**Hungarian Association of Agricultural Informatics**
**European Federation for Information Technology in Agriculture, Food and the Environment**

**Journal of Agricultural Informatics. 2015 Vol. 6, No. 2**
**journal.magisz.org**

# Land Suitability Assessment For Effective Crop Production, a Case Study of Taita Hills, Kenya

Mark K. Boitt[1], Charles N. Mundia[2], Petri K. E. Pellikka[3], John K. Kapoi[4].

INFO
Received 16 Apr 2015
Accepted 4 Jun 2015
Available on-line 29 Jun 2015
Responsible Editor: M. Herdon

Keywords:
DEM, RUSSLE, NDVI, Land Suitability, Soil Erodability

ABSTRACT

Agriculture is the backbone of Kenya's economy. Agriculture in Kenya is characterized by low productivity due to low external inputs, lack of good farming practices, soil erosion, and other losses. In most farming regions of the country, agriculture depends entirely on rainfall which sometimes is scarce. The problem of selecting the correct land for the cultivation of certain crops is a long-standing and mainly empirical issue. The objective of this study is to extrapolate and generate a crop suitability map showing areas suitable for agricultural activities in Taita Hills in Kenya. It utilizes the information on environmental condition, altitude, rainfall and other relevant parameters of the case study where the variability of rainfall and recurrent droughts have a great impact on the lives of people whose livelihood is mainly dependent on subsistence agriculture. The methods used include development of elevation models, watershed mapping, climate variability mapping, soil erosion mapping that incorporates the revised universal soil loss empirical (RUSSLE) model and multi-criteria evaluation analysis. The analysis was done using the sum weighted overlay analysis of soil erodibility, slopes, vegetation index and rainfall availability in the modeling. Four categories were achieved and mapped out: most suitable, more suitable, less suitable and least suitable. The research implies that there can be both suitable areas and unsuitable areas for crops in Taita Hills. The study helps farmers to be aware of the environmental conditions of their agricultural land and the impacts that may arise due to varying climate conditions on their cropping patterns.

## 1. Introduction

Many researchers have tried to prepare a standard framework for suitable and optimum agriculture land use. FAO (1996) classifies agricultural potential based on soil and environmental characteristics into five classes including highly suitable, moderately suitable, marginally suitable, currently not suitable and permanently not suitable. There have been instances of frequent crop failures of late. The occurrence of hydro-climatic events such as droughts and floods increase in many parts of the country (e.g. Taita Taveta County), causing severe socio-economic impacts that include food insecurity, famine, deaths, epidemic diseases, pests and economic losses among others. These impacts seem to spread over large areas and differ in severity, magnitude and duration. The problem has caused public outcry for good information on agricultural farming practices for planning and management purposes. A suitability assessment is an important phenomena for a region or a country to engage in more

[1]Mark K. Boitt
Department of Geomatic Engineering and GIS, Jomo Kenyatta University of Agriculture and Technology, Nairobi P.O Box 62000 - 0200, Nairobi, Kenya.
mboitt@jkuat.ac.ke
[2] Charles N. Mundia,
Institute of Geomatics, GIS and Remote Sensing, Dedan Kimathi University of Technology, P.O Box 657 - 10100, Nyeri, Kenya.
ndegwam@yahoo.com
[3] Petri K. E. Pellikka
Department of Geosciences and Geography, University of Helsinki, P.O Box 68, FI-00014 University of Helsinki, Finland.
Petri.pellikka@helsinki.fi
[4]John K. Kapoi
United Nations High Commissioner for Refugees P.O. Box 43801-00100 Westlands Nairobi, Kenya.
karantili@gmail.com/kipterer@unhcr.org

rational planning and optimizing resource use for the present and in the future (Zomer et al., 2008, Malczewski et al., 2001 & Bojórquez et al., 2001).

Land suitability refers to the ability of a portion of land to tolerate the production of crops in a sustainable way. Such kind of analysis allows identification of the main limiting factors for the agricultural production and enables decision makers (Joerin et al, 2001 & Miguel et al., 1998) to develop crop managements that is capable of increasing the land productivity (Rabia 2012; Pererira & Duckstein, 1993; Marull et al., 2007).

