Journal of Agri-Food and Applied Sciences
Available online at jaas.blue-ap.org
©2014 JAAS Journal. Vol. 2(8), pp. 242-252, 31 August, 2014
E-ISSN: 2311-6730

Overlaying Spatial Parameters to Determine the Most Suitable Irrigation Strategies in Bugesera Region, Eastern Rwanda

Jean-fiston N. Mikwa[1*], Cush N. Luwesi [2], Rose A. Akombo[2], Adrie Mukashema[1], Innocent Nzeyimana[3], Albert Ruhakana[4], Mary N. Mutiso[2], Joseph M. Muthike[2] and James M. Mathenge[2]

1-Faculté des Sciences Agronomiques, Université de Kisangani, Kisangani, RD Congo
2-Department of Geography, Kenyatta University, Nairobi, Kenya
3-National University of Rwanda, Faculty of Agriculture science, Kigali, Rwanda
4-Rwanda Agriculture Board, Department of Natural Resource Management, Kigali, Rwanda

Corresponding Author: Jean-fiston N. Mikwa

Received: 25 June, 2014 *Accepted: 20 July, 2014* *Published: 31 August, 2014*

ABSTRACT

In the year 2002, USAID's FEWSNET programme started warning about a looming food crisis in Bugesera region of the Eastern Province of Rwanda, which would be exacerbated by water scarcity. This study attempted to map potential irrigable lands of that agro ecological zone using spatial information to determine the most suitable areas that can be included in the national development agenda. The methodology consisted of overlaying different irrigation parameters derived from the processing of the Landsat Aster 2006 radar image and Digital Elevation Models (DEM) using appropriate software packages, namely ILWIS 3.3, ERDAS Imagine 8.7 and ArcGIS 9.2. These tools enabled us determine Land use and Land cover classification of the study area that fits to the soil characteristics, geology, topography and hydrology of Bugesera highlands. Maps resulting from this overlaying process display different types of layer classes according to each irrigation purpose. In most of the cases, only two classes of slope gradients, the soil texture, water proximity, and Land use/ cover type were found to be the most economic and suitable for irrigation purpose in Bugesera region, owing to their high water holding capacity. These were related to surface irrigation and all other possible types of irrigation, mainly sprinkler and drip irrigation. Overlaying these spatial models is an new way of thinking for irrigation development and agricultural water optimization in the Eastern Region of Rwanda in general and Bugesera region in particular

Keywords: Spatial information, satellite Image, topographic map, Digital Elevation Model, irrigation, Land use, Land cover.
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INTRODUCTION

Since the year 2002, USAID's FEWSNET programme keeps on warning the Government of Rwanda (GOR) on the looming food crisis in Bugesera region of the Eastern Province of Rwanda (IRWIN, 2003). Rwanda's policymakers were however challenged by such a lack of food security triggered by demographic pressure, pressure on natural resources and a concern for the effects of climate (MINAGRI, 2008). These issues have led policy-makers to search for strategies to improve food security and economic growth in the region, while optimizing the use of natural resources (MINECOFIN, 2002). Thanks to the recent scientific knowledge on the interaction between atmospheric processes, water and land cover/ land use, which shape the climate system in general, and precipitation in particular, as well as the resilience of natural resources (Mann ., 1998; Crowley, 2000;

Ike and Eludoyin, 2013; Akombo, 2014). This understanding of earth features led to the parameterization of management priorities with the aim of achieving sustainability in the use of water and land resources in the course of climate change (FAO, 1992; O'Brien and Leichenko, 2000; Luwesi, 2012a, 2013; Mathenge, 2014). This knowledge can be combined with potential Earth observation techniques to provide detailed information on effective monitoring of agricultural resources and ecosystems (Eastman, and Fulk, 1993; Schmugge and Engman, 1996; Dobos ., 2000; Bathgate and Duram, 2003; Krol, 2004; Mango ., 2011; Getachew and Melesse, 2012).

