**Climatological Human Comfort Using Heat and Humidity Index (Humidex) in Gadingkulon, Malang**

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**Abstract.** A human living in certain area was controlled by dynamic environmental condition. The dynamic changes of environment condition including temperature and humidity were the main factor influencing the climatological human living comfort. Various of those factors were specific and unique following the characteristics of that area. Most characteristics of that determined to analyse temperature and humidity were elevation and land coverage. The more difference of both elevation and land coverage were, the more various human living comfort was. That condition could be measured by Heat and Humidity Index (Humidex) using temperature and humidity data. Gadingkulon was one of area where landcover changes took place fast enough. The vegetation changes to be built-up areas were dominated by residential area nowadays. This research aims to analyse Humidex of Gadingkulon followed by dominant influencing factor of the index, whether elevation or land cover. To do so, both SRTM 30 meters imagery and Landsat 8 OLI/TIRS satellite imagery was used to present spatial distribution of elevation and vegetation indices (NDVI), respectively. Correlation of elevation to Humidex and NDVI to Humidex were measured statistically. Linear regression was also used to show the mathematical relationship of both variables to Humidex. The result showed that determination coefficient of elevation to Humidex was 0,70 (it means that contribution of 70%) which was more correlate than that of NDVI to Humidex. Comparing the previous correlation, NDVI to Humidex’s correlation only delivered the contribution of 58 % influencing human living comfort. It strongly indicated that climatological comfort of human living was more controlled by elevation. The difference of landcover density was not quite strong enough to control that comfort condition of Gadingkulon.

1. Introduction

Urban people life intensely depends on environmental quality, including air condition. Good and comfort air conditions deliver better life comfort, so it can support all people's activities [1]. Certain temperatures and humidity conditions will determine air comfort [2]. Those weather elements influence heat stress conditions, primarily in a residential area [3]. Heat stress condition is one of the microclimate phenomena found in a built-up area [4].

The residential or settlement area belongs to a vulnerable area of heat stress condition since high people activities. Comfort analysis had been done in Jakarta City using the Temperature Humidity Index (THI). THI showed physiological comfort [5]. The result showed comfort proportion which is uncomfortable with 22,1 %, half comfortable of 71%, and only comfortable of 7%. Another eligible single index depicting heat stress conditions for a human living is Humidex. Humidex is a biometeorological index that had been used widely. Specifically, Humidex often used to assess outdoor thermal discomfort [6]. Humidex is obtained by both temperature and humidity showing actual heat conditions felt by humans [7], [8]. The natural parameter reputed to influence Humidex values is wind velocity [9]. But, another research resulted that there is no relationship between wind velocity and Humidex [6]. The sensitivity of Humidex to wind velocity is at a low value [10]. The number of a motor vehicle and the scope of green open space are also reputed to be non-natural parameters influencing Humidex value [9], [11].
In a spatiotemporal perspective, Humidex analysis is very useful to depict spatially about thermal comfort characteristics, primarily in the environmental planning context [12]. Outdoor thermal discomfort using Humidex can be used in various scopes. Enrico [13] used Humidex to know human discomfort because of climate change in Europe. Vysoudil [14] used Humidex applied in several urban and suburban areas of Europe. His research resulted in the conclusion that if Humidex applied on a regional scale, so the Humidex will show less accurate results than temperature as a simpler indicator. Geletič [12] used Humidex to know human discomfort at the heatwave occurred. On a smaller scale, Humidex was also used as green open space management, for instance as a hospital environment and indoor environment [6], [15]. In this research, Humidex analysis was done in Gadingkulon Village, Malang Regency, East Java. The objective is to acquire spatial distribution of climatological human comfort using Humidex, and its relationship between topographic and vegetation condition in the research area.

2. Methods

2.1 Data Collection

The research was done in Gadingkulon Village, Malang Regency which covers the area of 4.53 km² [16]. Meteorological data acquisition was taken in November of 2018 which is still early rainy season. The data was acquired in that November since it was still influenced by the end dry season of October. Those meteorological data include air temperature (°C) and relative humidity (%). Data acquisition was done by volunteers by multiple times in a day along 7 series of days. There are 37 points taken by purposive random sampling. Gadingkulon area was divided into several 500 x 500-meter grids area using fishnet tools in GIS. The data are randomly taken from each grid by a total of 3-5 points.

The research also used Landsat 8 OLI/TRS imagery of 2018 November which cloudiness below 10%. Landsat 8 OLI/TRS has 30 meters of spatial resolution and 12 m of accuracy spatial resolution [17]. Data acquired from Landsat 8 OLI/TRS is the Normalized Difference Vegetation Index (NDVI). Other raster data are the Digital Elevation Model (DEM) from Shuttle Radar Topographic Mission.
(SRTM) which has 30 meters of spatial resolution, respectively [18]. Both raster data and satellite imagery were obtained from https://earthexplorer.usgs.gov/.

