Thermal Variation and Socio-Environmental Inequality in Taipei Basin

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1 ABSTRACT

This study assesses the coupling features of socio-environmental depriviation for heat adaptation through the case study of urbanised areas within Taipei Basin. Multiple data including weather, green space features and socio-economic attributes are used to understand their interplay across urban neighbourhoods. Using the weather records from 28 weather stations located inside Taipei Basin and its surrounding hills, this study maps spatial variation of wind dynamic and temeprature at daytime and night-time in summer months between 2011 and 2020. Spatial statistical analysis was conducted between this climatological information, green spaces, and socio-economic status of aging, household income, and education levels.

The result shows that summer temperature is unevenly distributed and has diurnal difference. Downwind areas tend to be warmer both during the day and night, even though the development in these areas might be less intensive and have more green and blue spaces. Further analysis with socio-economic status of these areas finds that some downwind communities are also socio-economically more disadvantaged. This spatial pattern suggests an unfair consequance due to past urbanisation, which put vulnerable commnities at higher heat risk. Nature-based interventions should therefore prioritise the reduction of such impacts through a more systematic consideration of land use zoning, wind path, and mechenism for compensation.

Keywords: socio-ecological system, urban planning, spatial inequality, heat risk, nature-based solutions

2 INTRODUCTION

Conserving and reintroducing nature into built enviornments for rehabilitating ecosystem functions and natural process of cities is urged by the latest global agendas on climate chagne for buffering impacts and for adapting to extreme weather. It is increasingly recognised that climate impacts, vulnerability, and resources for responses are unevenly distributed across space in cities, leading to climate injustice. The spatial inequality to climate risk is particularly manifested in heatwave events. Some neighourhoods are subjected to higher heat exposure and less adaptive capacity than the others. This inequality is socio-ecologically bonded, and is often produced by past urban planning and development decisions. Studies based on USA cities often found an association between higher heat risk at socio-economically deprived areas due to its lack of green spaces. Whilst studies in Paris and Taipei demonstrated a different result, suggesting socio-economically disadvantages are are not necessarily to expose to higher temperature in summer (Shih, 2022).

Nevertheless, increasing green and blue spaces for cooling and ventilation is one of the strategies to reduce urban heat. Delivering effective and justice cooling outcomes via this nature-based strategy requires understanding of not only city's natrual ventilation, but also the socio-economic variations across its neighbourhoods. To this end, this study adopted weather infromation of air temperature, wind speed, and wind direction together with geographical features of Taipei basin to understand the specific local climate with socio-economic variation. It is expected to identify areas subjected to higher heat risk in summer.

3 CASE STUDY AREA

This study took the urbanised areas of Taipei Basin as a case study area, including parts of the juristition of Taipei City and New Taipei City (Fig. 1). This includes 991 urban neighbourhoods in the basin area, which is surrounded by hills and forested mountains. The area covers approximately 2,726 km2 and has population estimated to 6.67 million by 2014. The basin sitting in the Northern Taiwan is connected to the sea on the north via the Tamshui river and on the East via the Keelong river. The Da-han River running from the central to the south-west of the basin is another main river corridor of the basin. Due to its specific geographical features that keep heat inside the basin and intensive urbanisation in the past, urban heat island effect has

