Identification of suitable fodder production areas using irrigation from shallow groundwater in Ethiopia

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Background

Agriculture is the most important economic sector in Sub-Saharan Africa. In Ethiopia, agriculture contributes more than a quarter of the gross domestic product (GDP) and export earnings. Livestock is an integral part of the agricultural system in Ethiopia, accounting about 40% of the economy, and provides employment to over 30% of the agricultural labour force. Livestock serves as a source of food, cash income, and farm power for ploughing and transportation. Despite Ethiopia's significant livestock population, largest in Africa, productivity in the sector is constrained by a shortage of feed, seasonality, feed quality, market linkages, and lack of access to basic veterinary services. Since livestock constitutes a large part of smallholders' livelihood, developing a better fodder production system would contribute to poverty reduction and social-ecological resilience by improving livestock productitivty through addressing bottlenecks in the quantity and quality of feed. The Innovation Lab for Small Scale Irrigation (ILSSI) project at the Texas A&M in collaboration with the Innovation Lab for Livestock Systems at the University of Florida have been working to identify suitable sites for fodder production in Ethiopia using promising small-scale irrigation practices that could improve productivity, environmental sustainability, household income, and nutrition. The fodder crops studied include Napier (*Pennisetum purpureum*), alfalfa (*Medicago sativa*), and desho (*Pennisetum glaucifolium*). The study also evaluates the irrigation potential of groundwater using simple water-lifting technologies.

Feed production potential assessment

The potential suitable land for sustainable fodder production in Ethiopia was identified using a GIS-based Multi-Criteria Evaluation (MCE) technique. The suitability analysis was done by mapping major factors affecting the suitability of the land for fodder production followed by reclassifying, assigning weights, and overlaying factors to develop a single-index fodder suitability map. The key factors were identified based on literature recommendation and expert feedback in the region (Akıncı et al., 2013; Chen et al., 2010; Mendas and Delali, 2012; Worqlul et al., 2015; Worqlul et al., 2017). The study included biophysical factors such as climate (rainfall, and evaporation), soil (soil texture, pH, and soil

depth), land use, and slope while the socio-economic factors included access to market and feed demand, which was represented by proximity to paved roads and livestock density, respectively. The source and spatial resolution of the data is shown in Table 1. The fodder crop types for the study were selected by the International Livestock Research Institute (ILRI) through on-farm trials during phase I of the ILSSI project and the potential for selected fodder crops to fit into the different agro-ecological settings in the country. The fodder crops selected were Napier (*Pennisetum purpureum*), alfalfa (*Medicago sativa*), and desho (*Pennisetum glaucifolium*). The selected crops have potential to improve household income and nutrition if scaled sustainably. The crop characteristics such as absolute and optimal growing temperature, soil pH, and depth conditions were obtained from Ecocrop (2000) and FAO (2011). The crop characteristics of the selected fodder crops is presented in Table 2.

Table 1: Source and spatial resolution of input data for the fodder suitability analysis.

Data	Source	Spatial resolution (m)
Land-use	Global Land Cover Datasets (GlobeLand30)	30
Soil	Africa Soil Information Service (AfSIS), 2015	250
Soil pH	Africa Soil Information Service (AfSIS), 2015	250
Soil depth	Africa Soil Information Service (AfSIS), 2015	250
Digital Elevation Model (DEM)	Enhanced Shuttle Land Elevation Data from the United States Geological Survey (USGS), 2000 released in 2015	30
Road network	Digital Chart of the World (DCW), 2006	--
MODIS potential evaporation (mm)	MOD16 Global Terrestrial Evapotranspiration Data Set (2000 – 2010)	1,000
Rainfall (mm/year)	Ethiopian National Meteorological Agency (ENMA) from 2000 to 2010	--
Fodder crop characteristics	FAO-EcoCrop database	--
Livestock population density	Ethiopian Central Statistical Agency (ECSA)	--

The groundwater data from the British Geological Survey (BGS) was used to evaluate irrigation potential of the groundwater using simple water lifting technologies such as pulley and bucket, rope and washer pump, and solar pump. In a previous study, the BGS depth to groundwater and potential borehole yield were compared with an observed groundwater yield data in the central part of Ethiopia, and the result indicated a reasonable performance in capturing the observed potential borehole yield (Worqlul et al., 2017). The BGS's depth to groundwater and potential borehole yield data were overlaid to evaluate accessibility and potential of the groundwater to cultivate fodder in the most suitable land.

