CGIAR Sustainable Intensification of Mixed Farming Systems

Recommendation domains for conservation agriculture (CA) in Eastern and Southern Africa

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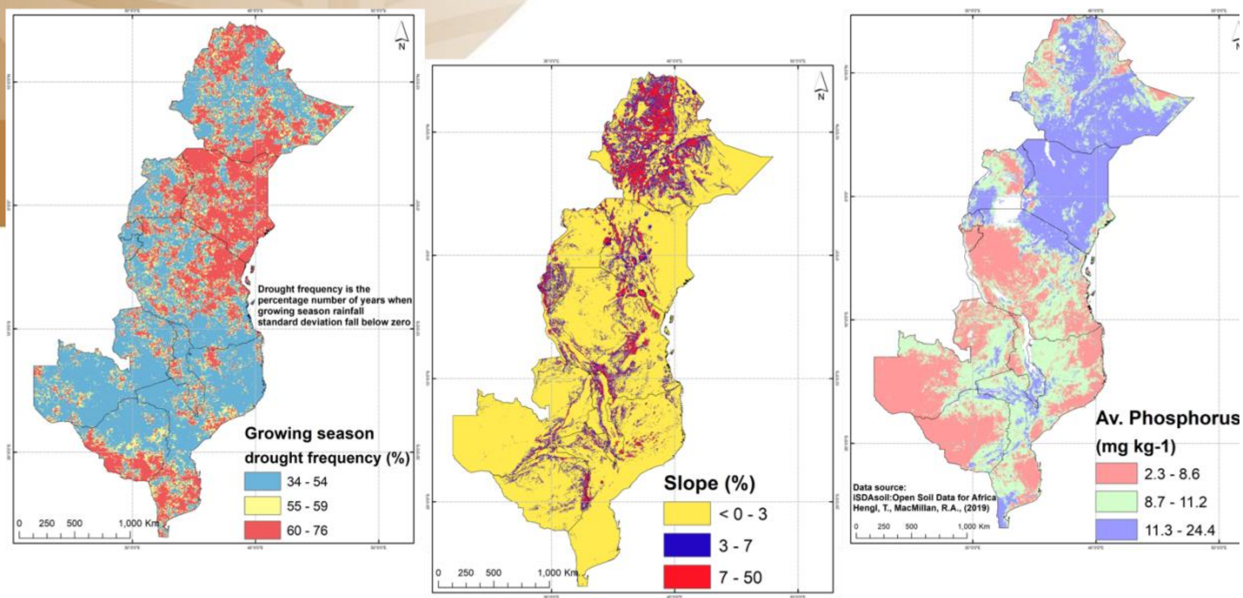

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The Sustainable Intensification of Mixed Farming Systems Initiative aims to provide equitable, transformative pathways for improved livelihoods of actors in mixed farming systems through sustainable intensification within target agroecologies and socio-economic settings.

Through action research and development partnerships, the Initiative will improve smallholder farmers' resilience to weather-induced shocks, provide a more stable income and significant benefits in welfare, and enhance social justice and inclusion for 13 million people by 2030.

Activities will be implemented in six focus countries globally representing diverse mixed farming systems as follows: Ghana (cereal–root crop mixed), Ethiopia (highland mixed), Malawi: (maize mixed), Bangladesh (rice mixed), Nepal (highland mixed), and Lao People's Democratic Republic (upland intensive mixed/ highland extensive mixed).

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Background

Conservation agriculture (CA) is a sustainable agronomic practice that is increase resilience of farming systems to the effect of soil degradation, climate change, and reduced soil water. It is known to improve crop productivity against dwindling biophysical and soil resources. Hence, it is being promoted in east and southern Africa as a climate-smart technology that can buffer against the effects of extreme weather events. The countries of the ESA present diverse socio-economic and biophysical scenarios for agricultural development, such as overutilization of natural resources, poor land use management and soil degradation due to high demographic pressure. CA is recommended to mitigate these challenges. Due to the heterogeneity of the farming landscapes in the ESA countries, CA technology needs to be appropriately deployed to have maximum benefits. Conservation agriculture (CA) technologies are applicable in diverse biophysical conditions ranging from low to high rainfall areas with varied edaphic conditions (Thierfelder et al., 2014). The main factors influencing the effectiveness of CA approaches are the environment's socio-economic and biophysical conditions. Geospatial techniques have been used extensively to facilitate the integration of socio-economic and environmental variables in the development of recommendation domains (Muthoni et al., 2017). Open-source gridded data from remote sensing platform is increasingly available to support the development of spatially explicit recommendations. Recommendation domains (RDs) are spatially contiguous zones where specific development policies, investments and livelihood options, and technologies are likely to be most beneficial, enhancing faster adoption rates. In this study, we have used multi-source high-resolution geospatial data to characterize the biophysical and socio-economic environment in nine east and southern African countries. Geospatial analysis generated spatial maps of the recommendation domains for CA. The analytics results will guide extension and development agencies in targeting the most suitable zones to promote the efficient allocation of resources and reduce the risk of technology failure.

Material and methods

Recently released gridded data representing the climatic, topographic, edaphic, and socio-economic variables (Table 1) was applied in the recommendation domain analysis. Rainfall amount and distribution is the most critical factor that drives agricultural productivity. CA practices help conserve soil moisture in rain-limited environments and minimises soil loss due to erosion in high rainfall ecology. Monthly satellite rainfall estimates were downloaded from the Climate Hazards Group InfraRed Precipitation with Station data version two (CHIRPS-v2) from 1981-2022 (Funk et al., 2015). CHIRPS-v2 data was produced by combining gauge station and satellite precipitation estimates to create gridded rainfall time series for trend analysis and seasonal drought monitoring. From this set of time series rainfall data, we generated the annual mean total rainfall and growing season rainfall distribution characteristics, such as the frequency of droughts and floods in the study area.

Gridded soil physical and chemical properties from iSDA database (Hengl et al., 2021) was downloaded and aggregated to the original 30m to 1 Km^2 spatial resolution using the geodata R package. The soil layers include the soil texture, pH, Organic Carbon, and Total Nitrogen (Table 1). The iSDA soil physical and chemical properties dataset was created using machine-learning techniques from recent field soil surveys and legacy data (Hengl et al., 2021). Soil texture plays a significant role in soil water, and nutrient availability to crops, and yields are higher in well-drained soils than in poorly drained texture soils (Rusinamhodzi et al., 2011). Soil pH is an important secondary determinant of heavy metal transport, such as Aluminium ions, affecting their water solubility in the soil. Soil slope is another critical factor influencing CA adoption. It determines drainage and soil loss through erosion which is proportional to slope steepness. CA has been established to minimize soil degradation through minimum tillage and mulching effects. Gridded soil slope was generated from the SRTM elevation data and was downloaded from the NASA USGS.

The relevant socio-economic data for CA adoption used in this analysis includes human population density, livestock density, and measures of accessibility to markets. Human population density affects CA adoption as it determines food demand levels and the degree of farming intensification. Cattle density influences the volume of crop residues left for CA practices; the higher the cattle density, the lower the crop residue quantity to be employed for CA. The human population density dataset was obtained from the Gridded Population of the World (GPW), version 4, produced by the Center for International Earth Science Information Network (CIESIN) of Columbia University, USA. The livestock density data in the study came from the Gridded Livestock Density Global - 2010 (GLW 3), with a spatial resolution of 10km (Gilbert et al., 2018).

Another essential socio-economic factor explored for CA adoption was the market access measured as travel time to cities of 20,000 inhabitants. Market accessibility is crucial for CA adoption as it determines the availability of agro-inputs, extension services and ease of selling agricultural produce. Farmers in geographies with good market access have a solid incentive to uptake new technologies for increased productivity. Market access data used in the study was obtained from the travel time to a city of 20000 raster data at a 30 arc-seconds (about one km²) resolution (Nelson, 2019). Since there exist diverse land use categories in the target countries, we employed the cropland extent data from Digital Earth Africa to limit the area of possible CA adoption. A summary of critical variables that restrict or enhance CA practices' suitability is listed in Table 1.

Table 1. Biophysical and socio-economic variables selected for mapping recommendation domains for conservation agriculture practices

No	Variable name	Abbreviation	Original resolution	Units	Source
Precipitation variables					
1	Total growing season rainfall	Rainfall	~5 km	mm	CHIRPS (Funk et al. 2015) 1981-2022
9	Standardised rainfall anomaly	Rainfall Anomaly			Derived from Rainfall
	Frequency of droughts	Drought	~5 km		"
	Frequency of flooding	Flood	~5 km		"
Soil variables					
27	Soil texture	Texture		Class	https://envirometrix.nl/isdasoil-open-soil-data-for-africa/
Socio-economic variables					
28	Cattle density-weighted	Cattle density	~10 km	Heads	(Gilbert et al., 2018)
29	Market access	Market access	~1 km	minutes	(Weiss et al., 2018)
	Human population density 2020	Pop density	~1 km		Gridded Population of the World (GPW), v4
Vegetation productivity/ phenology					
30	Cropland extent	CropExt	~30/10 m		https://www.digitalearthafrica.org/platform-resources/services/cropland-extent-map
Terrain variables					
31	Digital elevation model	DEM	~30 m	m	(METI and NASA, 2011)
32	Slope	slope	~30 m	%	Generated from DEM

Recommendation domain development

The rainfall, slope, and soil texture layers were reclassified into different categories. Following Tesfaye et al. (2015) a factorial combination of the classes (Table 3) was applied to identify the biophysical potential of CA in the current cultivated areas. The combinations of biophysical factors representing the rainfall, slope and soil texture were used as indicators of plant water supply, drainage, and erosion. These were used to delineate three biophysical potentials of CA namely, high potential (HP), moderate potential (MP) and low potential (LP).

Similarly, the three socio-economic variables were reclassified into two classes each. Human population density >100 persons/km² was categorized as high potential while <=100persons/km² was low. Cattle density <50 was classified as having high potential for CA due to lesser competition of crop residues, while cattle density >=50 was considered low potential. Market access was classified into travel time less than three hours was considered high potential due to lower transaction costs, while more than three hours were considered the low potential for CA adoption.

Table 2. Criteria for categorizing biophysical variables into potential zones for conservation agriculture practices.

Slope (%)	**Rainfall (mm)**		
	400 – 1,000	**1,000 – 1,500**	**>1,500**
TG1[a]			
0–3	HP	MP	LP
3–7	HP	HP	LP
7–50	HP	HP	MP
TG2			
0–3	LP	MP	MP
3–7	LP	MP	LP
7–50	LP	HP	LP
TG3			
0–3	MS	LP	LP
3–7	HP	MP	LP
7–50	HP	HP	MS

High potential (HP), moderate potential (MS), marginal potential (LP). [a]Texture Group1 (TG1) surface soil texture other than sand, loamy sand, and clay; TG2 sand and loamy sand; TG3 heavy and light clay.

Results

Figures 1 – 15 show the biophysical conditions that determine the suitability of CA practices in ESA region. Figures 16 – 21 show the spatial variation of the social-economic factors that influence the adoption of CA practices. Figure 22 and Figure 23 present the biophysical and socio-economic potential of the CA practices in the ESA region. Finally, the recommendation domain of CA is shown in Figure 25. The largest contiguous zone showing the highest potential for CA occurs in Malawi (Figure 25).

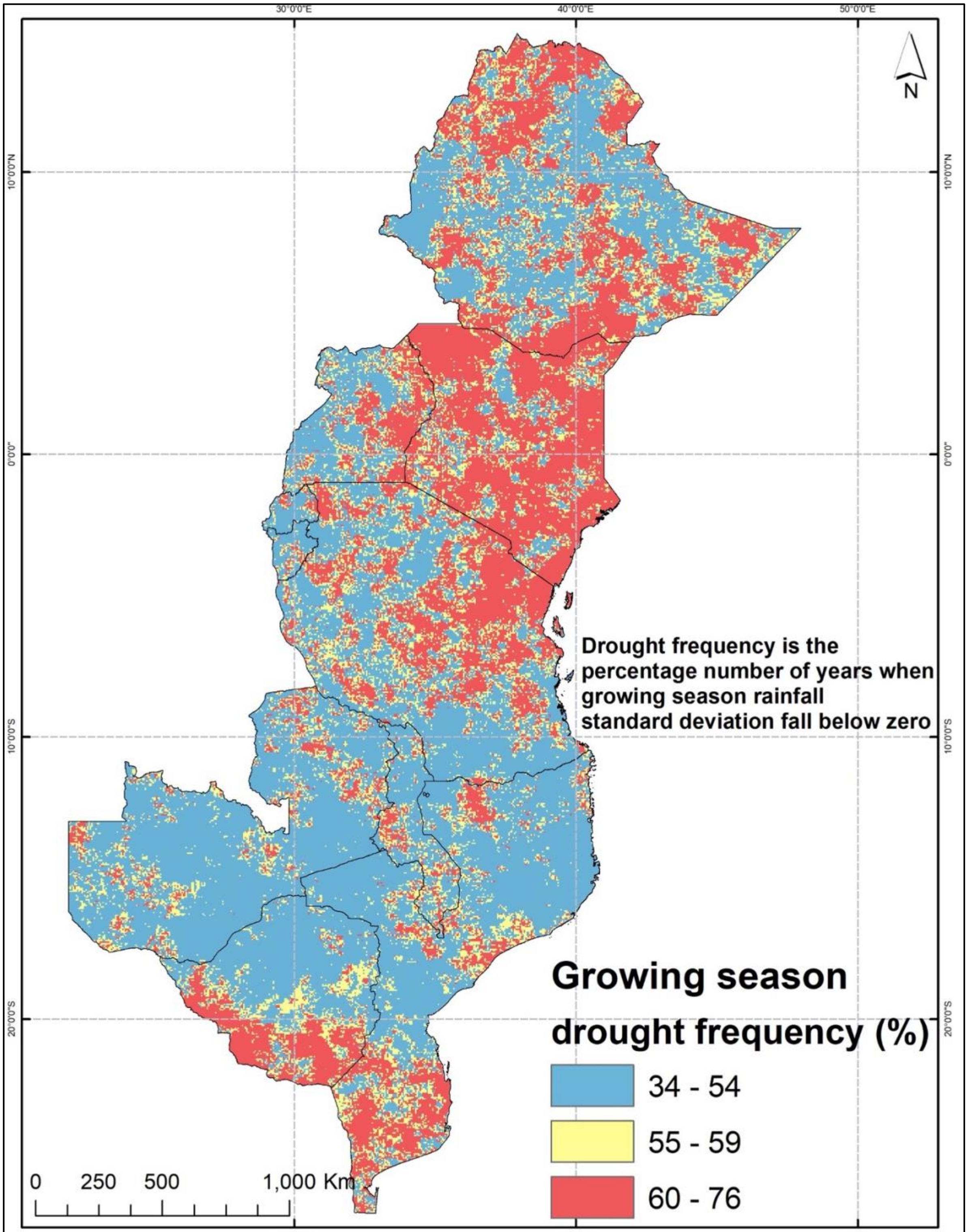

Figure 1. The percentage frequency of growing season drought (1981-2022) in the east and southern Africa (ESA) region.

