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Conceptualizing Spatial Heterogeneity of Urban Composition Impacts on Precipitation Within Tropics

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Abstract: Urban composition has exacerbated precipitation patterns. Rapid urbanization with dynamic composition and anthropogenic activities lead to the change of physical environment, especially land-use and land cover which subsequently magnifies the environmental effects such as flash floods, extreme lightning, and landslides. Due to extreme and elevated temperature trends with exacerbated rainfall patterns, these environmental effects become major issues in tropics. Albeit several studies pointed out that rapid urbanization induced precipitation, studies about the heterogeneity of urban composition on precipitation variables are still limited. Thus, this paper review studies about precipitation pattern in relation to the heterogeneity of urban composition that successfully integrates geographical information system (GIS) and remote sensing techniques to enhance the understanding of interactions between precipitation patterns against heterogeneity of urban composition. This article also addressed the current state of uncertainties and scarcity of data concerning remote sensing techniques. Evidently, with a comprehensive investigation and probing of the precipitation variables in the context of urbanization models fused with remote sensing and GIS, they put forward powerful set tools for geographic cognition and understand how its influence on spatial variation. Hence, this study indicated a great research opportunity to set the course of action in determining the magnitude of spatial heterogeneity of an urban composition towards the pattern of precipitation.

Keywords: Heterogeneity of urban composition, precipitation forecasting model, precipitation patterns, urban form

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1. Introduction

About 55% of the world's population today lives in urban areas, and the proportion is expected to increase to 68% by 2050. On that account, rapid urbanization has increased the population in urban areas, gradually changing the physical urban environment. Rapid urbanization is a result of anthropogenic activities such as land use, deforestation, industrialization, and transportation which caused massive change in the urban composition. (Abd El-Hamid, 2020; Bherwani, Singh, & Kumar, 2020; Patra, Sahoo, Mishra, & Mahapatra, 2018; Sun, Gao, Li, Wang, & Liu, 2019) Intensive urban growth is believed to have disrupted the hydrological cycle, contributing to the increase in UHI, thus intensifying the magnitude of precipitation. It is interconnected in such a way that changes and increase in land-use area alters the annual temperatures that cause the alteration of precipitation patterns (Abd El-Hamid, 2020; Bherwani et al., 2020; Labedens, Scartezzini, & Mauree, 2018; Paul et al., 2018; M. Ren, Xu, Pang, Liu, & Du, 2020). Thus, the extreme dynamics of precipitation patterns contribute to flash flooding in the city since more natural landscapes have been replaced with impervious surfaces, resulting in the reduction in water infiltration into the ground and accelerating runoff to the streams. The study on the dynamics of the composition of urban planning in relation to precipitation is thus essential to improve future urban planning.

Major flash flood events for the past years (1926, 1996, 2000, 2001, 2002, 2003, 2004, 2006, 2007, 2008, 2010, 2011, 2013, 2014, 2015, 2016) in major cities have lately become a major concern (Buslima et al, 2018; D/iya et al, 2014). Arguably, floods are considered the most severe type of disaster in Malaysia. Massive flood control measures, structural and non-structural measures that are costly, have been proposed. Nevertheless, occurrences of flash flood events in cities are still rampant. Therefore, it is important to revisit the matters to achieve sustainability goals and balance urban growth and flood management. Flash floods have been extremely disruptive, leading to financial, environmental, and human losses. (Eni, Razali, & Maimun, 2020; Shah, Mustaffa, & Yusof, 2017; F. Tangang et al., 2017; Tun et al., 2015). According to (Ahmad, Ushiyama, & Sayama, 2017), intermittent and heavy rain coupled with the change of surface characteristics caused by rapid urbanization has increased the number of flood disasters.

The condition of urban climate is believed to be affected by the urban heat island (UHI) phenomenon, which has altered the meteorological phenomena in urban areas, including precipitation rates (Elsayed, 2012; Isa, Wan Mohd, Salleh, & Ooi, 2018). UHI is a phenomenon brought on by human activity and urbanization. It happens as land conversion within an urban region absorbs more heat, making the urban area somewhat warmer than its surrounds. Changes in surface characteristics cause accelerated climate warming and amplified heat waves because of this UHI phenomenon which later affect the precipitation intensity and frequency of pattern in different ways (Carter, Marshall Shepherd, Burian, & Jeyachandran, 2012; Hand & Shepherd, 2009; Jin, Kessomkiat, & Pereira, 2011; Marshall Shepherd, Carter, Manyin, Messen, & Burian, 2010; Mitra, Shepherd, & Jordan, 2012; Niyogi et al., 2011; Paul et al., 2018; Shepherd, 2013; Zhong et al., 2008) . The phenomenon of urban heat islands (UHI) is a distinct climate condition in Malaysia because it influences air quality and societal comfort (Salleh, Latif, Pradhan, Wan Mohd, & Chan, 2014). Different surfaces in urban areas act as a heat source and ele-vated temperature producing urban heat islands that exacerbate precipitation com-pared to non-urban regions. More studies by previous researchers (R. Jiang et al., 2020; Patra et al., 2018; Wei et al., 2020; Xu, 2019; Zhang, Villarini, Vecchi, & Smith, 2018) suggest that rapid urbanization increases water runoff and more extreme peaks as a result of substantial infiltration reductions but also affects the amount, frequency, duration, and intensity of heavy precipitation requiring further exploration. Therefore, a comprehensive urban composition study such as loss of green space, changes in land-use and land cover change, and waterbody analysis that affect urban precipitation may have broadened the scope of the study.

Even though it is recognised that urbanization is likely to cause a change in the precipitation pattern, some studies indicate that it may differ depending on the situation and climatic regime (Li et al., 2020; Liu & Niyogi, 2019). In Singapore's case, the precipitation was highly affected by sea breezes since the downwind part of Singapore is still precipitated over the upwind part (Li, Koh, Panda, & Norford, 2016). As depicted above, the amount of information obtained demonstrates a large variability. Since the goal is to understand the precipitation pattern in the direction of urban composition, simplifying the generic urban geometries would be better suited to the study.

