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Environment suitability mapping of livestock: A case study of Ethiopian indigenous sheep and goats

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ABSTRACT

Demand for livestock products is increasing as climate volatility threatens animal productivity and welfare. Therefore, novel technologies and approaches to meet these challenges are required. Geo-informatics and geo-visualization can address a critical question in this endeavor -where can improved indigenous, newly developed and composite breeds be introduced while retaining optimal productivity and resilience to climatic and environmental volatility? Here, a case study of four and two Ethiopian indigenous breeds of sheep (Atsbi, Doyogena, Horro, Menz) and goats (Abergelle, Yabello), and geo-informatics based spatial analytics generating, for each breed, a suitability index map is presented. The analysis reveals overlapping and breed-specific enviro-geographic and ecological suitability niches. More than 51% of Ethiopia is unsuitable for the optimal performance of the six breeds. The proportions of unsuitable land are 64.84% (Menz), 53.44% (Horro), 76.98% (Doyogena), 83.53% (Atsbi), 82.37% (Abergelle) and 63.89% (Yabello). The suitable production range for the four sheep breeds show a slight overlap, but that of the two goat breeds did not. The goats are best suited to the drylands, but the niche for Abergelle is in the north, and that of Yabello is in the south of Ethiopia. The heatmaps suggest that the mean annual temperature and precipitation have the largest contribution in the classification of geographic areas into suitability classes. Our results provide insights for targeting location specific species- and breed-interventions, and with climate change trajectories and natural resource base abundance, will be a major criterion for building resilient livestock production systems. Furthermore, ecological suitability mapping can allow practitioners to evaluate potential geographic ranges for newly-developed, experimental, and improved livestock breeds to design sustainable and innovative agro-ecological solutions.

1. Introduction

Climate change, food nutritional security, environmental sustainability, socio-economic changes and animal welfare are challenges that are and will face the global community and necessitate the development of sustainable livestock management strategies. Agro-technological advances including biodiverse livestock, genetic improvement and development of local, new and composite breeds and their introduction to varied production environments are some of the strategies being undertaken to mitigate against some of the challenges. Thus, elucidating the spatial distribution of livestock species and breeds can inform their geographic deployment with reasonable probability of success to improve livestock production system efficacy and is at the foundation of sustainable strategies for intensifying livestock production.

Given the concerns regarding future climate change impacts on livestock and food nutritional security and the need to sustainably rear more productive animals, the pertinent question remains, “where can alternative and productive livestock breeds be introduced”? In the field of geospatial sciences, there is an increasing abundance of climate and biophysical data, improved resolution of satellite imagery, and computational tools that are capable of processing large volumes of geospatial data. The analysis can generate biogeographic suitability maps which

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Table 1
GPS coordinates of the central location of the geographic heartland of the study breeds.

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

can be of considerable value for enhancing the impact of livestock genetic improvement initiatives. Geospatial analytics has found application in for instance mapping suitable territories for land use (Malafant, 1998; Kalivas and Apostolopoulos, 2005), determination of patterns of disease and parasite transmissions (Cringoli et al., 2007), establishing the extent of the ecological tolerance of a domestic livestock *vis a vis* its wild ancestor (Pitt et al., 2016) and predicting breed suitability for different agro-ecologies (Lozano-Jaramillo et al., 2018). Here we applied an ensemble of geo-informatics tools and approaches combined with climate data to generate environmental suitability heatmaps for four and two indigenous breeds of sheep and goats, respectively from Ethiopia based on presence-only data. We hypothesized that the current geographic location of the breeds is a good indicator of their ecological requirements in other geographic areas in the country and most likely globally.

2. Materials and methods

2.1. Conceptual framework for the study

This case study was carried out in Ethiopia and it combines geo-informatics tools and climate data to predict habitat distributions and generate suitability heatmaps for four and two indigenous breeds of sheep and goats, respectively. Ethiopia presents the ideal country for modeling pockets of environments that are suitable to breeds outside their geographic home range due to its complex topographic and geographic features with a strong impact on spatial variation in weather patterns (Mengistu, 2003; Zeleke et al., 2013). The premise of the study is that whether improved genotypes (indigenous or exotic) can reciprocate their improved performance under new environments remains speculative. The underlying concept of 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 primary location/environment or it’s geographic origin/heartland. Thus, the geographic ‘heartland’ of a breed, and its associated bio-physical characteristics can form the basis to identify other similar geographic areas where the breed can perform optimally. The