## 2. Study Area

Taita Hills (03 25’ S and 38 20’ E) are the northernmost part of the Eastern Arc Mountains of Kenya and Tanzania covering an area of approximately 850 km2 (Figure 1). They are characterized as an island of fertile mountain area surrounded by the dry bush lands of Tsavo East and West National parks situated about 150 km from the coast of Kenya immediately south of the Mombasa – Nairobi (Soni, 2005). The hills make up the administrative divisions of Wundanyi and Mwatate in Taita-Taveta County. These ancient Precambrian hills sit an altitude ranging from 1200 – 2200 meters a.s.l rising from the Tsavo Plains (Pellikka et al., 2012).

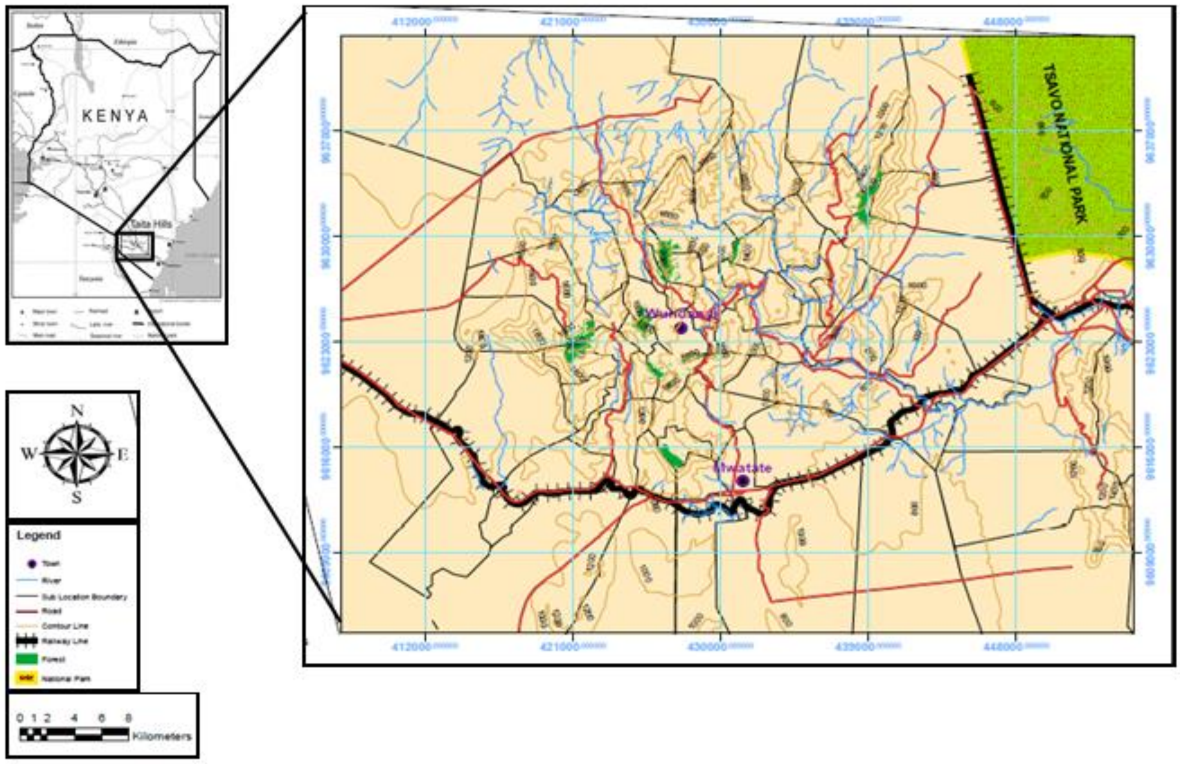


**Figure 1.** Taita Hills Map

The main basis of the living in the highlands is intensive agriculture, which is the main source of livelihood for 78% of people in the district (Pellikka et al., 2012). The population has doubled within 30 years and the highest growth rates are reported among the younger age groups. The pressure on land also results in increased human-wildlife conflicts as well as land use disputes between farmers and managers of sisal plantations and national parks (Pellikka et al., 2012).

### 2.1. Demographics, Agriculture, Terrain and Climate of Taita Hills

The population of the whole Taita-Taveta county has grown from 90,146 persons in 1962 to approximately 280,000 in the year 2009 (KNBS, 2010). According to Clark (2010), population growth has been a central driving factor behind rising environmental pressure. The population distribution is varied with most people living in the high potential areas of the foot slopes of the hills and in urban centres (NEMA, 2009). The upward trend of population growth in the Taita hills started in the mid

1920's (Soni, 2005). By the end of 1960's population had almost tripled from the 40,000 in the early 1930's to about 111,000 in 1969 (Figures cited by Mkangi (1978)).