2.2 Data Processing

Data acquired from field were temperature (°C) and relative humidity (%). Those data were used to obtain Humidex values. The formula to calculate Humidex as shown below.

\[
\text{Humidex} = T + \frac{5}{9}(e - 10) \quad \text{......... (1)}
\]

\[
e = 6.112 \times 10^{(\frac{7.5T}{(237.7+T)})} \times \frac{H}{100} \quad \text{......... (2)}
\]

Occasionally, Humidex was used as an indicator of thermal comfort for the outdoor environment [15], [19]. Combination of temperature and humidity give better result as a feeling indicator of thermal discomfort since of dry air. However, it was also compared using temperature and humidity as an influencing factor individually [20]. Humidex corresponds to bioclimatic condition and bioclimatic comfort/discomfort as shown in Table 1. Bioclimatic comfort/discomfort is the sensation of thermal condition felt by the human body [21].

| Humidex | Bioclimatic Condition | Bioclimatic Comfort/Discomfort |
|---------|-----------------------|-------------------------------|
| H < 27  | Comfort               | Bioclimatic Comfort           |
| 27 < 30 | Little Discomfort     |                               |
| 30 < 40 | Discomfort            |                               |
| 40 < 45 | Great Discomfort      | Bioclimatic Discomfort due to Overheating |
| 45 < 54 | Dangerous             |                               |
| H > 54  | Heat stroke imminent  |                               |

Landsat 8 OLI/TRS satellite imagery was used for obtaining NDVI values. NDVI can show vegetation [23]. The formula to calculate NDVI as shown below.

\[
\text{NDVI} = \frac{NIR - \text{Red}}{NIR + \text{Red}} \quad \text{......... (3)}
\]

NDVI values indicate agricultural vegetation health [24]. If it was corresponded to disaster, so NDVI can indicate dryness condition of vegetation [25]. In this research, NDVI was addressed to show vegetation condition to indicate climatological human living shown by Humidex.

3. Result and Discussion

3.1 Daily Temporal Variation of Humidex

Both temperature and humidity data acquisition for generating Humidex were done as multiple times along day for 7 days. Mihăilă [21] stated that Humidex was more relevant for short times analysis, for instance for several days. Humidex analysis for long times analysis will deliver partially correct (monthly humidex), non-representative, even erroneous results (for instance, in seasonal humidex). Figure 2-4 showed the spatiotemporal variation of Humidex in the morning time, day time, and evening time.
Figure 2 showed morning Humidex distribution ranging in comfort to little comfort condition. In location points of 31-37 have comfort humidex. The areas cover up to 22% of the total area which is mostly appeared as paddy field/irrigated agricultural fields. The settlement located near to paddy field also has comfort humidex. Little discomfort morning humidex was felt in locations that are not as paddy field. Little discomfort humidex scopes about 78% of the Gadingkulon area as cluster prone distribution in eastward and westward. Humidex depends on temperature and humidity. Scoccimarro [13] explained that Humidex may be decreased by reducing relative humidity along with increasing air temperature which is primarily occurred inland. That is reasonable since humidex was measured in the morning time.

Figure 3 depicted the Daytime Humidex condition. Along with daytime, Humidex showed climatological changes for human living comfort. Location points of 25-37 have comfort Humidex. The areas are mostly covered as paddy fields and unirrigated agricultural fields. The comfort area is up to 38% of the research area. Location points of 1-13 which are comprised as settlement, unirrigated agricultural field and fruit plantation have little discomfort humidex. Location points 15-22 as unirrigated agricultural field and fruit plantation have discomfort conditions. Near areas to the highway also have a similar condition. This causes that 59% of the research area is under little discomfort and discomfort condition. Those conditions were distributed spatially from the center to westward of the research area. Residential areas (sample point of 23) have great discomfort conditions for climatological human living. They cover up to 2% of the whole research area in Gadingkulon. Daily Humidex will often change. Mehrotra [3] explained that humidex changes will be more sensitive in built-up space located in a heterogeneous urban area. In the daytime between 12.00-14.00 p.m, Humidex reached up to the highest value (great discomfort condition). In the research area, built up is only as settlements clustered in several locations.
Humidex condition changed in the nighttime. In the location point of 1-23, generally, humidex indicated little discomfort condition. It was up to 58% of the Gadingkulon area. In the sample point of 24-34, Humidex showed comfort conditions in areas dominated by settlement, paddy field, and
unirrigated agricultural field. The comfort condition was up to 38% of the research area. Discomfort condition was felt in location points of 20 and 23 which are covered as settlement and highway and be up to 5% of the research area. This research is appropriate with research done by Mehrotra [3]. He implied that at 6.00-8.00 p.m. (cooling hours), Humidex had indicated cooling thermal impact. Research done by Suwasono [11] showed an almost similar result with this research. In the daytime, Humidex started to increase and in the evening time, it began to decrease.

