The Accuracy of LCZ maps Generated by the World Urban Database and Access Portal Tools (WUDAPT) Method: A Case Study of Hong Kong

Chao REN[1, 2, 3] *, Ran WANG[2], Meng CAI[2], Yong XU [2] , Yinsheng Zheng[1], Edward Ng[1, 2, 3],

1. School of Architecture, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong
2. The Institute of Future Cities(IoFC), The Chinese University of Hong Kong, Shatin, N.T., Hong Kong
3. The Institute of Environment, Energy and Sustainability(IEES), The Chinese University of Hong Kong, Shatin, N.T., Hong Kong

* *Corresponding Author*

Abstract: The Urban Heat Island (UHI) is a hot topic, especially in Asian cities, because their booming economics and rapid urbanization have intensified the UHI effect. The Local Climate Zone (LCZ) scheme was developed by Stewart and Oke to provide researchers worldwide with a standard way to conduct urban heat island studies. Recently, the World Urban Database and Access Portal Tools (WUDAPT) and its level 0 method have emerged as new initiatives to generate LCZ maps of cities around the world by using free online resources.

Hong Kong is a high-density city with its own complex urban morphology types and characteristics. It was therefore selected as a case study to examine whether or not the WUDAPT level 0 method is applicable to high density cities. In this paper, the preliminary results from adopting the WUDAPT level 0 are given. Three versions of a Hong Kong LCZ map have been developed to check and understand the following issues: 1) to check the overall accuracy of LCZ classes of the WUDAPT Level 0 product; 2) to find out the accuracy of detected built up areas of Hong Kong (mainly LCZ 1- 6); 3) to find out how the training sample's size (or selecting area) affects its corresponding LCZ class accuracy; 4) to evaluate the WUDAPT level 0 method's performance. The study results can help other researchers of high density cities to understand the WUDAPT's advantages and limitations better, and also further develop the WUDAPT Method.

Keywords: WUDAPT (World Urban Database and Access Portal Tools), Local Climate Zone (LCZ), High Density Cities, Accuracy Comparison, Urban Heat Island (UHI)

1. Introduction

The Urban Heat Island (UHI) effect is regarded as one of the significant characteristics of urbanization with the economy booming in the 21st century (Wang & Bai, 2008). Researchers around the world have conducted UHI studies using their own scientific methods, but there was a lack of an international standardized research approach for UHI studies until the Local Climate Zone (LCZ) concept was developed by Oke and Stewart (2012). The LCZ system generates a climate-oriented classification of metadata (Stewart & Oke, 2009). It not only includes a set of representative parameters describing local urban morphology, but also associates the corresponding UHI effect. Due to the standardized LCZ definition and classification hierarchy, this new system can easily be adopted in a UHI study for one city, but also can be used for comparison of different UHI studies of several cities.

Since 2012, a new initiative named World Urban Database and Access Portal Tools (WUDAPT) has been developed to generate LCZ maps and collect urban morphology data of the world

(Mills *et al.*, 2015). It takes advantages of free data sources, uniform development procedures, easy manipulation and an open-source results database.

This paper focuses on discussing whether or not the WUDAPT level 0 method is applicable to high density cities, and exploring its limitations and advantages. Hong Kong was selected for a case study on high density cities. This study aims at: 1) generating an LCZ map of Hong Kong according to the standardized procedure of the WUDAPT method; 2) comparing different versions of LCZ maps using different sets of training samples in order to detect the influence of training sites on the final LCZ map with the help of confusion matrices and statistics; 3) evaluating the adoption of WUDAPT method to carry out LCZ mapping of Hong Kong, and point out its limitations in a high-density city as well as putting forward future work on LCZ mapping by using the WUDAPT method. The study results can help other researchers of high density cities to understand the WUDAPT method's advantages and limitations better, and also further develop the WUDAPT method.

2. Literature Review

2.1 Local Climate Zone (LCZ)

Since the UHI phenomenon was first documented by Howard in 1818, many researchers around the world have conducted studies to capture and understand their own city's UHI effect. However, there was no standard method to follow. Local Climate Zone (LCZ) is a newly-developed concept which aims at linking land use types with their corresponding UHI effect directly (Stewart and Oke, 2012).

