A LAND SUITABILITY ANALYSIS OF THE VHEMBE DISTRICT, SOUTH AFRICA, THE CASE OF MAIZE AND SORGHUM

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ABSTRACT:

Sustainable development goals (SDGs) 1 and 2 stand for "No poverty" and "Zero hunger" respectively. Achieving these goals cannot be separated from promoting sustainable agriculture and ensuring livelihoods, especially for rural communities. This study sought to determine the suitability of land for the cultivation of maize and sorghum crops in Vhembe District, South Africa. The study applied the Analytical Hierarchy Process (AHP) and the Weighted Linear Combination (WLC), multi-criteria decision-making techniques, for criteria weights calculations and suitability maps calculations respectively within a Geographic Information System (GIS) environment. Six criteria were used; Soil pH, Soil Structure, Rainfall, Maximum Temperature, Minimum Temperature and Elevation. A consistency ratio (CR) of 0.035 was obtained for maize criteria weights and 0.036 for sorghum criteria weights. The results revealed that only limited portions of the whole district are highly suitable for the cultivation of Maize with 15.01% and Sorghum with 19.39 of the land arable for farming. This suggests lower maize and sorghum crops yields in the district and the paper recommends more cultivation of other drought resistant crops other than maize and sorghum.

1. INTRODUCTION

1.1 General Introduction

The main aim of Sustainable Development Goals (SDGs) launched by the United Nations in 2015 is focussed at "ending poverty, protecting the planet and ensuring prosperity for all" (UN, 2015). Such a bold aim calls for action in understanding the relationships between the condition of the land, environmental factors that determine the productivity of land and the subsequent agricultural productivity of land in regions of the world that have long been known for agricultural activity. This is important because ending poverty cannot be considered in isolation from food security, and prosperity cannot be envisaged with empty stomachs. Hence, ensuring food security in a sustainable manner stands out as being paramount to achieving the aim of SDGs, especially when considering the fact that highly industrialized agriculture is among the driving forces of global environmental change (Adegbeye et al., 2020). As such, understanding the vulnerability of agricultural land for the production of staple food for local communities in the face of climate change is necessary as it has the potential to inform agricultural policy frameworks and directives on appropriate land use and management (Haggblade et al., 2017).

Various scholars have undertaken studies aimed at analysing the suitability of land for a multiplicity of purposes, among others, ecological land suitability (Sani et al., 2016), land use planning (Chen et al., 2011), service delivery using AHP (Parry et al., 2018) and the production of rain-fed staple crops using a variety of methods. For example, Munene et al. (2017) conducted a land suitability analysis for the production of soya beans using the Weighted Linear Combination (WLC) method and criteria such as Texture, Phosphorus, pH, Drainage, Slope, Wetness, Elevation, and Distance to market. Also, Bonfante et al. (2015) investigated the impact of climate change on land suitability for maize using Hybrid Land Evaluation system considering the daily minimum and maximum temperature, and precipitation. Teixeira et al. (2013) studied heat stress on crops (wheat, maize, rice, and soybean) using the FAO/IIASA Global Agro-Ecological Zones model (GAEZ) considering daily maximum and minimum temperature. Lastly, Bagherzadeh and Gholizadeh (2016) evaluated the suitability of land for alfalfa using machine learning methods (ANN and TOPSIS). These have all conducted such studies at different geographical scales and for different purposes and making use of different suitability criteria depending on the desired outcomes.

In the case of South Africa, maize and sorghum are amongst the most important staple food grains with maize at the top of the list (D'Haese et al., 2013; Bienabe, Vermeulen, 2011). Consequently, this research has focused on analysing the suitability of land for the production of maize and sorghum in

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the Vhembe district, South Africa. The work combined the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC) methods and applied Geographic Information Systems. The AHP was used to determine criteria weights as in (Akıncı *et al.*, 2013) and the WLC was used to aggregate the "preference information" (Chou, 2013) as expressed in terms of the criteria weights, which led to the subsequent ranking of land suitability types.