The Eastern Province of Rwanda has faced several periods of drought over the last two decades, owing to insufficient rainfall input and thus significantly constraining agricultural production and fruition (FEDRA, 1994; UNEP ., 2007). Verdoodt and Van Ranst (2003) described this region as being very poor to moderately suitable for agriculture due to annual rainfall limitations and mean temperatures ranging from warm and dry, a dry season lasting for three months with an average temperature of about 21 °C. The aftermath of drought that occurred between 1998 and 2000 required emergency strategies and plans to develop, among others, an irrigation master plan (MINECOFIN, 2002; District de Bugesera, 2006; Haboubacar, 2006). According to FAO (1995) recommends the intensification of irrigation as one of the most important tools that African countries shall give priority over the next few decades. The need for irrigation is justified to ensure constant water supply for agricultural production, which is generally low in arid and semi-arid regions dominated by savannas and pastoral activities (MINAGRI, 2008).

The enhance irrigation potential in the Bugesera region, there is urgent to adequately understand not only agro-climatic conditions of the region but also topographic, geological, hydrological and economic characteristics of this region. The latter may present both constraints and opportunities for the development of the agricultural sector through irrigation. This study attempted to map the characteristics of potential irrigable lands of Bugesera agro ecological zone using available geospatial information (GIS and remote sensing) to determine the most suitable areas that can be included in the national development agenda, namely the Rwandan Vision 2020, Economic Development and Poverty Reduction Strategy (EDPRS) and National Agricultural Policy (FAO, 1992; MINECOFIN, 2002; MINAGRI, 2008). Geospatial information technologies are effectively applied in agricultural fields such as forestry, irrigation, drainage, fertilization, groundwater investigations, pumping, erosion, disaster management and others (Dent and Young, 1981; Lagacherie, 2004; Maniraguha, 2005; Forrester, 2007; Mukashema, 2007; Maeda ., 2010; Ngonzo ., 2010; Mango ., 2011; Mkaya, 2013). They provide very cost-effective, time and energy saving data for managing and monitoring natural resources and disasters (Luwesi, 2010; Luwesi ., 2012b; Maeda, 2012; Luwesi and Bader, 2013; Ngonzo, 2013). The following sections provide methodological approaches used in this study to identify areas where can be established irrigation water infrastructure, results obtained from the study and their discussion, as well as conclusions and recommendations.

MATERIALS AND METHODS

Study area

Location

Bugesera region is located in the south-east of the Eastern province of Rwanda (Figure 1). The study area lies between latitude 2°01’55’’ S and 2°24’45’’ S and between longitude 29°56’50’’ E and 30°23’19’’ E, covering a total area of 1,303 Km^2. This area is delimitated in the North-East by the Nyabarongo River, in the west by the Akanyaru River. In the south, it makes border with Republic of Burundi from which it is separate in south-east by the Lake Rweru and south-west by the Lake Cyohoha (Haboubacar, 2006).

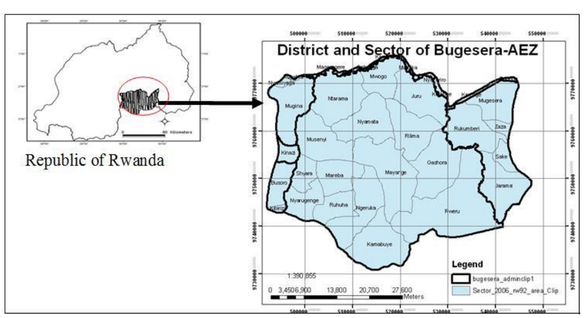

Figure 1. Bugesera District from the Map of Rwanda (Source: Adapted after CGIS-NUR)

Population and Human Development

The total population in Bugesera region in 2006 was approximately 266,775 people, with an average households’ size of 5 people (Bugesera District, 2006). This population density ranged from densely populated, in rural areas of Ruhuha (a crossborder trade centre shared with the Republic of Burundi), to fairly populated (in urban areas of Nyamata). This population is constituted of both Hutu and Tutsi tribal groups, most of whom are agriculturalists and livestock keepers, respectively. It shall however be noted that nearly 60% of households own less than 1 hectare of land and the main livelihood for a majority of people is their unskilled their labour in exchange of food, either directly (through food for work) or through a remuneration that just enables them purchase foodstuffs from the market (IRIN, 2003). The most vulnerable groups are made of female and child headed households, elderly and lonely people, who usually depend on food aids (UNEP, 2007).