The LCZ scheme adopts urban land use types in detail on the basis of the thermal properties of different types of land covers, and provides researchers with a standard quantitative method to describe the physical properties of urban morphology and explain their corresponding urban climatic properties (Stewart & Oke, 2009; 2010). Thus, there are seventeen types of LCZ. Ten of them are building types (LCZ 1-10) and seven are land cover types (LCZ A-G). Determining factors of each LCZ class consist of sky view factor (SVF), aspect ratio, building surface fraction, impervious surface fraction, pervious surface fraction, height of roughness elements and terrain roughness class (Stewart & Oke, 2009). According to the LCZ scheme, different cities can be classified and their own LCZs can be generated after analyzing the land use types, morphology features and functions. All are in the same system to study the UHI phenomenon.

Since 2012, urban climatologists have done a series of studies using different manipulation methods in order to develop the LCZ classes for their own cities. The main methods are manual sampling, Geography Information System (GIS)-based method and object-based image analyzing method (Bechtel & Daneke, 2012; Gamba et al., 2012; Lelovics, Unger & Gál, 2014; Mitraka, Del Frate, Chrysoulakis & Gastellu-Etchegorry, 2015; Bechtel et al.,2015). However, some principal limitations of each can be found:

1) Manual sampling method. : This requires operations staffs equipped with lots of related professional knowledge and they must be very familiar with local areas. This method cannot be widely spread to be easily adopted by other researchers. It also potentially decreases the accuracy of classification.
2) Conducting a GIS-based method. This requires obtaining precise GIS data of the targeted city for calculating the value of determining factors of each LCZ class. Normally its results can reach high accuracy, but the limitation is that GIS data is not complete and available for not every city.

3) Object-based image analyzing method. Remote sensing images are collected and used to extract LCZ classes by analyzing their own spatial and spectral data. Where higher resolution remote sensing images can be collected, higher accuracy LCZ classification can be achieved. However, a high cost would be expected. Also the data processing can be complicated and required advanced remote sensing knowledge.

2.2 The World Urban Database and Access Portal Tools (WUDAPT)

To achieve a simple procedure, using free data sources and easy application of LCZ classification, a new satellite image-based method, the World Urban Database and Access Portal Tools (WUDAPT) has been developed (Bechtel et al., 2015). The WUDAPT is an international collaboration program, targeting at collecting, storing and processing worldwide urban climate data as well as providing government officials, scholars, architects and planners with reference data and maps so as to assisting relevant studies, policy-making and urban planning (Mills, Ching, See, Bechtel & Foley, 2015). The WUDAPT aims to provide users with three levels of product. The Level 0 product is relatively rough LCZ maps with multi-category information; The Level 1 product has much more accurate prediction data and possibly spatial distribution of specific information, but still contains coarse estimation; and the Level 2 product provides the most accurate information about urban morphological characteristics (Mills, Ching, See, Bechtel & Foley, 2015). Up to now, worldwide researchers' effort has mainly focused on the WUDAPT Level 0 method and product.

The general process of generating a LCZ map by using the WUDAPT method includes three steps (Figure 1). 1) Remote sensing images are collected and processed by remote sensing software; 2) Google Earth is used to select training samples for later LCZ classification; and 3) LCZ classification is conducted using a piece of geographic information processing software called SAGA GIS.

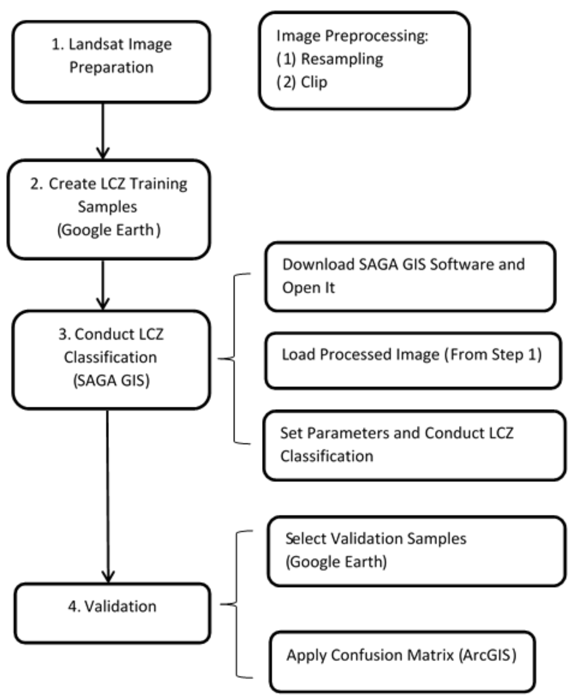


Figure 1 Work Flow of the WUDAPT Level 0 Method (Bechtel et al., 2015)

There are three main advantages of WUDAPT. 1) WUDAPT follows specific standards and steps of data collection and data processing. 2) Required data, software and generated results of WUDAPT are all free, and can be accessed easily by the public. Everyone can refer to, share, and do further processing of these results. 3) Data generated by this process can be applied to other studies, such as urban climate studies, public health studies and so on (Feddema, Mills & Ching, 2015).

