International Journal of Undergraduate Research and Creative Activities

Volume 12 | Issue 1 | Article 5

January 2020

Object-based image analysis of slum settlements: A case study from Dar es Salaam, Tanzania

Peyton A. Moran
pmoran@una.edu

Ethan Willis
ewillis4@una.edu

Sunhui Sim
ssim@una.edu

Recommended Citation

Moran, Peyton A.; Willis, Ethan; and Sim, Sunhui (2020) "Object-based image analysis of slum settlements: A case study from Dar es Salaam, Tanzania," *International Journal of Undergraduate Research and Creative Activities*: Vol. 12: Iss. 1, Article 5.
DOI: 10.7710/2168-0620.0294
Available at: https://digitalcommons.cwu.edu/ijurca/vol12/iss1/5

IJURCA: International Journal of Undergraduate Research & Creative Activities

Volume 12 Article 5

May 22, 2020

Object-based image analysis of slum settlements: A case study from Dar es Salaam, Tanzania

Peyton A. Moran
University of North Alabama, pmoran@una.edu

Ethan Willis
University of North Alabama, ewillis4@una.edu

Sunhui Sim, PhD
University of North Alabama, ssim@una.edu

Abstract
In recent years, slum settlements developed in nations, due to increases in population density and a lack of land use planning (Dar Ramani Huria, 2016). Remote sensing provides city planners, engineers, and local officials the ability to analyze past, present, and possible future growth of slum settlements and inadequate access to urban services (water, garbage disposal system, etc.). The research aims to extract building footprints of slum settlements in Dar es Salaam, Tanzania. Therefore, the purpose of this research was to employ remote sensing methods, in order to identify and extract slum settlements in the observed area. High resolution imagery (0.3 meters), provided by Worldview 3 was used to assess urban structures within two wards in Dar es Salaam, Tanzania (Manzese & Tandale). Overall, this research provided evidence that Object-Based Image Analysis is a beneficial and useful process in capturing slum settlements, considering that it had captured up to 118,500 square meters of slums. Slum settlement mapping provides the following for citizens of slum settlements: access to water, improved sanitation, secure tenure, or more durable housing. Slum settlement mapping leads to a better understanding of future land use planning, the local economy, and housing regulations.

Keywords
Slum, object-based image analysis, Dar es Salaam, Tanzania, Worldview-3, Geography

Peer Review
This work has undergone a double-blind review by a minimum of two faculty members from institutions of higher learning from around the world. The faculty reviewers have expertise in disciplines closely related to those represented by this work. If possible, the work was also reviewed by undergraduates in collaboration with the faculty reviewers.

Acknowledgments

This research was supported by a Freddie Wood Research Grant from the Department of Geography at the University of North Alabama. The undergraduate authors were provided $1,600 scholarships to travel to Dar es Salaam, Tanzania, by the College of Arts and Sciences. Faculty travel was sponsored by the Ben H. Craig Professorship of Geography. WE are grateful to our faculty mentor, Dr. Sunhui Sim, for her guidance in completing this research and model.

https://digitalcommons.cwu.edu/ijurca/vol12/iss1/5
DOI: 10.7710/2168-0620.0294

Slum development is significant in many developing regions of the world, most famously Sub-Saharan Africa, Latin America, and portions of Asia. These regions host at least 24% of their population in slum-like housing (Kuffer, Pfeffer, & Sliuzas, 2016). Local officials and researchers have employed many different methods to identify and resolve the issue of unplanned areas and slum settlements across the globe. Recent research evinces that remote sensing has the capability to correctly identify and map slum settlements quickly and efficiently.

Few of the words linked to slum settlements, such as informal housing, migrant housing, sub-standard housing, and unplanned areas, reflect their key indicators: insecure tenure, lack of adequate access to water, lack of access to acceptable forms of sanitation, overcrowding, and durability of housing (Kuffer, Pfeffer, & Sliuzas, 2016). Although many definitions of slums pertain to the qualitative forms of infrastructure, remote sensing can directly deal with the physical exterior components (Wurm, Taubenbock, Weigand, & Andreas, 2017). The use of remote sensing in slum settlement mapping has the potential to assist local officials in pro-poor policy development, to inform land-use and sustainable environmental planning, and to improve understanding of a local economy.

This research and model proposes the use of remote sensing and object-based image analysis (OBIA) in identifying and mapping slum settlements using Dar es Salaam, Tanzania, as a case study. Some benefits of this model include determining number of slums, population in a slum settlement neighborhood, and the amount of land they occupy. Such a model would provide analysis of slums more accurate that the currently popular technique of automated image classification (Wurm & Taubenbock, 2017). It will also provide efficient methods for those interested in remote sensing extraction methods in the future.

