Impact of seasonal urban greening variability on land surface temperature in Benin (West Africa).

Akakpo Bokon Alexis (ab_akakpo@yahoo.fr)
WASCAL, Climate Change and Human Habitat, Doctoral Research Programme, Federal University of Technology, PMB 65, Minna, Niger State, Nigeria https://orcid.org/0000-0001-8537-3540

Okhimamhe A. Appollonia
WASCAL, Climate Change and Human Habitat, Doctoral Research Programme, Federal University of Technology, PMB 65, Minna, Niger State, Nigeria

Orekan A.O. Vincent
University of Abomey-Calavi, Faculty of Human and Social Sciences, Geography Department, Laboratory of Biogeography and Environmental Expertise, BP 677 Abomey-Calavi, Benin Republic

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Abstract

Urban greening quantification and seasonal variation impact for surface temperature mitigation have been poorly understood and monitored in Benin. We have attempted to assess of season variability of normalized difference vegetation index (NDVI) using Landsat 7 and 8 data to get more accurate information about the vegetation tendency and effects on urban surface temperature mitigation. Monthly satellite derived NDVI series were collected using Google Earth Engine open-source while observed surface temperature were obtained at National Agency of Meteorology in Benin. We performed Mann-Kendall trend test to assess the significance of the trend chats. ANOVA followed by SNK test was applied to examine seasonal variation on NDVI significance. Likewise, a simple linear regression was applied to show the relationship between surface temperature and NDVI variables. No significant linear trends (p-values > 0.05) were observed for annual vegetation index (NDVI) and surface temperature. The NDVI tendency decreased from 2000 to around 2011 and started to increase up to 2020. However significant difference (P-Value < 0.001) between seasons was found for the mean NDVI and January-March period showed the lowest values of mean NDVI. Despite the negative relationship between annual mean land surface temperature (LST) and NDVI, the dry seasons showed a positive correlation in each city. Thereby, judicious urban management of water availability such as greenery irrigation would be more helpful for ensuring the sustainable urban surface temperature mitigation.

Introduction

Cities are complex ecosystems that are mostly affected by ecological consequences of uncontrolled urban growth that can be briefly summarized as increasing urban heat, degradation of air, water and soil cycles and quality, trouble in land-use and cover, loss of biodiversity, change in climate as well as transport congestions and social vices (Siddiqui et al., 2018). Urban green infrastructure (urban forests, wetlands, parks, street trees, small gardens, green roofs, and walls) that is the hybrid of greenery and built systems has therefore evident impacts as strategy to improve for adapting and mitigating climate change issues as well as providing good quality of life in the world (Norton et al., 2015; Scott et al., 2016). Urban vegetation and trees have effective reduction impacts on air temperature through shading radiation and evapotranspiration functions (Wang et al., 2016). For instance, pedestrian greening within the Catania University campus reduced by 1.00°C the air temperature (Detommaso et al., 2021). Anamika & Pradeep (2016) in reviewing urban vegetation roles in air pollution found that urban trees were actor for O_3, PM_{10}, NO_2, SO_2, CO molecules pollution removal in range of 711,000 metric tons per year over 55 US cities. However, these urban greenery functions are made more efficient when vegetation phenology and structure are also agreed.

Changes in urban vegetation phenology may have significant implications for carbon cycles with feedbacks on urban ecosystem climate. Indeed, dense foliage cover is followed by simultaneous increases transpiration rates (increased canopy conductance), decreased albedo through reducing shortwave radiation absorbed and increased ground aerodynamic roughness that can favour air turbulence and the sensible heat transfer to and from the atmosphere (Piao et al., 2019). Moreover, there is high correlation between vegetation development and season variation in tropics (Ayanlade, 2016; Ayanlade & Howard, 2019). Then, the cooling effects induced by urban vegetation should be also changed by seasons in years. The study carried out by Jeong et al. (2009) demonstrated a high decreasing correlation between the growth vegetation and the increased rate of surface temperature in spring. Likewise, a study found some asymmetric responses of vegetation development to autumn and spring warm effects (Li et al., 2018). However, these seasonal variations in the relationship vegetation-air temperature can vary significantly with region (Jeong et al., 2009).

Many cities in Benin Republic are experiencing an uncontrolled urbanization with consequences on urban heat expression that have inevitably impacted on the health and the daily lives of local residents (Lanmandjèkpogni et al., 2019; Falolou et al., 2020). Moreover, it was recognized that the development and good management of urban vegetations contribute enormously to the mitigation and adaption of this heat effect in the country (Osseni et al., 2015; Teka et al., 2017). However, the quantification and temporal variation of the contribution of these vegetations in urban warming reduction is needed for sustainable urbanisation planning. This paper examines urban vegetation trend with surface temperature, characterize the seasonal variation of urban greening and assesses the influence of the greenness in urban areas on land surface temperature reduction in Benin (West Africa).

Methods

Study Area

The cities of Porto-Novo (6°26'- 6°31' and 2°34'- 2°41') and Parakou (9°15'- 9°27' and 2°31'- 2°45') were chosen as the case study. They are respectively the second and third largest and fastest growing cities in Benin (Lohnert, 2017). The population of Porto-Novo was 264,320 inhabitants and the population of Parakou was 255,478 inhabitants (INSAE, 2016). Porto-Novo is located in the southern region while Parakou in the central region of the country (Fig. 1).

Porto-Novo has a wet tropical climate (Subequatorial climate) with annual rainfall estimated at 1200 mm/year (Houngla et al., 2019). Two rainy seasons (usually from April to July and September to November) and two dry seasons (month of August and December to March) were observed in this area (Ahokpossi, 2018). Parakou has dry tropical climate (Sudano-Guinean climate) and the average annual rainfall was between 1170 and 1200 mm/year (Neuenschwander et al., 2011; Miassi & Dossa, 2018; Lanmandjèkpogni et al., 2019) and characterized by a unimodal rainy season from June to October with a peak in August (Lanmandjèkpogni et al., 2018).