3. Methodology

3.1 Study area

Hong Kong is a high-density city with a sub-tropical climate, covering 1,104.43 square kilometers, with a population over 7 million. 70% of Hong Kong is hilly and rugged. Livable land covers less than a fifth of the entire area of Hong Kong, mainly distributed in areas along Victoria Harbour, Kowloon Peninsula and northern parts of the New Territories. Due to lack of suitable land for housing, urbanization in Hong Kong has tended towards a high density development model since the 1950s. According to the Hong Kong Observatory (HKO)'s historical records, urban wind speed has been decreasing, and urban air temperature has been rising, since the 1960s (Lam, 2006). This may be aggravating the UHI effect in downtown areas of Hong Kong. Because of Hong Kong's complex urban morphological characteristics and high rise building types, it was chosen as a study area to examine whether or not the WUDAPT level 0 method is applicable to high density cities.

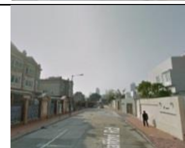
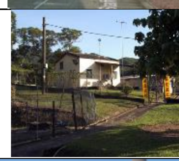
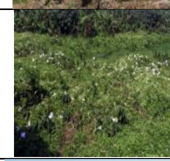
Figure 2. (Left) Map of Hong Kong; (Right) Downtown area of Hong Kong Island

3.2 WUDAPT Level 0 method and main steps

The study followed the main procedures in Figure 1. Firstly, Landsat 8 satellite images of Hong Kong were downloaded from the United States Geological Survey (USGS) website. The reason why Landsat 8 satellite images were chosen is that they include thermal information which can be used for classifying and mapping LCZs. After collecting relevant images, a remote sensing software named ENVI was used to re-sample the raw image into a raster format at 300m resolution that is suitable for a Hong Kong LCZ study (Lau *et al*., 2015), and to clip the image to fit into the study area.

Secondly, training samples of each LCZ class were selected by polygon digitizing from Google Earth. A typical LCZ training sample is a polygon which contains certain types of LCZ information. Training samples are used to provide learning samples for the same type of LCZ classification. In this study, according to the local situation and expert knowledge, all 17 types of LCZs can be found in Hong Kong (Table 1). For each LCZ type, around 20 training samples were selected and saved in the KML format, which can store the geographic data from Google Earth.

Table 1 Examples of Site View of 17 Types of LCZs in Hong Kong

Built types	Examples of Site View	Built types	Examples of Site View	Land cover types	Examples of Site View
LCZ 1 Compact high-rise		LCZ 4 Open high-rise		LCZ A Dense trees	
LCZ 2 Compact mid-rise		LCZ 5 Open mid-rise		B Scattered trees	
LCZ 3 Compact low-rise		LCZ 6 Open low-rise		C Bush, scrub	
LCZ 7 lightweight low-rise		LCZ 9 Sparsely built		D Low plants	
LCZ 8 Large low-rise		LCZ 10 Heavy industry		E Bare rock/ paved	
				F Bare soil/ sand	
				G Water	

Next, both those pre-processed Landsat images and training samples were input into the SAGA GIS software. According to the different spectral features contained by those Landsat images and training samples, different LCZ classes can be detected and extracted.

3.3 Accuracy Assessment

For accuracy assessment, a confusion matrix was used to assess the performance of the WUDAPT Level 0 method on LCZ classification. Firstly, a new set of ground truth samples was randomly selected and digitized from Google Earth as validation samples that were used to estimate the previous LCZ classification's accuracy. This independent subset of numbers comprised about 0.5% of each previous developed LCZ class. Secondly, the above-produced LCZ map was processed with ground truth samples by using the spatial analysis function of ArcGIS to extract a new classified LCZ map. The pixels of the extracted polygons were counted by the statistical function in the ArcGIS software. Finally, the calculation result was saved in a confusion matrix table. It lists the number of correctly and incorrectly classified pixels with the reference data in rows and the classifier results in columns.

4. Results and Analysis

Figure 3 shows the LCZ map of Hong Kong, the WUDAPT Level 0 product. The majority of LCZ classes are in the built types of LCZ 1, 3, 4 and 5, and the land cover types of LCZ A, B, C and G. From Table 2, the overall accuracy is only about 60.2% with a Kappa coefficient of 0.54. The highest accuracy can be found in the LCZ classes 3 and 6. Those with an accuracy lower than 50% are mainly in the LCZ classes 5, 10, B and F. Due to the small samples, the accuracy test for LCZ 7, 8 and 9gave a score of 0.