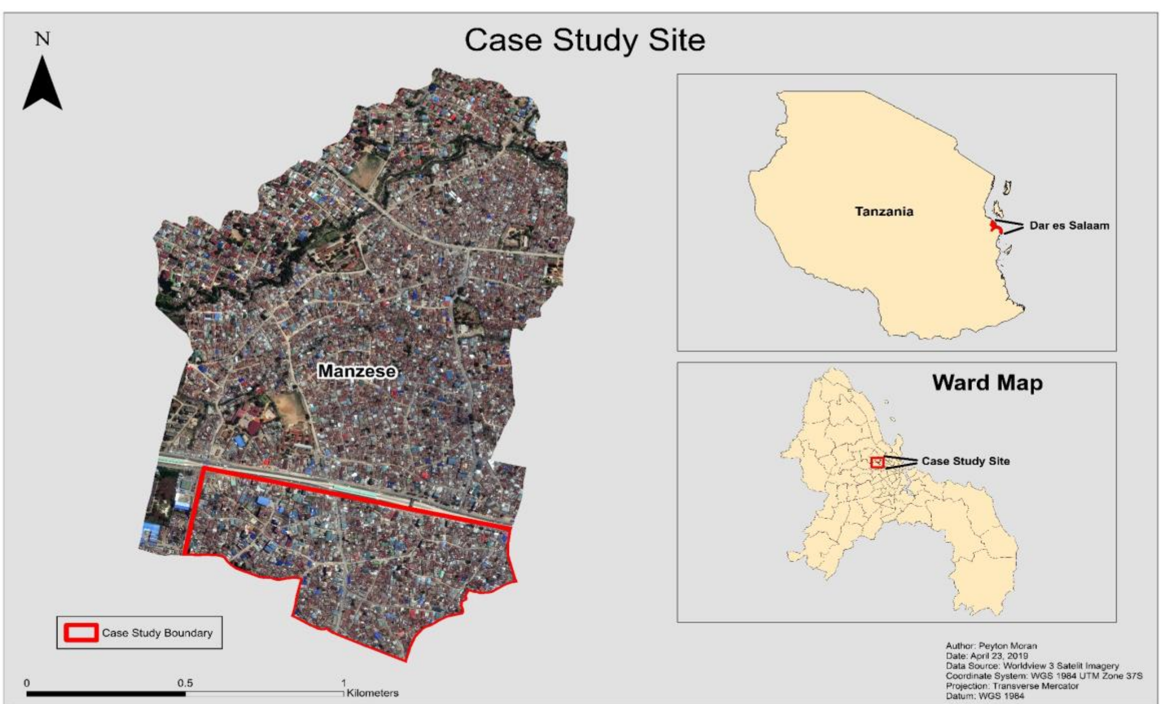

Figure 1. Map of site observed in Dar es Salaam, Tanzania.

Literature Review

Rather than simply classifying an image on a per-pixel basis, OBIA is the method used to group and segment similar pixels into shapes and polygons. This means that it may consider the shape, size, context, and spectral properties of a pixel while classifying objects. OBIA has become increasingly popular in remote sensing because it measures far more than just a pixel's reflectance value (Blaschke, et al., 2014).

Around 32% of previous slum mapping research models have used OBIA, becoming primary method used for feature extraction in remote sensing (Kuffer, Pfeffer, & Sliuzas, 2016). For example, in one research model, informal settlements in Johannesburg, South Africa, were observed over a twelve-year period in order to understand the temporal and dynamic changes. High resolution spatial imagery (0.15 meter, 0.5 meter) was used to extract the informal units from the imagery itself. One of the first steps of this research was to delineate roofed land cover, also known as buildings. By doing this, it provided a more efficient method than use classification methods (such as fuzzy criteria analysis or maximum likelihood) to delineate remaining land cover that had not yet been extracted. These methods were completed so that informal units could be clustered or grouped together. When compared, there was approximately a 250% growth rate in roof area coverage and a 400% growth rate in the total number of households. Accurate imagery, Census data, and remote sensing provide cost-efficient methods for local officials to analyze households and population within the slums (Williams, Quincey, & Stillwell, 2015).

Another recent research model of slums and migrant housing in the Pearl River Delta of China (Guangzhou) used imagery form LANDSAT, SPOT5, and Quickbird2 with the minimum spatial resolution of 2.5 m x 2.5 m. First, migrant housing neighborhoods were identified in the study area so as to more efficiently classify the data later. Once the neighborhoods and urban structures had been identified in the pixel-based classification process, homogenous areas (based on color, size, shape, and compactness) were then clustered into potential migrant housing polygons. This method enabled distinguishing of migrant housing from other urban areas in Guangzhou. The model provided an overall accuracy assessment of 68%m considered about average. Minimizing the study area and using improved spatial resolution imagery may well have improved these results (d'Oleire-Oltmanns, Coenradie, & Kleinshmit, 2011).

Figure 2. slums in Manzese, May 23, 2018.

In a third study observing termite mounds in Bahia, Brazil, the objective was to test the effectiveness of feature extraction methods in OBIA. Some of the feature extraction processes used included raster pixel processor, raster object creator, raster object operator, raster to vector conversion, vector object operator, vector object processor, and vector cleanup properties. This method proved effective with a 90% accuracy rate between the mapped termite mounds and the actual number of termite mounds (Sim & Lee, 2014).

It is crucial that researchers, city planners, and other community stakeholders understand the importance of OBIA; this method employs powerful techniques to measure population, housing, and sanitation in slum areas. Despite the detail enabled by this powerful tool, more research is needed to understand its effectiveness for urban areas.

Methods

For this research model, the ERDAS Imagine Objective module was used to carry out feature extraction methods for slum settlements within the study area. A method similar to previous feature extraction models was used, with minor changes implemented (Sim & Lee, 2014). Figure 3 displays the step-by-step procedure used, to receive the final product, which were building footprints of slums.

Study Area. The study area of this research is part of a ward district, Manzese, in Dar es Salaam (Figure 1). Manzese covers 1.86 square kilometers (Dar Ramani Huria, 2016). This district is well known for having a prominent amount of slum settlements (Figure 2). Although there are no statistics on slum settlements for this district, there has been research completed on slum development throughout the city of Dar es Salaam, which has a reputation for slum settlements. Potentially up to 83% of the city is made up of unplanned areas and slum settlements (UN-HABITAT, 2010). Only a section of southern Manzese was used in this model, however, as OBIA was unable to effectively identify slum settlements with both neighborhoods in view.