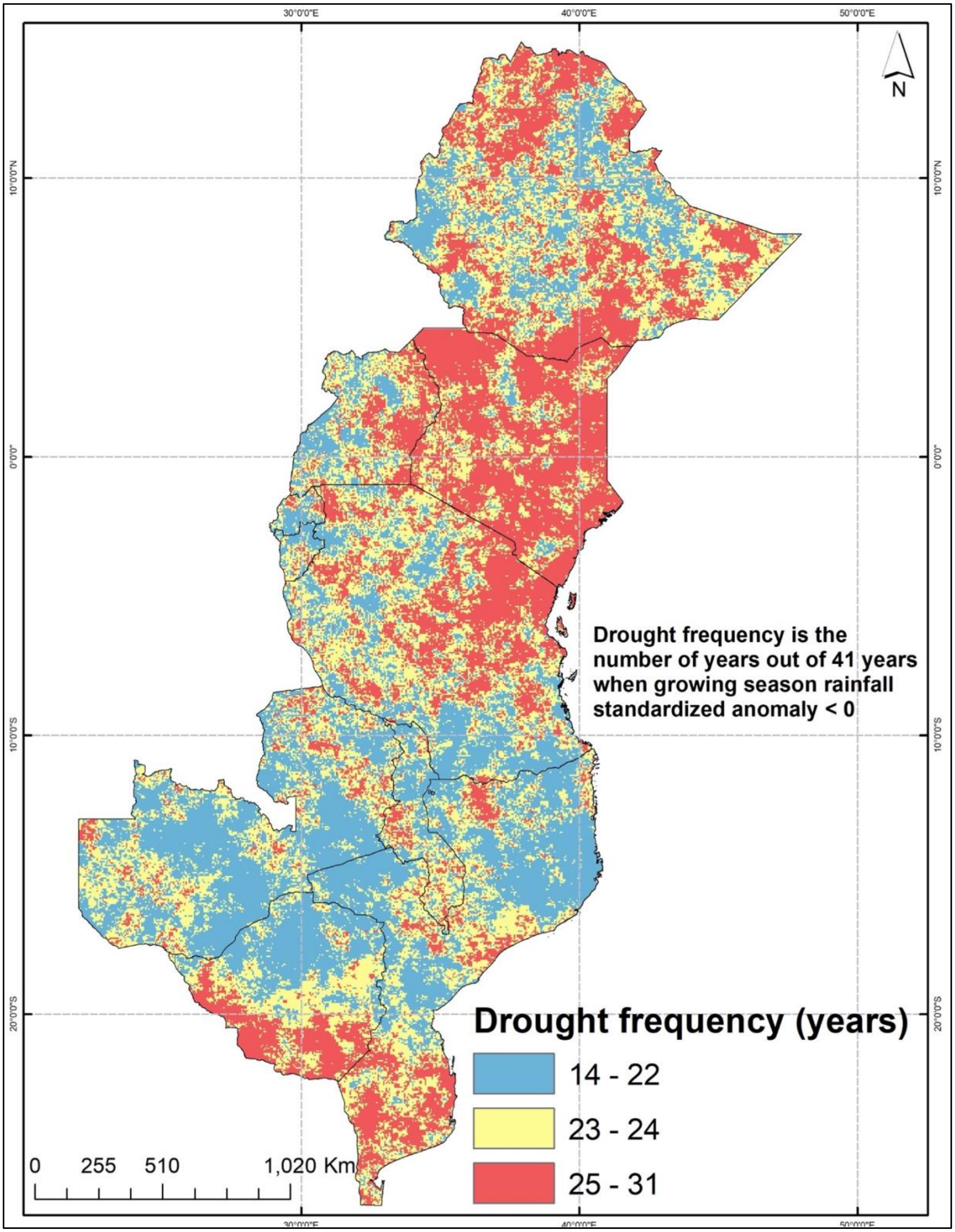

Figure 2. The number of growing seasons experiencing droughts from 1981to 2022 the east and southern Africa (ESA) region.

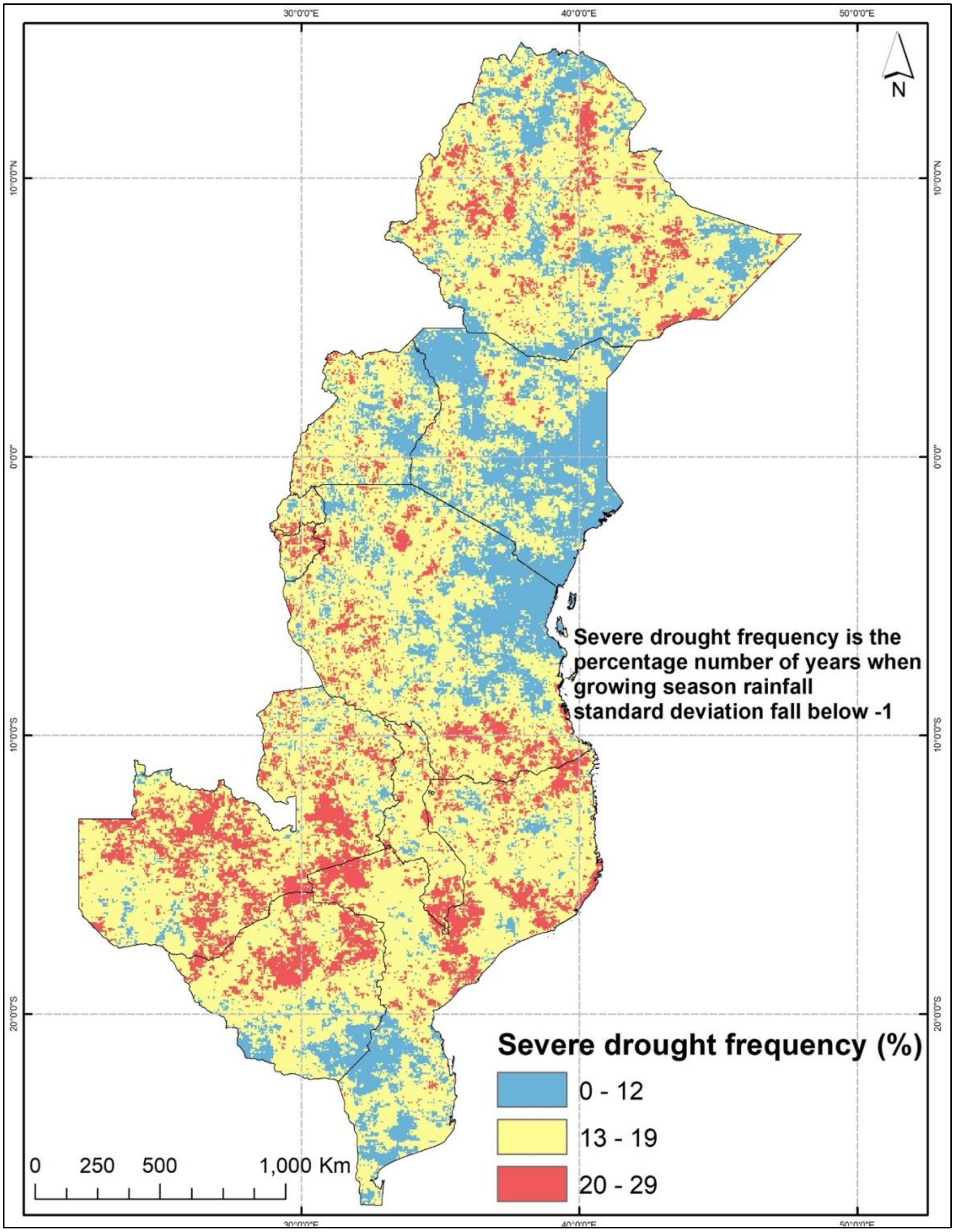

Figure 3. The percentage of growing seasons experiencing droughts from 1981 to 2022 in the east and southern Africa (ESA) region. Severe droughts were defined as rainfall anomalies less than 1 standard deviation.

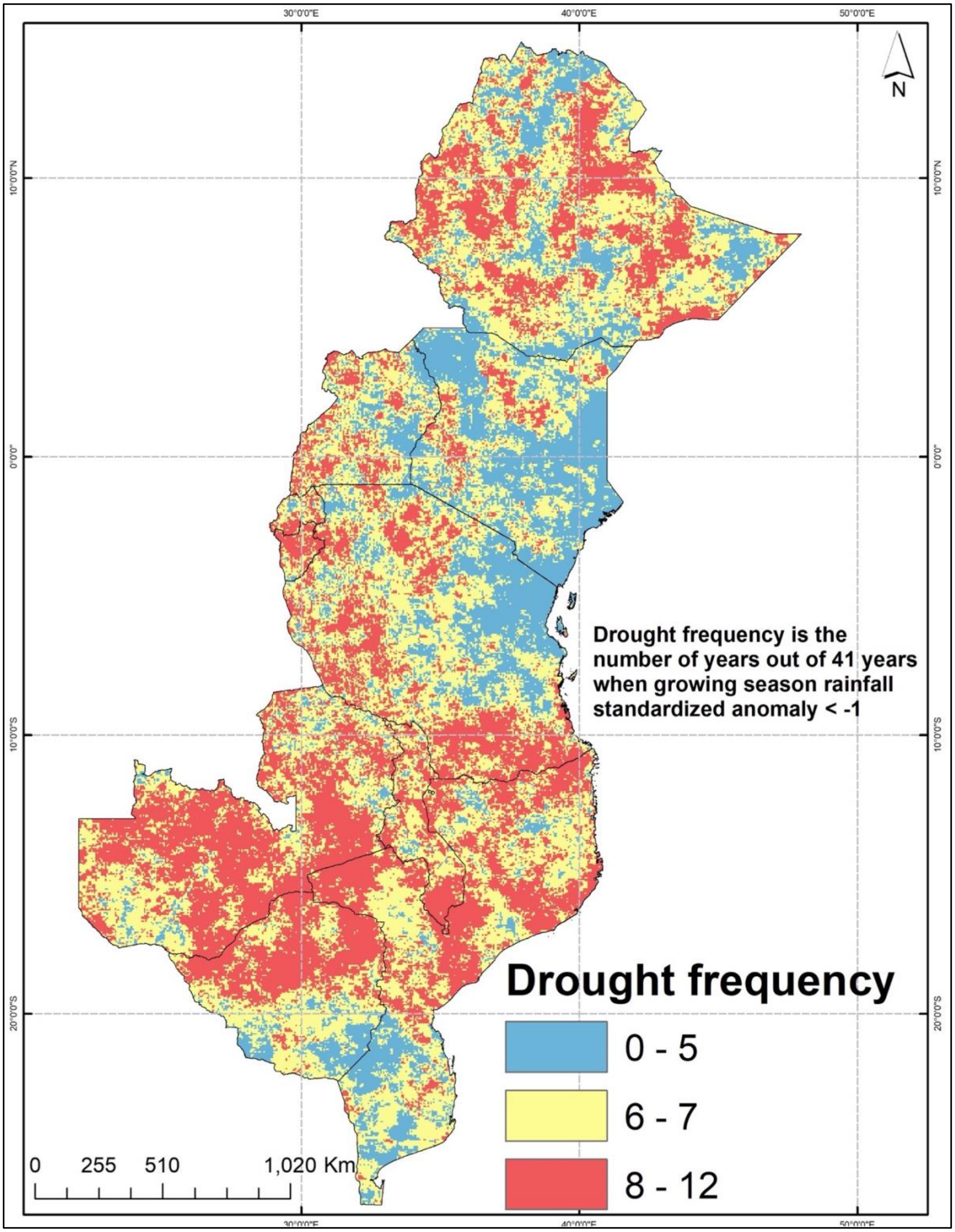

Figure 4. The number of growing seasons experiencing droughts from 1981 to 2022 in the east and southern Africa (ESA) region.