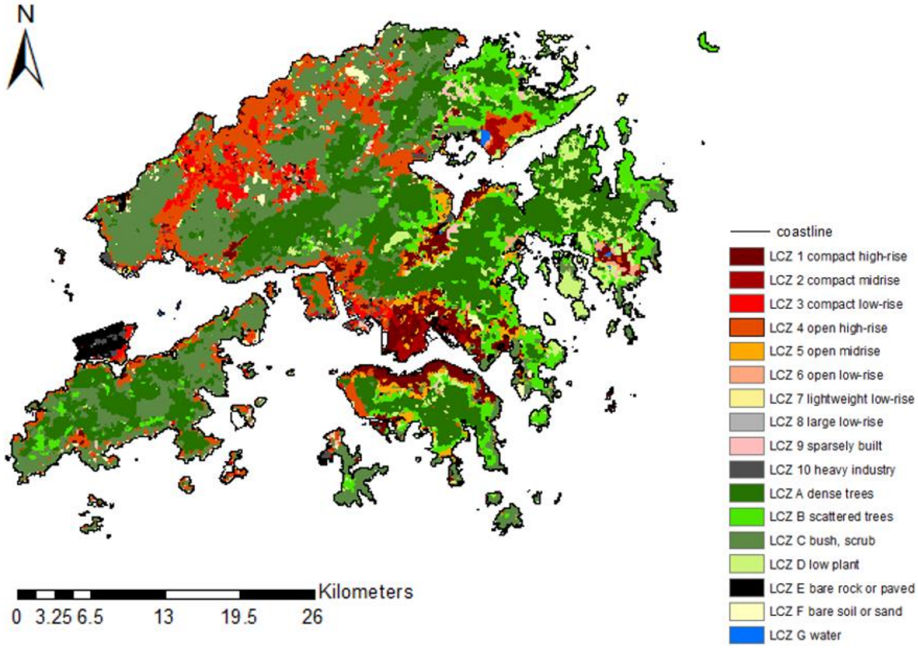


Figure 3 LCZ Map of Hong Kong (Version 1)

Table 2 Confusion Matrix of LCZ Map in Hong Kong (Version 1)

	LCZ 1	LCZ 2	LCZ 3	LCZ 4	LCZ 5	LCZ 6	LCZ 7	LCZ 8	LCZ 9	LCZ 10	LCZ A	LCZ B	LCZ C	LCZ D	LCZ E	LCZ F	LCZ G	Number of Actual Pixels	Producer's Accuracy
LCZ 1	100	3	1	14	5	0	0	0	0	0	0	0	0	0	1	0	9	133	75.2%
LCZ 2	4	20	11	9	5	0	0	0	0	1	0	0	0	0	1	0	0	51	39.2%
LCZ 3	5	0	166	4	0	0	0	0	2	0	0	0	12	0	0	0	0	189	87.8%
LCZ 4	44	1	1	222	58	0	0	0	0	4	4	0	6	0	0	0	6	346	64.2%
LCZ 5	11	7	13	5	21	1	0	0	0	0	2	4	12	0	0	0	1	77	27.3%
LCZ 6	0	0	0	4	0	7	0	0	5	0	1	8	25	0	0	1	0	51	13.7%
LCZ 7	0	0	1	0	0	1	0	0	0	0	0	0	2	0	0	0	0	4	0.0%
LCZ 8	1	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	2	9	0.0%
LCZ 9	0	0	0	2	0	0	0	0	0	0	0	3	23	0	0	3	0	31	0.0%
LCZ 10	3	0	9	14	1	0	0	3	0	5	0	0	3	0	1	0	2	41	12.2%
LCZ A	1	0	4	28	0	0	0	0	0	0	326	116	45	1	0	5	0	526	62.0%
LCZ B	0	0	1	1	5	0	0	0	0	0	5	52	116	0	0	15	0	195	26.7%
LCZ C	1	0	0	7	8	0	0	0	0	0	0	109	489	5	10	21	0	650	75.2%
LCZ D	0	0	0	0	0	0	0	0	0	0	0	2	23	9	0	0	0	34	26.5%
LCZ E	4	1	7	3	2	0	0	3	0	6	0	0	0	0	51	0	170	247	20.6%
LCZ F	0	0	0	10	0	0	0	0	0	0	0	0	61	0	0	7	1	79	8.9%
LCZ G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	318	318	100.0%
Number of Predicted Pixels	174	32	214	326	105	9	0	6	7	19	338	294	817	15	64	52	509		
User's Accuracy	57.5	62.5	77.6	68.1	20.0	77.8	0.0	0.0	0.0	26.3	96.4	17.7	59.9	60.0	79.7	13.5	62.5		
Overall Accuracy (%)	60.15																		
Kappa Coefficient	0.5431																		

