RESEARCH PROGRAM ON Livestock

More meat, milk and eggs by and for the poor

Mapping breeds to appropriate production environments: a case study of Ethiopian indigenous sheep and goats

Layal A[1], Haile A[2], Rischkowsky B[2], Biradar C[1], Mwacharo JM[2]

[1]International Centre for Agricultural Research in the Dry Areas (ICARDA), Cairo, Egypt.

[2]Small Ruminant Genomics, International Centre for Agricultural Research in the Dry Areas (ICARDA), Addis Ababa, Ethiopia.

ILRI INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE
ICARDA Science for resilient livelihoods in dry areas
CIAT International Center for Tropical Agriculture Since 1967 Science to cultivate change
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
SLU

CGIAR is a global partnership that unites organizations engaged in research for a food-secure future. The CGIAR Research Program on Livestock provides research-based solutions to help smallholder farmers, pastoralists and agro-pastoralists transition to sustainable, resilient livelihoods and to productive enterprises that will help feed future generations. It aims to increase the productivity and profitability of livestock agri-food systems in sustainable ways, making meat, milk and eggs more available and affordable across the developing world. The Program brings together five core partners: the International Livestock Research Institute (ILRI) with a mandate on livestock; the International Center for Tropical Agriculture (CIAT), which works on forages; the International Center for Research in the Dry Areas (ICARDA), which works on small ruminants and dryland systems; the Swedish University of Agricultural Sciences (SLU) with expertise particularly in animal health and genetics and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) which connects research into development and innovation and scaling processes.

The Program thanks all donors and organizations who globally supported its work through their contributions to the CGIAR system.

Editing, design and layout—(Organization Name) …….

Cover photo—Caption (photo credit: Organization Name/Name of photographer).

ISBN: ……

Citation: Layal A, Haile A, Rischkowsky B, Biradar C, Mwacharo JM 2019. Mapping breeds to appropriate production environments: a case study of Ethiopian indigenous sheep and goats. International Centre for Agricultural Research in the Dry Areas (ICARDA). Research Report, Addis Ababa, Ethiopia. ICARDA

Patron: Professor Peter C Doherty AC, FAA, FRS
Animal scientist, Nobel Prize Laureate for Physiology or Medicine–1996

Box 30709, Nairobi 00100 Kenya
Phone +254 20 422 3000
Fax +254 20 422 3001
Email ilri-kenya@cgiar.org

ilri.org
better lives through livestock

ILRI is a CGIAR research centre

Box 5689, Addis Ababa, Ethiopia
Phone +251 11 617 2000
Fax +251 11 667 6923
Email ilri-ethiopia@cgiar.org

ILRI has offices in East Africa • South Asia • Southeast and East Asia • Southern Africa • West Africa

Contents

1 Abstract

Environmental suitability analysis is an important step in planning livestock development activities because of its efficiency to allocate improved and new livestock breeds to their most appropriate habitats for optimal production while minimizing adverse effects on the environment. This study used geoinformatics based spatial analytical tools, to develop breed-specific similarity index maps to determine productive biophysical environmental zones for four (Atsbi, Doyogena, Horro, Menz) and two (Abergelle, Yabello) breeds of Ethiopian indigenous sheep and goats, respectively. Initial results indicate a broad scale pattern showing varying degrees of suitable environments for the two species. Specifically, Menz and Horro are highly suitable in 7.79% and 6.09% of the total land area of Ethiopia, respectively and Doyogena and Atsbi have a restricted geographic range. Although, the suitable production environments for the four sheep breeds show a slight overlap, that of goats did not. Abergelle is best suited to the drylands of northern Ethiopia while Yabello is suitable to the southern ones. Our results provide insights for targeting location specific breed interventions, which together with climate change trajectories and natural resource base, will be a major criterion for building resilient production systems. Further analysis, including micro climatic variability, feed stock potential and ecological carrying capacity, will be required to refine species-by-breed agroecological niches.

2. Introduction

In the effort to develop sustainable conservation plans and programs for either a species, breed or strain, collection of data on their current habitats, as well as the availability of suitable habitats within a country or regions, is important. Various attempts to mapping the habitat distribution of specific livestock breeds and species are limited to recording and characterizing the current production habitat. Therefore, data concerning habitat suitability outside the geographic range of the species or breed are often neglected. However, collecting these data through direct field surveys requires enormous human resources, funding, and time. Geographic information systems (GIS) based approaches provide a useful way to examine whether a breed can be introduced to new areas, by identifying environments that are similar to the ones where the breed has either evolved over generations or been developed/improved *in situ* over time. This allows researchers to avoid mortalities or reduced performance which results when breeds are introduced to the wrong environments.

In the last few decades, attention towards understanding the characteristics of preferred habitats of specific species/breeds and the distribution of potentially suitable habitats led to a marked increase in interest in the use of Ecological Niche Modeling (ENM) or Species Distribution Modeling (SDM) (Merow et al. 2013; Fourcade et al. 2014). ENM/SDM involves the utilization of statistics, ecology, Geographic Information System (GIS), and even Remote Sensing (RS) to develop estimations of suitable niche for species across predefined landscapes (Franklin and Miller 2009), and it can also be extrapolated over space and time

(Elith and Leathwick 2009; Franklind and Miller 2009). The modeling is useful for guiding the appropriate dissemination and conservation of improved indigenous genetics as a means of finding potential dissemination sites. Such modeling can be conducted using a variety of alternatives, including heuristic models (e.g., BIOCLIM (Beaumont and Hughes 2007), combinatorial optimization (e.g. GARP (Fitzpatrick et al. 2007), statistical models (e.g. GAMs (Jensen et al. 2008), and machine learning (e.g. ANN (Ostendorf et al. 2001; Berry et al. 2002; Harrison et al. 2006); MAXENT (Phillips et al. 2006, Sinclair et al. 2010)). The most popular approach so far for ENM/SDM is the use of Maximum Entropy (Maxent) algorithms (Belgacem and Louhaichi 2013) which has shown higher predictive accuracy in identifying distributions and habitat selection of wildlife in spite using presence-only records (without the need of absence data) and "background" sample of environments in the region of interest (Phillips et al. 2006; Phillips and Dudık 2008). Being a general-purpose machine learning method, Maxent offers a precise and straight forward mathematical formulation to characterize probability distribution across user-defined landscapes (Phillips et al. 2006; Merow et al. 2013).

Ethiopia is a country with significant agro-ecological diversity and diverse landforms that are associated with the Great Rift Valley that runs the length of the country. The effects of the landforms on soil formation processes, local climates, the distribution of water resources, and vegetation patterns has resulted in a variety of farming systems that farmers have developed to exploit distinct combinations of local agricultural resources. Combined with its large number of sheep and goat breeds, Ethiopia therefore presents an ideal country to model pockets of environments that are suitable to particular livestock breeds across the country outside their geographic home tracts.

3. Materials and Methods

3.1 Study location and type of data used

This study was carried out in Ethiopia where community-based breeding programs (CBBP) and their offspring's are growing in demand. CBBP's typically relate with farmers of low-input production systems with a common interest to improve their animal genetic resources (ICAR-FAO 2000; Mueller et al 2015). Community-based breeding increases the productivity and profitability of indigenous breeds without undermining their resilience and genetic integrity, and without expensive (and potentially diversity-reducing) interventions (Haile et al 2010). The development of better performing and well adapted indigenous breeds of livestock through the CBBP initiatives or even crossbred animals through government and non-government agencies, has led to an increase in demand for the improved genotypes across large geographic areas. There is need to identify suitable environments under which such breeds would perform optimally.

The underlying concept for assessing the environments which a "new" or "potentially improved breed" could be introduced without compromising its performance or survival lies in the identification of environments that are similar, or close in characteristics, to its original endemic location/environment i.e. it's geographic origin/heartland. Thus, the geographic 'heartland' of a breed, the place where the breed evolved over many generations and their associated biophysical characteristics form the basis for identifying other similar geographic areas where the breed could perform optimally. The methodology for assessing similarity takes into consideration the permanent characteristics of the biophysical environment including climate, topography and soils. In similarity analysis, the value of a parameter or index at one location, the "match location", is compared with other ("target") locations to quantify the degree of similarity (De Pauw et al., 2011; Robertson et al., 2008). The thematic pattern for the original habitat of each breed was used to represent the "match location". The "target location" was taken to be the entire geographic area in Ethiopia. The similarities in temperature, precipitation, landforms and soils were mapped separately for each breed using individual similarity indices. The indices were then combined to obtain an overall similarity index for the natural environment.

3.2 Methods and analytical techniques

The spatial data used in this study consisted of "Presence-Background" (PB) data recorded within a one (1) km spatial-resolution radius, which was considered to be a suitable scale for Ethiopia. The "PB" data entailed presence-only specie/breeds records and a "background" sample of environments in the region or home tract of the species/breed. The following categories of data were used in the study. Data on temperature and precipitation was obtained from the WorldClim 2.0 (Hijmans et al., 2005a) database. The data consisted of average monthly climate data from the year 1970 to 2000. This dataset had a spatial resolution of approximately 1 km^2 and was created by interpolation using a thin-plate smoothing spline of observed climate at weather stations, with latitude, longitude, and elevation as independent variables (Hutchinson, 2004). To model landform similarity, the Shuttle Radar Topography Mission Global SRTM30 Digital Elevation Model from Earth Explorer database (USGS, 2012) also at one (1) km^2 resolution was used. The digital soil map of the world and derived soil properties developed (FAO-UNESCO, 1995) was used to model soil pattern similarity. A combination of these datasets was used to model the overall similarity in the natural production environments.

3.3 Mapping the original heartland of the breeds

This study used four and two breeds of Ethiopian indigenous sheep and goats, respectively (Table 1). GPS coordinates were recorded from the most centralized location within the geographic heartland of each breed using the handheld Garmin GPSMAP 64st tool. The coordinates were plotted on the map of Ethiopia using the ArcGIS.10 platform (Figure1). The geographic location and distribution of the study breeds/populations in Ethiopia were further confirmed from published reports (ESGPIP 2009; Farm Africa 1996). Based on the published distribution maps, two breeds/populations of sheep (Menz and Horro) and one of goat (Abergelle), matched the breeds selected for this study. The published sheep and goat distribution maps were geo-referenced following the country geographical boundaries. The distribution boundaries of Menz and Horro sheep and Abergelle goat were digitized using head up digitizing in ArcGIS.10 platform (Figure1). For the two remaining breeds of sheep (Doyogena and Atsbi) and one of goat (Yabello), buffer zones of two (2), five (5) and ten (10) km radius around the GPS coordinates were generated (Figure 2). The European Space Agency's layer of land cover for Ethiopia (2015; Figure 3; http://geoportal.icpac.net/layers/geonode%3Aethiopia_landcover2015_4), the land form map of Ethiopia and the buffer shape file for Yabello goat, Doyogena and Atsbi sheep were overlaid on each other and used to delineate their geographic distribution boundaries (Figure 4).

3.4 Mapping climate similarity

The similarity in the patterns of precipitation and temperature were determined using ICARDAs' in-house developed Visual Basic climatic similarity program. The other similarity factors were determined using the ArcGIS.10 software. The data input for the Visual basic climatic similarity program was in the form of global climatic grids composed of 12 mean monthly precipitation and average temperature surfaces. For each geographic heartland of the breeds/populations, two files with temperature and precipitation match values were required as inputs. Each of these files had two pairs of values denoting the minimum and maximum thresholds for each variable. These files were obtained by defining two points that represent the annual maximum and minimum values for each climatic factor in the heartland of each breed/population. The mean monthly temperatures and precipitation were extracted and used as input values in the Climatic Similarity program.