Table 2: Characteristics of selected fodder crops considered to estimate the potential production area in Ethiopia (Ecocrop, 2000; FAO, 2011).

Fodder	Optimal temperature (°C)	Absolute temperature (°C)	Optimal soil PH	Optimal soil depth (cm)	Optimal rainfall (mm)
Napier	25 - 40	15 - 25 & 40 - 45	5.0 - 6.5	> 150	> 1500
Alfalfa	21 - 27	5 - 21 & 27 - 35	6.5 - 7.5	> 150	600 - 1200
Desho	20 - 25	15-20 & 25 - 35	5.5 - 7.0	50 - 150	700 - 1200

Potential Land Suitability for Irrigation

The suitability analysis indicated that slope and soil properties (i.e depth, and pH) were the most important factor for the suitability of land for fodder production in Ethiopia. Those factors reflect the integrated effect of the role of land management and soil health on the suitability of land for fodder production. The road proximity and livestock population showed a modest influence on the land suitability for fodder production while land use, rainfall deficit, soil texture, and temperature were the least important factors affecting the suitability of the land for fodder production. The preliminary suitability analysis showed that the suitability score ranged from 45% to 94%, 48% to 94%, and from 42% to 91% for desho, napier alfalfa, respectively. The smallest value represents the least suitable land and the highest value represents the most suitable land (Figure 1). A constraint map that exclude unsuitable areas such as waterbody and protected area were applied and the most suitable land were identified with a user-defined threshold suitability value. The suitable land extracted for a variable threshold from 80% to 94% (with a 1% increment) from the preliminary suitability map and the respective area above the threshold was plotted (Figure. 1d). For example, at a 85% threshold, ~8.7% of the Ethiopian land (about 17,720 km^2) is highly suitable for desho production through small scale irrigation followed by napier (4%) and alfalfa (2%).