5. Discussion

5.1 The built types (LCZ 1 to 6)' accuracy of WUDAPT Level 0 product

The Hong Kong downtown area is famous for its high density and high rise urban morphology. In Hong Kong, the average building tower height is about 60m above the ground level. In these areas, ground coverage by buildings can reach 100%. In urban areas, the plot ratio ranges from 5 to 11. According to the LCZ scheme, the LCZ 1 to 6 represents and covers most urban morphology types. They should be important classes in the Hong Kong LCZ study. To better understand these classes' accuracy in the WUDAPT Level 0 product, the real building height data was collected from the Planning Dept. of the Hong Kong Government and incorporated to calculate the building height distribution values of the LC1 to 6. This is also because building height values can be estimated according to the street view of selected site in Google Earth, and are easier to obtain than other parameters defined by LCZ scheme such as building coverage ratio and sky view factor.

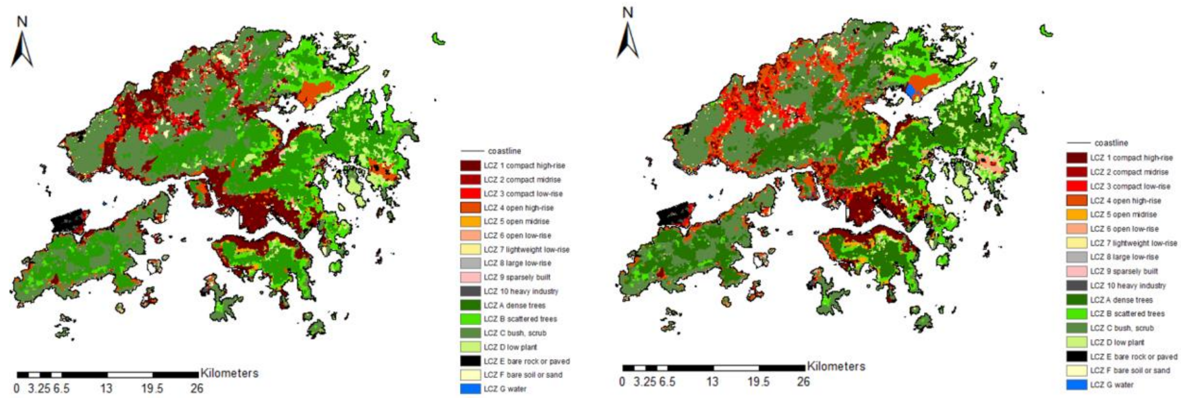
The results are shown in the Table 3. It was found that the accurately detected LCZ classes are LCZ 3 and 6 which are mainly low rise areas. For mid or high rise areas, no matter they belong to open or compact built types, their accuracy results are relatively low, especially for the LCZ 4 (open high rise).

Table 3 Building Height Statistic Results of LCZ 1-6 Classes (Version 1 of LCZ Map)

LCZ Class	Building Height (meters)	Version 1
LCZ 1 Compact high rise`	< 25 m	66.61%
	> 25m	**33.39%**
LCZ 2 Compact mid rise	< 10m	24.16%
	10-25m	**40.63%**
	> 25m	35.21%
LCZ 3 Compact low rise	< 3m	0%
	3-10m	**89.44%**
	> 10m	10.56%
LCZ 4 Open high rise	< 25 m	94.03%
	> 25m	**5.97%**
LCZ 5 Open mid rise	< 10m	68.01%
	10-25m	**21.70%**
	> 25m	10.29%
LCZ 6 Open low rise	< 3m	0%
	3-10m	**93.92%**
	> 10m	6.08%