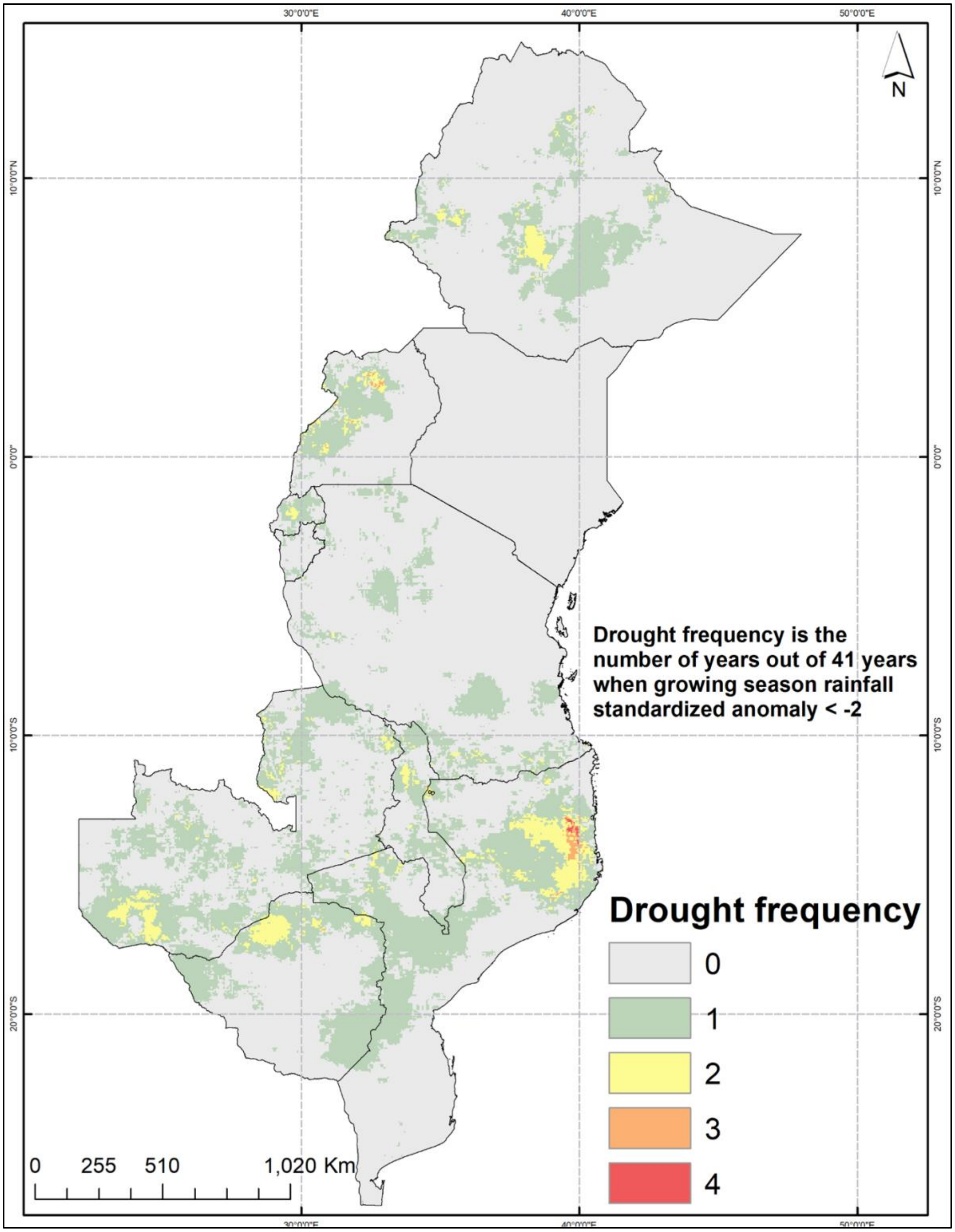

Figure 5. The number of growing seasons experiencing severe droughts from 1981 to 2022 in the east and southern Africa (ESA) region.

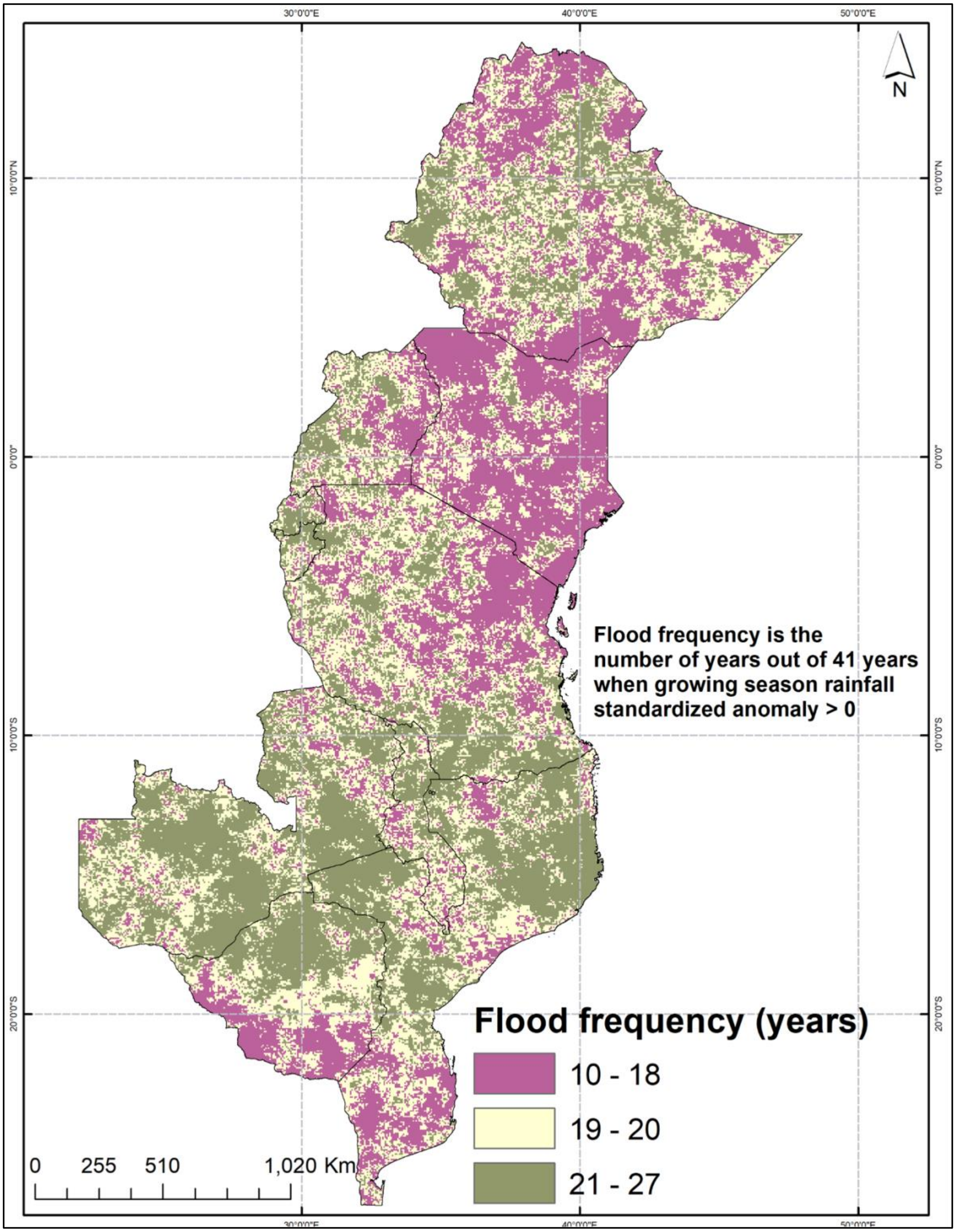

Figure 6. The number of years experiencing flood in the growing season (1981-2022) in the east and southern Africa (ESA) region.

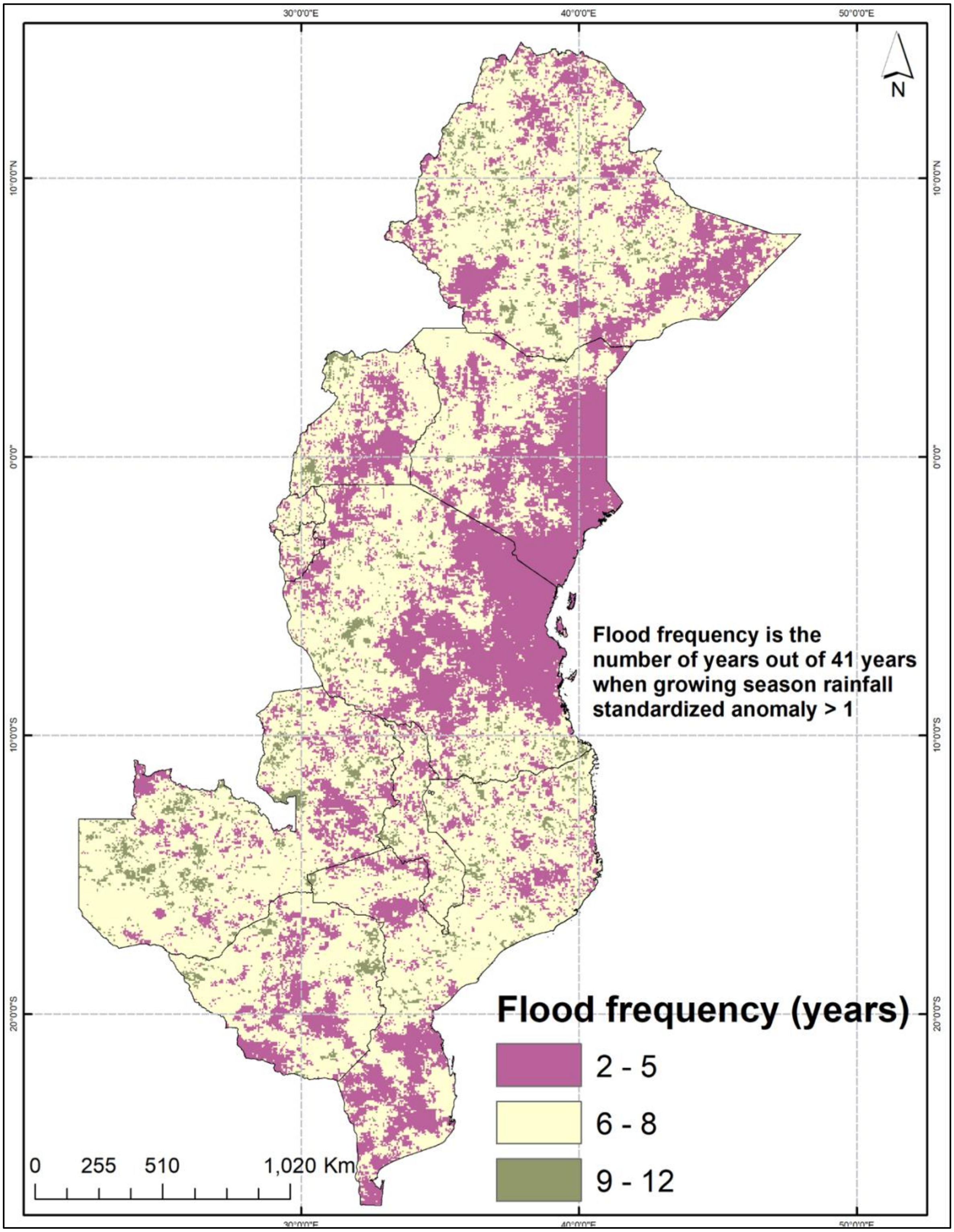

Figure 7. The number of years experiencing more than moderate floods in the growing season (1981-2022) in the east and southern Africa (ESA) region.