The natural vegetation is almost non-existent in urban area of Porto-Novo (Osseni et al., 2015). While tree plantations and gallery forests are mostly observed in urban areas of Parakou (Miassi & Dossa, 2018).

Data

The urban green-stuff importance and productivity is widely characterized by the normalized difference vegetation index (NDVI) (Li et al., 2017; Malik et al., 2020). The data used in this paper included the NDVI image collections and observed land surface temperature. Monthly satellite derived NDVI series were collected on the two cities using Google Earth Engine open-source (https://code.earthengine.google.com). The observed monthly temperature data were obtained at the National Agency of Meteorology of Benin from 1990 to 2020. Due to the limitation in meteorological data for certain periods, we completed the missing data with remote sensing data from Landsat images with high-resolution radiometer sensors of Landsat 7 (2000 to 2013) and Landsat 8 (2014 to 2020). Land surface temperature was obtained using Google Earth Engine codes recently created by Ermida et al.(2020)

(https://code.earthengine.google.com/?accept_repo=users/sofiaermida/landsat_smw_lst.).

Analysis

We performed the linear-trend analyses on annual mean of NDVI and land surface temperature using a non-parametric over the time period of 2000-2020 (Li et al., 2018). Mann-Kendall test was applied to assess the significance of the trend chats (Mondal et al., 2012). The analysis of variance (ANOVA) was used after checking normality and homogeneity of data to examine the significance of year-seasons (Trimester periods) variation on vegetation index (NDVI). Student-Neuman-Keuls (SNK) test was applied to make difference in means once ANOVA test was significant. A simple linear regression was applied to show the relationship between surface temperature and NDVI. R core software version 4.0.3 (R Core Team, 2019) was employed in all statistical analyses.

Results

Changes in urban vegetation index (NDVI) and land surface temperature (LST) from 2000 to 2020

The test of Mann-Kendall showed no significant linear trend in annual NDVI data (p-values > 0.05). Likewise, no significant linear trend was found in annual LST for data from the combined cities and the city of Parakou (p-values > 0.05). However, a significant linear trend was moderatly found in annual LST data for the city of Porto-Novo (p-values = 0.023). Therefore, an upward trend can be attribute to the annual LST data of Porto-Novo (Fig. 3).

We also noted a decreasing tendency of NDVI from 2000 to 2011 and an increasing up to 2020 (Fig. 2).

Seasonal variation of vegetation index (NDVI)

The vegetation index (NDVI) assessed according to the annual quarters (sensibly season variation) from 2000 to 2020 showed significant difference (P-Value < 0.001) for the combined cities as well as for each city (Table 1). The mean NDVI for January-March period was significantly low for the combined cities and Porto-Novo. In opposite, the period of April-June had the high mean NDVI value (Table 2). Regarding of

July-September and October-December periods, no statistically different has was found (Table 2). However, the situation of Parakou was a bit different from Porto-Novo. Although the period of January-March still kept the low mean NDVI value, no significant difference was found for the remaining periods of the year (Table 2).

Table 1
Summary of ANOVA model on vegetation index (NDVI)

City	df	Sum sq	Mean sq	F-Value	P-Value
Both cities	3	0.701	0.233	19.46	6.71e-12***
Porto-Novo	3	0.503	0.167	16.45	8.3e-10***
Parakou	3	0.234	0.078	5.76	0.000***
Signif. codes: '***'= 0.001					

Table 2
Mean, standard deviation (Std) and difference structuration of vegetation index

Period	Both cities		Porto-Novo		Parakou	
	Mean	Std	Mean	Std	Mean	Std
Jan-March	0.147[a]	0.051	0.137[a]	0.054	0.162[a]	0.043
April-June	0.255[b]	0.133	0.260[b]	0.119	0.245[b]	0.146
July-Sept	0.202[c]	0.151	0.200[c]	0.139	0.213[b]	0.159
Oct-Dec	0.213[c]	0.077	0.195[c]	0.063	0.233[b]	0.085
Means with the same letter are not significantly different (SNK test).						

Urban surface temperature and seasonal NDVI influence

Figure 4 showed the linear regression analysis between annual LST and NDVI for the combined cities. On this figure, each point showed the mean LST and NDVI value linked to urban area, the red smoothly line was the result of linear simulation and the function of linear regression was also exhibited at the top. It could be therefore understood that the regression analysis result showed a significant inverse correlation between mean LST and NDVI values (p-value = 0.01165, Fig. 4). Therefore, we can suggest that a seasonal time with more vegetation cover (higher NDVI) induced correspondingly greater rates of evapotranspiration and lead to the land surface and atmosphere latent and sensible heat exchange in comparison to the seasonal period with few vegetation covers at the same areas. Similar result was obtained for each individual city (Porto-Novo: p-value = 0.02 and Parakou: p-value = 0.000; Table 3). However, when considering the individual season periods, the regression analysis showed the positive correlation between mean LST and NDVI values for January–March for Porto-Novo (Table 3 and Fig. 5) and April–June for Parakou (Table 3 and Fig. 6). This finding means that urban vegetation may not induce a moderate land surface temperature reduction at these periods respectively in Porto-Novo and Parakou.