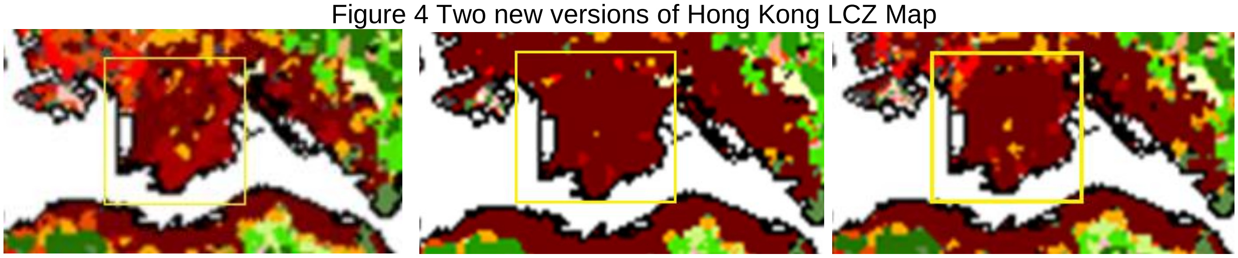
5.2 The impact of training sample's selecting area size on the accuracy result

The previously-developed LCZ map shown in Figure 3 is named as Version 1. After checking the results of LCZ classes' spatial distribution pattern with the actual urban morphology of Hong Kong, it is noted that some compact high-rise buildings (LCZ 1) have been misclassified into compact mid-rise building class (Figure 5 a). For minimizing the error caused by subjective judgement and better understanding how the selecting areas of training samples effect on the accuracy result, another two LCZ maps (Version 2 and Version 3) were generated and shown respectively in Figures 4a & 4b. All followed the same work flow listed in Figure 1. New training samples were selected in both version 2 and 3. For the selecting area size of the LCZ 1's training samples, version 1 used about 0.3 square kilometers; version 2 used about 0.6 square kilometers; and version 3 used about 0.4 square kilometers.



a) Version 2; b) Version 3

Figure 4 Two new versions of Hong Kong LCZ Map



a) Version 1 b) Version 2 c) Version 3

Figure 5 LCZ map for Kowloon Peninsular Areas (shown within the yellow boundary)

Through the comparison of three versions of LCZ maps of the Kowloon Peninsular area, it can be seen that compared with version 1, version 2 classifies more of the area as LCZ 1, and some mid and low rise areas also are mis-classified into the LCZ 1 class. Version 3 is the best one of out of three. On one hand, it can detect those compact high rise areas; on the other hand, it can also differentiate the LCZ classifications. It can therefore be concluded that 0.3-0.4 square kilometers is the appropriate area size for training samples for Hong Kong LCZ mapping. Selecting too large training sample areas can result in lower accuracy. Thus, the boundary of the selection polygon should be away from the other neighbouring built or land cover types to make sure the selected areas represent homogeneous urban morphological characteristics.

5.3 The overall accuracy of the WUDAPT Level 0 product

For better understanding the overall accuracy of the WUDAPT Level 0 product, the accuracy assessments were also conducted for both new versions of the Hong Kong LCZ map. Table 4 shows the confusion matrix result of version 2 and Table 5 shows the matrix for version 3. Together with Table 2, it can be seen that however the training samples are selected, the overall accuracy of all three versions only can be improved by 7%. In general, the overall accuracy ranges around 60%. A possible reason may be poor data quality of the Landsat 8 image.

Table 4 Confusion Matrix Table of Version 2 of Hong Kong LCZ Map

	LCZ 1	LCZ 2	LCZ 3	LCZ 4	LCZ 5	LCZ 6	LCZ 7	LCZ 8	LCZ 9	LCZ 10	LCZ A	LCZ B	LCZ C	LCZ D	LCZ E	LCZ F	LCZ G	Number of Actual Pixels	Producer's Accuracy
LCZ 1	118	1	0	7	0	0	0	0	0	0	0	0	0	0	0	0	5	131	90.08%
LCZ 2	53	8	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	61	11.27%
LCZ 3	47	0	132	2	0	0	0	0	0	3	0	0	12	0	0	0	0	196	67.35%
LCZ 4	181	0	0	8	0	0	0	0	0	0	0	0	3	0	0	1	2	195	4.10%
LCZ 5	36	0	6	6	14	1	0	0	0	0	1	4	3	1	0	3	2	77	18.18%
LCZ 6	0	0	0	0	0	7	0	0	0	0	0	0	1	0	2	0	0	10	70.00%
LCZ 7	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	4	0.00%
LCZ 8	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	0.00%
LCZ 9	0	0	0	0	0	0	0	0	0	0	4	0	26	0	0	1	0	31	0.00%
LCZ 10	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0.00%
LCZ A	1	0	0	3	0	0	0	0	0	0	112	11	0	0	0	0	0	127	88.19%
LCZ B	1	0	0	1	0	0	0	0	0	0	6	3	18	0	0	0	0	29	10.34%
LCZ C	2	0	0	0	0	0	0	0	0	0	1	20	194	0	0	1	0	218	88.99%
LCZ D	0	0	0	2	0	0	0	0	0	0	0	5	17	8	0	2	0	34	23.53%
LCZ E	4	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	2	9	0.00%
LCZ F	0	0	0	0	0	0	0	0	0	0	0	0	71	0	0	7	1	79	8.86%
LCZ G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	318	318	100.00%
Number of Predicted Pixels	456	9	139	32	24	9	0	0	0	5	124	43	345	9	2	15	332		
User's Accuracy	25.9	88.9	95.0	25.0	58.3	77.8	0	0	0	0	90.3	7.0	56.2	88.9	0.0	46.7	95.8		
Overall Accuracy (%)	60.17																		
Kappa Coefficient	0.5454																		