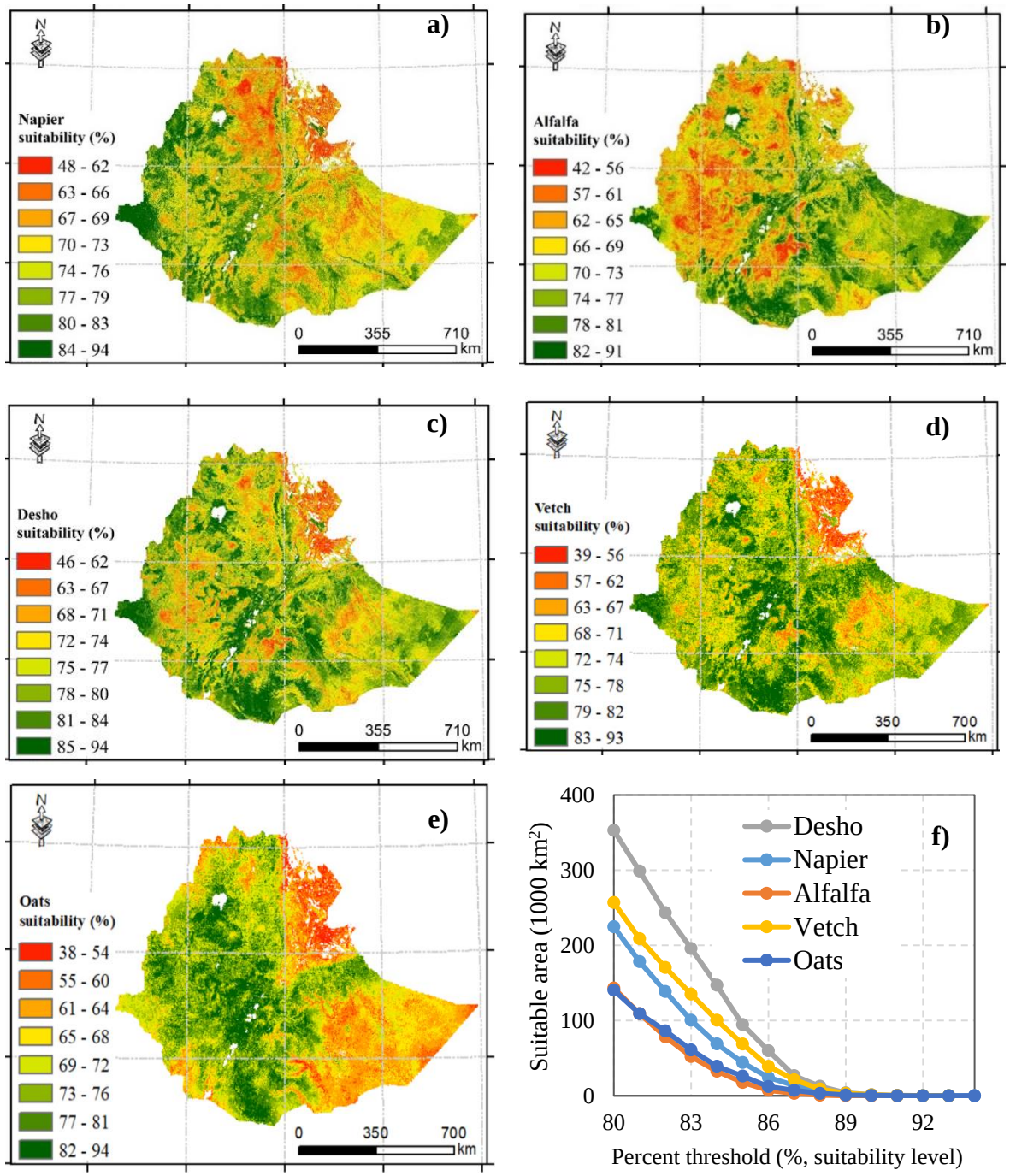

Figure 9: A preliminary suitable land for fodder production. a) Napier, b) Alfalfa, c) Desho, d) Vetch, e) Oats and f) Fodder production suitable area (in 1000 km^2) at different suitability levels. For example, 22,600 km$^{2\ of}$ land is suitable for Napier production at a level of 80%. The highest shows the most suitable area for fodder production while the lost value indicates the least suitable land for the respective fodder.

Groundwater Availability and Fodder Potential Area

The average groundwater potential yield in the highly suitable land for desho production is ~4.3 l/s; and ~4 l/s and 5.8 l/s for desho, napier alfalfa, respectively. The depth to groundwater estimated using the BGS data indicated that on average groundwater could be accessed at an average depth of 27 m, 17 m, and 22 m for desho, napier, and alfalfa, respectively. The groundwater assessment indicated a substential potential and accessibility for a small-scale fodder production in Ethiopia. Since there is a higher rainfall variability in Ethiopia, groundwater can serve as a source of irrigation buffering the rainfall variability.

Conclusions

The study estimated the potential suitable area for fodder production, considering biophysical and socioeconomic factors. The results indicated that there is substantial suitable land for fodder production in Ethiopia. The suitable areas for fodder production are also located in areas where there is sufficient groundwater resource, which could be utilized using simple water-lifting technologies. Sustainable use of the groundwater for fodder production will ease major livestock production constraints through producing better quality and quantity feeds. We believe this study will provide valuable insight to decision-makers, practitioners, and the private sector to scale fodder production in Ethiopia.

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Reference

Akıncı, H., Özalp, A.Y. and Turgut, B. 2013. Agricultural land use suitability analysis using GIS and AHP technique. Computers and electronics in agriculture 97, 71-82.

Chen, Y., Yu, J. and Khan, S. 2010. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. Environmental Modelling & Software 25(12), 1582-1591.

Ecocrop 2000 Ecocrop Database, FAO. Nations, F.a.A.O.o.t.U. (ed), Rome.

FAO 2011. Grassland Index. A searchable catalogue of grass and forage legumes.

Mendas, A. and Delali, A. 2012. Integration of MultiCriteria Decision Analysis in GIS to develop land suitability for agriculture: Application to durum wheat cultivation in the region of Mleta in Algeria. Computers and Electronics in Agriculture 83, 117-126.

Worqlul, A.W., Collick, A.S., Rossiter, D.G., Langan, S. and Steenhuis, T.S. 2015. Assessment of surface water irrigation potential in the Ethiopian highlands: The Lake Tana Basin. Catena 129, 76-85.

Worqlul, A.W., Jeong, J., Dile, Y.T., Osorio, J., Schmitter, P., Gerik, T., Srinivasan, R. and Clark, N. 2017. Assessing potential land suitable for surface irrigation using groundwater in Ethiopia. Applied Geography 85, 1-13.