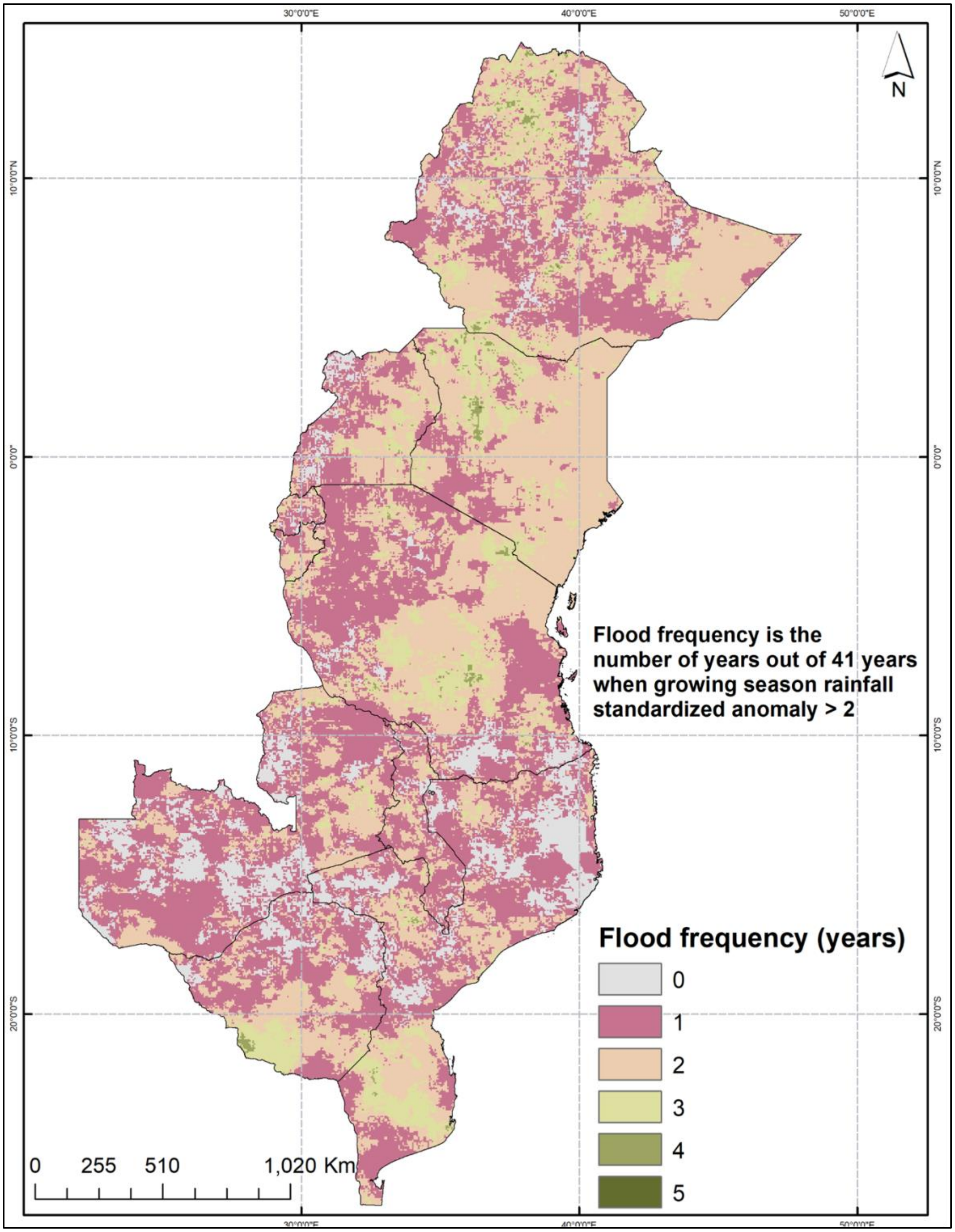

Figure 8. Map of the number of years experiencing severe floods in the growing season (1981-2022) in the east and southern Africa (ESA) region.

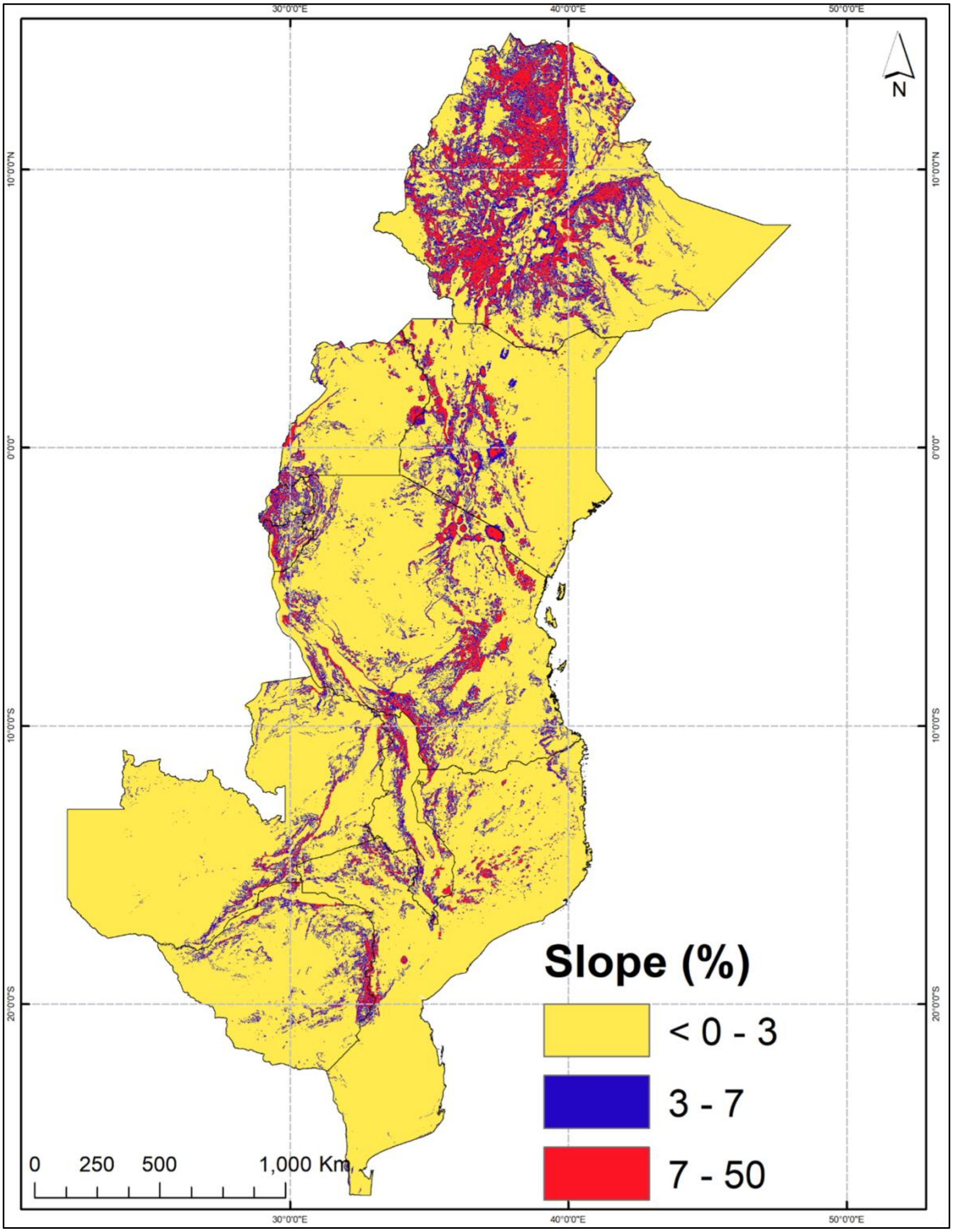

Figure 9. The slope gradient presented in percentage in the east and southern Africa (ESA) region.

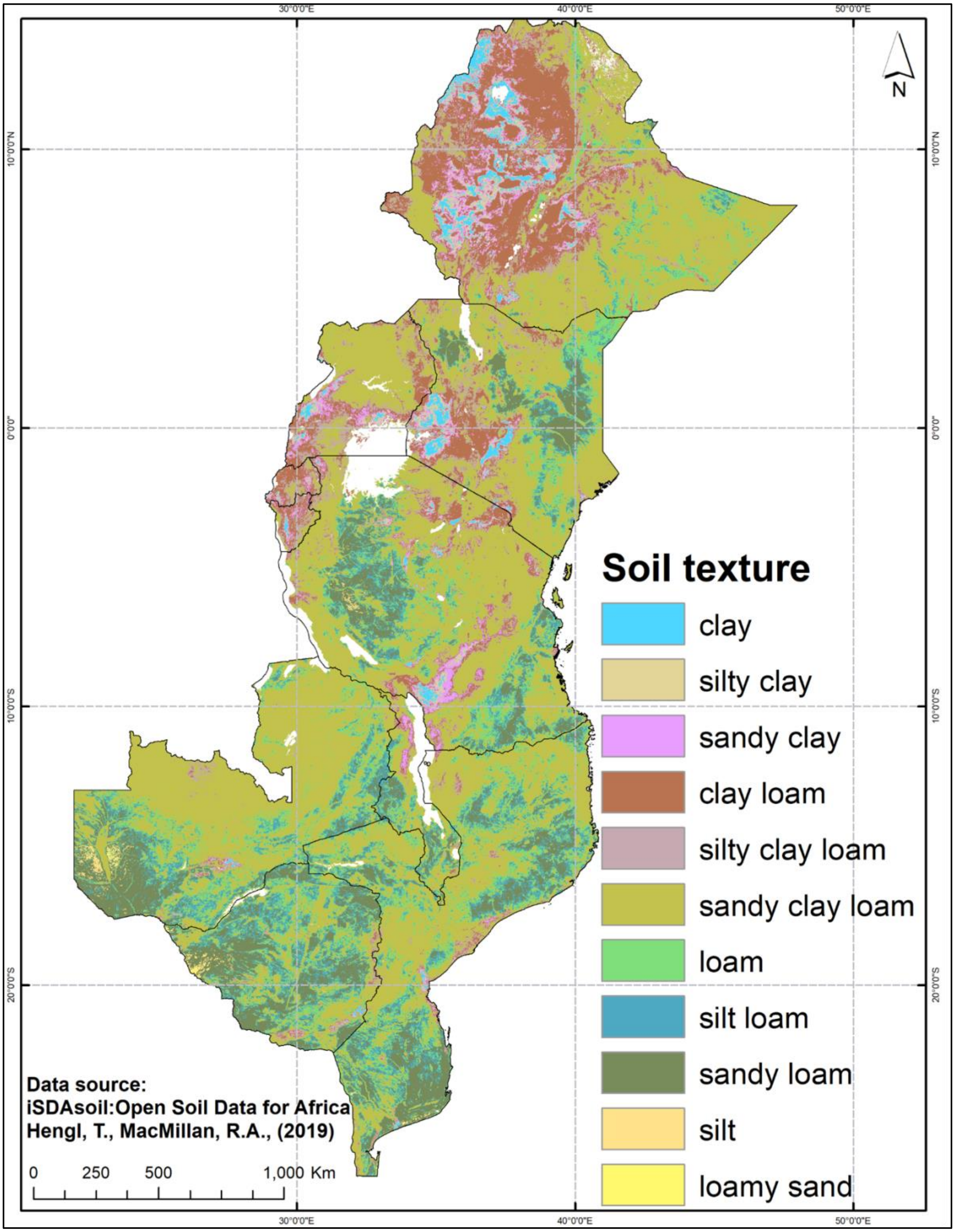

Figure 10. Spatial variation of the soil texture classes in the east and southern Africa (ESA) region.

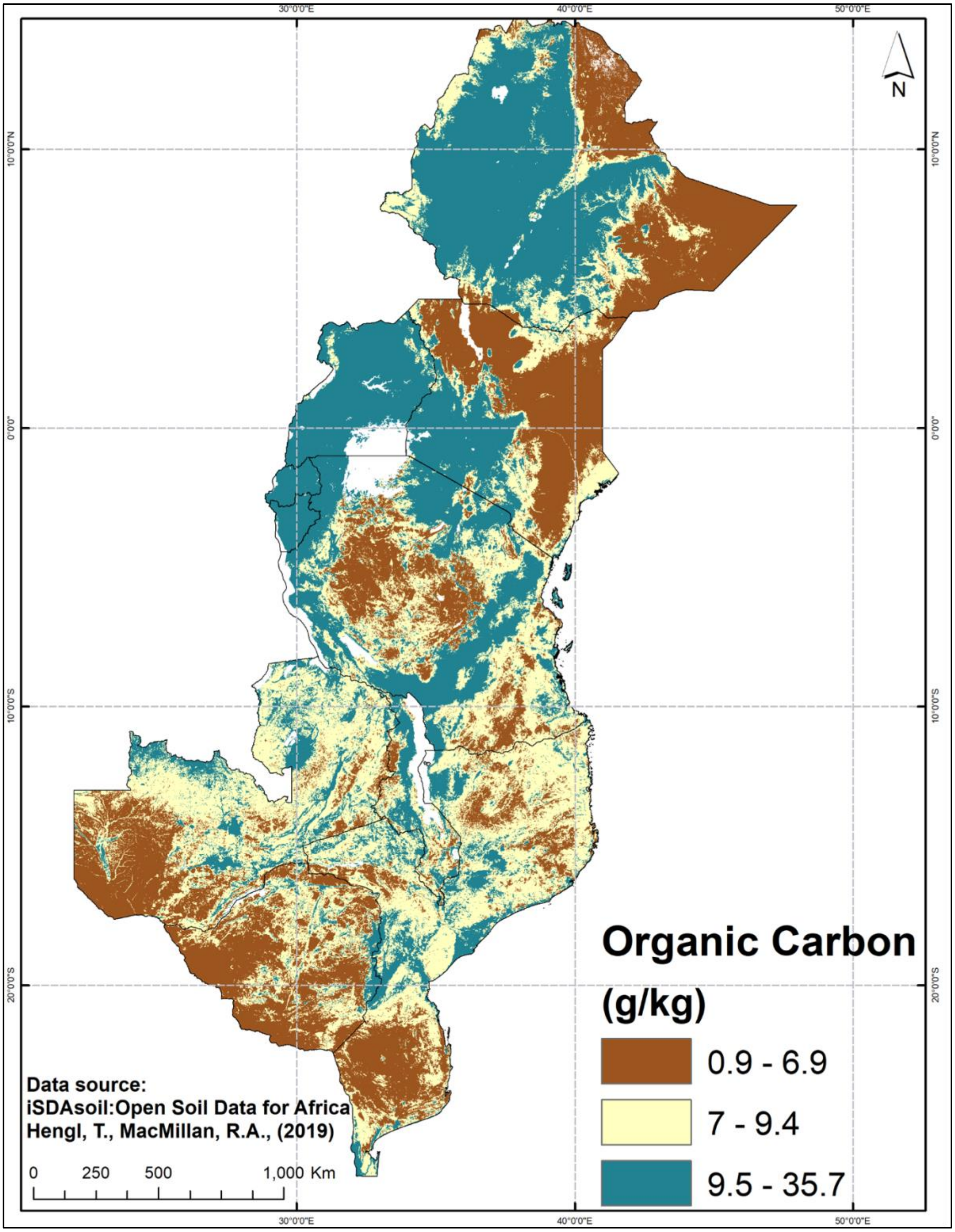

Figure 11. Soil organic carbon content in the east and southern Africa (ESA) region.