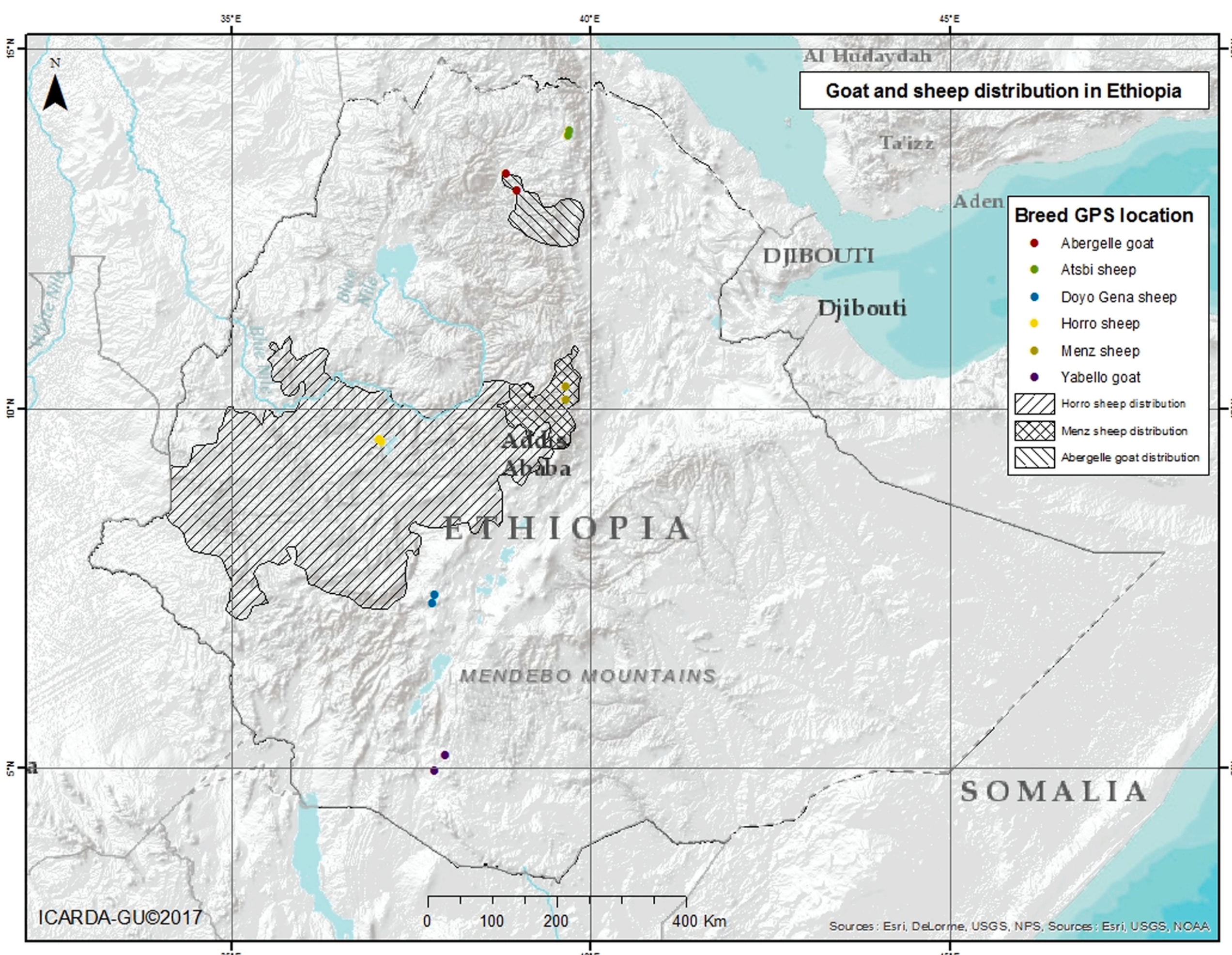

Fig. 1. The GPS locations and the digitized distribution boundaries for Horro, Menz and Abergelle breed.

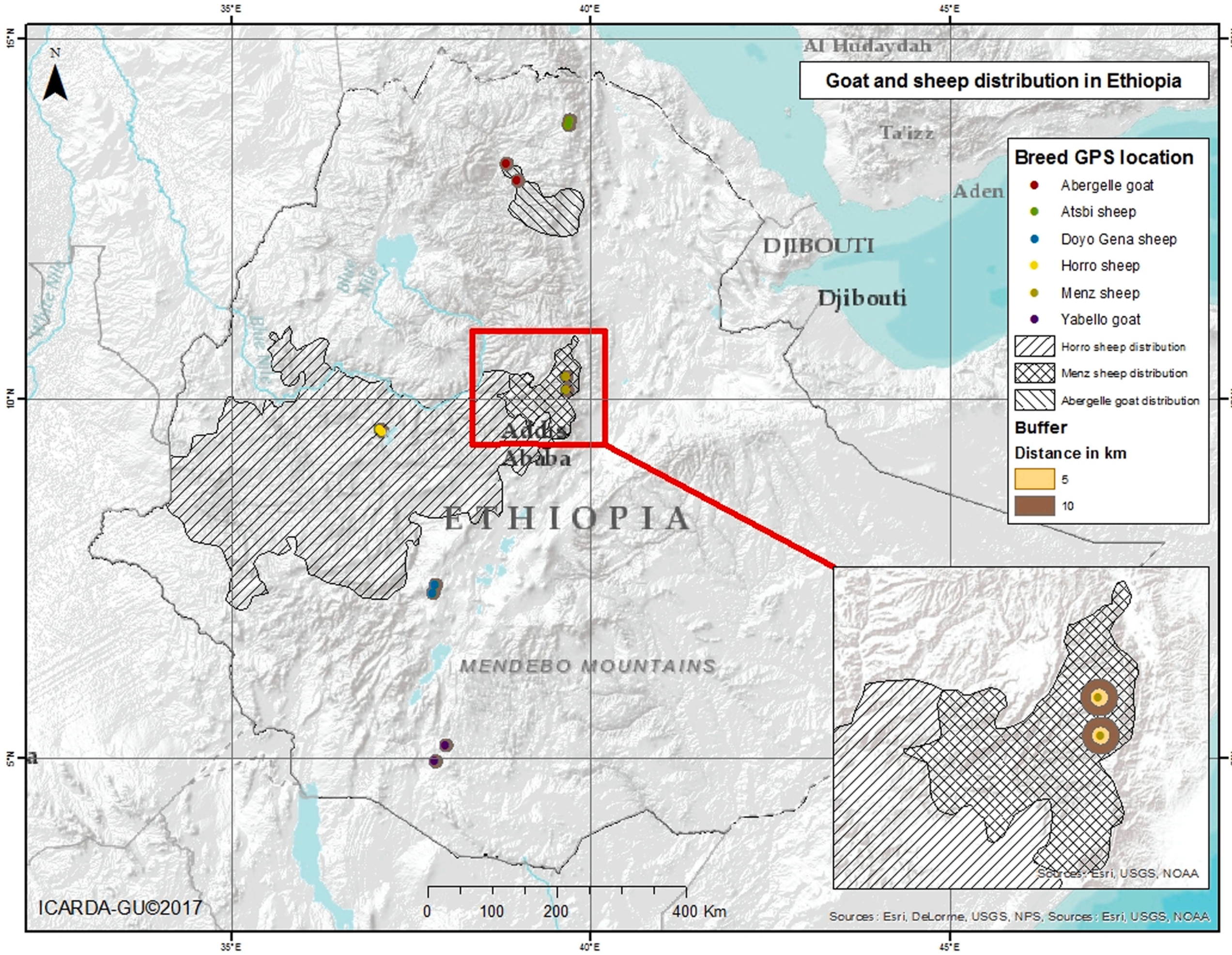

Fig. 2. The buffer zones of 5 and 10 km radius around the GPS points. The inset is a zoom in on Menz sheep.

methodology for assessing similarity takes into account permanent characteristics of the biophysical environment including climate, topography and soils. In this study, the thematic pattern for the original habitat of a breed was used to represent the “match location” while the “target location” was the whole of 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 generate an overall similarity index for the natural environment.

2.2. The study breeds and mapping their heartland

The case study used four and two indigenous breeds of sheep and goats from Ethiopia (Table 1). GPS coordinates were recorded from the most centralized location in the geographic heartland of each breed using the Garmin GPSMAP 64st tool (Table 1). The coordinates were plotted on the map of Ethiopia using the ArcGIS.10 platform (Fig. 1). The geographic location and distribution of the six study breeds were further confirmed from published reports (ESGPIP, 2009; FARM Africa, 1996). The published distribution maps of the sheep and goats were geo-referenced following geographic boundaries. The distribution boundaries of Menz and Horro sheep and Abergelle goat were digitized using head up digitizing in ArcGIS.10 platform (Fig. 1). For Doyogena and Atsbi (sheep) and Yabello (goat), buffer zones of two (2), five (5) and ten (10) km radius around the GPS coordinates were generated (Fig. 2). The European Space Agency layer of land cover (2015; http://geoportal.icpac.net/layers/geonode%3Aethiopia_landcover2015_4; Supplementary Fig. S1;), the landform map of Ethiopia, and the buffer shape file for Doyogena, Atsbi and Yabello were overlaid on each other to delineate their boundaries of distribution (Fig. 3). The range of potential suitable habitats for each breed was visualized and assessed with a heatmap.

2.3. Spatial data and analytical framework

The spatial data used here consisted of presence-background (PB) information recorded within a one (1) km spatial-resolution radius. The PB data entailed presence-only breed records and a background sample of environments in the geographic home-tract of a breed. Data on temperature and precipitation was obtained from the WorldClim 2.0 (Hijmans et al., 2005) database. The data consisted of average monthly climate data from 1970 to 2000. The 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, 2007). To model landform similarity, the Shuttle Radar Topography Mission Global (SRTM) 30 Digital Elevation Model (DEM) from Earth Explorer database (USGS, 2012) at one (1) km^2 resolution was used. The digital soil map of the world and derived soil properties (FAO-UNESCO, 1974) was used to model soil pattern similarity. A combination of these datasets was used to model the overall similarity in the natural production environments of each breed and thus their suitable environments.