1.2 Study Area Description

Vhembe District Municipality (Figure 1) is a Category C municipality located in the Northern part of Limpopo Province of South Africa. The District shares borders with Capricorn District municipality to the East, and Mopani District municipality to the West. Vhembe District also shares borders with Zimbabwe and Botswana in the North West, and with Mozambique in the South East (Mokganya & Tshisikhawe, 2018). The district has a total area of 2,140,708 hectares of which 249,757 hectares are considered to be arable land. The total population of the Vhembe District was estimated at 1 294 722 people as per the 2011 Census and at 1.43 Million as per StatsSA's Midyear population 2017 (Limpopo Provincial Treasury, 2018).
Vhembe District is characterized by a subtropical climate. Its temperatures range from a minimum of 10ºC during winter to a maximum of 40ºC in summer with an annual rainfall of approximately 500mm of which 87.1% falls between October and March. The agricultural system in Vhembe is characterized by two types; namely large-scale commercial farming and small-scale subsistence farming.

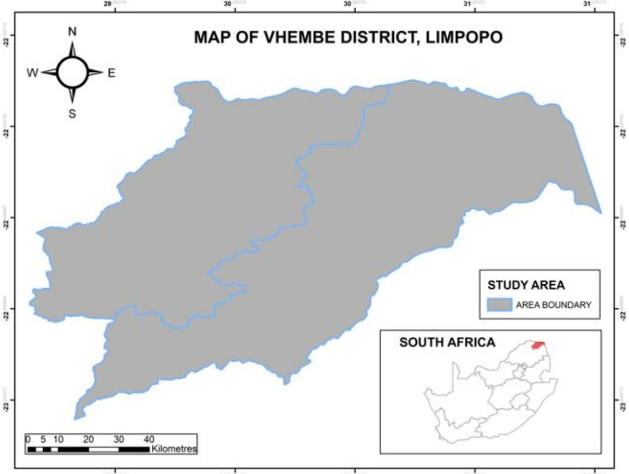

Figure 1. Study Area: Vhembe District, South Africa; Source: (Vhembe District Municipality, 2016).

There are currently two existing agricultural hubs in the Vhembe, Levubu and Nwanedi, with an additional hub, Nandoni, being developed (Vhembe District Municipality, 2016).

2. MATERIALS AND METHODS

2.1 Data

The data that was used in conducting this study was obtained from the South African Department of Agriculture, Land Reform and Rural Development and from the Agricultural Research Council (ARC) of South Africa. Table 1 provides a description of the data used in this study.

Data Type	**Description**
Temperature	Temperature readings throughout the Republic of South Africa between the years 2002 and 2003. This was used to obtain the minimum annual temperature and maximum annual temperature in the Vhembe District.
Precipitation	Precipitation readings between the years 2002 and 2003 throughout the Republic of South Africa. This was used to obtain average annual rainfall in the Vhembe District.
Physical and Chemical properties of Soil	Soil structure and Soil pH readings used to obtain Soil structure and Soil pH for Vhembe District
Topography	Elevation readings were used to obtain the elevation of the study area.
Boundary and other shapefiles	Boundary shapefiles were used to demarcate and clip datasets to the boundaries of the study area.

Table 1. Data Description; Source: ARC

The Elevation raster, Natural soil pH raster, Rainfall-Mean annual raster, Maximum Annual Temperature raster, Minimum Annual Temperature raster, and structurally favourable soils raster data were gathered to develop a land suitability analysis model for maize and sorghum crops.

2.2 Criteria identification and data reclassification

Literature was reviewed to identify the criteria or factors that play the most important roles in determining the growth of maize and sorghum. The following criteria were identified: Soil structure, Soil pH, Elevation, Minimum temperature, Maximum temperature, and Rainfall (du Plessis, 2003; DAFF, 2010; Butchee *et al.*, 2012). Data relating to these factors were reclassified into four classes according to the suitability classification scheme of the Food and Agriculture Organization of the United Nations (UN) that is, Highly suitable, Moderately suitable, Marginally suitable and Unsuitable (FAO, 1976).