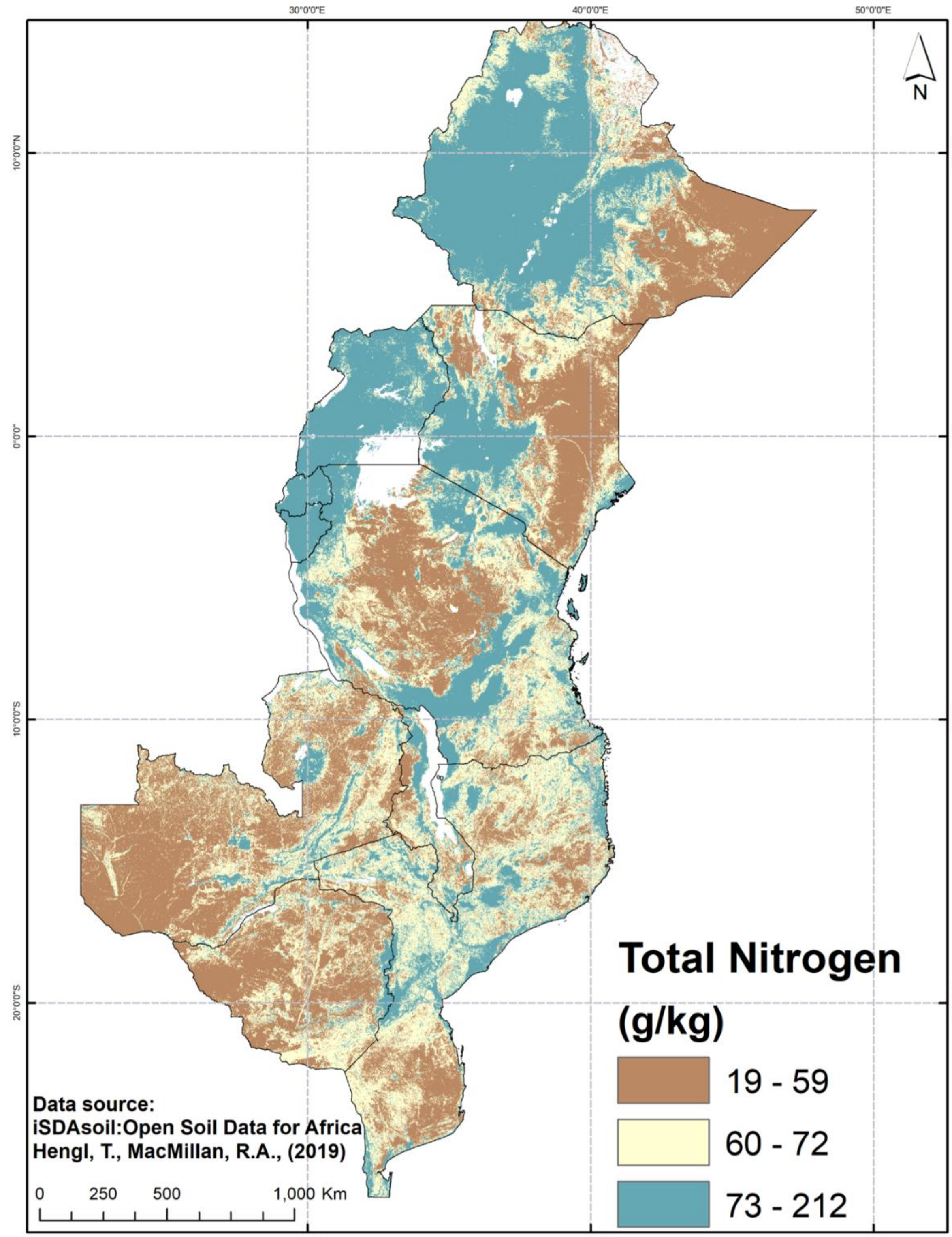

Figure 12. Soil total nitrogen content in the east and southern Africa (ESA) region.

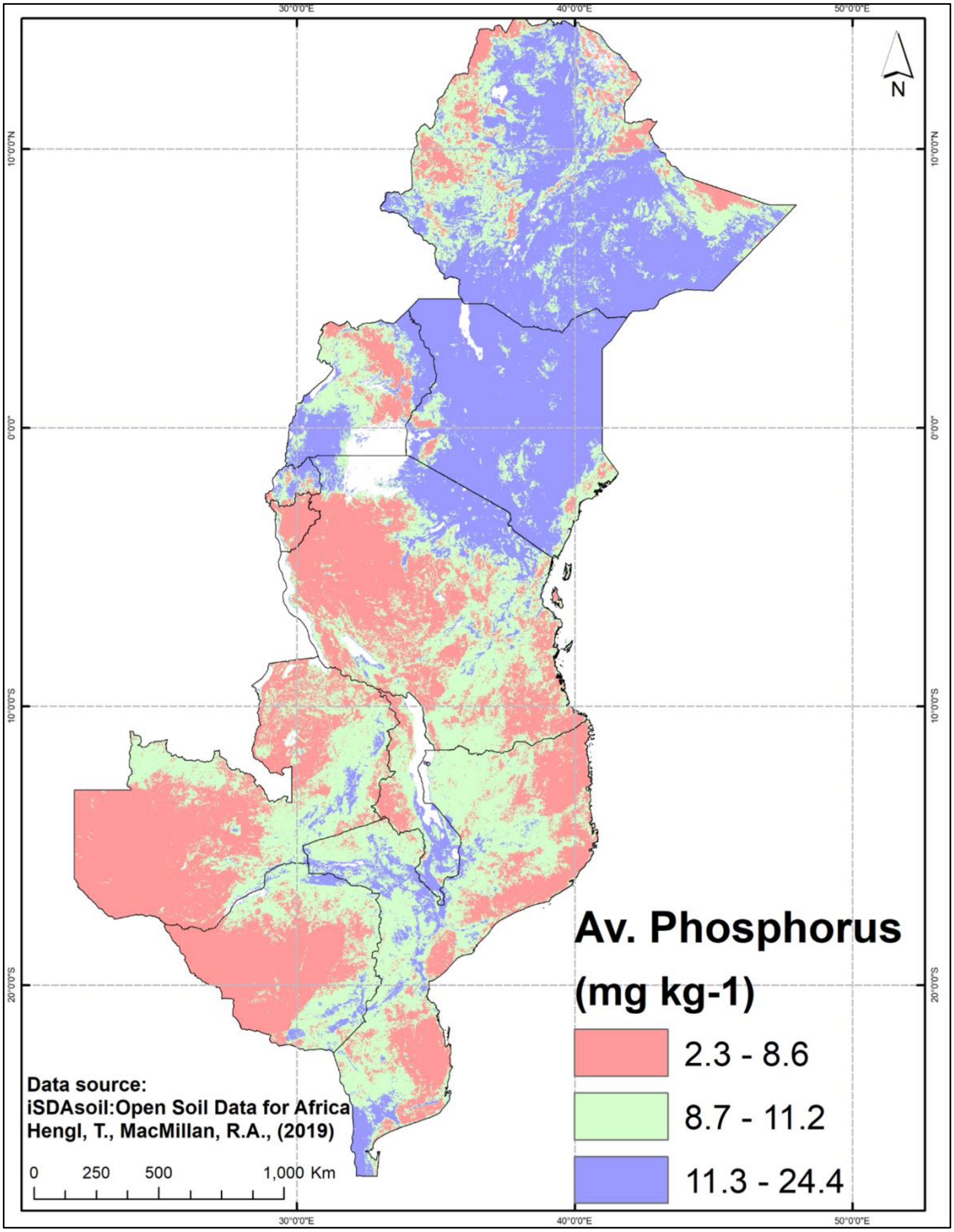

Figure 13. Soil available phosphorus in the east and southern Africa (ESA) region.

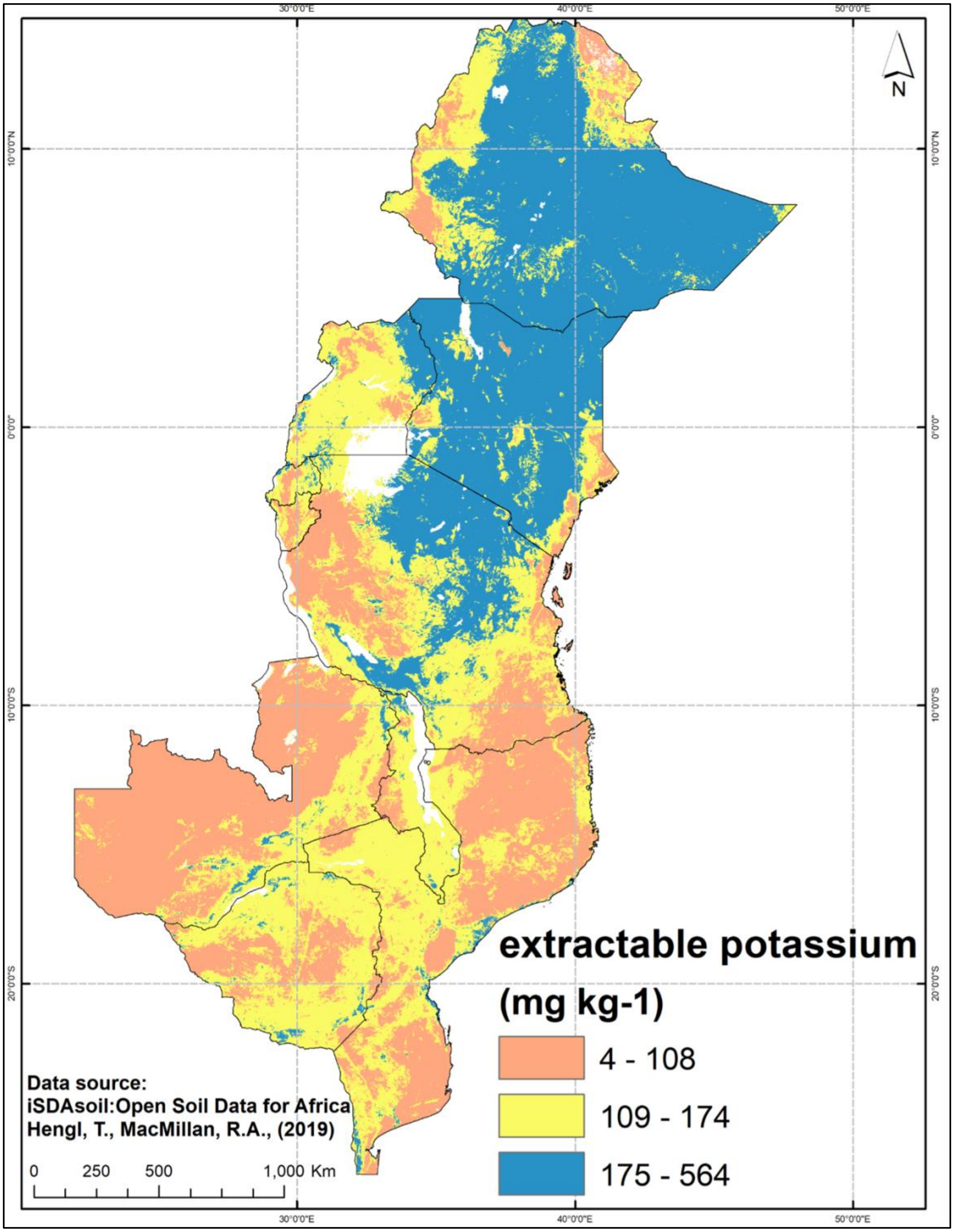

Figure 14. Map of soil extractable potassium in the east and southern Africa (ESA) region