The two similarity indices, which are a distance functions I_1 and I_2 representing respectively, air temperature and precipitation, draw inspiration from the 'Match Index' concept developed in the CLIMEX software (Sutherst, 1999). They model the drop in similarity under increasing dissimilarity for air temperature Δ_t and precipitation Δ_p, respectively, as follows:

(Eq. 1) $$I_1 = e^{\left(-\frac{\Delta t}{\sigma_t}\right)} \ and \ I_2 = e^{\left(\frac{\Delta p}{10 \times \sigma_p}\right)}$$

with $\sigma_t[\,^\circ C^{-1}]$ and $\sigma_p[mm^{-1}]$ being user-defined calibration constants. Further details are available in De Pauw et al. (2011). The combination of the two distance functions, representing temperature (I_1) and precipitation (I_2), were then used to assess climatic similarity following De Pauw et al. (2011) as shown below:

(Eq. 2) $$S = Min(I_{1(\Delta_t)}, I_{2(\Delta_p)})$$

with Min being the lowest of the two values

3.5 Mapping soil similarity

Soil similarity was measured by comparing the composition of the soils in the heartland of each breed with the soil composition of each land pixel across Ethiopia, using Sørensen similarity index (Ref!) which was applied to Soil Management Groups (SMG). The SMG's were defined as G1, G2 ... G13 with the following caveats: i) If G1 was not present in the breed's heartland and the target pixel, no similarity index was calculated; ii) If G1 was present in the breed's heartland but not in the target pixel, or vice versa, the similarity index was zero; iii) For all the other cases, the similarity index for SMG G1 was calculated following De Pauw et al. (2011) as follows:

(Eq. 3) $$Sim_{soil_{G1}} = \frac{Min(\%G1_d, \%G1_t) \times 2}{\%G1_d + \%G1_t}$$

with Min being the lowest value of the two, $\%G1_d$ the proportion (%) of SMG G1 in the soil composition of the breed's heartland, and $\%G1_t$ the proportion (%) of SMG G1 in the soil composition of the target pixel. Steps i to iii were repeated for SMG's G2, G3 ... to G13. The overall soil similarity was then calculated as a weighted average of the similarity indices for each SMG following De Pauw et al. (2011) as follows:

$$\text{(Eq. 4)} \qquad Sim_{soil_{all}} = \sum_{i=1}^{13} Sim_{soil_{Gi}} \times \frac{\%G_{i,d}}{100}$$

with $\%G_{i,d}$ being the proportion (%) of SMG G_i in the soil composition of the breed's heartland.

3.6 Mapping landform similarity and composition

Landforms were grouped into three classes, L1, L2 and L3, representing plains, hills and mountains, respectively based on the concept of "Relief Intensity (RI)" (Ref). Using the SRTM 30 DEM, the "RI" was derived from the maximum elevation difference between two neighboring pixels in ArcGIS.10 using the focal statistic tool. The values for each cell location on the output raster were determined on a cell-by-cell basis as: Focal Range = Focal Maximum – Focal Minimum. The "RI" integer output raster was then re-defined as follows: L1 = Plains (RI: 0 - 50 metres), L2 = Hills (RI: 50 - 300 metres) and L3: Mountains (RI: > 300 metres).

For each breed's heartland, the landform composition was calculated as percentage plains (%L1), hills (%L2) and mountains (%L3), respectively. The approach used to assess landform composition was similar to that used to assess soil similarity. It involved the comparison of the landform composition within the breed's heartland with the landform of each land pixel in Ethiopia; the only difference being that in the latter the landform is homogeneous i.e. 100% L1, L2 or L3, respectively. As with landform similarity, the defining procedures were: i) If L1 was not present in the breed's heartland and the target pixel, no similarity index was calculated, ii) If L1 was present in the breed's heartland but not in the target pixel, or vice versa, the landform composition index was zero, iii) In all the other cases the index for landform composition L1 was calculated following De Pauw et al. (2011) as follows:

$$\text{(Eq. 5)} \qquad Sim_{L1} = \frac{(\%L1_d)\times 2}{\%L1_d + 100}$$

with $\%L1_d$ being the proportion (%) of landform composition L1 within the landform composition of the breed's heartland. The three steps (i-iii) were also performed for landforms L2 and L3.

3.7 Mapping the similarity in all the evaluated factors

The overall similarity was calculated as the lowest of all the evaluated factors as follows:

$$\text{(Eq. 6)} \qquad S_{overall} = \text{Min}\ (S_{climate}, S_{LF}, S_{soils})$$

with $S_{climate}$ being the minimum of the $S_{precipitation}$ and $S_{temperature}$ similarity indices, S_{LF} representing the landform similarity and S_{soils} the soil similarity indices, respectively.

4. Results and discussion

4.1 Identifying important environmental variables and model evaluation

We generated the predicted distribution of potentially suitable habitats across Ethiopia for four breeds/populations of sheep and two of goats based on observed overall similarity compounded with climatic and environmental variables. According to the calculations of the relative contributions of climatic and environmental variables to the overall similarity model, there were two variables that could be considered to have the most contribution to the model. These two variables, precipitation and climate variability, accounted for xxx and xxx%, respectively to the final result of the prediction. This suggests that the suitability of habitat for breed suitability mapping are strongly influenced by precipitation and climate. The latter is not surprising because the climate modelling included both precipitation and temperature. Precipitation determines water and forage availability and when combined with temperature, they determine the length of the growing periods, disease, and parasite (endo- and ecto-) prevalence. In spite of this result, temperature, soil and landform similarities were the most poorly determining factors of environmental suitability.

4.2 Predicted distribution of potential suitable habitats for the study breeds/populations

For Menz and Horro sheep and Abergelle goat the digitized boundaries from two published reports were used to delineate the breed's heartland areas, because the GPS coordinates fell within the digitized boundaries (Figure 2). For the Doyogena and Atsbi sheep and Yabello goat two-, five- and ten-kilometre buffer radius were much smaller compared to their heartland areas. Furthermore, there was no noticeable difference in the temperature and precipitation range to define two points that represent the annual maximum and minimum match values for each climate factor in their heartland distribution areas. Thus, the land cover for Ethiopia, from the European Space Agency including the landform map based on SRTM 30 "RI" and 10 km GPS buffer zone radius for the three breeds were overlaid and used to define the heartland distribution boundaries of Doyogena and Atsbi sheep and Yabello goat breeds. Figure 3 shows how the derived boundaries were drawn to cover homogeneous land cover areas.

For each of the study breeds, six maps were generated. These represented similarities in temperature, precipitation, landforms, soil patterns, overall climatic and overall global similarity in all the evaluated variables that defined the overall characteristics of each breeds heartland environment. To emphasize on the area that is considered suitable across Ethiopia for introducing any of the study breeds, the overall global similarity in all the evaluated variables were merged into four broad categories *viz* 1) Low suitability (0.0 – 25.0% probability), 2) Less suitability (25.0%-50.0% probability), 3) Medium suitability (50.0%-75.0% probability) and 4) High suitability (> 75.0% probability). The results show large variability in the distribution of the suitable environments for the two species and their breeds across Ethiopia. The zonal statistics function was used to summarize suitability for all the evaluated factors in the form of maps and synthesis tables. The percentages for each suitable class, which allow comparisons to be made between the different breeds in terms of potential adaptation to a new target area, are presented in Table 2. The results show that Menz (Figure 5) and Horro (Figure 6) sheep have the widest potential geographic distribution span of the highly suitable geographic area than the other breeds. Their suitable areas cover 7.79% and 6.09%, respectively of the total land area of Ethiopia, and Doyogena (Figure 7) and Atsbi (Figure 8) have restricted geographic ranges within which they are expected to be best suited to perform. According to the result, a large percentage of Ethiopia (>51%) has been projected to be of low suitability for the optimal performance of the six breeds analysed. The numbers consisted of 64.84% (Menz), 53.44% (Horro), 76.98% (Doyogena), 83.53% (Atsbi), 82.37% (Abergelle) and 63.89% (Yabello) (Table 2). Although, the suitable production range for the four breeds show a slight overlap, that of the two breeds of goats did not. Although both breeds of goats are best suited to perform in the dryland's environments, the niche for Abergelle is northern Ethiopia (Figure 9) and that of Yabello is in southern Ethiopia (Figure 10). The highly suitable ranges for Menz, Horro and Doyogena sheep overlap in Central Ethiopia while that between Atsbi and Menz overlap in the North of Ethiopia. This suggests that the Menz sheep could be suitable in all the geographic areas where the other three breeds of sheep are highly suitable.

The predicted medium and highly suitable habitats for the four breeds of sheep were distributed mainly in the highlands and mountainous areas of Ethiopia. These are normally the cold wet environments where feed is always available. The lowland areas were predicted to be less, medium and highly suitable as the habitat for goats. This suggests specialization of habitats between the two species. It can be explained by the fact that goats are more of inquisitive and selective feeders being able to utilize more nutritious and large variety of feed resources including grass and bushes that predominate the drylands. This ability to graze and browse places the species at a comparative advantage. Sheep on the other hand are mainly grazers and therefore suitable to areas where grass comprise the main feed resource.

The temperature similarity across the country for all the breeds (Figures 11 to 16) is higher than the precipitation similarity (Figures 18 to 23). The annual average temperature for Ethiopia ranges from 4 to 30^{O}C for each breed while in the heartland distribution areas (Figure 17) in general, the annual mean temperature ranges from 7 to 27^{O}C. Therefore, most of the breeds temperature similarity have high values that cover large areas the country. Figure 12 shows that for Horro sheep, most of the country have very high similarity values (0.9 to 1.0). This is probably because the heartland distribution area for the breed is very large and therefore covers a wider range of temperatures than the heartland of the other breeds. On the other hand, the precipitation similarity for Horro sheep (Figure 19) shows a restricted geographic range, the high similarity values are within or close to the breed's heartland. This corresponds to the overall precipitation pattern of Ethiopia (Figure 24) and the precipitation range within the breed's heartland. The mean annual rainfall of Ethiopia ranges from 141 mm in the arid areas of eastern and northeastern regions of the country to 2,275 mm in the southwestern highlands (Berhanu et al. 2013). This is due to the complex topographical and geographical features of the country which have a strong impact on the spatial variation of climate in general and rainfall patterns in particular (Zeleke et al. 2013). The climatic similarity (Figures 25 to 30) clearly shows the effect of the "law of the most limiting factor", the overall similarity can never be higher than the lowest of the evaluated similarity indices (De Pauw et al., 2011). Based on the complexity and uniqueness of soil patterns within the heartland areas of each breed, the soil similarity patterns (Figures 31 to 36) may vary substantially between breeds: the more generic these soil patterns are, the more likely they are to occur elsewhere (De Pauw et al., 2011). Figure 31 shows that the soil patterns in the heartland area of Doyogena sheep are more generic than the soil patterns in the heartland area of Horro sheep (Figure 30) even though Horro sheep have a wider distribution area than Doyogena sheep. Finally, landform similarity is generally high (Figures 37 to 42) between all the breeds. Landform similarity for Horro sheep (Figure 38) is higher than that of Abergelle goat (Figure 41). This is probably because hills are widely spread than mountains in Ethiopia.

5. Conclusion and Recommendation

Similarity models are useful tools to determine the potential distribution range of species and breeds outside their home-range environments. These models are "statistical" models that do not attempt to describe cause and effect between model parameters and response (Guisan and Zimmermann, 2000). For example, the incidental environmental requirements are dependent on the climatic conditions that currently exist in the landscape. Furthermore, in this study the soil and landform were evaluated by their own similarity index approaches. Our results provide insights for targeting location specific breed interventions, which together with climate change trajectories and natural resource base, will be a major criterion for building resilient production systems. However, further analysis, including micro climatic variability, feed stock potential and ecological carrying capacity, will be essential to refine species-by-breed agroecological niches. Climate similarity can be done to model the effect of climate change on the potential suitable area for introducing breeds under current and future climate change scenarios.

6. References

Berhanu, B., Melesse, A. M., & Seleshi, Y. (2013). "GIS-based hydrological zones 768 and soil geo-database of Ethiopia". *CATENA*, 104, 21–31. doi:10.1016/j. 769 catena.2012.12.007

De Pauw, E. Rischkowsky, B. Abou-Naga, A. Ansari-Renani, H.R. Boujenane, I. Gursoy, O. (2011) Final Report of Project "Practical Application of Production Environment Descriptors for Animal Genetic Resources – country case studies for sheep and goat breeds" (Letter of Agreement of FAO with ICARDA PR 43410) ICARDA, Aleppo, Syria.

ESGPIP (Ethiopian Sheep and Goat Productivity Improvement Program) 2009. Sheep breeds of Ethiopia: A guide for identification and utilization. Technical Bulletin No. 28. https://issuu.com/esgpip/docs/technical_bulletin_no.28.

Guisan, A. and Zimmermann, N. E. (2000) "Predictive habitat distribution models in ecology." *Ecological Modelling*, 135(2-3) pp. 147–186.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G. and Jarvis, A. (2005) "Very high-resolution interpolated climate surfaces for global land areas." *International Journal of Climatology Int. J. Climatol.*, 25(15) pp. 1965–1978.

Hutchinson MF (2004) Anusplin version 4.3. Centre for Resource and Environmental Studies. The Australian National University, Canberra.

Robertson, M. P., Kriticos, D. J. and Zachariades, C. (2008) "Climate matching techniques to narrow the search for biological control agents." *Biological Control*, 46(3) pp. 442–452.

Sutherst, R.W. 1999. CLIMEX: predicting the effects of climate on plants and animals. CSIRO.