2.3 Criteria weighting using the analytical hierarchy process (AHP)

The Analytical Hierarchy Process (AHP) as described by Saaty (2008) was used to calculate criteria weights for both maize and sorghum. Two pairwise comparison matrices were developed with their subsequent normalized pairwise comparison matrices. This was done to weigh and determine the importance of each criterion in the growth of maize and sorghum. Consistency checks were performed for each normalized pairwise comparison to validate the two sets of criteria weights, one for the cultivation of maize and the other for the cultivation of sorghum. The consistency checks were done by calculating the consistency ratio (CR) and the random index (RI) for each normalized pairwise comparison matrix. A consistency ratio of 0.035 was obtained when checking the validity of criteria weights for maize, a ratio which falls much below the threshold of 0.1 and a random index of 1.24 was obtained. Similarly, a consistency ratio of 0.036 and a random index of 1.24 was obtained when checking the validity of criteria weights for the cultivation of sorghum. As can be noticed, the random index is the same for maize and sorghum. This is due to the fact that the number of criteria used to determine suitable locations for maize and sorghum was the same.

2.4 Suitability Analysis: Weighted linear combination

Once the criteria were weighted for the Maize and Sorghum crops using the AHP method in Microsoft Excel, the weights were then applied in the Weighted Linear Combination (WLC) method using ArcGIS 10.6.1 to determine the different levels of land suitability for the cultivation of Maize and Sorghum in the Vhembe District. The WLC method was applied by using the following formula:

$$S = \sum w_i x_i \quad (1)$$

Where S= suitability
W_i= weight of criterion I
X_i = criterion score of criterions i (Al-hanbali et al., 2011).

The Weighted Linear Combination method was used to aggregate the “preference information” (Chou, 2013) as expressed in terms of the criteria weights, which led to the subsequent ranking of land suitability types.

3. RESULTS

3.1 Analytical Hierarchy Process

The analytical hierarchy process was determined, and this is discussed in detail in the ensuing sections.

3.1.1 Criteria weights for the cultivation of maize and sorghum

The following criteria weights were obtained after making use of the analytical hierarchy process method as per the guidelines in (Akıncı et al., 2013). The guidelines consist of a consistency check procedure to validate the AHP results as presented by (Saaty,2008).

CRITERIA WEIGHTS RANKING FOR THE CULTIVATION OF MAIZE		
Criterion Rank	**Criterion Name**	**Criteria Weight (%)**
1	Soil pH	22.10
2	Soil Structure	21.97
3	Rainfall	20.46
4	Elevation	13.08
5	Minimum Temperature	11.47
6	Max Temperature	10.94
Total		***100***

Table 2. Criteria weights ranking for the cultivation of maize; Source: Authors (2020)

A consistency ratio of 0.035 was obtained for maize criteria weights and a consistency ratio of 0.036 for sorghum criteria weights. These ratios are below the threshold of 0.10 set by (Saaty, 2008).

CRITERIA WEIGHTS RANKING FOR THE CULTIVATION OF SORGHUM		
Criterion Rank	**Criterion Name**	**Criteria Weight (%)**
1	Soil pH	22.71
2	Soil Structure	19.88

3	Max Temperature	15.22
4	Elevation	14.86
5	Minimum Temperature	14.85
6	Rainfall	12.99
Total		***100***

Table 3. Criteria weights ranking for the cultivation of sorghum; Source: Authors (2020)

When comparing Tables 2 and 3 above, it is evident that Soil pH ranks the highest followed by soil structure. In the case of Maize, rainfall ranks third whereas in the case of Sorghum, maximum temperature ranks third and rainfall ranks sixth instead. It is not surprising to have Soil pH rank first since it is a major determinant of plant growth. Soil pH influences the availability of essential nutrients. Soil pH is also very interesting in the sense that a pH reading of below 7 is indicative of acidity of the soil and any pH reading above 7 is indicative of alkalinity of the soil. Few plants, however, tend to be more acidic than alkaline and few tend to be more alkaline than acidic and Maize does not fall under any of the two categories hence Soil pH is of great importance for the optimum growth of Maize.

Soil Structure is ranked second highest after Soil pH for both Maize and Sorghum. This is due to the important role played by soil structure in the growth of a plant. For example, soil structure determines how plant roots grow and are distributed underground as the structure of the soil impacts on soil temperature, aeration and availability of water in the soil (Ball et al., 2004). Soil structure relates to the physical and/or mechanical properties of the soil which are also linked to climatic factors such as temperature and rainfall. Hence, "Rainfall" ranked third after "Soil Structure" for Maize. Rainfall is an important factor as it determines soil moisture from which the crop draws water, especially in the case of Maize, a crop that requires between 450 to 600 mm of water per season for optimal yield (du Plessis, 2003). Rainfall ranked sixth for Sorghum because Sorghum is a more drought-resistant crop as opposed to Maize which tends to be water-intensive when compared to Sorghum.