Table 5 Confusion Matrix Table of Version 3 of Hong Kong LCZ Map

	LCZ 1	LCZ 2	LCZ 3	LCZ 4	LCZ 5	LCZ 6	LCZ 7	LCZ 8	LCZ 9	LCZ 10	LCZ A	LCZ B	LCZ C	LCZ D	LCZ E	LCZ F	LCZ G	Number of Actual Pixels	Producer's Accuracy(%)
LCZ 1	116	11	0	8	3	0	0	0	0	0	0	0	1	0	1	0	16	156	74.4
LCZ 2	13	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	13.3
LCZ 3	7	0	157	17	0	0	0	0	1	0	0	0	13	0	1	0	0	196	80.1
LCZ 4	69	0	0	111	5	0	0	0	0	1	0	0	6	0	1	0	2	195	56.9
LCZ 5	15	0	10	12	15	4	0	0	1	0	1	4	10	1	1	0	0	74	20.3
LCZ 6	0	0	2	5	0	9	0	0	5	0	6	7	17	0	2	1	0	54	16.7
LCZ 7	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	4	0.0
LCZ 8	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	0.0
LCZ 9	0	0	0	1	0	0	0	0	0	0	0	0	30	0	0	0	0	31	0.0
LCZ 10	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0.0
LCZ A	1	0	0	4	0	0	0	0	0	0	111	12	1	0	0	0	0	129	86.0
LCZ B	1	0	1	0	0	0	0	0	0	0	4	3	20	0	0	0	0	29	10.3
LCZ C	1	0	0	0	0	0	0	0	0	0	0	23	191	0	1	1	1	218	87.6
LCZ D	0	0	0	3	0	0	0	0	0	0	1	0	21	9	0	0	0	34	26.5
LCZ E	2	0	2	0	0	0	0	0	0	1	0	0	0	0	1	0	2	8	12.5
LCZ F	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0	7	2	79	8.9
LCZ G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	318	318	100.0
Number of Predicted Pixels	229	13	179	162	24	13	0	0	7	2	123	49	381	10	8	9	343		
User's Accuracy	50.7	15.4	87.7	68.5	62.5	69.2	0.0	0.0	0.0	0.0	90.2	6.1	50.1	90.0	12.5	77.8	92.7		
Overall Accuracy (%)	67.65																		
Kappa Coefficient	0.6277																		

Table 6 Building Height Statistics of LCZ 1-6 Classes of Versions 1, 2, 3

LCZ class	Building Height (meters)	Version 1	Version 2	Version 3
LCZ 1 Compact high	< 25 m	66.61%	83.43%	67.87%
	> 25m	**33.39%**	**16.57%**	**32.13%**
LCZ 2 Compact mid	< 10m	24.16%	33.30%	34.22%
	10-25m	**40.63%**	**46.26%**	**40.49%**
	> 25m	35.21%	20.45%	25.30%
LCZ 3 Compact low	< 3m	0%	0%	0%
	3-10m	**89.44%**	**92.51%**	**89.81%**
	> 10m	10.56%	7.49%	10.19%
LCZ 4 Open high	< 25 m	94.03%	95.43%	97.15%
	> 25m	**5.97%**	**4.57%**	**2.85%**

LCZ 5 Open mid	< 10m	68.01%	69.13%	84.92%
	10-25m	**21.70%**	**24.65%**	**9.98%**
	> 25m	10.29%	6.23%	5.10%
LCZ 6 Open low	< 3m	0%	0%	0%
	3-10m	**93.92%**	**95.70%**	**60.79%**
	> 10m	6.08%	4.30%	39.21%