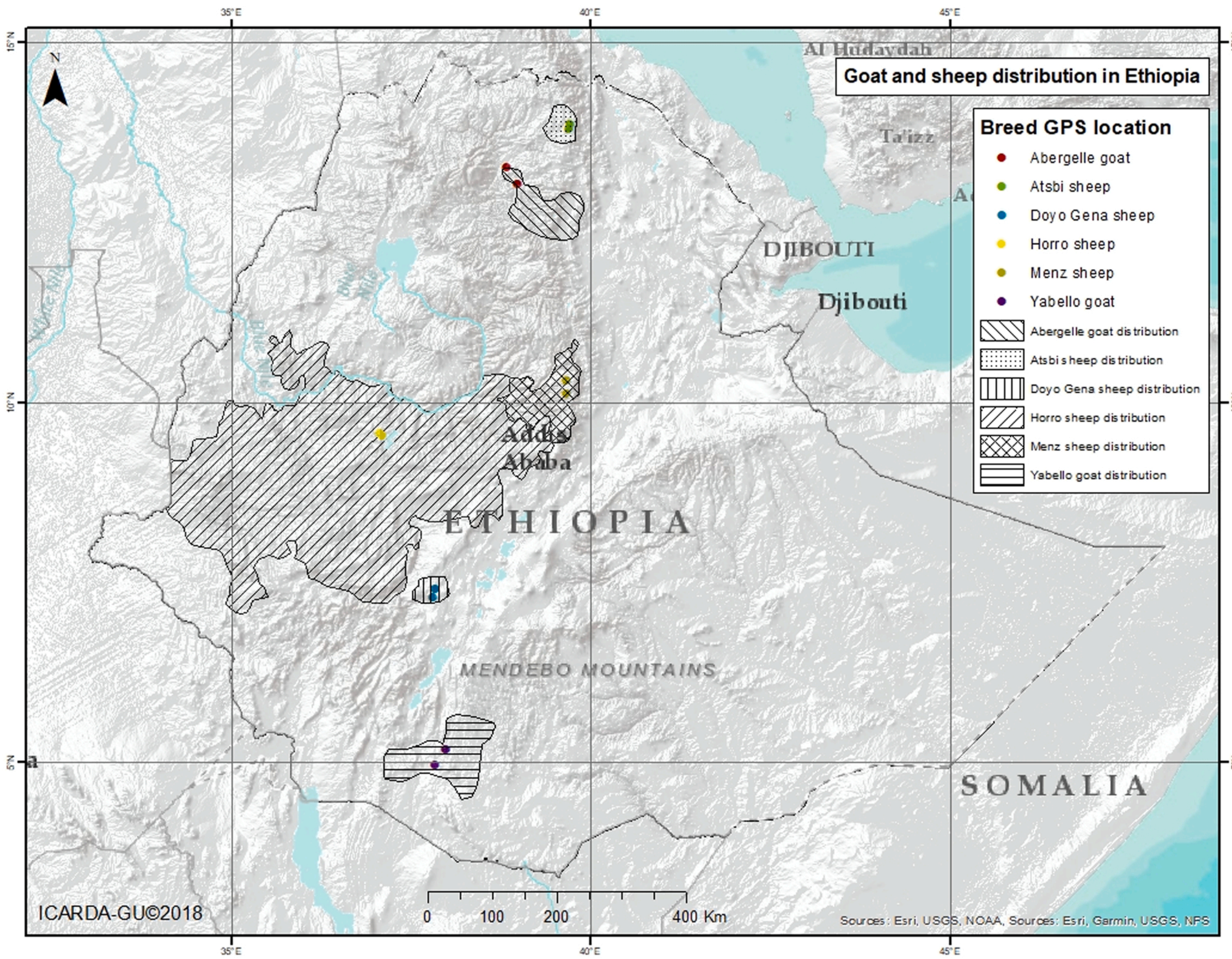

Fig. 3. The digitized breeds boundary distribution in Ethiopia.

2.4. Mapping climate similarity

Temperature and precipitation were used to map patterns of climate similarity. These two climatic parameters are important as they determine feed and water availability for livestock under traditional management. The similarity in the patterns of precipitation and temperature were determined using ICARDAs' in-house visual basic climatic similarity software. The other similarity factors were determined using the ArcGIS.10. The data input for the visual basic climatic similarity program was in the form of global climatic data grids composed of 12 mean monthly precipitation and average temperature surfaces. For each geographic heartland of the breeds, 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 which represented the annual maxima and minima for each climatic factor in the heartland of the breed. Mean monthly temperature and precipitation were extracted and used as input values in the Climatic Similarity program.

The two similarity indices, which are 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 (Kriticos et al., 2015). They model the drop in similarity under increasing dissimilarity for air temperature Δ_t and precipitation Δ_p, respectively, as follows:

$$I_1 = e^{\left(-\frac{\Delta_t}{\sigma_t}\right)} \quad and \quad I_2 = e^{\left(\frac{\Delta_p}{10 \times \sigma_p}\right)} \tag{1}$$

with $\sigma_t\left[^{\circ}C - 1\right]$ and $\sigma_p\left[mm^{-1}\right]$ 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:

$$S = Min\left(I_{1(\Delta_t)}, \quad I_{2\left(\Delta_p\right)}\right) \tag{2}$$

with "Min" being the lowest of the two values. The overall mean annual temperature heatmap for Ethiopia and the temperature similarity heatmaps for the six breeds across the country are shown in Supplementary Figs. S2 and S3–S8, respectively. The mean annual precipitation heatmap in Ethiopia and the precipitation similarity heatmaps for the six breeds across Ethiopia is shown in Supplementary Figs. S9 and S10–S16, respectively. A combination of the precipitation and temperature similarities were used to generate a climate similarity map for Ethiopia (Supplementary Fig. S17) and for each breed (Supplementary Figs. S17–S21).

2.5. Mapping soil similarity

We mapped soil similarity due to its strong association with livestock feed quality as well as water retention capacity. Soil similarity was measured by comparing the soil composition in the heartland of each