Another case of extreme precipitation is Malaysia. The average precipitation is between 2000mm to 4000mm all over the region (Ahmad et al., 2017). Particularly along the coastline, where extreme rainfall and flooding can be expected during specific monsoons (Salleh, Abd Latif, Wan Mohd, & Chan, 2012) Nevertheless, Kuala Lumpur is understood to be a spatially heterogeneous city in Malaysia reported to receive maximum solar radiation; thus, the tendency to experience more extreme precipitation in the future (Ahmed, Mekhilef, Shah, & Mithulananthan, 2019) .Another study conducted by (Li et al., 2020) recently found an abnormal behaviour of precipitation in Kuala Lumpur (Ooi et al., 2018), which quantify the effects of urbanization on extreme rainfall and identified the potential mechanism for the extreme hourly rainfall intensities are enhanced as follows: -

i. In the late afternoon, the air above the urban surface, which is well heated during the day, has enough buoyancy to start rising.
ii. To replace this rising air, low-level air from the surrounding area converges and is heated by the city, which produces enough heat to sustain this circulation, and
iii. The rising tropical moist air condenses.

Therefore, rapid urbanization and precipitation variables has raised three important research questions:

i. How does the different heterogeneity affect the precipitation pattern?
ii. What are the interrelationships between urban composition heterogeneity and precipitation?

Numerous studies have attempted to examine land use and land cover changes using remote sensing and GIS techniques for data collection purposes. The images are obtained as sensors can manipulate, interpret, and visualize images captured. (Abd El-Hamid, 2020; Ibrahim, Samah, & Fauzi, 2014; Patra et al., 2018; Sharma, Chaudhry, & Singhai, 2017). However, restricted studies were carried out on the contribution of the heterogeneous urban area to the pattern of precipitation to a more systematic and comprehensive sustainable urban planning(Eni et al., 2020; Mei et al., 2020; Patra et al., 2018; C. Ren et al., 2012; Zhu et al., 2019) .In Malaysia, urban planning has long been practiced; however, it lacks a theoretical framework that synthesizes the diverse and essential aspects of heterogeneity (Bherwani et al., 2020; Eni et al., 2020; Ibrahim et al., 2014). It is recognized from the above literature that urban development subsequently changes land use and land coverage that has severely impacted rainfall intensification. Numerous studies have been carried out on the association between rapid urbanization and precipitation intensification. Still, minimal studies have yet to examine the heterogeneity in urban composition concerning the intensification of precipitation. This paper attempts to review all studies related to urban composition with the intensification of rainfall.

Urbanized landscapes are highly dynamic and complex with highly fragmented morphology that is heterogeneity in composition. Patterns of change differ in major cities and metropolitan cities. Therefore, a detailed inventory of landscape conditions and monitoring of change is needed to obtain reliable data for good decision making. However, urban heterogeneities and the impact of urban morphology cannot be represented by simple surface parameterization as it does not represent horizontal and vertical surfaces. Therefore, established methods in defining the reclassification of land use will be adapted accordingly (Labedens et al., 2018; Sharma et al., 2017; Xu, 2019).

Thus, this paper's rationale lies in analyzing the spatiotemporal urban dynamics over time, changes in precipitation patterns in terms of precipitation amount, precipitation frequency, mean precipitation intensity, and precipitation duration. It is essential to understand the context of rapid urban growth with environmental challenges such as vulnerabilities to natural events and climate change impacts. This paper provides an insight into possible methods to advanced techniques and capabilities in im-proving urban planning development and sustainable utilization of urban land use. Therefore, the availability of heterogeneity of urban composition data is necessary for a comprehensive environmental modeling study.

Wong, Yusop, & Ismail, (2018) used ground observations data obtained from Malaysian Department of Irrigation and Drainage (DID), Global Summary of the Day (GSOD), Global Telecommunication System of the World Meteorological Organization (WMO-GTS), and the Global Energy and Water Balance Experiment (GEWEX) research programme Asian Monsoon Experiment (GAME) archive. It clarifies the need to further study the climatic condition in Kuala Lumpur and further improve urban planning development.

Figure 1 presents the spatial variation of mean monthly temperatures of Peninsular Malaysia, divided into three decades of 1975-1984, 1985-1994, and 1995-2006. It is noted that Klang Valley encountered a higher degree of temperature between 0.35°C/decade to 0.5°/decade than in the northern and southern parts of the Peninsular. The mean temperature in Klang Valley is said to have increased approximately by 1.2° C warmer in a 20years period. Thus, the temperature rise may have caused by rapid urbanization and industrialization in Klang Valley (Wong et al., 2018). Therefore, it can be assumed that the rainfall intensity in Klang Valley is mainly due to local convection caused by intense heating of the land surface.

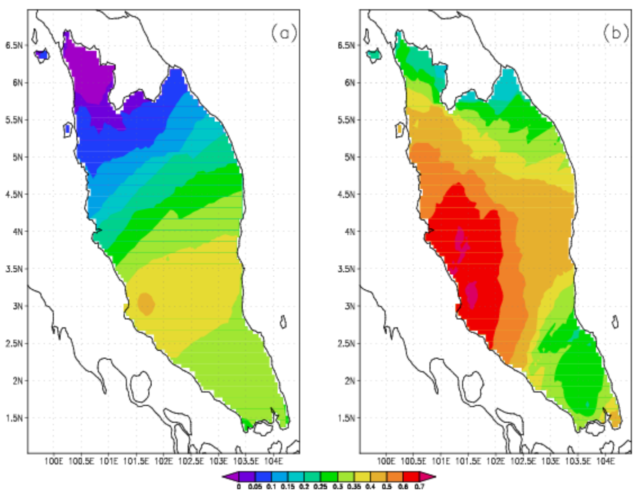

Fig. 1 - Decadal temperature between (a) differences between baseline 1975-1984 and intermediate decade 1985-1994 (b) differences between intermediate 1985-1994 and most recent decade 1995-2006. (Wong et al., 2018)

Malaysia is geographically located between two large oceans, the Pacific Ocean and the Indian Ocean, and these oceans intently influence its climate. Therefore, Malaysian climatology is strongly dominated by two monsoon regimes, namely the southwest monsoon (dry period) and the northeast monsoon (wet period) (Tangang et al., 2017) .The southwest monsoon commences in May, characterized by low-level south-westerly winds, while the northeast monsoon commences in November, characterized by the north-easterly winds; usually, both monsoons lasted for 3-4months (Fakaruddin, Yip, Mat Adam, Chang, & Abdullah, 2017).