USGS EarthExplorer (2012) Global 30 Arc-Second Elevation (GTOPO30) [Online] [Accessed on 7th Jon 2015] Available online at: http://earthexplorer.usgs.gov/

Zeleke, T. Giorgi, F. Mengistu, G T. Diro, G T. (2013) "Spatial and temporal variability of summer rain fall over Ethiopia from observations and a regional climate model experiment." *Theor Appl Climatol* 111(3–4):665–681.

Table1: GPS coordinates of the central location of the geographic heartland of the study breeds/populations.

Species	**Breed/Population**	**Longitude**	**Latitude**
Sheep	Menz	39.658428	10.310420
	Menz	39.665905	10.122854
	Horro	37.062366	9.574480
	Horro	37.092065	9.549573
	Doyogena	37.834110	7.412174
	Doyogena	37.798297	7.299537
	Atsbi	39.702837	13.880200
	Atsbi	39.691315	13.817803
Goats	Yabello	37.979159	5.179145
	Yabello	37.833607	4.953657
	Abergelle	38.979670	13.039025
	Abergelle	38.822472	13.275109

Table 2: Percentage in suitability classes for all evaluated factors

Species	**Breed**	**Low suitable**	**Less suitable**	**Medium suitable**	**High suitable**
Sheep	Menz	64.84	17.33	10.04	7.79
	Horro	53.44	28.58	11.88	6.10
	Doyogena	76.98	14.69	6.83	1.49
	Atsbi	83.53	10.40	5.56	0.51
Goats	Abergelle	82.37	11.88	4.13	1.62
	Yabello	63.89	24.64	11.35	0.12

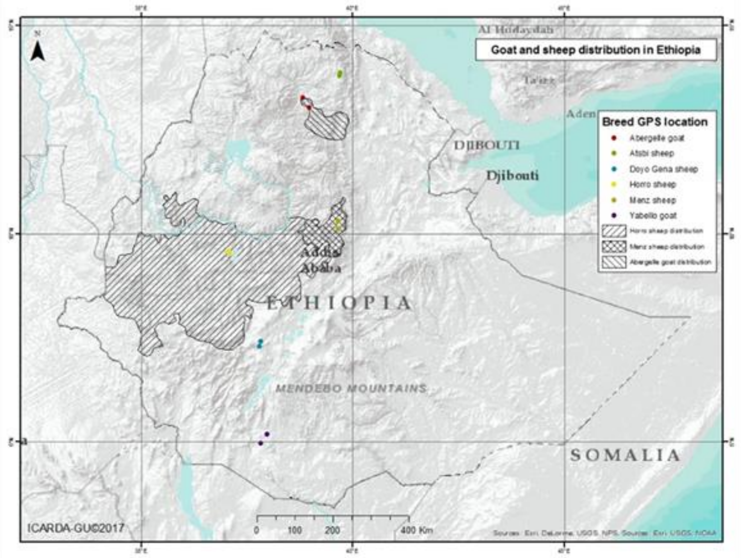

Figure 1: Shows the GPS location of the breed and the digitized distribution boundary for Horro, Menz and Abergelle breed.

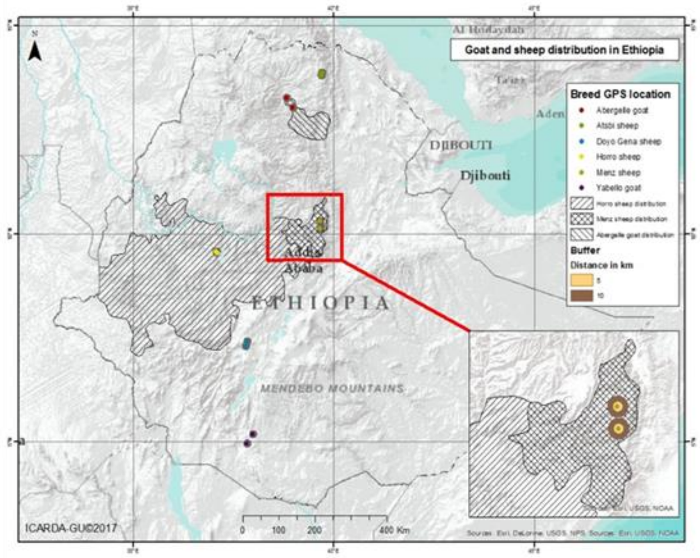

Figure 2: Shows a buffer of 5 and 10 km around the GPS points, the inset is a zoom in on Menz sheep for better visualization.

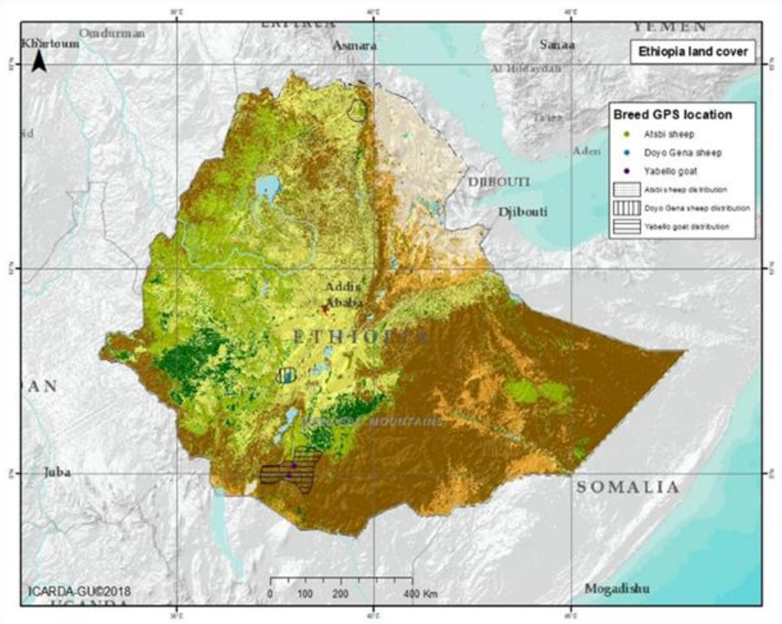

Figure 3: Shows Land cover for Ethiopia 2015 obtained from the European Space Agency (http://geoportal.icpac.net/layers/geonode%3Aethiopia_landcover2015_4 accessed 14/02/1209).

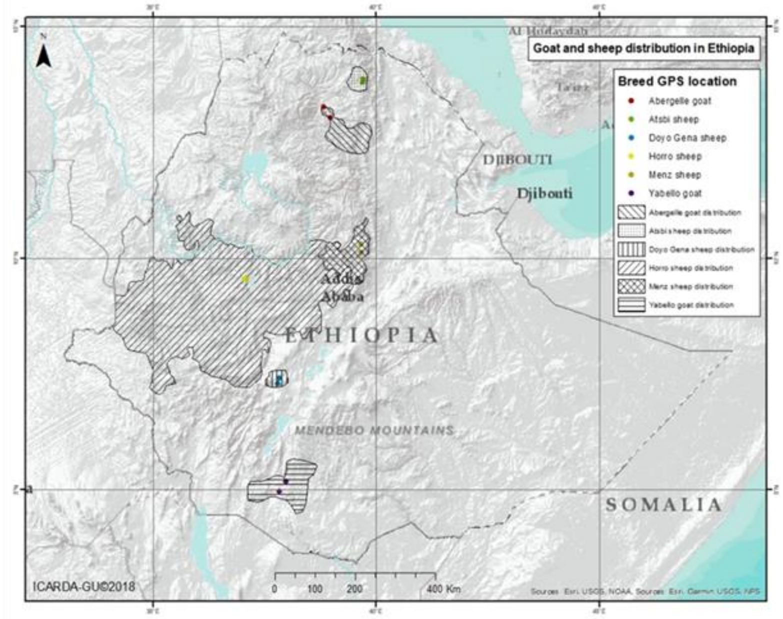

Figure 4: Shows all digitized breeds boundary distribution in Ethiopia.

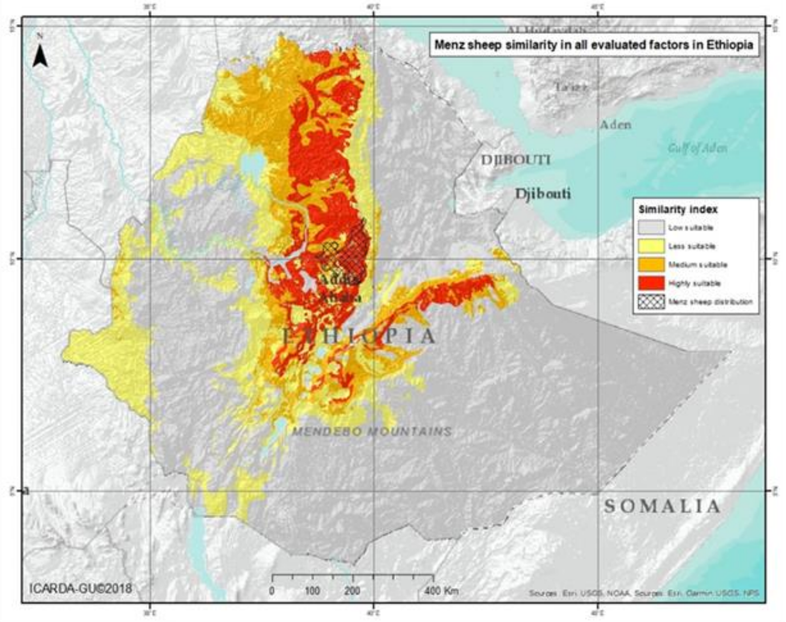

Figure 5: Similarity in all evaluated factors for Menz sheep in Ethiopia

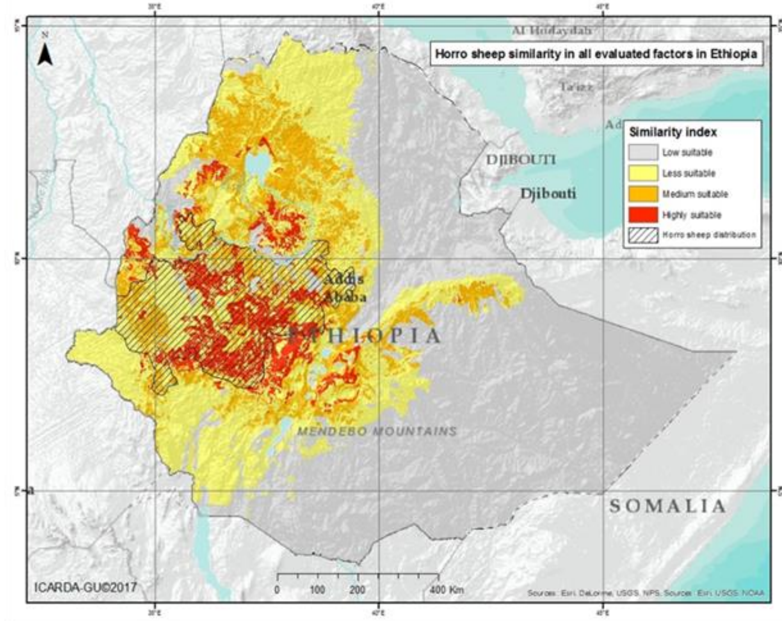

Figure 6: Similarity in all evaluated factors for Horro sheep in Ethiopia.