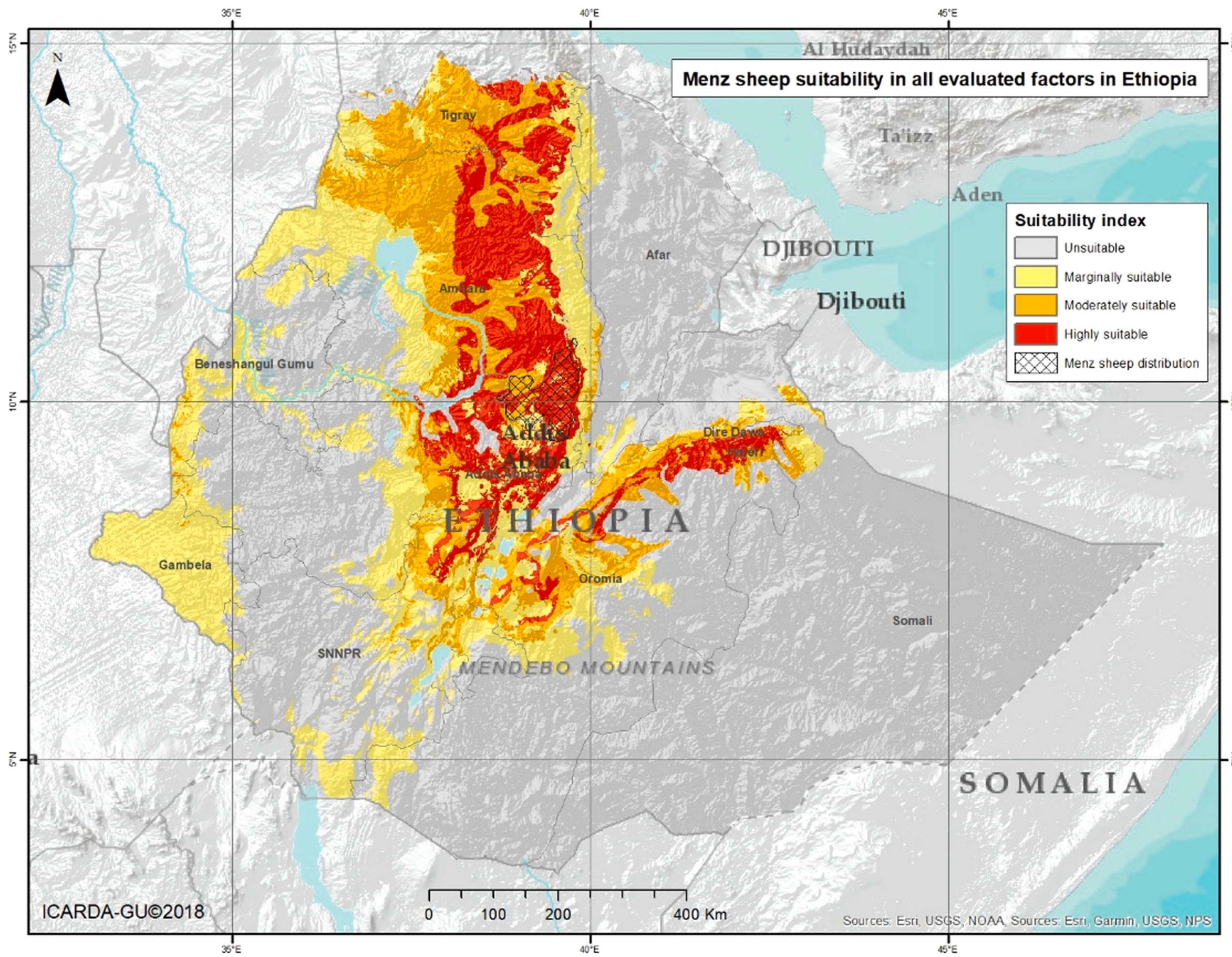

Fig. 4. The geographic suitability map for Menz sheep across Ethiopia based on all the evaluated factors.

breed with the soil composition of each land pixel across Ethiopia, using Sørensen similarity index (Sorenson, 1948; Sørensen, 1957) 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 G1 was calculated following De Pauw et al. (2011):

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

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 (De Pauw et al., 2011):

$$Sim_{soil_{all}} = \sum_{i=1}^{13} Sim_{soil_{Gi}} \quad \times \quad \frac{\%G_{i,d}}{100} \tag{4}$$

with $\%G_{i,d}$ being the proportion (%) of SMG G_i in the soil composition for the breed's heartland. The soil similarity heatmaps for each breed are shown in Supplementary Figs. S22–S27.

2.6. Mapping landform similarity and composition

Landforms influence ambient temperatures which in turn affect livestock productivity and health. In this study, landforms were grouped into three classes, L1, L2 and L3, representing plains, hills and mountains, respectively based on the concept of "Relief Intensity (RI)" (Szafraniec, 2012). Using the SRTM30 DEM, the "RI" was derived from the difference in maximum elevation 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 m), L2 = Hills (RI: 50–300 m) and L3: Mountains (RI: > 300 m).

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 the same as that used to assess soil similarity. It involved the comparison of the landform composition within the breed's heartland with the landform composition of each land pixel in Ethiopia; the only difference being that in the former 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 a breed's heartland and the target pixel, no similarity index was calculated, ii) If L1 was present in a 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):

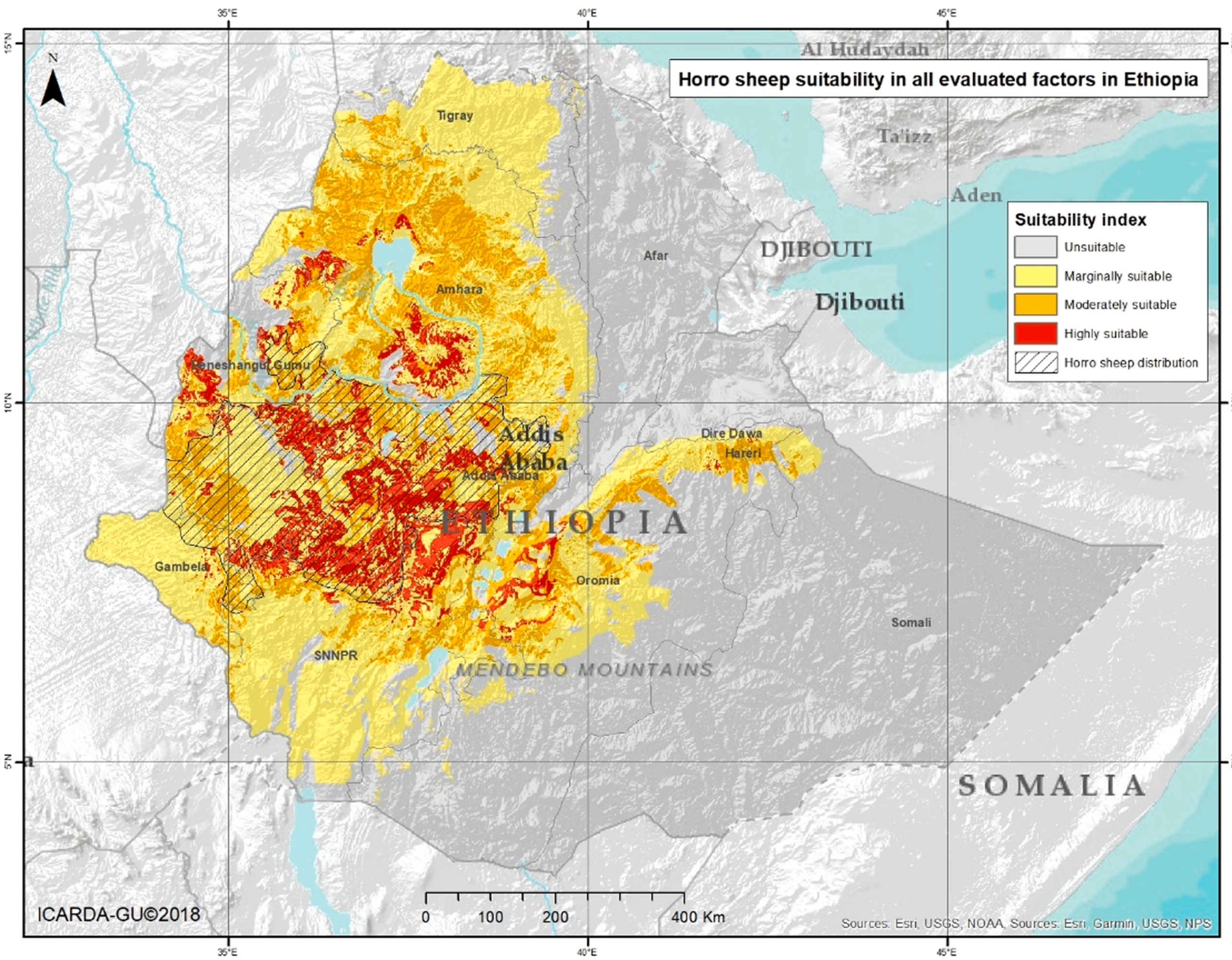

Fig. 5. The geographic suitability map for Horro sheep across Ethiopia based on all the evaluated factors.

