RETRIEVAL OF LOCAL CLIMATE ZONES AND THEIR LINKAGES TO LAND SURFACE TEMPERATURE USING REMOTE SENSING IN HARARE METROPOLITAN CITY, ZIMBABWE

Terence Darlington Mushore[1,2,*]

[1]Physics Department, University of Zimbabwe, P.O. Box MP167, Mount Pleasant, Harare, Zimbabwe
(tdmushore@mail.com)
[2]Discipline of Geography, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, P/Bag X01, Scottsville, Pietermaritzburg 3209, South Africa

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ABSTRACT

This study sought to determine Local Climate Zones (LCZs) in Harare metropolitan City, using Landsat 8 multi-spectral and multi-temporal data. The World Urban Database and Access Portal Tool (WUDAPT) and Support Vector Machine classifiers were applied. Training datasets were extracted from Google Earth as prescribed by the WUDAPT procedure. Before image classification, we tested the separability of the LCZs, using the Transformed Divergence Separability Index (TDSI) based on the digitized training datasets and Landsat 8 data. Derived LCZs were then linked with Landsat 8 derived Land Surface Temperature (LST) for the cool and hot seasons. TDSI values greater 1.9 were obtained indicating that LCZs were highly separable. Comparatively, the WUDAPT method produced more accurate LCZs results (Overall accuracy = 95.69%) than the SVM classifier (Overall accuracy = 89.86%) based on seasonal Landsat 8 data. However, SVM derived accuracies were within the acceptable range of at least 80% (overall accuracy) in literature. Further, LST was observed to be high in LCZs with high built-up density and low vegetation proportion, when compared to other zones. Due to high proportion of vegetation, sparsely built areas were at least 1°C cooler. Although LCZs are usually linked at 2m air temperature, they also strongly explain LST distribution. This work provides insight into the importance of mapping LCZs in third world countries where such information remains scarce.

1. INTRODUCTION

There is a global call for studies which use LCZs in urban areas for input into World Urban Database and Access Portal Tools (WUDAPT) (Ching et al., 2018). Currently, progress in urban climate science is retarded by lack of useful information that describes aspects of the form and function of cities at detailed spatial resolution (Bechtel, et al., 2015). WUDAPT is being developed to gather and disseminate LCZs information. Bechtel, et al. (2015) developed WUDAPT protocols, which are easy to understand, use freely available data such as medium resolution remote sensing imageries` and can be applied by someone with limited knowledge in spatial analysis or urban climate science. There is a severe lack of studies that map LCZs in urban areas of Africa and more specifically in Zimbabwe. To date only the LCZ map for Khartoum, Sudan has been completed and successfully shared on the WUDAPT website (http://www.wudapt.org/cities/in-africa/).

In view of the above, the objectives of this study are i) to contribute to WUDAPT by using Landsat data to map LCZs of Harare metropolitan city in Zimbabwe, ii) to compare the WUDAPT procedure (which uses Random Forest classifier) with the Support Vector Machines (SVM) classifier for improving LCZ mapping accuracy

and iii) to link the spatial structure of LCZs with land surface temperature in different seasons in Harare.

1.1 Description of study area

This study was conducted in Harare, the capital and largest city of Zimbabwe in Southern Africa (Figure 1). The climate is generally humid with an average temperature of 18°C and mean annual rainfall of 850mm (Torrance, 1981). The hot season (mid-September to mid-November) was chosen in this study because it is the warmest period hence ideal for understanding extreme thermal conditions (Manatsa et al., 2013).
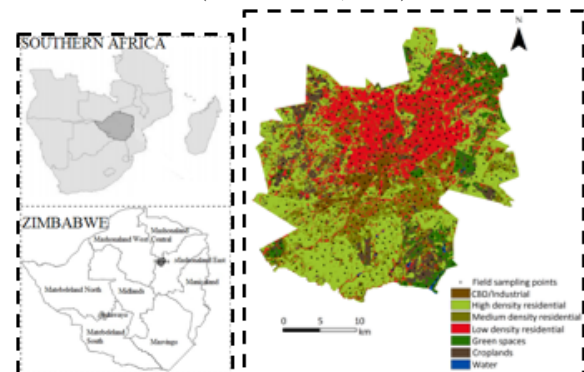

Figure 1: Location of the area under study area and field sample collection points

Table 1 provides description of major land use and land

cover classes in Harare (Mushore et al., 2017). High density built-up areas dominate the south-western half of the city, which include the Central Business District, industrial areas and high density settlements. Low and medium density built-up areas mostly occupy the north-eastern residential suburbs (Wania, et al., 2014; Mushore et al., 2016). According to Wania, et al. (2014), 'leafy' suburbs in the north are mainly occupied by high income strata while low income strata populate the high density residential areas in the south.