3.2 NDVI – Elevation – Humidex Relationship
This research was looking for the NDVI-Elevation-Humidex relationship. The statistical method was often used to show a relationship among parameters. Ma’rufatin [26] stated that there was a strong negative relationship between Green House Gas (GHS’s) and air temperature. However, that condition related indirectly to Humidex. Humidex was also influenced by changes in daytime-nighttime. In another condition, the Humidex trend would decrease at the point which wind chill decreased, and heavy rainfall occurred [27]. Humidex condition would be physiological parameters of the human living condition including body temperature, systolic and diastolic blood pressure and also pulse rate [28].

Correlation and regression had been many used for showing the Humidex parameter relationship [7], [26], [28]. In this research, correlation testing was done to know the variable's contribution of elevation and NDVI to Humidex. The testing result of the Humidex-Elevation correlation showed that the correlation values were about 0.70, whereas the Humidex-NDVI correlation was about 0.58. It implied that the contribution of elevation to Humidex was higher than that of NDVI to Humidex. Zalakeviciute [29] explained that although relative humidity was similar to a high elevation, the air was still in low water vapor. Water vapor of air is another form of humidity. The daily dynamic amplitude of water vapor in the air has a similar amplitude to daily temperature amplitude changes. It caused similarity amplitude changes to Humidex [14]. Besides correlation testing, this research implemented Regression testing. Multiple Regression was done to show the causality relationship between Elevation-NDVI and Humidex in Gadingkulon Village. Regression result can be shown as below:

\[
\text{Humidex} = 9.34247 + 0.02357 \times \text{Elevation} \quad \ldots \ldots \quad (4)
\]
\[
\text{Humidex} = 3.34121 + 44.18392 \times \text{NDVI} \quad \ldots \ldots \quad (5)
\]

The separation between formula 4 and 5 due to the different type of data. Elevation data type is continuous, while NDVI data type is discrete. Figure 5 depicts the elevation and NDVI Line Plot based on humidex and predicted humidex. Predicted humidex can be result from formula 4 and 5. The line in the figure 5 showed that humidex and predicted humidex are correspond to each other.

![Figure 5. Elevation and NDVI Line Plot Based on Humidex and Predicted Humidex](attachment:image.png)
Figure 6. NDVI – Humidex

Figure 7. Elevation – Humidex
Vegetation located in the maximum temperature period area indicates the condition of the low transpiration level [14]. Analysis done in the downtown of Toronto pointed out that a little proportion of vegetation and low humidity level caused low Humidex and high air temperature coming from absorption radian in a built-up area [30]. Figure 6 showed a Humidex distribution layer that was overlaid above the vegetation condition layer. Vegetation condition was acquired from NDVI classified into 3 classes which were Low-Density Vegetation, Moderate Density Vegetation, and High-Density Vegetation. Occasionally, comfort and little comfort condition areas area located separately in moderate to high-density vegetation areas. The other way, discomfort to great discomfort areas are located in low-density vegetation areas. These results agreed with research done by Herdt [30]. Discomfort conditions could be reduced by an increment of vegetation density [11].

The meteorological condition of a mountainous area (high elevation) is quite different from that condition of the low elevation area. The mountainous area has a diurnal temperature variation. Besides that, relative humidity also belonged to be various depending on temperature and cloud cover [29]. Humidity was also controlled by local atmospheric pressure that would be increasing along with increasing elevation [31]. Different from humidity, air temperature conditions would be decreasing along with increasing elevation [32]. Based on field condition, Gadingkulon is located in the eastward slope of Kawi mountain with an elevation of 640-1115 m above mean sea level. Meteorological condition changes in mountainous will influence climatological human living represented as Humidex. Figure 5 depicts the spatial distribution of Humidex in each elevation rise. The distribution of comfort Humidex is located in a low elevation area of 640-783 m above the mean sea level. The moderate elevation area of 783-940 m above means sea level belongs to the discomfort area. Little discomfort area is located in a high elevation area of 940-1115 m above mean sea level, whereas great discomfort is felt in an area with an elevation of 780 and 1012 m above mean sea level.

4. Conclusion
Climatological Human Living Comfort could be represented by using Humidex. Humidex is a combination of indices between air temperature and relative humidity. Humidex mapping in Gadingkulon showed that there was daily Humidex variation in the morning time, day time, and night time. In the morning time, most Gadingkulon area was in comfort condition and the other was in a little discomfort. The condition of little discomfort and discomfort area dilated in the day time. Exactly, great discomfort was mostly felt in the built-up area. In the night time, discomfort began to decrease (cooling hours). Most areas were in comfort with little discomfort condition. Occasionally, comfort condition was felt in high-density vegetation and lower elevation areas. The cause of it agreed with other research results by Zalakeviciute who implied that there was decreasing of water vapor in high elevation [29]; by Herdt who stated high-density vegetation will increase Humidex [30] and Suwasono [11]; and the research result concluded that humidity was influenced by local atmospheric pressure and temperature was influenced by elevation changes [32]. Correlation and multivariant regression test applied for Gadingkulon case has given evidence that high elevation and high-density vegetation is not always to be the main factor that can increase the human living comfort level.

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