However, though Soil pH and Soil Structure rank highest for Maize and Sorghum, their respective weights differ for the two crops. The weight of Soil pH for Sorghum is slightly higher than that for Maize and the weight of Soil Structure for Sorghum is lower than that for Maize, this is due to the fact that Sorghum is a hot weather crop and which implies that soil structure does not affect Sorghum the same way it would affect Maize. It is also worth noting that the criteria weights are also a representation of the sensitivity of each criterion. The higher the weight, the greater the sensitivity and impact of the criterion on the ranking structure.

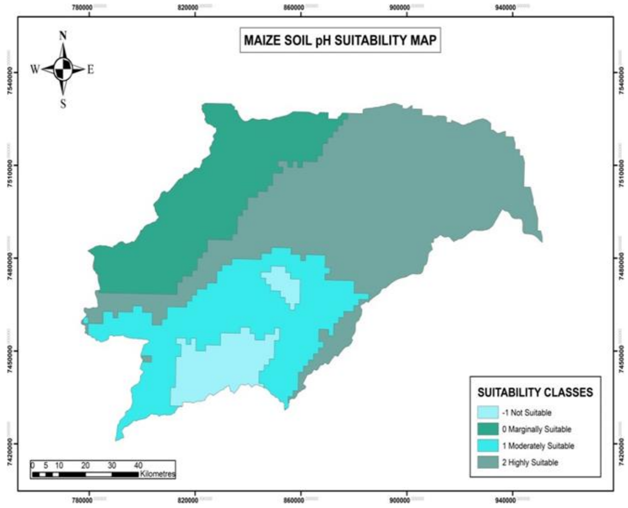

Figure 2. Criterion variability map for maize: Soil pH; Source: Authors (2020)

Figures 2,3,4 and 5 represent criteria variability maps for maize and sorghum for the two highly ranked criteria, that is soil pH and soil structure.

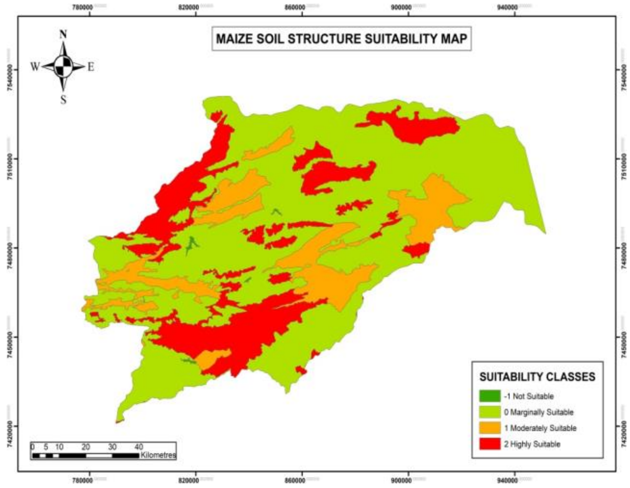

Figure 3. Criterion variability map for maize: Soil structure; Source: Authors (2020)

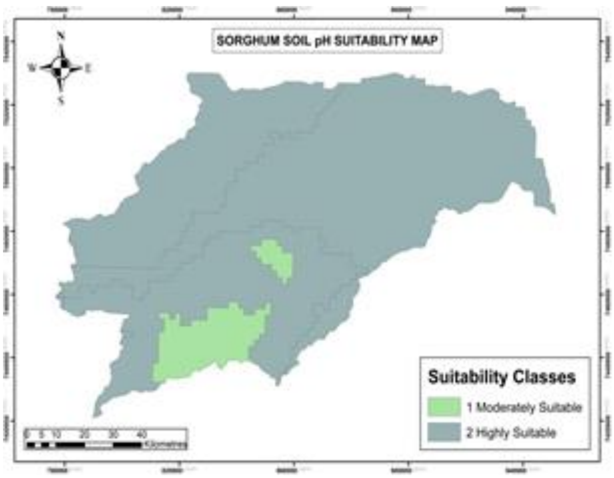

Figure 4. Criterion variability map for Sorghum: Soil pH; Source: Authors (2020)