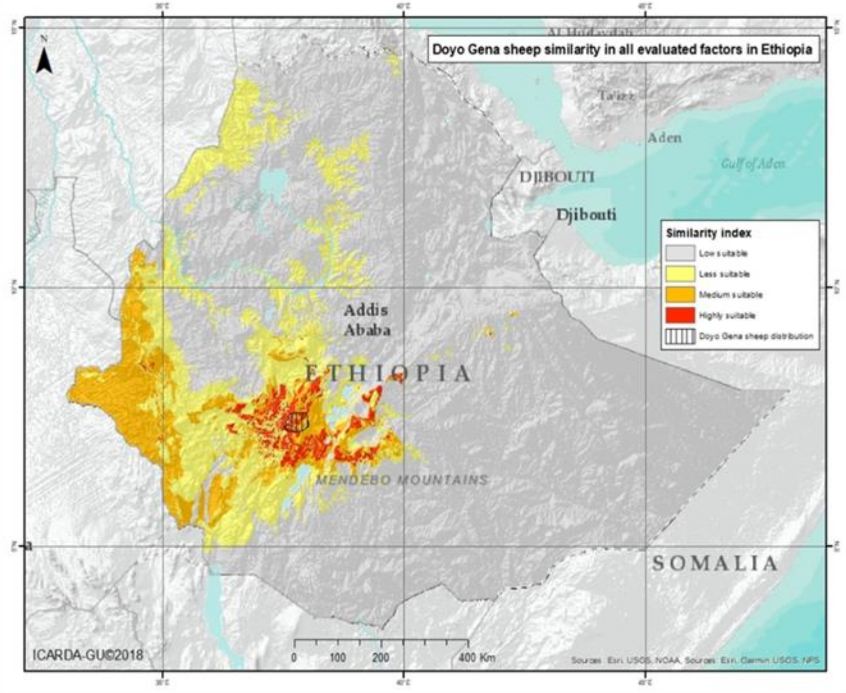

Figure 7: Similarity in all evaluated factors for Doyogena sheep in Ethiopia

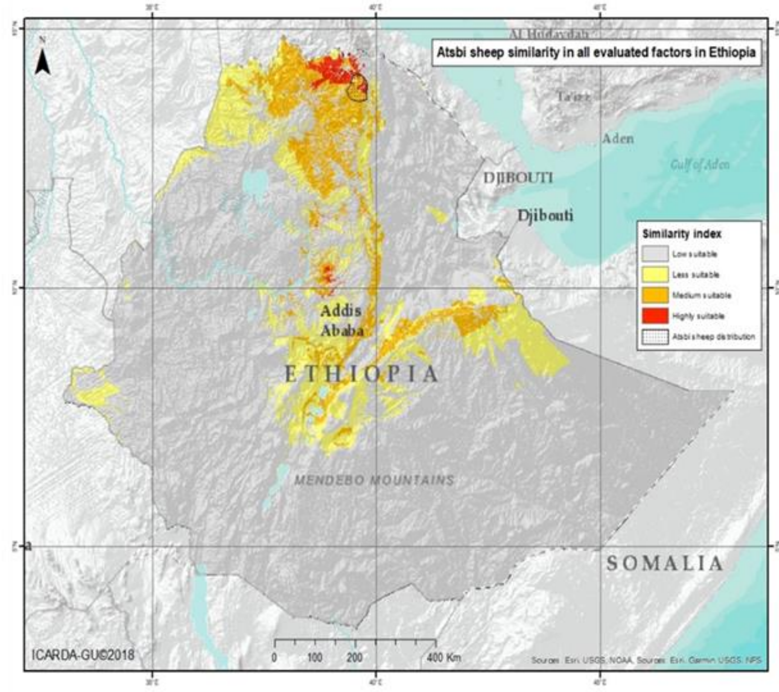

Figure 8: Similarity in all evaluated factors for Atsbi sheep in Ethiopia.

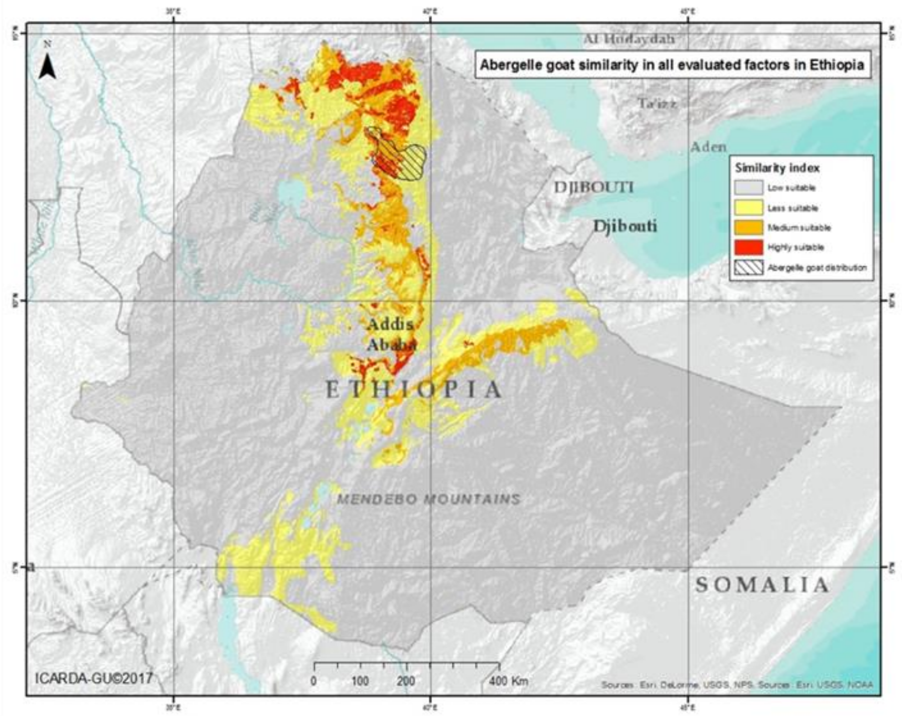

Figure 9: Similarity in all evaluated factors for Abergelle goat in Ethiopia

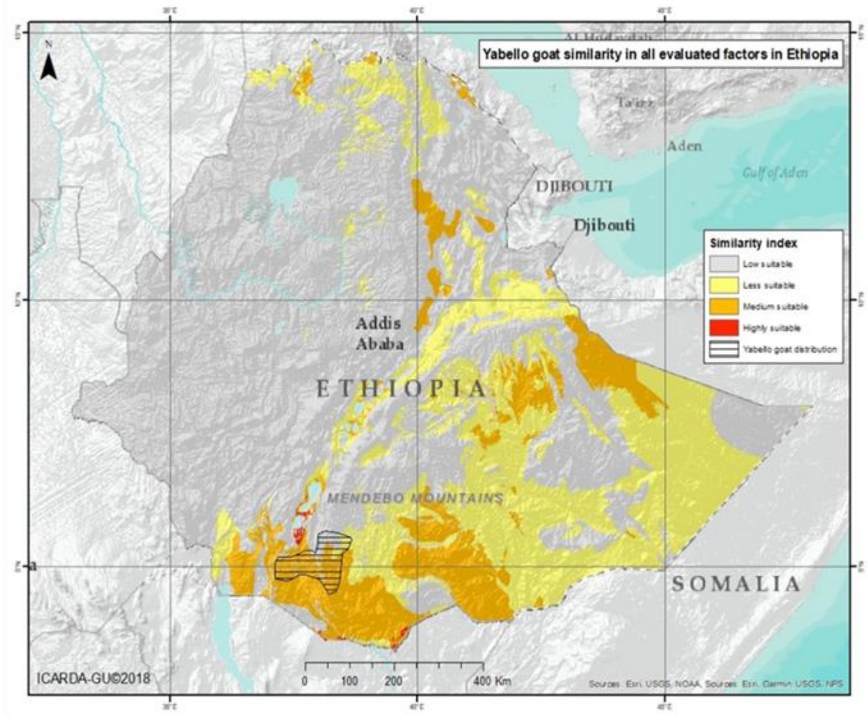

Figure 10: Similarity in all evaluated factors for Yabello goat in Ethiopia.

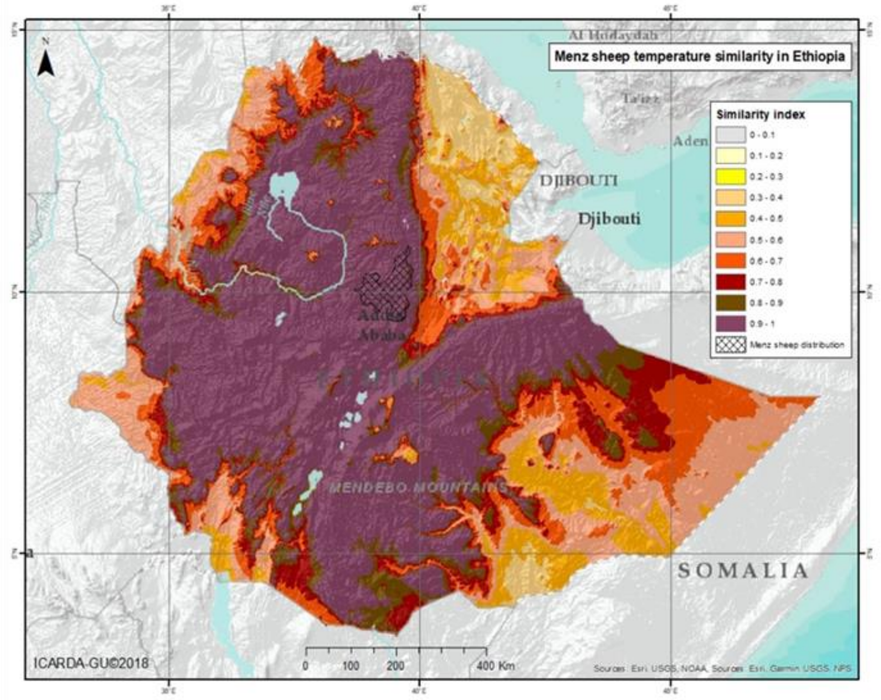

Figure 11: Temperature similarity for Menz sheep in Ethiopia

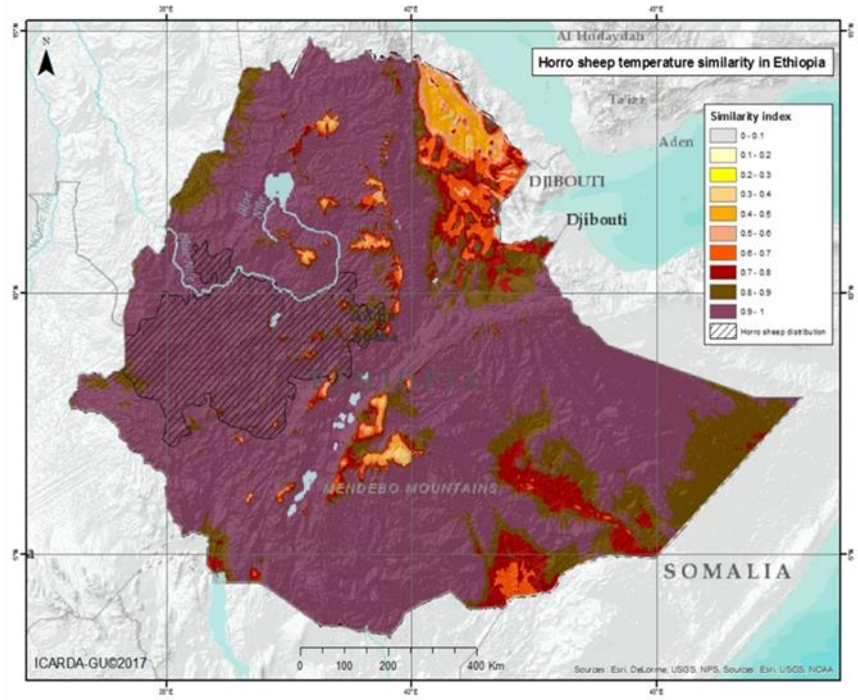

Figure 12: Temperature similarity for Horro sheep in Ethiopia.

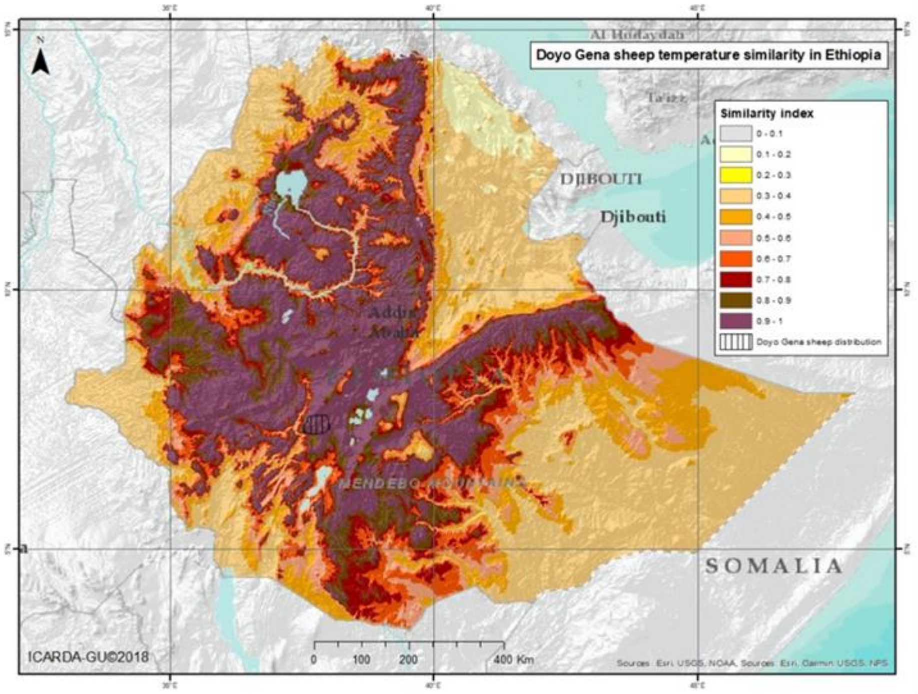

Figure 13: Temperature similarity for Doyogena sheep in Ethiopia.