$$Sim_{L1} = \frac{(\%L1_d) \times 2}{\%L1_d + 100} \quad (5)$$

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. The landform similarity heatmaps generated in this study are shown in Supplementary Figs. S28–S33.

2.7. Mapping the similarity in all the evaluated factors

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

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

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.

3. Results

3.1. Predicted distribution of potentially suitable habitats for the study breeds

For each study breed, six heatmaps were generated. These represented similarities in mean annual temperature (Supplementary Figs. S2–S8), mean annual precipitation (Supplementary Figs. S9–S15), climate (Supplementary Figs. S16–S21), soil similarity patterns (S22-S27), landforms (S28-S33), and overall global similarity incorporating all the evaluated variables that were used to derive the geographic suitability heatmap of each breed (Figs. 4–9). For simplicity, a summary suitability index which was derived from a scale of 0–1 for the similarity index of the six variables tested was developed by merging the scales (0–1) from the overall global similarity for the evaluated variables into four broad categories viz 1) unsuitable (0–0.25), 2) marginally suitable (0.25–0.50), 3) moderately suitable (0.50–0.75) and 4) highly suitable (>0.75). The results show large variability in the distribution of the suitable environments for the two species and breeds across Ethiopia.

From the overall suitability heatmaps, we calculated (for each breed) the total land area for the four suitability classes (Supplementary Table S1) and in each of the 9 regional states and 2 chartered cities in Ethiopia (Supplementary Table S1). This allowed comparisons to be made between breeds and geography (regional states/chartered cities). The percentage of area in Ethiopia predicted to be highly suitable for each breed is shown in Table 2. The predicted percentage values for sheep ranged from 0.5118 (Atsbi) to 7.7912 (Menz) while for goats, Yabello had the lowest value (0.1238) and Abergelle the highest (1.6231%). Across the 9 regional states and 2 chartered cities in Ethiopia, the percentage of area predicted for the four suitability classes differed between breeds (Supplementary Table S1). The heatmaps showing the geographic spread of the four suitability classes for each breed across Ethiopia are shown in Figs. 4–9. Menz and Horro sheep had the largest range of highly suitable habitat while Atsbi and Yabello had the smallest geographic range of their highly suitable habitat. For Menz, the regional

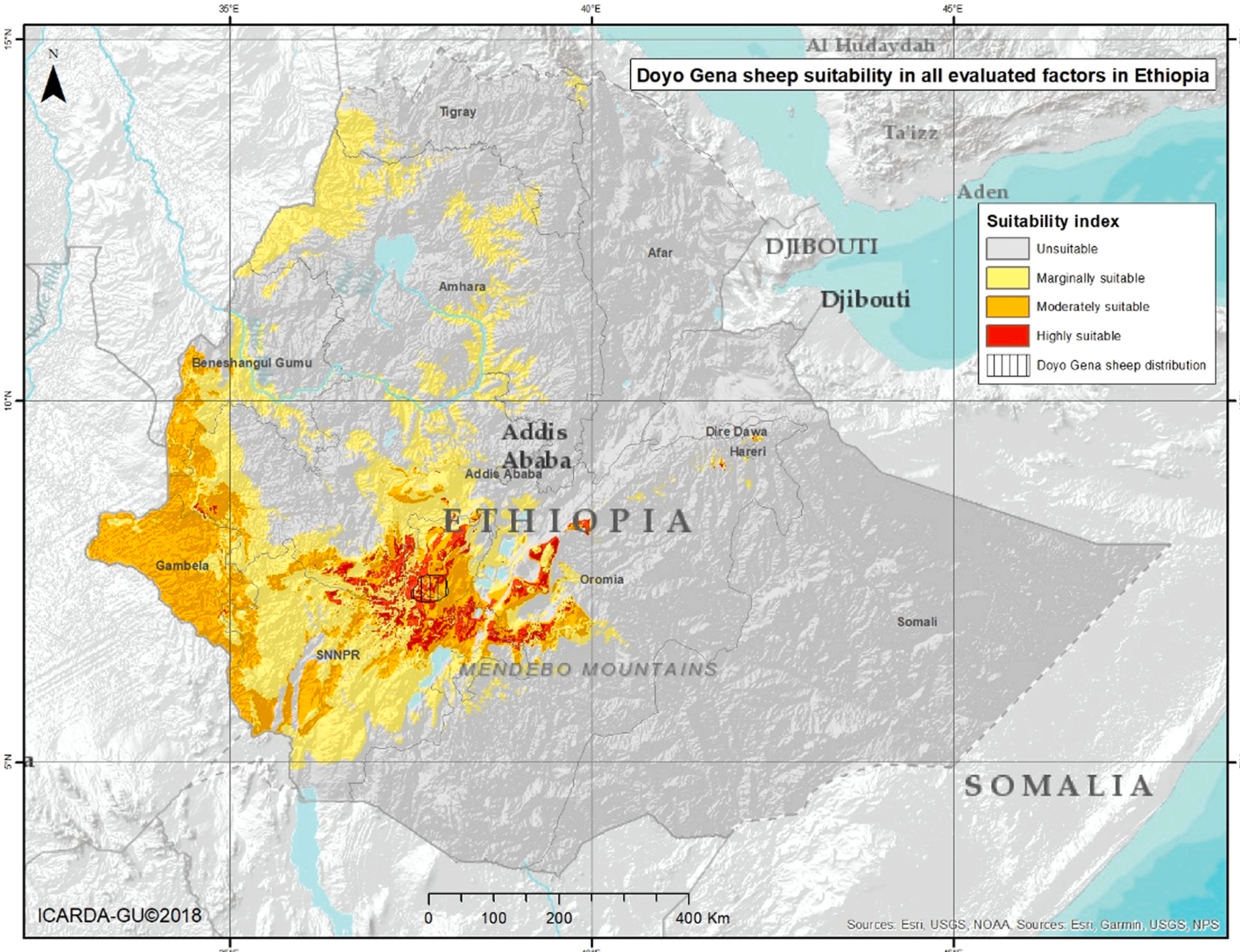

Fig. 6. The geographic suitability map for Doyogana sheep across Ethiopia based on all the evaluated factors.

states with the highest geographic area predicted as being highly suitable for it were Addis Ababa (79.126%), Hareri (69.977%), Amhara (28.058%) and Tigray (23.221%) (Supplementary Table S1). For Horro, the regional states with the highest percentage of area predicted as being highly suitable for it were Addis Ababa (39.482%), Benishangul Gumuz (21.198%), Oromia (11.911%) and SNNPR (9.875%). For Atsbi and Doyogana, only 9.951% and 8.950% of Tigray and SNNPR regional states, respectively were highly suitable for the breeds. For Abergelle, 23.714% of Tigray and 8.414% of Addis Ababa were predicted to be highly suitable for it. For Yabello, the geographic areas that were suitable for it across the 11 regional states were less than 1.0% (Supplementary Table S1).