Table 3
Linear regression and correlation coefficients for the relationship between LST and NDVI

Periods	Regression functions	df	r	R-sq
City of Porto-Novo				
Annual	LST = 28.300 -1.489×NDVI	248	-0.138	0.019
Jan-March	LST = 28.798 + 1.757×NDVI	61	0.112	0.012
April-June	LST = 28.721–1.784 ×NDVI	58	-0.22	0.048
July-Sept	LST = 26.536 – 0.078×NDVI	58	-0.026	0.0007
Oct-Dec	LST = 28.300–0.716×NDVI	58	-0.074	0.005
City of Parakou				
Annual	LST = 28.110–1.398×NDVI	216	-0.427	0.182
Jan-March	LST = 29.515–1.315 ×NDVI	48	-0.036	0.0013
April-June	LST = 28.462 + 0.332×NDVI	48	0.037	0.0014
July-Sept	LST = 25.615 – 0.135×NDVI	48	-0.048	0.0023
Oct-Dec	LST = 28.547–4.091×NDVI	48	-0.427	0.183

Discussion

Greenery seasonal dynamics is more crucial for monitoring urban environment. We have attempted to understand the quarterly variability of NDVI using Landsat data to get more accurate information about the vegetation effects on urban land surface temperature reduction. Along this, NDVI varied from year to year in cities. A similar trend was globally observed with a decreasing trend from 2000 to 2011 and an increasing trend from 2011 to 2020. This finding can be explained by the national commitments to vegetate cities with the governmental project “10 million people – 10 million trees” instituted in 2013 (MCVDD, 2019). Therefore, this governmental project would awake spirit in good management and safeguard of the existing urban vegetation in these cities. Likewise, the project goal was that each inhabitant must plant at least one tree per year with careful monitor. Moreover, the particular changes among cities could be the response to the vegetation density and the plant species diversity changes in these cities (Kinyanjui, 2011; Zohoun et al., 2020; Sehoun et al., 2021). The land surface temperature (LST) followed similar trend for the combined cities as well as for the cities taken individually. This result can be attributed to the changes in vegetation index. The land surface temperature was globally in decreasing (Fig. 3) with increasing NDVI (Fig. 2). The same findings were mentioned by Zhao et al. (2019) on factors affecting the decreased temperature. Likewise, a study in the horn of Africa has also found a negative relationship between air temperature and vegetation cover (Ghebrezgabher et al., 2020). However, although efforts were born to improve greenery in Beninese cities, a significant linear trend of LST was occurred in the city of Porto-Novo. We can justify this finding by the weakness in the management and monitoring of planted trees. It can be likely due to the density of built area (lack of areas for trees plantation), introduction of plant species without resident contentment (Osseni et al., 2014). Therefore, the NDVI trend was also somehow degraded in this city (Fig. 2).

A very significant difference was shown between seasonal variations of vegetation index (NDVI). This finding can be justified by season-wise vegetation statuses in the cities. Therefore, not only urban vegetation state varied according to space but also it varied with respect to climatic period (Malik et al., 2020). For combined cities as for individual studied cities, the period of January-March had the significant low mean NDVI value. This result can be similar to Piao et al. (2019), who found a low value for the period of June-July on the city of Nanjing (China). Then, the authors explained this difference by the interference of cloud and rain occurring. Other study found that during January to April in India, the vegetation showed very low NDVI because during this period very few leaves were available to reflect NDVI signature (Malik et al., 2020). The periods from January to March and April-June respectively in south and centre Benin, refer to dry season when overall vegetation features are in water stress (Ahokpossi, 2018; Oussou et al., 2022). Moreover, a link could be also made between the vegetation index and the vegetation phenology (Su et al., 2020). Likewise, it was also demonstrated that the seasonal variability is more important to describe the variation in phenological expression of urban vegetation (Li et al., 2017; Piao et al., 2019). Thereby, Su et al. (2020) went further to make relationship between season period and canopy phenology that are very determining in vegetation index importance. Along this, what should be the impacts of both seasonal and NDVI variability on land surface temperature in the study areas?

Annual mean LST builds a moderate negative correlation with NDVI in the combined cities as well as in separate cities. The similar result was found by many researchers who demonstrated an inverse correlation relationship between LST and NDVI whatever the land use types and polygons (Yue et al., 2007; Richards et al., 2020). But although the cooling effects that greening can procure to urban areas were widely demonstrated, the vegetation physiology due to environmental conditions can have strong impacts on this service (Norton et al., 2015). Thereby, the assessing seasonal variability in relationship between LST and NDVI, revealed a moderate positive correlation between LST and NDVI in the periods of January to March and April to June respectively for Porto-Novo (Figs. 5) and Parakou (Fig. 6). This finding expressed that the increase in urban vegetation in these cities respectively for these above periods could not decrease the LST. We can justify this finding by the occurrence of dry season at these periods respectively in Porto-Novo and in Parakou. Therefore, the vegetation that would be experiencing water stress cannot have great rates of evapotranspiration, then can lead higher surface temperature (Norton et al., 2015). Porto-Novo and Parakou usually experience respectively strong dry period with high water stress from January to March (Ahokpossi, 2018) and April to June (Ahokpossi, 2018; Lanmandjèkpogni et al., 2018). So, a wise investment in water availability such as urban greening irrigation would be more adequate for ensuring a sustainable urban surface temperature mitigation as well as other ecosystem service providing (Norton et al., 2015).

Conclusion

No significant linear trends were observed for annual vegetation index (NDVI) and land surface temperature (LST) in the study areas. The NDVI tendency decreased from 2000 to 2011 and increased from 2011 to 2020. The city of Porto-Novo showed a moderate particularity in terms of linear significance in trend for land surface temperature (LST). The period of January to March showed the lowest values of mean NDVI. We also found a negative relationship between annual mean LST and NDVI. But, a seasonal positive correlation between LST and NDVI was shown for the periods of January-March and April-June respectively in Porto-Novo and Parakou. These periods coincide with the dry seasons and the vegetation usually express water stress. Thereby, a wise urban management for water availability such as greenery irrigation would be more helpful for ensuring sustainable urban surface temperature mitigation.

Declarations

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Author contribution statement

Akakpo Bokon Alexis: Conceptualization, Methodology, Data curation, Formal analysis, Validation, Writing - original draft, Writing - review & editing, Visualization. Professor **Okhimamhe Appollonia A**.: Principal supervisor of the work. Professor **Orekan A.O. Vincent** associate supervisor of the work.