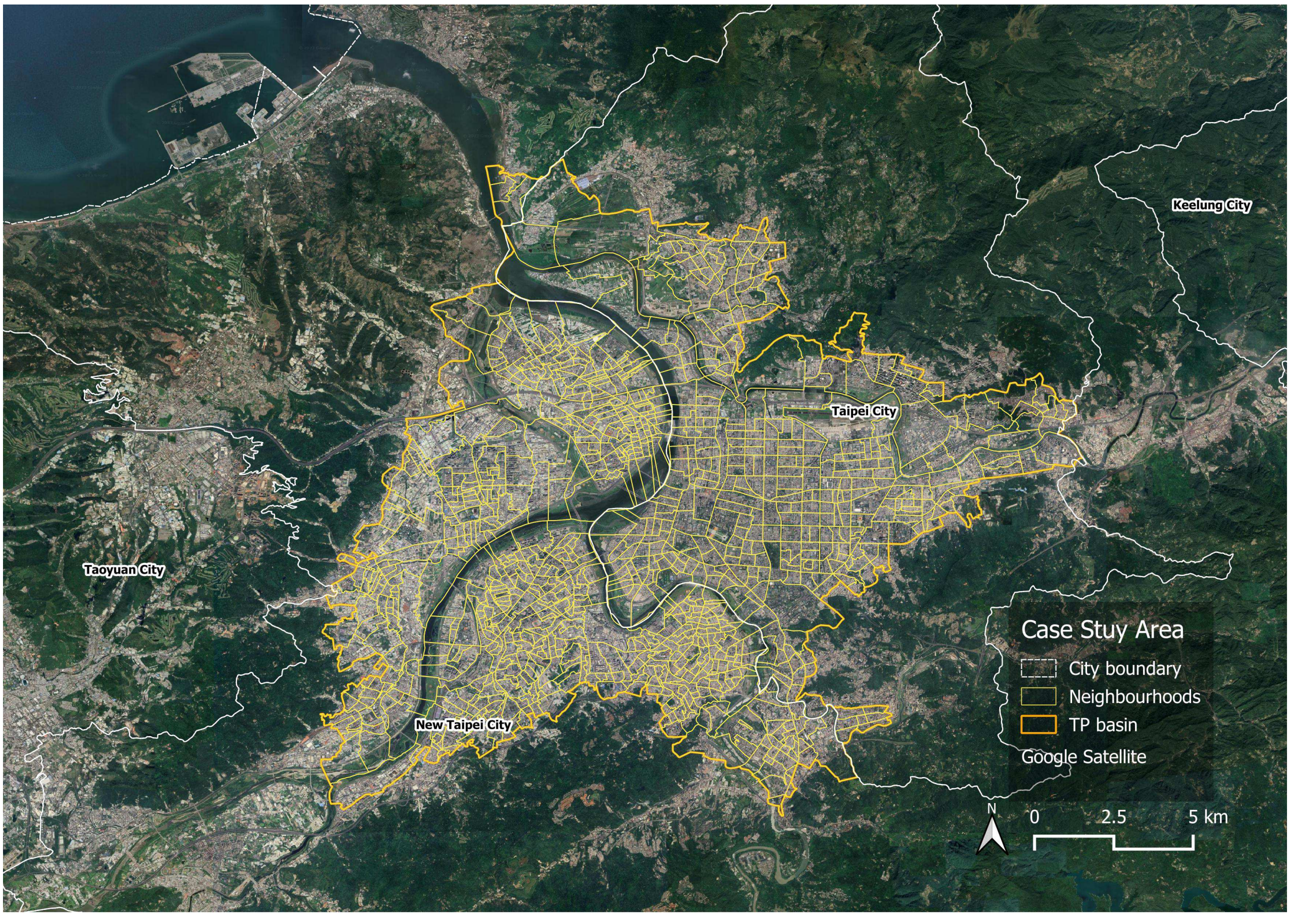

Fig. 1: The Location of Case Study Area.

4 DATA AND METHODS

4.1 Weather Data and Compilation

Weather information used for analyses was collected from 28 weather stations located either in the basin or on surrounding hills by the Central Weather Bureau in Taiwan. Daily records during June to September between 2011 and 2020 were retrieved in hourly basis. Twenty-one stations have completed data for ten-years, wereas 7 stations have less information spaning from 2 to 9 years. Data were aggregated to represent daytime (from 07:00 to 18:00) and night-time (from 19:00 to 06:00). Descriptive statistics were computed to produce mean temperature, average wind speed and major wind direction for further analysis and mapping.

4.2 Socio-economic Data

For understanding socio-economic conditions of across urban neighbourhoods, this study adopted aging index, education level and household income in 2020, which were gained from the Socio-Economic GIS platform of Ministry of the Interior in Taiwan Government. Aging index was calculated by the ratio of the elderly population (aged 65 years and over) to the younger population below 14 years old per hundred people. Education level is defined as the percentage of population holding a bacheloar degree and above. Household income was measured by median value of income within a given neioghourhood.

4.3 Green Space Interpretation

This study utilised high resolution satellite imagery from Sentinel 2 to interpretate the distribution of green spaces of the case study areas. The Sentinel imagery was acquired at 7:41am on 12 March 2019 from U.S. Geological Survey. Using the near-infrared and red bands, this study calculated the Normalized Difference Vegetation Index with equition of (NIR-R)/(NIR+ R) to identify the degree of greenness.