Data Source. The data acquired for this model and analysis was necessary so that slum settlements could be evaluated in the study area. The image used was acquired from the Worldview 3 satellite. Worldview 3 provided an image of 0.3-meter spatial resolution, which gave the research and model efficient use.

Procedure. The following procedure discusses the step-by-step process in which slum settlements were extracted from the study area:

1. Raster Pixel Processor (RPP): This step required the use of the single feature probability (SFP) function. SFP allows a user to make training samples for both the desired object (in this case, slum settlements) and background features (i.e., roads, cars, urban open space). See Figure 4.
2. Raster Object Creator (ROC): The segmentation function was used next so that pixels that were both spatially connected and have similar reflectance values were segmented together (Blaschke, et al., 2014). See Figure 5.
3. Raster Object Operator (ROO): Four ROO functions were employed, including *dilate*, *probability*, *size*, and *reclump*. In our model, the *dilate* function observed every pixel within a three-pixel range in order to determine the likelihood that the pixel belongs to the slum settlement itself (Figure 6). *Dilate* was primarily helpful in capturing the edges of roofs within the observed area. The *probability* filter function measures the likelihood in which an object is similar to the previously defined training samples during SFP. The minimum specified probability used in this analysis was set at 75%. If any object observed was measured at less than the specified minimum probability, it was simply removed from the dataset (Figure 7). After this, a *size* filter was applied, which removed any objects that had fewer than 1,000 pixels (Sim & Lee, 2014). See Figure 8. This function removes any objects (i.e., trash cans, cars, fences) that were not slum settlements. Then, the *reclump* function was used so that any previously split object was grouped back together with the object (Figure 9).

4. Raster to Vector Conversion (RVC): The polygon trace function was used, so that the original object layer could be transformed from a raster data format and into a vector data format (d'Oleire-Oltmanns, Coenradie, & Kleinshmit, 2011).
5. Vector Object Operator (VOO): The two functions used were *generalize* and *island filter*. The *generalize* performs a process in which each slum settlement's edges were smoothed and unnecessary vertices were filtered out (Figure 10). Next, the *island filter* function was employed to get rid of any holes within the slum settlements or polygons being observed. *Island filter* analyzes whether there are missing pixels within an object. Once the function assesses the missing areas, additional pixels are placed to the polygon. See Figure 11.
6. Vector Object Processor (VOP): The process employed while using VOP was the *rectangularity function*. The function measures how similar each polygon formed is to a rectangle, so that a final building footprint was made (Figure 12). After completing the use of the ERDAS Imagine Objective, both the area (sq. meters) and percentage of slum settlements in the observed area were calculated (Williams, Quincey, & Stillwell, 2015).

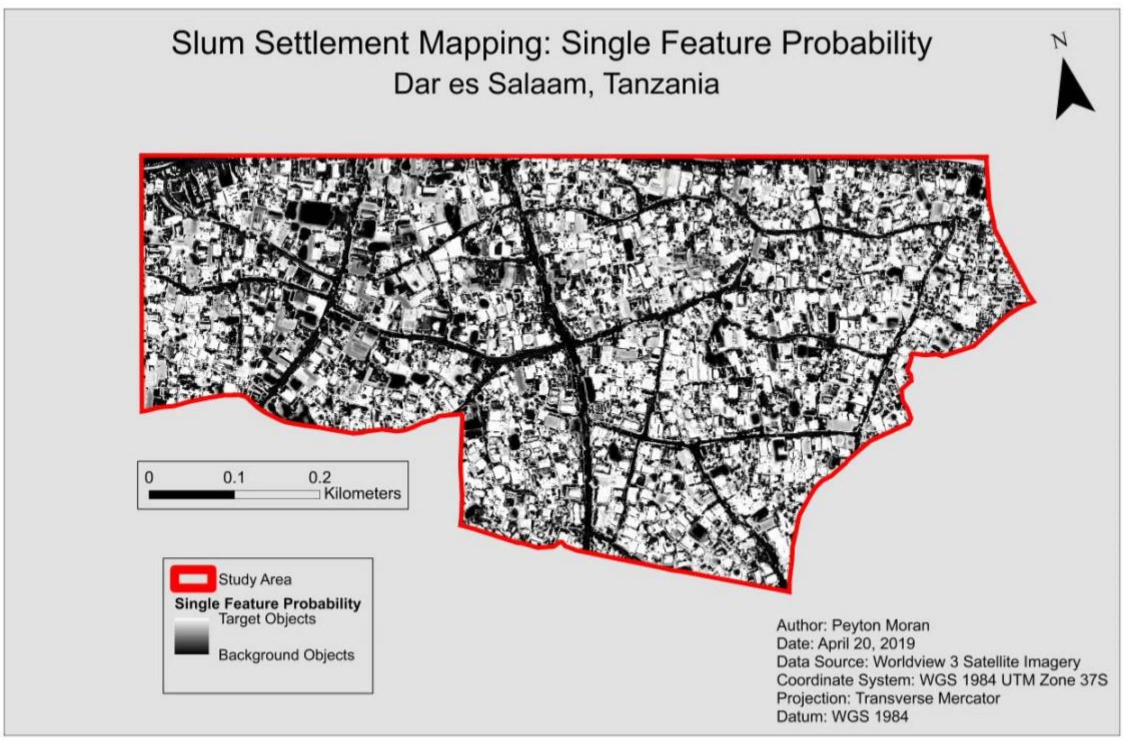

Figure 4. Single feature probability method in (step 1).