From the results, a large proportion of Ethiopia (>51%) was projected to be unsuitable for 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) (Supplementary Table S1). Although, the suitable production range for the four sheep breeds overlap slightly, that of the two goat breeds does not. The two breeds of goats are best suited to dryland environments with the niche for Abergelle being in northern Ethiopia (Fig. 8) and that of Yabello is in southern Ethiopia (Fig. 9). These suitable environments are close to their geographic homelands.

The heatmaps appear to suggest that the mean annual temperature (Supplementary Fig. S2) and the mean annual precipitation (Supplementary Fig. S9) are the key variables in the classification of geographic areas into the four broad suitability classes. This is because temperature and rainfall patterns mirror the overall patterns depicting the suitability of each breed (Figs. 4–9). This is unsurprising as these two factors are the main determinants of feed and water availability for livestock and the appropriate thermal environments for optimal performance under traditional management.

4. Discussion

Environment suitability mapping has been less studied for livestock although it is potentially critical for the success of investiments in the livestock sector and achieving long-term impacts. Exotic animal breeds introduced in new environments often demand high investments in feeds and veterinary health care due to poor adaptation. In recent times, there has been an increased demand for improved indigenous breeds which are now being introduced to environments that differ from the ones they were bred and improved in/for. Whether such indigenous genotypes can perform optimally in the new environments remains enigmatic as it has not been investigated in a systematic manner. To address this issue, we applied GIS tools and an analysis of climatic, landform and soil characteristics to model geographic areas within Ethiopia that can be considered to be highly suitable for the optimal performance of four and two indigenous breeds of sheep and goats, respectively. The analysis was informed by the observation that improved indigenous genotypes, which are the products of community-based breeding programs, were being distributed throughout the country in environments that differ from the ones in their home tracts from where the selection improvement was done. Due to the high correlation between environmental factors and animal performance, the

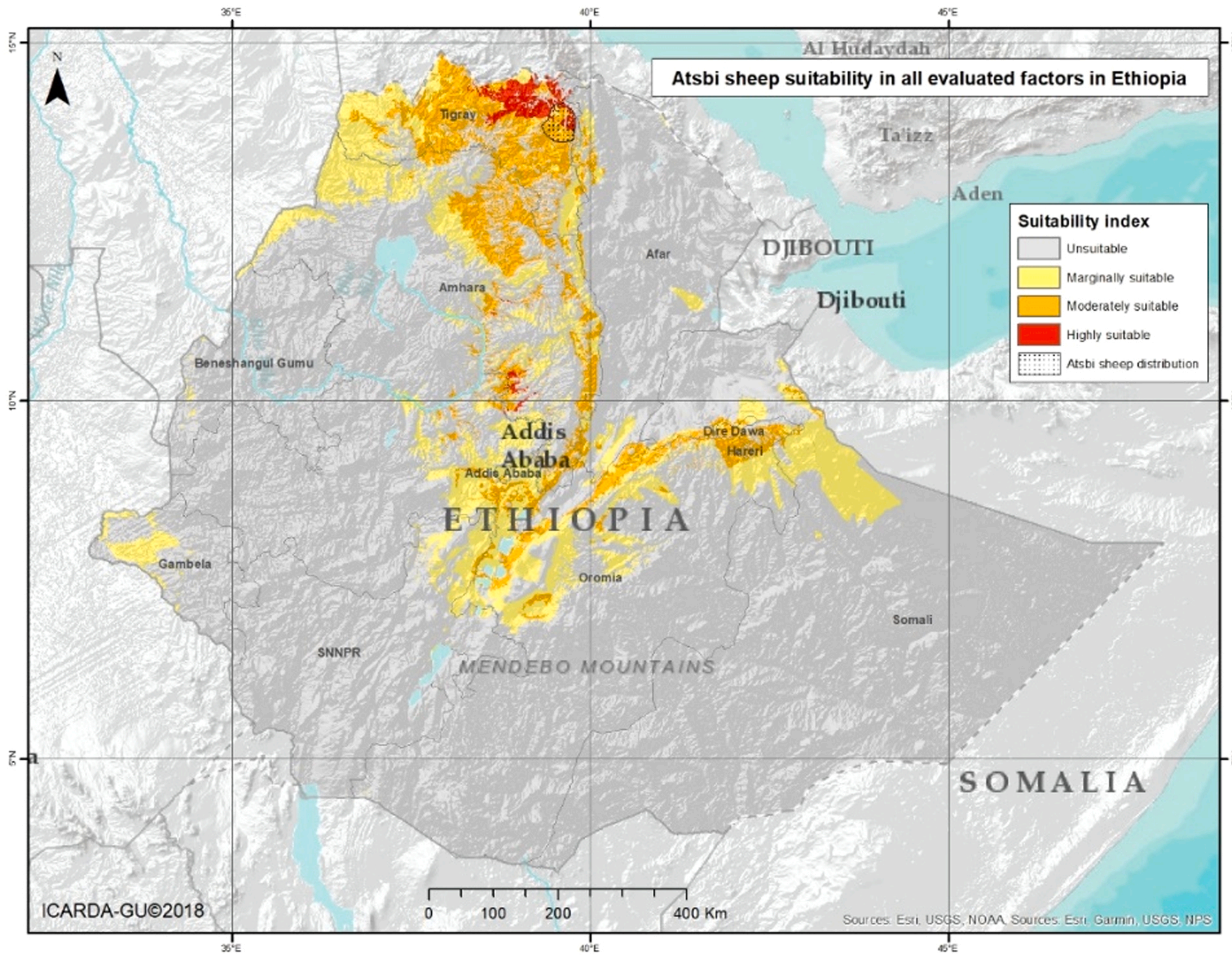

Fig. 7. The geographic suitability map for Atsbi sheep across Ethiopia based on all the evaluated factors.

findings of the study are expected to inform the delivery of best performing livestock genotypes to rural communities and their suitable environments.

GIS-based tools and approaches have found wide application in wildlife, land-use planning, arable agriculture and range-resource mapping and most recently in livestock studies. They have been used to delineate grazing grounds in regions where land has been fragmented (Kalivas and Apostolopoulos, 2005), to characterize production systems (Malafant, 1998), and to analyze the spatial link between indigenous breeds and areas of livestock use (Bertaglia et al., 2007). GIS tools have also been used to evaluate the spatial structure of animal populations, and patterns of disease transmission (Cringoli et al., 2007). Pitt et al. (2016) used GIS approaches to examine the ecological tolerance of the wild ancestor of domestic chicken and determine the success of domestication and global dispersal of the domestic variant. So far there are very few studies (Lozano-Jaramillo et al., 2018) that have used GIS tools to predict breed suitability for different agro-ecological zones. Most recently, Gheyas et al. (2021) used a combination of ecological niche modeling and genomic data to reveal drivers of local adaptation in African indigenous chicken.