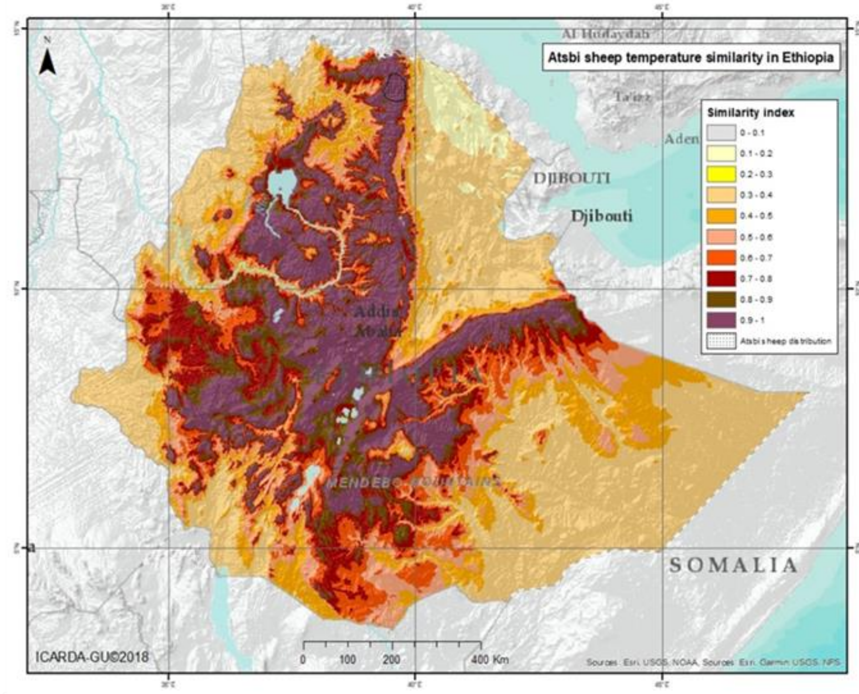

Figure 14: Temperature similarity for Atsbi sheep in Ethiopia.

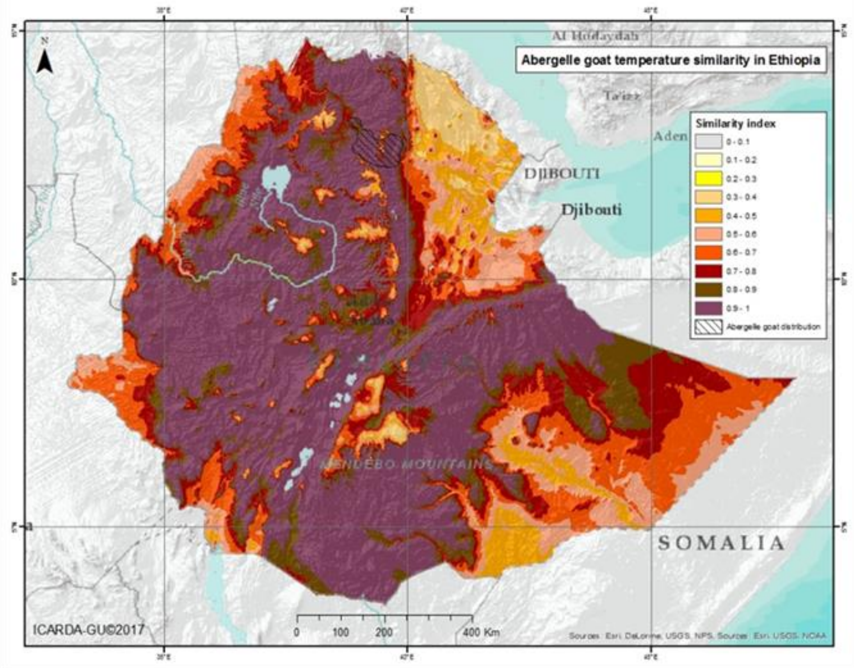

Figure 15: Temperature similarity for Abergelle goat in Ethiopia.

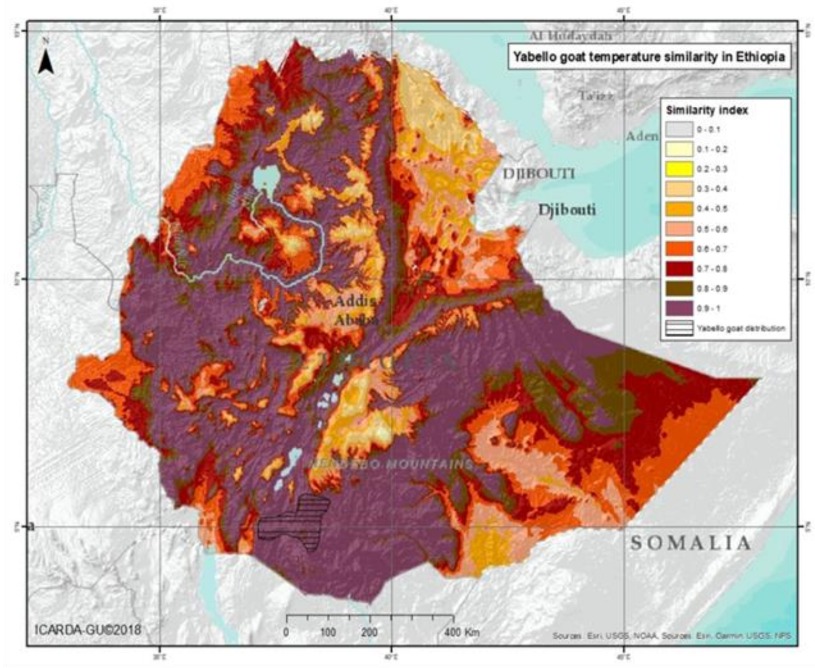

Figure 16: Temperature similarity for Yabello goat in Ethiopia.

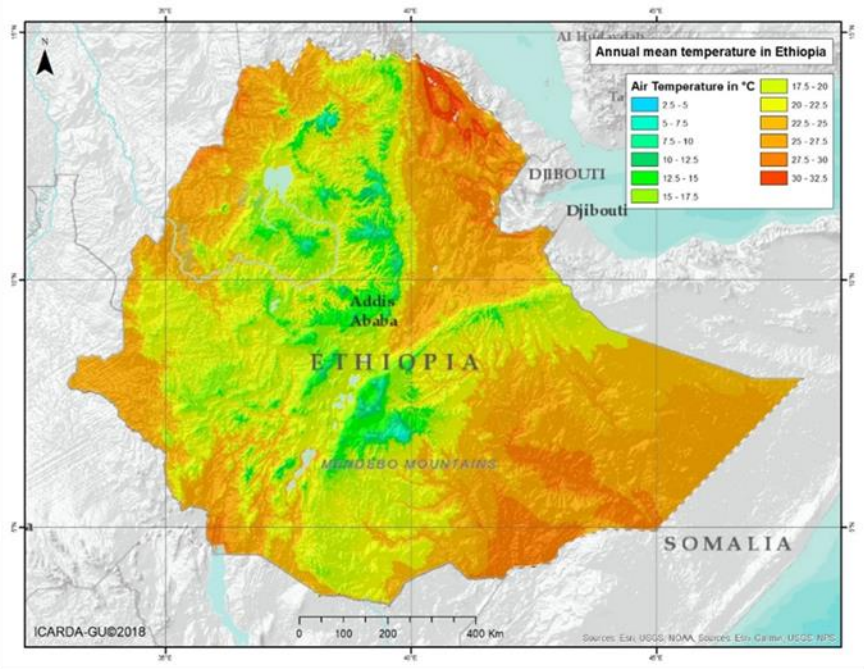

Figure 17: Annual mean temperature in Ethiopia.

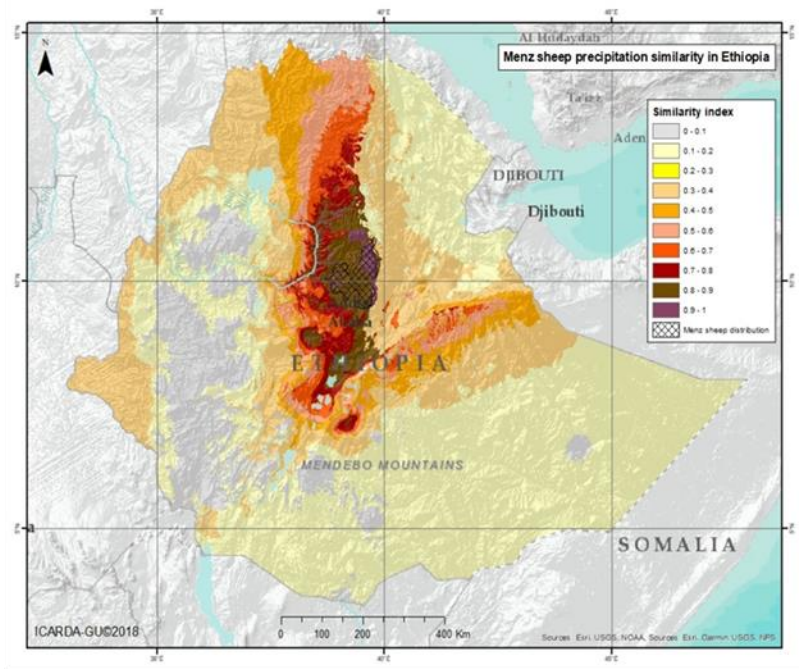

Figure 18: Precipitation similarity for Menz sheep in Ethiopia

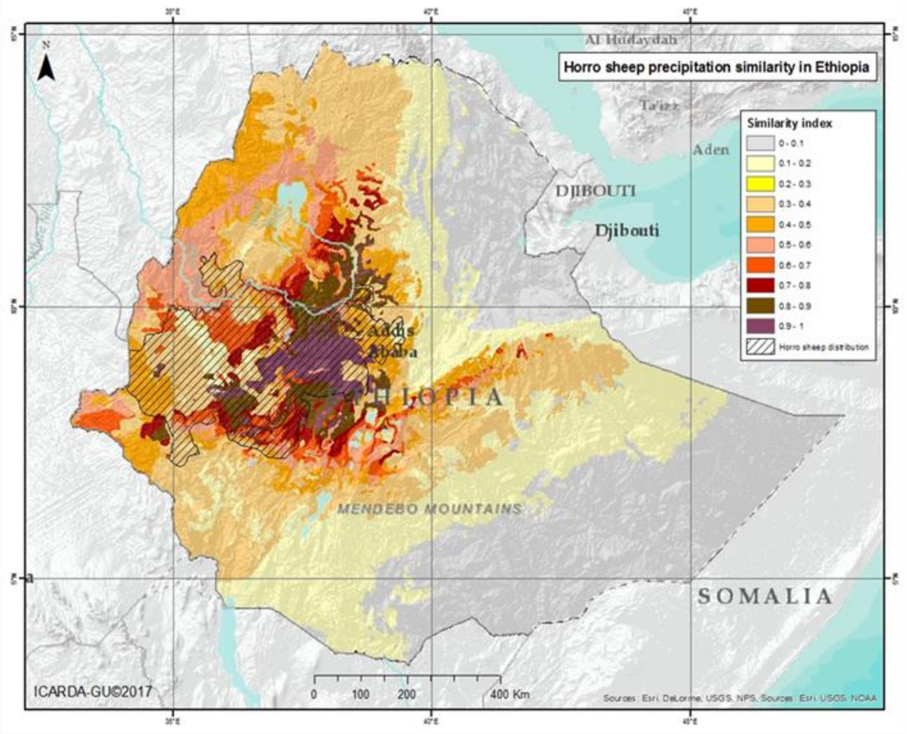

Figure 19: Precipitation similarity for Horro sheep in Ethiopia.