Table 1 - Monsoon Rainfall Contribution in Peninsular Malaysia 1975-2006 (Wong et al., 2018)

Annual Rainfall (mm)	NEM (Nov -Mar) Rainfall		SWM (May - Sep) Rainfall		SWM (May - Sep) Rainfall	
	Mm	%	mm	%	mm	%
2243	1034	44	864	37	1898	81

A 31-years analysis carried out by Wong (Wong et al., 2018) indicated that both monsoons contribute 81% of the annual total rainfall over Peninsular Malaysia. In this study, 44% of the annual rainfall occurred during the North-East Monsoon (NEM) period, and 37% occurred during the Southwest Period.

Since there are two main seasons, namely Northeast and Southwest monsoon seasons, a comparison between wet and dry periods should be done to understand the relationship between radar reflectivity and rain rate.

According to Wong (Wong et al., 2018),the annual mean temperature trend of Peninsular Malaysia from 1975-2006, including both during monsoon seasons. There were increase temperature trends of 0.32° Celsius/decade and 0.31° Celsius/decade, respectively, over the 32 years. The warming trends were similar to those extracted from Tangang et al., (2012), indicating a trend of between 2.7-4.0° Celsius/years. The increased temperature of 0.3° Celsius/decade suggests a similar outcome to the simulation done by MMD and NAHRIM, where the country will be warmer at about 2° Celsius in the next 50 years.

Table 2 - Monsoon Rainfall Contribution in Peninsular Malaysia 1975-2006 (Wong et al., 2018)

	Observed	Projected (by 2050)
Temperature	0.6-1.2°C per 50years (1969-2009)	• 1.5-2°C increase
Rainfall (amount)	No appreciable difference	• (-) 5% to (+) 9% change in regions within PM • (-) 6% to (+) change in regions within Sabah and Sarawak
Rainfall Intensity	Increased by 17% for 1hour duration and 29% for 3hour duration (2000-2007 compared to 1971-1980)	• Increase in extremes within wet cyclesIncrease in frequency of extreme weather
Sea Level Rise (SLR)	1.3mm/year (1986-2006, Tanjung Piar, Johor)	• 0.5m rise (Global high worst case at 10mm/year)

Annual and both monsoons rainfall trends were extracted from (Wong et al., 2018)presented an increasing trend in the mean annual rainfall from 1975-2006. The study indicates that there are significantly 7mm/season/year of increasing trends during NEM seasons.

2. Material and Method

2.1 Urban Composition and Heterogeneity

The growth of urbanization alters the natural climate, sometimes known as the urban micro-climate. Some microclimate parameters are cause by natural factors at both the macro (latitude and continental position, for example) and mesoscale (water bodies, elevation gain or loss, natural land use, etc.) (Bailey, 1996; Bherwani et al., 2020). Critical factors affected UMC including urban, vegetation, water bodies, and urban (Ahmed et al., 2019; Bherwani et al., 2020).

With the increasing trends in urbanization and global warming patterns, it is crucial to consider microclimate trends as diverse regions with varying latitude, temperatures, and climate patterns (Shrestha, Thapa, & Gautam, 2019). Since the two primary energy sources, which are solar radiation and variation of solar energy, cause variables in the temperature of the region. Consequently, affecting regions' moisture content, temperature, and winds of the atmosphere. Other factors to take into account are the variation in the thickness of the atmosphere and the solar radiation and elevation and the undulating landscape, further affecting the vertical path of air in a locale as it produces variety in air motion.

Malaysia is located between 0° 51' to 6°43' in North latitude, and 99°38' to 119° 16' in east longitude (Ng, Adam, Inayatullah, & Kadir, 2014) indicates that Malaysia is located within the equilateral hot zone and humid tropical. It obtains a bundle of solar radiation (monthly average of 400-600MJ/m²) (Ahmed et al., 2019). Here, it is also important to consider precipitation variables with heterogeneous urban composition, as urbanization is known to exacerbate the evaporation and transpiration of surfaces, thereby altering the precipitation pattern (Figure 2).

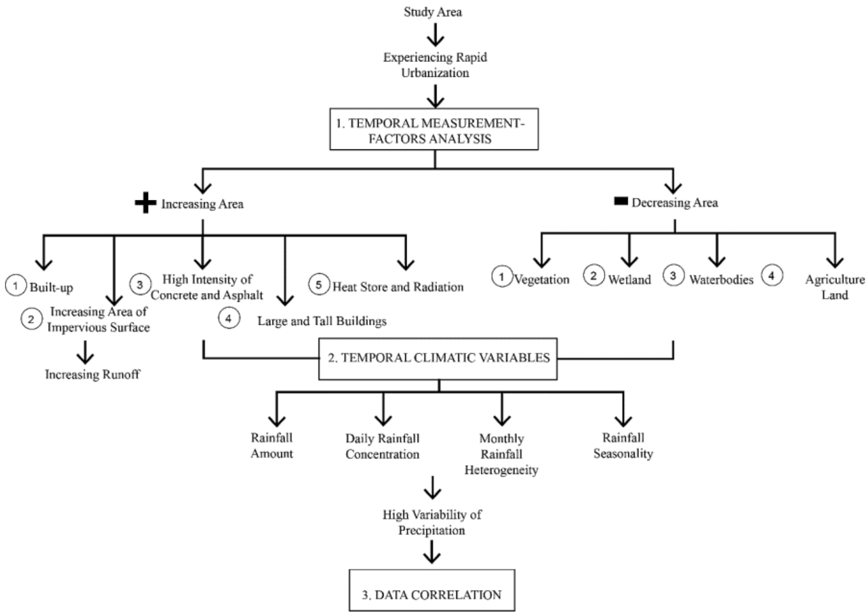

Fig. 2 - Identification of factors affecting the anomalies of rain precipitation due to the urbanization process (Modified after Patra (Patra et al., 2018))

The use of regional land is reflected in the degree of spatial heterogeneity. Social scientists, on the other hand, think of urban areas in terms of demographic and social factors like governmental and jurisdictional boundaries, spatial continuity, population density, and size, and certain socioeconomic indices of connection like commuter zones. As a result, the measures of LULC classification will be the sole focus of this study.