4.4 Spatial Statistics Analysis

In order to gain a spatially contineous weather information, spatial interpolation was used to generate mean temperature and average wind speed of unobserved areas between stations. Co-Kriging was applied for interpolation via Quantum GIS software, using the elevation of stations as an additional variable to refine the predition of average wind speed and temperature. Accordingly, both daytime and nighttime wind speed and temperature were visualised and extracted to be combined with the socio-economic attributes of each neighbouhood via the zonal statistic methods. These two sets of data were initially computed by IBM SPSS to assess the weight and the direction of their linear relationship using the Pearson correlation coefficient.

5 RESULT

5.1 Temperature variation of the cities

The highest average air temperature was observed around Shipai (30.92°C), followed by Shezih (30.82°C), Lujhou (30.72°C), Taipei (30.63°C), and Shihlin (30.62°C) during the day-time of June to Septemper. At night-time, higher temperature was found in Lujhou (28.48°C), Sanchong (28.20°C), Shipai (28.17°C), Sinzhuang (28.13°C) and Shihlin (28.13°C). Obviously, Shipai, Lujhou, Shihlin, which are located to the north of the basin, was covered by higher air temperature regardless of day- or night- time in summer.

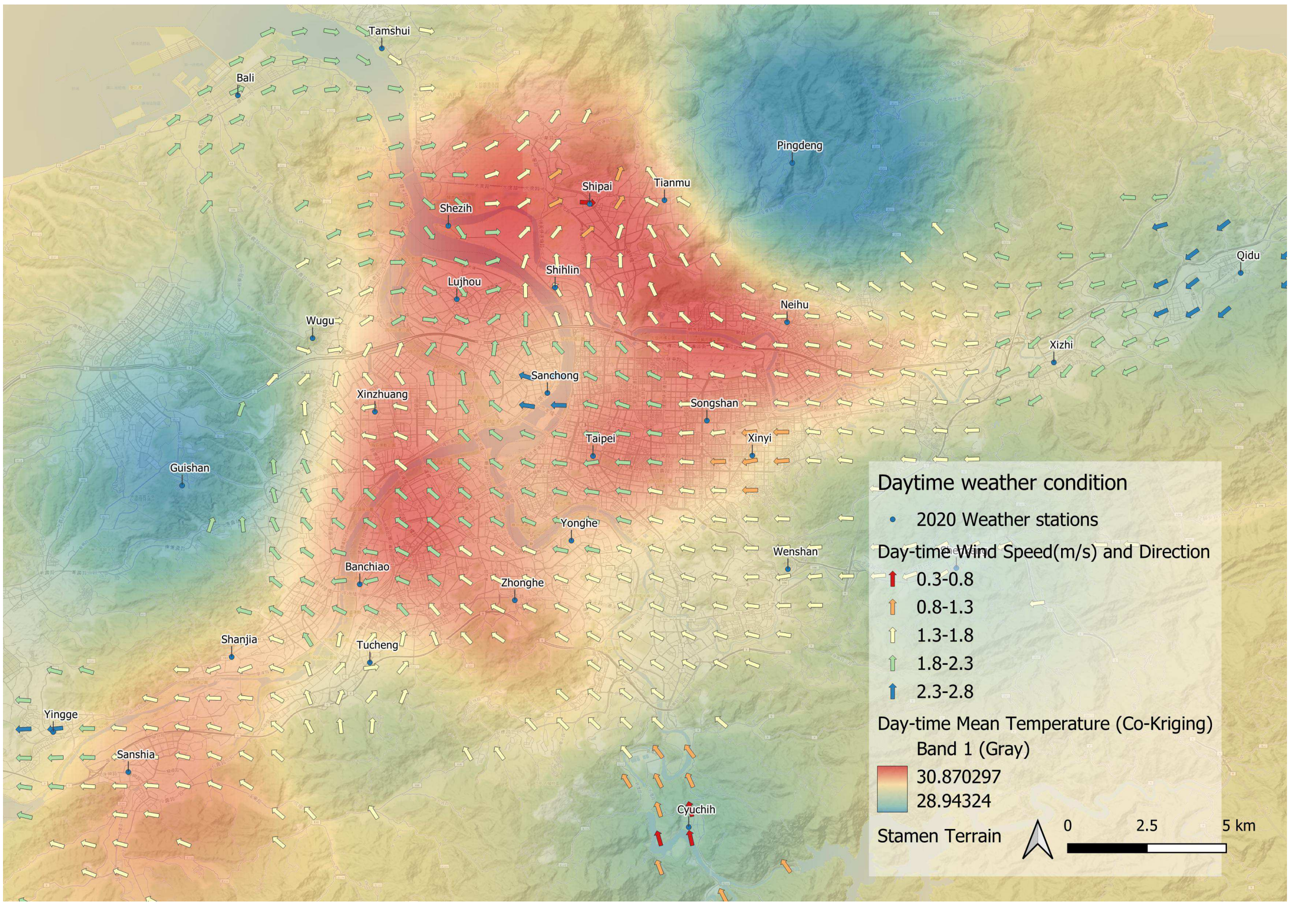

Fig. 2: Average air temperature and wind speed at day-time of Taipei Basin.

5.2 Spatial association between green infrastructure and air temperature

The correlation analysis between daily temperature and NDVI against urban neighbourhoods suggested a weak negative relationship between the degree of greenery and mean air temperature (r(889)=-.24, $p<0.001$) at a significant level in summer. However, the visualisation of the distribution of green spaces and mean air temperature showed that some suburban areas are subjected to higher temperature despite of greater green coverage. This is particularly obvious in Shezih, where has measured with the second highest temperature during the day. This phenomenon might be related to downwind heating as described below.

ISBN 978-3-9504945-2-5. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, H. R. KAUFMANN – Ljubljana, Slovenia

