban Heat Island as with the results of correlation analysis between temperature and Moisture Index with a correlation value -0.766. The more areas of the body of water will reduce the area affected by the Heat Islands. Other factors that influence the occurrence of Urban Heat Island in Makassar City are the wide road network. Road surfaces made of asphalt and concrete and lack of greening on the side of the road to increase Urban Heat Island based on the results of correlation analysis between the width of the road network and temperature with a correlation value of $R = 0.65$.

References