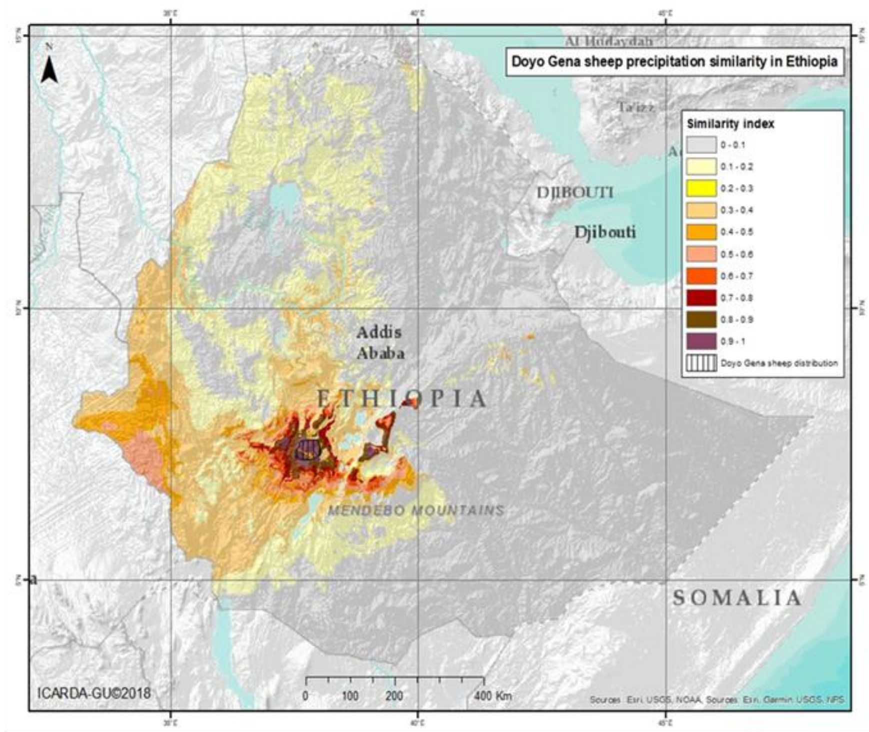

Figure 20: Precipitation similarity for Doyogena sheep in Ethiopia.

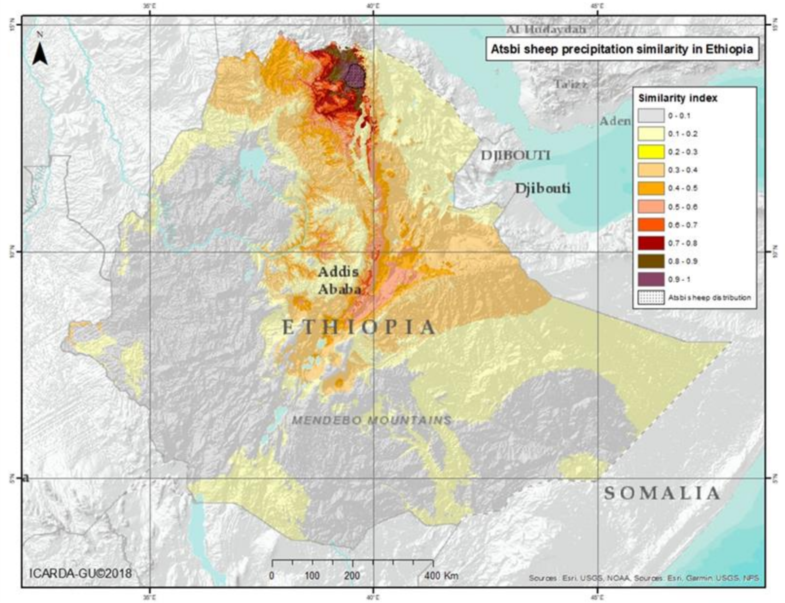

Figure 21: Precipitation similarity for Atsbi sheep in Ethiopia

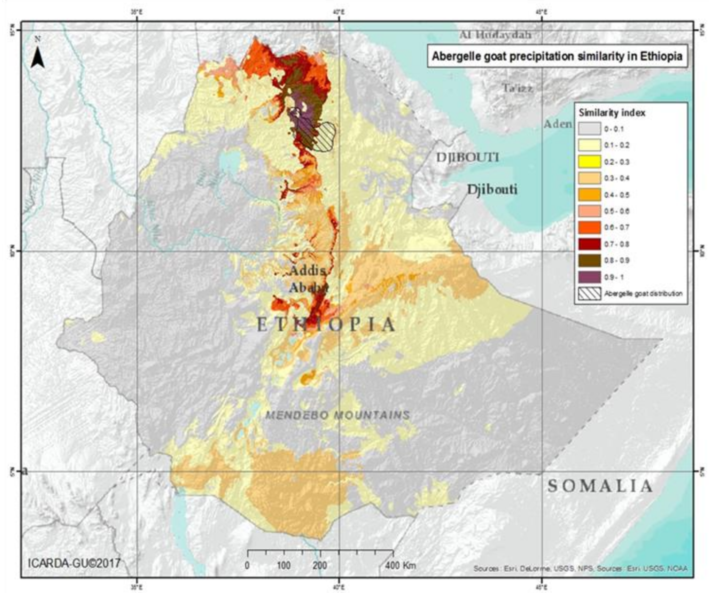

Figure 22: Precipitation similarity for Abergelle goat in Ethiopia.

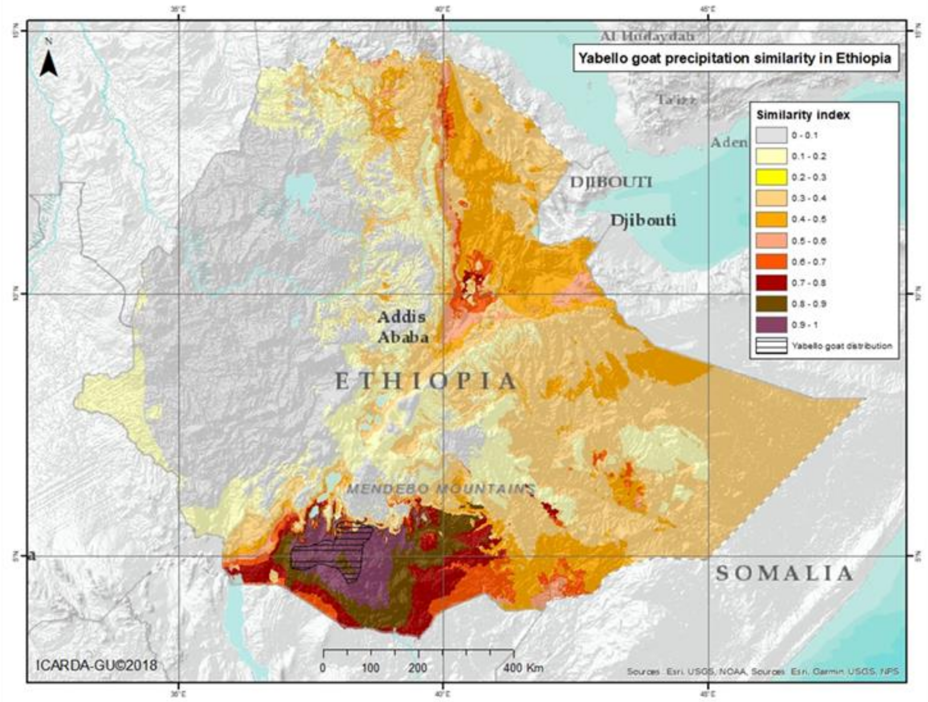

Figure 23: Precipitation similarity for Yabello goat in Ethiopia.

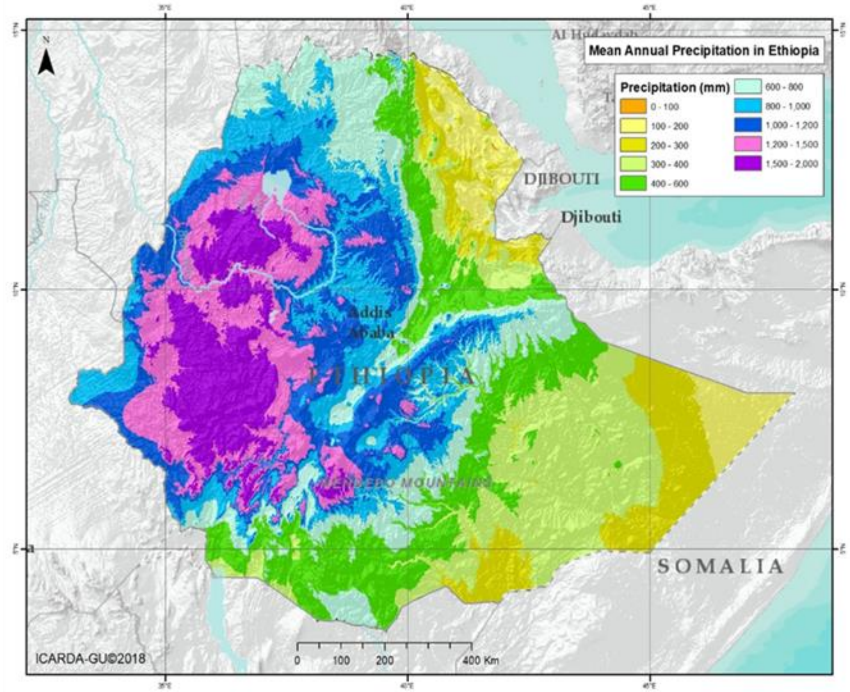

Figure 24: Mean annual precipitation in Ethiopia.

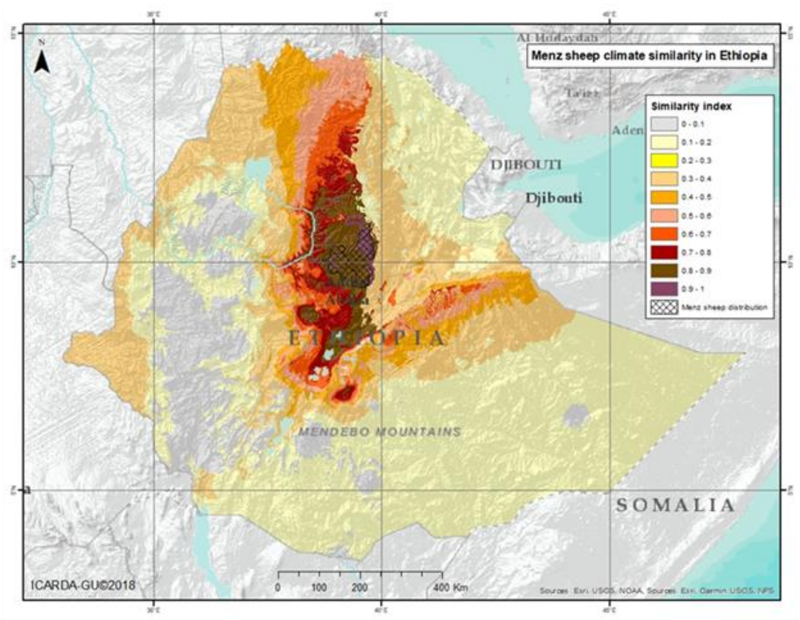

Figure 25: Climate similarity for Menz sheep in Ethiopia.

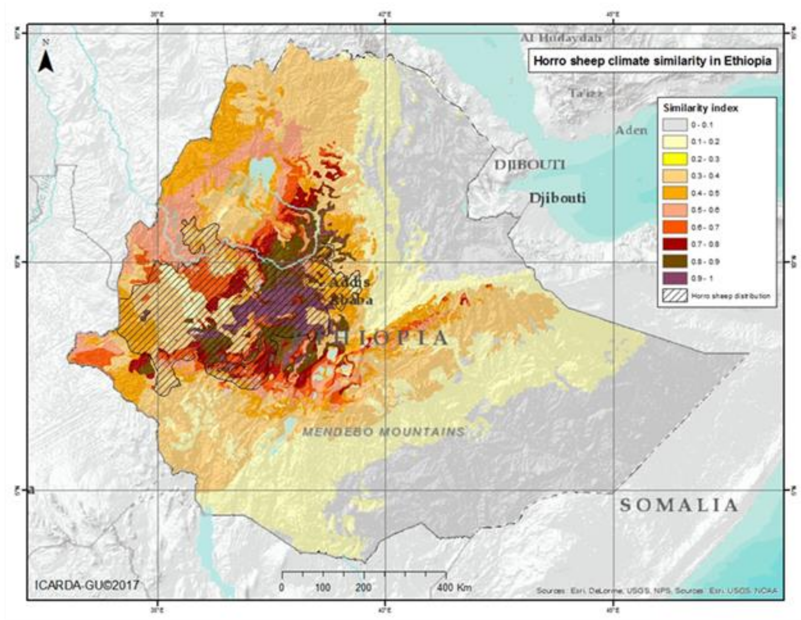

Figure 26: Climate similarity for Horro sheep in Ethiopia.