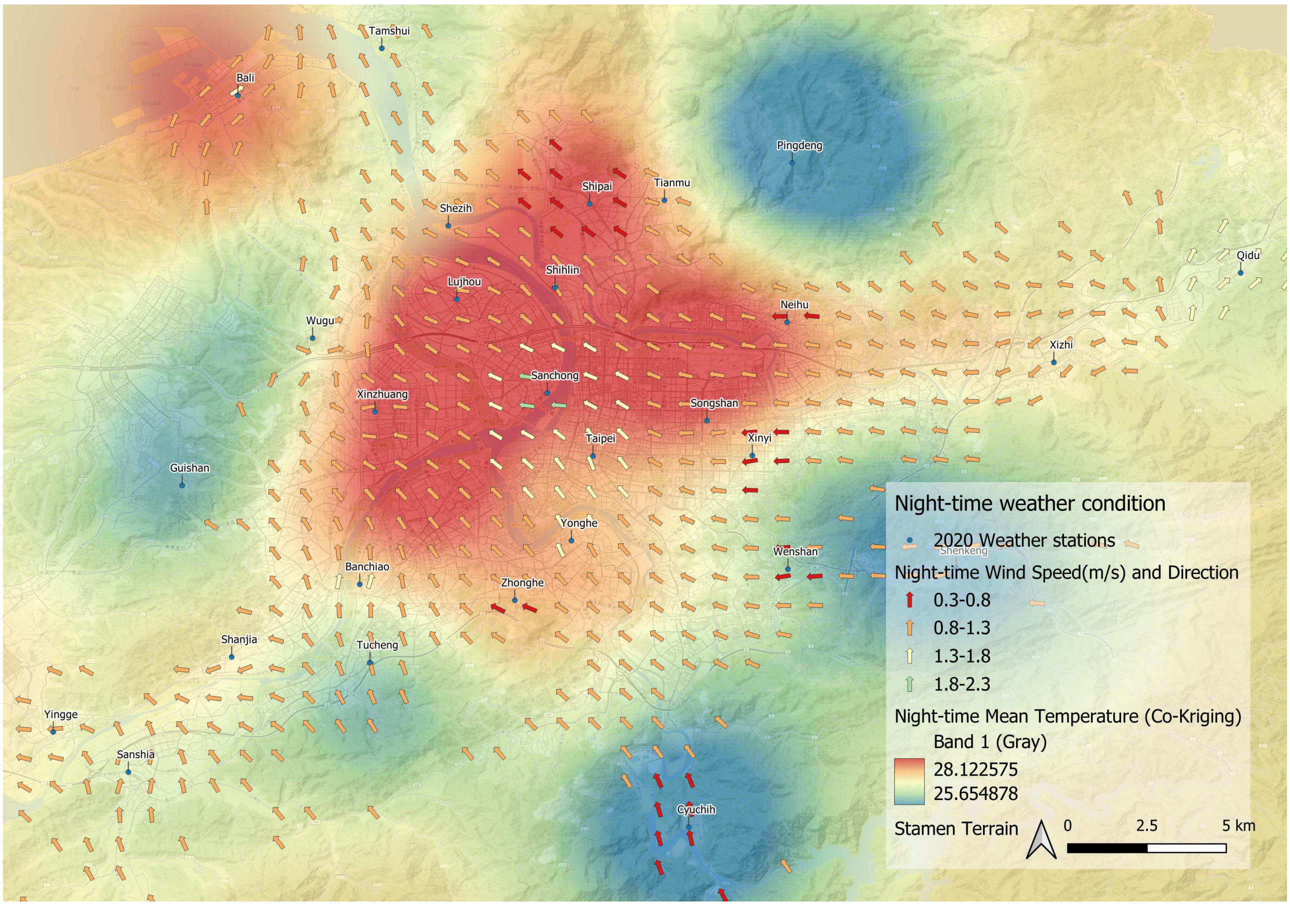

Fig. 3: Average air temperature and wind speed at nighttime of Taipei Basin.

5.3 Wind flows and influences on air temperature

The wind pattern showed a diurnal difference. Due to its closeness to the sea, a sea-land circulation was observed. Sea breeze from the North entred the basin through the Tamshui River and can reach Sanchong. According to the geogrpaphyical features of Taipei Basin and the analysis of prevailing wind in summer, the east side of the basin is strongly influenced by the wind coming from the Keelong River all day, whereas west side of the basin subjected to higher frequency of southeast wind.

The major downwind areas were identified as the Northern region of the basin, including Shihpai, Shezi, Shihlin, and Luzhou areas (Figures 2 and 3). During the day, the incoming sea-breaze from Tamshui River tended to encounter hot air from the city at this region (Fig. 2). This wind dynamic as well as the mountain barriers on the north may cause wind turbulence and stop hot air to be quickly discharged from the river valley. At the nighttime, land breeze from the south of mountains was more prevailing (Fig. 3). Yet the wind speed at night is relatively weak and might not be able to effectively bring hot air out of the basin from Tamshui River either.

Coversely, despite being the main air exit of the South-West side of the basin, areas around Shanjia, Sanshia, and Yingge along the Da-han river valley showed relatively low temperature. The air path displayed in Fig. 2 and 3 suggested that hot air from New Taipei City might turn northward and hence imposed less influence on this region. The fresh and cooler air joined from the southern hills might further cool down the valley. Overall, upwind areas are mostly cooler in summer.

5.4 Socio-economic association with weather conditions

Mean air temperature was negatively correlated with aging index, average household income, and education level at a weak but significant level. Mean wind speed showed a moderate and negative relationship with average household income and education level. This suggests socio-economic more deprived areas tended to live in environments that subjected to poor ventilisation. Some of them could be also hotter.