LULC class	Description
Central Business District (CBD)	Areas with very high density of buildings and a very high proportion of impervious surface that include central business district and industrial areas.
High density residential (HDR)	High density of buildings and also including low vegetation cover fraction.
Medium density residential (MDR)	Moderate to high income residential areas with moderately spaced out buildings and high vegetation cover fraction.
Low density residential (LDR)	High income residential areas with spaced out buildings and high vegetation cover fraction.
Croplands (Cr)	Areas where intra-urban agriculture is practised including research sites which could be bare in the dry season
Green-spaces (Gr)	Areas covered by grasslands and clusters of tree characterised by high vegetation fraction even during the dry season.
Water (Wt)	Areas covered by water bodies or wetlands.

Table 1: Description of general land use and land cover types identified in Harare

2. METHODOLOGY

2.1 Remote sensing data collection and pre-processing

Cloud-free Landsat 8 imagery of path/row 170/72

acquired in 2017 during the cool and hot seasons on dates shown in Table 2 were used. The rainy and post rainy seasons were avoided due to unavailability of cloud free images. The imagery were downloaded free of charge from the United States Geological Survey's (USGS) earth explorer website. Three dates per season were used to incorporate intra- and inter-seasonal Local Climate Zone variations into mapping procedure.

Date acquired	Season	Average weather conditions during acquisition hour		
		Air temperature (°C)	Relative Humidity (%)	Wind speed (m/s)
17 June 2017	Cool	17.0	51.7	2.8
19 July 2017	Cool	17.7	45.0	1.8
20 August 2017	Cool	16.8	49.3	2.9
21 September 2017	Hot	22.3	42.8	2.9
23 October 2017	Hot	26.0	26.8	3.2
8 November 2017	Hot	29.2	15.7	2.5

Table 2: Cloud-free Landsat 8 imageries used for LCZ and LST retrieval in this study

2.2 Digitizing of classification training samples and LCZ separability test

For each LCZ class, representative samples were digitized from Google Earth in the form of polygons in line with the WUDAPT methodology, guided by knowledge of the study area and field survey conducted. The sample representing each class was digitized from fairly distributed locations across the study area in order to incorporate intra-class variability. Evaluation of the suitability of the training samples digitized from Google Earth to perform classification was done by statistically testing for separability using the transformed divergence separability index. The Transformed Divergence Separability Index (TDSI) was used to test the extent to which LCZs can be distinguished from each other using Landsat 8 multi-spectral data. TDSI ranges between 0 and 2; the closer to 2, the better the classes can be separated from each other. Values of TDSI below 1 imply that the two classes being compared are not easy to separate, using a given remote sensing dataset. In such cases classes whose TDSI is low may be combined to allow further tests until appreciable values are obtained and classes can be easily distinguished using remote sensing. LCZ mapping would only proceed if the zone types in the study area were acceptably separable using the digitized training LCZ samples and Landsat 8 datasets.

2.3 Retrieval of local climate zones from Landsat data

Classification of local climate zones is split into two sub procedures namely (i) Digitizing of training sites and pre-classification test for class separability and ii) Local climate zone classification by applying two classifiers (Random Forest – RF and Support Vector machines – SVM) and statistically comparing the accuracy in mapping. The separability test was done to ensure that the classes are clearly distinct. High separability between classes was meant to provide confidence to proceed with the classification. Land surface temperature retrieval A single channel approach using Band 10 of Landsat 8 was used to retrieve land surface temperature (LST) from thermal infrared data for each of the 6 imagery scenes.