Finally, Bugesera region has a widespread road network that connects all the sectors and villages ("Imidugudu"). Though most of sectors and cells do not have tarmac roads, they are however accessible and well maintained by the local administrations (Mushinzimana, 2012). The main centres are regularly supplied with electricity, tap water and telecommunication, the big centre of Ruhuha having both fixed and mobile telephones. National and private schools, a referral Hospital situated in Nyamata town and small health centres registered in different sectors provide education and healthcare to the whole region. These institutions have sustained human development in this region (Bizimana, 2007).

Topography and Climatology

Bugesera region is a large plateau located at an altitude of 1,323 to 1,544 m and bordered by the fluvial depositions of the Nyabarongo. The landscape is very broken and consists of a range of hills and valleys. However, like in any area of the Eastern region of Rwanda, the climate of ranges from hottest to driest of the country due to its rainfall limitations. It receives average annual rainfall of about 850 mm to 1,000 mm, falling in a bi-modal rainy season. The region experiences 7 months of and average temperatures of 21°C. This climate is acknowledged to be too dry for optimal plant growth, its agro-ecological conditions ranging from very poor to moderately suitable for agriculture development (Verdoodt and van Ranst, 2003).

Geology and Soils

Dark schist intercalated by quartzite feature the geology of Bugesera region (Neel, 1968). There are granites level on the slopes of the tabular hills covered by materials drifts of schist and quartzite. These soils are generally less or fairly deep, well drain, clayey, sandy clay or sandy silt, ranging from advanced deterioration to very advanced. Soil degradation ranges from severe in the western highlands to moderate and low in the central plateau and eastern plains, respectively.

The underground rocks are characterized by accumulation of iron oxides in the hard layer. This is explained by the succession of wet periods by dry ones during which high evaporations lead to cementing. During the wet seasons several components are carried by several meters of depth, while high evaporations occur during dry periods thus leading to cementing of boggy and argillaceous soils in deep valleys. There are vertisols characterized by high mineral nutrients' content with very low organic compounds. They are hard when dried up and melt and become muddy during the rainy season. Sandy clay soils, which are suitable for construction and manufacturing of bricks, are found at the edge of lakes, swamps and marshes. They are rich in humus and fruitful for agriculture production.

Vegetation and Agricultural Land Use

Owing to its increasing population pressure on the natural vegetation, most of forests in Bugesera region have been converted into agricultural lands. Hence, the natural vegetation found in the region mainly comprises of plants tolerant to drought in particular the grassy species such as *Asparagus falcatus*, *Aloe dawei*, *Rhynchaosia minima* among others and of woody dominated by *Acacia spp*., *Euphorbia spp.*, Cactus, *Cyperus papyrus*, *Grevillea robusta*, *Pinus* (Bizimana, 2007).

The region is dominated by savannas in the lowlands, grasslands in the dry valleys and the plates of hills, and shrublands covering the hills. In addition to the savanna graminaceous and thorny bushes, a vegetation of steppe type features the region and is mainly compounded of *Acacias*, *Euphorbia*, and *Cactus*. Galleria forest covers alluvia plains on the edge of lakes, swamps and marshes, which are stagnant waters of the puddle pools. It is represented by association of *Acacia siberiana* ("umunyinya") and other species such as "umuko", "umuvumu", "umusave", "umusasa", and papyrus ("urufunzo"). These vegetations are rich in humus and strongly desired by pastoralists in search of better pastures. The grassy savannas found in the dry valleys and plates of hills are predominantly made of *Botriochlora, Hyparrhenia, Filipendula*, *Sporubulus*, *Pyramidalis, Themeda* and *Triandria* species. Shrubby savannas are scattered among the above vegetations and include various types of strewn shrubs and grasses of the meadows.