	Aging Index	Average Household Income	Education level

Mean Air Temperature	Pearson Correlation	-.109**	-.085**	-.179**
	Sig. (2-tailed)	.001	.007	.000
	N	991	991	991
Mean Wind Speed	Pearson Correlation	.064*	-.384**	-.409**
	Sig. (2-tailed)	.045	.000	.000
	N	991	991	991

Table 1: Correlation between weather conditions and socio-economic attributes. (**Correlation is significant at the 0.01 level (2-tailed; *Correlation is significant at the 0.05 level (2-tailed)).

The spatial distribution aging, average household income and education levels of neighghourhoods further showed that the downwind areas of Shezih is subjected to both higher summer temperature and lower socioeconomic status. Yet, although upwind area of Xinyi tended to be weathier, more educated, cooler, but have lower average wind speed. This complicated socio-environmental association might further connected to development characteristics of the areas.

6 CONCLUSION

This study spatially interpolated air temperature, wind speed, and prevailing wind direction to observe weather variation accross spaces of Taipei Basin. One of the findings from this assessment suggests upwind areas tended to be cooler whereas downwind areas of Northern basin were hotter in summer. This temperature distribution is attributeable to the specific topography of the basin which is more difficult to discharge hot air. The wind coming from city centre further brought hot air to the downwind areas and increase their temperature even they might be located in less developed suburban areas. The findings on temperature, greenery, and socio-economic association is to some extent consistent to previous studies suggesting socioeconomic disadvantaged areas are hotter. However, such socio-enviornmental relationship tended to be weak. It is noteworthy that poor ventilisation might be a more prominant factor in summer for socio-economically deprived areas.

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