The indigenous cloud forests have suffered substantial loss and degradation for several centuries as abundant rainfall and rich soils have created good conditions for agriculture. Between 1955 and 2004, approximately half of the cloud forests in the hills have been cleared for agricultural lands (Pellikka et al., 2009). Population growth and increasing areas under cultivation for subsistence farming have caused a serious scarcity of available land in the hills and contributed to the clearance of new agricultural land in the lowlands (Clark 2010). Currently, it is estimated that only 1% of the original forested area remains preserved (Pellikka et al., 2009).

The agriculture in the hills is characterized by intensive small-scale subsistence farming. In the lower highland zone and in upper midland zone, the typical crops are maize, beans, peas, potatoes, cabbages, tomatoes, cassava and banana. In the slopes and lower parts of the hills with average annual rainfall between 600 and 900 mm, early maturing maize, sorghum and millet species are cultivated. In the lower midland zones with average rainfall between 500 and 700 mm, dryland maize varieties and onions are cultivated, among others. Located in the inter-tropical convergence zone, the area has a bimodal rainfall pattern, the long rains occurring in March–May and short rains in November-December. The region has two crop growing seasons, which coincide with the long and the short rains (Jaetzold & Schmidt, 1983). Together, both crop growing seasons account for 150–170 days. The land is prepared during the dry season, and the crops are seeded prior to the short rains and long rains. Harvesting takes place after the end of the rainy seasons.

Taita Hills is facing a population growth and intensification of agriculture, which is the major economic activity for the Taita community (Boitt et al., 2014) with Horticulture dominating the agriculture based economic activity in the area (NEMA, 2009). Despite the large importance of agricultural activities for the economy and food security in the Taita Hills, the expansion of croplands imposes serious threats for the environment. Understanding the driving forces, tendencies and patterns of land changes is an essential step for elaborating policies that can harmonize land use allocation and natural resources conservation. Land use and soil erosion are closely linked with each other, with local climate and with the society. The expansion of agricultural areas in the Taita Hills and changes in precipitation patterns associated with climate change are imminent threats for soil conservation (Maeda et al 2010).

The crops grown in Taita Hills follow the altitudinal pattern of the area which in turn influences the Agro-ecological zones present. In the lower highland zone and in upper midland zone, the typical crops are maize, beans, peas, potatoes, cabbages, tomatoes, cassava and banana (Jaetzold & Schmidt, 1983). In the slopes and lower parts of the hills with average annual rainfall between 600 and 900 mm, early maturing maize, sorghum and millet species are cultivated. In the lower midland zones with average rainfall between 500 and 700 mm, dryland maize varieties and onions are cultivated, among others (Maeda, 2011). Maize and beans are the most important food crops and are mainly grown for subsistence. Other pulses are also grown and are mainly intercropped with maize. Planting of sorghum and millet in the hills is however rare, because their acceptance as food crops is low due to their unpopularity as food (NEMA, 2009). Arrowroot and cassava are very important food crops and an alternative when the maize crop fails. Sweet and Irish potatoes are also grown and consumed locally. The main livestock products are meat, milk, and hides (NEMA, 2009). Dairy production is more common in the upper zone of the Taita hills where the climatic condition and small land holdings are favorable for zero-grazing. The types of dairy cattle found in those areas are Friesian, Ayrshire, Guernsey and Jersey as well as crossbreeds. However, Taita Hills lack beef production because of small farm sizes (NEMA, 2009).

The Taita Hills complex rises above the erosional plains of the lowlands with small inselbergs. Its terrain pattern is largely contributed with geological processes whereby it is constituted by three major blocks namely the Sagalla, Taita and Kasigau (NEMA, 2009). The Taita Hills are block-faulted basement (crystalline) rocks in the Mozambique belt composed of Precambrian paragneisses from metamorphosed pelitic arenaceous and calcareous sediments from about 290 to 180 million years ago (NEMA, 2009). The surrounding plains lay at 500 - 600 m above sea level, while the highest peak of

Taita Hills, Vuria, reaches up to 2208 m (Pellikka et al., 2012). Generally, the terrain pattern of Taita Hills varies from 600 m to about 2200 m.a.s.l (Boitt et al., 2014).