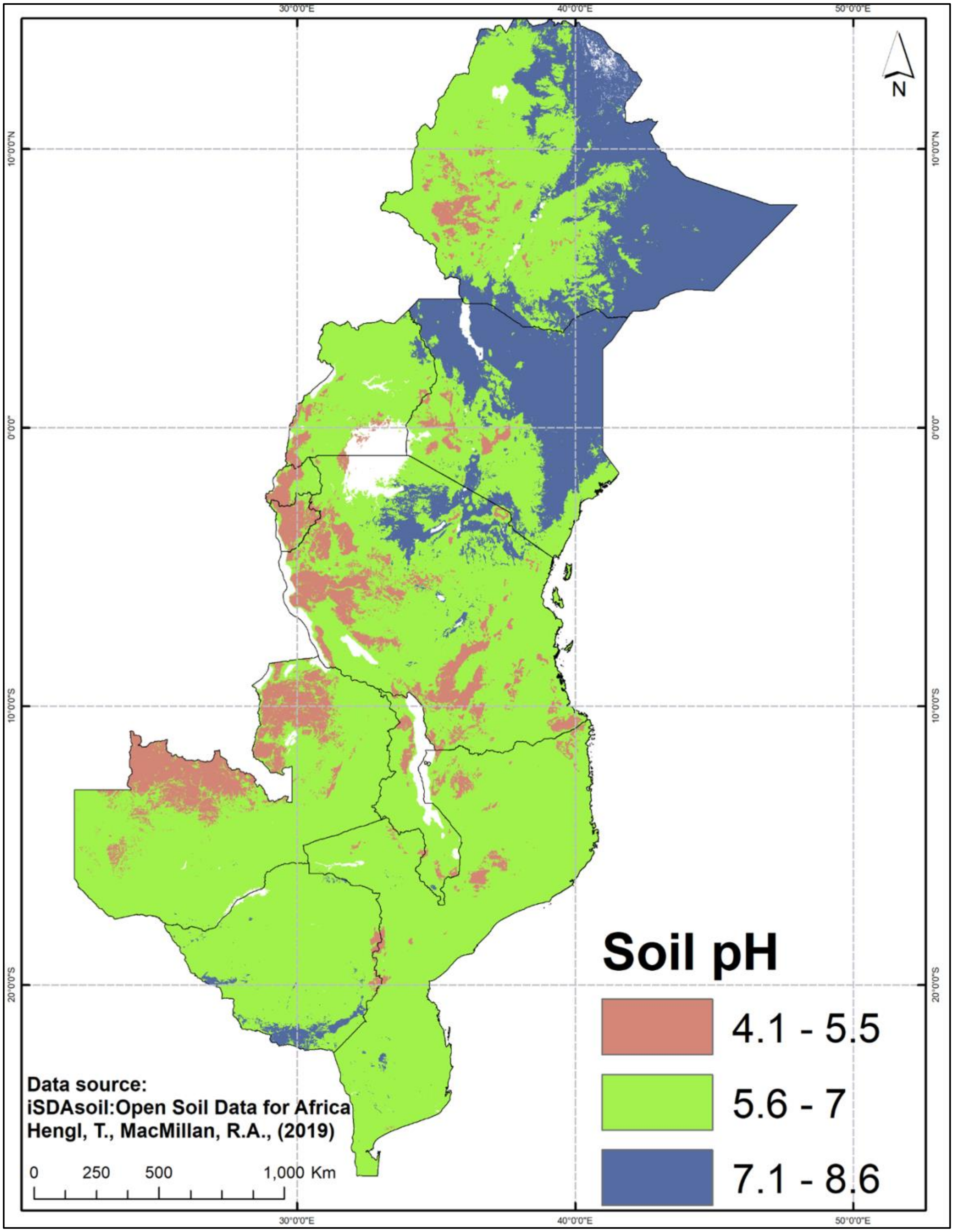

Figure 15. Map of soil pH in the east and southern Africa (ESA) region.

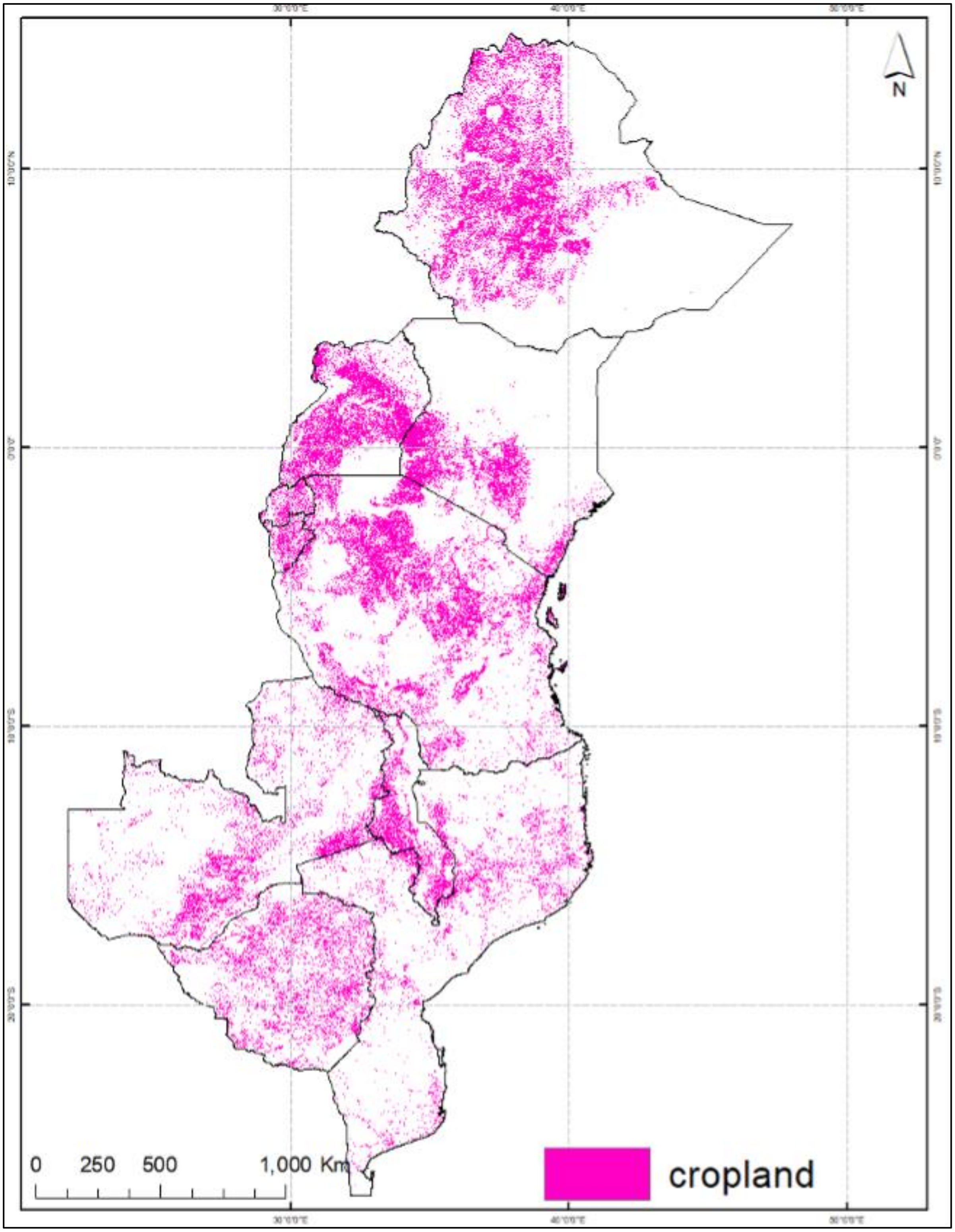

Figure 16. The cropland extent in 2019 generated by Digital Earth Africa.

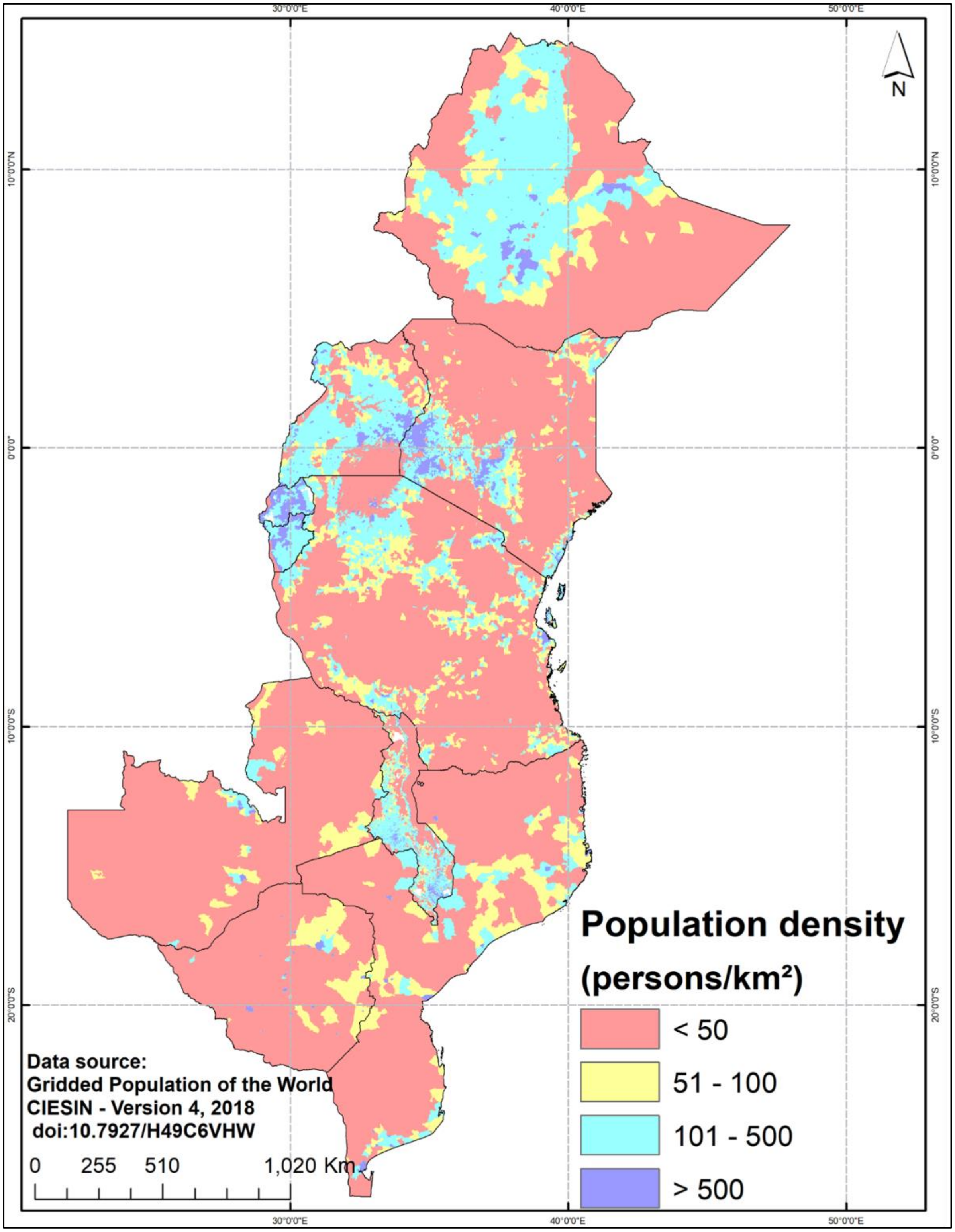

Figure 17. Map of the human population density in the east and southern Africa (ESA) region.

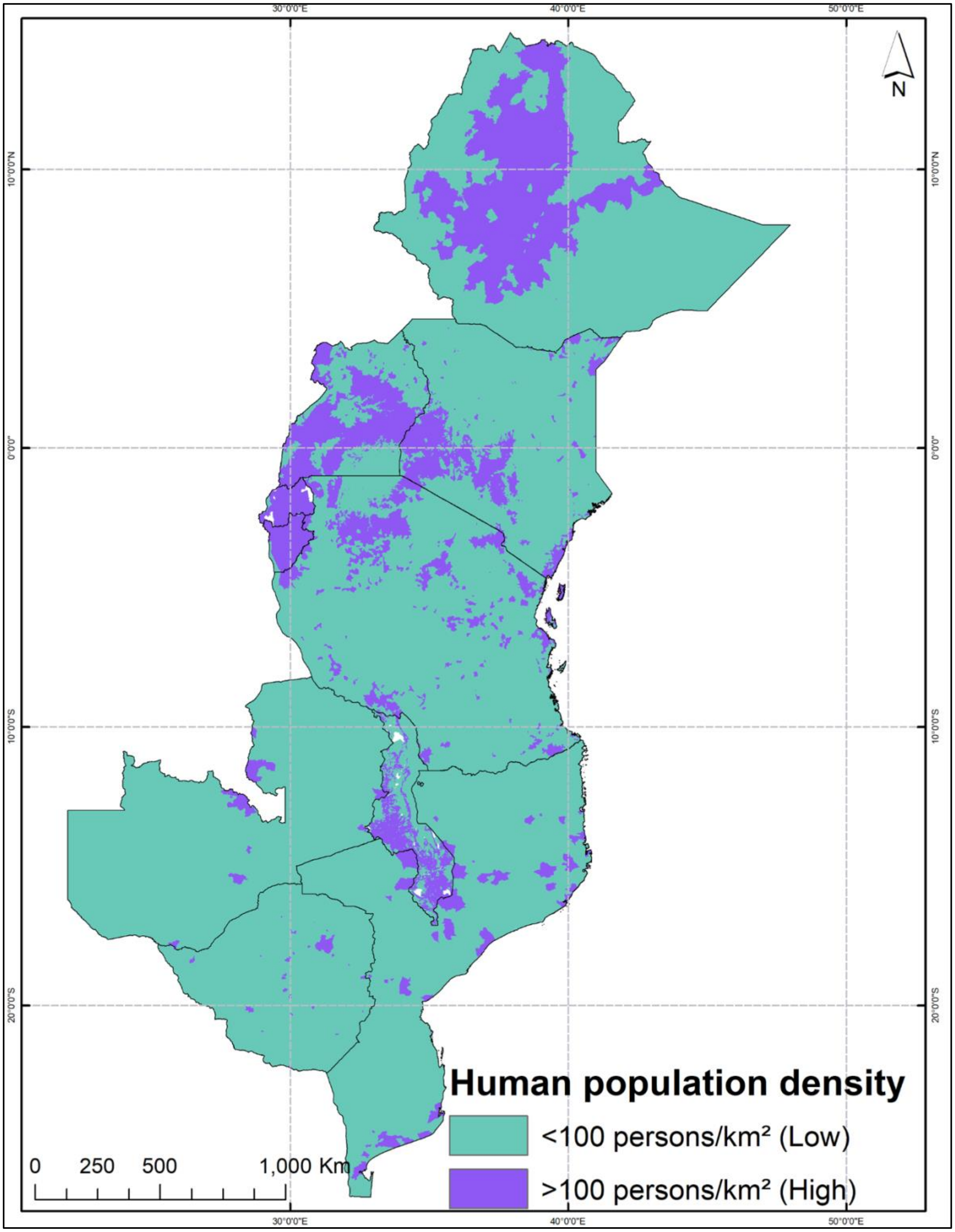

Figure 18. Human population density classified into two categories for identifying recommendation domains of the conservation agriculture in the east and southern Africa (ESA) region.