Major crops grown in the region include maize, sorghum, sweet potato, bean, manioc, groundnut, pineapple and banana. The farming system is mainly traditional type and offers very little profitability. It is an extensive agriculture without rationalization of the exploitation. However, new farming methods are gradually introduced through vulgarization with demonstration fields and diffusion of selected varieties. The land is also strongly threatened by erosion. This erosion led to strong depletion of soil fertility and to a degraded land.

Methodological approaches

Model Design

An irrigation decision support tree was developed through integration of the overlaying function of computerized spatial models used in the study. A flow chart explains the different steps followed by the researcher to come up with an irrigation decision (Figure 2). This logical framework has 3 main components: Input, Output and Irrigation Spatial Decision product. The latter depends on the types of overlaying layers used in the model design.

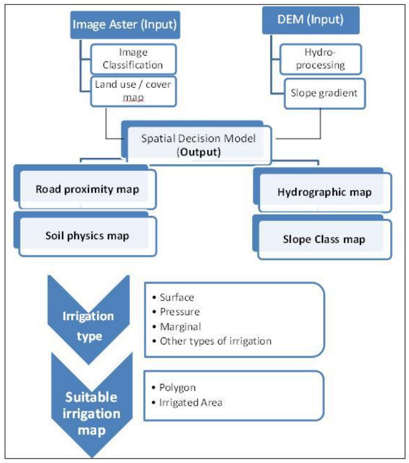

Figure 2. Conceptual framework of the study

Data Input and Processing

Data for mapping the irrigable lands of Bugesera region were acquired from the Centre of GIS of the National University of Rwanda (CGIS -NUR). The study used a Radar Satellite images (ASTER) for 2006 and topographic map of Eastern Rwanda (scale = 1:150,000) for 1988. These raster data were compiled into a multi–thematic geo-database for the agro-ecological zone of Bugesera region to the generate the following main layers: soil types, DEM, topographic and hydrographical layers, and land use/ cover types. In addition, high resolution digital topographic data and radar images were generated from the Shuttle Radar Topography Mission (SRTM). The SRTM enabled the modelling of the terrain and mapping of the land of most of the Eastern Rwanda. Table 1 provides details of the ASTER image used in this study.

These data were first geo-referenced and corrected for sensor irregularities. They were then processed using appropriate mapping and/or remote sensing software packages, namely ILWIS Academy 3.3, ERDAS Imagine 8.7 and ArcGIS 9.2.

ILWIS Academy 3.3 was used to generate slope gradient ($\tan\beta$ in percentage) and terrain parameters and develop a Digital Elevation Model (DEM), specifically under DEM Hydro-processing module.

Using linear filtering procedure, the first derivatives (DEM_dx, DEM_dy) in X, Y directions per pixel, respectively, were calculated. Positive DEM_dx values in the output map meant that the terrain went up from left to right, while negative DEM_dx values meant that the terrain went down. The slope gradient was then calculated using the following formula found in ILWIS command line:

$\tan\beta$ = 100 * HYP (DEM_dx, DEM_dy) / PIXSIZE (DEM_dx, DEM_dy) (Equation 1)

An elevation contour map was developed from the DEM to derive the contour interval and generate different terrain parameters for hydrological analysis. Finally, a contour map containing 25 m equidistant contour lines was created in the same project as soil map. Thereafter, many layers (topography, geology/ soil, hydrology, etc.) were put into a spatial combination in the ArcMap platform of ArcGIS 9.2 to enable description and determination of potential irrigable lands as well as type of irrigation, in Bugesera region of Eastern Rwanda. ERDAS Imagine 8.7 and ArcGIS 9.2 software packages were thence involved to enable the digitalization of the topographic map and overlaying process.

Finally, the following classification of land use and land cover of the study area was derived from the 1998 topographic map (scale = 1:150,000): (1) Forest and banana (or other trees crops); (2) Lakes; (3) Marshland; (4) Grassland (Bushland); and (5) cropland (Agriculture).