The Taita Hills are strongly influenced by the Indian Ocean, forming a barrier to moisture-laden winds (Salminen, 2004). As a result, the area has two rainy seasons, one occurring during March-May and a shorter one during November-December. The mean annual rainfall ranges from 1332 to 1910 mm, with the southern and eastern slopes receiving more rainfall than western and northern slopes (Omoro et al., 2013) In addition, some parts of the Taita Hills receive cloud precipitation (Jaetzold & Schmidt, 1983). The amount of additional rainfall due to cloud precipitation (sometimes referred to as occult or horizontal precipitation) is unknown and difficult to quantify. Stadmüller (1987) reported relative values for cloud forest in the humid tropics ranging from 7 to 159% of annual rainfall while Bruijnzeel et al. (2010) reports that through fall exceeds annual rainfall in upper montane cloud forests by about 20% on average.

Recent past research by the National Environment Management Authority (NEMA) in the Taita-Taveta County Environment Action Plan for the period of 2009 – 2013, reveals that Taita Hills receive the highest amount of rainfall compared to other parts of the county. The high potential areas in the Taita Hills receive more than 900 mm of rainfall per annum (e.g. Wundanyi 1300 mm and Wesu 1400 mm) with temperatures average of 15 – 200C. The medium potential areas receive 700 to 900 mm, with higher temperatures, and evaporation (NEMA, 2009).

With increased regional slope, erosion systems have developed and have rendered the land unusable for agriculture and construction purposes. In areas more suitable for agriculture, uncontrolled deforestation, poor vegetation cover and overgrazing has led to removal of topsoil, leading to intense red patches and silting of local water supplies. The main causal factors are uncontrolled deforestation, overgrazing, surface compaction and poor land management. The impacts are severe; the loss of top soil leading to silting of reservoirs and rivers, a chronic reduction of soil fertility near the gully system, and the actual loss of productive land.  (Sirviö et al., 2004 & Pellikka et al., 2012).

## 3. Methodology

The research was based in Taita Hills where the land is characterized with hilly topography. It is this nature of topography it possesses that almost all physiographic characteristics and consequently human activities are linked to. For this reason, the research considered a 3D data that formed the basis of all analysis and therefore a Digital Elevation Model (DEM) of Taita Hills was used. Apart from the DEM, the study utilized other data files amongst is soils data file which was in vector format and with associated attributes – soil drainage and pH. The analysis carried out necessitated consideration of the amount and nature of precipitation associated with the area of study a fact that led to incorporate Mean Annual Rainfall data which was in raster format. This was followed by using Mean Annual Temperature (raster format) data forming part of the data list. Since the research results are for the benefit of the human population including farmers, county government of Taita-Taveta, and stakeholders, the study considered having data on administrative spatial settlement units and therefore Sub-locations (in vector format).

With crop suitability mapping being the main focus of the research, all local factors positively and negatively affecting crop farming in Taita Hills were explored. It was concluded that crop farming in this area is not only affected by amount and distribution of rainfall, temperatures, altitude, and soils properties but also soil erosion. The analysis was consequently procedurally broken down into seven (7) phases:

***i) Three dimensional mapping***

Land suitable for crop farming in Taita Hills is to a large extent affected by the topography. The study therefore considered running 3-D analyses that have direct impact on the crop farming suitability situation.  Since soil erosion has been spotted to be significantly affecting crop farming in Taita Hills, slope was treated as one of the determinant of soil erosion. The *slopes* in Taita Hills were then generated and mapped. *Contours* were then generated using the DEM. Water and eroded materials flowing from higher elevations follow certain pattern depending on the nature of the land which the study wanted to find out and therefore all **watersheds** were analytically delineated still using the DEM with the aid of Global Mapper Software.

***ii) Mean annual rainfall mapping***

The mean annual rainfall spatial distribution from the original data was mapped. Areas that receive the highest (high elevations and windward side) and lowest rainfall (low elevations and lee-ward side) were consequently identified.

***iii) Soil mapping***

Soil erosion levels are partially a product of soil variables. The variables combined for this mapping is the soil drainage, texture and organic contents. The study therefore used the soils data to map the drainage properties of soils in Taita Hills revealing the spatial distribution of this soil property.

***iv) Mean annual temperature mapping***

The mean annual temperature data was used in generating a map showing the spatial variations in temperatures within the area of study. This was used to infer the levels of evapo-transpirations.

***v) Soil erosion mapping***

Soil erosion was treated as one of the major determinants of crop farming in Taita Hills with areas associated with high soil erosion realizing low crop yields as opposed to areas with low or no soil erosion. GIS was used to model soil erosion by use of USLE/RUSLE (Wischmier & Smith, 1978; Renard et al, 1997) soil loss empirical model.