https://digitalcommons.cwu.edu/ijurca/vol12/iss1/5
DOI: 10.7710/2168-0620.0294

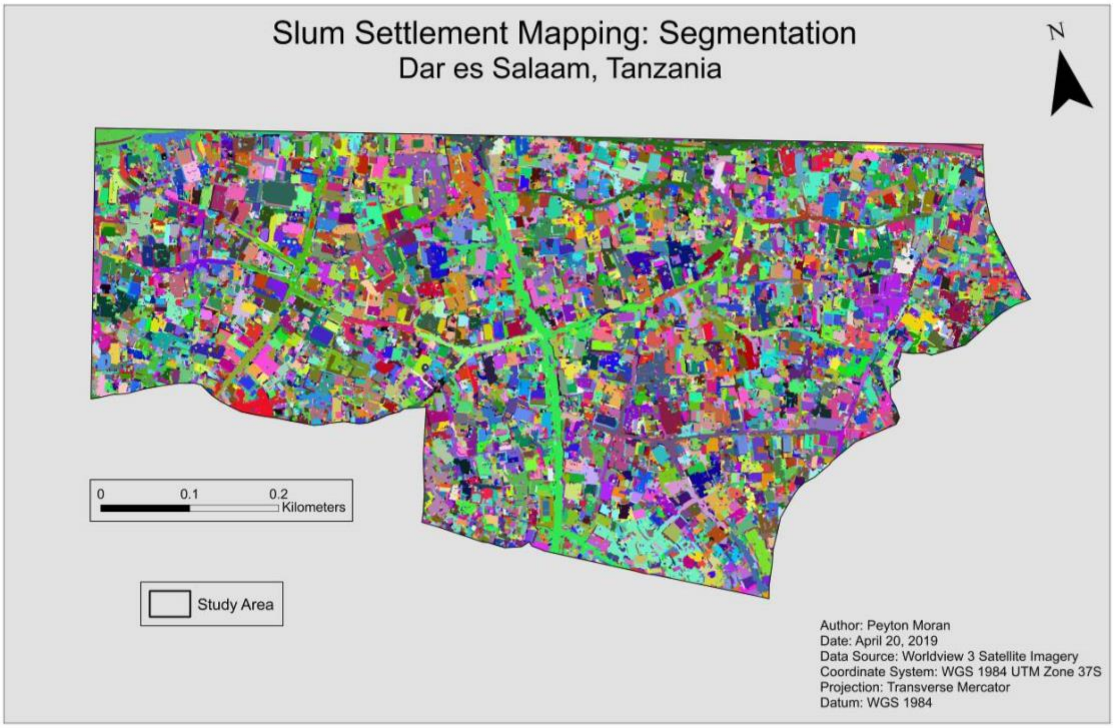

Figure 5. Segmentation method (step 2).

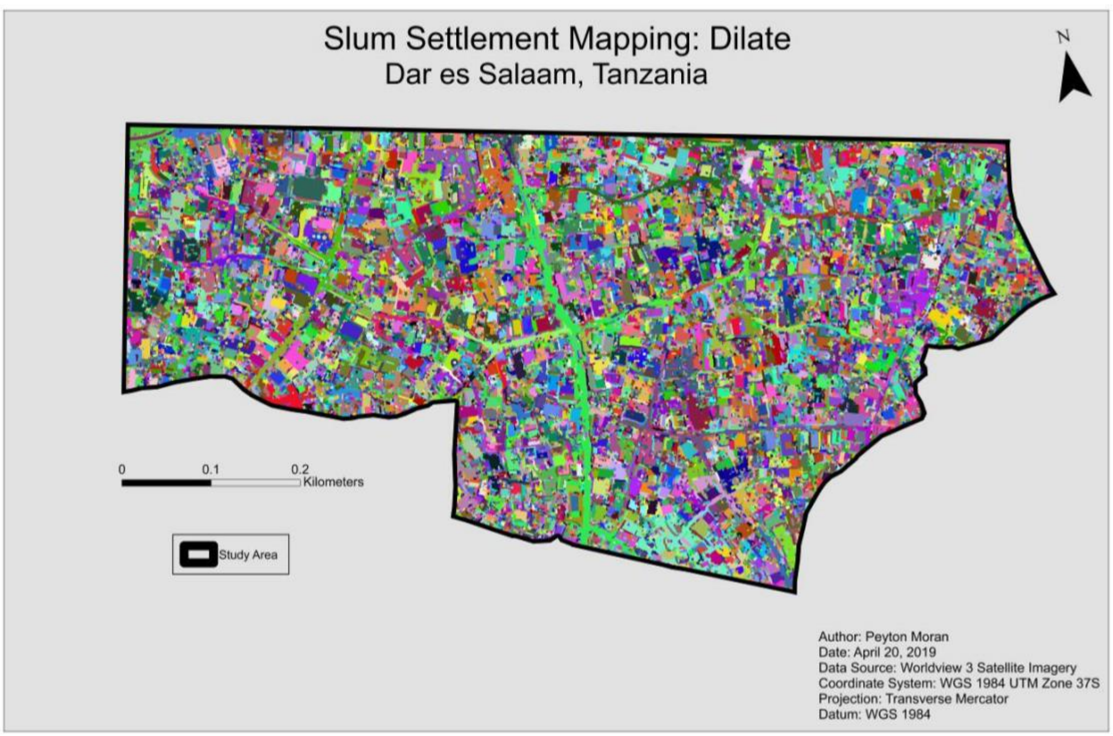

Figure 6. Dilate function (step 3).