In this study, six heatmaps representing similarities in temperature, precipitation, landform, soil pattern, climatic (temperature and precipitation) and overall global similarity in all the evaluated factors that defined the characteristics of the heartland environment of four and two breeds of Ethiopian indigenous breeds of sheep and goats were generated. The heatmaps were used to predict geographic region suitability for the six breeds across Ethiopia. Our results suggest of the four breeds of sheep studied, three (Menz, Horro, Doyogana) have an overlapping range of highly suitable habitats outside their geographic heartland. However, the geographic range that is highly suitable for Atsbi sheep is restricted to the north of the country in Tigray regional state and has a slight overlap with that of Menz sheep. In general, the areas that rank as highly suitable for the four breeds of sheep are as was expected in the Ethiopian highlands. These are areas with high precipitation, low ambient temperatures, high human density and a large proportion of the land is used for arable agriculture. The areas that were predicted to be highly suitable for the two breeds of goats showed no overlap. The one for Abergelle goats was in the north while that of Yabello goats was in the south of the country. This suggests possible agro-eco-climatic and geographic niche specialization between the two goat breeds. Indeed, the analysis shows that Yabello goats are moderately suited to geographic areas to the south, southeast and pockets of central and northern Ethiopia while a large percentage of the geographic areas that are either highly or moderately suitable for Abergelle goats are to the north of Ethiopia. For Yabello goats, these are low-altitude rangelands that are most often hot and dry while for Abergelle they are mostly high-altitude rangelands which are most often cold and dry.

Our modeling predictions suggest that the highly suitable areas for the four breeds of sheep and two of goats extend beyond their current geographic home range. This suggests the breeds can perform well across a large geographic range in Ethiopia as demonstrated in a recent study (Abate et al. (2020). The authors observed that improved Bonga rams that were distributed in four areas in the south of Ethiopia were performing better than the local variants. The predictions were sensitive

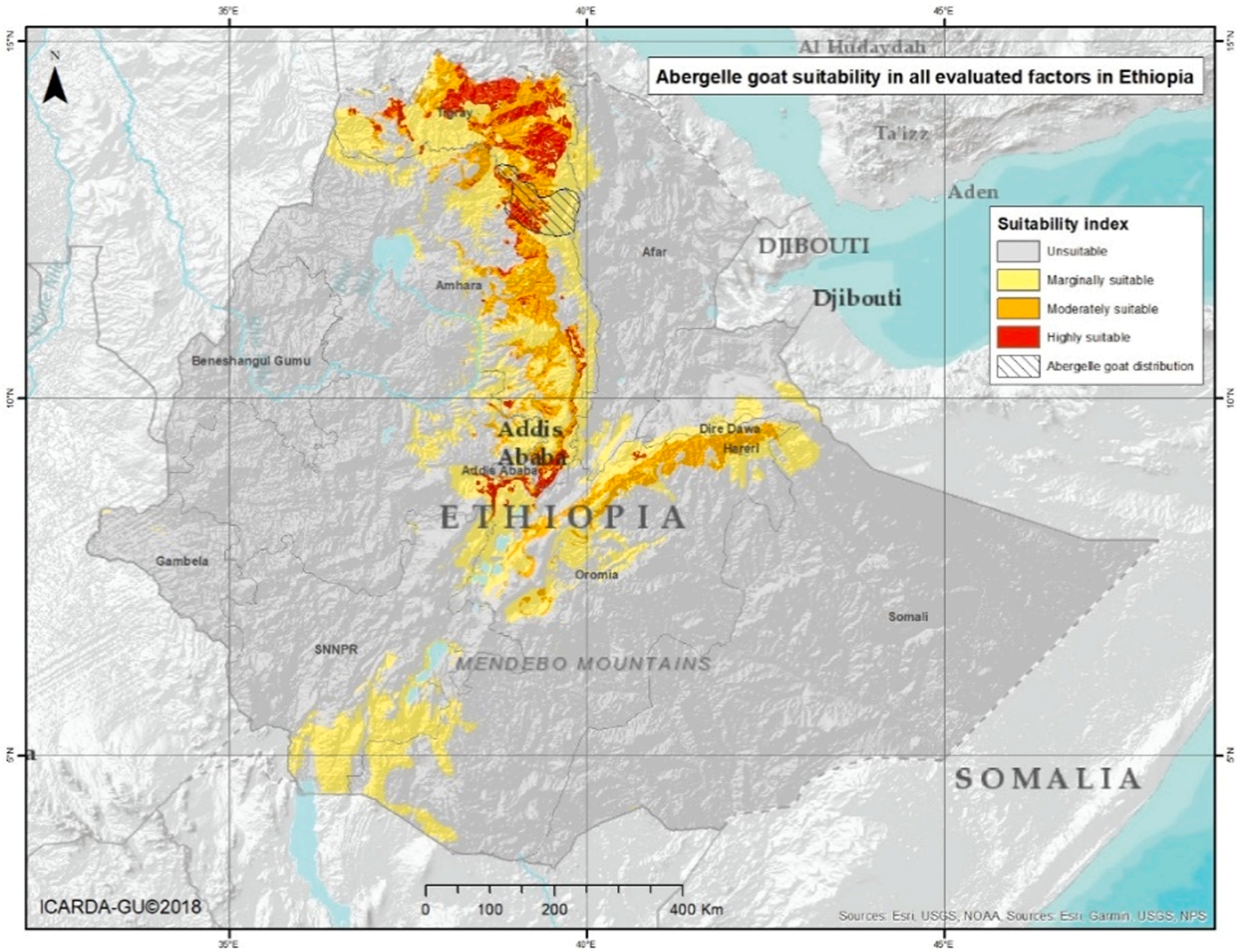

Fig. 8. The geographic suitability map for Abergelle goat across Ethiopia based on all the evaluated factors.

enough to not only predict overlapping geographic ranges between breeds but also areas that were specific to breeds. For instance, the highly suitable geographic area for Horro sheep ranges from central Ethiopia to the west and north-west of the country. The one for Menz sheep also ranges from central Ethiopia extending to the north and northeast of the country. The highly suitable geographic areas of Doyogana and Atsbi were however restricted. This finding is relevant given that knowledge on the environmental conditions affecting the performance of a breed is critical for decision-making targeting the introduction of improved breeds to ensure optimal performance or, the determination of potential areas to establish in situ conservation and management of flocks. The fact that there was no overlap in the geographic range that is highly suitable for the two species is in itself informative. The predicted medium and highly suitable habitats for the four breeds of sheep are mainly in the highlands which are most often cold and wet with abundant feed resources and high human population density. The lowland areas which are most often dry and hot with scarce feed and water resources and low human population density, were predicted to be of moderate and high suitability for goats. The production systems also differ; tethering is commonly practiced in the highlands while open extensive grazing is the management system in the drylands. Smaller flock sizes characterize the highlands compared to the lowlands. This has two implications. First, the two species are appropriate for different production systems and may explain the high population density of sheep in the highlands and the same is observed for goats in the lowlands (Getachew et al., 2010). Second, there is geographic-habitat niche specialization between the two species. Goats, which are mainly browsers and highly inquisitive selective feeders can utilize more nutritious and large variety of feed resources including grass and bushes that predominate the drylands. Sheep on the other hand, are mainly grazers and therefore are best suited in areas where grass is the main feed resource.