The spatial differences in the levels of soil erosion in Taita Hills by using mean annual rainfall to compute the rainfall intensities with intensity (Knijft et al, 1999) and a thresholds of 40mm and above was deemed erosive in the computation, soil erodibility (Harison et al, 2012); a combine of soil texture, available water content and gravel, study area population (KNBS 2010). The slope generated from DEM as detailed in (Morgan R.P.C, 1978 & Mitasova et al., 1996) as the determinants used in the modeling. The slope factor was a combine of slope length and steepness; LS factor, (Mitasova et al., 1996) and the vegetation index derived from the NDVI and the land use for the study area.

This task was accomplished by running sum weighted overlay of these determinants which were priori made raster data formats. In nature, rainfall, slopes and soil erodibility contributed varying magnitudes towards soil erosion phenomenon, a fact that was considered in this analysis. This phase of analysis was therefore done with two different ratios of weights in the sum weighted overlay analysis. The analysis was first done with ratio 3:2:1 of soil erodibility, slopes, vegetation index, and rainfall erosivity and population index carried equal weights in the modeling. After logical considerations of the situation in Taita Hills, the variable were validated with site visits to the specific locations of erosion and was found to be corresponding with the results obtained.

***vi) Soil pH mapping***

The relationship of soils pH and the levels of yields associated with them were studied and the same was linked to the situation in Taita Hills. Consequently, all soils with soil pH zero (0) were categorized as lowest crop yields soils, those with soil pH of ranges 5.1-5.3 & 8.3 were categorized as low crop yields soils, and soils with pH ranges of 5.7-6.4 & 7.9-8.0 were taken as soils which give high crop yields. This analysis was then mapped to bring out the spatial aspect.

***vii) Crop land suitability mapping***

This is the final phase of this analysis which the whole study was aimed at. Crop farming in Taita Hills was thought to be affected by soil erosion, soil pH, rainfall and temperature. The mapping categorized Taita Hills in four (4) crop suitability conditional zones terming them as *most suitable*, *more suitable*, *less suitable* and *least suitable*. All these aspects were analysed and mapped in the prior phases; they were therefore used to run a sum weighted overlay with the aid of Arc GIS. The categorization was thought in a way that all regions with lowest temperatures but high rainfall and least soil erosion as well as soil pH ranges that realize high crop yields to be the most suitable for crop farming. Whereas, regions which record low temperatures, above average rainfall, low soil erosion, and soil pH ranges which realize high crop yields to be more suitable for crop farming.

Less suitable regions for crop farming are thought to be areas with high temperatures and average rainfall but with high soil erosion and soil pH range which realizes low crop yields. Least suitable regions in Taita Hills for crop farming are taken to be those which record highest temperatures and low rainfall but with highest soil erosion and soil pH which realizes lowest crop yields (Table 1).

**Table 1.** Multi-criteria Analysis Parameters.

<table>
<tr><th>Mean Annual Temperature Level</th><th>Mean Annual Rainfall Level</th><th>Soil Erosion Levels</th><th colspan="2">Soil pH (Crop yields)</th></tr>
<tr><td>Lowest</td><td>Low</td><td>Least</td><td colspan="2">Lowest</td></tr>
<tr><td>Low</td><td>Average</td><td>Low</td><td colspan="2">Low</td></tr>
<tr><td>High</td><td>Above Average</td><td>High</td><td>High</td><td>High</td></tr>
<tr><td>Highest</td><td>High</td><td>Highest</td><td colspan="2">Highest</td></tr>
</table>

## 4. Results and Discussions

The results obtained from this research study were presented in form of maps. The use of fuzzy logic and of fuzzy sets theory applied as a means to arrive at a decision in this context. The fuzzy logic was used where the input variables were subjected to the modelling in ArcGIS. Fuzzy logics are the process of formulating the mapping from inputs to an output using fuzzy logic methods. The fuzzy logic mapping provides a basis for decision making, and logical arrangements of variables. The process of fuzzy logic inference involves Membership functions, Logical Operations, and If-Then Rules (Jiang & Eastman, 2000; Riad et al., 2011). The product outcome was reclassified into four main classes; less suitable, least suitable, more suitable and most suitable.

The results that were obtained from this research study were presented in form of maps that showed the scenarios in Taita Hills (Figure 2).