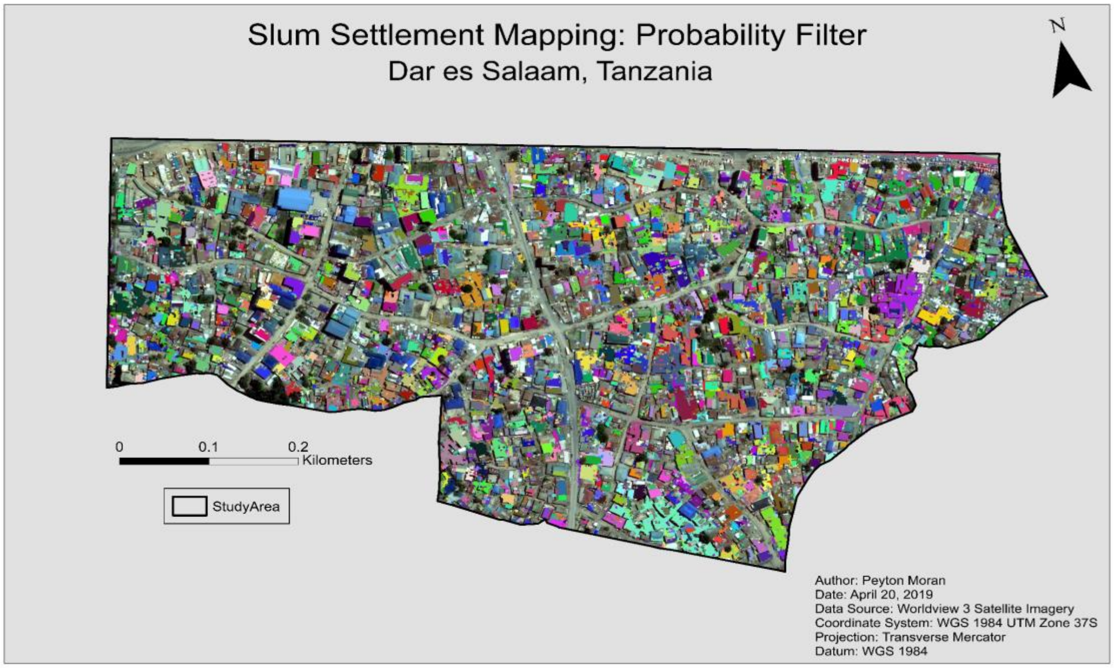

Figure 7. Probability filter (step 3).

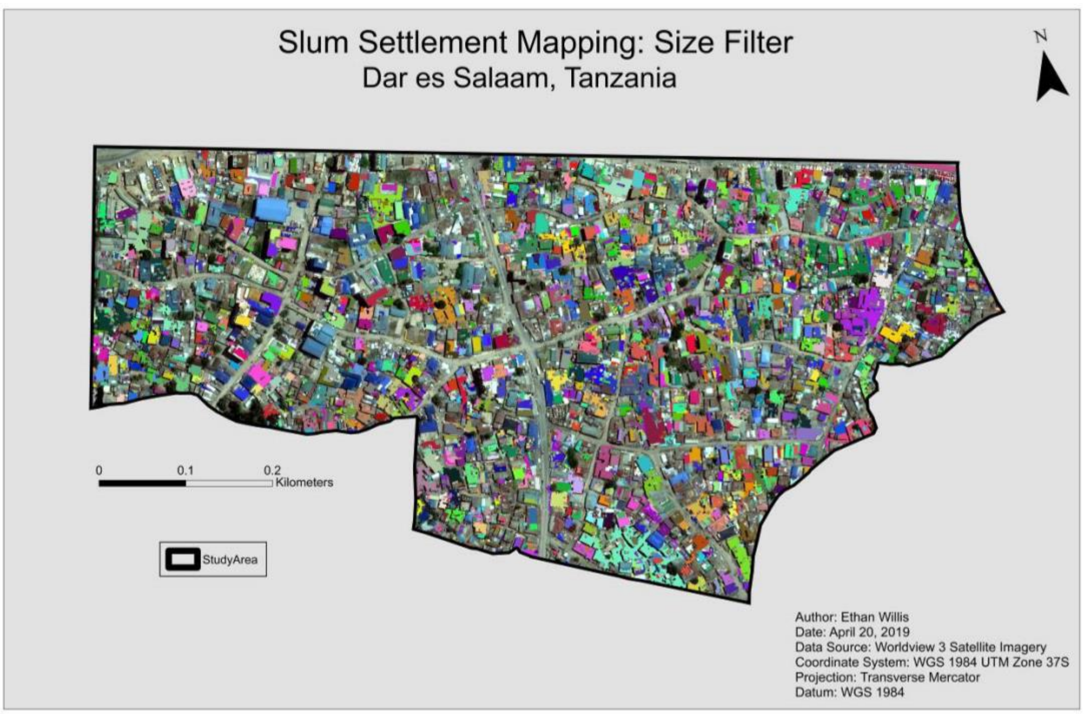

Figure 8. Size filter (step 3).