Table 7 Percentage Distribution of Main Built Types of all Hong Kong LCZ Classes

	Version 1	Version 2	Version 3
LCZ 1	5.00%	16.86%	7.81%
LCZ 2	1.20%	0.09%	0.15%
LCZ 3	3.28%	2.13%	4.01%
LCZ 4	12.31%	4.53%	9.15%
LCZ 5	2.06%	1.10%	1.79%
LCZ 6	0.62%	0.57%	0.98%

For built areas, based on the statistical analysis of building height values distribution of LCZ 1-6, the classes most accurately detected are LCZ 3 and 6 for all three versions (Table 6). Mid and high rise areas are poorly extracted, although they form the majority of the built area in the Hong Kong LCZ map. Thus, it can be concluded that the WUDAPT Level 0 method needs to be improved for LCZ mapping of high density cities, and especially that high resolution satellite images should be employed to capture high density urban morphology characteristics.

For land cover types, the relatively lower accuracy can be found mainly in LCZ B, E and F. The reasons for this need to be analyzed. Further detailed vegetation information, such as the normalized difference vegetation index (NDVI) and high resolution satellite images should be taken into account for improving accuracy of classification of land cover types.

6.Conclusion

This study adopted the WUDAPT Level 0 method to develop a Hong Kong LCZ map and corresponding classifications. By comparison of three versions of a Hong Kong LCZ map, it can be confirmed that the current WUDAPT Level 0 method cannot detect and extract high and mid-rise built types accurately. Due to Hong Kong's complex and unique high density high rise urban and building morphology, high resolution satellite images and improved mapping methods should be considered. For example, building footprints and types can be factored in to improve the built types' accuracy result.

This paper focuses on built-up areas, while the accuracy of land cover types, especially in rural area has been less studied and validated. Besides, when assessing classification accuracy of LCZ1-6, only building height values are referred to analysis. Other parameters of metadata should be taken into account in the next study.

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References

Bechtel, B., Daneke, C. (2012) Classification of Local Climate Zones Based on Multiple Earth Observation Data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 5*(4): 1191–1202..

Bechtel, B., Alexander, P. J., Böhner, J., Ching, J., Conrad, O., Feddema, J., & Stewart, I. (2015). Mapping local climate zones for a worldwide database of the form and function of cities. *ISPRS International Journal of Geo-Information, 4*(1), 199-219.

Feddema, J., Mills, G., & Ching, J. (2015) Demonstrating the Added Value of WUDAPT for Urban Climate Modelling. Paper presented at the 9th ICUC, Toulouse, France

Gamba, P., Lisini, G., Liu, P., Du, P., & Lin, H. (2012). Urban climate zone detection and discrimination using object-based analysis of VHR scenes.*Proceedings of the 4th GEOBIA, Rio de Janeiro, Brazil*, *79*.

Howard, L. (1818). The Climate of London: deduced from Meteorological observations, made at different places in the neighbourhood of the metropolis (Vol. 1). W. Phillips, sold also by J. and A. Arch.

Lam, C. Y. (2006). *On climate changes brought about by urban living*. Paper presented at the PGBC Symposium 2006-"Urban Climate + Urban Greenery", Hong Kong.

Lau, K. K. L., Ren, C., Shi, Y., Zheng, V., Yim, S., & Lai, D. (2015) Determining the optimal size of local climate zones for spatial mapping in high-density cities. Paper presented at the 9th ICUC, Toulouse, France.

Lelovics, E., Unger, J., & Gál, T. (2014) Design of an urban monitoring network based on local climate zone mapping and temperature pattern modelling. *Climate Research, 60*: 51-62.

Mills, G., Ching, J., See, L., Bechtel, B., & Foley, M. (2015). An Introduction to the WUDAPT project. In *9th International Conference on Urban Climate, Toulouse.*

Mitraka, Z., Del Frate, F., Chrysoulakis, N., & Gastellu-Etchegorry, J. P. (2015, March). Exploiting Earth Observation data products for mapping Local Climate Zones. In *Urban Remote Sensing Event (JURSE), 2015 Joint* (pp. 1-4). IEEE.

Stewart, I. D., & Oke, T. R. (2009). A new classification system for urban climate sites. *Bulletin of the American Meteorological Society*, *90*(7), 922-923.

Stewart, I., & Oke, T. (2010). Thermal Differentiation of Local Climate Zones using Temperature Observations from Urban and Rural Fields Sites.

Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, *93*(12), 1879-1900.

Wang, X., & Bai, J. L. (2008). Recent Advances in Urban Heat Island Studies with Future Prospects. *Journal of Foshan University (Natural Science Edition)*, *26*(1), 53-56.