The mapping concept for this suitability analysis using GIS is very important to farmers in the current situation of global climate variations. Coupled with the Agro-ecological zones and having shown that in this research study, there shall be zone shifting in the coming years, precisely 2050, then farmers need to be aware of this situation so that they get prepared in time (Boitt et al., 2014). This study employs climate analysis and geophysical parameters in which the assumption is that the geophysical parameters won't affect or won't contribute so much to change however with the issue to do with soil erosion, due to huge amount of rains, the soil types and drainage pattern of Taita Hills can be of importance or consideration.

Soil erosion in Taita Hills is caused mainly by the intensive agriculture, cutting down of tress and even overgrazing. Huge amount of indigenous tropical cloud forest has been lost to agriculture between 1955 and 2004 although a balance was created by large-scale planting of exotic pines, eucalyptus, grevillea, black wattle and cypress on barren land during the same period which has not contributed much to the productivity of water catment or more agricultural yield. The investiment in this tree planting has not so far improved erosion downstream as the surfaces are still bare not fully covered by underneath vegetation that can reduce the rate of surface run-off. Indigenous forest loss may adversely affect ecosystem services in Taita Hills (Pellikka et al., 2009). From site visits and field measurements, the impacts of climate change to agricultural land in the region will be severe in the future if nothing is done to reduce such effects.