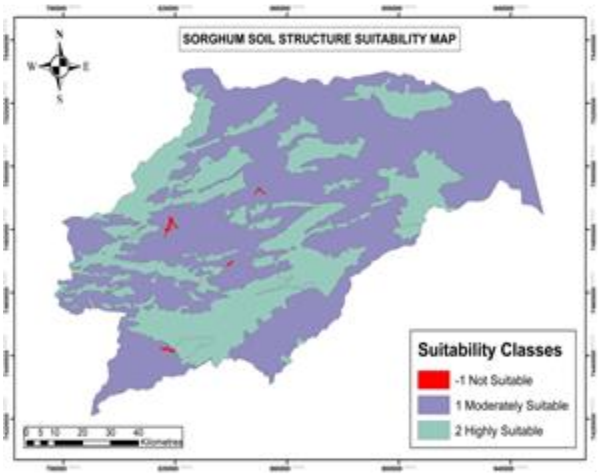

Figure 5. Criterion variability map for Sorghum: Soil structure; Source: Authors (2020)

It is worth noting that the criteria maps on Figures 4 and 5 display two and three suitability classes instead of four as suggested in previous works (FAO, 1976). This is due to the fact that after reclassification of attribute values relating to soil pH and soil structure in light of the growth requirements of sorghum, it was found that the attribute values can be classified only into two and three classes instead of four as previously determined by other studies.

3.2 Results of suitability analysis

The results of suitability analysis were determined by the study and these are presented in the ensuing sections.

3.2.1 Suitability results for maize

The suitability analysis of maize was determined and presented in Figure 6 below. As can be observed below and based on a further analysis of the results, only 152, 841 ha of the whole district is highly suitable for Maize which constitutes 15.01 % of the total area of the district.

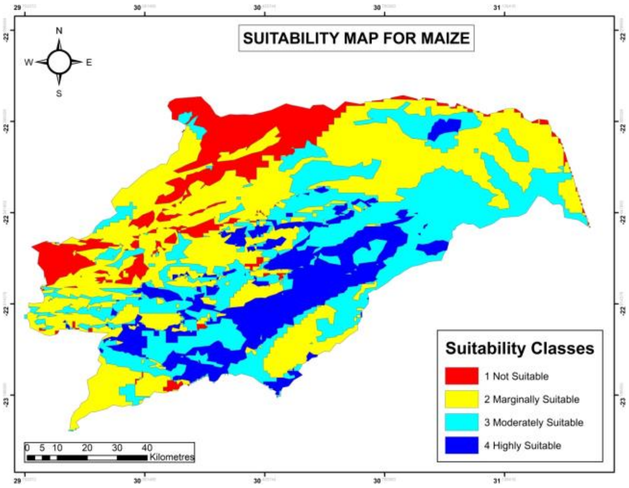

Figure 6. Suitability map for maize; Source: Authors (2020)

The map also shows that when combined together, the areas that are highly suitable and moderately suitable for Maize are less than 50 % of the total area, that is they add up to 46.76% which is slightly higher than the total area earmarked as marginally suitable. Therefore, most of the land is either marginally suitable or unsuitable because the state of growth factors such as soil pH, soil structure and rainfall is not conducive for the growth of Maize in most parts of the district, and these factors or criteria carry the highest weights.

3.2.2 Suitability results for sorghum

The suitability analysis of sorghum was determined and presented in Figure 7 below. Based on the figure below and further analysis of the results, only 197, 370 ha (19.39%) of the whole district is highly suitable for Sorghum.

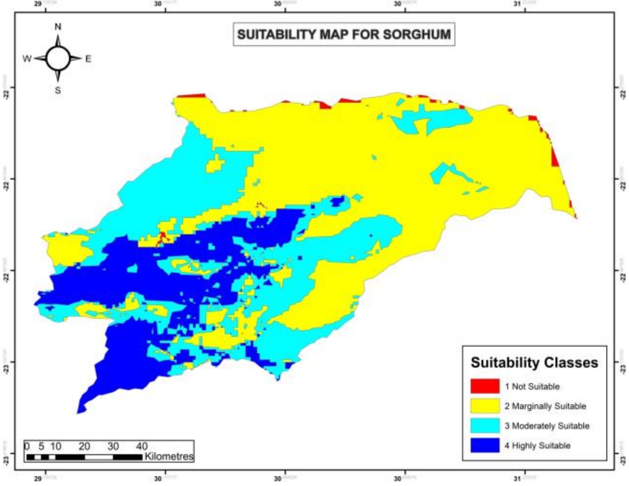

Figure 7. Suitability map for sorghum; Source: Authors (2020)