Land use/ cover change detection was done by comparing identical classes on the topographic map to categories identified on the 2006 ASTER satellite image using ERDAS Imagine 8.7 software. The supervised classification of the digitized topographic map was applied to the satellite image by means of ArcGIS 9.2. The difference map was then generated using a default matrix (intersection) in ArcGIS that enables the creation of output files containing classes with overlapping class values among inputs. A percentage change was calculated by area of each class.

Selection of Suitable Irrigation Areas

Once the geo-database was compiled, each of the layers could be used as decision variable. Sequential GIS intersections between the layers at desired areas (polygons) were selected and non-relevant areas were filtered out. To select the optional irrigable land, which obey the conditions, a sequence of layers' intersections was performed in ArcGIS, and the suitable polygons were depicted.

RESULTS AND DISCUSSION

Irrigation Model Design by Layers of Slope Gradient

The use of slope is one of the most suitable approach for determining irrigable areas in Bugesera region. Figure 3 displays a slope classification showing four classes of irrigation defined in the study, namely: Surface irrigation (0-2 %), all possible types of irrigations (2-6 %), Pressure Irrigation (6-25 %) and Marginal irrigation (25-65 %).

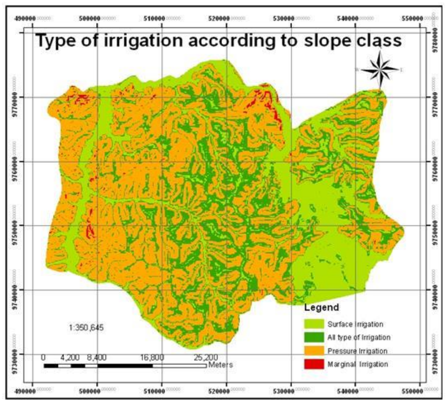

Figure 3. Types of irrigation retained in Bugesera according to slope classification

To produce a map of the most suitable areas for irrigation, two classes of slope gradients were retained: the one for surface irrigation and the other one for all possible types of irrigation. Surface irrigation encompassed border, furrow and Basin irrigations, while all possible types of irrigation included surface, pressure and marginal irrigation strategies. These two classes of slope gradients were found to be the most economically viable for irrigation purpose in Bugesera region, owing to their high water holding capacity. After overlaying them, Figure 4 reveals that the potential irrigable areas (in blue) in Bugesera region amounted to 915 km^2 with surface, pressure, marginal and all other types of irrigations accounting for 220,358,780.83 m^2, 464,304,511.75 m^2, 6,707,811.43 m^2 and 223,628,895.99 m^2, respectively.

It shall be noted that pressure and marginal irrigation strategies can also be adopted for other decision making processes. Pressure irrigation encompasses both sprinkler and drip irrigation. However, leveling strategies will be needed prior to setting such types of irrigation schemes. For instance, radical terraces shall first be established on steep slopes ranging between 13 and 25 %, and progressive terraces on slopes of 6 to 12 %.

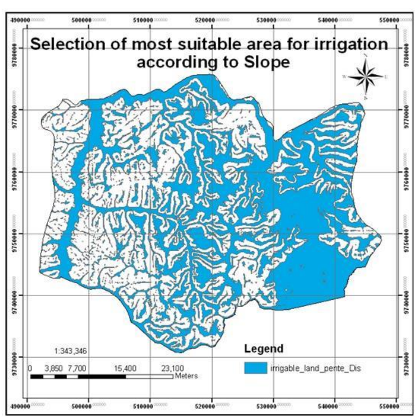

Figure 4. Suitable irrigable lands in Bugesera region according to slope gradient

Irrigation Spatial Model by Layers of Clay Soil Texture

There is a possibility to irrigate the study area based on its clay soil characteristics as shown in Figure 5.