During various periods and geographical locations, heterogeneity in land use and land cover will show certain characteristics and differences that contribute to the uneven distribution of various concentrations within the region (He, Yu, Li, & Zhang, 2020; A. Jiang, Liu, Czarnecki, & Zhang, 2019; Qu, Jiang, Li, Shang, & Zhou, 2020; Song, Wang, Ge, & Xu, 2020). However, it is particularly challenging in heterogeneous tropical landscapes such as Kuala Lumpur. The characterization of these urban areas is usually derived from satellite images with defined LULC measures that have become the basis for analyzing many socio-ecological issues. The LULC change can later be quantified with different available software such as ERDAS and ENVI. Further, landscape metrics can be derived from the classified satellite images in FRAGSTATS software.

The development and widespread application of landscape metrics have characterized numerous landscape patterns. Landscape metrics consist of quantitative landscape indicators that have been expanded to quantify fundamental components of landscape patterns. To determine the impact of land-use difference, which can be related to urbanization, four landscape metrics are employed. Typically, area metrics, edge measurements, form metrics, and aggregation metrics are used to describe the spatial characteristics of urban landscapes, according to the literature patch density and mean patch size are the two measurements that makeup area metrics. The mean patch size is a useful metric for describing changes in the demography of urban areas because it corresponds to the pattern that is more concentrated and continuous throughout the city.

2.2 Precipitation Variables in the Context of Land Use and Land Cover Change

Several authors have pointed out the potential dangers of ignoring the precipitation pattern for global warming mitigation as it is accompanied by significant changes in land change and disturbances. This study's primary motivation is to analyses the heterogeneity of urban composition towards the pattern of precipitation in Malaysia. Hence, a study on local urban features, land use, and land cover to quantify the amount of precipitation needs to be performed to incorporate the correct values to be incorporated according to the land surface heterogeneity.

Table 3 - Spatial Heterogeneity in Land Use Land Cover Change-related study

No	Researchers/Criteria	Analysis	Data Source	Program
1	Guo et al. (2020) Impact of Urban Morphology and Landscape Characteristics on Spatiotemporal Heterogeneity of Land Surface Temperature.	The geographically weighted regression model explores the spatial heterogeneity of LST influencing factors.	Landsat TM Landsat OLI DEM	Landscape metrics using FRAGSTATS 4.2 software: Landscape indices for the land use in each grid 300x300m.
2	He et al. (2020) Exploring the Influence of Urban Form on Land-use Efficiency from A Spatiotemporal Heterogeneity Perspective: Evidence from 336 Chinese Cities	To Characterize Urban Form	Landsat TM Landsat ETM Landsat OLI	Landscape metrics: • area metrics (patch density, mean patch size) • edge metrics • shape metrics • aggregation metrics
3	Xu et al. (2019) Assessing the adaptive capacity of urban form to climate stress: a case study on an urban heat island Relationships with Large-scale Climate Oscillations in a Tropical Country, Singapore 1980-2018	Urban Form Calculation	IKONOS satellite data Digitisation of traditional land use maps ENVI software	Landscape indices • patch density • shape index • compactness • contiguity ENVI software to obtain land use information
4	Guo et al. (2020) Impact of Urban Morphology and Landscape Characteristics on Spatiotemporal Heterogeneity of Land Surface Temperature.	To assess habitat diversity and land cover change in a disturbance-dominated post-mining landscape.	Landsat TM Landsat ETM Landsat OLI ERDAS Imagine 9.1	Maximum Likelihood Classifier for landscape metrics. ERDAS Imagine 9.1 to obtain land use information
5	Labadens et al. (2019) Effects of Future Urban Planning on the Urban Heat Island Intensity	To obtain a significant morphology for the whole country	WRF MODIS Land Cover Classification	Satellite Images MODIS Land Cover Classification
6	Zhao et al. (2020) Spatiotemporal Characteristics of Urban Surface Temperature and Its Relationship with Landscape Metrics and Vegetation Cover in Rapid Urbanization Region.	Urban Form Calculation	The effect of land-use/landcover and landscape patterns on the urban thermal environment	Landscape metrics using FRAGSTATS 4.2 software ENVI software to obtain land use information
7	Tang et al. (2020) Linking Land-use Change, Landscape Patterns, and Ecosystem Services in Coastal Watershed of South-eastern China	To characterize and compares the land-use land cover change	Landsat TM Landsat ETM ENVI software	Landscape metrics using FRAGSTATS 4.2 software: Landscape metrics: • patch density • patch density of category I • area_mn • contagion index • shannon's diversity index