Declaration of competing interest

Authors declare no conflict of interest

References

1. Ahokpossi, Y. (2018). Analysis of the rainfall variability and change in the Republic of Benin (West Africa). Hydrological Sciences Journal, *63*(15–16), 2097–2123. https://doi.org/10.1080/02626667.2018.1554286

2. Anamika, A., & Pradeep, C. (2016). Urban Vegetation and Air Pollution Mitigation: Some Issues from India. Chinese Journal of Urban and Environmental Studies, *04*(01), 1650001 (10p). https://doi.org/10.1142/s2345748116500019
3. Ayanlade, A. (2016). Seasonality in the daytime and night-time intensity of land surface temperature in a tropical city area. Science of the Total Environment, *557–558*, 415–424. https://doi.org/10.1016/j.scitotenv.2016.03.027
4. Ayanlade, A., & Howard, M. T. (2019). ace temperature and heat fluxes over three cities in Niger Delta. Journal of African Earth Sciences, *151*, 54–66. https://doi.org/10.1016/j.jafrearsci.2018.11.027
5. Detommaso, M., Gagliano, A., Marletta, L., & Nocera, F. (2021). Sustainable urban greening and cooling strategies for thermal comfort at pedestrian level. Sustainability (Switzerland), *13*(6), 1–23. https://doi.org/10.3390/su13063138
6. Ermida, S. L., Soares, P., Mantas, V., Göttsche, F. M., & Trigo, I. F. (2020). Google earth engine open-source code for land surface temperature estimation from the landsat series. Remote Sensing, *12*(9), 1–21. https://doi.org/10.3390/RS12091471
7. Falolou, L. F., Orekan, V., Houssou, C. S., & Euloge, K. (2020). Caractérisation des ilots de chaleur dans la Commune de Porto-Novo et ses alentours [Characterization of heat islands in the Municipality of Porto-Novo and its surroundings]. International Journal of Progressive Sciences and Technologies, *20*(2), 442–456.
8. Ghebrezgabher, M. G., Yang, T., Yang, X., & Eyassu Sereke, T. (2020). Assessment of NDVI variations in responses to climate change in the Horn of Africa. Egyptian Journal of Remote Sensing and Space Science, *23*(3), 249–261. https://doi.org/10.1016/j.ejrs.2020.08.003
9. Houngla, E. J. H., Hinson, C. D. T., Gbankoto, A., & Anani, B. C. (2019). Characteristics of urban market gardening in Porto-Novo, Republic of Benin, West Africa. International Journal of Agricultural Science, *4*, 66–76.
10. INSAE. (2016). *Effectif de la population des villages et quartiers de villes du Bénin. Rapport final, RGPH-Recensement Général de la Population et l'Habitat 4è édition. Cotonou, Benin*.
11. Jeong, S. J., Ho, C. I., & Jeong, J. H. (2009). Increase in vegetation greenness and decrease in springtime warming over east Asia. Geophysical Research Letters, *36*(2), 1–5. https://doi.org/10.1029/2008GL036583
12. Kinyanjui, M. J. (2011). NDVI-based vegetation monitoring in Mau forest complex, Kenya. African Journal of Ecology, *49*(2), 165–174. https://doi.org/10.1111/j.1365-2028.2010.01251.x
13. Lanmandjèkpogni, M. P., Codo, F. D. P., & Yao, B. K. (2019). Urban growth evaluation by coupling descriptive analysis and Zipf ' s rank-size model in Parakou (Benin). Urban and Regional Planning, *4*(1), 1–8. https://doi.org/10.11648/j.urp.20190401.11
14. Lanmandjèkpogni, M. P. S., De Paule Codo, F., Yao, B. K., & Aina, M. P. (2018). Seasonal Variation of Nutrient Pollution and Suspended Solids in the Drainage Network of Okpara Basin in Parakou (North-East of Benin). Journal of Environmental Protection, *09*(13), 1359–1371. https://doi.org/10.4236/jep.2018.913084

15. Li, F., Song, G., Liujun, Z., Yanan, Z., & Di, L. (2017). Urban vegetation phenology analysis using high spatio-temporal NDVI time series. Urban Forestry and Urban Greening, *25*, 43–57. https://doi.org/10.1016/j.ufug.2017.05.001

16. Li, Z., Xia, J., Ahlström, A., Rinke, A., Koven, C., Hayes, D. J., Ji, D., Zhang, G., Krinner, G., Chen, G., Cheng, W., Dong, J., Liang, J., Moore, J. C., Jiang, L., Yan, L., Ciais, P., Peng, S., Wang, Y. P., … Luo, Y. (2018). Non-uniform seasonal warming regulates vegetation greening and atmospheric CO 2 amplification over northern lands. Environmental Research Letters, *13*(12), 124008. https://doi.org/10.1088/1748-9326/aae9ad

17. Lohnert, B. (2017). Migration and the Rural-Urban Transition in Sub-Saharan Africa. In *Journal of Applied Physics* (Vol. 69, Issue 3). Centre for Rural Development. https://edoc.hu-berlin.de/bitstream/handle/18452/19070/SLEDP-2017-05-Migration and the Rural-Urban.pdf?sequence = 1

18. Malik, S., Pal, S. C., Das, B., & Chakrabortty, R. (2020). Intra-annual variations of vegetation status in a sub-tropical deciduous forest-dominated area using geospatial approach: a case study of Sali watershed, Bankura, West Bengal, India. Geology, Ecology, and Landscapes, *4*(4), 257–268. https://doi.org/10.1080/24749508.2019.1633219

19. MCVDD. (2019). *Rapport Biénal actualisé du Bénin à la Convention Cadre des Nations Unies sur les Changements Climatiques*.

20. Miassi, Y., & Dossa, F. (2018). Influence of the Types of Fertilizers on the Economic Performance of the Market Garden Production in Parakou Town, Northern Benin. Agricultural Research and Technology, *15*(1), 1–6. https://doi.org/10.19080/ARTOAJ.2018.15.555944

21. Mondal, A., Kundu, S., & Mukhopadhyay, A. (2012). Mann-Kendall Test: A Case Study of North-Eastern Part of Cuttack District, Orissa. International Journal of Geology, Earth and Environmental Sciences, *2*(1), 70–78.

22. Neuenschwander, P., Sinsin, B., & Goergen, G. (2011). *Nature Conservation in West Africa: Red List for Benin*. International Institute of Tropical Agriculture.

23. Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape and Urban Planning, *134*, 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018

24. Osseni, A. A, Mouhamadou, T., Tohoain, B. A. C., & Sinsin, B. (2015). SIG et gestion des espaces verts dans la ville de Porto-Novo au Benin. TROPICULTURA, *332*(2), 146–156.

25. Osseni, Abdel Aziz, Sinsin, B. A., & Teka, O. (2014). Facteurs de contrôle de la diversité des plantations d'alignements dans la ville de Porto-Novo au Bénin. Revue Internationale Des Sciences et Technologie, *10*(4), 200–208.

26. Oussou, F. E., Ndehedehe, C. E., Oloukoi, J., Yalo, N., Boukari, M., & Diaw, A. T. (2022). Characterization of the hydro-geological regime of fractured aquifers in Benin (West-Africa) using multi-satellites and

models. Journal of Hydrology: Regional Studies, *39*, 1–24. https://doi.org/10.1016/j.ejrh.2021.100987

27. Piao, S., Liu, Q., Chen, A., Janssens, I. A., Fu, Y., Dai, J., Liu, L., Lian, X., Shen, M., & Zhu, X. (2019). Plant phenology and global climate change: Current progresses and challenges. Global Change Biology, *25*(6), 1922–1940. https://doi.org/10.1111/gcb.14619
28. R Core Team. (2019). *R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from* https://www.R-proje ct.org/.
29. Richards, D., Fung, T., Belcher, R., & Edwards, P. (2020). Differential air temperature cooling performance of urban vegetation types in the tropics. *Urban Forestry & Urban Greening*, *50*(June 2019), 126651. https://doi.org/10.1016/j.ufug.2020.126651
30. Scott, M., Lennon, M., Haase, D., Kazmierczak, A., Clabby, G., & Beatley, T. (2016). Nature-based solutions for the contemporary city/Re-naturing the city/Reflections on urban landscapes, ecosystems services and nature-based solutions in cities/Multifunctional green infrastructure and climate change adaptation: brownfield greening as an a. Planning Theory and Practice, *17*(2), 267–300. https://doi.org/10.1080/14649357.2016.1158907
31. Sehoun, L. C., Osseni, A. A., Orounladji, M., Lougbegnon, T. O., & Codjia, J. C. T. (2021). Diversité floristique des formations végétales urbaines au Sud du Bénin (Afrique de l ' Ouest). Rev. Mar. Sci. Agron. Vét., *9*(2), 266–273.
32. Siddiqui, A., Siddiqui, A., Maithani, S., Jha, A. K., Kumar, P., & Srivastav, S. K. (2018). Urban growth dynamics of an Indian metropolitan using CA Markov and Logistic Regression. The Egyptian Journal of Remote Sensing and Space Sciences, *21*, 229–236. https://doi.org/10.1016/j.ejrs.2017.11.006
33. Su, Y., Liu, L., Liao, J., Wu, J., Ciais, P., Liao, J., He, X., Liu, X., Chen, X., Yuan, W., Zhou, G., & Lafortezza, R. (2020). Phenology acts as a primary control of urban vegetation cooling and warming: A synthetic analysis of global site observations. Agricultural and Forest Meteorology, *280*, 107765. https://doi.org/10.1016/j.agrformet.2019.107765
34. Teka, O., Togbe, C. E., Djikpo, R., Chabi, R., & Djossa, B. (2017). Effects of Urban Forestry on the Local Climate in Cotonou, Benin Republic Email address : Agriculture, Forestry and Fisheries, *6*(4), 123–129. https://doi.org/10.11648/j.aff.20170604.13
35. Wang, Z. H., Zhao, X., Yang, J., & Song, J. (2016). Cooling and energy saving potentials of shade trees and urban lawns in a desert city. Applied Energy, *161*, 437–444. https://doi.org/10.1016/j.apenergy.2015.10.047
36. Yue, W., Xu, J., Tan, W., & Xu, L. (2007). The relationship between land surface temperature and NDVI with remote sensing: application to Shanghai Landsat 7 ETM + data. International Journal of Remote Sensing, *28*(15), 3205–3226. https://doi.org/10.1080/01431160500306906
37. Zhao, W., He, J., Wu, Y., Xiong, D., Wen, F., & Li, A. (2019). An analysis of land surface temperature trends in the Central Himalayan region based on MODIS products. Remote Sensing, *11*(8), 1–19. https://doi.org/10.3390/rs11080983

38. Zohoun, P. E., Djaouga, M., Zakari, S., Baloubi, D. M., & Yabi, I. (2020). Diversité, structure des arbres et description du boisement dans les concessions de l'espace urbain de Parakou au centre du Bénin. Journal of Applied Biosciences, *154*, 15842–15852. https://doi.org/10.35759/jabs.154.1