The raw thermal infrared digital numbers were converted to LST by adopting steps used by Weng et al. (2004). The procedure involved conversion of digital numbers to radiances, radiances to brightness temperatures and finally brightness temperature to land surface temperature (emissivity correction). Emissivity maps for the area were obtained as detailed by Sobrino et al. (2004) using normalized difference vegetation index (NDVI) based approach separately for each of the 6 imagery scenes. Similar Sobrino, et al. (2004), NDVI value of 0.2 was used for a purely soil pixel and 0.5 for a purely vegetation pixel. Average land surface temperature maps for the cool and the hot season were computed since three temperature maps were computed per season. In order to establish the link between LCZ and LST, spatial overlay of the two maps and data extraction using the zonal statistics tool in ArcMap10 were used. Using the zonal statistics tool, we retrieved the average LST for each LCZ.

3. RESULTS AND DISCUSSION

3.1 Test of separability of Local Climate Zones

The transformed divergence separability index ranged between 1.958 and 2. Although "Compact mid-rise" and "Compact low-rise" were the least separable, the TDSI value of 1.958 was very high indicating that the two were highly separable using the training samples for each LCZ type digitized from Google Earth and Landsat 8 data. Overall, all the LCZ were highly separable from each other using the digitized samples as shown by high TDSI values (very close to 2). Due to similarities, Chen et al., (2017) were forced to combine "Heavy industry" with "Large low-rise" LCZ in Taipei because they were not clearly distinct.

3.2 The LCZ map of Harare

Figure 2 shows the high accurate LCZ maps of Harare produced by the Support Vector Machines classifier (Figure 2a) and the WUDAPT approach (Figure 2b). Visual inspection show similarities between the maps from both approach especially the general distribution of classes. "Sparsely built" LCZ covered most of the northern half of the city. The "Compact mid-rise" and the "Compact low-rise" LCZ occupied the central part of the city. The southern half is occupied mostly by the "Bush/scrubs" and the "Light-weight low-rise". The "Dense trees" LCZ occupied more area in the northern half than the south. The results concurred with Kamusoko, et al. (2013) who observed that built-up densities are high in the southern half of the city.
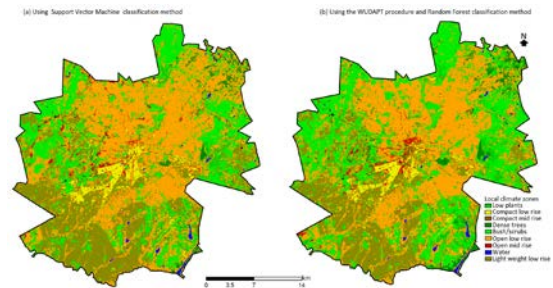

Figure 2: Local climate zones map for Harare metropolitan city obtained using (a) SVM classifier and (b) WUDAPT method (Random Forest classifier)

3.3 Accuracy of classification per analysis type

Overall accuracies were greater than 85% for both methods which indicates very high mapping accuracy. Although both methods mapped LCZ with very high accuracy, the WUDAPT method was more accurate (OA=95.7%) than the SVM (OA=89.9%). The Random Forest based WUDAPT approach was found to be superior to SVM when multi-temporal Landsat 8 from different seasons of the same year were used as input data. The McNemar's Statistic (Z) was 26.02 (>1.96) implying that the difference between WUDAPT method based- and SVM based LCZ mapping was statistically significant at 95% confidence interval.

3.6 Average temperature for LCZ

Visual inspection of Figure 3 shows that the northern half was cooler than the southern half in both the cool and hot seasons. For example, in the hot season land surface temperature ranged between 35 and 45°C in the southern areas compared to a range between 20 and 35°C in the north-western half of the city. Combining Figure 4 and Figure 3 indicated that very warm areas corresponded with "Compact mid-rise", "Compact low-rise" and "light-weight low-rise" which occupied most of the southern areas. High temperatures were recorded in the "Compact mid-rise" LCZ due to high heat absorption by the concentrated buildings. Walls of tall buildings absorb a lot of heat while closely packed buildings impede heat removal by wind resulting in elevated surface temperatures. High rise buildings also reduce the sky view factor implying reduction in the amount of radiation lost to outer space (Blake et al., 2011) resulting in more heat trapped within built-up area and enhanced surface warming. "Compact low-rise" buildings absorb a lot of heat due to low vegetation fraction and packed buildings. Coolest areas (LST<35°C) coincided with the "Water", "Sparsely built" and "Dense trees" LCZs. The "Water" areas had low daytime surface temperature during the day in both seasons due to high latent heat transfer and evaporation cooling. Sparse built and dense green LCZs had low surface temperature because of abundance of vegetation which according to Odindi, et al. (2015) increase cooling by evaporation. The findings are also in tandem with Perera & Emmanuel, (2018) who, in Colombo, observed temperature decrease from densely