The results show that less than 1% of the entire area is not suitable for the cultivation of Sorghum, a reality that is mainly due to the fact that Sorghum is a drought-resistant crop and thus, it is likely to grow in most areas of the district with variations in yield potential. It is worth noting that areas highly suitable for Maize are not highly suitable for Sorghum. This explains the difference in requirements for the growth of the two plants in terms of Soil pH, Soil Structure, Rainfall, Minimum Temperature, Maximum Temperature, and Elevation.

4. DISCUSSION

4.1 Implications for policy, climate change and livelihoods

The results were evaluated to determine the implications for policy, and these are discussed in detail in the ensuring section.

4.1.1 Implication for policy

The results obtained imply that policies advocating for agricultural development as a means of achieving local economic development should build their strategies based on the outcome of land suitability analyses as it may appear that the crops that form part of their strategies cannot be produced sustainably on available land for agriculture. The analysis of the suitability of land for the cultivation of maize and sorghum has revealed that there is limited availability of highly suitable land for the cultivation of maize and sorghum. It would not be surprising to find out that there is also limited suitable land for the cultivation of other crops. Further, the results also imply that the provisions of laws such as the Spatial Planning and Land Use Management Act (SPLUMA) (Act No. 16 of 2013) should be implemented with careful consideration of the suitability of land for a wide range of uses. For example, the SPLUMA Act places on municipalities the responsibility to develop their respective Spatial Development Frameworks (SDFs) under Section 20 of the act. The SDF should outline the spatial vision of each municipality and inform the use and management of land. The act also requires municipalities to develop their respective land use schemes as are necessary for the use and management of land in their areas of jurisdiction. These two instruments, SDFs and Land Use Scheme cannot be well developed without taking into consideration the suitability of land for a wide range of uses including agricultural use.

4.1.2 The implication for climate change and livelihoods

The results highlight the impact of climate change on not just the agricultural industry but also on the spatial configuration of areas in terms of land uses as the outcome of land suitability analysis has the potential to inform the spatial vision of a city, district or province. In the case of the implication for climate change and agriculture, it appears that highly suitable land for agricultural purposes, not only for maize and sorghum, will keep shrinking as changes in climatic variables or factors such as temperature and precipitation become more noticeable over the years. This, however, does not mean that agricultural activities should cease; it simply means that as climate change becomes more apparent in an area the determination of land suitability for crops, needs to be undertaken so as to inform decision making on the crops to grow. This will assist in determining whether it is viable to continue with the culture of the same crops or new crops should be introduced for which land is still or has become suitable to ensure food security. The proportion of highly suitable, moderately suitable, marginally suitable and not suitable lands for the cultivation of maize and sorghum implies that local residents should think of new livelihoods, especially those residents who rely on subsistence farming. Furthermore, alternative crops that are suitable for the areas should be identified.

5. CONCLUSION

In conclusion, the study has found that only 15.01% of the land in Vhembe district is highly suitable for the cultivation of maize whilst only 19.39% of the whole area is highly suitable for the cultivation of sorghum. It was also found that soil pH and soil structure rank the highest determining factors for the growth of maize and sorghum. The small proportions of highly suitable land for maize and sorghum have implications for policy and livelihoods. In terms of the policy, it was determined that the provisions of laws such as the Spatial Planning and Land Use Management Act (SPLUMA) (Act No. 16 of 2013) should be implemented with careful consideration for the suitability of land for a wide range of land uses. Although the limited suitability for the cultivation for maize and sorghum does suggest the secession of agriculture in the Vhembe district, it should mean that as climate change becomes more apparent in an area, the suitability of land for crops needs to be undertaken so as to determine whether it is still viable to continue with the culture of the same crops or new crops should be introduced for which land is still or has become suitable to ensure food security. The paper concludes by recommending local residents to think of new livelihoods, especially those residents who rely only on subsistence farming.

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