Figures

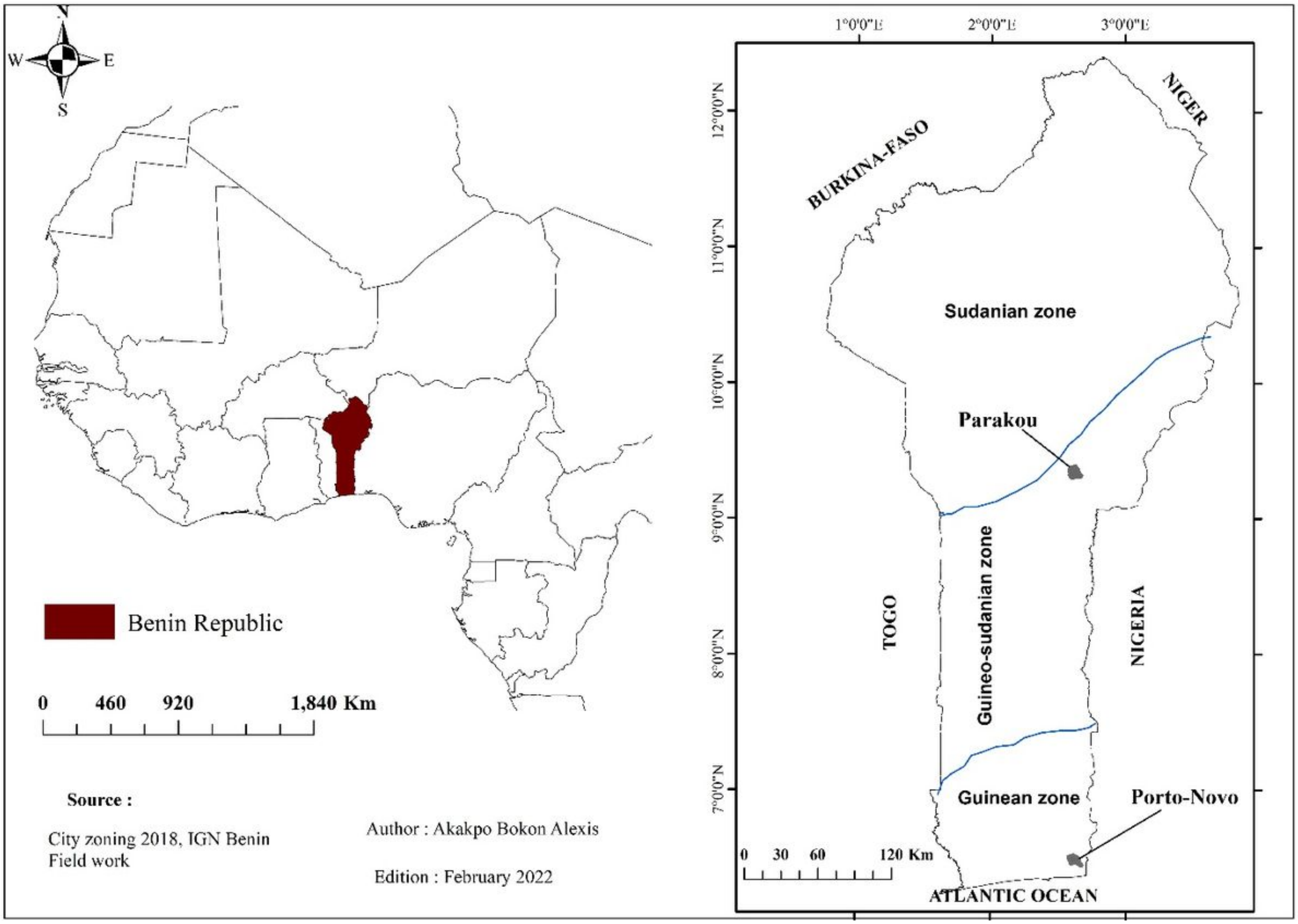

Figure 1

Location map of the case study cities

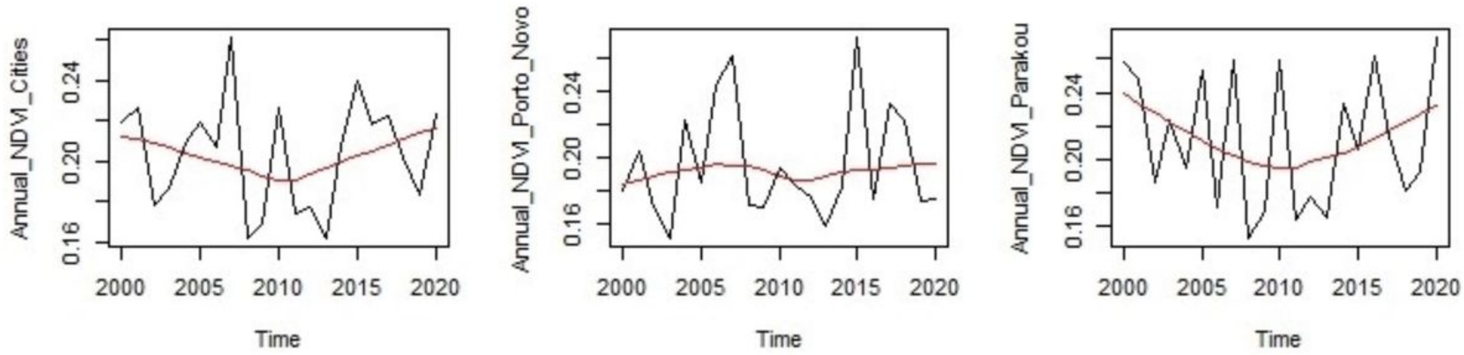

Figure 2

Trend of annual normalized difference vegetation index (NDVI) from the years 2000 to 2020