Table 4 - Precipitation Variables in the context of urbanization - related study

No	Researchers/Criteria	Region	Analysis	Concluding Remarks	Data /Scale	Methodology
1	F. Wei, et. al. (2020) Exploring the Driving Factors of the Spatiotemporal Variation of Precipitation in the Jing-Jin-Ji Urban Agglomeration from 2000 to 2015	Beijing, Tianjin, and Hebei, China	Quantitatively analyzed the dominant, interaction, and sensitivity factors that affect precipitation changes	Urbanization can enhance the explanatory power of spatial variation of urban precipitation through interaction with natural/meteorological factors, and all the dominant interaction factors show a nonlinear enhancement trend.	The meteorological data, such as precipitation, air relative humidity, average WIN, and so on, were collected from the historical monitoring data of the National Meteorological Center of China.	Linear Regression Analysis Geographic Detector
2	M. Ren, et. al. (2020) Spatiotemporal Variability of Precipitation in Beijing, China during the Wet Seasons	Beijing, China	To evaluate the changes in precipitation patterns in the context of global climate and urbanization	the average annual precipitation in wet seasons showed a downward trend, while the simple daily intensity index (SDII) showed an upward trend	Analyzed using up-to-date daily and hourly precipitation data from observation stations.	Linear Fitting Method, 5year moving average method Spatial Interpolation Mann-Kendall nonparametric test The Kriging Interpolation
3	R. Jiang et. al. (2020) Quantifying Precipitation Extremes and their Relationships with Large-scale Climate Oscilllations in a Tropical Country, Singapore 1980-2018	Singapore	To quantify the precipitation extremes in Singapore	the variability in precipitation extremes for the past several decades during the period of 1980–2018 in Singapore, and reveals possible climate change impacts of large-scale global climate oscillations on precipitation	twenty meteorological stations with the longest temporal coverage and fewer missing data	Precipitation Indices Mann-Kendall nonparametric test Pearson's Correlation and Wavelet Analysis
4	Y. Li, H. J. Fowler. D. Argueso, S. Blenkinsop, J. P. Evans, G. Lenderink, X. Yan, S. B. Guerreiro, E. Lewis, X. F. Li (2020) Strong Intensification of Hourly Rainfall Extremes by Urbanization	Kuala Lumpur, Malaysia	To examine changes to extreme rainfall intensities in urbanized Kuala Lumpur, Malaysia	hourly intensities of extreme rainfall have increased by ~35% over the last three decades, nearly 3 times more than in surrounding rural areas, with daily intensities showing much weaker increases.	Fifteen stations around Kuala Lumpur which have >80% data completeness for the period 1981–2011 were used. Hourly rainfall data was de-clustered by using only the maximum hourly intensity for each day to ensure event independence. Daily intensity was calculated by summing hourly intensities over each calendar day.	Q95index Mann-Kendall nonparametric test Weather Research and Forecasting (WRF) model
5	J. Liu, D. Niyogi (2019) Meta-analysis of urbanization impact on rainfall modification		A systematic meta-analysis	Urbanization modifies rainfall, such that mean precipitation is enhanced by 18% downwind of the city, 16% over the city, 2% on the left and 4% on the right with respect to the storm direction. The rainfall enhancement	Case studies versus climatological assessments, observational versus modelling studies and for day versus night	Quantitative assessment and analysis Storm behaviour during daytime and night-time events

				occurred approximately 20–50km from the city centre.		
6	L. Xu, et. al. (2019) Assessing the adaptive capacity of urban form to climate stress: a case study on an urban heat island	Xiamen City, China	Correlations between UHI and urban form and correlations among urban form indicators.	Using the statistically significant urban form indicators that were identified by the correlation analysis, a regression analysis model was built to investigate the effects of urban form on UHI	Calculation of urban form, the determination of climate stress and land use modelling. urban form drivers: urban planning aspects (e.g. population density, land use mix, road density and percentage of green open space) and landscape features (e.g. shape complexity, contiguity and compactness)	Urban Form Calculation Pearson Correlation Analysis
7	M. Wu, Y. Luo, F. Chen, W. K. Wong (2019) Observed Link of Extreme Precipitation Changes to Urbanization over Coastal South China	Coastal South China	Investigate changes in hourly precipitation	Statistically significant increase of hourly precipitation intensity leads to higher annual amounts of both total and extreme precipitation over the PRD urban cluster in the rapid urbanization period (about 1994–2016) than during the pre-urbanization era (1971 to about 1993), suggesting a possible link between the enhanced rainfall and the rapid urbanization.	Hourly precipitation data in 1971 to 2016 from 61 rain gauges are combined with historical land use change data	Landsat TM/ETM 95th percentile Man-Kendall Test F Test Tropical Cyclones Test Extreme Rainfall Events (EXREs)
8	S. Paul, S. Ghosh, M. Mathew, A. Devanand, S. Karmakar, D. Niyogi (2018) Increased Spatial Variability and Intensification of Extreme Monsoon Rainfall due to Urbanization	Mumbai, India	The intensification in rainfall is however prominent at few pockets of urban regions, that is seen in increased spatial variability.	Extreme precipitation will be reflected on station rainfall only when the stations are located inside the urban pockets having intensified precipitation	The WRF-MUCM simulations resemble the observed distributed rainfall. WRF-MUCM also produces intensified rainfall as compared to the WRF-SUCM and WRF-NoUCM (without UCM)	Weather Research and Forecasting (WRF) Single Layer Urban Canopy Model (WRF-SUCM) Multi-Layer Urban Canopy Model (WRF-MUCM)
9	X. Zhu, Q. Zhang, P. Sun, V. P. Singh, P Shi, C. Song (2018) Impact of Urbanization on hourly precipitation in Beijing, China: Spatiotemporal Patterns and Causes	Beijing, China	Changes in precipitation intensity, amount, duration, and timing were investigated, and extreme precipitation indices were defined by percentiles and consecutive precipitation processes	Results indicated that impacts on precipitation varied with the type of urbanization. Urban areas with the highest population density were dominated by the slightly longer precipitation duration, higher precipitation intensity and larger precipitation amount with lengthening consecutive dry days.	The hourly precipitation data from 20 automatic weather stations for a period of 2011–2015 were analyzed using the circular statistical analysis and grange causality test technique.	Precipitation Indices Classification of Precipitation Types K-means cluster analysis Circular statistical method

10	S. Siswanto, G. J. V. Oldenborgh, G. V. D. Schrier, R. Jilderda, B. V. D. Hurk (2016) Temperature, extreme precipitation, and diurnal rainfall changes in the urbanized Jakarta city during the past 130 years	Jakarta, Indonesia	Trends and variability in temperature, extreme precipitation, and changes in the diurnal cycle over Jakarta have been analyzed.	The increase in the daily maximum temperature is stronger than the increase in mean and minimum temperature, although the trend in minimum temperature is stronger during the last 50 years. The mean diurnal cycles of Jakarta temperature and precipitation have changed markedly as well	Using a newly available 134-years long record of daily and 114-years hourly observations at Jakarta observatory	Standard normal Homogeneity Test (SNHT) The Petit Test The Buishand Range Test The Von Neumann Test

Numerous researchers have proven that rapid urbanization has induced precipitation variables and risk developing cities (Table 4). Confronted by this challenge, it is pivotal for urban planners to understand the future risk of their planning to adapt to climate stress. In this study, it is found that the integration of remote sensing ang GIS - in assessing the heterogeneity in urban composition to precipitation variables is viable.