DOI: 10.7710/2168-0620.0294

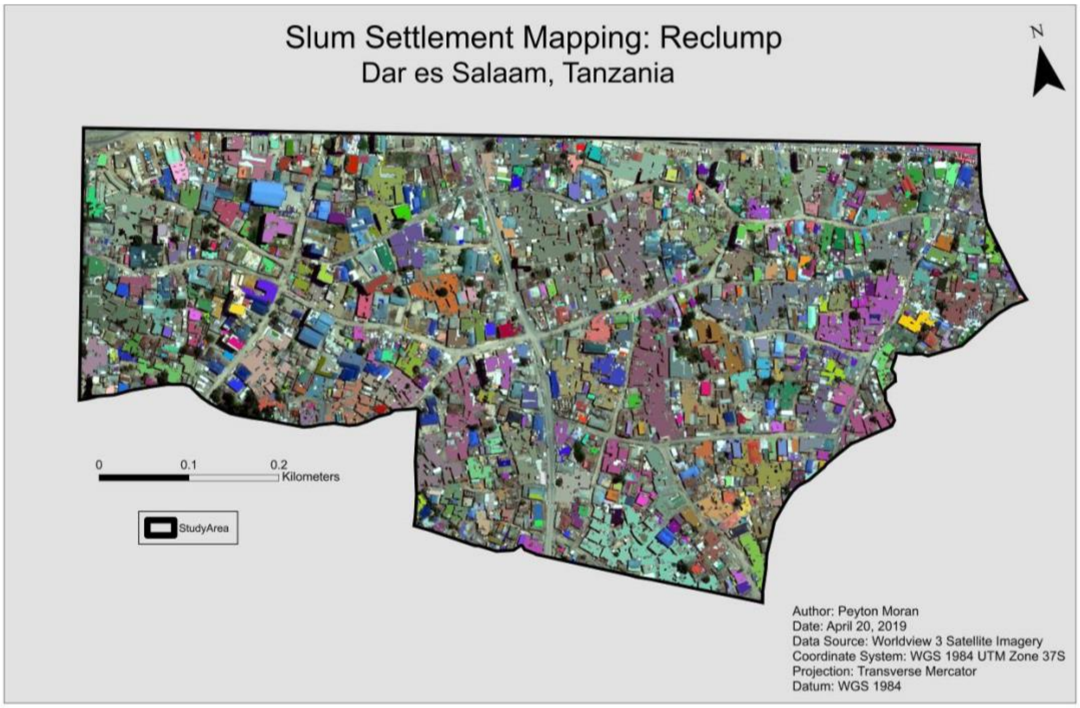

Figure 9. Reclump function (step 3).

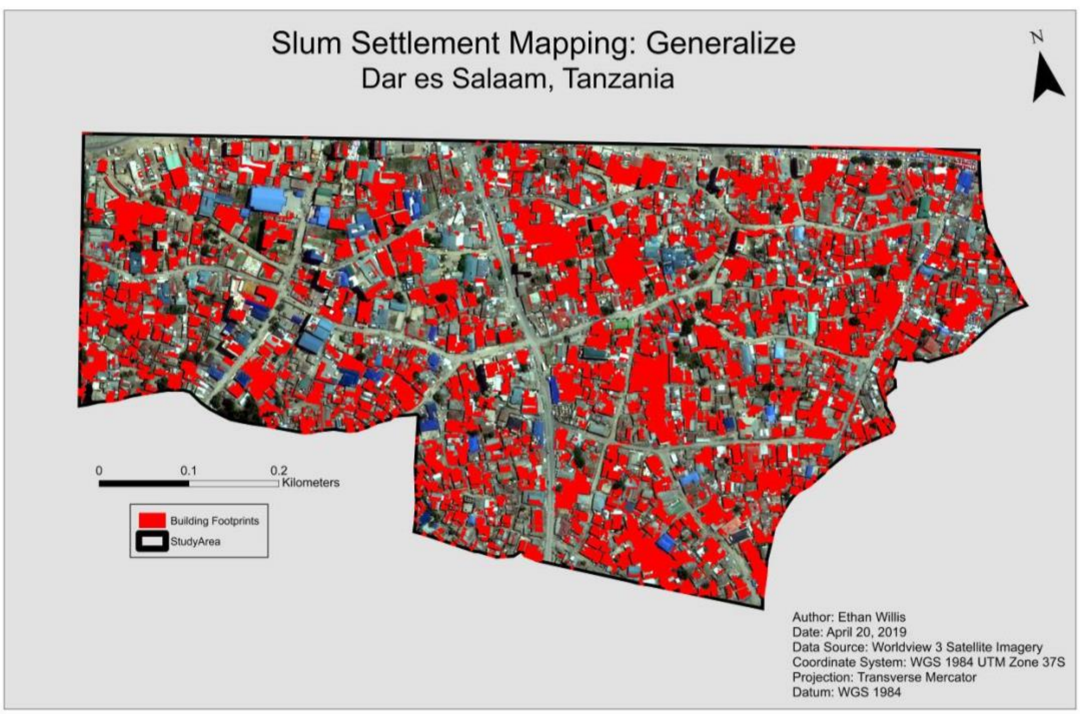

Figure 10. Generalize function (step 5).