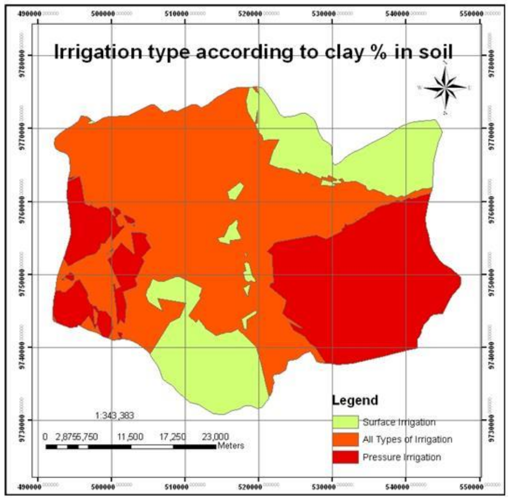

Figure 5. Types of irrigations based on clay compounds in the soil

The study found five (5) soil classes in Bugesera region according to the percentage of clay compounds in the soil. However, three (3) of these were retained for irrigation purpose, namely: (1) low clay content soils (0-20% of clay), suitable for pressure irrigation; (2) fair clay content soils (0-20% of clay), suitable for all possible types of irrigations; and, (3) high clay content soils (30-50% of clay), suitable for surface irrigation.

As indicated in the first map overlaying strategy, only two irrigation types were considered as economic and technically viable because of their high water holding capacity, namely surface irrigation and all other possible types of irrigations. After overlaying these two classes in areas were clay soil was found, the study came up with a total irrigable land of 1,190.16 Km^2 in Bugesera region fragmented as follows: (1) Surface irrigation: 245,619,159.2 m^2; (2) Pressure Irrigation: 346,739,511 m^2; (3) All possible irrigation types: 597,796,514.3 m^2.

Irrigation Strategy based on Sandy Soil Texture

If irrigation can be undertaken in areas dominated by clay soils, it is also possible to irrigate sandy characteristic areas in the Eastern Province of Rwanda. Figure 6 shows three (3) types of irrigable lands defined in Bugesera region according to the percentage of sand in the soil, though four (4) possible classes could be delineated in the study area. The classes retained encompasses surface Irrigation (0-20% of sandy soil), all possible types (20-40% of sandy soil) and pressure irrigation (40-60% of sandy soil). After overlaying surface irrigation and all other possible types of irrigations, a total of 1,192.04 Km^2 of irrigable lands was delineated in Bugesera region. The latter encompassed 190,286,496.76 m^2 for surface irrigation, 562,035,968.22 m^2 for pressure Irrigation and 439,712,305.40 m^2 for all types of irrigations.

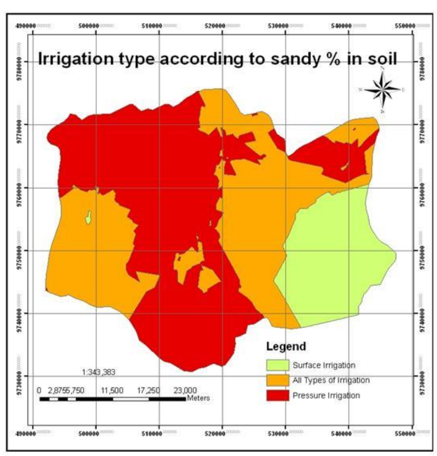

Figure 6. Irrigation types in Bugesera by the percentage of sandy soil

Irrigation based on the Proximity to Road/ Hydrographic Network

Using the available information on the road network in Bugesera region, the study determined the suitability of irrigable lands therein based on the constraint of transport of inputs and produce, and water availability. Proximity to roads and water courses was set at a maximum distance of 3 km. The main assumption was that the proximity of lands to communication infrastructure and water courses would have an economic impact on the agricultural production by lowering the costs of transaction and increasing accessibility to the market (Frenken ., 2007; Menzel and Fornahl, 2010; Neffke, 2011). Since there exists a wide road network and hydrographic system in the Bugesera region, potentials for irrigation are everywhere the region, especially in the extreme eastern and southern, as well as northern and western parts of the region (Figure 7).