Most of the researcher utilises rainwater station gauge data to measure rainfall intensities and amounts (Buslima, Omar, Jamaluddin, & Taha, 2018; Malek, Zayid, Ahmad, Ya'Acob, & Bakar, 2020; Mei et al., 2020; Safiah Yusmah et al., 2020) .And most rainfall data have been calculated using the nearest rank method of 95th percentile. The definition is that the number of observations is enormous, and the probability distribution is continuous. P-th percentile is often given in the text to sort from least to the greatest value. It is obtained by calculating the ordinal rank (n) using the formula below:

$$\boldsymbol{n = \frac{P}{100} \times N} \quad (1)$$

The most common correlation used in the above studies are Pearson correlation and Kendal rank correlation. Correlation is an analysis to measure the strength of association between two variables and the relationship's direction. The value varies between 1 and -1 in determining the strength of the relationship. The goal of using any of these methods is to be lightweight, easy to use, that allows computation of many different kinds of correlations. The formula are as follows: -

i. Pearson's correlation: The most common correlation method. It corresponds to the covariance of the two variables divided by the product of their standard deviations. (https://easystats.github.io).

$$\boldsymbol{r_{xy} = \frac{cov\,(x,y)}{SD_x \times SD_y}} \quad (2)$$

ii. Pearson's correlation: The most common correlation method. It corresponds to the covariance of the two variables divided by the product of their standard deviations.

$$\boldsymbol{T_{xy} = \frac{2}{n(n-1)} \sum_{i<j} \quad sign(x_i - x_j) \times sign\,(y_i \times y_j)} \quad (3)$$

3. Result and Discussion

3.1 Application of Remote Sensing and GIS

Data collection on Land Use and Land Cover (LULC) at various spatiotemporal scales, remote sensing has been extensively used. However, the temporal frequency and the spatial resolution are often sacrificed when choosing remote sensing data for a large-scale and long-term LULC. Gaofen-6 satellite imaging does provide detailed information; however, the expense is high for repeated observations over a wide area (Ai, Zhang, Chen, & Li, 2020). Other sensors such as NOAA-AVRHH and EOS-MODIS, however, provides high temporal frequency and wide coverage, but its spatial is too course for detailed tracking of LULC variability (Vogelmann, Gallant, Shi, & Zhu, 2016). Due to continuous image acquisition by Geographical Survey Landsat (GSC) satellites of the Earth's land surface, data on the gravitational field and other physical parameters that are not present in conventional data are now available. There have been 8 Landsat spacecraft with various sensor types in total. The types are as follows: -

Table 5 - Showing types of Landsat satellites (Source: http://gsp.humboldt.edu/)

Satellite	Launch	Decommissioned	Sensors
Landsat 1	July 23, 1972	January 6, 1978	MSS/RBV
Landsat 2	January 22, 1975	July 27, 1983	MSS/RBV
Landsat 3	March 5, 1978	September 7, 1983	MSS/RBV
Landsat 4	July 16, 1982	June 15, 2001	MSS/TM
Landsat 5	March 1, 1984	2013	MSS/TM
Landsat 6	October 5, 1993	Did not achieve orbit	ETM
Landsat 7	April 5, 1999	Operational	ETM+
Landsat 8	February 11, 2013	Operational	OLI/TIRS

Data from Landsat 4, 5, 7, and 8 is crucial if the study requires analysis of spatiotemporal changes. Different sensors consist of various spectral bands that range in different colour wavelengths with a different spatial resolution. The brief explanation of the sensors are as follows:

1. *Multispectral Scanner (MSS)*
   The Landsat Multispectral Scanner (MSS) images consist of four spectral bands ranging from the visible green to the near-infrared (IR) wavelengths with 60m spatial resolution.
2. *Thematic Mapper (TM)*
   It is an instrument consist of seven spectral bands with a spatial resolution of 30m for band 1 to 5 and 7
3. *Enhanced Thematic Mapper*
   Enhanced Thematic Mapper Plus (ETM+) includes a panchromatic band (Band 8) with increase spatial resolution at 15m.
4. *Operational Land Imager (OLI)*
   Operational Land Imager (OLI) measures in the visible, near infrared, and short- wave infrared positions of the spectrum.
5. *Thermal Infrared Sensor (TIRS)*
   Thermal Infrared Sensor (TIRS) measures land surface temperature in two thermal bands with a technology that applies quantum physics to detect heat.

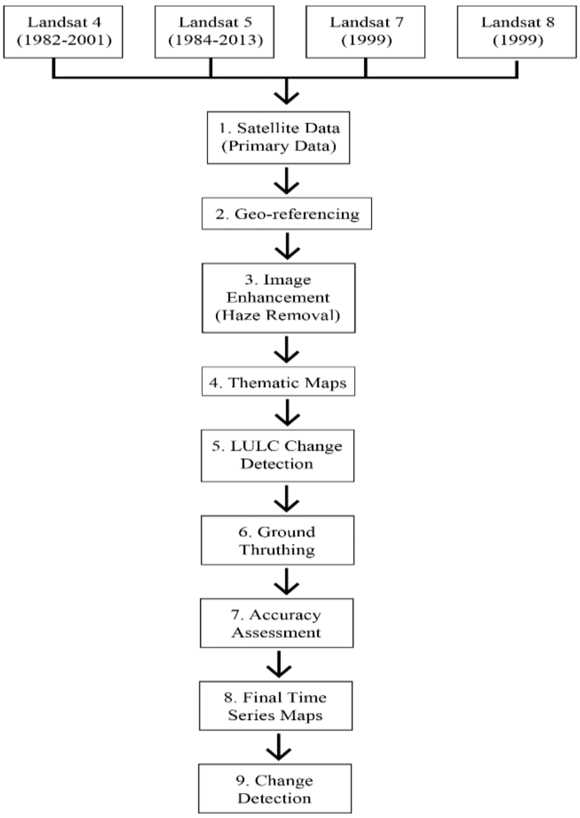

Fig. 3 - Flow Diagram of the Land Use Land Cover Extraction (Adopted from Sharma (Sharma et al., 2017))

Satellite images will be interpreted to obtain the land use information (Figure 3). Subsequent, spatial data in urban areas will be simplified into 13 types, adopted method from (Shou, Gao, & Lu, 2020) (Table 6) as urban form can be too complicated, and the data is mere to prove the analysis. Based on the land use data, the landscape metric to be analyzed using FRAGSTATS and ArcGIS software. The urban form comprises physical patterns, layouts, and structures that structure the urban environment. Therefore, the urban form is expected to be quantified from the perspective of urban planning and landscape ecology. The most classic indicators are population density, land use mix, road density, and green open space percentage. Numerous studies have been conducted on rain precipitation using remote sensing technology in collecting rainfall data, such as Tropical Rainfall Measuring Mission (TRMM), Himawari, GSMap, and USA Goes-16. These meteorological satellites provide continuous atmospheric observations and monitoring for weather and a wide variety of environmental phenomena. However, TRMM is the only satellite that provides the longest data available.