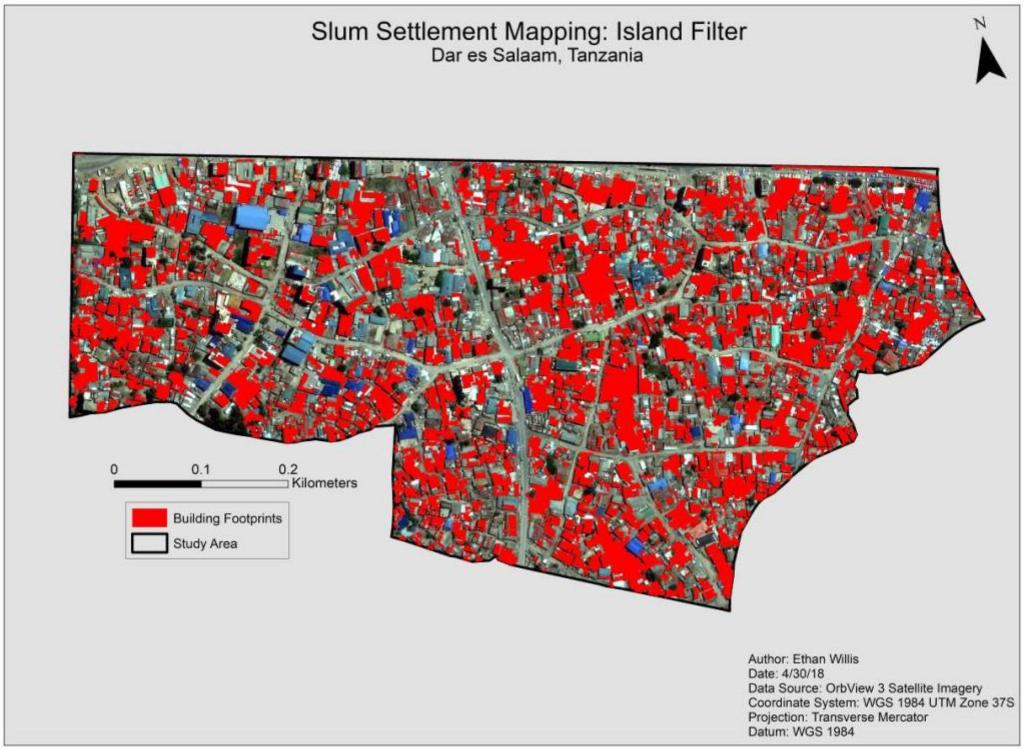

Figure 11. Island filter function (step 5).

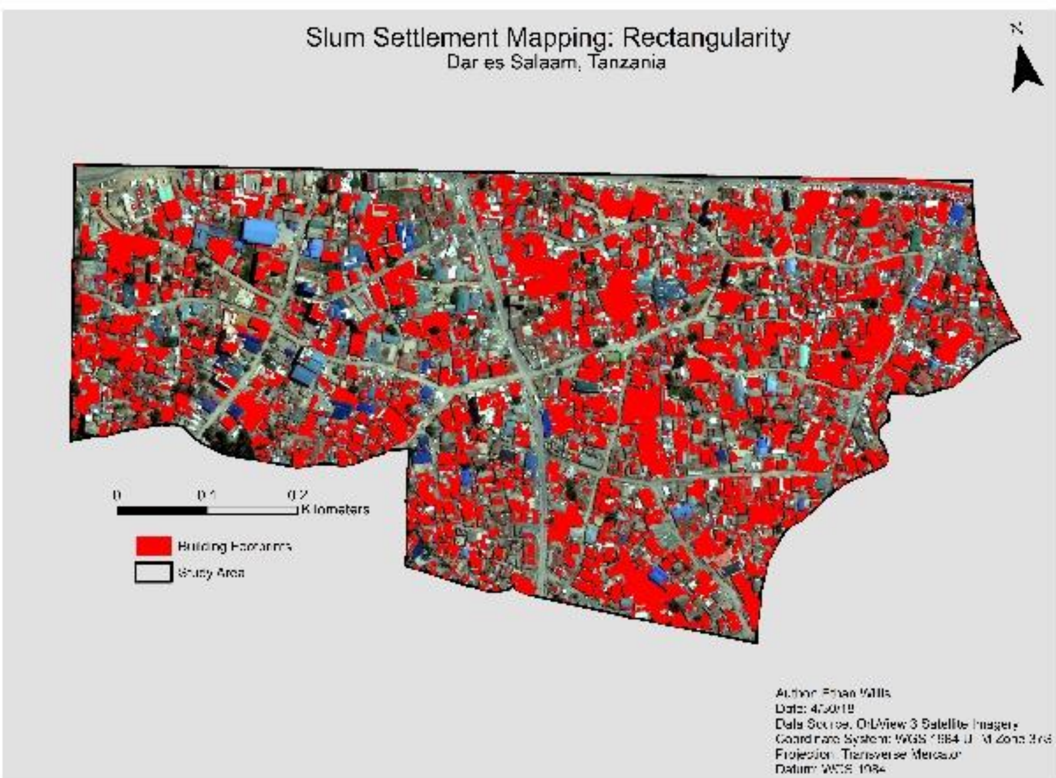

Figure 12. Rectangularity function (step 6).

DOI: 10.7710/2168-0620.0294

Results

In the observed area, 32% of the extracted features or buildings were slum settlements—the result of our input criteria in the ERDAS Imagine Objective. The results also display that 118,500 square meters of the area consists of slum settlements. A visual comparison between both the output building footprints and the original satellite image shows that not every slum settlement was captured using the ERDAS Imagine Objective. There are many reasons as to why this may have occurred, such as varying rooftop characteristics (i.e., tin, plastic), compactness, and shade.

Random stratified sampling was used to assess the accuracy of this research. A total of 100 points were generated throughout the case study site. The sample points were visually interpreted on the Worldview 3 image, yielding an overall accuracy assessment of 75%. Although the process did not capture each and every slum settlement in the observed area, it still seemed to capture an adequate amount for a successful analysis to be completed.