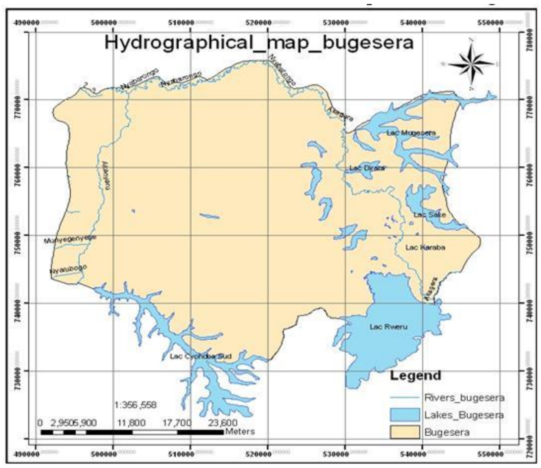

Figure 7. Hydrographic network of Bugesera region

Figure 8 shows areas where irrigation efficiency will be much supported by slope and water proximity parameters in Bugesera region, while Figures 9 and 10 add soil type (clay and sand, respectively) to this map by the matching the three (3) layers: (1) slope layer that is suitable for surface irrigation and all suitable irrigation types, namely surface irrigation, sprinkler irrigation and drip irrigation; (2) water proximity layer which provides a buffer zone of 3 km; and (3) soil texture layer for clay and sand compounds in the soil.

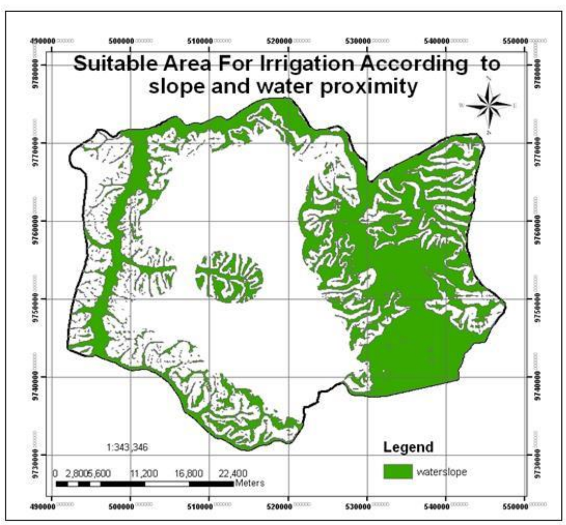

Figure 8. Suitable irrigation according to slope and water proximity

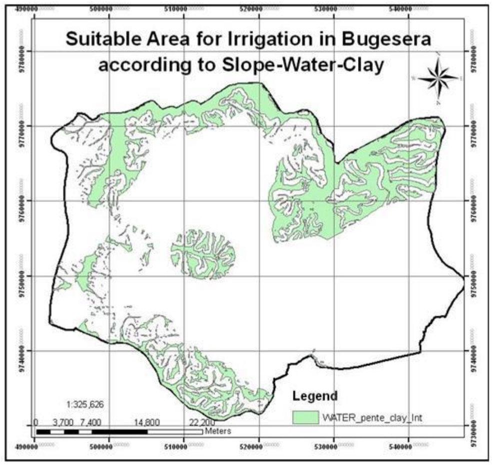

Figure 9. Suitable irrigable lands based on slope, water proximity and clay soil

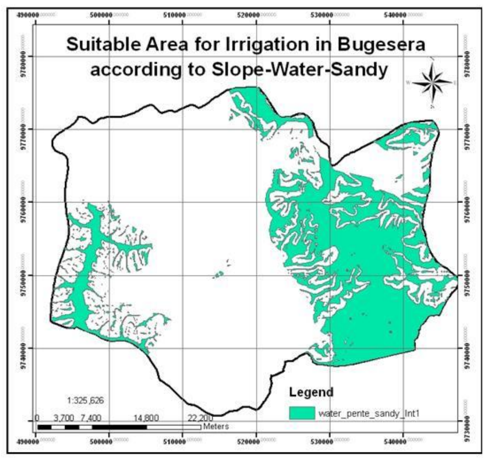

Figure 10. Irrigation decision by overlaying slope, water proximity and sand soil

Irrigation Decision by Types of Land Use and Land Cover

The agro-ecological map of Bugesera was used to determine the most suitable areas for irrigation. Figure 11 shows different classes of land use/ cover that were considered using identical or similar classification, which encompassed: (1) Forest and banana; (2) Lakes; (3) Marshland; (4) Bushland; (5) Cropland.