Table 6 - Land Use Re-classification using ENVI software

<table>
<tr><th>No.</th><th>Original Land Use Type</th><th>Re-classified Land Use Type</th><th>Class Number</th></tr>
<tr><td>1</td><td>Forest</td><td>Forest</td><td>1</td></tr>
<tr><td>2</td><td>Farmland</td><td>Farmland</td><td>2</td></tr>
<tr><td>3</td><td>Commercial Land</td><td rowspan="4">Commercial Land</td><td rowspan="4">3</td></tr>
<tr><td>4</td><td>Land for Business Affair</td></tr>
<tr><td>5</td><td>Entertainment Supporting Land</td></tr>
<tr><td>6</td><td>Other Service Facilities Land</td></tr>
<tr><td>7</td><td>Industrial Land</td><td>Industrial Land</td><td>4</td></tr>
<tr><td>8</td><td>Warehouse Land</td><td>Warehouse Land</td><td>5</td></tr>
<tr><td>9</td><td>Urban Residential Land</td><td>Urban Residential Land</td><td>6</td></tr>
<tr><td>10</td><td>Rural Residential Land</td><td>Rural Residential Land</td><td>7</td></tr>
<tr><td>11</td><td>Administrative Land</td><td rowspan="7">Public Services and Administration</td><td rowspan="7">8</td></tr>
<tr><td>12</td><td>Cultural Facilities Land</td></tr>
<tr><td>13</td><td>Education & Research Land</td></tr>
<tr><td>14</td><td>Sport Land</td></tr>
<tr><td>15</td><td>Medical and Health Land</td></tr>
<tr><td>16</td><td>Municipal Utilities</td></tr>
<tr><td>17</td><td>Other Public Supporting Facilities Land</td></tr>
<tr><td>18</td><td>Green & Square Land</td><td>Green Space</td><td>9</td></tr>
<tr><td>19</td><td>Road</td><td rowspan="3">Road</td><td rowspan="3">10</td></tr>
<tr><td>20</td><td>Railway</td></tr>
<tr><td>21</td><td>Highway</td></tr>
<tr><td>22</td><td>Intercity Transportation Land</td><td>Intercity Transportation Land</td><td>11</td></tr>
<tr><td>23</td><td>Water</td><td rowspan="2">Water</td><td rowspan="2">12</td></tr>
<tr><td>24</td><td>Ocean</td></tr>
<tr><td>25</td><td>Specially designated Land</td><td rowspan="2">Other</td><td rowspan="2">13</td></tr>
<tr><td>26</td><td>Unused Land</td></tr>
</table>

3.2 Tropical Rainfall Measuring Mission (TRMM) Satellite Precipitation Data

The utilisation of satellite radar data as a calibrator for ground radar as the time of sample taken may differ. The cloud moving vector algorithm cannot correctly estimate the development of the precipitating cloud. Tropical Rainfall Measuring Mission (TRMM) satellite as an alternative to conventional rain gauge measurement. Data retrieval for many regions worldwide seems to be a potential. However, for a local scale, rainfall is contentious due to inherent uncertainties (Mahmud, Numata, Matsuyama, Hosaka, & Hashim, 2015). According to Mahmud et al., the uncertainties to the rain rate to the effective temporal scale such as:

i. The insensitivity of the TRMM precipitation algorithms to low and high precipitation clouds.
ii. The course grid size of the TRMM data for resolving local rainfall patterns. Therefore, it is recommended to use the rain gauge data to measure rainfall at the micro-level.

3.3 Rain Gauge Data

Rain gauge data is typically used for data validation measurement depicted from remote sensing satellites. Rain gauge data contain consistent historical data and measurement of data at the micro-level. A total of 984 rain gauges covering entire Peninsular Malaysia (Mahmud et al., 2015) can be obtained from the Malaysia Department of Irrigation and Drainage. Vast amounts of rain gauge data can be collected to provide a high resolution of rainfall information at both spatial and temporal scales. The rain gauge will be conducted daily with 24hr observation.

3.4 Mean Precipitation Over an Area

Rain gauges represent a one-point sampling of the areal distribution of storm. In determining the rainfall intensity and frequency in a heterogeneity land use, it is required to convert the rainfall gauge station's point into a value average over a catchment. There are three methods in total use to calculate the value average which is i) Arithmetic mean method, ii) Thiessen-polygon method, and iii) isohyetal method (Ribeiro, Almeida, Cox.. et al., 2021).

i. Arithmetic mean method

This method is rarely used in practice. The average precipitation over the catchment area is taken as the arithmetic mean of the station values using the method.

$$\underline{\boldsymbol{P}} = \frac{\boldsymbol{P_1+P_2+\cdots Pi+\cdots Pn}}{\boldsymbol{N}} = \frac{\boldsymbol{1}}{\boldsymbol{N}}\sum_{\boldsymbol{i=1}}^{\boldsymbol{N}} \quad \boldsymbol{Pi} \qquad (4)$$

$\underline{P}$ = Average of a series of numbers
P_1 = Series of numbers
N = The count that series of numbers

ii. Thiessen-polygon method

The rainfall recorded at each station is given a weightage based on the area closest to the station. The procedure in determining the area is by joining all the stations to form a network of triangles. Then, bisectors perpendicular to the triangles are drawn to create a polygon around each station. Thiessen-polygon method is preferable to the arithmetical mean method because some weightage is given to the various stations on a rational basis. Furthermore, the rain gauge outside the selected site area will be used effectively.