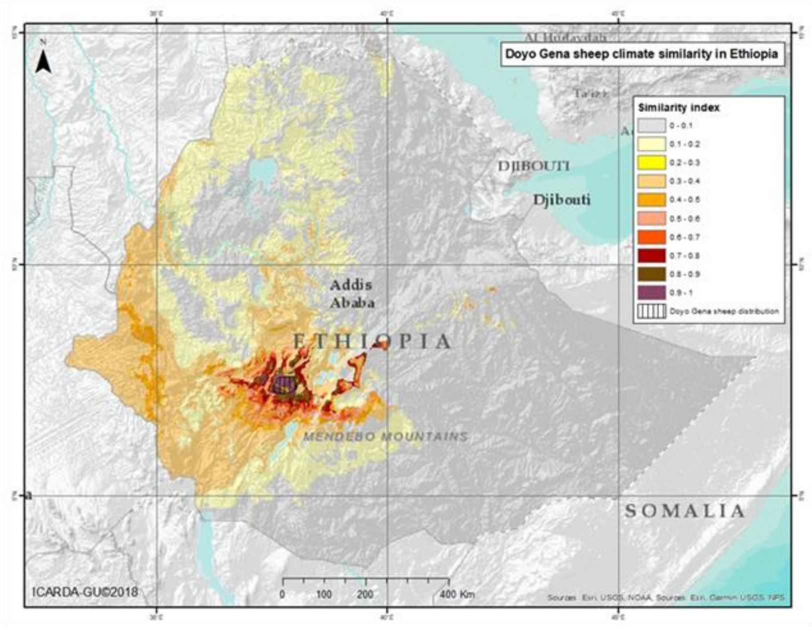

Figure 27: Climate similarity for Doyogena sheep in Ethiopia.

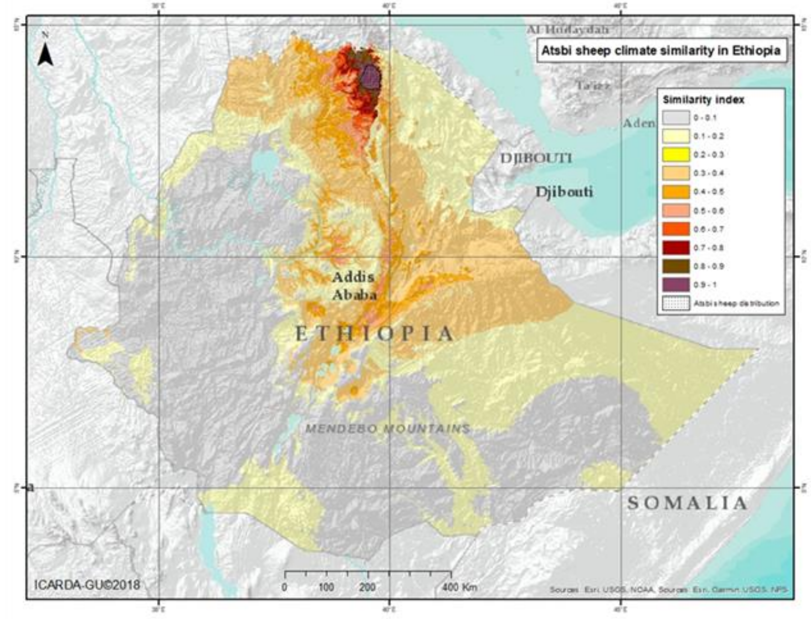

Figure 28: Climate similarity for Atsbi sheep in Ethiopia.

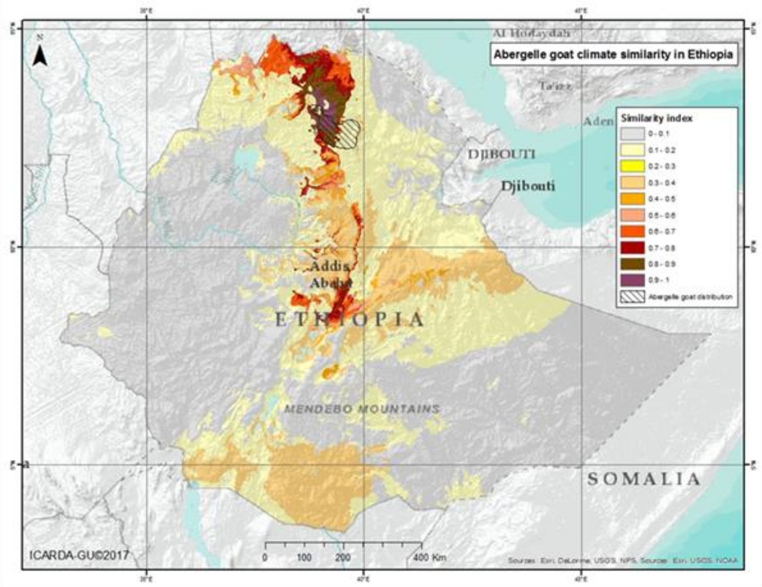

Figure 29: Climate similarity for Abergelle goat in Ethiopia.

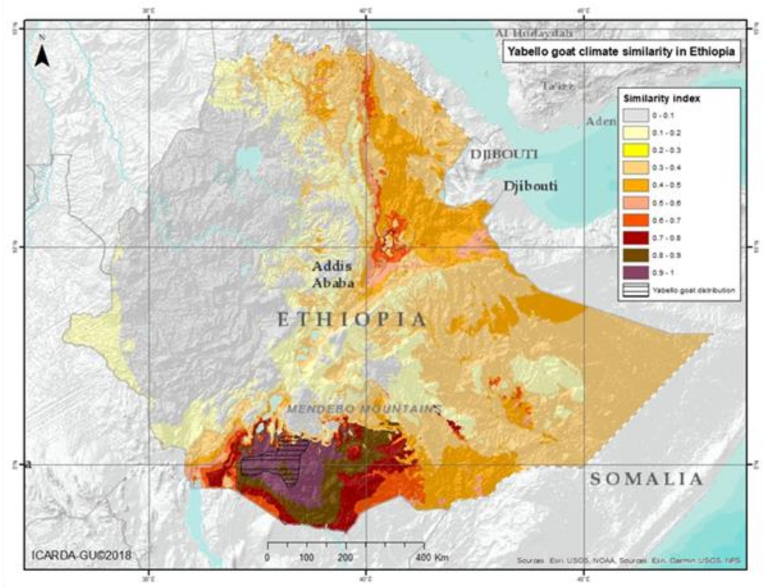

Figure 30: Climate similarity for Abergelle goat in Ethiopia.

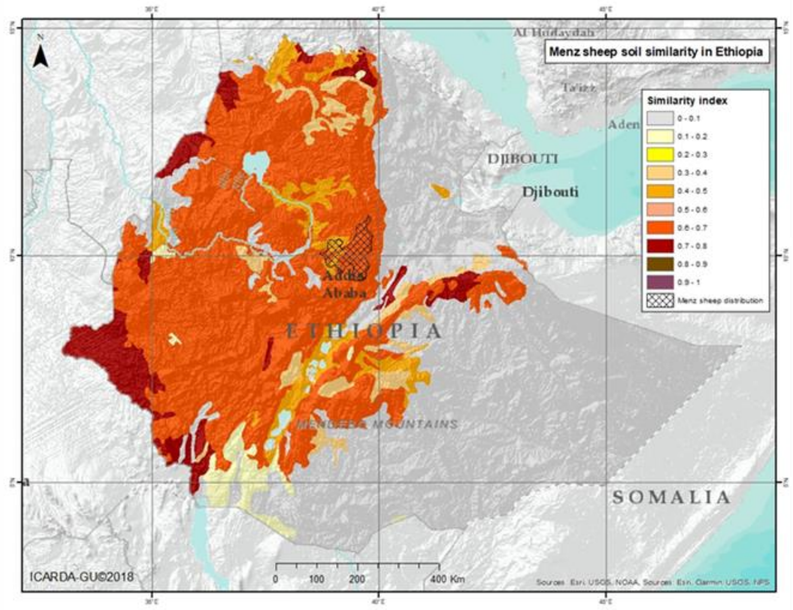

Figure 31: Soil similarity for Menz sheep in Ethiopia.

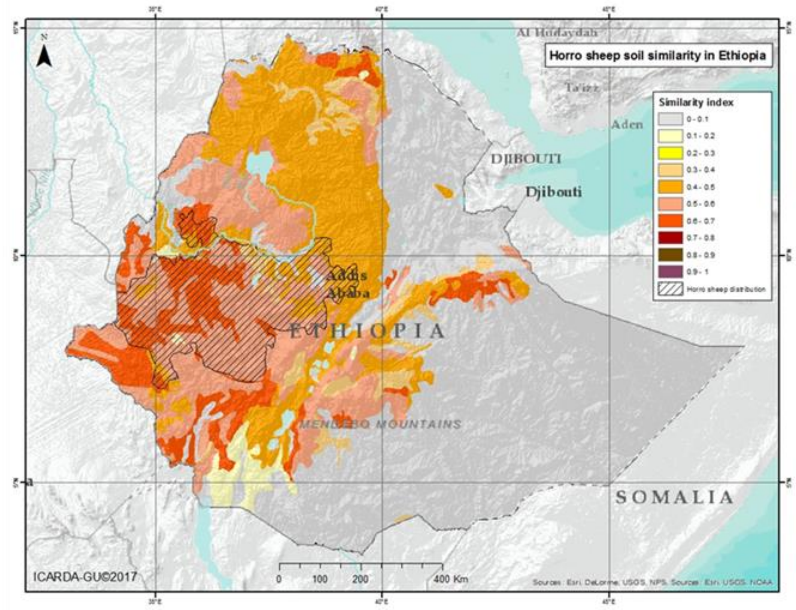

Figure 32: Soil similarity for Horro sheep in Ethiopia.

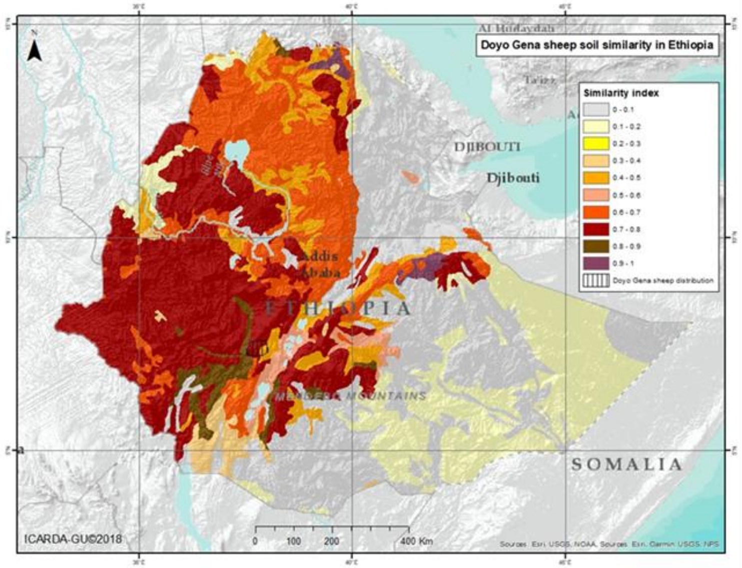

Figure 33: Soil similarity for Doyogena sheep in Ethiopia

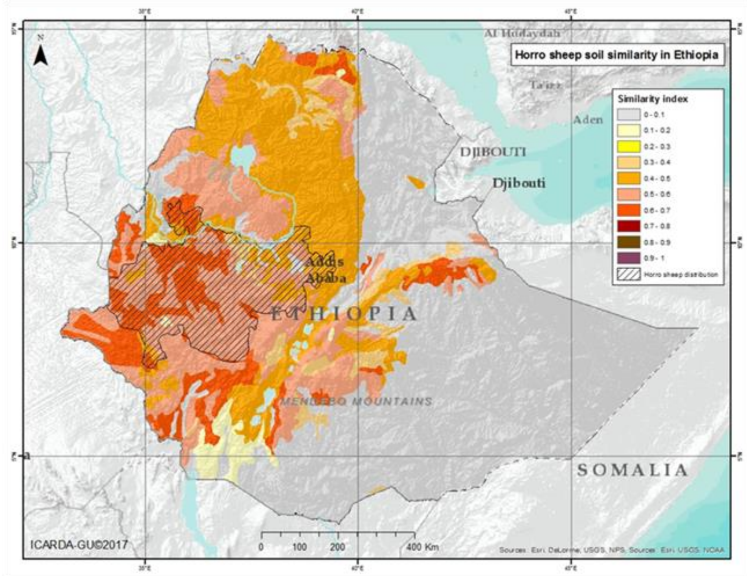

Figure 34: Soil similarity for Horro sheep in Ethiopia.