The environment-breed suitability modeling predictions employed here can be of practical use in the design and execution of breeding programs/plans, introducing a breed to a new geographic area and environment, and/or long-term climate change mitigation targeting a breed and environment; the target being to predict appropriate pockets of environments (micro-environments) in a country, region or continent for specific breed(s). The use of the approach to mitigate effects of climate change is especially important due to the influence of environmental factors on animal performance, and in understanding the mechanisms of livestock adaptation to challenging environments. Our breed suitability prediction can be extended and extrapolated to include recently developed phenotype distribution models that consider productivity to capture the response of phenotypic traits as a function of environmental conditions (Smith et al., 2017). The potential application and usefulness of phenotype distribution models in livestock studies was recently demonstrated (Lozano-Jaramillo et al., 2019). The study highlighted the importance of acknowledging the role of environment in predicting productivity in scavenging chicken. It recommended the use of phenotype distribution models in livestock breeding to develop breeds that better fit their target production environment.

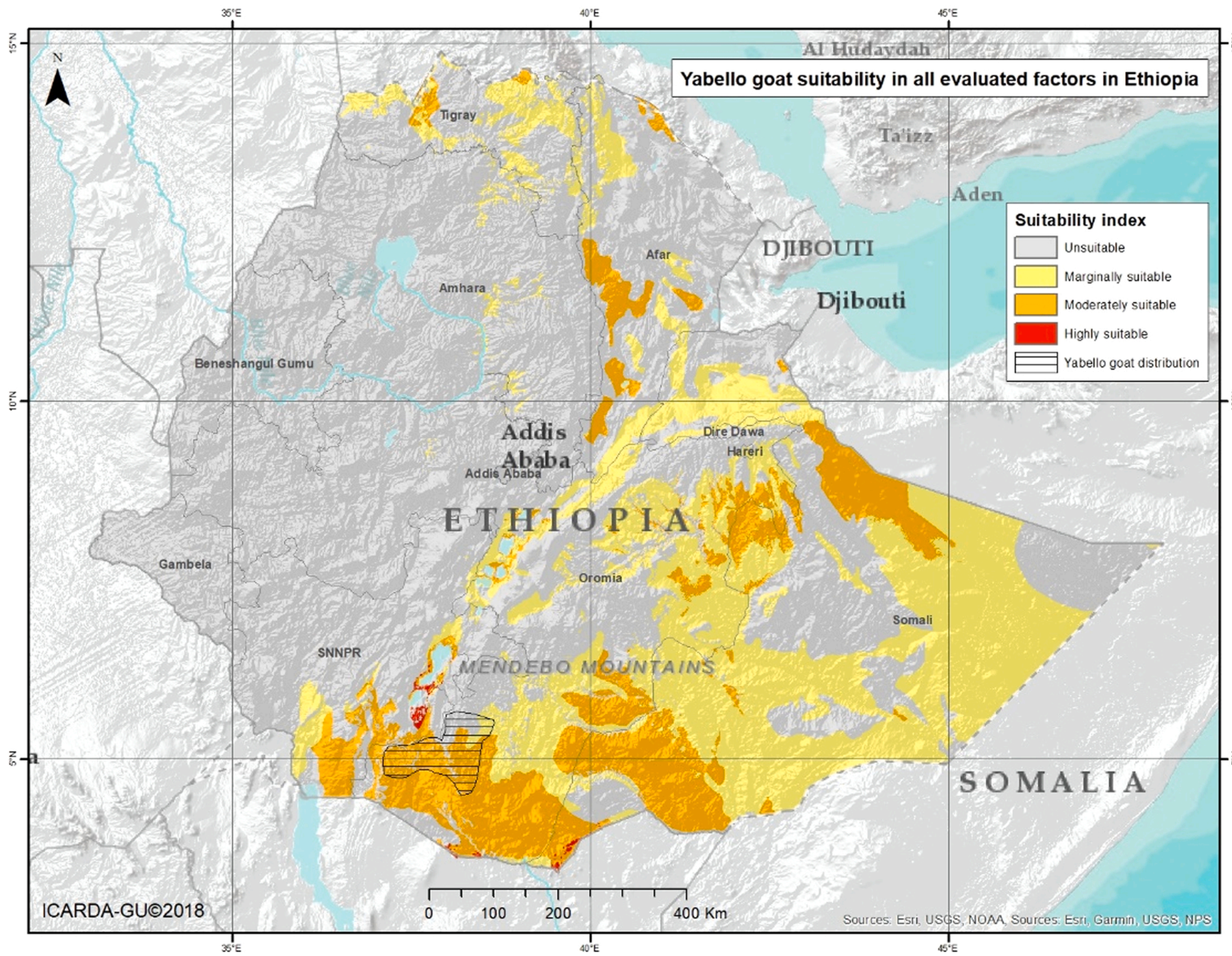

Fig. 9. The geographic suitability map for Yabello goat across Ethiopia based on all the evaluated factors.

Table 2
Percentage (%) in suitability classes for the four (sheep) and three (goat) breeds analysed in this study.

Species	Breed	Unsuitable	Marginally suitable	Moderately suitable	Highly 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

5. Conclusion

Matching genotypes to their environments can be challenging when designing breeding programs and/or out-scaling improved breeds to farmers. Generating breed suitability maps using prediction algorithms that make use of geo-informatics tools and approaches have potential to circumnavigate such challenges. These models are statistical and do not attempt to describe cause and effect between model parameters and response variables (Guisan and Zimmermann, 2000). Such prediction modeling offer useful tools to determine potential suitable habitats and/or generate information that can be used to determine where to introduce a breed, or which breed is better suited for which environment. Our analysis demonstrated using sheep and goats in Ethiopia, the usefulness of such an approach and the results can provide insights for targeting location-specific breed interventions, which together with climate change trajectories and natural resource base, are a major criterion for building resilient production systems. The approach can be implemented and applied to different livestock breeds and locations, and also predict impacts of different climate change scenarios on breed distribution. However, further analysis, including micro climatic variability, feed stock potential, ecological carrying capacity and production, will be essential to refine species-by-breed agro-ecological niches.

CRediT authorship contribution statement

L. Atassi: Data curation, Formal analysis, Writing – review & editing. **A. Haile:** Conceptualization, Funding acquisition, Resources, Writing – review & editing. **D. Solomon:** Resources. **T. Demissie:** Resources. **B. Rischkowsky:** Conceptualization, Funding acquisition, Resources, Writing – review & editing. **C. Biradar:** Data curation, Formal analysis, Writing – review & editing. **J.M. Mwacharo:** Conceptualization, Funding acquisition, Resources, Writing – original draft, Writing – review & editing.

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Conflict of interest statement

We the participating authors formally declare that we have no conflict of interest in relation to the submitted manuscript to Small Ruminant Research.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.smallrumres.2022.106775.

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