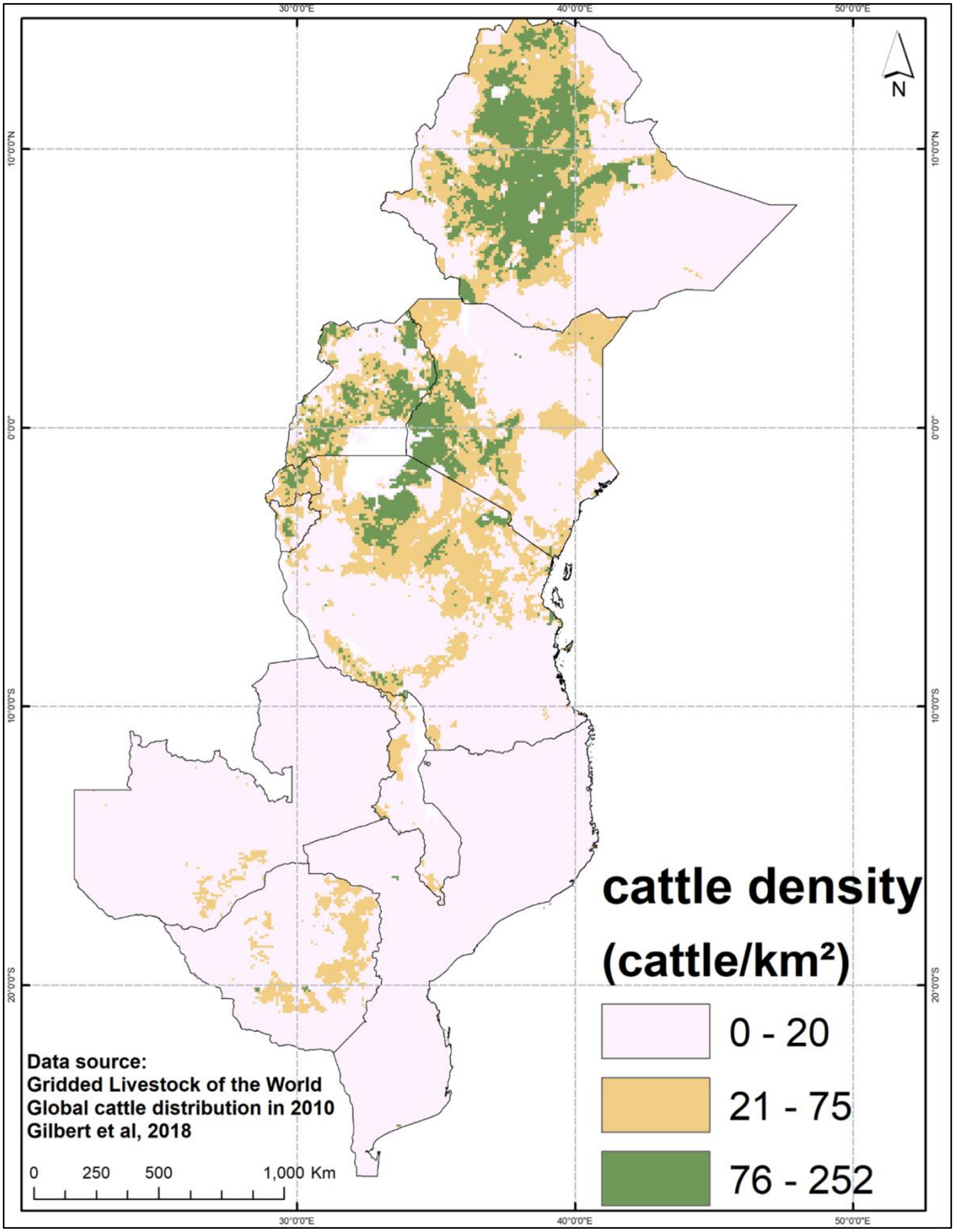

Figure 19. Map of cattle density in the east and southern Africa (ESA) region.

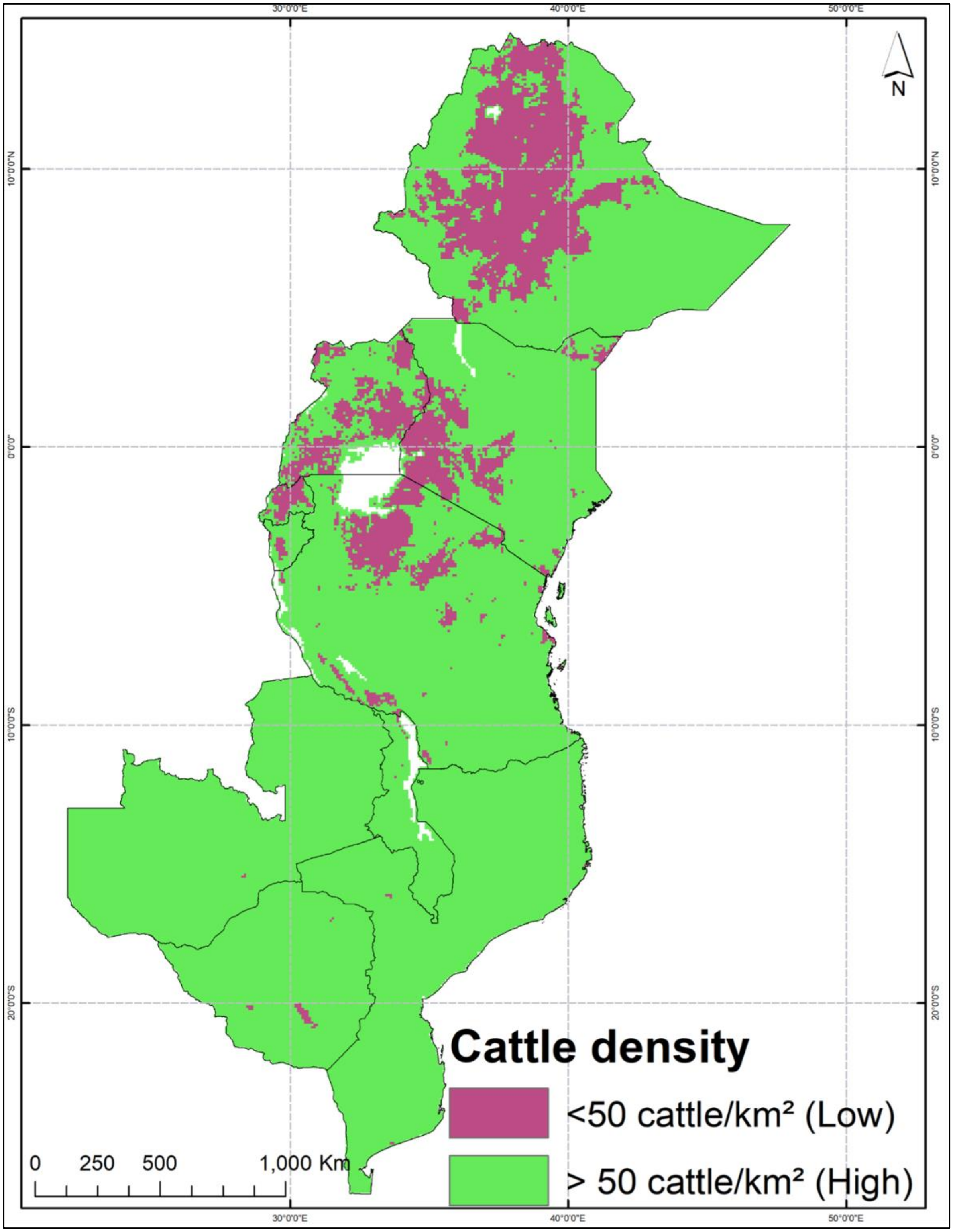

Figure 20. Map of cattle density classified into two categories for identifying recommendation domains of the conservation agriculture in the east and southern Africa (ESA) region.

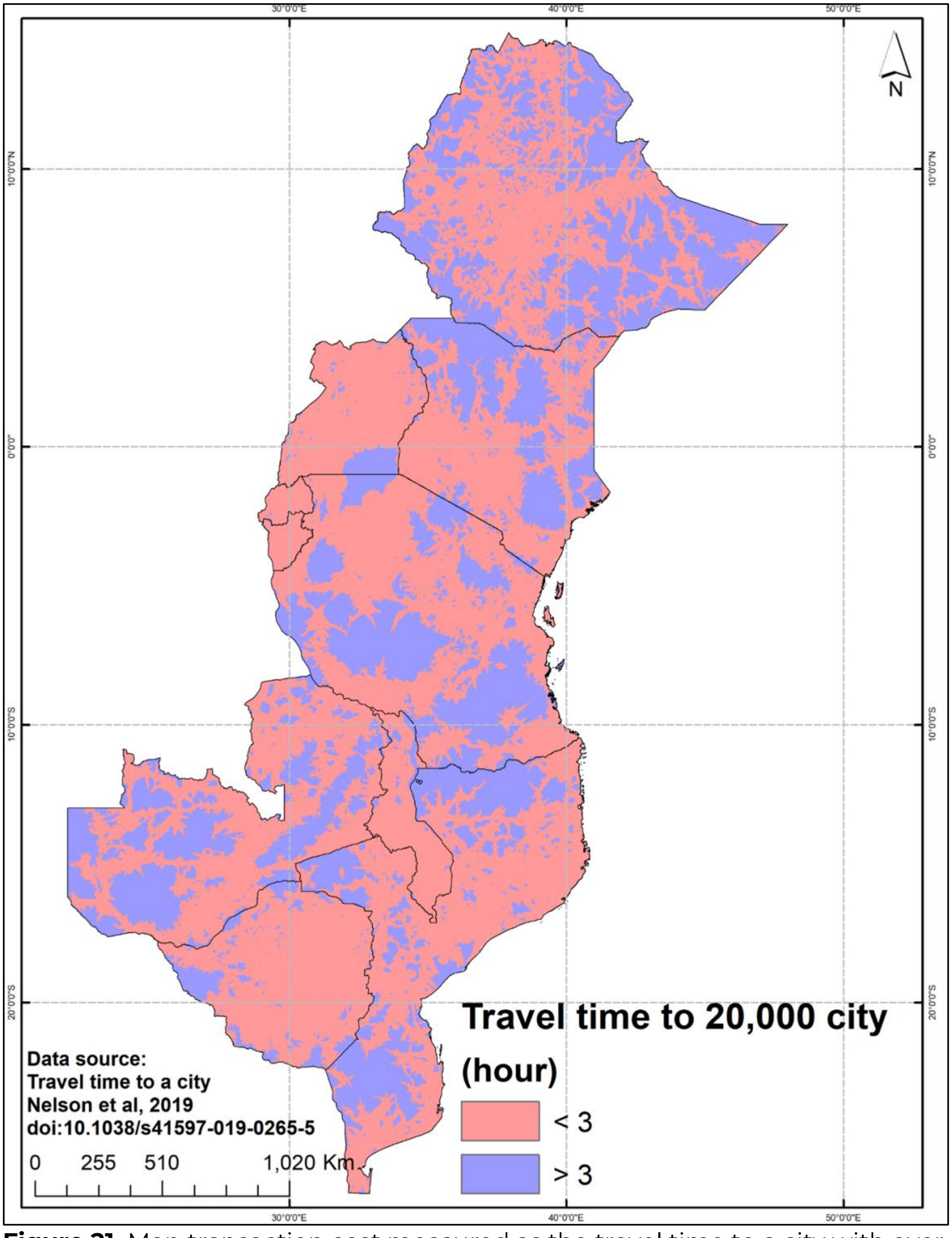

Figure 21. Map transaction cost measured as the travel time to a city with over 20,000 inhabitants identifying recommendation domains of the conservation agriculture in the east and southern Africa (ESA) region.