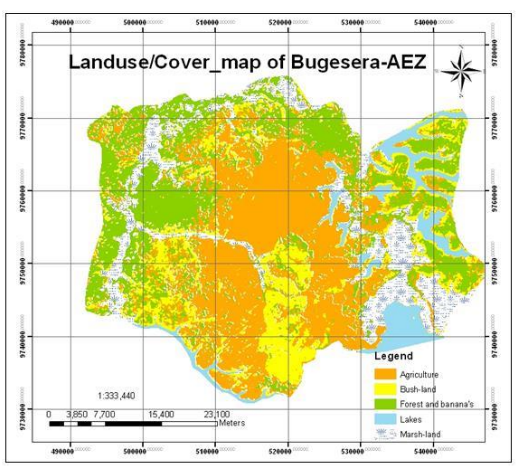

Figure 11. Land-use / cover map of Bugesera region

This classification was mainly based on the slope of the terrain and the distribution of rainfall. Results show that Bugesera region is dominated by croplands (536,068,355.35 m^2), forest and bananas (485,202,893.84 m^2) in the lowlands along with Marshland (177,496,091.50 m^2) and Lakes (166,249.27 m^2), while the bushland (131,066,410.90 m^2) occupies most of the dry valleys and the plates of hills. However, when it comes to irrigation in Bugesera region, consideration will be given to croplands and marshlands. It will not be advisable to convert forests and bushland into on-farm irrigable lands, since most of them have already been used for agricultural land uses despite their ecological functions. Maize, sorghum, sweet potato, bean, manioc, groundnut, pineapple and banana are being grown there using traditional type of farming, which is mostly not profitable. Agricultural extension is also done without rationalization of land, though new farming methods are being gradually introduced to disseminate new or selected crop varieties.

Irrigation Suitability by Overlaying All Spatial Parameters

After having assessed different irrigation options, Figure 12 provides a description of the most suitable areas for irrigation, when conditions of slope gradient, soil texture, water availability, proximity to road network, and land use/ cover types are met. Results indicate that, in such conditions, the most suitable irrigable lands will cover a total area of 1,034,397,180.45 m^2 in Bugesera region.

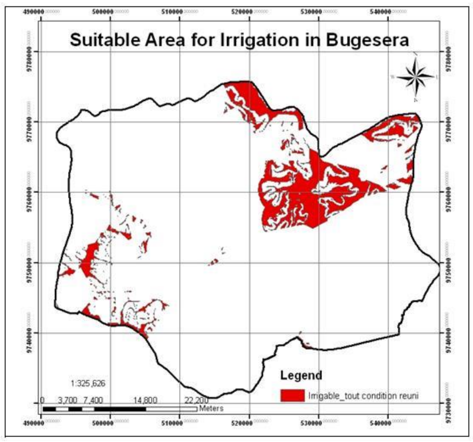

Figure 12. Suitable irrigation areas by overlaying all spatial parameters

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study aimed at overlaying different spatial models developed by integrating GIS and Remote Sensing approaches. It provides a logical framework for mapping the most economic and technically viable irrigable lands in the Eastern Province of Rwanda. Spatial models considered in this study encompassed different layers of slope gradients, soil texture (clay and sandy soils), water availability, proximity to the road network (within 3 km), and Land use/ cover types. In most of the cases, only two among the classes defined were found potentially suitable for surface irrigation and other irrigation types, mostly pressure irrigation (sprinkler and drip irrigation). By overlaying these different types of spatial parameters to detect the most suitable irrigable lands and estimate their areas based the study has made a significant contribution in science. It has introduced a new kind of thinking for irrigation development and agricultural water optimization in the Eastern Province of Rwanda in general, and Bugesera region in particular.

Recommendations

This study methodological approach enables the use of spatial data to derive the most suitable lands for irrigation in Bugesera region. However, it is recommended that further studies evaluate that methodology using participatory approaches. Fieldwork shall be conducted with involvement of the local populations and NGOs to collect new data that would ascertain and validate results obtained above.

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