$$\underline{\boldsymbol{P}} = \frac{\boldsymbol{P_1A_1 + P_2A_2 + \cdots + P_mA_m}}{\boldsymbol{A_1 + A_2 + \cdots + A_m}} \qquad (5)$$

$\underline{P}$ = Average of rainfall all over the catchment
P_1 = Series of stations with rainfall values
A_1 = The areas of the respective thiessen polygons

iii. Isohyetal method

It is considered one of the most accurate methods, but it depends on the analyst's skill and experience. It requires the plotting of isohyet, a line joining the points of equal rainfall magnitude and calculating the areas enclosed either between the isohyets or between an isohyet and the boundary. The area between the two adjacent isohyets is then determined with a planimeter.

$$\underline{\boldsymbol{P}} = \frac{\left[\boldsymbol{a_1}\left(\frac{\boldsymbol{P_1+P_2}}{\boldsymbol{2}}\right) + \boldsymbol{a_2}\left(\frac{\boldsymbol{P_2+P_3}}{\boldsymbol{2}}\right) + \cdots + \boldsymbol{a_{n-1}}\left(\frac{\boldsymbol{P_{n-1}+P_n}}{\boldsymbol{2}}\right)\right]}{\boldsymbol{A}} \qquad (6)$$

$\underline{P}$ = Average of rainfall over the catchment
P_1 = Rainfall values corresponding to the isohyets
A_1 = Corresponding interisohyetal areas

Table 7 - Comparisons Between Methods for Calculating Average Rainfall

Arithmetical mean method	Arithmetical mean method	Isohyetal method
i. Assumes uniform rainfall distribution. ii. Very seldom occurs. iii. The easiest way to use but less accurate	i. Assumes linear variation. ii. Uses when gauges are not uniformly distributed. iii. Can use gauges outside the watershed. iv. Commonly used for flat and low rugged areas	i. Assumes linear variation. ii. Uses when gauges are not uniformly distributed. iii. Can use gauges outside the watershed. iv. The most accurate method if the contours are drawn correctly. However, to obtain the best results, good judgment in drawing the

	isohyets and assigning the proper mean rainfall values to the area between them is required.

In conclusion, the isohyetal method allows judgment in drawing a contour map. Accuracy is dependent mainly on the person performing the analysis and the number of gauges. In comparison, the Arithmetical mean method uses simple linear interpolation. The advantages can be combining both methods where the area close to the gauge is defined by linear interpolation. The rainfall over the area is determined from the isohyetal method. It will also eliminate when analyzing several different storm events with a variety of different gauges.

4. Discussion and Conclusion

Studies on the precipitation patterns and urban expansion have been fully explored. However, little emphasis has been made on the heterogeneity of the urban composition and precipitation pattern. Heterogeneity of the urban composition of the Intended study will be in the context of physical and spatial differentiation. Past studies have proven that urban modification does affect the intensity and frequency of precipitation events. The intended study seeks to further explore the change in the urban modification with respect to physical and spatial differentiation and their relations to the intensity and frequency of precipitation events at the micro level. As shown in Figure 4, the gaps and opportunities can be classified into three categories: input, solution, and application. Acknowledging the diverse spatial characteristics and their impact on precipitation patterns is recognized as a crucial aspect in the field of urban microclimate research. Consequently, this presents a new avenue for enhancing urban climate management through the integration of mapping techniques and the incorporation of factors that influence precipitation patterns. This approach offers the potential for refining existing solutions and serves as a valuable reference for revising urban planning policies or facilitating sustainable urban development, where applicable.

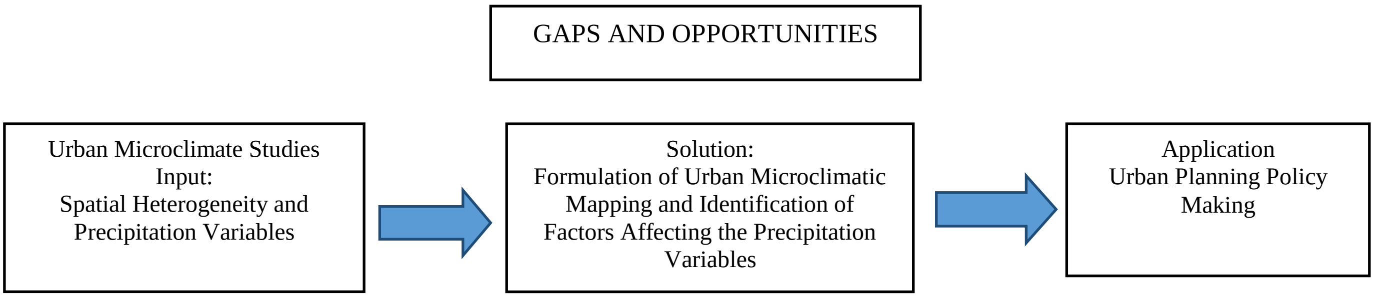

Fig. 4 - Gap and Research Opportunity

In the unparallel era of growing urbanization, ‘The New Urban Agenda’ (NUA) has reached a consensus on the urban planning as an incentive for cities in achieving the positive outcomes of urbanization, pursuant to the ‘2030 Agenda for Sustainable Development’. It will present a paradigm shift based on the science of the cities by re-addressing the manner in which cities and human settlements are planned, designed, and developed.

The massive expansion of urban features and changes in the water bodies, vegetation, cultivation has led to a change in the precipitation variables. Rapid development has threatened the sustainability of the development process by affecting critical environmental components like rainfall. Therefore, it is necessary to develop a systematic and comprehensive planning for the sustainable development of the cities. An integrated approach to urban planning is to ensure that the conditions are monitored at the micro-level.

This paper sought to examine the current progress and research that look into the composition of urban heterogeneity, focusing on the urban variables and their impacts on precipitation. Past researchers have focused on urban form calculation, land use land cover analysis to climate stress and LST. However, limited studies have focused on the urban-precipitation heterogeneity analysis. Although the complexity of the process may be difficult to model and uncertainties exist, the impact of the heterogeneity and understanding the process associated with urbanization are essential. Study and convergence of current research fields may therefore strengthen our understanding of the changes which will facilitate the development of planning strategies and to minimize the negative impacts of future urban growth.

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