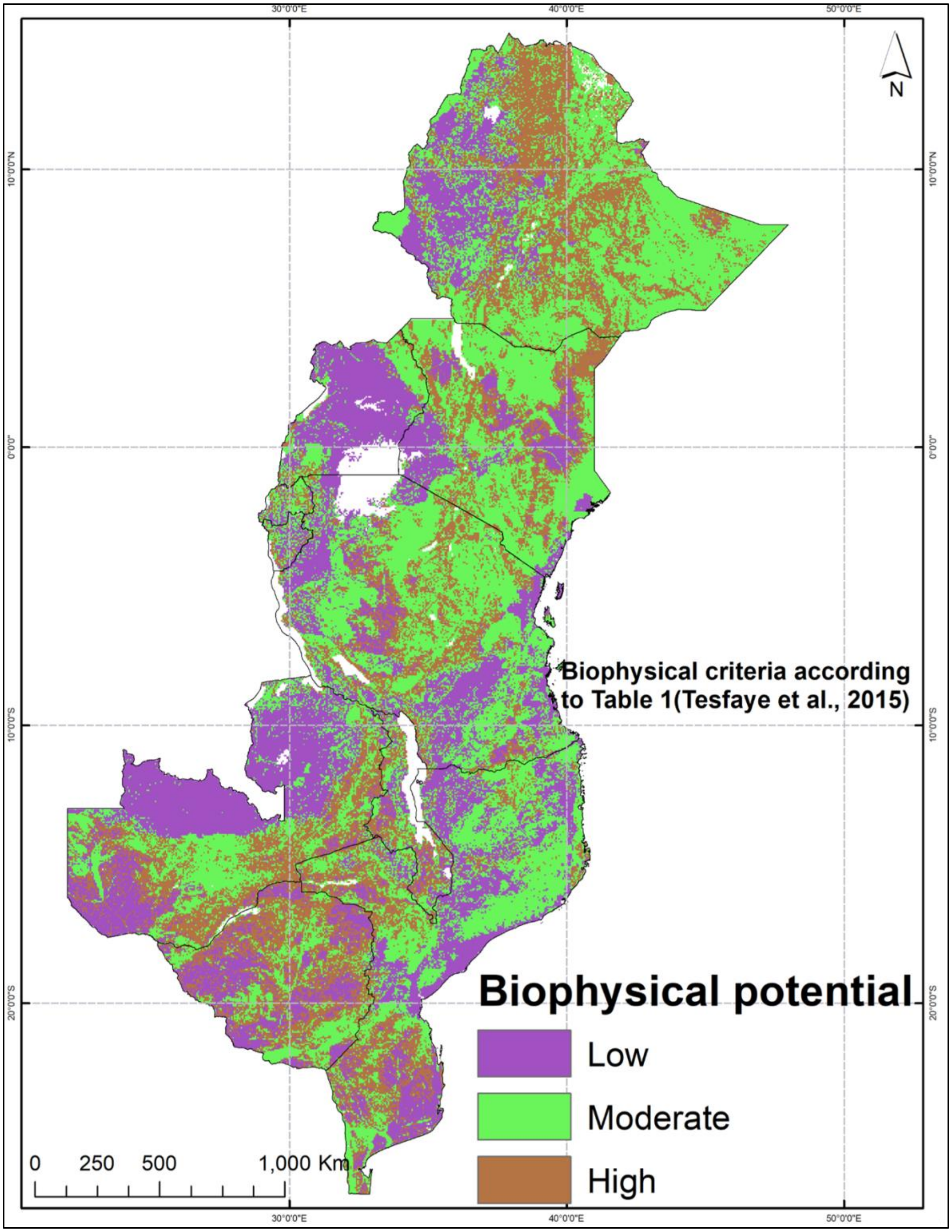

Figure 22. The biophysical potential of conservation agriculture in the east and southern Africa (ESA) region.

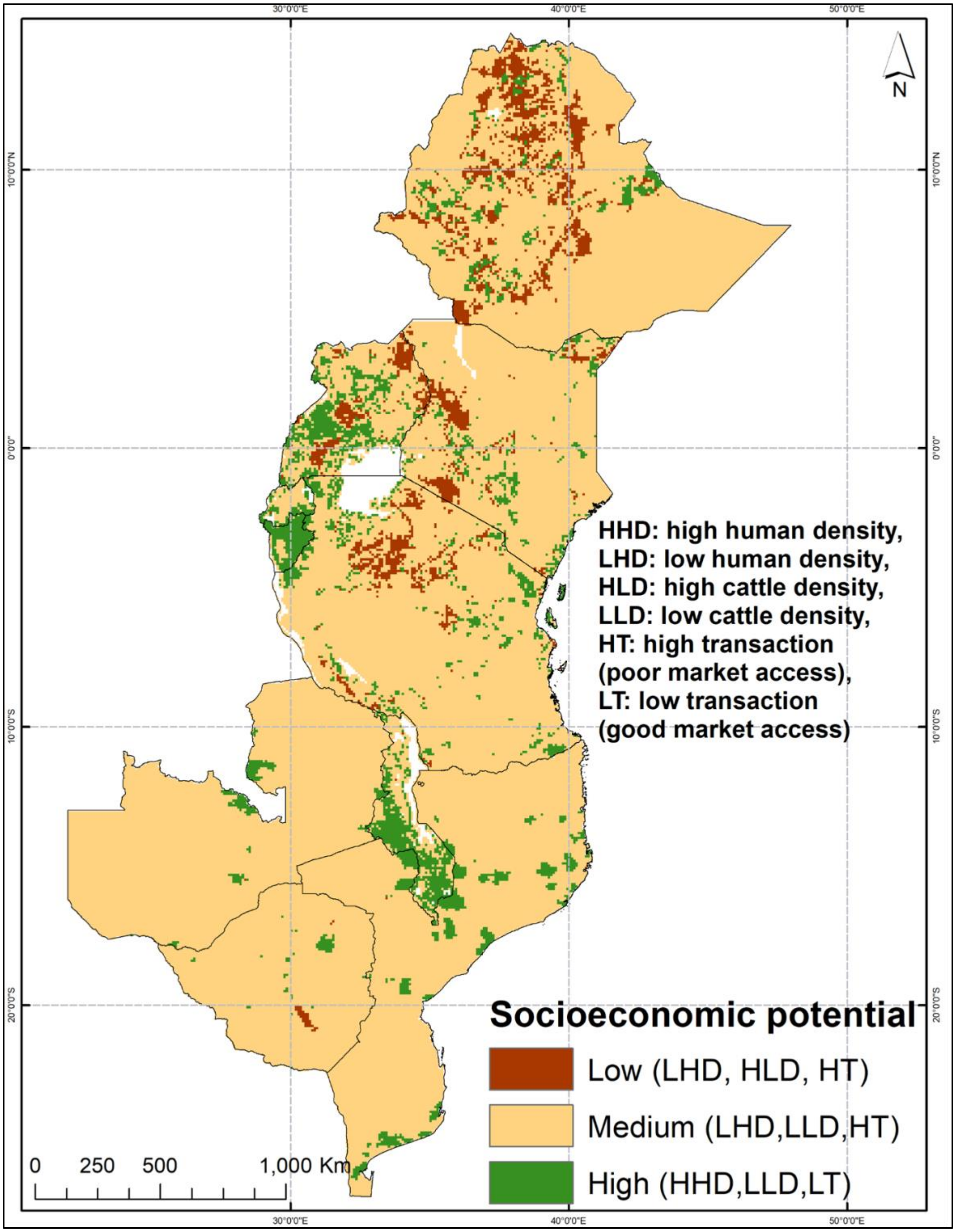

Figure 23. The socio-economic potential of conservation agriculture in the east and southern Africa (ESA) region.

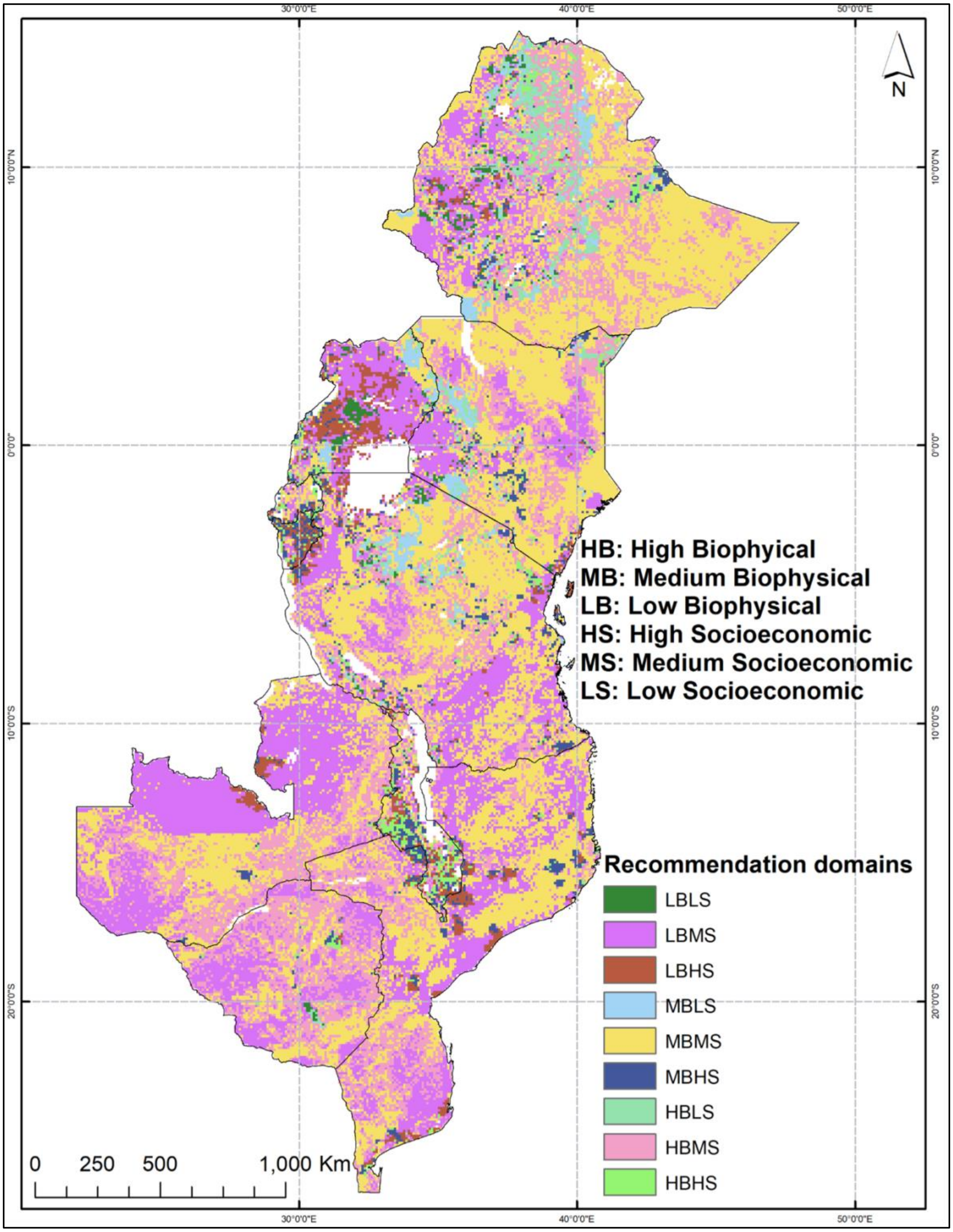

Figure 24. Map of the recommendation domains of conservation agriculture in the east and southern Africa (ESA) region.

References

1. Funk, C. et al., 2015. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. Scientific Data, 2(1): 150066.
2. Gilbert, M. et al., 2018. Global distribution data for cattle, buffaloes, horses, sheep, goats, pigs, chickens and ducks in 2010. Scientific Data, 5: 180227.
3. Hengl, T. et al., 2021. African Soil Properties and Nutrients Mapped at 30–m Spatial Resolution using Two-scale Ensemble Machine Learning. Scientific Reports, In Press.
4. Muthoni, F.K. et al., 2017. Sustainable recommendation domains for scaling agricultural technologies in Tanzania. Land Use Policy, 66: 34-48.
5. Nelson, A., 2019. Travel time to cities and ports in the year 2015.
6. Rusinamhodzi, L. et al., 2011. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. Agronomy for Sustainable Development, 31(4): 657.
7. Tesfaye, K., Jaleta, M., Jena, P. and Mutenje, M., 2015. Identifying Potential Recommendation Domains for Conservation Agriculture in Ethiopia, Kenya, and Malawi. Environmental Management, 55(2): 330-346.
8. Thierfelder, C. et al., 2014. Conservation agriculture in Southern Africa: Advances in knowledge. Renewable Agriculture and Food Systems, 30(4): 328-348.

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