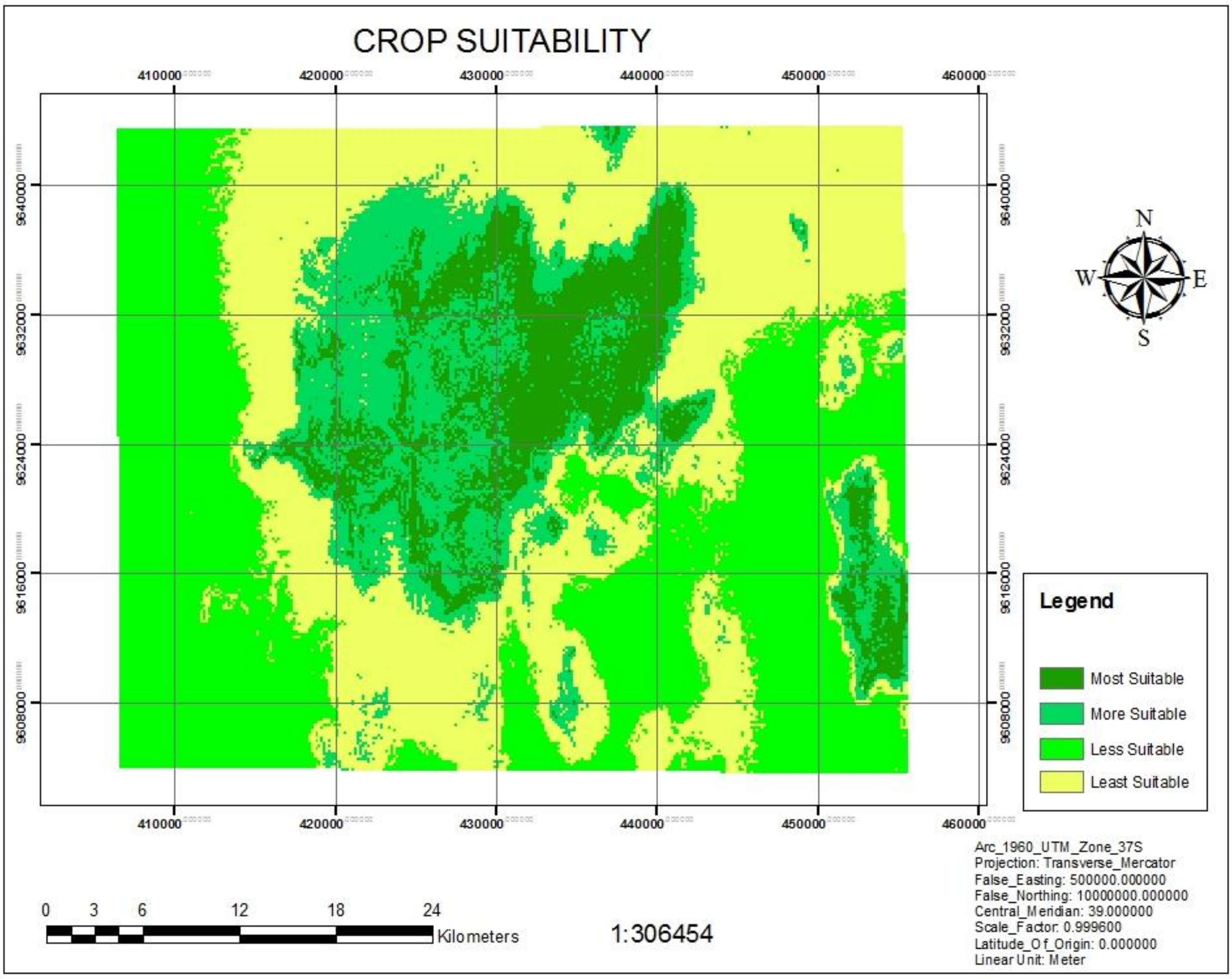


**Figure 2.** Crop-Land Suitability map for Taita Hills.

The implication of this study is a picture of what farmers need to know in regard to the best areas to grow their crops. In the areas which are most suitable for agriculture, farmers may not be forced to put so many efforts in order to realize a good harvest. In areas which are least suitable, it would be of importance for farmers either to put more fertilizers, do irrigation or in the event that it doesn't go on as they expect, change crops that are planted in those areas.

## 4. Conclusion

A suitability map was created based on the approach that was adopted. It is shown that there can be suitable areas and unsuitable areas for crops in Taita Hills and it doesn't imply that farmers in unsuitable areas cannot grow crops in their farms but rather this study helps them to be aware of the environmental conditions and its impacts that may arise with the varying climate conditions in the future. It is a tool that can be used to plan and manage agricultural activities for a better yield.

## References

A. A. Miguel, R. Peter, A. T. Lori, (1998) The Potential of Agro-ecology to Combat Hunger in the Developing World, A 2020 Vision for Food, Agriculture and the Environment.

Boitt, M. K., Mundia, C. N., & Pellikka, P. (2014) Modelling the Impacts of Climate Change on Agro-Ecological Zones–a Case Study of Taita Hills, Kenya. Universal Journal of Geoscience 2(6): 172-179, 2014; http://www.hrpub.org.

Bojórquez-Tapia, LA, Diaz-Mondragon, S, & Ezcurra, E (2001) GIS-based approach for participatory decision making and land suitability assessment. International Journal of Geographical Information Science, 15(2): 129-151. ISS N1365-8816 print/ISS N-3087 online©2001 Taylor & Francis Ltd; http: //www.tandf.co.uk/journals doi: 10.1080/13658810010005534

Clark L. M., D. A. Roberts, B. D. Clark (2005) Hyperspectral discrimination of tropical rain forest tree species at leaf to crown scales. Journal of Remote Sensing of Environment, Elsevier. doi: 10.1016/j.rse.2005.03.009

E. E. Maeda (2011) Agricultural Expansion and Climate Change in Taita Hills- An Assessment of Potential Environmental Impacts, University of Helsinki; ISSN-L 1798-7911ISSN 1798-7911(print)ISBN 978-952-10-6752-5(paperback)ISBN 978-952-10-6753-2(PDF) http://ethesis.helsinki.fi

F. A. Harison, O. A. Boasiako, A. Wakaitusi, T. A. Eric (2012) Estimation of Soil Erodibility and Rainfall Erosivity Patterns Over Agro-ecological Zones of Ghana, Soil Science and Environmental Management Vol.3, No. 11, 275-279, 2012. Universal Journal of Geoscience 2(6): 172-179, 2014http://www.hrpub.org; doi: 10.13189/ujg.2014.020602

FAO (1996) Agro-Ecological Zoning, Guidelines. Food and Agricultural Organization of the United Nations, Rome.

Jaetzold, R., & Schmidt, H (1983) Farm management handbook of Kenya. Natural conditions and farm information, 11.

Jiang, H., & Eastman, JR (2000) Application of fuzzy measures in multi-criteria evaluation in GIS. International Journal of Geographical Information Science, 14(2): 173-184. ISSN1365-8816print/ISSN1362-3087online©2000Taylor&FrancisLtdhttp://www.tandf.co.uk/journals/tf/13658816.htm doi: 10.1080/136588100240903

Joerin, F., Thériault, M., & Musy, A (2001) Using GIS and outranking multicriteria analysis for land-use suitability assessment. International Journal of Geographical information science, 15(2): 153-174. ISSN 1365-8816 print/ISSN1362-3087online©2001 Taylor & Francis Ltd; http://www.tandf.co.uk/journals doi: 10.1080/13658810051030487

KNBS, I (2010) Macro: Kenya Demographic and Health Survey 2008-09. Calverton, MD: Kenya National Bureau of Statistics and ICF Macro, 430.