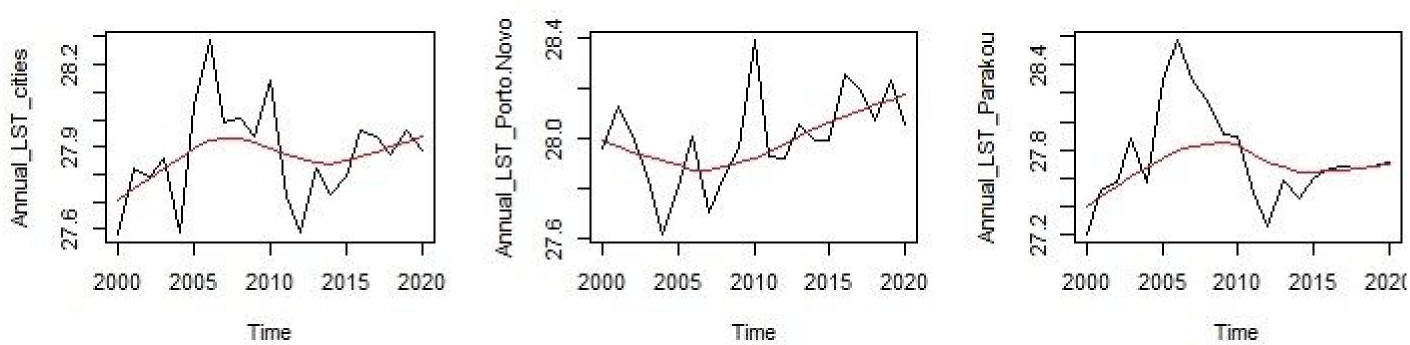

Figure 3

Trend of annual land surface temperature (LST) from the years 2000 to 2020

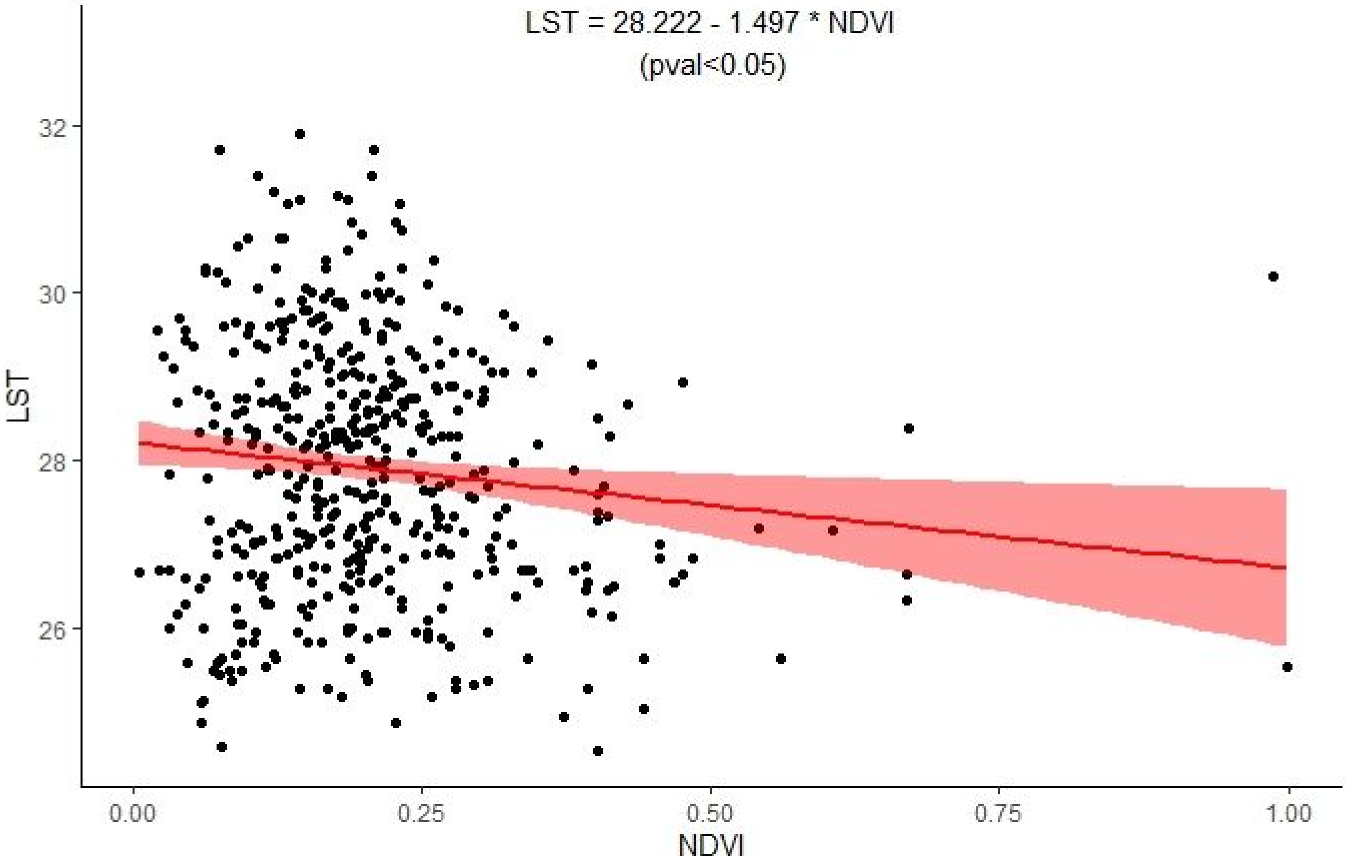

Figure 4

Scatter plot linear regression of mean LST and NDVI for both cities