Discussion

OBIA has proven to be a reliable and efficient process to capture slum settlement objects with remote sensing. The findings of this research and model hold the potential to affect three individuals and groups: remote sensing users, city planners, and local citizens of slum settlements. For remote sensing users, OBIA has the ability to observe and analyze groups of pixels that are similar in color, size, texture, and compactness (Blaschke, et al., 2014). Other models that are often used by remote sensing professionals and researchers include contour models, machine learning, pixel-based analysis, statistical models, or visual image interpretation. Visual interpretation of objects in an image can become quite strenuous because it requires users to create individual layers or polygons for each observed object. By contrast, pixel-based analysis is incapable of observing the complexity of objects.

Another group of individuals that would be positively affected by the use of OBIA in slum settlement mapping are city planners and local officials. Slum identification mapping can assist local officials and city planners in housing-related policy, to establish land ownership, to implement urban services (i.e., waters, garbage disposal systems, asphalt roads, schools), and to assess the local economy (Kuffer, Pfeffer, & Sliuzas, 2016). One of the primary issues national governments and other organizations routinely struggle to negotiate is establishing land and home ownership, due in part because there is no land ownership in these unplanned areas. Previous research has shown, however, that both the government and the residents of slum settlements need to begin an integrated approach in decision-making (Bolay, 2006). OBIA can enable city planners to identify neighborhoods that are most affected by insecure tenure and a lack of urban services. If city planners and local officials use these results to improve housing, living, and health conditions for the residents, it may exponentially increase the quality of life for slum residents. It may also decrease the number of slums in the area itself.

Although other research and methods have provided compelling results, OBIA seems preferable because it evaluates groups of pixels, based on color, shape, texture, compactness, and so forth. This study demonstrates OBIA is able to observe and analyze a multitude of objects to determine whether it reflects a slum settlement. The model may provide city planners, local officials, and remote sensing users the opportunity to delineate what may and may not be slum settlements in Dar es Salaam and other cities across the globe. Through this research and further modeling, it is our hope that OBIA can provide the means to an improved, healthier, and durable neighborhood for slum settlement citizens.

References

Blaschke, T., Hay, G. J., Kelly, M., Lang, S., Hofmann, P., Addink, E., & Tiede, D. (2014). Geographic object-based image analysis: Towards a new paradigm. *ISPRS Journal of Photogrammetry and Remote Sensing*, *87*(100), 180–91.

Bolay, J. C. (2006). Slum and urban development: Questions on society and globalization. *The European Journal of Development Research, 18*, 284–98.

Dar Ramani Huria. (2015). Manzese [Web page]. Retrieved from https://ramanihuria.org/en/manzese

D'Oleire-Oltmanns, S., Coenradie, B., & Kleinshmit, B. (2011). An object-based classification pproach for migrant urban housing in the mega-urban area of the Pearl River Delta (China). *Remote Sensing*, *3*(8), 1710–23.

Galetti, C. S., & Myint, S. W. (2014). Land use mapping in a mixed urban-agricultural arid landscape using object-based image analysis: A case study from Maricopa, Arizona. *Remote Sensing*, 6(7), 6089–6110.

Kohli, D., Sliuzas, R., & Stein, A. (2016). Urban slum detection using texture and spatial metrics derived from satellite imagery. *Journal of Spatial Science*, 61(2), 405–26. https://doi.org/10.1080/14498596.2016.1138247

Kuffer, M., Pfeffer, K., & Sliuzas, R. (2016). Slums from space: Fifteen years of slum mapping using remote sensing. *Remote Sensing*, *8*(6), 1–29. https://doi.org/10.3390/rs8060455

Li, J., Li, Y., Chapman, M. A., & Ruther, H. (2005). Small format digital imaging for informal settlement mapping. *Photogrammetric Engineering and Remote Sensing*, *71*(4), 435–42. https://doi.org/10.14358/PERS.71.4.435

Nobrega R.A.A., O'Hara C.G., Quintanilha J.A. (2008) An object-based approach to detect road features for informal settlements near Sao Paulo, Brazil. In Blaschke T., Lang S., Hay G.J. (Eds.) *Object-Based Image Analysis* (pp. 549–78). Springer. https://doi.org/10.1007/978-3-540-77058-9_32

Sim, S., & Lee, D. (2014). Object-based feature extraction of Google Earth imagery for mapping termite mounds in Bahia, Brazil. *International Electronic Conference on Sensors and Applications*. Remote.

UN-HABITAT. (2010). *Informal Settlements and Finance in Dar es Salaam, Tanzania* [PDF]. Nairobi: Shaaban A. Sheuya. Retrieved from https://unhabitat.org/informal-settlements-and-finance-in-dar-es-salaam-tanzania.

Williams, N., Quincey, D., & Stillwell, J. (2015). Automatic classification of roof objects from aerial imagery of informal settlements in Johannesburg, South Africa. *Applied Spatial Analysis* and Policy, *9*, 269–81.

Wurm, M., & Taubenbock, H. (2017). Detecting social groups from space: Assessment of remote sensing-based mapped morphological slums using income data. *Remote Sensing Letters, 9*(1), 41–50. https://doi.org/10.1080/2150704X.2017.1384586

Wurm, M., Taubenbock, H., Weigand, M., & Andreas, S. (2017). Slum mapping in polarimetric SAR data using spatial features. *Remote Sensing of Environment, 194*, 190–204. https://doi.org/10.1016/j.rse.2017.03.030

https://digitalcommons.cwu.edu/ijurca/vol12/iss1/5
DOI: 10.7710/2168-0620.0294