built LCZ such as "Cmpact mid-rise" to LCZ type with high density of vegetation such as the "Dense trees" as well as "Water" areas. Chen et al., (2017) cordially also observed that higher urban development and building density are associated higher thermal loads in Taipei.
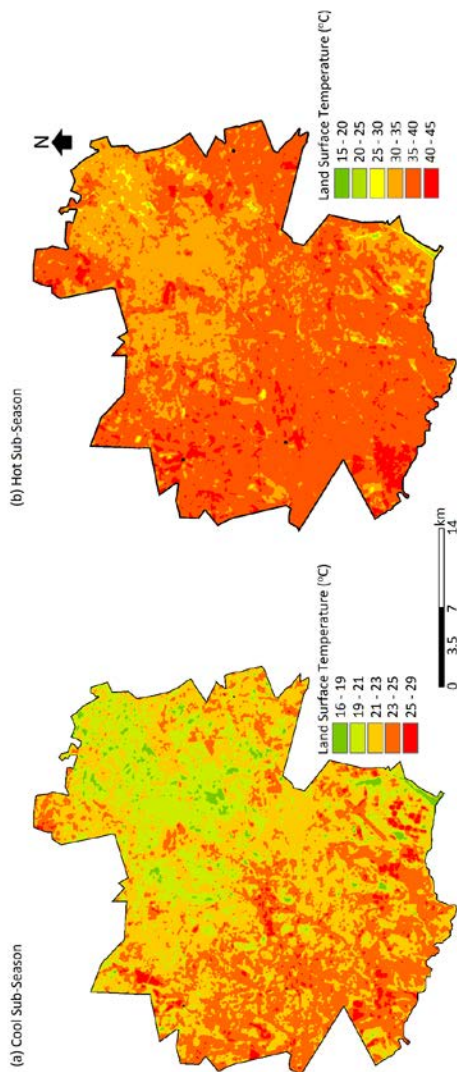

Figure 3: Land surface temperature at coincident time with LCZ map (a) in the cool and (b) the hot season
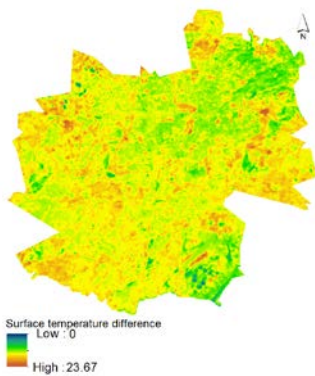

Figure 4: Summer-winter surface temperature difference

Figure 4 shows that the summer-winter temperature difference was higher in built LCZs than in other areas.

As expected, the "Water" and the "Dense trees" LCZs were the coolest with average land surface temperatures of 10 and 19.8°C, respectively, in the cool season (Figure 5). The "Compact mid-rise" was the warmest (38.8°C in the hot and 24.9°C in the cool season) followed by the "Compact low-rise" (37.8°C in the hot and 23.5°C in the cool season) and the "Light weight low-rise" (37.5°C in the hot and 23.3°C in the cool season). Similarly, in Kochi India, maximum heat intensity was recorded in "Compact mid-rise" while intense cooling was recorded in "Sparsely built" areas in all seasons (Thomas, et al., 2014).
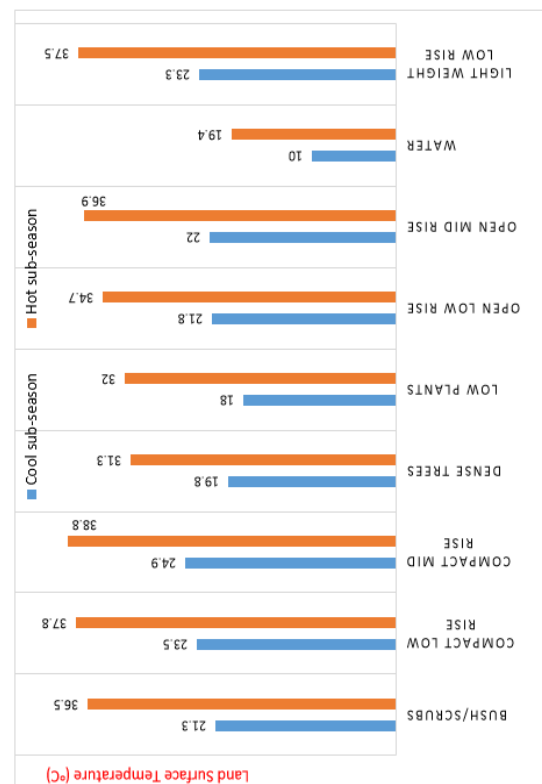