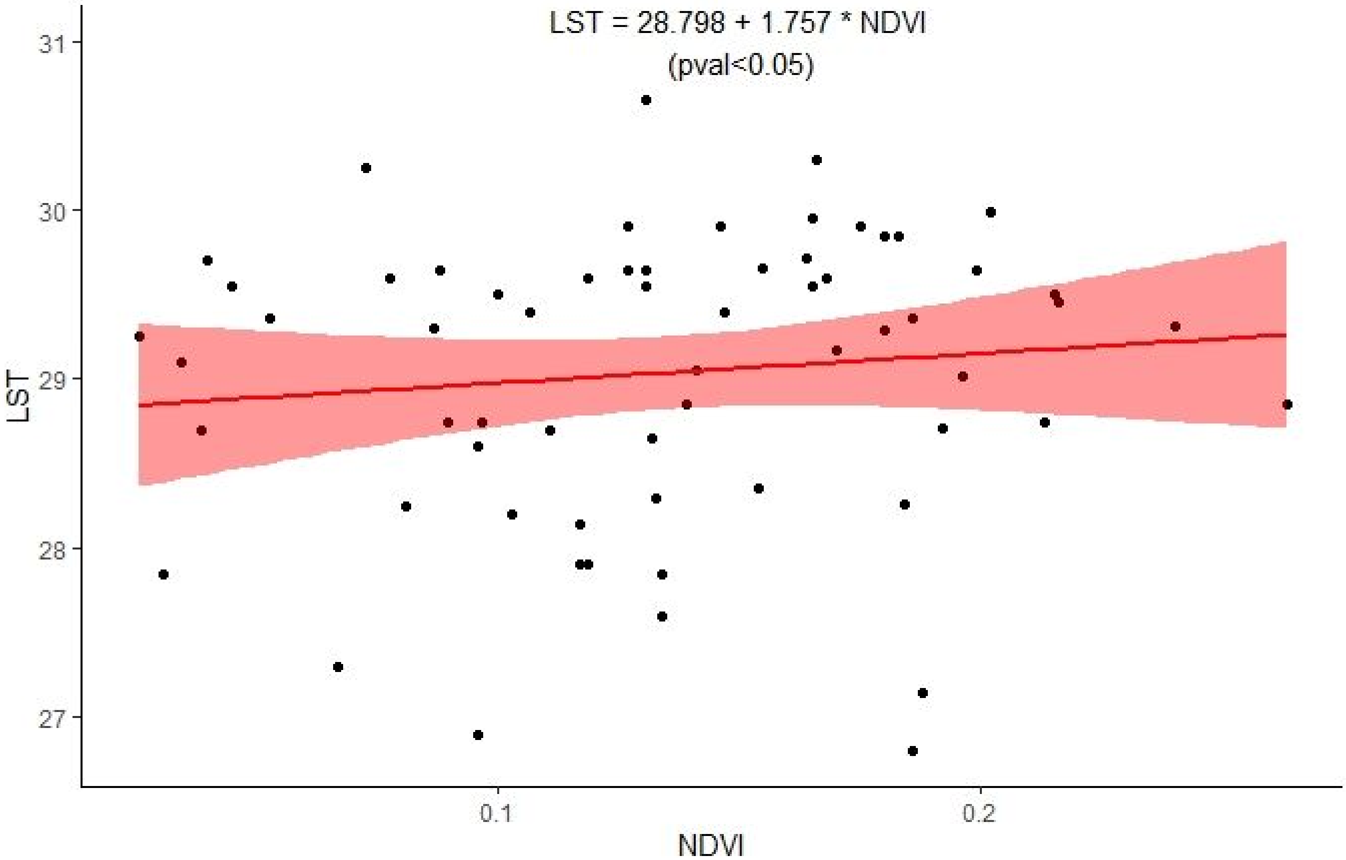

Figure 5

Scatter plot linear regression of mean LST and NDVI for January-March period in Porto-Novo

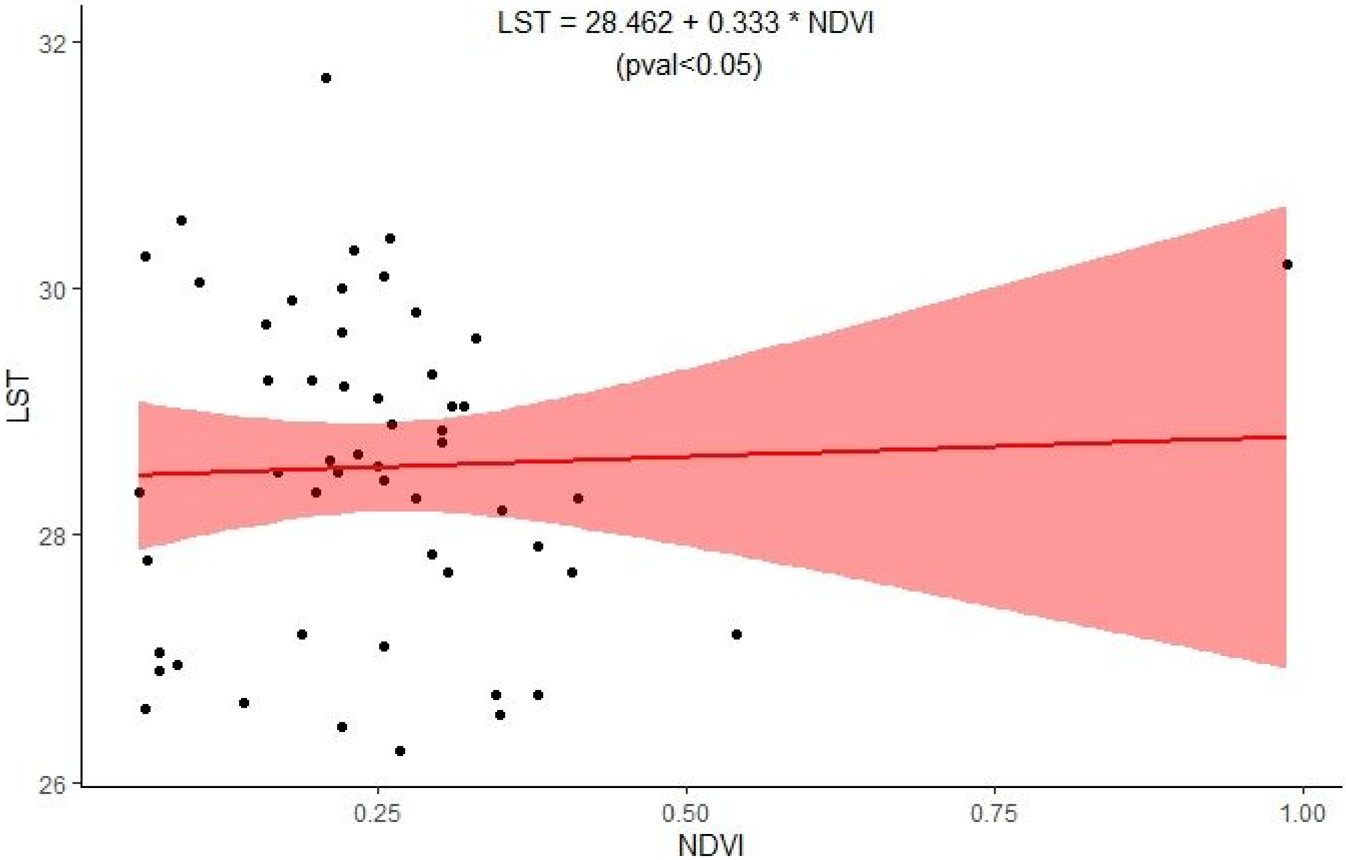

Figure 6

Scatter plot linear regression of mean LST and NDVI for April-June period in Parakou