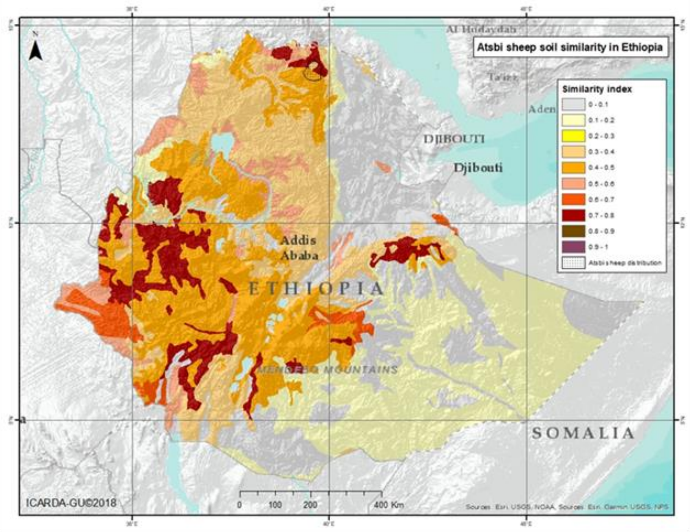

Figure 35: Soil similarity for Atsbi sheep in Ethiopia.

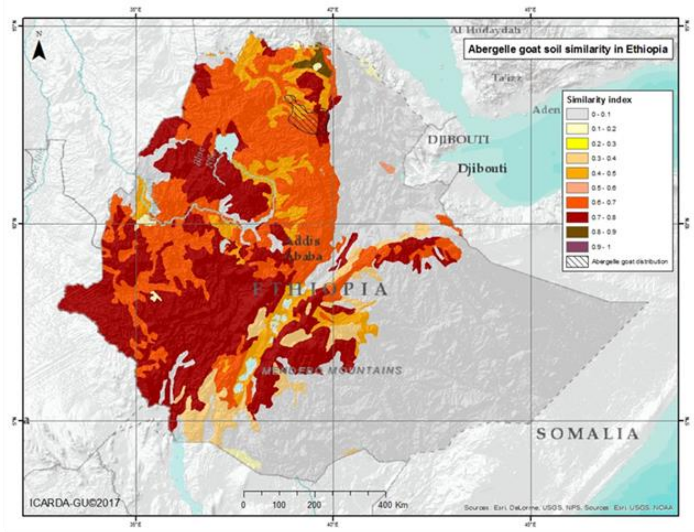

Figure 36: Soil similarity for Abergelle goat in Ethiopia

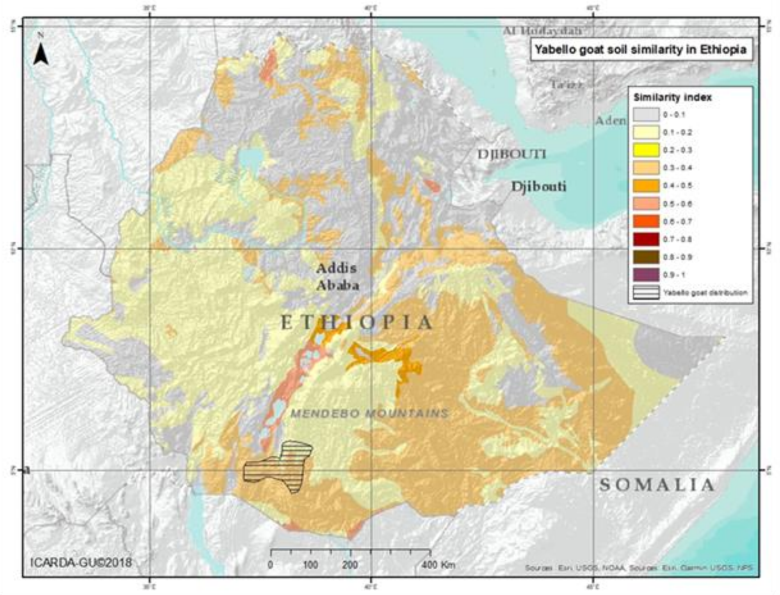

Figure 37: Soil similarity for Yabello goat in Ethiopia.

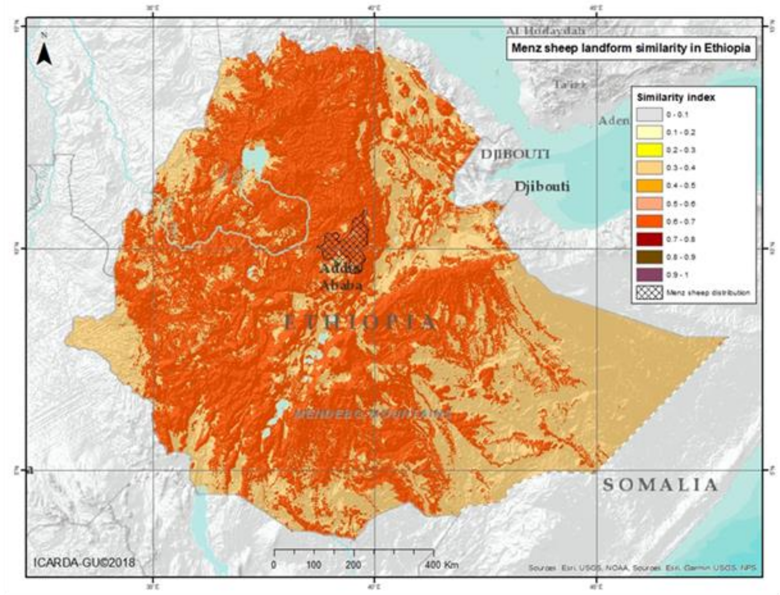

Figure 38: Landform similarity for Menz sheep in Ethiopia

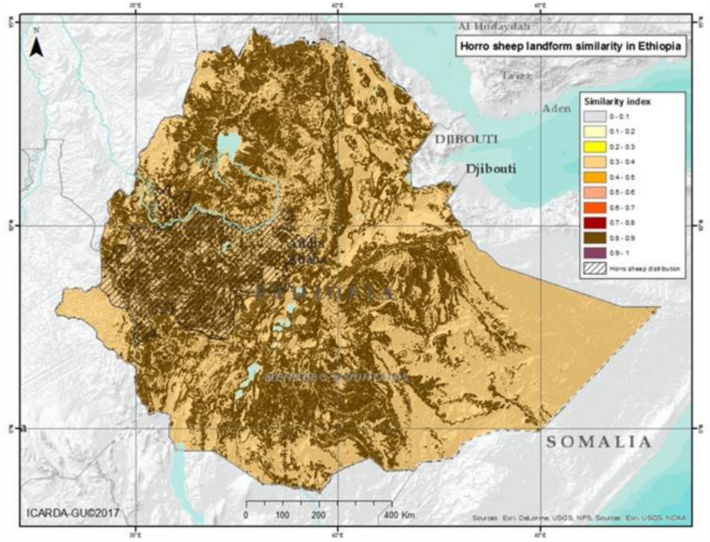

Figure 39: Landform similarity for Horro sheep in Ethiopia.

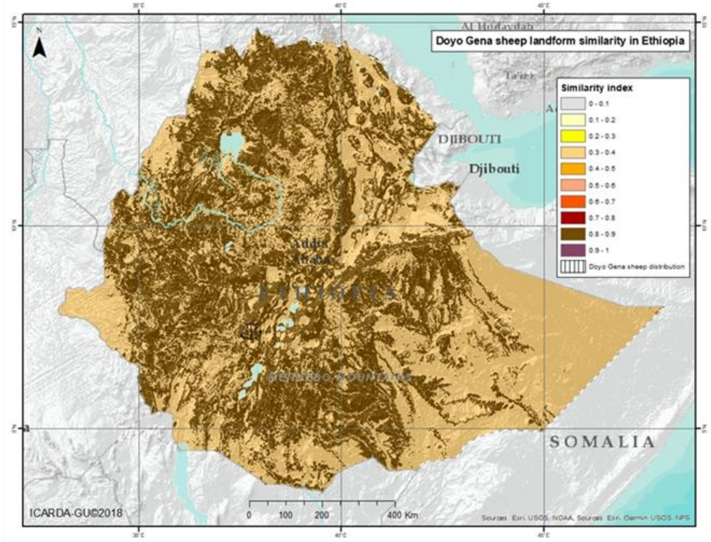

Figure 40: Landform similarity for Doyogena sheep in Ethiopia.

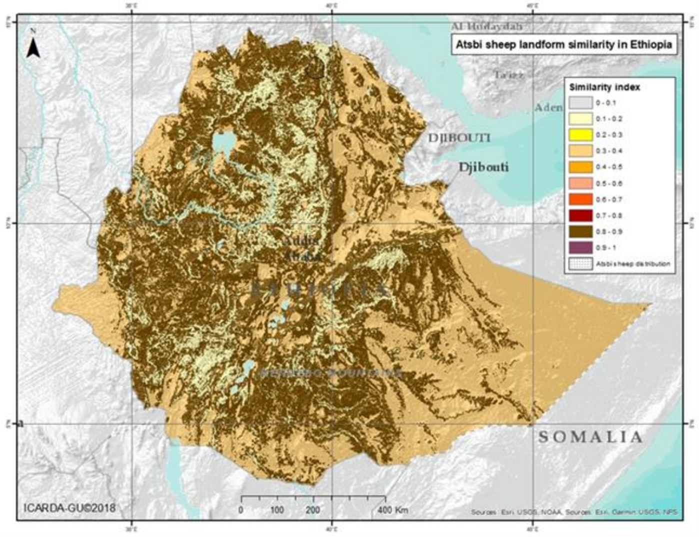

Figure 41: Landform similarity for Atsbi sheep in Ethiopia.

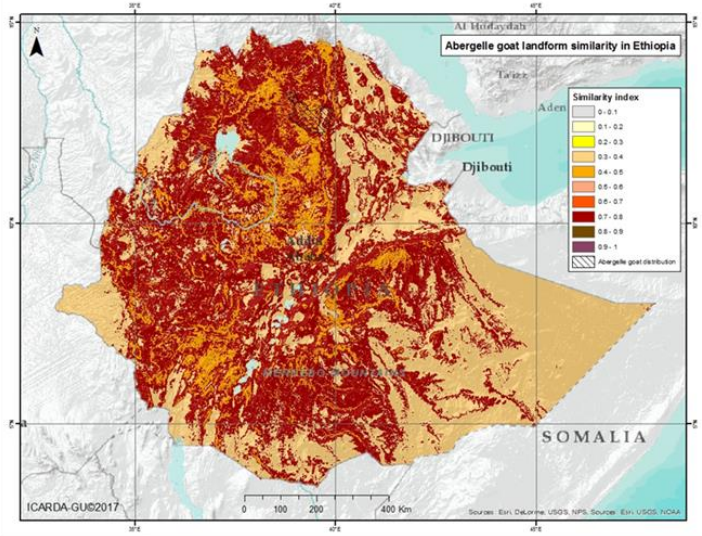

Figure 42: Landform similarity for Abergelle goat in Ethiopia.

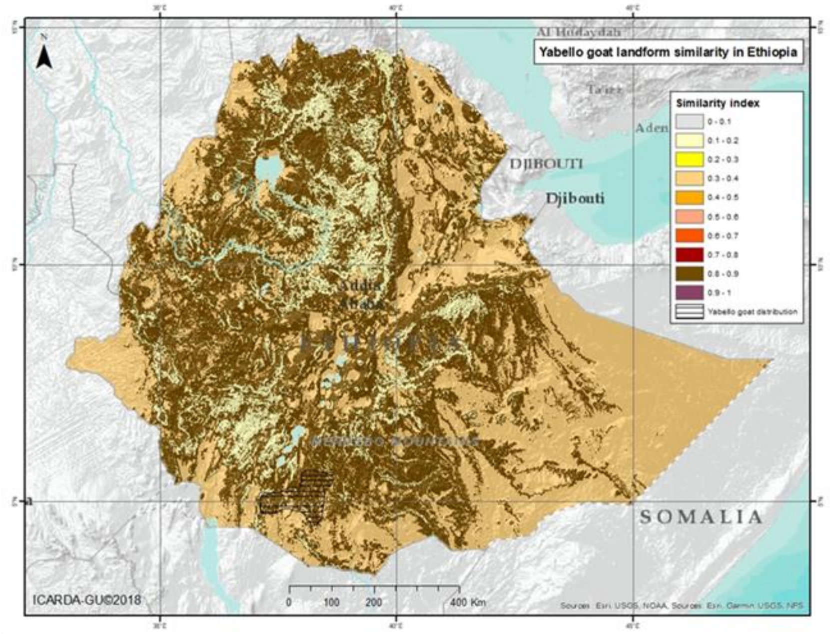

Figure 43: Landform similarity for Yabello goat in Ethiopia.