Figure 5: Relationship between LCZ and LST in Harare for the cool and hot seasons

4. CONCLUSIONS AND RECOMMENDATIONS

WUDAPT procedure in comparison to the SVM classifier using Landsat 8 multi-spectral and multi-temporal datasets were applied to determine and map the Harare Metropolitan City's LCZs. Nine LCZ types were identified and analysis showed that the classes were highly separable. Results showed that both the WUDAPT procedure and the SVM based approach mapped LCZ for Harare with acceptable high levels of accuracy. Intense heating was recorded in high impervious and densely built-up LCZs while intense cooling was observed in sparsely built, densely vegetated and water bodies' LCZs. The study recommends that more research should be done to continuously improve the accuracy of the

procedure by testing potential of new datasets and classifiers.

5. LIST OF REFERENCES

Chen, Y., Lin, T. P., & Lin, Y. C. T. (2017). Modeling the urban thermal environment distributions in Taipei Basin using Local climate zone (LCZ) (LCZ), (March), 31–34.

Mushore, T. D., Odindi, J., Dube, T., & Mutanga, O. (2017). Understanding the relationship between urban outdoor temperatures and indoor air-conditioning energy demand in Zimbabwe. *Sustainable Cities and Society*, *34*(June), 97–108. https://doi.org/10.1016/j.scs.2017.06.007

Bechtel, B., Alexander, P. J., Böhner, J., Ching, J., Conrad, O., Feddema, J., Mills, G., See, L., & 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.

Ching, J., Mills, G., Bechtel, B., See, L., Feddema, J., Wang, X., Ren, C., Brousse, O., Martilli, A., Neophytou, M. and Mouzourides, P., (2018). World Urban Database and Access Portal Tools (WUDAPT), an urban weather, climate and environmental modeling infrastructure for the Anthropocene. *Bulletin of the American Meteorological Society*, (2018).

Kamusoko, C., Gamba, J., & Murakami, H. (2013). Monitoring Urban Spatial Growth in Harare Metropolitan Province, Zimbabwe. *Advances in Remote Sensing*, 2 322-331.

Manatsa, D., Morioka, Y., Behera, S. K., Yamagata, T., & Matarira, C. H. (2013). Link between Antarctic ozone depletion and summer warming over Southern Africa. *Nature Geoscience*, 6, 934-939.

Thomas, G., Sherin, A., Ansar, S., & Zachariah, E. (2014). Analysis of urban heat island in Kochi, India, using a modified local climate zone classification. *Procedia Environmental Sciences*, 21, 3-13.

Torrance, J. (1981). Climate handbook of Zimbabwe. *Zimbabwe Meteorological Services, Harare*.

Wania, A., Kemper, T., Tiede, D., & Peter Zeil, b. (2014). Mapping recent built-up area changes in the city of Harare with high resolution satellite imagery. *Applied Geography*, 46, 35-44.

Blake, R., York, N., Curitiba, A. G., Tokyo, T. I., Horton, R., & York, N. (2011). Urban climate: Processes, trends and projections. *First Assessment Report of the Urban Climate Change Research Network*, 43-81.

Perera, N. G. ., & Emmanuel, R. (2018). A "Local Climate Zone" based approach to urban planning in Colombo, Sri Lanka. *Urban Climate*, 23, 188–203. https://doi.org/10.1016/j.uclim.2016.11.006