Knijft,V.J.M, R.J.A Jones and L. Montanarella (1999) Soil Erosion Assessment in Italy.European Soil Bureau

Malczewski, J (2004) GIS-based land-use suitability analysis: a critical overview. Progress in planning, 62(1): 3-65. doi: 10.1016/j.progress.2003.09.002

Marull, J., Pino, J., Mallarach, JM., & Cordobilla, MJ (2007) A land suitability index for strategic environmental assessment in metropolitan areas. Landscape and urban planning, 81(3): 200-212. doi: 10.1016/j.landurbplan.2006.11.005

Mitasova, H., Hofierka, J., Zlocha, M., & Iverson, L. R. (1996) Modelling topographic potential for erosion and deposition using GIS. International Journal of Geographical Information Systems, 10(5), 629-641. doi: 10.1080/026937996137918

Mkangi, G. C. (1978) Population growth and the myth of land reform in Taita. PhD Theisis, 226.

Morgan, R. P. C. (1978) Field studies of rain splash erosion. Earth Surface Processes, 3(3), 295-299.

NEMA. (2009). Environment Action Plan, Taita Taveta District; 2009-2013. Ministry of Environment and Mineral Resources, Kenya, National Environemt Management Authority . Nairobi, Kenya: Government Press.

Omoro L.A., M. S. (2013) Tree biomass and soil carbon stocks in indigenousforests in comparison to plantations of exotic species in the Taita Hills of Kenya. Silva Fennica, vol. 47, 3-4. doi: 10.14214/sf.935

Pellikka P. K., B. J.F. Clark, A. G. Gosa, N. Himberg P. Hurskainen, E. Maeda, J. Mwang'ombe, L. M. A. Omoro and M. Siljander (2013) Agricultural Expansion and Its Consequences in the Taita Hills, Kenya. In Paolo Paron, Daniel Olago and Christian Thine Omuto, editors: Developments in Earth Surface Processes, Vol. 16, Amsterdam: The Netherlands, pp. 165-179. doi: 10.1016/b978-0-444-59559-1.00013-x

Pellikka, P. K., Lötjönen, M., Siljander, M., & Lens, L (2009) Airborne remote sensing of spatiotemporal change (1955–2004) in indigenous and exotic forest cover in the Taita Hills, Kenya. International Journal of Applied Earth Observation and Geoinformation, 11(4), 221-232. doi: 10.1016/j.jag.2009.02.002

Pereira, JM., & Duckstein, L (1993) A multiple criteria decision-making approach to GIS-based land suitability evaluation. International Journal of Geographical Information Science, 7(5): 407-424. doi: 10.1080/02693799308901971

Rabia, AH. (2012) A GIS based land suitability assessment for agricultural planning in Kilte Awulaelo district, Ethiopia. The 4th International Congress of ECSSS, EUROSOIL 2012 “soil science for the benefit of mankind and environment”, pp: 1257, 2-6 June, Bari, Italy.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool and D.C Yoder (1997) Predicting Soil Erosion by Water; A guide to Conservation Planning with the Revised Universal Soil Loss Equation(RUSLE).USDA,Agriculture Research Service.Agric Handbook,703;384

Riad, PH., Billib, MH., Hassan, AA., & Omar, MA (2011) Water scarcity management in a semi-arid area in Egypt: overlay weighted model and Fuzzy logic to determine the best locations for artificial recharge of groundwater.

Salminen, H. (2004) A geographic overview of Taita Hills, Kenya. University of Helsinki, Department of Geography. Department of Geography, University of Helsinki.

Sirviö T., A. Rebeiro-Hargrave, P. Pellikka (2004) In the Proceedings of the 5th African Association of Remote Sensing of Environment Conference, 17-22 Oct. 2004, Nairobi, Kenya

Soni, E. (2005) Livelihood capital, strategies and outcomes. Nairobi, Kenya: World Agroforesty Centre. Retrieved December 1, 2014.

Stadmueller, T. (1987) Cloud Forests in the Humid Tropics. A Bibliographic Review. Costa Rica: CATIE.

Zomer, RJ., Trabucco, A., Bossio, DA., & Verchot, LV. (2008) Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation. Agriculture, ecosystems & environment, 126(1): 67-80. doi: 10.1016/j.agee.2008.01.014.